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NATIONAL PRIORITIES AND FEDERAL RESEARCH AND DEVELOPMENT PROGRAMS

HEARINGS

BEFORE THE

SUBCOMMITTEE ON PRIORITIES AND ECONOMY IN GOVERNMENT

OF THE

JOINT ECONOMIC COMMITTEE CONGRESS OF THE UNITED STATES

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NATIONAL PRIORITIES AND FEDERAL RESEARCH AND DEVELOPMENT PROGRAMS

MONDAY, MAY 20, 1974

Congress of the United States,
Subcommittee on Priorities and
Economy in Government of the
Joint Economic Committee,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10:05 a.m., in room 318, Russell Senate Office Building, Hon. William Proxmire (chairman of the subcommittee) presiding.

Present: Senator Proxmire.

Also present: Richard F. Kaufman, general counsel; William A. Cox, Jerry J. Jasinowski, Larry Yuspeh, professional staff members; Michael J. Runde, administrative assistant; Leslie J. Bander, minority economist; and Walter B. Laessig, minority counsel.

Opening Statement of Chairman Proxmire

Chairman Proxmire. The subcommittee will come to order. The hearing we begin today is the sixth in the annual series of inquiries concerning national priorities initiated by the Subcommittee on Priorities and Economy in Government. This year we plan to look at selected aspects of Federal spending for research and development to gain an insight into how resources in this critical area are being employed.

Federal R. & D. spending will rise from $15.9 billion in fiscal 1973 to $16.8 billion in 1974. An additional $800 million will be spent for R. & D. facilities in 1974 and in addition to that, more than $700 million will be spent by the Defense Department for independent R. & D. Total spending for R. & D., insofar as we are presently able to figure it, will be about $18.3 billion in 1974.

Today we will look at a very small aspect of the Government's R. & D. effort, the work being done at the Army's laboratory in Natick, Mass. The Natick Laboratories has successfully developed a process to convert waste materials into glucose.

The work at the Natick Laboratories is small compared to the overall Government R. & D. program; in fact, it is infinitesimal in terms of the dollars spent—less than $500,000 up to now or less than 0.003 percent—three one-thousandths of 1 percent—of Federal R. & D. expenditures for 1974.

But the potential consequences of the Natick work are enormous. It would be foolish to look for a cure-all to the problems of food and fuel maintained viable 12,000 strains of microorganisms—fungi—associated with the biodegradation of military supplies in various parts of the world. Consequently, we have developed the scientific skills needed for the prevention, control or acceleration, of the deterioration process associated with these microorganisms.

On July 1, 1971 the Natick Laboratories was directed by the Army Materiel Command to add to its basic mission, studies that would lead to practical pollution abatement processes that would help the Army comply with the National Environmental Policy Act of 1969, Public Law 91–190, dated January 1, 1969, and the Presidential Executive Order No. 11507, dated February 4, 1970, on prevention, control, and abatement of air and water pollution at Federal facilities.

Following a period of soul-searching, coordination and problem definition, we concluded that the overall pollution abatement program at the Natick Laboratories should cover two major areas:

(1) Water pollution.

(2) Solid wastes.

Our efforts in water pollution are geared to the abatement and disposal of water pollutants associated with the manufacture of munitions and explosives.

Because we at Natick are responsible for the development and specification for the largest volume of consumables (that is food and clothing) by the military, we feel morally obligated and duty-bound to assist in the disposal of solid wastes associated with military operations at posts, camps and stations, and in the field. In 1972 Army installations in the United States alone accumulated 500,000 tons of trash which had to be disposed of. Most of this trash was buried. Our program in solid wastes at Natick Laboratories covers several studies that will ultimately lead to the attainment of two principal objectives. These are:

(1) Reduce to a minimum the quantity of waste now disposed of in the environment.

(2) Processing and/or conversion of such wastes into useful products to achieve maximum energy and resources recovery that is economically practicable.

Cellulose is the world's most abundant organic compound with an annual net yield from photosynthesis estimated at 100 billion tons. This is approximately 150 pounds of cellulose per day for each and every one of the Earth's 3.7 billion people. Furthermore, it is annually replenishable. The energy to produce this vast quantity of cellulose comes from the Sun and is fixed by photosynthesis. Much of the cellulose ends up as waste, particularly in municipal trash (40–60 percent), animal feedlots, wood waste, and agricultural waste.

America's trash pile for 1973 was estimated recently by the EPA at 130 million tons—enough to fill garbage trucks that, if lined up bumper to bumper, would stretch from New York to Los Angeles, three abreast. That, indeed, is a lot of trash.

Having the knowledge, the skills and the scientific staff that developed the techniques needed to prevent and control the degradation of military materiel exposed to the biological environment, Natick Laboratories decided to apply the same knowledge and skills of the same scientists to devise techniques that would accelerate the breakdown and disposal of cellulosic wastes.

Conversion of cellulose to glucose can be done by either acid hydrolysis or by enzymatic processes (1–11). There are various advantages in the use of enzymes to hydrolyze cellulase instead of acid. When using acid, expensive corrosion proof equipment is required. Waste cellulose invariably contains impurities which will react with the acid producing many unwanted byproducts in the digest. The enzyme, on the other hand, is specific for cellulose so that the glucose is fairly pure and constant in composition.

We at the U.S. Army Natick Laboratories are developing an enzymatic process, which is based on the use of the cellulase enzyme derived from a mutant of the fungus trichoderma viride isolated and developed at the Natick Laboratories. A schematic diagram of such process is shown in figure 2.[1]

Our first step is the production of the enzyme. This, we accomplish by growing the fungus trichoderma viride in a culture medium containing shredded cullulose and various other nutrients. After 5–10 days the fungus culture is filtered and the solids discarded. The clear straw-colored filtrate is the enzyme solution that is used in the saccharification reactor. Prior to its introduction into the reactor, the enzyme broth is assayed for cellulase and its acidity adjusted to a pH of 4.8 by addition of a citrate buffer. Milled cellulose is then introduced into the enzyme solution and allowed to react with the cellulase to produce glucose sugar. You will note that saccharification takes place at atmospheric pressure and low temperature 50°C. The unreacted cellulose and enzyme is recycled back into the reactor, and the crude glucose syrup is filtered for use in chemical, microbial, and/or fermentation processes to produce chemical feedstocks, single cell proteins, fuels, solvents, et cetera.

The key to this process is the production of high-quality cellulase from trichoderma viride. To date, we have defined the conditions needed to produce the enzyme in quantity. We have also developed mutant strains that produce two to four times as much cellulase as the wild strain. In this area we feel that we have yet to reach the upper limit.

Another important variable to be optimized is the preparation of the substrate. The insolubility and crystallinity of pure cellulose and the presence of lignin in waste cellulose make it a most resistant substrate. The most satisfactory pretreatment we have found is ball milling. This reduces the crystallinity and particle size of the cellulose and increases its bulk density. Consequently, more cellulose is available for conversion to sugar in the reactor. Figure 3[2] shows the percent conversion of a number of pure and waste celluloses by the culture filtrate of trichoderma viride.

Saccharification is slow for crystalline cellulose such as cotton or untreated rice hulls or bagasse. Pot milling greatly increases their reactivity. Shredded or milled papers make good substrates. The Black-Clawson fiber fraction from the hydropulping separation of municipal trash, is an excellent material, especially after milling. The same is true for the dry cellulose fraction separated by air classification of municipal trash by the Bureau of Mines' process. These waste

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[1] See fig. 2, p. 8.
[2] See fig. 3, p. 9.

Conversion of Waste Paper Products to Glucose Sugar

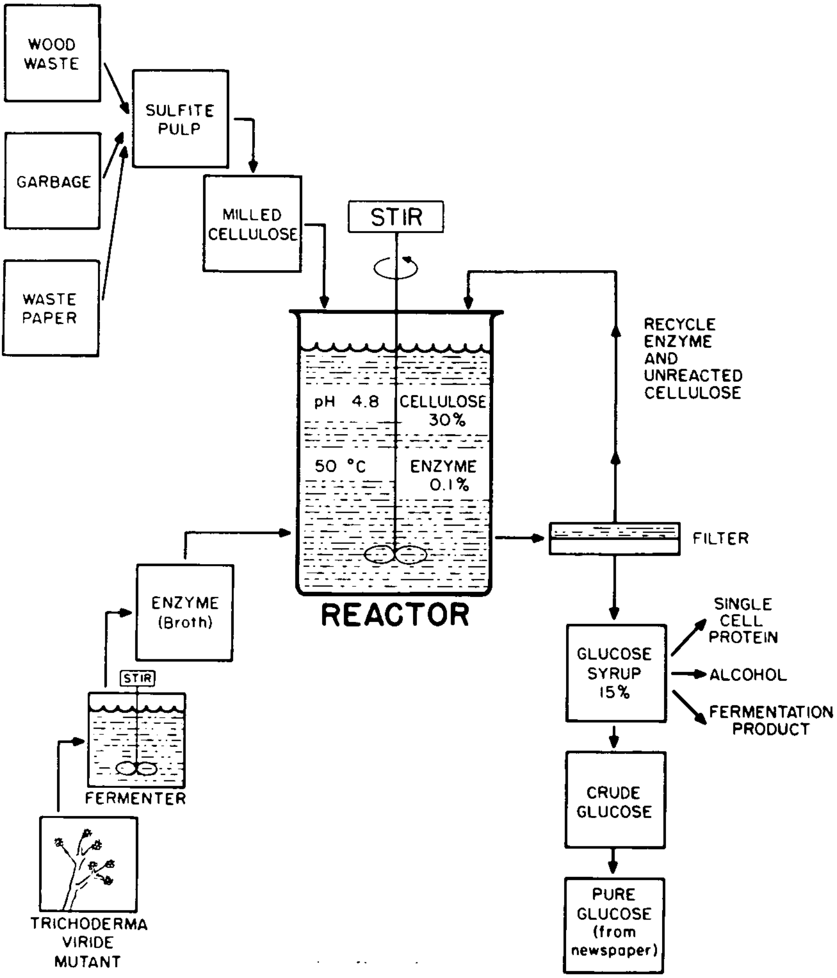

Figure 2

HYDROLYSIS OF CELLULOSE BY TRICHODERMA VIRIDE CELLULASE

	% SACCHARIFICATION			
Substrate	1 hr	4 hr	24 hr	48 hr
PURE CELLULOSE				
Cotton — Fibrous	1	2	6	10
Cotton — Pot Milled	14	26	49	55
Cellulose Pulp SW40	5	13	26	37
Milled Pulp Sweco 270	23	44	74	92
WASTE CELLULOSE				
Bagasse	1	3	6	6
Bagasse - Pot Milled	14	29	42	48
Corrugated Fibreboard Mighty Mac	11	27	43	55
Corrugated Fibreboard Pot Milled	17	38	66	78
Black Clawson Fibers	5	11	32	36
Black Clawson Pot Milled	13	28	53	56
Bureau of Mines Cellulose	7	16	25	30
Bureau Mines Pot Milled	13	31	43	57

Figure 3

PRETREATMENT OF NEWSPAPER

	% Saccharification			
Newspaper (Boston Globe)	1 hr	4 hr	24 hr	48 hr
Mighty Mac - Mulcher	10	24	31	42
Jay Bee - Paper Shredder	6	12	24	27
Pot Mill	18	49	65	70
Sweco Mill	16	32	48	56
Granulator-Comminutor	6	14	24	26
Fitzpatrick (Hammer Mill)	10	16	25	28
Majac (Jet Pulverizer)	11	15	26	29
Gaulin (Colloid Mill)	9	17	27	31
Soaked in Water	7	13	24	28
Boiled in Water	4	9	21	26
Treated 2% NaOH	8	14	28	35
Viscose	15	30	44	51
Cuprammonium	18	35	52	58

Figure 4

HYDROLYSIS OF MILLED NEWSPAPER IN STIRRED REACTORS

Enzyme Protein mg/ml	Newspaper %	Temp C	Glucose 1 hr %	Glucose 4 hr %	Glucose 24 hr %	Glucose 48 hr %	Sacchar-ification %
0.7	5	50	1.0	2.0	2.8	-	50
0.7	5	50	1.0	2.0	2.3	-	42
1.0	10	50	2.1	3.1	5.5	7.3	66
1.6	10	45	2.0	3.6	5.4	6.5	59
1.6	10	50	2.3	4.2	6.4	6.3	57
0.8	15	45	1.5	2.8	5.3	7.7	46
0.8	15	50	0.8	2.8	6.1	6.3	38
1.8	15	50	3.2	6.0	8.6	10.0	60

Reactor Volume 1 Liter Stirred 60 RPM pH 4.8

Figure 5

ENZYMATIC CONVERSION OF WASTE CELLULOSE

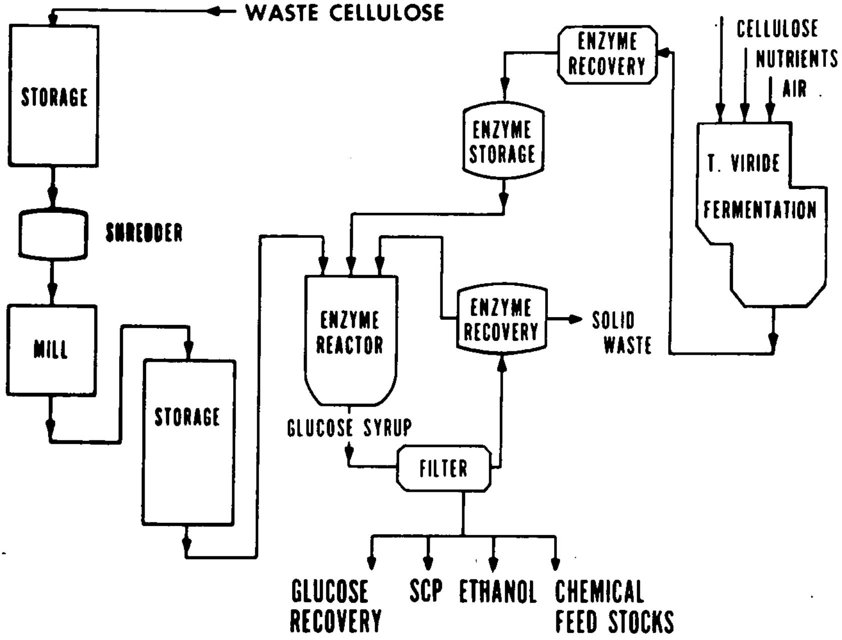

Figure 6

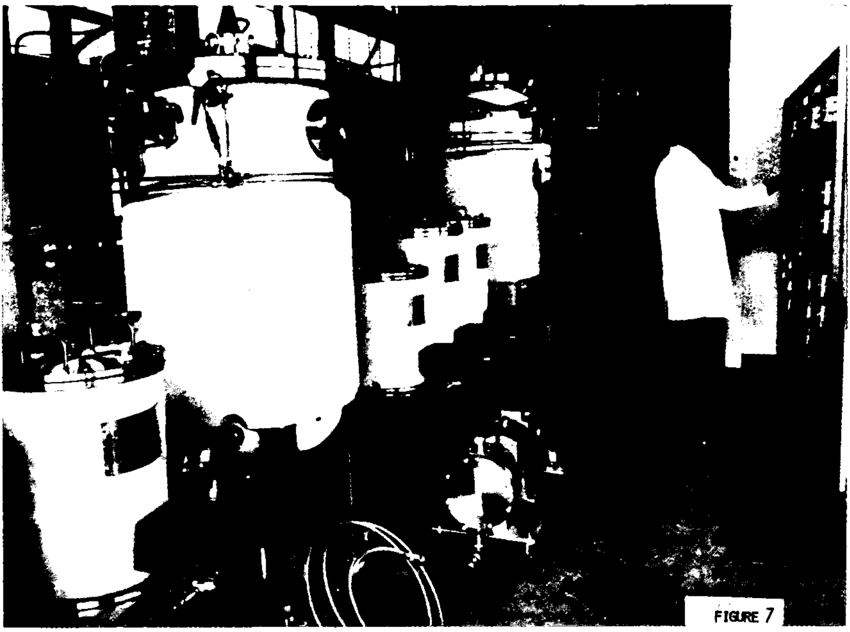

FIGURE 7

Chairman **Proxmire**. Mr. Spano, I would like to follow up on that last remark first, before I get into some of the other questions.

What I think struck the national imagination and has made people particularly interested in this is that it comes along at a time when we are all conscious of the very serious shortage of oil. I realize that this is not the only purpose, and I realize that this is not the only way in which this can be exploited and used. But let me ask just a couple of questions about that first.

COST ESTIMATES OF ETHYL ALCOHOL PRODUCED BY THE NATICK PROCESS

The cost, as I understand it, of producing ethyl alcohol from a similar process used to be estimated at around $1 a gallon. The cost of being able to manufacture ethyl alcohol through the means that you have just described, as I understand, has been estimated at around 20 cents a gallon, very roughly. And the reason why this is applicable, of course, to oil and fuel is that it is possible to mix 50 percent of your fuel as ethyl alcohol and 50 percent gasoline without a radical change in the internal combustion engine, and with a more substantial change it is conceivable at least to run the engine completely on ethyl alcohol without any oil at all. And with no change at all you could use 20 or 25 percent, a very substantial percent of ethyl alcohol, to reduce the need for oil.

Now, I would like, first, to ask if that very rough approximation that I got from reading the newspapers and that I got from other sources is roughly correct or incorrect?

Mr. **Spano**. When it comes to cost, sir, it is very difficult for us to estimate these costs at this time, since we have not really done the process studies on a pilot scale. I have seen some figures myself where the actual cost of producing alcohol—that is the processing cost is only 20 cents per gallon. I believe this was published in the last issue of Science, which was devoted completely to energy. In that issue Mr. Calvin indicated that the processing costs would be around 20 cents per gallon.

Chairman PROXMIRE. Can you give us that reference? Science magazine, what month?

Ms. MANDELS. April 19, 1974.

Chairman PROXMIRE. And who wrote the article.

Mr. SPANO. Mr. Calvin from California.

Chairman PROXMIRE. The University of California at Berkeley?

Mr. SPANO. Yes. The 20 cents per gallon is the processing cost, just to make the alcohol itself.

Chairman PROXMIRE. How authoritative is this article by Mr. Calvin?

Mr. SPANO. I think it is quite accurate.

Chairman PROXMIRE. Has it been challenged by anybody else?

Mr. SPANO. Not that I know of, sir.

Chairman PROXMIRE. Has it been supported by anyone in the scientific community that you may know?

Mr. SPANO. I have seen other quoted prices that state that the production costs of ethyl alcohol, just the processing costs, are 19.7 cents per gallon or approximately 20 cents. This does not include the cost of the sugar. In order to achieve a 20 cent cost rate at the plant itself it would mean that the glucose that is used to make the alcohol would have to be free. In other words, the cost of the front end of the process in handling the trash and the separation of the materials we could recover would have to pay for the glucose process, so that the price of glucose would come down to zero.

Chairman PROXMIRE. Does that seem logical?

ETHYL ALCOHOL—PRODUCTION COST 32 CENTS PER GALLON IF GLUCOSE COST IS 1 CENT A POUND

Mr. SPANO. Not really, sir. However, we could reduce the cost of glucose quite a bit.

Chairman PROXMIRE. What do you assume the cost of the sugar would be, then? I want to get as realistic a figure as I can get. And I realize that this is all speculative now because you have not constructed the pilot plant, and many elements are going to have to enter into it. But I would like to get as reasonable an estimate as we can at this stage, recognizing that it has to be tentative.

Mr. SPANO. Mr. Calvin indicates that the cost of glucose for making alcohol at 84 cents a gallon would be 5 cents per pound. It takes 12.8 pounds of glucose to make 1 gallon of alcohol. If we could reduce the price of glucose to a penny a pound, then we would charge 12.8 cents for the glucose required to make 1 gallon of alcohol and 20 cents for the processing costs of the alcohol. On this basis, the overall cost would be 32.8 cents per gallon.

Chairman PROXMIRE. Then the cost of the ethyl alcohol would be 32, 33, 34 cents a gallon, something like that?

Mr. SPANO. If the glucose is down to a penny a pound.

Chairman PROXMIRE. And are you confident that that is realistic?

Mr. SPANO. I am very hopeful.

Chairman PROXMIRE. And then, you said something about the possibility of economies that were balanced by product benefits, or something of that kind that would reduce the cost perhaps to zero. What was that based on?

TARGET COST OF THE ETHYL ALCOHOL—20 CENTS PER GALLON IF COST OF DUMPING TRASH ASSUMED

Mr. SPANO. Rough figures—and these are very rough, sir, do not pin me down on these—I think if we run a complete resource recovery process—and perhaps Mr. Wilson, who will follow me, can shed some light on this—if we run such a process and take into account the dumping costs of the trash, which has to be disposed of by the communities and the States, and recover the ferrous, non-ferrous, and the glass, the whole bit for recycling and the organic fraction for enzymatic conversion, then for a plant whose capacity is 500 tons per day, we could possibly reduce the glucose cost by a penny a pound. And that is a lot.

Chairman PROXMIRE. Then, if you reduce it by a penny a pound, then you end up again with a balancing benefit, and 20 cents would be the ultimate cost?

Mr. SPANO. Yes. If we are able to cancel completely the cost of glucose by the balancing benefits of the resources recovery process.

Chairman PROXMIRE. What you are saying is that because they now have to pay to get rid of their garbage it amounts to an economic cost, a drain on resources, that would pretty much compensate for the cost.

AVAILABLE WASTE FROM WHICH ETHYL ALCOHOL COULD BE PRODUCED

Now, how about the volume of potential production? You have indicated that there is a tremendous amount, I think you said something like a hundred billion tons a year in the world, and enormous amounts, of course, in this country. But that is the volume of the raw material. It is almost infinity. But how about the prospects of production in sufficient volume to provide a significant part, say, of the need for gasoline or fuel oil?

Mr. SPANO. May I have Mr. Nystrom answer that?

Chairman PROXMIRE. Yes.

Mr. NYSTROM. If you divide the wastes into the three categories, urban wastes, animal wastes—which are feedlot wastes—and agricultural wastes, these would be the three main sources of trash. From urban wastes in the country—readily collectible dry organic matter—there would be about four times ten to the seventh tons per year.

Chairman PROXMIRE. I am not talking about the availability of materials. I would assume that that is ample. I may be incorrect, and correct me if I am, but the impression I get is that there is plenty of that. The problem is what kind of production volume you would need, and whether or not this could be in the enormous amount that would be necessary to provide a significant alternative source of fuel to oil.

2.4 PERCENT EQUIVALENT OF GASOLINE PRODUCTION FROM THE CELLULOSE FRACTION OF URBAN WASTE

Mr. NYSTROM. If you were to convert the cellulosic fraction of that four times ten to the seventh tons of urban wastes, you would come up with 2.4 percent of the present gasoline production. Again this is just from urban waste.

Form animal feedlot waste, conversion of the cellulosic fraction present in the two times ten to the seventh tons of wastes you would come up with an additional 1.2 percent of the present gasoline production.

And if you were to take the agricultural wastes, which are about 20 times ten to the seventh tons, you would come up with about 9.62 percent of the present gasoline production.

If you totaled them you would come up with about 13.26 percent of the total gasoline production in the United States at this time.

Chairman PROXMIRE. That is less than I thought it was. I thought you had an unlimited amount of raw material here.

Mr. NYSTROM. The figure that Mr. Spano quoted was the total amount of organic carbon that is fixed by photosynthesis, and this means trees that do not normally wind up as wastes. But if we were to go to crop farming, we could produce large amounts of cellulosic materials. We would actually grow crops just to produce cellulose for this process.

Chairman PROXMIRE. But as far as using wastes are concerned, the amount would be about 14 percent in total of the consumption of oil and gasoline, is that right?

Mr. NYSTROM. That is correct.

Chairman PROXMIRE. Now, how about the capital requirements? Is it too soon to make any kind of an estimate as to what kind of capital it would take to invest and make this kind of an enormous conversion?

Mr. SPANO. First of all, sir, may I say that this is something that I put together personally to give you an idea of what it would take to build a single production plant to handle 500 tons of trash per day and convert its cellulosic fraction to glucose.

Chairman PROXMIRE. Let us go back to say that an increase of 14 percent, after all, that is not 50 percent, it is not 80 percent. But it is still a colossal increase in available production. Shortage of gasoline, I do not think, has been that great, perhaps close to it. But it seems to me that bringing on that much more supply would by itself result in a far healthier supply and demand situation, and perhaps a somewhat reasonable moderation in price.

Disregarding the technical cost aspect, which would be another factor in reducing the price, the fact that you have that additional supply.

GLUCOSE FROM THE PROCESS CAN BE USED AS A CHEMICAL FEEDSTOCK

Mr. SPANO. As a matter of fact, there is no reason why the glucose itself cannot be used as a chemical feedstock to save the petroleum that is now being used to make petroleum chemicals. So whether we use it as a fuel to power automobiles, or actually make plastics and other chemicals that are now being made from petroleum, we could actually achieve practically the same savings.

Chairman PROXMIRE. And how about the capital requirements, have you had a chance to make any estimates on that, or am I getting a little ahead of you?

CAPITAL REQUIREMENTS OF PILOT PLANT CONSTRUCTION

Mr. SPANO. It is a little premature. But I will give you an idea of what it would cost and what I would do if I had to make that decision This is my personal judgment and I am not committing the Army or anyone else. To expedite the exploitation of this new technology various actions should be taken. For example, on the basic side we must emphasize the mutations work. It is our feeling that it is possible to increase the cellulase production from the fungus strain at least tenfold, that is a least 1½ times as good as we have today. This will cut down the cost.

Chairman PROXMIRE. I am a little confused with those figures. You say 10 times?

Mr. SPANO. Not as we have today, but tenfold better than the wild strain we started with.

Chairman PROXMIRE. I see. One and a half times what you have today, or ten-fold over the wild strain?

Mr. SPANO. That is right.

Chairman PROXMIRE. And rather than the 14 percent that was estimated a minute ago you can expect at least 20 percent?

Mr. SPANO. This gives us greater rates of production and conversion. In other words, if we get more cellulase enzymes——

Chairman PROXMIRE. You are talking about increasing the total volume but reducing the cost?

Mr. SPANO. That is right, that is basically what we are looking for. This would have a tremendous impact in the reduction of the cost of the gluclose.

We would like also to initiate some work on finding some strains to break down the lignin, because about 50 percent of the cellulose waste shows up in the solids as lignin. Maybe we could convert the lignin also into the sugar fraction. Of course, we will have to optimize the process itself. The prepilot work that we are starting now is geared to optimize the various processes within the overall process. This work has to be emphasized. Upon completion of the prepilot studies it is desirable to scale up the process to 200,000 pounds per month. This would be the demonstration pilot process.

Our schedule, as I see it, would be as follows: At the present time, our capacity with a prepilot plant is around 6 tons per year, which is about 1,000 pounds per month. We would go up to 1,200 tons per year in the pilot unit the regular pilot, and then I would propose to run a full-scale plant to process 500 tons of trash per day. Of this about 250 tons per day would be the cellulosic fraction trash processed.

Chairman PROXMIRE. You would be handling 500 tons of trash per day?

Mr. SPANO. Per day.

Chairman PROXMIRE. And about 250 tons——

Mr. SPANO. 250 tons of that would be cellulosic material.

Chairman PROXMIRE. What is the timetable for that?

Mr. SPANO. Assuming that we start at time x, the prepilot work should be completed in 1.5 years. So x plus 18 months for example.

Then the real pilot demonstration unit would be scheduled for completion in *x* plus 3 years. And the full scale operational plant would be scheduled for full operation by *x* plus 6 years. So I would say by 1980 we would have a plant that could handle 500 tons of trash per day operationally.

Chairman PROXMIRE. How many tons?

Mr. SPANO. 500 tons per day.

Chairman PROXMIRE. At one plant?

Mr. SPANO. One plant. Now, this would cover a community or a city of about 200,000 people.

Chairman PROXMIRE. Now, how far off are we from getting on a national basis a very substantial contribution to our need for oil for fuel purposes, especially gasoline? Would this be another 5 years?

Mr. SPANO. Sir, at the rate we are going I do not think we are really going to move that fast. This program would have to be really emphasized. As a matter of fact, this is what it would take, the cost estimates coming directly from me and no one else. We feel that in order to do this job we will need approximately 28 people, 28 man-years, to work on this particular program. And it is broken out as follows: On the prepilot side the studies will cost us about $2½ million. The actual pilot would cost us a little over $3 million. And the full-scale plant at today's dollars would cost us about $12½ million.

Now, if we are going to go into the actual building of the plant 3 years from now, that is, if we started today, and 3 years later we start the actual building of the plant, and if we assumed that because of inflation the cost increase will be about 15 percent per year, the price of the overall plant would run to about $19 million.

Chairman PROXMIRE. I am not sure whether you or maybe some of our other witnesses are better qualified to talk about translating this into meeting our national needs. I understand this is an Army lab and you have the function of handling the wastes that are a problem for the military. You have done a brilliant job in that respect, and I think you have contributed greatly to it. It has real implications as far as the national economy is concerned. But are you prepared, or do you know of any of our witnesses that are prepared to talk about it?

Mr. SPANO. Yes, sir, we are.

Chairman PROXMIRE. Then, I will confine my questions to this area, and the other witnesses will be able to talk about the implications of this for the future.

Can you tell us what the implications are for municipal and agricultural effects if these wastes can be used in this way?

Mr. SPANO. Are we talking about health effects?

NATIONAL PRIORITIES IMPLICATIONS OF THE NATICK PROCESS

Chairman PROXMIRE. The waste materials are the most likely candidates. I think Mr. Nystrom gave us some. And I would like to know what the implications are for municipal and agricultural purposes. This would be a matter of easing the burden on the municipal governments, right?

Mr. SPANO. Right.

Chairman PROXMIRE. Most of these wastes came from agriculture. I worked on a dairy farm last year, and they gave me a job that they figured a Senator would be well qualified to handle, which was handling the shovel and so forth. And I was impressed by the use of agricultural wastes at that point, I was impressed in more ways than one. But it is a remarkable system in which, as you know, the wastes are put on to the manure spreader and then they go right out in the field, and they use it, they do not waste it, they need it. And if they do not use it for that purpose they have to buy other fertilizer.

So what are the agricultural implications here?

Ms. Mandels.

Ms. **Mandels.** In the small farm it is wonderful to spread manure back onto the ground. But in concentrated feedlots it is impossible, the transportation makes it too expensive. This is a major water pollutant, it is a nuisance to the community, so conversion of animal feedlot wastes is an acute problem, and anything to convert this into something useful would be very helpful.

Chairman **Proxmire.** Is this what you did have in mind, Mr. Nystrom, when you gave us that estimate?

Mr. **Nystrom.** That is right, this is feedlot wastes.

Chairman **Proxmire.** Not the wastes on the farm?

Mr. **Nystrom.** That is right.

Ms. **Mandels.** When we talk about that low percentage, that is the collectible trash which is already being piled up in a small location. It is a different matter to pick up diffuse trash. If you could get it you would have a great deal more.

Chairman **Proxmire.** How about the municipal system we have now?

Ms. **Mandels.** Again, that is collectible trash that is now ending up in the dump.

Chairman **Proxmire.** How much of the municipal and animal wastes produced each year can be used?

Is that what you gave me, Mr. Nystrom?

FIFTY PERCENT OF ALL TRASH WASTE IS READILY COLLECTIBLE

Mr. **Nystrom.** You mean of the readily collectible trash? It is roughly 50 percent.

Chairman **Proxmire.** About half.

Mr. **Nystrom.** About half is cellulose.

Chairman **Proxmire.** Can you go through very quickly the calculations again showing how much glucose is produced by what amount of waste materials or substrate and the amount of ethyl alcohol or feed to be produced from glucose?

Mr. **Nystrom.** Sure. You may have those figures if you want them.

On the urban wastes, the 1 times 10 to the 7th tons per year of dry organic matter going into the calculations could be converted into roughly 2.4 percent of the total gasoline production. Again this is the present gasoline production of the United States.

Of the animal wastes, it would be 2 times 10 to the 7th tons per year which we could readily collect would be converted into 1.2 percent of the total present gasoline production.

In the agricultural wastes, 20 times 10 to the 7th tons per year could be converted into about 9.6 percent of the total gasoline production, for a grand total of about 13.2, 13.3 percent of the total gasoline production.

Chairman PROXMIRE. Ms. Mandels, can you explain what ethyl alcohol is, how it can be used as a fuel, and for other purposes, and what needs to be done with the glucose to produce the ethyl alcohol, or ethanol, as it is sometimes called?

WHAT ETHYL ALCOHOL IS

Ms. MANDELS. Ethyl alcohol is drinking alcohol. It is produced either from ethylene, which is a hydrocarbon, or it can be produced from sucrose, which is cane sugar, or from glucose by fermentation by a microorganism. I think Mr. Reed will be telling you about his use of it as a fuel, so I will leave that to him.

As Mr. Spano said, about 13 pounds of glucose is required to produce a gallon of alcohol.

Is that the question that you asked?

If I might interject a comment——

HOW GLUCOSE IS MADE INTO ETHYL ALCOHOL

Chairman PROXMIRE. What I had in mind is what has to be done to glucose to make it into alcohol?

Ms. MANDELS. This is a known technology.

Chairman PROXMIRE. It is done all the time?

Ms. MANDELS. Yes.

Chairman PROXMIRE. And it is a simple process?

Ms. MANDELS. Basically, it is what the moonshiner does. He ferments it with a microorganism, and then he distills it.

Chairman PROXMIRE. Is that how you turn glucose into alcohol?

Ms. MANDELS. Yes.

FOOD POTENTIAL OF THE NATICK PROCESS

Chairman PROXMIRE. Can you also elaborate on the feed potential in your process? I have emphasized oil because that is what is in the front of many of our minds, but I think it has an even greater potential in the long run for food than petroleum.

Ms. MANDELS. I think so. Particularly in undeveloped countries when you have glucose and you grow yeast on it you can direct your fermentation according to the conditions either to get mainly alcohol or yeast cells. Yeast cells are about 50 percent protein, and they can be eaten by humans. And you could take glucose on that chart and make single-cell protein, as we call it. In this case the yield is much greater. If you think of 1,000 pounds of trash per person in the United States, and assume that 50 percent of this is cellulose, you can produce 500 pounds of glucose. If you ferment that glucose to ethanol you would get 30 gallons, which is a very small percentage of your energy. If you fermented half of that glucose to yeast you would get 25 pounds of yeast. This would be enough to feed a person for a year. So our need for energy calories is an order of magnitude greater than food. As food it can be a much larger contribution. In the United States we have not thought much about single-cell protein, but it can be used as an animal food which could substitute for soybean meal and fish meal which have been scarce and expensive this past summer.

Chairman PROXMIRE. And so is it suitable for human consumption directly, or is it fed to animals?

Ms. MANDELS. Single-cell protein for human consumption is still controversial. We are not working on this. There are many people working on single-cell proteins from waste carbohydrates, and even from hydrocarbons. Whether that is suitable for human food is controversial. However, we could eat a certain amount of it. It is less controversial as animal food. And, of course, the animal feed eventually winds up as human food.

Chairman PROXMIRE. I understand that a number of private corporations have contacted you in recent weeks to inquire about the cellulose conversion process. Can you tell us why your process can be superior to their method or for converting cellulose?

NATICK PROCESS SUPERIOR TO ALL OTHER EXISTING ONES

Mr. SPANO. As I mentioned in my statement, sir, the advantage of using enzymes is their specificity of action in the process itself. The cellulase just breaks down the cellulose. Normally, if one uses acid, the acid breaks down other products which may be present in the trash. So this is probably one of the reasons why the enzymatic process is a lot more attractive than some of the other processes that they are looking at now.

Chairman PROXMIRE. Can you give us the names of the firms who have contacted you by visiting you or telephoning or writing you?

Mr. SPANO. Yes. From the standpoint of producing glucose we have had people from Union Carbide, W. R. Grace, Du Pont, Charles Pfizer Co., and Gulf. From the standpoint of disposing of wastes, St. Regis Co., the Kimberley-Clark people, Weyerhaeuser, TVA, and various States. The State of Oregon apparently has 800,000 tons of straw annually that they would like to dispose of. At the present time, they are burning it and having a rough time. The State of Connecticut, some communities in Pennsylvania, the State of Rhode Island, and the State of Indiana also have made inquiries.

We also have had inquiries from foreign countries, Guatemala, France, India, Mexico, Russia, Cuba, Brazil, and England.

These people in foreign countries have interest primarily in single-cell protein.

Chairman PROXMIRE. Do you have any kind of discrimination in making this available? Is it made available to everybody that inquiries?

KNOW-HOW FROM THE NATICK PROCESS OPEN TO ALL WHO ARE INTERESTED

Mr. SPANO. No, sir. As a matter of fact, we have provided strains to practically everybody.

Chairman PROXMIRE. My question is, do you make it available to everyone?

Mr. SPANO. Yes.

Chairman PROXMIRE. How about Russia, the Soviet Union?

Mr. SPANO. They have received some of our strains, yes.

Chairman PROXMIRE. Have you checked with the State Department, or anybody else, as to whether or not you should follow that policy with respect to the Soviet Union?

Ms. MANDELS. Actually, the State Department brought scientists from the Soviet Union to visit, and we gave them cultures, and all of our information.

Chairman PROXMIRE. So you have fully explained the process to them, and given them samples of the culture you have developed; is that correct?

Ms. MANDELS. That is correct.

Chairman PROXMIRE. To the best of your knowledge, which of the firms are actively engaged in their own research on the process, and which of them have expressed an interest in implementing your finding?

Mr. SPANO. We know for sure that at least three companies are working on single-cell protein not based on our work.

Chairman PROXMIRE. Not based on your work?

Mr. SPANO. Yes, sir.

Chairman PROXMIRE. What firms are those?

Mr. SPANO. Amoco, I believe, is planning to put up a 10-million-pounds-per-year plant for single-cell protein. This plant will be on stream in about 1 or 2 years. British Petroleum, of course, has a large plant.

Chairman PROXMIRE. They are the people who are making this from petroleum?

Mr. SPANO. That is right.

Chairman PROXMIRE. And not from trash?

Mr. SPANO. No, sir. Nobody is making it from trash as far as I know.

Chairman PROXMIRE. Nobody is interested in making it from trash so far; is that right?

Mr. SPANO. That is right.

Mr. NYSTROM. General Electric is actively involved in converting feedlot wastes. And they are actively involved in converting that into single cell protein to feed back to the rumen of the cow. They have a rather large interest in that area. However, this is not for human consumption; it is for animal feed.

WHICH GOVERNMENT AGENCIES HAVE CONTACTED THE NATICK TEAM?

Chairman PROXMIRE. Which government agencies have been contacted and what have been the nature of your conversations with them? First, the Federal Government.

Mr. SPANO. We have had discussions with the Tennessee Valley Authority. The TVA people are interested in disposing of a lot of sawdust. We have talked to the Federal Energy Office recently, the National Science Foundation—and that is about it.

Chairman PROXMIRE. And then, you indicated earlier what State and local agencies have contacted?

Mr. SPANO. Yes, sir.

Chairman PROXMIRE. You gave us that?

Mr. SPANO. Yes.

Chairman PROXMIRE. Ms. Mandels, I understand that the Soviet Union sent a delegation of scientists who talked to you about your work. Can you tell us what the nature of your discussions with them was, when it occurred, what they were interested in, and what you told them, and whether you gave any culture samples, and so forth?

Ms. MANDELS. Yes. They visited us in October 1972. And this was the scientific and educational cooperation with the Russians which was set up about that time. They were brought by Mr. Halverson of Brandeis who was on that committee. They came through the laboratories and they saw everything, we withheld nothing, we gave them cultures and information. In fact, we had been in mail communication with the Russians before that, because they had expressed a great deal of interest in our process. And it is not a classified type of thing.

SOVIETS HAVE SENT A TEAM, BUT HAVE NOT EXCHANGED ANY OF THEIR KNOW-HOW

Chairman PROXMIRE. Were you able to ask the Soviet scientists about their work in cellulose conversion?

Ms. MANDELS. We have asked them, but so far we have not received a reply. However, the scientists who visited us are not directly involved in this work, they were people higher up, more the administrative type.

Chairman PROXMIRE. It has been a year and a half, they took your cultures, and all the information that you had, and you have gotten nothing back from them, it has been a one-way street, is that right?

Ms. MANDELS. Essentially, that is true.

Chairman PROXMIRE. It seems reasonable to me that the Soviet Union has the same interest in conserving resources and developing low-cost food and fuel as we have. It is a great political as well as economic problem, as we know, between the countries. Is it fair to say that you candidly answered their questions and told them what they wanted to know, but they were not as accommodating with you?

Ms. MANDELS. I am not sure it was deliberate, sir. It may be just bureaucracy.

Chairman PROXMIRE. You are part of our bureaucracy.

Ms. MANDELS. Yes. But they met me directly. When our delegation visited Russia, I believe they were very well received and shown everything. I think that if any specific question were not answered it may well be that they got lost along the line.

Chairman PROXMIRE. Did you make any effort to pursue to find out by correspondence? If they were not the right people, if they were the top officials who brought this information and material back to their scientists, did they not communicate with you by mail or otherwise?

Ms. MANDELS. Until the Russians visited Natick it was rather difficult for people in an Army lab to communicate, because we have our security, too.

SOVIET DEVELOPMENT OF CELLULASE PROCESSES

Chairman PROXMIRE. Do you have any knowledge of the extent to which they have developed this process now, either with the knowledge that they got from Natick or elsewhere in Russia, or in any other country?

Ms. MANDELS. They have done a good bit of work on acid hydrolysis. And I believe they are not too satisfied. They are really just moving into enzymatic hydrolysis. Glucose is made today from corn starch, 10 years ago it was made by acid hydrolysis. It has just shifted to the enzyme process. I would say cellulase is favored now because the acid process is not satisfactory. Up until now the enzymatic process was not sufficiently developed to be a substitute.

Chairman PROXMIRE. Do you have any knowledge of whether or not the Soviet Union has been able to develop a more efficient process converting cellulose to glucose?

Ms. MANDELS. I would say they are behind us.

Chairman PROXMIRE. But are they about at the level they were before this Natick breakthrough?

Ms. MANDELS. I do not think they have worked so much on actual conversion of cellulose to glucose by enzymes as we did. As far as I know it is not in the published literature.

Chairman PROXMIRE. Have they contacted you in any way since then, and indicated any further interest, or tried to get any further information?

Ms. MANDELS. Only through people like Mr. Halverson and Mr. Humphrey at the University of Pennsylvania, who went with the American delegation to Russia, and who came back and spoke to us.

Chairman PROXMIRE. Of course, the people at Natick were doing scientific work. It does not do much good for other scientists to have it if they are not going to work on it.

Ms. MANDELS. Everything we have is published and is available to everyone.

HOW THE VISIT FROM THE SOVIET TEAM WAS HANDLED

Chairman PROXMIRE. Mr. Spano, what is the policy with regard to the visit by the Soviet scientists, who decides on how much information to give them, and who in the Army or the State Department talked to you about their visit?

Mr. SPANO. We had a call from the Office of Science and Technology before they came to visit with us. And the policy was—well, we decided what to give them, we discussed this whole process. It had been cleared with the White House that the process would be discussed with them. And since this was not classified, we saw no reason why we should not exchange information with them.

RUSSIANS SPEND $800,000 ON EQUIPMENT RELATED TO THE NATICK PROCESS

Senator PROXMIRE. I understand that the Russians bought equipment from the same firm from which you bought your prepilot plant from, and that they spent roughly twice the amount you did. Is this correct? Can you give us the figures?

Mr. SPANO. I would like to refer that question to Mr. Nystrom, the project officer on that program.

Mr. NYSTROM. It is roughly four times.

Chairman PROXMIRE. They spent four times as much as we did on equipment?

Mr. NYSTROM. Right. One prepilot plant costs came to about $186,000. And they purchased equipment with a total value of about $800,000. Some of the reason for that difference in price is, they needed to purchase considerable amounts of spares, et cetera, to take back to the Soviet Union.

Chairman PROXMIRE. If they bought four times as much as we did, $800,000 compared to $186,000——

Mr. NYSTROM. They also purchased a small computer, and some of the technology from Fermentation Designed, Inc., to program this computer. This cost them roughly $200,000.

Chairman PROXMIRE. That was in addition to the computer they bought?

Mr. NYSTROM. No, this was the total amount, about $600,000 for fermentation equipment——

Chairman PROXMIRE. With three times as much for fermentation, and another $200,000 for the computer?

Mr. NYSTROM. That is right.

Chairman PROXMIRE. Is there anything we can do at this time to find out what they are doing and how much progress they have made? Do you not think an exchange of information with them would or could be useful in your effort at Natick?

Mr. NYSTROM. As far as we know, the equipment that they purchased and the specifications that were required, it looks like they are trying to develop a process to produce single cell protein from petroleum. However, they will not say for sure. The company that sold the equipment is interested in selling equipment, so they did not push the issue. With regards to the questions that I asked either there was a language barrier, or they did understand and did not want to relate the information. But again, from the equipment specs, it looks like they are interested in handling petroleum.

Mr. SPANO. I would like to add something, sir.

I agree with you in pursuing this; that is, to try to get the information from them. I do not think we have actively pursued it ourselves, to get this information. So we really cannot say that they have denied us this information.

Chairman PROXMIRE. I do not mean to give the impression of taking a hostile attitude here. I think wherever we can cooperate with any nation in the world, the Soviet Union, China, or any other, we ought to. But at the same time, it seems to me that where there is a one-way street, they are getting more information from us and we are getting nothing from them, it is foolishness on our part.

You say they did not refuse to give us information, we just did not offer it. It may be that they are behind us. They are ahead of us in a few technologies, but they are behind us in most. But we can still learn a lot if we are as inquisitive and aggressive as we ought to be.

I think you have explained to me how much the Natick effort has cost so far, and how much is it expected to cost, the pilot plant $3 million, and a regular plant $12 million.

Mr. SPANO. At today's base prices.

Chairman PROXMIRE. The pilot plant would be around $3 million?

Mr. SPANO. That is right.

Chairman PROXMIRE. If the Army does not support the pilot plant operations, what will happen to the project?

Mr. SPANO. Sir, I cannot answer that. I have no idea where we could get the money.

DETERMINATION OF HOW ECONOMICAL THE PROCESS IS WILL COME IN THE NEAR FUTURE

Chairman PROXMIRE. Mr. Nystrom, the critical question is whether the costs of production through the Natick processes are economical relative to alternative ways of obtaining energy or food. What light can you shed on this question now, and when can we expect to get some answers based on hard data?

Mr. NYSTROM. I think we should start getting some answers rather quickly once we get into a full prepilot plant work, which we are ready to do probably by the end of June. The areas that need looking into have been singled out, and we know what work has to be done and in these particular areas. None of the problems look like they are unsurmountable. It is just a matter of committing enough manpower into this process to solve the problems.

We are taking a very detailed look at the process. We realize that we have to be competitive. And we are going to try to optimize the process to the best of our ability so that we can be economically competitive. Right now I would say we could compete with the price of glucose, if we wanted to go into that business.

Chairman PROXMIRE. As I understand the timetable on this, you would proceed in 18 months after you get the go ahead and the pilot plant would be in operation, is that right?

Mr. NYSTROM. That is correct.

Chairman PROXMIRE. And then how long before you are in a position to start building the regular plant?

Mr. NYSTROM. That again, would depend upon manpower and money.

Chairman PROXMIRE. On the assumption that the manpower and money is available.

Mr. NYSTROM. Another 18 months, I would say.

Chairman PROXMIRE. Another 18 months, then before you would complete the regular plant?

Mr. NYSTROM. That is correct. These are Mr. Spano's figures.

Mr. SPANO. I mentioned this before, sir. The time schedule that I would propose would be 18 months to run the prepilot plant, and then another 18 months to run the pilot plant. And then it would take 3 years to actually put up a large plant on stream.

PATENT POLICY ON NATICK PATENTS

Chairman PROXMIRE. Finally, Mr. Spano—I just have a few more questions— I understand that the Government owns two patents relating to the Natick discoveries. What is the Government's policy regarding access to the patents by private persons and foreign governments, and who establishes the policy for the Army?

Mr. SPANO. I checked with the legal department, and as far as I know, those patents that we own are free to be issued to anyone; that is, on a royalty-free basis. So anyone can ask for these patents, and they can be issued to them.

Chairman PROXMIRE. On the assumption that we want to develop this process as rapidly as possible and come on with as big a supply as we can—I think people are interested in the well-being of our country, and the well-being of mankind, and for that reason we would want it from the standpoint of food as well as energy—do you believe that the policy that we have been following is the best thing to do?

Mr. SPANO. That is, to issue the patents?

Chairman PROXMIRE. Just to make them available to anybody—foreign governments, American citizens—and anybody who wants them can have them?

Mr. SPANO. In order to get the thing developed as rapidly as possible, I see no other choice, sir.

Chairman PROXMIRE. And do you think that is the objective too, to get this developed as rapidly as you can.

Mr. SPANO I did not get the question, sir.

Chairman PROXMIRE. The purpose would be to get this developed as rapidly as possible?

Mr. SPANO. Yes.

Chairman PROXMIRE. One other alternative would be to do this on some kind of a basis in which you would let the private firms compete with commitments. In other words, if a firm would come in and promise to put in a very large amount of capital investment, and move ahead, that they might get an exclusive patent giving them an opportunity to make money but also giving them the kind of assurance and protection which they might logically insist on if they are going to make a big capital investment. I just do not want to see a situation where we have a great, rich scientific opportunity here, an economic opportunity, that we fail to take advantage of because there is no policy or program that is going to result in production.

Mr. SPANO. This is a policy that has to be set up at a higher level than NLabs. We are in no position to set up that policy. I think the Government has to make that policy.

Chairman PROXMIRE. Supposing for the record—I realize that you feel that the policy has to be made by the Government, but you folks are all close to this and you have invested a great deal of your own skill—if you have any suggestions for improving the policy, this generous policy, and making it more workable, we would appreciate hearing from you.

Ms. MANDELS. I think both of the patents relate to hydrolysis of pure cellulose, and any practical process is going to be based on waste cellulose. That process is not even patented; that is available in the literature.

Chairman PROXMIRE. At this point, anyway, I think it is too late to shut the barn door; it is just from the standpoint of future policies. We are interested, in this committee, in doing our best to try to make research effective in this country so that this can be translated into economic advantage for all of us. And we would like to learn from this kind of experience if we can. And it may be that—after all, you say that there are ways you can improve this, and you are working on it constantly. And it may be that we can follow a wiser policy here. So let us know what your recommendations are.

Mr. SPANO. We will, sir.

[The following information was subsequently supplied for the record:]

Government developed technology that may have a significant impact on a national or international basis should be given special consideration with regards to issuance of patents and patent licenses in order to assure the earliest practicable exploitation of such technology for the good of mankind.

Rather than granting royalty free licenses to everyone that applies for it, it would be desirable to grant an exclusive license to one or two industrial firms who would make a definite corporate commitment that would assure that the fruits of such technology would be available to the consumer at the earliest practicable date.

Exclusive licenses for a period of ten years would provide such corporations adequate time to profit from such technology with adequate safeguards that would prevent erosion of potential profits derivable from such new processes. In addition, if the risk is sufficiently high, it may be necessary also to grant such commercial firms certain tax breaks through expedited equipment depreciation.

This appears to be a good option that would assure the earliest possible exploitation of such developments for the benefit of the consumer.

Chairman PROXMIRE. As I say, you are real heroes. I think you have done a great job. And I hope that we can make this effective for the country and people everywhere as it promises to be.

Thank you very much.

Mr. SPANO. Thank you, sir.

Chairman PROXMIRE. Our next two witnesses, Thomas Reed and David Wilson, are both scientists at the Massachusetts Institute of Technology. We invited them to appear before us because of their well-known expertise in the general area under discussion today and because of their familiarity with the work at the Natick Laboratories and related efforts in other parts of the country.

We asked both gentlemen to visit the Natick Laboratories and give us their independent scientific judgments about the work there with particular reference to the energy implications. Tomorrow, we will hear from two experts, among others, to address the food implications of cellulose conversion.

Now, each of you gentlemen, Mr. Wilson and Mr. Reed, may summarize your prepared statements in your own way, and then we will have some questions. And I think it would also be a good idea to give us some notion of your scientific background and qualifications so that the record is clear about your expertise.

Mr. Reed, please proceed.

STATEMENT OF THOMAS B. REED, RESEARCH CHEMIST, ENERGY LABORATORY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. REED. Good morning, Senator and gentlemen. Thank you very much for this opportunity to appear.

I am a scientist at the Massachusetts Institute of Technology in Cambridge, Mass. I spend half my time at the MIT Lincoln Laboratory, where I work in solid state physics and solar energy. I am also the director of the Methanol Center at the MIT Energy Laboratory where we are testing the use of alcohol in automobiles. I previously worked for Union Carbide and Shell Oil. I have a doctor's degree in physical chemistry from the University of Minnesota.

I have become interested in the general question of the use of alcohol as a fuel, any alcohol, no matter how it is produced. And for that reason I would like to put the Natick Laboratory process in the perspective of other processes for making alcohol and show how alcohol could be a very useful fuel.

In developing the use of alcohol, there are two questions that must be answered. The first, is it a usable fuel, and is its use economical? The other is, if we agree that it is useful, then how are we going to produce it?

Before I answer these questions, I should mention that there are a large number of various kinds of alcohols known to chemists. But the public knows primarily of only two alcohols. There is wood alcohol, more properly called methanol, or methyl alcohol. And this is the kind which, if you drink it, you go blind, or it is the kind you can burn in a sterno heating unit inside a room with a clean blue flame. It was widely used as a fuel during the middle of the last century when it was produced as a byproduct of charcoal making for the steel industry.

After petroleum was discovered, and you could extract it by punching a hole in the ground, methanol could not compete economically, and its use as fuel stopped. As long as petroleum is sufficiently cheap, I am sure we will continue to use it. However, we are now approaching an era in which it may no longer be cheap, and so we must consider other fuels.

Ethanol, of course, is the beverage alcohol usually made by fermentation or from petroleum. You have already heard from Mary Mandels about its manufacture from waste, using enzymes.

Both alcohols burn very well in many fuel applications. But I would like especially to direct your attention to their use as automotive fuel, since this is one of the most difficult applications of any fuel. If you wish to heat your home, or fire an electric boiler, you can use coal or wood or trash, or any variety of materials. But my car is very fussy about its intake, and it will only run on gasoline or gasoline-alcohol mixtures.

I became interested in alcohols as fuels about a year and a half ago when I was reading about the proposed research in hydrogen, especially for automotive use. As a chemist, I felt that this would not become a reality for at least 30 or 40 years. My life expectancy may or may not carry me that far along, and as I was interested in fuels which would tide us over or be even better than hydrogen, I soon became interested in the use of the alcohols as automotive fuels.

Just before World War II, the French and Germans, anticipating the need of alcohol for munitions purposes, set up programs to produce great quantities of alcohol, and they used them regularly as additives for gasolines for 4 years. Cuba, Brazil, South Africa, and other countries which have agricultural surpluses of sugar still are converting sugar by ordinary fermentation techniques into alcohol and using it in their cars (Petrolbrax Corp.). If the sugar market is very good, they will sell it for sugar.

My experience has been primarily with methanol, but most of the properties of methanol are similar to ethanol. I would like to show you a few charts of our results to set the stage.

REED TESTS METHANOL AS A FUEL IN HIS FAMILY CAR

I have a 55-gallon drum of methanol in my garage, which I purchased last summer for about 40 cents a gallon. I have been experimenting using it first in one of my cars, an old car which I did not care much about; and second, in my brand new Ford Pinto. I am using a mixture generally of 10 percent methanol in regular gasoline. I feel that this is a good blend. No alterations were made to the cars.

At present, methanol is produced in this country at something like 1 percent of the level of our gasoline production. It may seem small, but that is a billion gallons a year. In order even to reach a 10-percent level, we would have to increase our total production by a factor of 10.

Therefore, for the time being, let us use the cars we have with the alcohol that we can produce as fast as we can produce it and as fast as it is economically justifiable to add it to our gasoline.

Chart 1[1] shows my results on my 1969 Toyota as a function of how much methanol we tested from 0–30 percent in the tank. You will notice that the fuel economy in miles per gallon increases as you add methanol, and then as you continue to add more and more it decreases over straight gasoline.

Since January this has become of prime interest to people.

METHANOL AND ETHANOL—THE ARGUMENTS ARE THE SAME

Chairman **PROXMIRE.** That is methanol, not ethanol?

Mr. **REED.** That is right. However, other people are using ethanol, and to a great extent what I am saying about methanol will apply also to ethanol. The details will be different.

Chairman **PROXMIRE.** So it looks as if there is an increase in efficiency up until about 15 percent, and then there is a gradual decline; is that right?

Mr. **REED.** That is right. And for other cars we have tested, the optimum would be for other values. In January, fuel consumption was our main concern. Starting 5 or 6 years ago, we became interested in pollution. The chart also shows the percent of carbon monoxide in the exhaust. With 10 percent methanol the carbon monoxide falls by a factor of not quite two.

Chairman **PROXMIRE.** I am quite surprised that the acceleration time is not increased, just because I have the simple-minded reaction from the fact that the racing drivers use methanol.

Mr. **REED.** If you will notice the chart, the top line shows that the seconds required to reach 60 miles an hour are decreased, so acceleration increased as you expected.

Chairman **PROXMIRE.** I see.

Mr. **REED.** As you say, the racing cars prefer pure methanol. As a teenager, my son would have been interested in the time required to get a way from a stoplight, and he would have been interested in the increased acceleration shown in the top line.

People used to say methanol would burn out the valves. We made some tests on exhaust temperature. We found the temperature goes down on the order of 20 to 30 degrees as you add 10 percent methanol—not a lot—but at least in the right direction, both to make it easy on the motor and to decrease emissions.

15 PERCENT METHANOL MIXTURE PROVIDES BEST PERFORMANCE

Chairman **PROXMIRE.** Is it fair to conclude, then, that in terms of economy, and in terms of temperature, and in terms of acceleration, you get a better performance in all cases with methanol up to a certain point, up to 15 percent or so on the basis of your studies?

Mr. **REED.** On the basis of our tests, that is fair to conclude. I should say that there are many people who agreed with us about increased mileage, and many who do not; everybody seems to agree that methanol will work about as well as gasoline.

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[1] See chart 1, p. 32.

Let me show you our second round of tests in chart 2.[1]

This is fuel economy on five cars that we have tested, just borrowing them from friends and taking them out and running them over a prescribed course. You see the tendency is for the fuel economy to rise again with methanol and then drop back again.

METHANOL GETS FEWER MILES PER GALLON

Chart 3 [2] shows the relative economics of methanol to gasoline. One of the characteristics of methanol which may be a drawback (but does not seem to be for racing drivers) is that methanol has less energy per gallon than gasoline and this might mean that you would have to use a larger gas tank to get around. In fact, the energy is about half that of gasoline per gallon. And so pure methanol cars get less miles per gallon. The line labeled 2 is the mileage corresponding to requiring 2 gallons of methanol to equal 1 gallon of gasoline. However, the lines with a 1½ show that all of our data on the cars, at least up to 10 percent, shows that methanol replaces gasoline at least 1 to 1, and maybe it even takes half a gallon of methanol to make 1 gallon of gasoline.

These results vary for different cars.

Chairman PROXMIRE. What you conclude here is that in some cars it takes 2 gallons of methanol to be an equivalent of 1 gallon of gasoline, and in others only one-half a gallon, depending on the cars; is that right?

Mr. REED. None of our data lines go below the one for one, unless you get out to 20 percent.

Chairman PROXMIRE. If you have 15 percent or more, then it is debatable.

Mr. REED. Exactly.

IN CERTAIN VOLUMES, A METHANOL MIXTURE IS CHEAPER THAN PURE GASOLINE

Last year the price of methanol was between 14 and 18 cents a gallon in tank car lots, and gasoline, purchased in the same quantity, ran from about 16 to 21 cents a gallon. Last month the quoted prices on methanol were 23 cents a gallon, and the quoted prices on gasoline was 30 or 31 cents a gallon.

So in mixtures, we believe that already methanol is a more economical fuel than gasoline even if you do not take into account lower pollution and increased performance.

One aspect of performance which I have not yet mentioned is emissions. Chart 4 [3] shows the emissions of CO for four cars. The CO has decreased on the order of a factor of two for the cars that had high pollution. The lowest line shows a 1972 Ford which is already meeting the standards. So emissions decrease with methanol addition in all cases.

Chart 5 [4] shows octane of methanol blends.

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[1] See chart 2, p. 33.
[2] See chart 3, p. 33.
[3] See chart 4, p. 34.
[4] See chart 5, p. 34.

The basic fuel has a little over 95 octane. (This is the research octane, incidentally) 10-percent methanol increased octane to about 98, and 25 percent took it up to 102 octane, which is the equivalent of very high octane fuel, essentially aviation fuel. So methanol improves octane in the same way that tetraethyl lead does.

Quite recently I spoke to the director of Long Line Research of the Volkswagen Corp. And they had recently been making tests along these lines. And he said that what attracted them very much was the octane-improving ability of the alcohols, ethyl alcohol, and methyl alcohol. In Germany, a small country, they are very worried about the quarter of a billion tons of lead that they are distributing around their landscape by using tetraethyl lead, so they are very attracted to the use of methanol.

I believe Detroit has recently become much more interested in methanol, because if you take the lead out of the gasoline the performance goes down. If you use catalytic converters performance decreases further. If you use methanol the performance will go back up.

There are a few technical problems in introducing methanol into the fuel distribution system as shown in chart 6.[1] One of them has to do with temperature. At sufficiently low temperatures pure methanol put in gasoline will separate into two mixtures, one at the bottom of your tank and the other on the top. I have been operating one of my cars some 10,000 miles, and I have gone through a Massachusetts winter using this mixture. I have had no difficulty in starting. The mixture starts better than ordinary gasoline. But when cold the engine has low power. This is not a desirable feature. If manufacturers produce alcohols as fuels rather than for chemical uses, they will produce an impure grade which has all the alcohols mixed together. And this grade has been called methyl-fuel. Methyl-fuel is more soluble in gasoline and will only separate at −30 degrees Fahrenheit (10-percent mix).

LOW TEMPERATURES RETARD STARTING PERFORMANCE OF A METHANOL MIXTURE

Chairman **Proxmire**. Your conclusion on that is that at very low temperature you may have a problem in starting and in some part of your tank and the other on the top. I have been operating one of my cars that right?

Mr. **Reed**. In the first 4 or 5 minutes on a cold morning after the car starts, it may stutter a little bit. After it warms up a minute or two it is OK. In any case, I do not think that this would be the big problem.

The problem that disturbs the oil companies is the behavior of blends of alcohol and gasoline in the presence of water, because gasoline is often carried on barges which have water in the bottom, it is stored in tanks in service stations which have water in the bottom, and, in fact, even your own gas tank may have a little water in the bottom. This is a two-edged sword. The good edge is, a lot of people put alcohol in their tank to take the water out of their tank.

Chart 7[2] gives the number of gallons of water that could be dissolved in 10,000 gallons of fuel. In 10,000 gallons of pure gasoline

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[1] See chart 6, p. 35.
[2] See chart 7, p. 35.

you can only dissolve 1 gallon of water. However, if you mix 10-percent methanol with gasoline it will now dissolve 10 gallons of water. This means that the condensation which normally occurs in tanks which are being used for fuel will be carried away by the gasoline. However, if you have more than 10 gallons in the bottom of your fuel tank, or your barge or tanker, then it will separate out into two phases, and you will have essentially pure alcohol on the bottom, and pure gasoline on the top. Therefore it would be necessary either to ship the methanol separately up to whatever point you have a dry system, or to shift to a dry system. We are planning to operate on the order of 500 cars at MIT, starting about August 1, with methanol blends and we will mix the alcohol and the gasoline at our local filling station for these tests.

As time goes by we are becoming more and more fussy about tanks and tankers leaking water contaminated with gasoline into the ocean, the rivers, or into our ground water. As time goes by we are tightening up our precautions on water getting into the gasoline. I do not look upon this as an insurmountable problem, but it does mean that at present we cannot put 10 percent methanol in a barge going up the Hudson River and expect it to arrive in Albany unless we have dried out the water at the bottom of the barge. This may be necessary, and I hope we will take steps to do it.

At present methanol is made primarily from natural gas. And with the cost of natural gas up these days in this country further production will probably be limited. However, there are other places in the world, such as Alaska and the Near East, where natural gas is being made and wasted. And in these cases it is very attractive to make methanol from those gases. In March a plan to make 25,000 tons per day of methanol from waste gas in Iran was started after a 3-year study. This methanol was then to be shipped to this country. A plant which produces 25,000 tons per day has been about 2½ times the total capacity of our present U.S. methanol production in this country. So that that one plant could have provided 2½ percent of alcohol in all our gas tanks. Unfortunately, it is over in the Near East, and maybe it will get here, and maybe it will not.

Chairman PROXMIRE. Could you summarize somewhat, Mr. Reed? We are a little short on time.

Mr. REED. Other sources are oil and coal. But I would like to focus your attention on the right-hand block of fuel sources in chart 8.[1] For the time being, the most attractive of these is municipal and agricultural refuse.

An alternate method of producing alcohol is hydrolysis of cellulose. You can make sugar from paper or wood and then make methanol. Plants are already underway in this country to start such production.

Twenty-five percent of our country is covered with commercial forests, and about 13 percent with commercial farmland. The wastes from forestry and agriculture at our present level would supply about 10 percent of our total fuel energy. If you began to do intensive cultivation of photosynthetic crops merely for fuel, we could just about support 100 percent of our use in this country. But we cannot go on increasing that 10 percent a year.

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[1] See chart 8, p. 36.

I mentioned previously that alcohol has an advantage that it can be stored in standard tanks, it is carried in standard pipelines and tankers, and it is particularly attractive for the internal combustion engine. However, ultimately, if our production of alcohol increases sufficiently, we can use it for space heating, electric power generation, and in particular it is the ideal fuel for the fuel cell.

In conclusion, let me say that the alcohols make a very attractive alternative fuel to petroleum. They are clean, and they are easily produced from natural materials and from fossil fuels.

Chairman PROXMIRE. Thank you very much.

[The charts referred to in Mr. Reed's oral statement, and the prepared statement of Mr. Reed follow:]

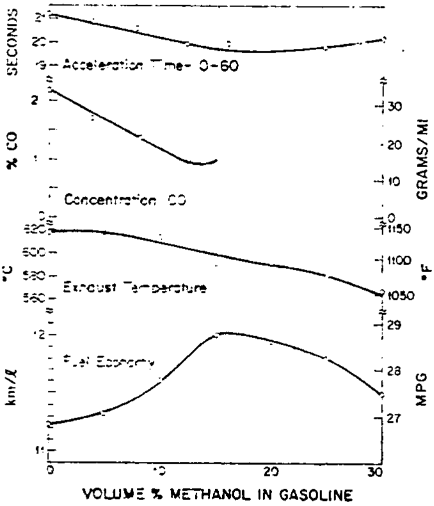

CHART 1.—Performance of a 1969 Toyota Corona with methanol-gasoline mixtures. *MPG*, miles per gallon.

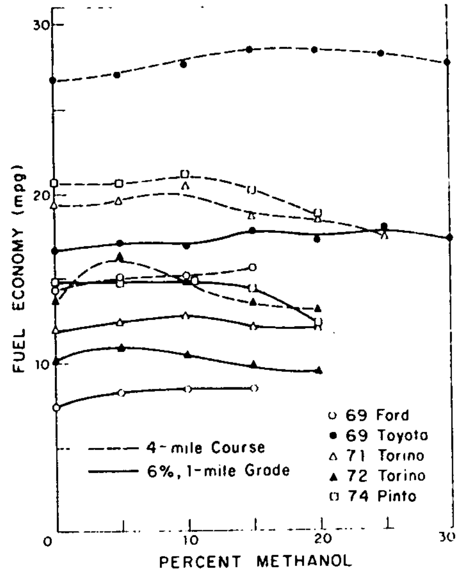

CHART 2.—Fuel economy with methyl-blend mixtures.

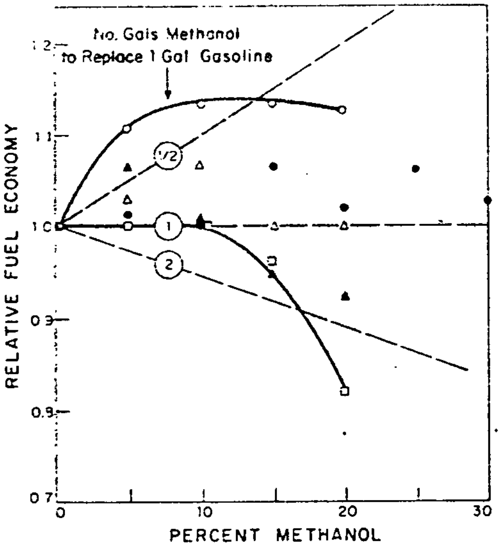

CHART 3

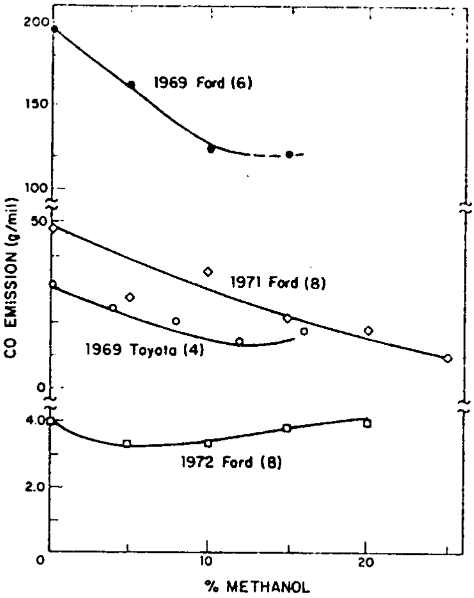

CHART 4.—CO emissions measured by tunable diode laser.

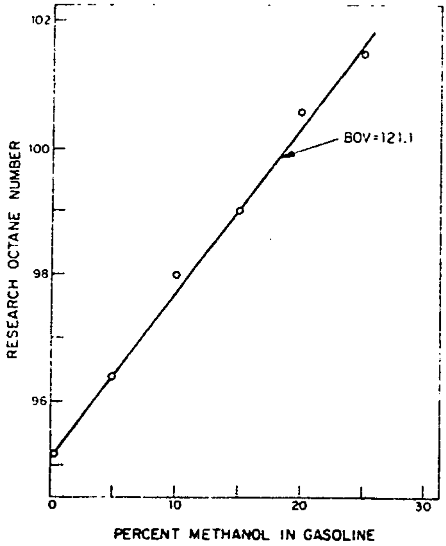

CHART 5.—Research octane number of methyl-blend mixtures

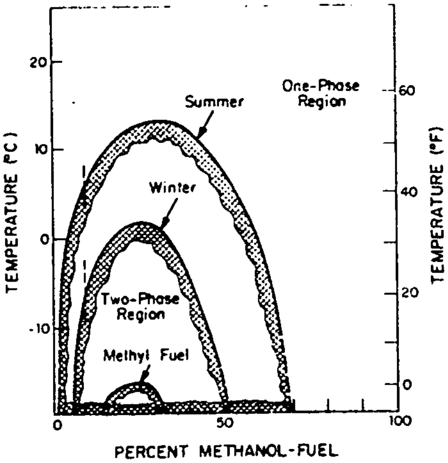

Chart 6.—Temperature separation of methyl-blends in winter and summer gasoline

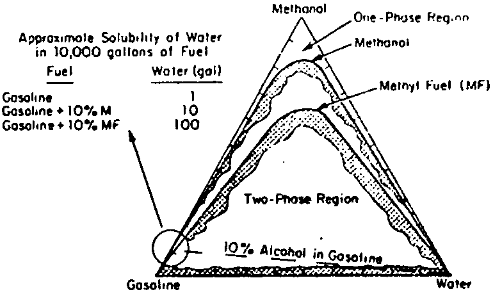

Chart 7.—Water solubility and separation with methyl-blend fuel

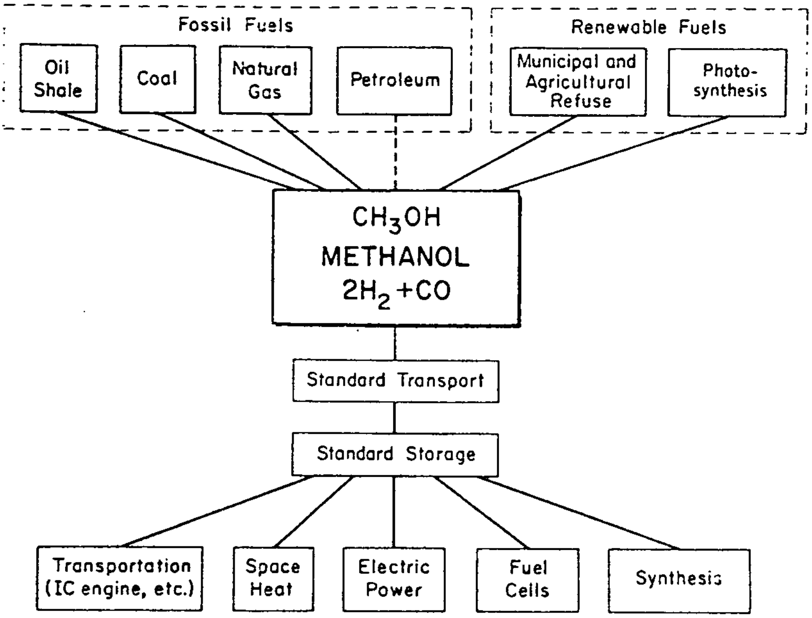

CHART 8.—Sources, transport, and possible applications of methanol.

PREPARED STATEMENT OF THOMAS B. REED

SYNTHETIC ALCOHOL FOR FUEL

Mother Nature has been very kind to us in providing petroleum as a seemingly infinite source of energy. In our technological infancy we have accepted this gift and learned to depend on petroleum products to heat our homes, drive our cars and provide clean electricity. Now we find that this source is dwindling and that in any case unwise and careless use of petroleum can destroy the quality of our environment and even life itself.

Was this a cruel trick of Mother Nature? As a pusher of free energy has she developed a dependency in us on plentiful energy, only to force us to return to the horse and the plow and the woodlot of two centures ago? No, because we have still great reserves of fossil fuel in less convenient form and we can even harvest our fuel from the enormous biomass being continually produced in forest and field, Nature's own solar energy scheme.

Because our initial gift of fuel was in the form of petroleum, we naturally have developed cars and furnaces that burn petroleum derived fuels. Now we are going to start making our own fuel from other energy sources, and I for one am convinced that another class of compounds, the alcohols, is simpler to make, environmentally safer to use, and will perform better in most applications.

In its widest sense the term "alcohol" refers to a class of compounds which contain carbon, hydrogen and one atom of oxygen per molecule, just as "hydrocarbon" refers to those compounds made up exclusively of hydrogen and carbon. Because they contain oxygen they have somewhat lower energy than the hydrocarbons, but they burn much more cleanly than the hydrocarbons. There are two members of the alcohol family that are familiar, sometimes too familiar, to us. Methanol, also called methyl alcohol or wood alcohol, is used for cooking as Sterno, as dri-gas and as the best racing fuel. Last year we made a billion gallons in this country and used it mostly for synthesis of plastics and as a solvent. It is the cheapest of the alcohols and sold last month in bulk for 23¢/gal while gasoline in bulk had climbed to 30¢/gal. It is a great fuel but a terrible beverage and if you drink to much you will go blind.

Ethanol, also called ethyl alcohol or grain alcohol, on the other hand is considered by many to make a superior beverage, though again too much can be just as deadly a poison as methanol. Man has been making it for ten thousand years by fermentation of grains and fruits. At present the price of ethanol is about four times that of methanol, but some exciting new methods of breaking down cellulose are being developed which could eventually make it even cheaper than methanol.

There are a host of other alcohols known to the chemist, but methanol and ehtanol are the most likely candidates to serve our liquid fuel needs. Methanol, produced by wood distillation during the manufacture of charcoal, was widely used for cooking and heating in the last century before oil was discovered. Ethanol was used mixed with gasoline by the French and Germans before World War II and is now used in South Africa and Brazil where it is made from surplus sugar.

We are now at a crossroads in our technological history where we as a nation must consider whether we wish to make synthetic petroleum fuels as our natural stores dwindle, or whether we wish to convert to the use of alcohol to fill our liquid fuel needs. In my opinion, it is technically possible immediately to begin conversion to the use of methanol, first as an additive to gasoline, and ultimately as a replacement for all other liquid fuels, and I will outline here my reasons, referring you to three papers which we have written on this subject for more details.[1,2,3] New discoveries may make the production of ethanol even cheaper than methanol, and most of the advantages listed here for methanol would apply for ethanol and other alcohols if they can be produced as cheaply. You will hear more about ethanol from some of the other speakers of this committee.

The automobile has been one of our greatest technological achievements, and I for one will fight very hard to keep some form of personal transportation and the freedom and effectiveness it gives me. By its very success however, it has created problems of pollution and petroleum shortages which we must solve or lose this necessary luxury. I first became interested in methanol as an automotive fuel when I learned that racing drivers prefer it to gasoline. My interest increased when I found that the Clean Air Car Race of 1970 and 1971 had been won by methanol fueled cars. I became seriously interested and began using it myself when I found that it was cheaper than gasoline if purchased in reasonable quantities.

I have been using a 10% mixture of methanol in gasoline for the last year in my cars and we have tested this mixture in a number of other cars, making no mechanical modifications. We find that a 10% mixture increases fuel economy up to 10% in some cars. We find that the methanol significantly increases the octane of the gasoline and prevents the "Dieseling" which plagues some cars. We find that the carbon monoxide emissions are decreased up to 70%. And we find that the engine has better performance, runs cooler and starts more easily in the winter.

With these advantages, you must ask why we are not already using these blends. I have spent a great deal of time talking to the oil and motor companies recently, and I find them cautiously interested in what looks like a solution to many of their problems. Although the data is scattered and contradictory, most experts will agree that these mixtures could be used and would have at least equal performance to gasoline. The foremost objection to the blends is their behavior in the presence of water.

Gasoline dissolves essentially no water, and so can be shipped and stored in tankers, barges and tanks that contain small amounts of water in the bottom. The methanol blends on the other hand will dissolve about 0.1% water, while other alcohols might dissolve up to 1% water, and so we use alcohols as dri-gas. Up to a point, this property is an asset and will keep our gas tanks and storage tanks free of the small amounts of water rising naturally from condensation. However, if this limit is exceeded, 90% of the alcohol in the gasoline is extracted by the water, resulting in a puddle of alcohol-water in the bottom of the tank or tanker.

Therefore, if methanol is to be used with gasoline, it will have to be added only after a point where water is removed. It could certainly be added at the filling

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[1] *Methanol: A Versatile Fuel for Immediate Use*, T. B. Reed and R. M. Lerner, Science *182*, 1299 (1973).

[2] *Improved Performance of Internal Combustion Engines Using 5–30% Methanol in Gasoline*, T. B. Reed, R. M. Lerner, E. D. Hinkley and R. E. Fahey, to be presented at the IECEC, August 26, 1974.

[3] *Sources and Methods for Methanol Production*, T. B. Reed and R. M. Lerner, presented at the THEME Hydrogen Conference, Miami Beach, Fla., March 18, 1974.

station from a separate tank using mixing pumps of the Sunoco variety. It can be blended before delivery to the filling station, provided the tanks are dry, or even farther upstream in the distribution system provided water is then excluded. We have recently become concerned about the discharge of ballast water into the ocean and leakage of petroleum into the ground water from underground tanks. If we improve our housekeeping practices for other environmental reasons, we may find that water separation of the alcohol is no longer a problem. Since the French and Brazilians have distributed these blends (with ethanol) over long periods, I feel sure that we could also solve these problems if the other advantages of alcohol are sufficiently important.

Last month, a Mr. J. B. Hawley Jr. of Mpls., donated $100,000 to MIT to investigate the opportunities and problems of methanol as a fuel. Mr. Hawley has made a great deal of money from his oil and gas wells, but they are running out and he hopes that we will find a superior substitute for the day when they stop producing. Since he is now 74, I presume his interest is as much for our children and grandchildren as for us. We are now planning to operate an experimental gas station with MIT students and faculty to test this mixture with about 500 cars for a year, to see whether any difficulties arise and what precautions are needed. We are also planning to run research engine tests on the methanol blends, to test the properties of the blends and to see if there are any toxicity and safety problems different from those of gasoline.

I have spoken first of the use of blends of methanol with gasoline to help alleviate some of our motor problems because I feel that this is a first priority. If we wish to use a 10% methanol blend in our cars, we will have to increase present production roughly tenfold, and this is unlikely to occur in less than five years, even if we make it a number one priority task. However, if we take this route, the next step would be the use of 100% methanol in specially designed cars, as well as methanol for power generation home heating and wherever else we use liquid fuels. One of the most attractive future uses is for fuel cells which prefer hydrogen, but whose second choice is clearly methanol.

Let me briefly consider the production of methanol and other alcohols. Methanol is made by passing a mixture of hydrogen and carbon monoxide (synthesis gas) over a catalyst at high pressure and low temperature. This process is similar to that used to make ammonia, and in fact methanol and ammonia are often made concurrently, an important consideration now that fertilizer is in short supply. This synthesis gas in turn is made by the *partial* combustion of fuel—any fuel. At present in this country, the price of natural gas is artificially low compared to other energy sources, so all of our methanol is made from gas. In Europe it is made from petroleum. In the future however, these sources will become too expensive, and I believe that we will make methanol in enormous quantities from coal, lignite and waste.

Our country has been blessed, not only with large oil deposits, but with a large share of the world's coal deposits. We should immediately start making them into the clean fuel, methanol. At a recent European energy conference it was estimated that methanol could be made from coal for 15–20% of the cost required to make gasoline from coal.

There is another source however which I would like to draw your attention to. In the last decade, waste—municipal waste, agricultural and forest waste—have become national problems of increasing proportion. How typical of American ingenuity to convert this fuel into a clean fuel for our cars! Union Carbide has recently developed a process that burns municipal waste with oxygen to produce a gas containing about 75% of the energy of the trash. This gas in turn is an ideal source for making methanol. Modifications of this process could also be used to consume forest and agricultural waste as well. The agricultural waste of Iowa alone is equivalent to that of a city of 180 million people! Although waste cannot supply all of our energy needs, these sources could supply about 10% of our present needs, with great benefit to the environment. Someday, if we run out of fossil fuels or consider that the environmental penalties of mining them are too great, we could obtain all of our present energy needs from giant farms of high output plants and trees.

Therefore I believe that alcohol is a very attractive synthetic fuel for our cars and other needs, and I believe that we should begin producing methanol from coal and waste as soon as possible to begin giving us energy independence starting in the Bicentennial year of our independence.

Chairman PROXMIRE. Mr. Wilson, please proceed.

STATEMENT OF DAVID G. WILSON, PROFESSOR, MECHANICAL ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. Wilson. Thank you, sir. It is a great privilege to be here, and I appreciate it very much indeed.

I am a professor of mechanical engineering at MIT, and the reason I am here——

Chairman Proxmire. Let me just interrupt to say, I did not hear Mr. Reed giving his full qualifications.

You are a professor of chemistry at MIT?

Mr. Reed. No; I am primarily in the laboratory doing solid-state research. But I have just been switched under a grant half time to the MIT Energy Laboratory.

Chairman Proxmire. And what is your background? You have written, I see, several articles or books.

Mr. Reed. Yes. I am a research chemist, with a scientific background. And the laboratory has become an information center for the alcohols.

Chairman Proxmire. Mr. Wilson, would you give us your background?

Mr. Wilson. My background is, for the last 8 years I have been on the faculty of MIT. Before that I worked on engine research and design of large diesel engines and gas turbines.

For the last few years I have been working on the development of methods for extracting resources from solid wastes.

In the last year I have been on a National Science Foundation study to try to evaluate the best research that has been done in solid-waste management in the last 1 to 5 years.

I am also on a panel of the National Academy of Sciences, reporting on alternative automotive engines to the EPA.

And I would say that all of the information I have heard from your witnesses this morning I agree with. I have seen nothing that I could disagree with. On the basis, for instance, of the summation that was given to us by GM, they agreed with the use of methanol.

As a result of working with the legislative body in Massachusetts, I underwent a minor conversion a few years ago from believing technology is the important thing, to realizing that your job is the most important in the country, and trying to advise you on policies is the most important task. And that policy will bring about a better technology rather than the other way around.

With regard to developments, there are exciting developments in the possible use of cellulose from our wastes. And cellulose does constitute around 50 percent of our municipal wastes, and a large percentage of the agricultural wastes. As you have heard, these can be processed into storage fuel or a storable food. The prospect of having a storable fuel is a very attractive one, because to make use of our wastes the markets have to be there, and the markets for heat that can be developed from wastes instantaneously (i.e. through incineration) have not been good.

DEVELOPING USES FOR SOLID WASTES

To put this in perspective, there are a large number of possibilities for developing either resources, which are obvious, or energy from solid wastes. One can, of course, just burn it. And all the inceneratoгs recently designed and put into commission in this country and in Europe have been fitted with steam-raising plants to raise steam for heating buildings or powering turbines, and sometimes they have not been economically successful, partly because the value of energy is so low—which is one of the points I would like to address—and partly because they have to produce steam when the refuse comes in, and that has not always been possible to sell the steam at those times.

One can also produce storable fuels simply by taking the cellulose and plastic out of the wastes by simple air classification and storing them for a period and burning them. This is done in St. Louis with the help of EPA funding. Others produce fuels by taking it (cellulose and plastic) out and compacting it. And this can be done commercially. One can take out the same cellulosic materials and pyrolize them. And you have heard a little bit about that, the process of burning with starved air, so that you produce charcoal on the one hand and tars and gases on the other.

One process that is being investigated by the Department of Agriculture recently to deal with wet wastes—and, of course, these other processes predominantly concern dry wastes—is one process that a private group has been working in, animal wastes, particularly feed-lot wastes. In the past they have tried to run compost plants on a viable economic basis, and it has not worked, because people have said, we can produce fertilizers much cheaper in Illinois or Florida, and ship them to our farms and put them on the fields, we can do that much cheaper than we can make the compost that is being produced in some central place and put it on our fields, because of the low value of the compost, and particularly because of the predominant costs of transportation.

I think that is a point, this has to be of concern when talking about dealing with our wastes by processes that have been touched on here, that we have enormous quantities of fuel potential in our forests, for instance. It would be highly desirable to take this fuel potential out of the forests, because otherwise forest fires with a great destructive potential are inevitable. You build up this time bomb of fuel that is bound to be hit by a lightning strike, if not by a careless match striker, and the fires will go up. But to remove this fuel from the forest, of course, requires a lot of transportation and handling. And the question is, is that handling going to use up more fuel than the value you get?

Now, while paying a great deal of credit for the exciting work that is being done, trying to put that into the perspective of all the other possibilities, is frighteningly difficult. This is what we have been commissioned by the National Science Foundation to do. And when they say, if you want to have a cost estimate of what the process is going to cost in the future, the worst place to go is to an academic: Even with a long industrial background I am frightened to predict prices.

So in your position, sir, to say which process the country should back is a very, very difficult task. Again, the position that we are in in the National Academy of Sciences panel working for the EPA is to say which automotive engine, battery, and so forth, should be the future automotive powerplant in the country.

With regard to policies, I would like to recommend a rather radical policy as an alternative to the two present branches of policy which offer themselves in general to legislators and policymakers. One is the policy of the free market. And the policy of the free market has been proving itself inequitable over the recent energy shortage, the mild crisis we have had, in which everything has happened according to the predictions that could be made very easily last year. Under the free market the oil companies have been allowed to change an amount of money that compensated for the shortage in the fuel. An enormous amount of money has come out of circulation and gone into the oil companies to pay for this extra cost of fuel. And this money has not come back into the economy—only some of it has—and some of it has gone overseas. And the result has been a mild depression. And if shortages spread to other areas—we have even iron and steel being forecast as being short in the next few years and many other minerals are obviously in extremely short supply. We will have similar problems. The overseas people are already beginning to learn from the practice of oil-producing countries to put their prices up. The potential for this extraction of money from the economy to go overseas or to go into particular small parts of the economy is frightening. And, of course, the imbalanced effect on poor people and rich people is very great. Poor people are suffering.

The usually considered alternative is a managed economy, one in which the Government states how much material shall be produced, and what shall be the engines of different cars, and when you will be allowed to be in your cars, and what days you should be allowed to get gasoline, when you should be allowed to use a gasoline-powered lawnmower or tractor, and so on. And the implications of this are rather frightening.

Yesterday when I was looking up some information on this area I came across a report by Mr. William O. Doub, an AEC Commissioner, in which he says this about the present energy policy. The job of his group:

> Was to plot out "flow charts" of all the hundreds of individual steps that a utility or other private applicant must go through to gain Federal approval of an energy project, whether based on coal, gas, oil, or nuclear fuel. This "gymnastic course" an applicant must traverse, Doub told a news conference, "had never really been explored before."
>
> Plotted out in fine print, the flow charts cover several yards of paper. Months of inquiry, according to the study's report, reveals:
>
> [P]ersuasive evidence that the energy regulatory system is so disjointed and complex that any organization or group seeking to deal with it must be prepared to encounter more financial expense, confusion, and frustration than appears reasonable or warranted. If this is true for well-financed groups, sophisticated in the ways of Federal energy regulation, it is infinitely more so for individual citizens and ad hoc citizen groups * * * without substantial resources or familiarity with the system.

You will hear from Mr. Sawhill tomorrow that the size of the Federal energy regulatory system is being increased very greatly. One would hope that this can be a streamlining influence, but it is probably going to mean a stultification of what already has to be done to solve our problems.

And, therefore, for this type of control system to spread over the economy is a frightening prospect.

POSSIBLE FEEDBACK TAX LEGISLATION

I would like to suggest a scheme which would automatically give an incentive to private industry to beat a path to the door to U.S.

the carbon black off and deliver it to the automotive tire manufacturers.

Obviously, if one increases the prices of natural gas and other fuels, processes like this—and we can repeat this in many companies—would be closed down immediately. Automotive tires which are presently being dumped in the ground or in the sea would suddenly become a resource for making new carbon black. That is an example, I think, of where Government can adjust the incentives to automatically encourage socially beneficial processes and activities rather than discourage them.

My mother-in-law used to say with regard to many of the laws on the books, "no good deed goes unpunished." And I think the present situation of the companies trying to make carbon black from tires is that they get punished by the regulation of fuel prices.

Thank you, Mr. Chairman.

Chairman PROXMIRE. Thank you very much.

[The prepared statement of Mr. Wilson follows:]

PREPARED STATEMENT OF DAVID G. WILSON

ENERGY FROM SOLID WASTES—NEEDED GOVERNMENT POLICY

Mr. Chairman, it is a great honor, a privilege, and a distinct pleasure to be invited to testify before your subcommittee today.

The immediate purpose of my testimony is to set the exciting developments of Mary Mandels and her fellow scientists and engineers at the U.S. Army Natick Laboratories, of improved processes for the production of fuels and foods from solid wastes, into an engineering and policy perspective.

You also asked me to comment on the role of government and private industry in the development and application of this new technology. I should like to recommend, quite strongly, a controversial approach, almost directly opposed to most current advocacy, and therefore one which would take political courage of high order to put into effect. This approach is nevertheless, I firmly believe, the only one which can simultaneously revitalize our economy and redirect it into socially and environmentally beneficial areas, and to do this with equity to all, and particularly the presently disadvantaged, with a reduction in the role of government.

Firstly, with regard to the potential new technology which the Natick Laboratories' development have made possible, the basic discovery was of an enzyme which could break down virtually all forms of cellulose. A mutation of this enzyme was then produced having greatly increased activity and productivity.

This new enzyme makes a long-used process for the conversion of cellulose into glucose much more attractive. Glucose can be used as a base for the production of certain foods, animal feeds, and fuels, particularly alcohols. Alcohol is particularly interesting because it has wide uses in industry, and it can also be added to gasoline in amounts up to ten percent without changes in engine design or carburetor adjustment being necessary. Currently available sources of cellulosic wastes would, if converted to ethyl alcohol, provide close to ten percent of current gasoline consumption in the U.S., so that the match of potential supply and potential demand is good.

There are, of course, many other ways of extracting the energy in organic wastes. The wastes may be burned in a steam-raising incinerator, and the steam may be used to heat buildings, power turbines, or drive air conditioners, as is being done in most of the modern European and U.S. incinerators. The wastes may be burned in a gas-turbine cycle, for instance that under development with EPA funding in California. Solid wastes may be classified so that the incombustible fraction drops out, milled, and burned with coal in a regular electric-utility boiler, as is happening in St. Louis, also with EPA funding assistance. The wastes can be milled, classified and bricketted, and sold as a sulphur-free solid fuel, which is a current commercial development. Municipal, agricultural and livestock wastes can be composted and one use recently investigated had been as "compost-fuel"—this is a commercial development which has been recently tested by the Department of Agriculture. Solid waste may be anaerobically decomposed to produce fuel gas—both EPA and the Bureau of Mines are supporting work in this area—and the same agencies as well as private industry are supporting or developing a large number of pyrolysis processes, which produce solid, liquid and gaseous fuels and other byproducts from solid wastes.

And cellulosic solid wastes can be converted into secondary materials, perhaps with a greater energy saving in some cases than if they were used for fuel and virgin materials were used in their place. Old newspapers can be made into new newspapers, into tissue, or containerboard, or building board, or roofing materials, and so forth.

The vital question is, then, which of these many processes for the reuse of solid wastes is the "best", and what value system shall be used to judge the best? Should the government choose one or more processes and help them along by subsidizing research or development or a demonstration?

Although much of my academic life is spent trying to obtain such government grants, and then in spending them, I believe that maximum welfare for the country lies in other directions with very different policies.

The currently accepted alternative policies, the "free" market and the controlled economy, are equally unattractive to Americans facing shortages in energy and a growing shortage in many materials. The free market is one in which apparently desirable activities, such as converting cellulose wastes to fuel, or exploiting wind power, are not undertaken by industry. Rather, industry seems to profit in times of shortage by raising prices and collecting greatly increased profits. The higher prices hurt poor people in particular, and hurt the economy by removing money from circulation (because much of the profit is spent abroad).

The controlled economy means rationing, controls and allocations. The government decides, through large numbers of civil servants, new agencies, and investigators, the various levels of need of individuals and of industries. Greatly increased policing is required to ensure some degree of fairness. Prices of energy, for instance, would be "rolled back" but the incentive this action gives to greater energy use, or waste, and to reduced energy production, have to be countered by vigorous government actions.

The controlled economy runs counter to all American traditions. It promises to sap the energy and enterprise of this highly energetic and enterprising people. It has had this effect dramatically in other controlled economies.

The policy which I should like to recommend is to set up what I term the "modified free market". That is, the free market must be modified to meet social requirements and to produce equity for rich and poor, for individuals and for industry.

The way in which the modified free market would work in the case of energy seems startling at first sight. The government would tax all energy coming from nonrenewable resources—coal, oil, natural gas, nuclear fuels. The entire proceeds of this tax—which is better named a "surcharge"—would be distributed equally to every adult resident as a uniform "energy bonus", regardless of how much energy he or she used. So the price paid by all consumers—home-owners, utilities, industry, the military services—would rise, but all residents would have greatly increased purchasing power. (A surcharge of twenty-five cents per gallon on oil would yield an energy bonus for forty-five dollars per month for every adult in the country).

The rationale behind this apparently radical proposal is that industry, or individuals, should not profit from the shortages of the earth's resources. They should make a fair, marketplace, profit on their skill in extracting and delivering these resources. Government should make the purely political decision of how much to reduce demand, and how much to stimulate the development of alternative energy sources, by raising prices.

The incentives produced by such a step are very powerful and entirely in directions which benefit society. Individuals find real savings in smaller cars, or car-pools, or in using public transportation, or in living closer to work. Industries and services using little energy are stimulated by the increased purchasing power. Industry finds the development of wind power, solar power. tidal power and so forth attractive. Sailboats become more attractive for recreation than power boats. Snowshoeing gains at the expense of snowmobiling. Double glazing and better insulation is more economical than the installation of a larger furnace.

But large cars would not be banned. Power boats would not be proscribed. People wishing to get their excitement or fulfillment in ways which use—perhaps even squander—energy would be paying their obligations to society. No censure or guilt need be experienced.

And the poor would be relatively better off that the rich. Their energy refund would be identical, but the rise in costs of energy-related goods and services would be less than the refund for all those consuming less than the national average.

Prices of oil and natural gas would be decontrolled when taxes were added. Price competition would resume its effectiveness. Truckers, for instance, would be allowed to pass on their extra costs. (Utilities and other monopolies would still be regulated).

The modified free market would work in a similar way for all scarce resources. Many nonferrous metals—and even iron and steel—are becoming short. The tax on resources should be a function of their scarcity. Exploration companies would have an incentive to find more reserves to lower the tax. Users would have an incentive to use recycled materials which would be untaxed, or to use lower-taxed substitutes. The funds collected, as in the case of the energy surcharge, would be distributed directly to consumers to give them increased purchasing power in alternative areas of the economy.

This type of policy leads to what can be called 'feedback legislation'. It produces self-adjusting changes from year to year. Crises and emergencies, such as we have faced, mildly, in energy and will face far more drastically in other resources, will be avoided. Industry and individuals will be able to plan ahead to meet anticipated changes.

It would be a great privilege to describe further, at another time, the workings of the modified free market in these and other areas. Thank you for your time and attention.

Chairman PROXMIRE. Your proposal, Mr. Wilson, is very interesting and highly imaginative, and it may be a very worthwhile proposal, although I may say that I have an intense aversion to increasing taxes at that rate, and that kind of redistribution would obviously have a colossal political reaction.

BENEFICIAL POSSIBILITIES FOR THE NATICK PROCESS ARE SIGNIFICANT

Let me get back to Natick to begin with. I think we have what could be a very exciting possibility here. The possibilities are that you could increase the supply of gasoline, for example, 10 to 15 percent, the supply of basic resource for gasoline, at least, by 10 or 15 percent, that in doing that by itself you would reduce the cost, because the cost of producing ethanol per gallon is less than the cost of producing gasoline, and in increasing the supply by this amount you would also tend to reduce the cost or the price, inasmuch as that additional supply would tend to permit with an elasticity of demand a lower price.

Furthermore, you have the fall-out of eliminating most of our wastes in the process. And in addition, you have many other options for this ethanol. And one of the most attractive options, of course, is in the food area.

With all that in mind, Mr. Reed, as you have heard, the subcommittee has received testimony this morning from Mary Mandels, John Nystrom, and Leo Spano, concerning the work they have done in Natick. As scientists both you and Mr. Wilson are familiar with the work that has been done at Natick, you have looked it over, regarding the breakdown of cellulose into glucose for use as food and fuel.

In addition to what you have told us, could you give the committee your evaluation of both the advantages and the problems involved in the Natick process very quickly?

Mr. Wilson, what would you say are the advantages here, and what are the problems as you see them?

NATICK PROCESS CREATES STORAGE FUEL

Mr. Wilson. The obvious advantages, sir, are the production of storable fuel, rather than producing heat which has to be used in one place—I should say a storable material. And as Ms. Mandels has emphasized, the primary raw material is glucose from which food can be made. And one can also produce alcohol, which is itself a raw material which can be used as a fuel, and can also be used for the plastics industry.

Chairman Proxmire. Mr. Reed, would you comment?

Mr. Reed. As a chemist my favorite model is Mother Nature. And I think that the best process is closest to the kind that nature itself uses so that we are using nature's way of doing things and the Natick process may someday give us natural energy production. However, I think at present we are a little further ahead in the industrial-type processes, and industrial alcohol will come first. But I have hopes that as Natick pursues what they are doing, and work out the problems of breaking down practical kinds of cellulose which we find in our dumps and trees, that that will actually take over from what to me is a cruder form, but at present more practical.

Chairman Proxmire. Since your specialty is solid waste disposal, Mr. Wilson, would you please outline what you think would be a logical method of supplying this process on a national scale? In other words, how easy is it to get the cellulose waste to the plants? A great deal of this would have to come from the farms, the feed lots, a great deal of it also from the disposal facilities of the cities and towns and villages. How would this be done?

HOW DO WE COLLECT THE SOLID WASTE FOR THE PROCESS?

Mr. Wilson. The best way is to try to latch onto the existing system. And we are now an urban people, I think 80 percent of the population lives in urban areas. At present the costs of handling solid municipal wastes are of the order of $30 a ton, of which $20 is the average countrywide cost of collecting the trash and deliverying it to some central point, which might be a land fill, and $10 per ton is for incineration, or other processes. So these central plants are the obvious places where reclamation processes of the type that we should be working on should go.

As to feed lots, I am less clear that this is an optimistic process for this. And I am not derogating it——

Chairman Proxmire. Let me just go back for a minute to the municipal trash. Unless you are going to have—and maybe you should have—a plant capable of conversion near our big population concentrations, in other words, hundreds of those all over the country, you are going to have a substantial transportation problem.

Mr. Wilson. Right.

Chairman Proxmire. Obviously, in the smaller towns and villages you are going to have to use their wastes, unless you are going to have a myriad of plants.

FIRST PLANTS IN MUNICIPAL AREAS

Mr. Wilson. It would not be economic for a long time to use rural towns' wastes. It gets dispersed very widely. We are lucky in that there is a good balance between the towns which may produce thousands of tons a day and local industries needs. New York has a landfill to which it takes 6,000 tons a day. And, of course, if you put up—and there is a reclamation plant being operated by private industry in northern Manhattan—a reclamation plant then you have got all the market for the products right there, too. So this is a very good match. It becames more economic in general, the larger the plant, the more economic is the processing.

Chairman Proxmire. So this would be a very appropriate usage.

Mr. Wilson. Yes.

Chairman Proxmire. In any city of 100,000 or more, Milwaukee or Madison in my State, for example.

Mr. Wilson. Yes.

Chairman Proxmire. And, of course, any of the eastern cities.

Mr. Wilson. There can be an optimum size, because, of course, as the solid-waste quantities get bigger, if you have trucks that have to drive 20 miles to the plant or to where there is an incinerator, the cost of the transportation may increase faster than the savings due to economies of scale.

Chairman Proxmire. A lot of feed lots are located on railroad terminals or railroad tracks in big cities, so there it might be appropriate to use rails.

Mr. Wilson. My suggestion is that the first plants should be put in the municipal areas.

Chairman Proxmire. Do you have any further information you could give the subcommittee regarding the economic factors and cost estimates, both the waste and the collection aspects? You did give us the breakdown, the $30 per ton, of which $20 is transportation, is that right?

Mr. Wilson. That is right. And that is an average, in many cities. In the one that I live in, Cambridge, Mass., collection costs are $40 a ton, and disposal costs are around $10 a ton. And those of us who have analyzed the present economic viability of reclamation of wastes of one sort or another, feel that a break-even disposal cost of about $5 or $6 a ton is probably the right area in which to put a reclamation plant. And I think that Mr. Spano and Ms. Mandels have emphasized that, that when you put in a plant to treat solid wastes, the cash flow is dominated, at least in the initial stages, by the fee you charge for receiving people's refuse.

PROCESSING CHEAPER THAN DUMPING

Chairman Proxmire. Mr. Spano, I see you nodding. If you take $5 or $6 for the disposal costs, in other words, $5 or $6 processing here compared to a $10 disposal cost that you could have in the usual municipal plant.

Mr. Spano. In the evaluations we have made we have found that for a 500-ton-per-day plant, the break-even point is around $4.35 for dumping, this is the disposal cost that Mr. Wilson is talking about. Usually one-third of the total cost is chargeable for handling and disposing solid wastes, and two-thirds is chargeable for the collection and transportation. So if you take one-third of the total cost as a credit to the plant, on the front side of the plant, the break-even point for a 500-ton-per-day system runs about $4.35 per ton.

Chairman PROXMIRE. Let me ask you this, Mr. Wilson. You are familiar with the engineering problems involved in the Natick processes. How much do you estimate that it would cost to build a full-scale operational plant to service a fairly large city, say, a city of half a million?

Mr. WILSON. I must not misrepresent myself, sir—I am not a chemical engineer. I am, however, familiar with the broad processes. I like to compare things with the cost of an incinerator plant. I cannot even estimate the cost of our own plants that we are developing at MIT. But I like to compare them with the costs of incineration, because in urban areas, with the revulsion of accepting trash for dumping, communities have gone increasingly to incineration. So if you compare this process with incinerators, those are costing, with the sophisticated air-pollution-control equipment that is required nowadays, between $15,000 and $20,000 per-ton- per-day capacity. In other words, if you have 1,000 tons per day to incinerate, about the minimum you can build an incinerator for now is about $15-million capital cost.

Chairman PROXMIRE. Then, 1,000 tons a day, on the basis of your experience, that would be appropriate for what size city?

Mr. WILSON. About a million people, or less.

And I cannot believe that the Natick process would cost anything like that. But, of course, a lot of that cost, in fairness to the incinerator, is for the land, the buildings, the access roads, the receiving area and cranes, all of which are common to any process. You have to have a place where the trucks can drive and dump their wastes. The cost of the incinerator furnaces are rather small.

Chairman PROXMIRE. Can you give us the cost of the process itself? Because I think if all these cities have from time to time, to build new disposal facilities, and build the access roads, and all that kind of thing, the land has to be acquired reasonably close. So give us simply the cost, then, for 1,000 tons a day for a city of a million people, just for the processing.

CHEAPER TO BUILD NATICK PROCESSING PLANT THAN TO BURN IT IN INCINERATOR

Mr. WILSON. This is to some extent a guess. But for incineration it (the processing cost) is about 50 or 60 percent. So that would be $7½ million to—let us say $7½ to $10 million for the process itself. The balance of that would be site costs, access roads——

Chairman PROXMIRE. $7½ to $10 million. And that would compare with an incineration facility——

Mr. WILSON. That was for the incinerator, sir.

Chairman PROXMIRE. How about for this—do you call this an incinerator?

Mr. WILSON. No, for this process, the Natick process, you need probably a larger area, and treatment tanks, which might put the costs up. But the sophistication of the process is far lower than is required for an incinerator.

Chairman PROXMIRE. So that the actual cost is less?

Mr. WILSON. I am sure that it costs less.

Chairman **Proxmire**. In other words, it would cost less to build a facility to process the wastes into glucose and then ultimately to ethyl alcohol and ethanol than it would to simply burn it and destroy it?

Mr. **Wilson**. Yes.

Chairman **Proxmire**. Mr. Spano, do you have any observation on that?

Mr. **Spano**. I would hesitate to make a positive statement on that, sir.

Chairman **Proxmire**. Does that seem logical to you?

Mr. **Spano**. It does. The handling of the solid waste as it comes in, that is, the front end of the process, which is the shredding, the classifying, the separation, of the organic fractions of the wastes for the glucose plant, and the inorganic fraction is separated for recycling. In effect the two plants operate side by side.

Chairman **Proxmire**. In other words, you have to have one plant for the glucose process, and another in which the material that you do not use for that purpose has to be recovered for recycling.

Mr. **Wilson**. And one cost that I should have emphasized is that for this process you do need shredding, (it is known by many names,), you need this process first. And that costs between $2 and $15 a ton. So it depends very much on the fineness with which this process has to be done.

Chairman **Proxmire**. It sounds to me—I am strictly a free enterprise man, I do not like to see the Government do anything we can avoid, but it sounds to me as if there are all kind of advantages in cities going ahead and doing this. We are going to have to work out some free system. We are going to get the efficiency of free enterprise. I am convinced that if we put free enterprise up against the Government it would do a lot better, because the motivations are a lot more powerful for cutting your costs in the private sector. So we will have to work out that kind of institutional adjustment.

IF FUEL COSTS RISE, ETHANOL BECOMES MUCH MORE ATTRACTIVE

Mr. **Wilson**. If you put up the price of fuel, everything else would handle itself. And I think the same thing applies to raw materials, if we put a surcharge—I think you cannot call it a tax, because a tax goes to the Government and stays there, and because a surcharge merely circulates and comes back—if one puts a surcharge on the use of scarce materials in proportion to their scarcity, it would be a self-adjusting tax year by year. Of course, you would put it on the raw materials that came from virgin stocks. Then, the incentive to use recycled material would be automatic and very strong. It is a balance point, and it is a very interesting period for the use of raw materials. Paper is an example. The price of paper is up from almost zero 2 years ago to almost $80 a ton FOB, on the west coast. So the interest in recycling paper to make newspaper or tissues is extremely strong. But the companies that are involved in this are saying:

> How can we be sure that it is not going to drop to zero as a result of this terrible instability which the secondary market has?
>
> We may put all these investments into it and a couple of years later find ourselves not able to sell the product.

This is where I believe the Government should adjust the tax in a way that repays the social cost of the processes.

Chairman PROXMIRE. Mr. Reed, do you want to comment?

Mr. REED. Yes. I think you are asking questions which in 2 years we could answer a lot better when Natick has had more experience. I have just finished a preliminary economic study on the making of alcohol by pyrolysis, in plants making 100 tons a day or 25,000 tons a day. I have estimated the costs taking various returns on the investment; and 15 percent with municipal funding, and 35 percent with industrial financing. I have assumed various costs for the fuel, $7 a ton for coal, and minus $5 a ton for wastes. I have calculated the cost of making alcohol at so many dollars a ton or so many dollar a gallon. I find that if you wish to start from classical fuels like coal, it is only economical to use very large plants making 25,000 tons a day. However smaller plants at the municipal level are very attractive economically for alcohol production from waste. Tests are being made already and plants are under construction.

Chairman PROXMIRE. Mr. Reed, you state in your statement, that the development of this method for breaking down waste cellulose into glucose would make ethanol cheaper to produce than methanol. Could you explain exactly what is involved in blending ethanol or methanol with gasoline?

Mr. REED. You mean taking the two together, in common? They are both soluble in gasoline at room temperature and down to fairly low temperatures. At the 10-percent level there is no necessity to change the automobile and you can put it in when you have it and leave it out if you do not have it. If you go to higher percentages you reach a point where it is necessary to alter the car, but it would require very minor alterations. It is quite feasible, to convert present cars to alcohol and I intend to change my car to pure alcohol in the summer. But I think it is even more feasible to design cars which are more attuned to the very high octane abilities of alcohol. And by 1990 or 2000 we will have plenty of time to do it, and then we will also be able to produce sufficient alcohol to use it without blending.

Senator PROXMIRE. You also suggest several times or places in the processes where you could blend ethanol or methanol with the gasoline. Are any of these preferable? And is there any indication economically as to what could be the best point where this could be done?

Mr. REED. Sunoco at present uses blending at the gas station, taking two fuels out of the ground simultaneously and mixing them to give a blend which you specify when you fill up at the gas station. However, I believe ultimately you would prefer to make the mixture further upstream at some intermediate shipping point, before they send it out to the local gas stations. And the only penalty for that is they would have to keep water out of the storage system beyond that point.

Chairman PROXMIRE. You list several advantages to gasoline blended with methanol, which is reduction in exhaust emission, and better performance, and other things. Do these advantages also apply to ethanol blend?

PERFORMANCE OF ETHANOL BLEND FUEL NOT COMPLETELY KNOWN

Mr. REED. Yes, to a greater or lesser degree. And that degree is at present unspecified. Various people have various results. The scatter in the data is a few percent, and the differences are a few percent. I understand that the University of Nebraska is starting a test of 2 million vehicle miles with ethanol, using State cars, probably about the same time we start our tests.

There is a test going on at Bartlesville, Okla., where the Bureau of Mines is running a methanol test. ICI in England has been running a fuel test.

Chairman PROXMIRE. Now, Mr. Wilson, you said that there were many other ways of extracting energy from organic wastes besides the one being discussed here today, the Natick process. Is the Natick process more or less efficient and cost-effective, in your opinion, than these other methods that you list in your statement?

Mr. WILSON. Sir, I do not know how we can find out at the moment. One of our efforts in the National Science Foundation study is to try to take the claims of various people—I am trying to give some sort of balance to them—for instance, there is a Mr. Andrew——

Chairman PROXMIRE. May I interrupt to say that I happen to be chairman of the subcommittee of the Appropriations Committee that handles appropriations for the National Science Foundation. They came before our subcommittee recently and asked for money for a process of making ethyl alcohol from grain. And we called their attention to the fact that Natick has a way of doing this that results in an ethyl alcohol that is cheaper than the raw material that is being used by any other process which they are funding for their experimentation, for their research. So that I just felt the National Science Foundation, at least as of 3 or 4 years ago, is not up to date on the marvelous progress made.

Mr. WILSON. We are all human. It is difficult. I do not know how to evaluate these. Mr. Andrew Porteous, who has been pushing an acid-hydrolysis process for a few years dealing with wastes, came out with extremely good figures. In short, the acid-hydrolysis process works with acid, and, therefore, it requires very expensive vessels. The process time is very much shorter than Natick's, and the number of vessels you need is less. And you end up with less pure and fewer byproducts.

Now, there are three or four parameters that somehow one has to juggle in one's mind and come out with a number. I like to believe that private enterprise is the one group able to take account of these parameters. But I expect we will need to get to the state where we can make more accurate estimates.

Chairman PROXMIRE. For the record, will you give us whatever estimates you can when you correct your remarks as to what your estimates are for these various alternatives, how practical they are as compared with the Natick approach?

Mr. WILSON. I would be delighted, sir.

[The following information was subsequently supplied for the record:]

DESIGN AND PERFORMANCE OF THE M.I.T. PROCESS FOR SEPARATING MIXED MUNICIPAL REFUSE

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Introduction

The M.I.T. approach to the problem of separating mixed municipal refuse differs from other developments of automated plants in several ways.

1. As much separation as is economically justifiable is carried out with refuse in the as-received condition. Only certain non-homogeneous items are comminuted. (In other mechanical processes all incoming refuse is comminuted or pulped before being processed in bulk).
2. The individual (larger) pieces of refuse are scanned by a number of sensors in series, with data from each sensor being fed to a minicomputer (figure 1). A decision about the allocation of each individual item to a category is not made until all sensors have recorded data. Subsequently, the refuse item can be allocated to one of a large number, perhaps 25, categories. (In contrast, most other sorting operations carry out a series of successive binary sorts into a limited number of predetermined categories).
3. The sorting performance of the plant can be modified by changes in computer instructions from day to day. The plant manager can thereby respond to changing market conditions. (In most other processes, the product mix is determined at design).
4. Pieces of refuse below a chosen size, including pieces from the comminuted heterogeneous refuse, are taken to a new type of multiple-output vortex classifier in which the refuse is sorted by density. (Most alternative classifiers are binary sorters).

Potential Advantages

The values available in municipal refuse are maximized if the refuse is maintained in an as-received condition. This is particularly true in the cases of paper products and glass. Clean, bundled newspaper and telephone books can be collected and discharged from the compaction truck virtually uncontaminated, but if they are then comminuted or pulped, the resulting mixture can lose a high proportion of its potential value. Glass bottles are also mostly undegraded in compaction trucks.[1]

By keeping refuse in the as-received condition so far as is possible, all options remain open. Various components may be recombined or kept separated and pulped, comminuted, incinerated, pyrolyzed, hydrolyzed and so on. In some cases the plant might be regarded as a "front-end" device for other processes.

Except for the computer and sensors, the plant uses conventional hardware and technology and should be considerably lower in cost than, for instance, an incinerator of the same capacity. The computer required is a low-cost device, and the sensors will likewise be a very small proportion of total plant cost.

Energy requirements of the sorting process are much lower than for alternative processes principally because of the absence of bulk comminution. Energy requirements for re-use of some of the products, eg bottles, will also be lower than if they were comminuted.

Potential Disadvantages

The plant relies on mechanical devices to separate incoming refuse into individual pieces. The heterogeneity of refuse is such that it is unlikely that any plant would be able to work completely automatically with refuse as input. Human oversight will be required, so that controls may be overridden when it seems necessary. Some of the components of refuse which traditionally give trouble are, for example, loose coils of rope or wire; large pieces of textiles such as stair carpets and rugs; and leaky containers of sticky or noxious materials. As these types of components cause problems in present refuse-treatment plants, the relative disadvantage which the present plant would experience might not be great.

Size reduction of municipal refuse conveys the very great advantage that the product approximates to a homogeneous mixture having properties which can be estimated fairly closely, and which can be subsequently handled and treated by equipment developed for bulk materials, for instance ore. We are trading this advantage for the savings in costs of size reduction and for the potential of greatly increased revenues from the process streams.

Physical Characteristics of Urban Refuse

The material composition of refuse on a mass-percent basis has been frequently studied.[2,3] Investigations at M.I.T. and at Middlebury College Vermont (where Frank Winkler has been working on a parallel program of sensor development and data analysis in collaboration with us), have gone beyond the study of mass composition to examine in detail the size and weight distribution of individual items found in municipal solid wastes. We have sought to answer such questions as: how many items per ton of refuse have dimensions larger than six inches; what fraction of the total weight do such items represent; what is the size and weight distribution of glass objects found in refuse; etc. In addition, we have carried out a detailed investigation of the qualitative nature of the refuse, breaking down principal categories such as paper into numerous sub-categories.

This investigation has been reported in reference 1. Figures 2,3, and 4 show some of the results which were used in process design and economic analysis.

Development and Design of the Large-Item Sorter

The selection of large items from a mixed mass of municipal wastes, to determine their composition, and to place them in one of a number of alternative streams, presents a considerable challenge. It is the process which has been carried out in manual sorting for many years. To reproduce the exact human procedure seemed inappropriate.

The M.I.T. approach consisted essentially of first singling out large items and then taking readings from a succession of sensors until the identity of the material or materials in each item could be determined with reasonable certainty.

The most difficult part of this process is the singling out: the separation of clumps of material into separate objects. A human being knows that he is looking at one item: a sensor receiving a varying signal for a short period of time cannot be instructed to detect whether it is looking at two items in close proximity or at one heterogeneous item. A person would either know immediately or would pick up part of the item to see if it came up as one piece or more. We used this procedure for taking data and we considered singling out items by means of a series of suction heads or grabs. We rejected this idea because we thought there might be too many items with surfaces too irregular or too porous to be picked up easily by suction.

We therefore chose the alternative route of spreading out the refuse to such an extent that there would be a high probability of there being a space surrounding each item. We also mechanically agitated the refuse mass to break up clumps. Both these functions were performed to a large extent on a two-deck vibrating screen. The input feed was divided among five or six streams at this vibrating screen, the whole assembly being termed a "presorter". Loose paper and plastic film were to be removed by an overhead fan and a transverse open-mesh belt. An overhead magnet and transverse moving belt were planned to remove the ferrous metals (figure 1).

Fines passed through the vibrating screen and larger items in two sizes were retained on the upper and lower decks.

A further tendency to single out individual items was obtained by allowing the refuse to fall for a short distance down a chute fitted to the end of the vibrating screen. At the end of the chute was the leading cart of a queue of similar carts. (In a full-scale plant, there would be several carts positioned below the end of the screen, each cart being the leading one in a queue on a separate loop track). When a large item fell into a cart, it broke a light beam which triggered an electromagnetic clutch, accelerating the leading cart and replacing it with another. The acceleration was accomplished by a rotating arm, carrying pins at the extremities, engaging in transverse channels on the underside of each cart. By impulsively moving this arm, by means of the electromagnetic clutch, through 180 degrees, the carts underwent simple harmonic motion during acceleration and deceleration.

As initially constructed, the accelerator could dispatch six carts per second. This provided another capability for clumps of refuse to be broken up. The delay period before the acceleration commenced could be adjusted so that a complete bottle, for instance, would be within the cart before it was accelerated. Should there be something adhering to the bottle, there would be a good chance of the two pieces becoming separated during the acceleration. The second item could then fall into the second cart. If the two pieces remained together in one cart, the different readings given by the sensors would lead to the contents of the cart being either recirculated to the input feed or sent to the hammer mill.

Design Specifications

A challenge encountered in the design of a sorter of this type was the randomness of the input feed. We characterized this randomness by specifying that the cart system must be capable of handling a maximum of five objects per lane in any one second and ten objects per lane in any four seconds. This performance specification was the result of a guess as to the performance of the presorter on raw refuse. It would probably need modifications in the light of experience. Choosing the specifications enabled other design choices to be made in the handling system, such as the maximum necessary number of carts in the accelerator-input queue, and the speed and cart density of the conveyor which moved the carts around the track after the initial acceleration period.

Cart Conveyor

A chain conveyor carrying spaced drive pins was used to move carts steadily around the track past the sensors and past the unloading stations.[4] The drive pins engaged a cam on the side of the carts. The cam was automatically released whenever a cart bumped the rear of a stationary cart in the accelerator queue. At the same time a coupling latch attached the two carts together.

Refuse-Sensor Interaction

As can be seen in the cross section in figure 5, the bottom of each cart incorporated slits aligned along the direction of travel. The sides of the cart bottoms were sloped so that all refuse in the category of large items would roll or slide to the point where at least some part of the item was over some part of the slit.

The proximity or contact sensors, which in the prototype were the metal detector and the impact sensor, were fitted in shaped housings which protruded through the slits of passing carts and which forced items of refuse in the carts to ride over the housings (figure 6). The infrared sensor merely focussed through the slit onto the rectangular area in which refuse should be found.

Unloading Arrangements

The processing by computer of readings from the sensors, the subsequent coding of each cart, and the reading system are described below. The results of these operations were that the cart passed along a series of reading stations, each of which had the capability of closing a circuit which would start the unloading process. The circuit was closed only when the code on the cart corresponded to the code which had been previously assigned to the reading station.

When the circuit was closed, a solenoid deflected a pivoted tubular cam under the track. A roller-bearing follower at the bottom of the approaching cart then engaged the cam and the bottom of the cart would be quickly opened by a toggle action. The cart would be still moving, and when sufficient distance had elapsed for any refuse items within the cart to have fallen into the hopper below, a second linear cam reclosed the cart bottom.

Design of Full-Size Plants

Certain modifications and refinements would be necessary for the incorporation of the pre-sorter and large-item sorter concepts into the design of a full-size plant. In addition, while some components, such as the vibrating screens, would become larger, other components, such as the cart systems, would simply be duplicated.

Maximum Feed Rate for Carts. An acceleration capability of about five carts per second seems to be a good match with presently forseeable sensing rates and with the flow-rate of vibrating screens. In addition, at, say, double this feed rate, impacts of refuse within the carts might break bottles and might cause the ejection of some other items.[4]

The permissible maximum rate of operation of the accelerator would obviously depend to some extent on the size of the carts. For plants having capacities greater than 100 tons per day, more than one lane of carts would be necessary. There would obviously be a cost saving in having at least two different sizes of carts, each cart size being fed by one deck of a multi-deck screen.

Number of Different Sizes of Carts and Number of Lanes Required. Malarkey analyzed the advantages and disadvantages of having one, two, and three carts sizes, and concluded that two cart sizes, ten inches and twenty-four inches wide, would be optimum. The number of cart lanes required for different plant capacities is shown in figure 7. Some of the assumptions used in devising this design figure are that the maximum velocity of the carts would be five feet per second; that the cart length would be at least twice the mesh size of the screen feeding it; and that the plant would operate 16 hours per day.

Development and Operation of the Instrumentation System

A survey of all apparent methods which might be used to obtain enough data on refuse items to permit some form of automatic classification of these items were made by Smith[5] and Senturia[6]. The survey covered the entire electromagnetic spectrum. from low-frequency radio waves (conductivity), to microwaves, infrared, visible, ultraviolet, and x-rays. The relative merits of the kinds of information which could be obtained in each spectral range were examined. In addition, acoustical methods were examined, including measurement of sound velocity, and the use of acoustic reflectometry with ultrasonic waves. The criteria used for selecting the methods for further development were as follows.

1. The sensor should be a multiple-output sensor, capable of providing a classification of a given piece of material into one of several categories.
2. If a sensor method was already available commercially, it should be employed. There were, in fact, no commercially available multiple output sensors except for highly sophisticated research-style instruments capable of examining highly detailed spectroscopic records and comparing them with standard spectra. These research-style instruments were judged unsuitable for the relatively coarse sorting operation envisaged for this plant, and they required either careful sample preparation or an undue length of time to produce a reading or both.
3. The combination of sensors selected should have a reasonable liklihood of being able successfully to separate the principal recyclable refuse components, these being glass, paper, metals, and plastics.
4. The objects being sensed should not require special preparation - eg. cleaning, etching, polishing, - and the readings should be capable of being made in air, rather than in a vacuum, so that "raw" refuse could be sorted.
5. Readings should be obtainable within a few milliseconds of exposure to the sensors, so that a small sorting plant could have a high throughput.

Sensor Selection

The results of that survey and of several preliminary experiments were that two sensors were selected for development, the infrared sensor and the impact sensor.

Infrared sensor. The infrared sensor[7] uses the principle that the spectrum of infrared light which has been diffusely reflected from a surface will show all of the major infrared-absorption lines characteristic of the reflector. By surveying the reflection spectra of many refuse items, a set of wavelengths was chosen which could indeed provide useful differentiations among classes of objects. A pattern-recognition algorithm using linear-separation techniques was developed which could successfully classify metals, glass, cellulose, and plastics on the basis of the relative intensities of the light reflected at the four infrared wavelengths (see figure 8). A prototype instrument which used a globar infrared source, a rotating filter wheel to select the four wavelengths, and a liquid-nitrogen-cooled InSb infrared detector was assembled.[8] The amplitudes of the photodiode signals corresponding to each wavelength were stored in analog track-and-hold memory circuits. This set of stored voltages constituted the "pattern" on which the pattern-recognition algorithm could work. The specific algorithm used has been published elsewhere.[9]

Rodgers [9,10] examined the variation in the relative intensities of the four wavelengths as a function of angle away from the specular or mirror-reflection angle of various materials. This diffusely scattered light contains spectral information about the contents of the reflecting surface. For example, the angular variation of the light reflected from polystyrene in figure 9 shows that at zero angle, the specular direction, the relative intensities of the four wavelengths are roughly constant, but as the direction varies away from the specular direction, one line (at 3.4 microns) is much weaker than the other three. This weaker line corresponds to a characteristic absorption in carbon-hydrogen chemical bonds, and can be used to identify materials containing such bonds.

Because of the angular variation of the spectral intensities from most materials (glass is a particularly difficult material in this regard), the optical alignment was adjusted so that, for typical object positions within the cart, the specular reflection would miss the collection mirror, thus guaranteeing in turn that only diffusely reflected light would reach the detector. Rodgers collected reflection data from a set of typical samples, and used the pattern-recognition algorithm to develop new parameters and a new sorting program. He also developed the necessary logic steps to control the writing device which would write the classification code on the cart containing the object under examination. The program calculates a classification every time the filter wheel rotates once (20 milliseconds). At the cart speeds used in the system, 20 milliseconds corresponds to a new spectrum every 1/4 inch. A record is kept of each classification. After the object passes out of view, the category which occurred most often is declared "the category" for that item. The system now is capable of nearly perfect classification of cellulose, plastics, glass and metals, using only a commercial metal detector and the infrared sensor. Later incorporation of the impact sensor will, it is hoped, further improve sorting accuracy and greatly increase the number of potential categories.

Impact Sensor. The impact sensor relies on the observation that the time dependence of the acceleration of a hammer or impact tool striking a refuse item is characteristic of the kind of material being struck.[11] An accelerometer is mounted on an impact tool which is allowed to strike the object under test. The shape of the impact waveform (figure 10) varies with the elastic and plastic properties of the material. The shapes of these impact waveforms can be quantitatively analyzed and used as a "pattern" for a pattern-recognition algorithm similar to that used for the infrared sensor. Hibberd [12] and Epstein [13] developed a working impact sensor which used an impact tool operating in free fall, track-and-hold memories to store parameters characteristic of the acceleration pulse, and a specially-built analog computer for implementation of the pattern-recognition algorithm.[14]

Vibrating impact sensor. Free-fall versions of the impact sensor were impossible to control when the object being struck had an irregular shape. Early experiments also showed that impact velocity had an effect on the shape of the impact waveforms. Therefore, shortly after the first demonstration of successful sorting with the free-fall impact sensor, Hibberd began the development of a vibrating impact sensor [15], a development which has been carried on subsequently by Kurtze.[16]

The idea behind the vibrating impact sensor is that one would like to control the velocity of the impact tool, and one would also like to make more than one impact with each sample. The impact tool is displaced at constant rate until it reaches a preset maximum, at which point the tool is rapidly reset to zero displacement for the start of another cycle. In this ideal picture, the impact tool is accelerated only at the turnaround points.

Kurtze has completed the construction and debugging of a computer interface originally designed by Lingel,[17] which accepts the impact waveform and reads from that waveform the peak acceleration, the time to peak acceleration, the maximum leading-edge slope, the maximum trailing-edge slope, and the time required for the waveform to fall to 10% of its peak. These five parameters constitute the pattern. The interface circuit successively converts each parameter to digital form, and reads the numbers into the computer.

Plant Assembly Tests

During the summer of 1973, final assembly was made of a prototype large-item sorter. The sensors were installed beneath the track and the computer was connected both to the sensors and to the code-writing device. Items were dropped into the carts from a feed conveyor, the carts carried the items over the sensors, the computer controlled the code-writing device, and code-reading devices activated dumping mechanisms. The sensors and carts operated satisfactorily, with high sorting accuracies.

Vortex Classification of Small Pieces

A device has been constructed which has classified particles according to density by allowing them to fall through an air vortex flow field and to change radial position under the influence of aerodynamic forces.

Purpose of Classifier

The vortex classifier was designed as a means of handling the small items either passing through the vibrating screen in the "presorter" section of the process, or those leaving the hammer mill after rejection by the large-item sorter.

Principle of Operation

A fluid vortex is defined as radial flow towards a sink with rotational flow superimposed.

Confined vortices are frequently used to separate out particles in gases and liquids, or to produce "light" and "heavy" fractions. Early in the present work it was determined analytically that the shape of the confining chamber could be made so that particles could take up equilibrium radii.[18] Furthermore, the equilibrium would be stable: that is, if a particle were disturbed from its equilibrium radius, it would tend to return.

The path a particle takes in approaching its equilibrium radius has been found to be a unique function of the density, and to a lesser extent of the drag coefficient, of the particle. The principle of the classifier is, then, that particles are injected into a fluid vortex of certain characteristics; that the particles spread out along varying paths as they approach their equilibrium radii, the paths depending largely on the density of the particles; and that they are collected at convenient points along these separate paths.

Experimental Work

Tests carried out in the air vortex classifier and parallel computer predictions of particle paths are reported by McCarthy.[19] A range of geometrical shapes - spheres, cubes, lamella of various thicknesses - sizes, and densities of particles was injected into the air classifier at mean radius and at the velocity and direction of the local component of tangential velocity. The transient paths of the particles as they approached their equilibrium radii were recorded by means of multi-exposure stroboscopic flash photography. These paths were compared with computer predictions based on calculations of particle motion under the influence of simple aerodynamic drag in a two-dimensional axisymmetric vortex. A sample of the results is shown in figure 11.

Very good agreement between experiment and computer prediction was obtained for all but very thin lamellar particles, for which in any case the drag coefficient was uncertain.

Predictions of Full-Scale Performance of Vortex Classifier

Two distinct ranges of operation of vortex classifiers are anticipated: for lighter-than-water materials such as plastics, woods and paper products; and heavier-than-water materials such as nonferrous metals and glass. In the first group air would be the classifying fluid, and water would be used for the second.

Predictions of the classifying performance for nonferrous metals in water are shown in figure 12. Separation in the transient mode is sufficiently rapid for several streams of particles to be handled in a single vortex. Power costs per ton should be a very small fraction of the potential value.

Predicted Costs and Income

Cost and income predictions, especially when made by the proponents of a process, are always suspect.

We have tried to be conservative in estimating the machinery cost for a 1000 ton-per-day plant at $1 million, and the site costs at $3 million.

The total salvage value of the site, buildings and machinery at the end of 10 years is assumed to be $1.5 million in constant dollars. The net daily amortization costs at 8 percent interest then amount to about $1650 (based on a 300-day year).

Daily Cash Flow

We shall assume that the plant is located in what is recommended as a minimum-disposal-cost area where the costs of disposing of the uneconomic fraction and the credit received for the processing of the incoming refuse equal $6 per ton. If these costs and credits were $10 or more per ton, as is the case in many urban and suburban areas, the cash-flow balance would be even more favorable.

We are also assuming low prices for the sale of the potential products. For instance, we list paper at $10 per ton, yet clean newspaper is presently (late 1973) fetching $80 per ton, FOB west-coast ports. Glass is included in the material being sold at $10 per ton, yet color-sorted glass realizes $20 per ton at glass-manufacturing plants and, at bottlers, about $100 per ton as brand-sorted, undamaged bottles. We have also tried to be conservative in the number of employees (10 per shift) and the average earnings. Nonferrous metals, of value from $200 per ton for aluminum to $400 per ton for copper are conservatively included in the $10-per-ton average value of the recoverable fractions.

Daily costs for 1,000 TPD plant

Amortization	$1650
Labor - 20 employees 8 hours, $10 per hr.	$1600
Disposal costs, 300 tons, $6 per ton	$1800
Utilities, insurance, taxes etc.	$ 450
	$5500

Daily income

Ferrous metals 100 tons @ $10	$1000
Paper 300 tons @ $10	$3000
Other large items 150 tons @ $10	$1500
Small items 150 tons @ $5	$ 750
Processing fees 1000 tons @ $6	$6000
TOTAL INCOME	$12,250
DAILY SURPLUS	$ 6750
Annual surplus (profit) -	300-day year $2,025,000

Costs Per Sort

If all the plant costs per day ($5500) are ascribed to the large-item sorter, which sorts 4500 large items per ton, and handles an input of 1000 TPD, the cost per sort is:

$$\frac{\$5500 \times 100 \text{ cents}}{4500 \times 1000} = 0.122 \text{ cents per sort}$$

A more realistic figure might be 0.08 cents per sort because of the considerable proportion of the input stream which is handled by the magnetic belt, the film extractor and the vortex classifier. This sorting cost, updated for current conditions, would be a guide to the manager of a plant when he chooses among alternative sorting strategies in his day-to-day adjustment of the sorting criteria.

Acknowledgements

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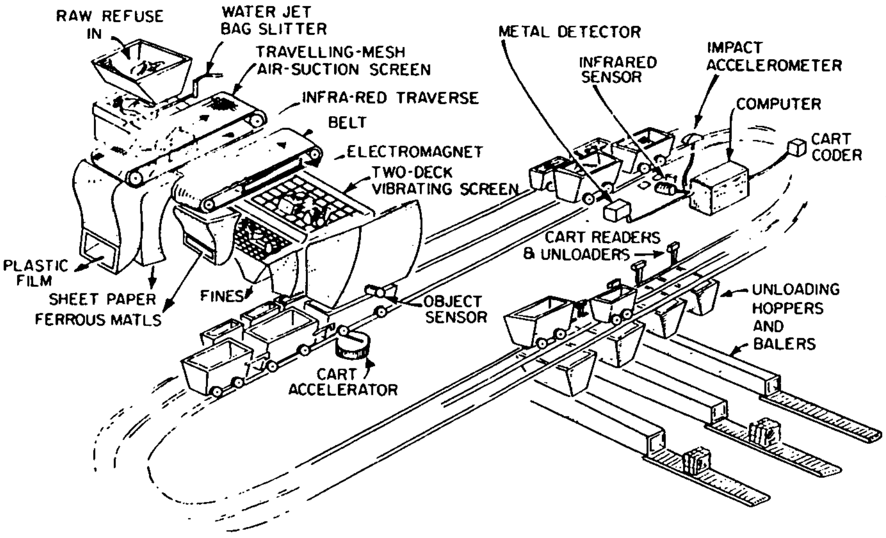


FIGURE 1 OVERALL VIEW OF PLANT

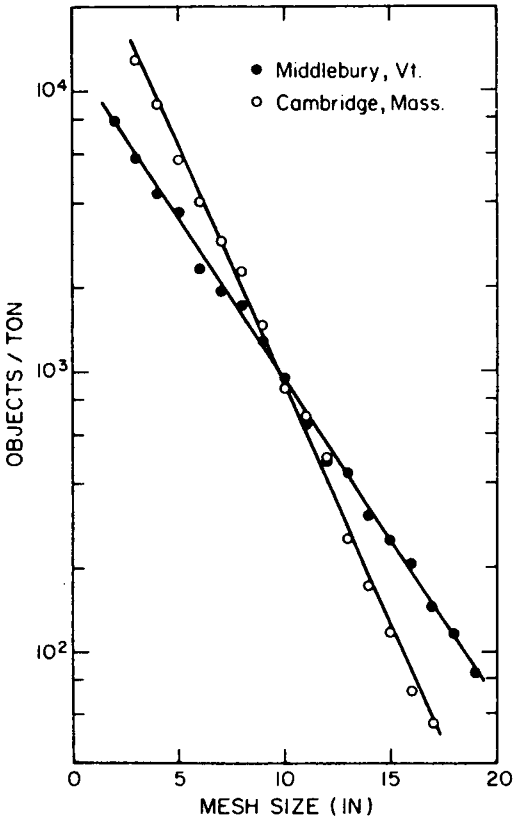


FIGURE 2 NUMBER OF OBJECTS PER TON OF RAW REFUSE WHICH WILL PASS THROUGH A SQUARE MESH

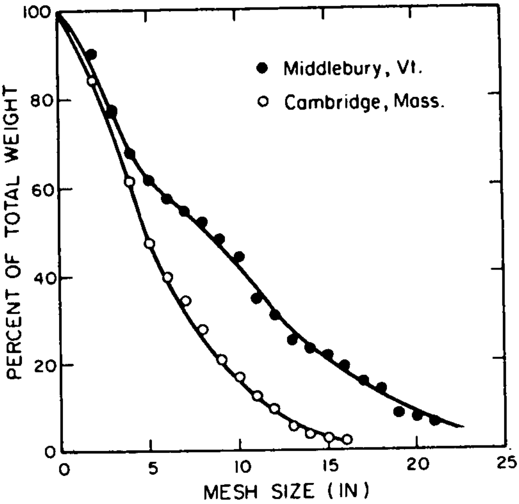
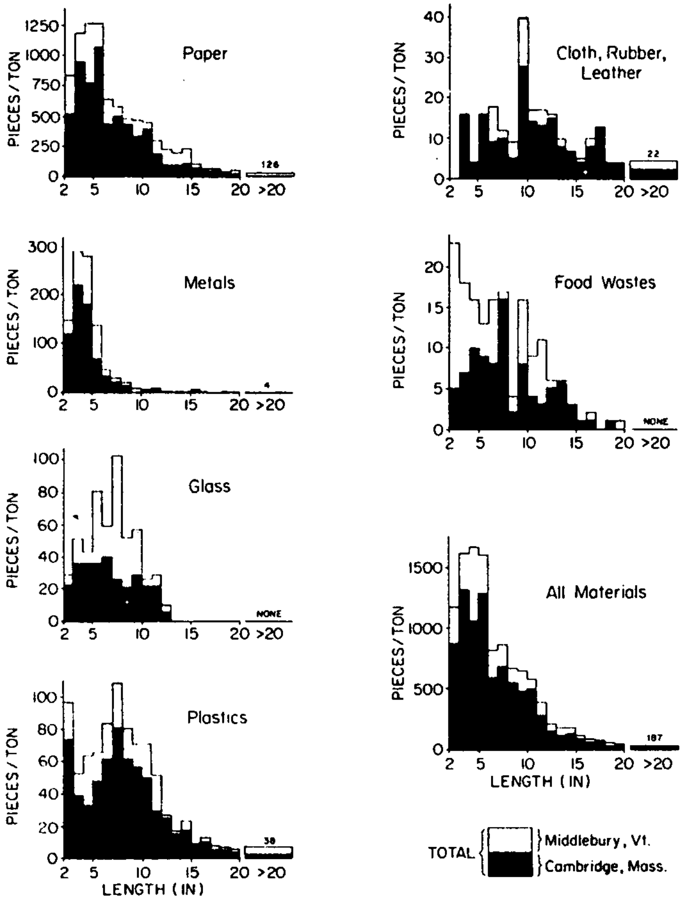


FIGURE 3 MASS-PERCENT OF OBJECTS WHICH WILL PASS THROUGH A SQUARE MESH



Total height of each bar gives weighted average of Cambridge and Middlebury data, with relative contributions indicated by shading. Note different vertical scales.

FIGURE 4 NUMBER OF OBJECTS PER TON OF RAW REFUSE VERSUS LONGEST DIMENSION FOR PRINCIPAL CATEGORIES

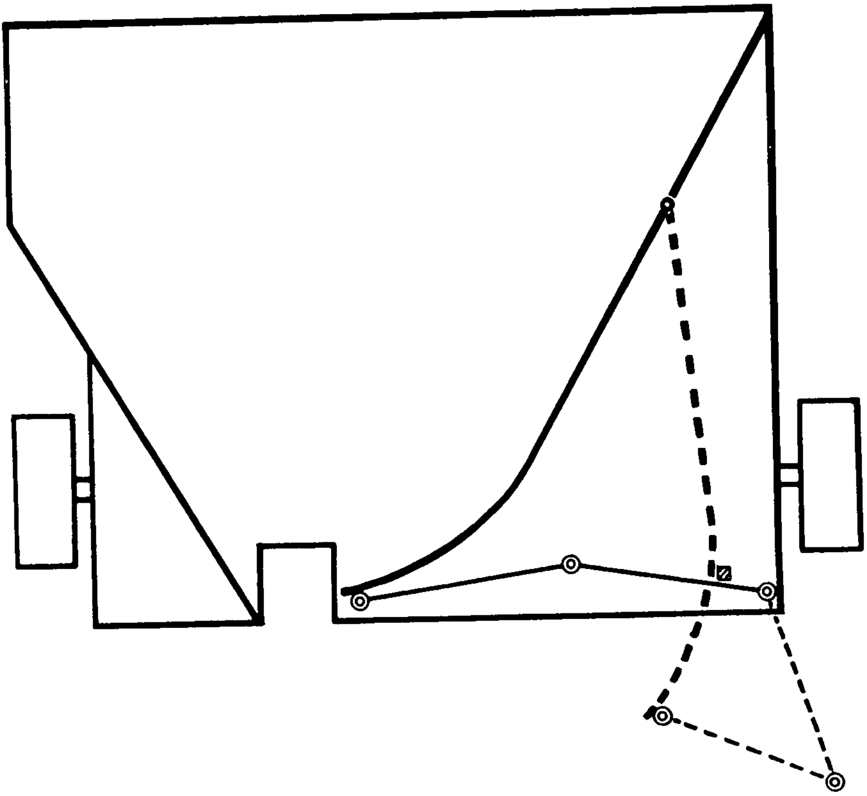


FIGURE 5 TOGGLE-ACTION LATCH FOR CART DOOR

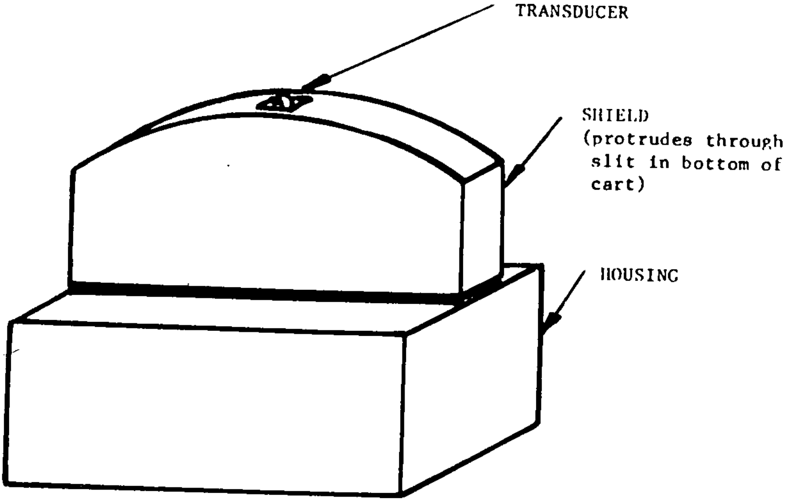


FIGURE 6 HOUSING FOR METAL DETECTOR AND IMPACT SENSOR

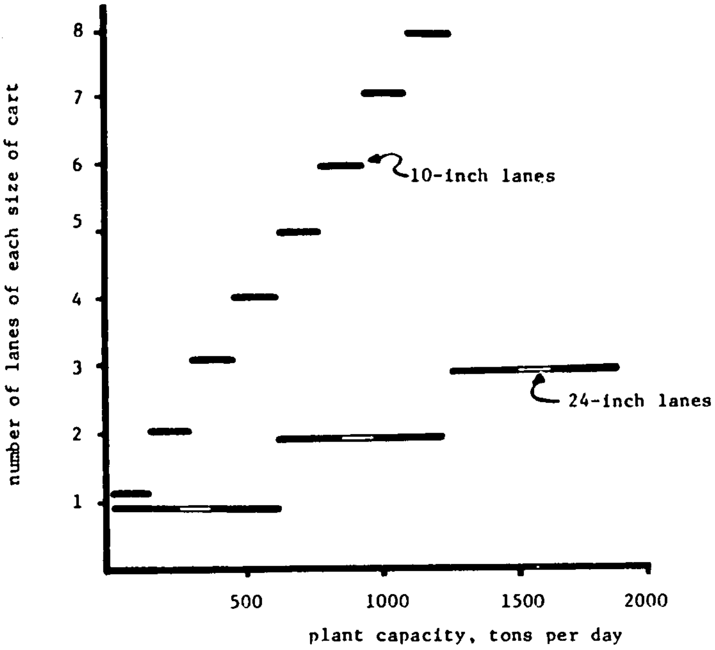
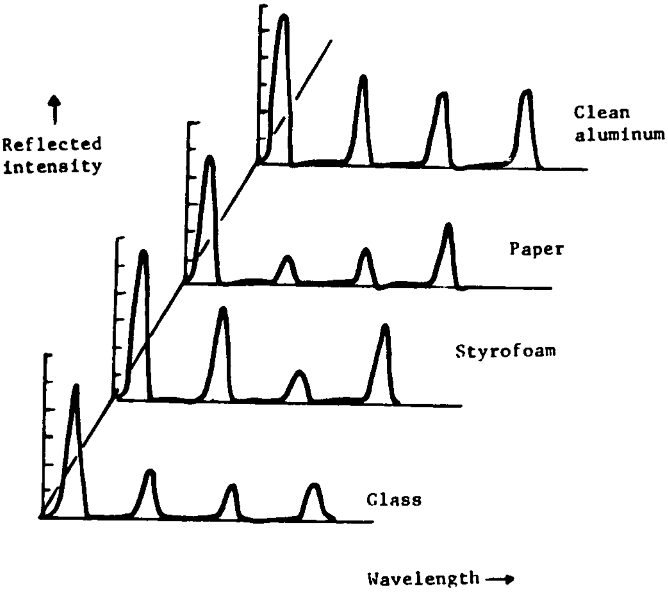


FIGURE 7 NUMBER OF CART LANES REQUIRED IN FULL-SIZE PLANT



The amplitudes of the four peaks constitute the pattern fed to the computer for classification

FIGURE 8 SAMPLE SPECTRA FROM THE INFRARED SENSOR

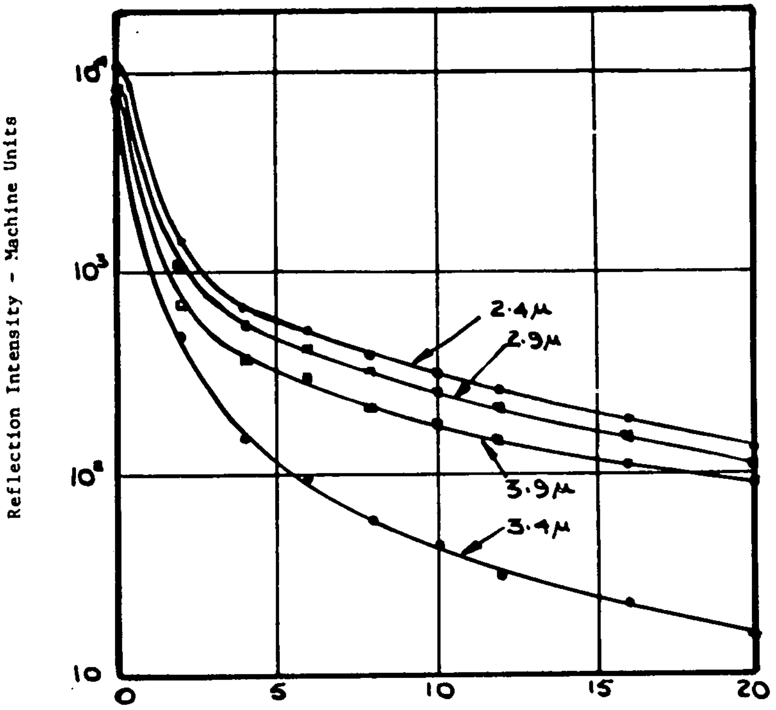
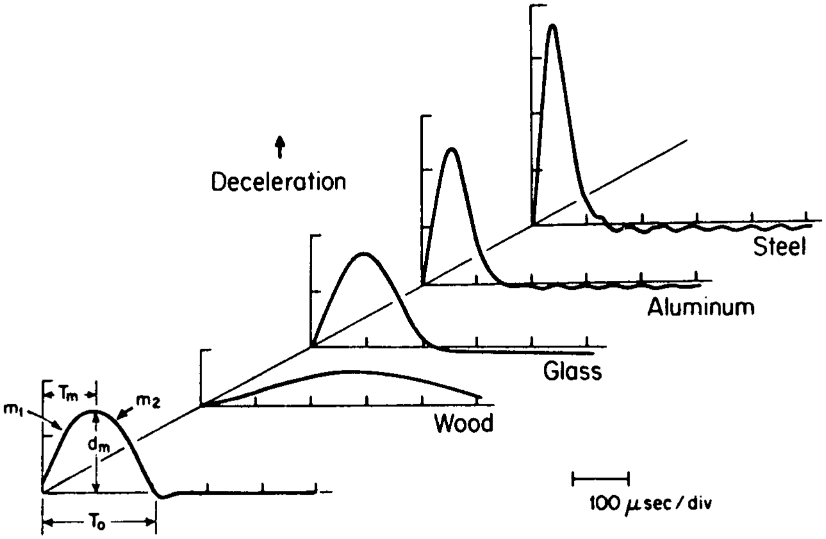


FIGURE 9 VARIATION OF THE REFLECTION INTENSITY WITH ANGLE FROM POLYSTYRENE AT FOUR WAVELENGTHS



Parameters such as ascending slope (m_1) peak height (d_m), and time-to-maximum acceleration (T_m) are measured electronically and fed to the computer for processing.

FIGURE 10 IMPACT-SENSOR DATA FROM TYPICAL SAMPLES

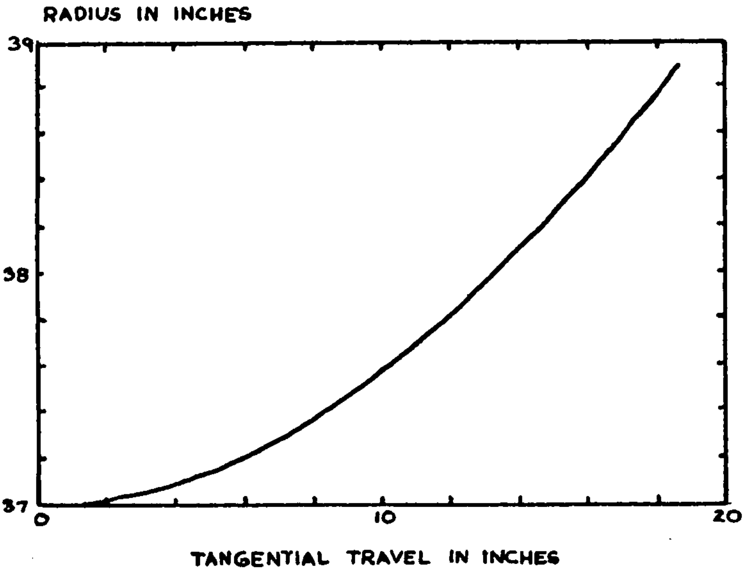


FIGURE 11 COMPUTER PREDICTION OF PARTICLE MOTION IN VORTEX CLASSIFIER

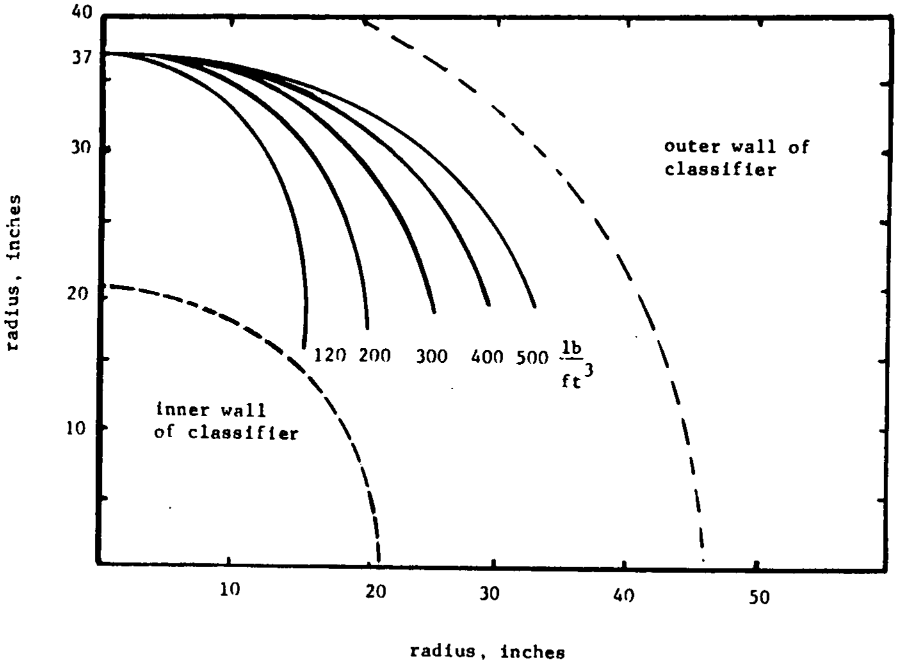


FIGURE 12 COMPUTER PREDICTIONS OF VORTEX CLASSIFICATION OF NONFERROUS METALS IN WATER

REVIEW OF ADVANCED SOLID-WASTE PROCESSING TECHNOLOGY

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ABSTRACT

This paper briefly examines recent research into various alternatives for solid-waste processing - size reduction, compaction, incineration with and without heat recovery, and the production of fuels or secondary materials from wastes - from the viewpoint of the policy maker.

Some of these alternatives are traditional, such as incineration and separation for reclamation. However, changing economics and the changing character of solid wastes have made past methods largely unsuitable for present conditions. In some areas, detailed research has filled, or promises to fill, the apparent needs. In general, however, confirmation of the research findings into full-scale, long-term operation is still lacking.

In other areas, such as size reduction and heat recovery, sufficient research has been carried out to indicate desirable policies, and either the economics or the environmental impact have proved sufficiently advantageous for these alternatives to have been accepted quite recently as being better on a number of counts than their immediate alternatives. Despite this acceptance, problems have been encountered, and research needs to be carried out to give guidance to the policy maker. For instance, in both these areas (size reduction and heat recovery), equipment reliability has occasionally been low and maintenance costs have been high. The reasons for these situations should be identified and avoiding action recommended.

There remain a number of alternatives where the work which has been carried out so far is essentially of an advocacy nature. Some of the alternatives for the production of fuels from wastes are in this category. The policy maker may understandably be confused. On the one hand, claims for extremely favorable economics are made. On the other hand, these supposedly attractive possibilities are not being adopted. We shall endeavor to suggest the promising areas.

PAST REVIEWS OF PROCESSING ALTERNATIVES

The present paper is extracted from the report to N.S.F. of a team headed by Dr. David H. Marks of M.I.T. into recent policy-related research in solid-waste management. Earlier reviews of processing alternatives are available. The comprehensive studies of solid-waste management edited by Golueke and McGauhey[1,2] and the abstracts and excerpts from the literature[3] are excellent discussions of research underway in the late sixties. From the nature of the research team, the emphasis tends to be on biological processes, with less-thorough treatment given to the mechanical-, civil- and chemical-engineering aspects.

Current practice is discussed thoroughly in the American Public Works Association's "Municipal Refuse Disposal"[4]. A British handbook covering European practice is "Public Cleansing" by Flintoff and Millard.[5] Because European work has in the past been somewhat more advanced than U.S. practice, this last book has an up-to-date approach, and can quote operational experience from many areas.

Two more-recent reviews of solid-waste practice have been by Glysson,[6] beautifully illustrated and well presented, and Wilson,[7] involving members of the present team.

SIZE REDUCTION

Summary

Size reduction has become an accepted method of solid-waste processing. A wide variety of processing methods and manufacturers are available. There are few reliable data presently available to enable a policy maker to choose among the available methods and types of equipment. A fact-finding tour of existing users is recommended before selection of new plant.

When applied to solid-waste processing, size reduction implies that large pieces of solid waste are torn, sheared, cut, or fractured, to produce smaller pieces. Reduction in size by the application of pressure is not included in this general category, except insofar as glass-like materials will break into smaller pieces whether they are sheared or compacted. There are several synonyms for size reduction in solid-waste processing: comminution; crushing, pulverization; hammermilling; mastication; grinding; or shredding. All these terms are used more or less interchangeably. In addition, "rasping" is a method of size reduction which is reserved for slow-velocity abrasion and shearing; "chipping" is a high-velocity cutting process reserved for the size reduction of tree branches and other wood.

Size reduction has been available for solid-waste processing for many decades, particularly in Europe. Size reduction was regarded as desirable for bulky refuse such as furniture and "white goods" (ranges, refrigerators, washing machines and the like). However, size reduction was also used in Britain and Europe for regular household refuse because it enabled the comminuted refuse to be sold as a soil conditioner.[8] Shredding of solid wastes became widely practised with the development of composting processing, particularly in Europe after the second World War. Although composting has not generally been successful, the beneficial properties which size reduction gives to solid wastes became more generally recognized, and is now being frequently used as a preprocessing method for landfilling, encouraged by the changing character of municipal refuse. Refuse has changed from being predominantly ashes from coal fires to being principally newspapers, paper and plastic packaging materials, and bottles and cans. Size reduction reduces the overall volume of refuse, particularly with the application of a low compaction pressure after processing; size reduction is required for composting and stabilization; most newly developed methods of automatic sorting for reclamation require size reduction before various types of air classification are used: size reduc-

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tion is needed before most pyrolysis processes; and some methods of incineration require prior size reduction.

In the last decade, size reduction by modern methods spread to this continent by way of Montreal. A commercial landfill was supplied from a transfer station where some reclamation was practised before the refuse was fed to Gondard hammermills (W. J. Johnson[9]). Johnson's report is excellent for the practical and financial details which are given. Some hand-picked separation and salvage was accomplished from the conveyor belt feeding the hammer mill. The milled refuse was trucked eleven miles to the company's own landfills. With Montreal wages and prices in the 1966-1970 period, cost averaged $2.12 per ton before salvage, and $1.57 per ton with credit for salvage. Subsequently, a demonstration size-reduction processing plant and landfill was started in Madison, Wisconsin, with the support of the Bureau of Solid-Waste Management of the Public Health Service.[10] This Madison work has been highly successful, and has been the catalyst for the surge in interest in and commitment to size reduction for U.S. solid waste. In the six years, 1968-1974, between 10 and 20 size-reduction processing plants, principally for landfill, have been commissioned or are being built in the United States.[11]

Recent research

An excellent review of alternative size-reduction methods and of some operational experience has been made by Patrick.[12] Very useful reports of tests of the characteristics of milled refuse in U.S. conditions have come from the Madison team.[13,14] Some of these are reviewed by Wilson.[7]

The advantages of size reduction for various purposes are offset to some extent by the high capital and running costs. The size reduction of solid wastes is not a process which can be regarded as trouble free, or which can be left to the operation of unskilled employees. Size-reduction equipment has considerable maintenance requirements. For instance, hammermills generally require that the impact edges of the hammers be retipped with hard-faced welding every 12 hours or so of operation. Stoppages are fairly frequent, particularly with equipment designed for low throughput. The higher the throughput, the larger is the required power level, so that with the largest hammermills currently in use, three-thousand-horsepower motors and large-inertia hammers and rotors give the potential of digesting a full-size automobile in 10 or 20 pounds and therefore the probability that such normally troublesome items as bedsprings, carpets, and coils of wire and rope will not cause a stoppage.

A study conducted at Battelle Memorial Institute[15] attempted to correlate costs of size-reduction equipment on the basis of the particle size of the product and the machine capacity in tons per hour. At the time of the study, insufficient hard data were available for close estimates to be given but trends were established. More recent work by Trezek[16] has had the aim of determining the minimum energy required to transform unified components into particles, with the aim of providing design data for new size-reduction equipment with lower maintenance costs. Many reports describing operating experience with recent size-reduction plants have recently been becoming available.[17, 18, 19] The National Center for Resource Recovery has conducted a study of the characteristics of the comminuted product of different types of equipment.[20]

This study is recommended for the careful documentation and analysis of all costs in connection with the NCRR proposal for a reclamation plant. Various size-reduction options and operations are reviewed. Costs of $2.00 per ton are anticipated.

COMPACTION AND BALING

Summary

Baling by high-pressure compaction is a viable process which can reduce the long-haul transportation costs of solid wastes and improve the properties of landfills. However, there is presently no known commercial baling operation which is profitable.

Review of past developments

The reduction of volume of solid wastes by the application of pressure has been a technique used at several stages of solid-waste handling and processing for many years. Refuse trucks have become generally fitted with compaction arrangements since the Second World War. In the same period, stationary compactors have been developed for use in apartment buildings, institutions, restaurants, hotels and commercial and industrial facilities. Domestic compactors have been introduced with considerable commercial success. All these applications of compaction use relatively low compaction pressures, generally below 50 pounds per square inch. Mean density produced by such pressures are generally less than 40 pounds per cubic foot or about 1,000 pounds per cubic yard.

Compaction for baling necessarily uses considerably higher pressures. At face pressures of the order of 1,000 pounds per square inch, typical municipal solid wastes begin to lock together when compacted so that the resulting bale can hold together without a container. Usually strapping is used as a safeguard.

The Japanese firm of Tezuka Kosan has probably received the most publicity for its compaction work.[21] Tezuka chose to experiment with a number of types of enclosure for its bales and to propose the use of the enclosed bales for various types of construction work. Bales have been enclosed in steel, concrete, and in chicken wire as a reinforcing for asphalt. However, since solid wastes contain a great deal of organic material which is not stable, such uses cannot in general rely on the mechanical properties of the bales. These uses therefore have not been found acceptable elsewhere.

The most detailed research into high-pressure compaction has been undertaken by Wolf and Sosnovsky[22,23] which is discussed below. The city of San Diego has also experimented with bales.[24]

The greatest volume of bales has probably been handled by Reclamation Systems Inc. of Cambridge, Ma., which installed two vertical Lombard presses, each of one-thousand-tons-per-day capacity, and which has been working at a low production level for the past three years.[25]

Baling research

The largest program of research into baling was sponsored by the American Public Works Association for the city of Chicago and the Bureau of Solid-Waste Management of the Public Health Service from 1967 to 1970.[22,23] The behavior of solid wastes during baling and the performance of the bales produced in subsequent handling were thoroughly investigated. Experiments were carried out with a scrap-metal baler having three rams producing bales 16 inches by 20 inches by a variable length. The face pressures were 94 psi for the first ram; 573 psi for the second ram: and up to 3,500 psi for the third ram. The comparatively small size of these bales would presumably make the results conservative, because solid waste has a characteristic size which is significant in these dimensions. It is possible, for instance, for a wad composed of a single newspaper to form a separation surface in a bale of this size, and the pressures required to penetrate this wad to form locking junctions would be very high. In a press having a cross section of 4 feet by 4 feet, as is used in the Reclamation Systems plant in Cambridge, Ma., components normally found in refuse would not be able to form such a separation surface.

In the APWA study, stable bales were found to be achieved at pressures of 2,000 psi and above, although sometimes a stable bale could be formed at pressures of 1,000 psi. No improvement was found at above 3,500 psi face pressure. These findings apply to reasonably dry refuse. When the refuse was sodden, as after exposure to rain, stable bales could not be formed. The limit of moisture content of paper for bale stability was found to be about 40 percent.

Refuse which had been previously comminuted (subjected to size reduction) was found to give good bales at lower pressures, but at over 1,500 psi face pressure, improvement due to precomminution was insignificant.

Baling was found to be especially beneficial for oversize wastes such as bedsprings, refrigerators, ranges and so forth.

After compaction, bales exhibit a spring back if they are not strapped. The increase in volume can go as high as 95 percent of the minimum, compacted, volume during the following 24 hours.

Bales were also shipped by rail for 700 miles and dropped from a height of 9 or 10 feet. It was found that bales compacted at pressures from 2,000 to 3,500 psi were stable under these rather extreme conditions. Bales made at 1,500 psi face pressure were stable but required some care in stacking. Bales which had been compacted two weeks seemed to be as stable as just-compacted bales.

The Wolf and Sosnovsky work is thorough, valuable for the wealth of data supplied and of generally high quality.

Needed research

Although some work was done in the APWA study on the decomposition of bales, showing that aerobic decomposition took place at least in the first two weeks of storage, the conditions of this investigation were not extensive enough for firm conclusions to be drawn for all circumstances. Reports from visitors to the Tezuka Kosan plant in Japan claimed that bales stored in the open had become a breeding place for flies. Newly made bales at Reclamation Systems in Cambridge are sprayed with an insecticide, showing that the possibility of fly breeding is at least recognized. Knowledge of decomposition processes in bales in various conditions is required.

The flammability characteristics of baled refuse needs further examination. It was formerly maintained that baled refuse would be unlikely to support combustion once the loose outer layers had burned off. However, the burning during a 24-hour period of between two- and four-thousand tons of baled refuse stored in the yards of Reclamation Systems showed that complete combustion is possible.

CONVENTIONAL INCINERATION

Summary

Conventional incineration is facing a difficult period in which stricter air-quality limits, higher standards for ash disposal, increased labor costs, and increased capital costs, are all putting the overall cost for incineration to very high levels. Despite the increased sophistication of present-day incinerators in the U.S., none is working in a wholly satisfactory manner. Research reports tend to be written from either an advocacy or antagonist viewpoint.

A widely recognized problem is the unreliability and high maintenance costs, often associated with the use of operators with a low level of training. Automatic operation of incineration would be highly desirable to eliminate the effects of the low skill level of most incinerator operators.

Two approaches which offer the possibility of a greatly increased degree of automatic control are suspension burning, which requires prior size reduction of refuse; and slagging operation, in which either the wastes or the products of combustion are melted. Both of these approaches have seen advances in the last few years, but neither appears to offer any prospect of a reduction of costs.

Present position of conventional incineration

The present position of conventional incineration was very competently reviewed by a study for the National Air-Pollution-Control Administration and summarized by Sarofim and Niessen[7]. Conventional non-slagging incineration uses temperatures from 1600F to 2000F. Typical refuse has an adiabatic flame temperature of just under 2000F with 100 percent excess air. Combustion is relatively easy to control with this large a proportion of excess air. However, the size of air-cleaning equipment has to be increased as the amount of air added increases.

Slagging operation requires furnace temperatures of around 3000F. This temperature is reached by typical refuse with zero excess air for combustion. In practice, an attempt to operate with zero excess air would mean that many parts of the refuse would not in fact burn. Slagging incinerators require one or more of the three following steps to bring about higher temperatures with the use of reasonable quantities of excess air.

1. Supplementary fuel
2. Use of enriched air or pure oxygen
3. Preheating of the combustion air

All three approaches have been tried. None can yet be said to have achieved complete success, although pilot plants have operated for significant periods. Slagging operation requires special, and expensive, furnace linings, none of which appear yet to have proved themselves in extended service. However, the Dravo incinerator at Wolfsburg, Germany, (using heat regeneration to the combustion air) has operated for at least two years.

Fluidized-bed incineration

A pilot study of the incineration of municipal refuse in a fluidized bed has been reported at West Virginia University.

A fluidized-bed combuster for comminuted solid wastes has also been developed by the Combustion Power Company in California as part of its contract with the Environmental Protection Agency for the development of a gas turbine to produce power from the burning of refuse.[26] This gives good data about the combustion of fluidized refuse.

In a fluidized bed, combustion air is fed from beneath a perforated plate through a bed of, typically, sand, which at above a certain fluidizing velocity becomes airborne and behaves somewhat like a liquid with a definite liquid-like surface. When this bed is preheated, for instance by the combustion of methanol, or natural gas, to perhaps 1200F, and subsequently small pieces of combustible material are fed into the bed, combustion takes place within the bed and the sand particles cause very high heat-transfer rates to the newly arriving solids.

The absence of hot spots leads to low emissions of oxides of nitrogen, which is a positive feature. A very good burnout is usually achieved up to the maximum loading for the bed.

On the negative side, fluidized-bed incineration is a relatively large user of energy because of the need for size reduction and the requirement that the combustion air, and in addition a small quantity of fuel-feed air, be pressurized. Presently anticipated costs per ton are higher than for alternative forms of incineration.

Air-pollution-control equipment

Until the early 1970's, the main requirement for the stack-gas-cleaning equipment of incinerators was to remove the particles and the visible smoke. As a result of the Clean Air Act of 1967-1970 there has been movement towards restriction of other emission besides particulates, such as carbon monoxide, nitrogen oxides, hydrocarbons, and hydrogen chloride. Some of these are removed in a so-called wet-bottom gas-quenching system. Water in excess of that required to cool the gases is sprayed from coarse nozzles in the flue and in contacting the gases absorb nitrogen chloride, sulphur oxides, organic acids, and some particulates.[7]

Gas quenching with water in this way reduces the volume of gas to be treated by subsequent particulate-removal methods. The two methods which can be used to reach the low particulate loading allowed by present codes are electrostatic precipitators and bag-house filters. Most new incinerators in recent years have been fitted with electrostatic precipitators, but there are signs of a movement towards bag houses or other types of fabric filter because of problems which have occurred with electrostatic precipitators and because of the higher collection efficiencies which are reached by fabric filters at particle sizes of the order of one micron. The Niessen and Sarofim report is a good guide to recent work in this area.[7]

Boettner et al[27] gave a good review of the combustion products which are to be expected from the combustion of the principal plastic polymers. They point out that toxic products can be released by the incomplete combustion even of pure hydrocarbon plastics such as polyethylene. Complete combustion of hydrocarbon plastics causes no environmental damage, producing only carbon dioxide and water (and heat), but the halogen-containing plastics, such as the vinyl chlorides, produce hydrochloric acid even when completely burned. Other plastics are discussed, but it is emphasized that even a cursory review of all the thousands of variations on the principal formulations would be presently impossible. It appears, therefore, that we must rely on the public-spiritedness of the manufacturers of synthetic materials not to produce substances which might, in certain circumstances, result in dangerous conditions being produced during incineration.

The deaths which have reportedly resulted from smoldering furniture containing urethane-foam padding represent a clear danger signal to incinerator operators.

INCINERATION WITH HEAT RECOVERY

Summary

To use the heat generated in incineration of solid wastes would seem to be an obvious conservation measure which would lead to cash savings. However, the history of heat-recovery incinerators in the United States has, at least until the 1973 energy crisis, been marked by general failures to produce the expected results.

Introduction

Heat-recovery incinerators have been designed to raise steam. Some of this steam has been used for in-plant use, such as running auxiliary turbines or feed-water desalination plants as at Oceanside, Long Island.[28] The Oceanside plant was among those plagued by tube-corrosion problems, mentioned below. When attempts have been made to sell the steam, the market has been found to be resistant because the quality of the steam (the temperature and the pressure) is generally lower than is desired for process applications and sometimes higher than is needed for heating applications; and the supply is uncertain. Accordingly, standby equipment is always necessary, and therefore the only credit that can be taken for this steam supply is the possible saving of fuel.[7] With low fuel prices, this saving has seldom paid the extra costs of the double connection for standby equipment. With increasing fuel costs and a decreased supply of energy the prospects for future heat utilization from incineration are much brighter. Niessen and Sarofim give a very good discussion of the costs and operating factors of various types of incinerators.[7]

Alternative methods of construction

Heat can be recovered from the combustion products of an incinerator either by having the combustion take place in a conventional, well-insulated combustion chamber (lined with fire-brick material) and leading the gases past convection steam generators: or the combustion chamber can be lined with steel tubes, probably welded together to form a so-called "water-wall" construction. Over the past decade the practice in Europe and in North America has been predominantly to go to water-wall construction. The European units, in Rotterdam, Munich, Paris and Amsterdam, supply steam to power stations (or, as in Paris, the incinerator might actually be part of a power station).[29] In this country, this type of operation has recently been experimented with in St. Louis under a federal grant, and is described in the next sections.

Steam-raising incinerators have suffered tube failures in this country and in Europe. At least a contributory factor has been the condensation of hydrochloric acid, formed from the combustion of polyvinyl chlorides. It is not clear at the time of writing that this problem had been completely solved. It has been claimed that a close control of gas-side and water-side temperatures will avoid condensation in critical areas. But controls are a principal need and a remaining problem area for incineration, as mentioned above.

SOLID WASTE AS A SUPPLEMENTARY FUEL

Summary

If refuse is subjected to some degree of separation of noncombustibles and is reduced in size, it can be burned in suspension in a common combustion chamber with other solid fuels.

Introduction

It was mentioned above that the unreliability of supply of solid wastes and their varying combustion characteristics would normally require that standby equipment be used when heat recovered during incineration is used for some purpose external to the incinerator. This applies particularly to refuse when it is burned in the as-received condition. In electricity-generation plants in Germany, two separate water-wall combustion chambers, one for refuse and one for conventional fuel, discharge their gases to common superheaters, economizers, air-pollution-control system, and stack.[7] A slightly different system proposed by Pacific Gas and Electric Company in San Francisco was to have two separate furnaces, with the steam from the refuse furnace delivered to superheaters in an adjoining conventional utility boiler. This necessity for duplication of capital plant reduces the attractiveness of incineration heat recovery.

Suspension burning

At the Meramec station of Union Electric in St. Louis, refuse which has been reduced in size to a maximum of two inches and air classified to remove most of the inorganic fraction is burned in suspension in a modified combustion chamber with a small grate to burn out any chunks which form or pass through the system.[30,31] Conventional pulverized-coal burners supply most of the energy (90%) in the same combustion chambers. In this approach the additional capital cost required to convert an existing utility boiler to one burning refuse is small, and the risk to disruption of the normal boiler operation, which is normally an overriding concern, is also small.

Operating problems in St. Louis have been principally the erosion of the pulverized-fuel supply tubes. The basic plant operation and control with combined firing has been quite successful.

This method of burning the air-classified light fraction of municipal refuse would seem to be one with wide applications

As preliminary to the St. Louis experiment, Hornerand Shifrin, Inc. carried out a detailed study of the use of solid waste in coal-fired utility boilers.[32] They concluded that problems should be minimal if refuse is comminuted to a size of about one inch, and if the refuse constitutes no more than ten percent of the heat input. The value of the refuse as fuel was stated to be $2.50 to $4.00 per ton (1972 price levels) so that the process should be attractive. The capacity of suspension-fired boilers is much more than enough to take all U.S. municipal solid waste generated even at the recommended low proportion of firing. No deterioration in ambient air quality, and even an improvement in some areas, was foreseen.

These predictions seem to be borne out by the progress so far of the St. Louis experiments. However, a final report of the economics and of any operational difficulties has not yet been seen.

CONVERSION OF SOLID WASTES INTO A STORABLE TRANSPORTABLE FUEL

Summary

Conversion of the energy of solid waste into a fuel (rather than directly into heat) seems to offer considerable promise. There are several alternative approaches under active investigation. At the present time, none seems to face insuperable technical difficulties. On the other hand, none has yet been developed to the point where major use in commercial markets has been found.

The following sections describe the principal alternative approaches.

Air-classified light fraction as bulk fuel

As was described above, when solid waste is comminuted and subjected to air classification, most of the inorganic materials remain with the heavier fraction, and the organic, or combustible, components are found with the light fraction.

The average fuel composition of the air-classified light fraction, on a dry-weight basis, is about 30 percent ash, 35 percent carbon, and less than 0.25 percent sulphur: and it has a heating value of about 6,000 Btu per lbm. Its heating value is therefore higher than that of wood and peat: about equal to lignite: and lower than that of hard coal. Although the heat content by volume is, under conditions of little or no compression, lower than that for coal, the material is sufficiently dense for transfer trailers serving refuse shredders to be weight-limited rather than volume-limited. In other words, increased density would not bring large savings in highway transportation.

The burning behavior of the air-classified light fraction has been studied for suspension burning both with and without auxiliary fuel, as in the St. Louis power plant and the Combustion Power Co. tests mentioned above. However, the burning characteristics in grate-type combustion chambers is not known. The National Center for Resource Recovery is proposing experimental work in this area. The large quantity of ash produced is a disadvantage of using this fuel in comparison with oil and gas in particular. Nevertheless, with the end of the cheap-fuel era there are likely to be abundant applications for this lower-cost energy source.

The air-classified light fraction may also be compressed into cubes and used as a solid fuel. The National Research Corporation of Fort Wayne, Indiana has produced cubes of one-and-a-half inches approximately which has been successfully burned experimentally in solid-fuel boilers.[33] This approach has obvious attraction: it should be considered in any evaluation of alternatives for reclamation.

Fuel-gas production from solid wastes

When organic materials are allowed to decompose anaerobically (digestion), carbon dioxide and methane are produced in approximately equal volumes. The theoretical quantities are that one pound of convertible waste yields 6.65 cubic feet of methane, and a like volume of carbon dioxide, at standard conditions of temperature and pressure.

Research on the anaerobic digestion of solid wastes to produce methane has been carried out at the Universities of California and Illinois[34,35] and, more recently, at Dynatech Corporation in Cambridge, Ma.[36]

In a digestion process, initial separation of the inorganic fraction is required. The organic fraction is slurried with water, and nutrients are added. Raw refuse sludge may be used as a nutrient, thus saving the costs of purchased nutrients and of sludge disposal.

The digestors proposed by Dynatech[36] consist of large circular tanks with floating covers. The contents must be stirred continuously. The aqueous feed stream to the digestors has to be heated to about 95-100F.

The products from the digestors are the gases, which must be scrubbed to remove the carbon dioxide: waste water, which must be returned to a sewage-treatment plant; and a dewatered cake, which can be incinerated for landfill. (There is also the possibility that this cake could be composted for use as a dry fuel:see below).

Dynatech's estimates of the cost of production of methane by the anaerobic process are $1 per million Btu, if the credit for the treatment of solid wastes is $10.65 a ton. Competitive fuel costs are approaching this figure.

The University of Illinois reports[34,35] give valuable details of experimental data. [redacted] Methane-production costs of less than 25% of Dynatech's figures are predicted, [redacted].

Compost fuel

Solid wastes, sewage sludge, cattle-feed-lot wastes, agricultural and food-canning wastes may all be stabilized by composting. Compost is normally considered to have one use: as a soil conditioner. The material may also be used as a fuel.

This use for compost has been pioneered by Cobey Environmental Controls Company in a test program with the Department of Agriculture at Beltsville, Maryland and the General Motors Corporation, which produces the Cobey-Terex mobile composter.[37] This device can be driven to straddle a long pile of refuse, shredding, aerating, and turning it as it goes. The heat produced by aerobic action and the drying effect of the wind combine to produce a stabilized storable product, compost, which can be used as a soil conditioner or as a fuel. Its calorific value is about 5,000 Btu per pound, approximately equal to that of lignite. This material has been proposed particularly for agricultural purposes, such as crop drying. It is rather similar to the air-classified light fraction discussed above in that it has similar heat content, density, and ash content, and has not been fully evaluated as a potential fuel to be used on various grates.

Pyrolysis

When organic materials are heated in the total or partial absence of oxygen, they break down into combinations of gases, liquids, tars, and solids (ash). The relative proportions of these various constituents change as the temperature is varied between 500F and 1500F, with gas production increasing and liquid production decreasing as the temperature increases. Comminution to two- to four-inches maximum size, and separation out of the inorganic fraction, is required for all processes except for that developed by Union Carbide.[38] The wastes are introduced into a chamber (reactor) and either hot inert gas under pressure, or a fluid bed such as sand, is introduced to heat the wastes. The process is either run on a batch basis, in which case the reactor has to be periodically filled and emptied, or on a continuous basis with approximately steady-flow conditions prevailing throughout the system.

Pyrolysis has the very large advantage that, in comparison with incineration, there are no gases or liquid products which have to be treated before discharge to the environment. The solids which remain after pyrolysis are inert and can be landfilled without more than the usual precautions being necessary against leaching.

The liquid fuel produced from pyrolysis has an average heating value of about 12,000 Btu per lbm; the low-sulphur char has a heating value of about 9,000 Btu per lbm. A high-heating-value gas, 600 Btu per cu. ft., can also be produced. At least one of these streams is normally required as a heat input to the process.

Research and development into pyrolysis is being actively pursued by the Bureau of Mines,[39] by Garrett Research[40], by Monsanto Envirochem,[33] Pan American Resources,[41] Union Carbide,[38] the Universities of West Virginia,[42] Oklahoma and California.[43]

The early work by Pan American Resources culminated in the installation of continuous-operating "Lantz" convertor at a Ford Motor Co. plant in the late sixties. It was not economically successful and was taken out of service.

This failure was of particular significance because of the extremely favorable predictions which were made for pyrolysis costs and income in Pan American Resources proposals.[44] Economic predictions for present pyrolysis processes are almost equally favorable, indicating frequently a very low per-ton cost or even a net income. While it is easy to identify costs which have not been considered, or the assumption of low interest rates and a tax-free status, for instance, a large proportion of the costs and income must simply be considered to be conjecture until a full-scale plant is operated.

Garrett Research has been operating a pilot pyrolysis plant of four tons per day, and is building a 150-ton-per-day demonstration plant in San Diego county, California. This plant will yield very valuable cost and operating data.

An approach to pyrolysis which avoids the expensive shredding process and some of the costs of transferring heat to the refuse in the externally heated systems is to confine solid waste with oxygen sufficient to burn some of the refuse and to produce melting temperatures; the remainder of the refuse is pyrolyzed; the steam and methane undergo a shift reaction to produce carbon monoxide and hydrogen.[38] This approach has been pioneered by Union Carbide which has a pilot plant operating at its plant in Tarrytown, New York. The slagging of the solids reduces the volume and the handling difficulty very greatly and produces a glass-like frit similar to that from the slagging incinerators. The system is potentially favorable and should be considered a serious contender in areas where disposal costs are high and where a market for high-Btu gas exists.

Production of ethyl alcohol by hydrolysis

The hydrolysis of the organic constituents of refuse to produce fermentable sugars and subsequently alcohol has been vigorously proposed by Andrew Porteous[45] In this process, wastes are to be comminuted and separated by, for instance, air classification. The organic fraction is pulped in water and fed to a reactor where sulfuric acid is added, and the mixture is heated to 230C. Maximum conversion to fermentable sugars is reckoned to take only a few minutes. Subsequently the mixture is cooled, neutralized with calcium carbonate and fermented for about 24 hours at 40C. An aqueous ethyl-alcohol solution is produced which can be distilled or rectified to give 95% ethanol. A high-BOD waste liquid stream is discharged and requires treatment.

With a refuse feed of 40-per-cent paper content and a treatment credit of only $3 per ton, Porteous predicts that this process would be profitable. No experimental work appears to be in progress on this approach, however.

An alternative approach to acid hydrolysis for the production of sugars from cellulose is enzymatic hydrolysis. The prospects for this process have been advanced by the research at the U.S. Army Natick Laboratories into mutants of enzymes which were found to attack clothing.[46] Enzymatic hydrolysis is slower than acid hydrolysis but has advantages in that the process is carried out at normal temperatures and pressures in reactors which can be made from less-expensive materials than the acid-resistant materials needed for acid hydrolysis. In addition, the byproducts, for instance the lignin, are in a relatively pure form and can be used for other processes or could be pyrolyzed, for instance.

The enzymes developed at Natick have been supplied to other laboratories, among them those at the University of California.

Careful experimental work in addition to some design studies are reported by Golueke.[1,2] Economic predictions under the conditions assumed were not highly favorable. However, as the authors stated, there were many unknowns which could change in favor of the process. One of these is the cost of energy. Under present conditions it is possible that biological fractionation would be an attractive process. How it would compare with the Porteous process seems to depend entirely on two sets of uncertain predictions for capital and operational costs, which in turn depend on predictions of rate processes occurring in large batches. Evaluation would seem to have to wait on demonstration-plant operation.

General survey

Freeman[45] gives voluminous and useful data on various alternatives for using the energy in solid wastes. The information is, however, limited. For instance, pyrolysis is treated as one process. He evaluates a process requiring very fine shredding. The economics of many processes evaluated can appear to be less favorable than may be the case for unconsidered variations.

SEPARATION PROCESSES

Summary

Reclamation by separation from solid wastes is likely to be economically viable if carried out in an area where the credit for solid-waste processing can be $8.00 per ton or more and where at least 500 tons per day can be processed for several years. In these circumstances, secondary-materials industries are likely to locate near a reclamation plant to take the products.

Introduction

Separation of solid wastes into more-or-less pure components is carried out in the belief that most of the individual waste components can find markets, or can at least be disposed of at very low costs, if these components are produced in fractions of sufficient purity. The markets for separated materials are discussed below. The technology for separation has to be aimed at producing the highest possible purity, or the least contaminants, because the per-ton prices obtainable for most secondary materials drop extremely rapidly with small mixtures of contaminants. For instance, steel with .02 percent copper is almost unsaleable; newspaper with plastic cups, asphaltic glues, or waxed cartons, for instance, is presently unsaleable, except possibly as a fuel. Even unadulterated glass can double its value if separated into primary colors.

Separation technology has followed three main approaches. The most popular approach is primary size reduction followed by air classification and subsequent processing of the light and heavy fractions. A second approach is to pulp the incoming solid waste in water and to carry out separation processes on the slurry so produced. A third approach is to separate the solid wastes insofar as possible in the as-received condition. These approaches are briefly reviewed below.

Methods based on air classification

Methods based on air classification can be described with reference to the proposals by the National Center for Resource Recovery[20] and the Bureau of Mines.[47] Both these are thorough proposals based on carefully obtained data and are recommended for consideration. Solid wastes are comminuted and fed to an air classifier. The light organic fraction is fed to a landfill, or an incinerator, or can be processed by any of the methods described above into a storable fuel, or may be sorted into plastic and paper fractions by a promising electrodynamic technique.[48] The ferrous component of the heavy fraction is magnetically separated, and the remainder is sorted by size. The smaller pieces tend to be glass, which can be fed to optical sorting machines produced by the Sortex Company to produce single-color, higher-value fractions. The larger pieces of the nonmagnetic heavy fraction tend to be nonferrous metals, which are sorted by heavy-media separators. Water elutriation is suggested by the Bureau of Mines to separate aluminum from the heavy organic fraction.

This approach is typical of a branched binary system,[7] in which a relatively large number of sorting devices are strung together, each device separating the flow into two streams. There are many choices to be made for the individual devices. None seems to be presently capable of yielding a high-purity product, although the contamination of most streams is sufficiently low for the products to be saleable. There are many directions being pursued to provide improved separation systems for various streams. A team at Vanderbilt University has developed apparently effective eddy-current separators for glass and nonferrous metals.[49] Avco Corporation and others are developing ferrofluids (suspensions of iron particles in kerosine, for instance, which vary in apparent density in strong magnetic fields) as alternatives to heavy-media separators.[50] Another alternative to heavy-media separators are fluidized beds,[51] which have been developed effectively at the Warren Spring Laboratory in Britain.

The National Center for Resource Recovery estimates that the breakeven credit for treating solid wastes with this type of system is about $7.50 per ton, (1973 dollars) in a typical urban area. Presumably this figure, already below the cost of new incineration plants, will fall as the credits for materials and energy increase (assuming continued increases in raw-material prices) and as better separation systems become available.

The research studies by the NCRR and the Bureau of Mines are of high quality and have been backed up with detailed analyses of, and experiments with, refuse pulverized and air classified by various means. The initial cost of such a plant should be relatively small. The potential revenues are not high but are predicted as being sufficient to lower the overall costs of refuse treatment in many areas. The Bureau of Mines work is not as firmly developed, and the economic predictions may tend to be optimistic.

Water-based systems

The first automated central-station solid-waste separation plant is a water-based system at Franklin, Ohio using the Black-Clawson paper-making Hydrapulper as the fundamental treatment unit.[52] Wastes are fed to this pulper without pretreatment, and a variety of screens and cyclones, and a magnet, are used for separation of the useable fibers, the ferrous metals, and the nonferrous metals and glass. The nonferrous metals and glass are sorted optically and magnetically by a multi-branch binary system developed by the Sortex Company.

The proportion of solid wastes reclaimed was initially about 15 percent (into useable fibers) and is increasing to 30 percent as the glass- and metal-recovery sections come on stream. Most of the remaining portion is incinerated.

The cost of this first plant was comparable to that of an incinerator. The operating cost is apparently somewhat less than would be the case for an incinerator (ie, of the order of $8 per ton). The figures are somewhat difficult to analyze because of the EPA demonstration grant and prior grants used for the development of the process. Presumably future larger plants with improved equipment would show favorable economics. Black Clawson has proposed a commercially financed plant for Hempstead, L.I., with, however, slightly higher operating costs being predicted.[53]

The Black Clawson system has been proved workable in the field. The economics in initial operation have not been as favorable as forecast, but continued development will lead to steadily improving figures. Because of the downgrading of the fibers, the revenues are unlikely to be as high as for an optimum dry-separation process.

Another system based on water separation is the John F. Tracy separation system, in which the key element is a water trough of the order of 60-feet long and 15-feet wide and 10-feet deep for a one-thousand-ton-per-day plant.[54] Wastes are dumped on an apron, where the larger bundles of paper and cardboard are removed manually. Oversized items such as automotive tires and white goods (refrigerators and so forth) can also be removed at this stage. The remainder is pushed into the tank and agitated, and the sink portion, almost entirely of inorganics, is removed by a drag conveyor onto a belt for magnetic separation of ferrous materials and for hand picking of the larger nonferrous fraction. The floating portion is chopped, pulped, screened, and digested.

The simplicity of this system has much to commend it. It is labor-intensive for high-value components and capital-intensive for the bulk, low-value components. Costs of about $9.00 per ton are predicted for treatment with an allowance for salvage income.

Raw-refuse separation

Traditional reclamation plants separated solid wastes in the as-received condition. The wastes were loaded in some manner onto a so-called "picking" conveyor belt, which in most plants was arranged to take the wastes up an incline to a second-floor level. People would be positioned by hoppers next to the belt, and each person would have responsibility for extracting from the flow of refuse passing by a particular class of large,saleable items. One person would remove newspaper, a second cardboard, a third glass and a fourth nonferrous metals.

This type of operation is still carried out in Europe and was the basis of plants run by Lone Star Organics in Houston[55] and by Sanitary Refuse Collectors in Montreal[9] until about 1971. It was shown by Darnay and Franklin[56] that at present secondary-material prices and wage rates such plants could no longer be economically viable.

An attempt to automate a plant of this type has been made at M.I.T.[57] under an EPA grant. The principal features of the M.I.T. approach are that the larger pieces of refuse are first sorted out for treatment on an item-by-item basis; these larger items are examined by a number of sensors in series; a decision is made by a minicomputer as to which among perhaps 25 categories the large items should be switched; and subsequently switching is accomplished by means of bottom-opening carts which pass over a series of hoppers feeding balers.

Separation of the large items is accomplished by means of a two-deck vibrating screen of perhaps eight-inch- and four-inch-mesh sizes. Loose paper and plastic film is sucked off by an overhead fan operating on the inside of an open-mesh belt. Separation of this stream into paper and plastic may be accomplished by means of the electrostatic process developed by the Bureau of Mines[48]. A magnet removes ferrous materials. The fines passing through the vibrating screens join the large items which are rejected as inhomogeneous by the sensing system and are passed to a small hammermill for further size reduction and size classification. Subsequently the small items are to be classified in a multi-stream vortex classifier.

This development is not at the proof-of-concept stage at which it could be immediately developed by manufacturers. This might be the case in 1975. The economics look favorable because of the absence of the need to comminute the entire input stream; the small energy requirements per ton; and the potentially high purity of the output streams. This type of plant also has the advantage that the materials being separated, or the purity of the materials, can be changed from day to day as market conditions fluctuate.

Markets for separated materials

Both the immediate and long-term future for the sale of secondary materials look very promising. There are several reasons for this.

1. Increasing population and increasing standards of living are continuing to push up consumption rates in most materials.
2. Shortages in some materials are making policy makers believe that predicted shortages in other materials might in fact occur. Accordingly, there is a move to anticipate the problems by beginning to incorporate secondary materials wherever possible.
3. The environmental movement of the last decade has lead to a large number of developments of uses for secondary materials, some of which are beginning to appear in the market place.
4. The energy costs of secondary materials are usually lower than those of primary materials, so that there is an economic incentive to use secondary materials.

The market for separated materials depends on geographical location, and the quantity which can be sold on a steady, week-by-week basis. The market traditionally varies greatly in capacity from year to year and even from week to week. This situation has prevented investment in recycling plants in the past. The market is likely to improve in the future for the reasons given above. In addition, once some large-scale recycling plants producing high-quality (or at least, known-quality) product streams in large volume with high reliability are established, industries will begin to rely on these sources of supply and the market fluctuations will diminish.

Two excellent reviews of the secondary-materials market are that by the National Center for Resource Recovery[58] and by Darnay and Franklin.[56] Much other valuable information about alternative reclamation processes is given in the NCRR report, and useful data showing the effect of labor rates on hand-picking methods, for instance, are presented by Darney and Franklin.[56]

OTHER PROCESSES

Composting

The food and plant wastes and paper products in solid wastes can be broken down into a humus-like product when acted upon by air-loving microorganisms in a controlled environment. There must be: sufficient humidity; sufficient thermal insulation to conserve the heat given off so that the temperature in the composting mass may rise to the 140F - 170F range; sufficient air in all parts of the mass; and sufficient nitrogen in a form which can be taken up by the microorganisms. Sewage sludge may be added to provide the humidity and the nutrients. Modern compost plants differ from one another in the manner in which the air is either added by blowers or allowed to permeate by natural diffusion.

The first composting system was, and is, to chop the wastes and to pile it into "windrows". These rows must be turned over every few days to ensure that the central parts do not become taken over by anaerobic bacteria (which work at low temperature, therefore they do not kill pathogenic organisms, and are foul smelling) and that the outer parts of the piles are occasionally subjected to high temperatures. Such a system requires a great deal of land area.

Mechanical composting systems are attempts to reduce the plant area required by accelerating the process in more closely controlled conditions than is possible in windrows and possibly by carrying out the process over a height on a number of levels.

In either case, the production of compost requires a considerable capital investment. The cost of producing compost in the two U.S. plants still operating, in Altoona, Pennsylvania[59] and Brooklyn, N.Y.[60] ranges from $10 to $30 per ton. With the credits received for treating refuse the compost can be sold for between $5 and $20 per ton (bulk and packaged prices) in Altoona and $18 per ton in Brooklyn.[58] The market potential for a low-value material such as compost selling at these prices is small.

Composting has vigorous advocates and equally vigorous detractors, a situation leading to the possibility of confusion in policy makers.

Leaders in composting research are Golueke and his co-workers at the University of California.[61]

An independent review of composting is given by Bodman[7]. A somewhat negative, but not necessarily biased, survey is made by the National Center for Resource Recovery[58] in its excellent review of the reclamation field.

In summary, composting as a process for municipal wastes is feasibly operationally but has proven uneconomical in all but two of the approximately twenty plants started in the U.S. in the last two decades.

The prospects for composting may improve as fuel costs increase and with them the costs of fertilizers. (However, the production and distribution of compost from central plants use a certain amount of fuel). A boost would be given to composting also by a research finding that humus or compost-like materials are a necessary addition to productive soils over the long term. Occasional findings of this nature have not received widespread support or confirmation. So long as farmers and gardeners feel that they can achieve satisfactory results from the use of low-cost synthetic fertilizers the market for compost will remain small.

Protein production

The hydrolysis process described earlier yields fermentable sugars, and these may be used for a wide variety of products besides the alcohol production suggested previously. One use is as a feed for the growth of Torula yeast, which presently is used as a poultry-food supplement. Uses of this type have been investigated by the Forest Products Laboratory[62] and reviewed by the NCRR[59] which concluded that at late 1972 prices the process would be marginally uneconomic. With rapidly increasing prices for protein supplements, this process may become economically viable.

Wet oxidation

The contacting of organic wastes with air or oxygen under high pressures (500 to 1000 psi) and moderate temperatures (300 - 350F) causes breakdown into carbon dioxide, organic acids, water and a low-volume residue. Wet oxidation has been used to sterilize and stabilize sewage sludge, but its relatively high cost (Golueke reports $49 - $60 per ton)[1] is causing it to be phased out. However, as Golueke reports, organic acids have not been recovered and sold, and estimates for the value of these products range up to $90 per ton of incoming waste. He considers it vital to extend laboratory-scale experimental work to pilot-plant levels so that closer estimates of performance can be made.

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The problem is, how we recycle this waste. And here we have a brilliant breakthrough that enables us to do it.

And unfortunately, Mr. Wilson, you tell us that there is no economic incentive for taking advantage of it, and to provide that economic incentive we must do something which nobody in Congress likes to envision, especially in an election year, increasing taxes, and increase taxes to a considerable extent.

Even if you redistribute it it is a problem. I think that we ought to consider whatever other options there are, including something that also tends to go against the grain, but which I think is necessary if we are going to get this moving. And that is some way in which we can enable people to take advantage of this and make a lot of money in the process. They will serve a great purpose in doing this, and they should make money. But to do it on the basis of increasing taxes—certainly, that is one which is available and we ought to give that every consideration, but we just must find a way of recycling these wastes. And the way you have described gives us an opportunity to greatly increase our supply, and ease the tremendous burden we have now. And if we can apply that in other areas, as you say, that is the answer to the doomsayers who say that we will use up all our resources by 2100.

Mr. Spano.

THE STATE AND LOCAL GOVERNMENTS SHOULD TAKE THE LEAD ON THE NATICK PROCESS

Mr. Spano. I just want to make one comment, sir.

The States now receive money from the Government to handle the solid wastes, because the responsibility for trash and urban wastes has been delegated back to the States. Now, there is no reason why some of that money that the States get cannot be plowed into this particular process, so that in getting this process that we have, we go into a complete resource recovery system and come up with a useful product. There is no reason why this cannot be done.

Chairman Proxmire. That is a good idea. If you would like to expand on that when you correct your remarks, I would welcome it. That is a very interesting option.

You say we ought to do it anyway?

Mr. Spano. That is right.

Chairman Proxmire. And provide millions of dollars for that purpose. Why not provide a clear direction and incentive that this must be used, or a portion of it.

[The following information was subsequently supplied for the record:]

Financing of the development, engineering and operation of solid waste processing centers could be easily done by earmarking for such a purpose, a fraction of the Federal Tax Revenue now shared with the individual states. Since the responsibility for the disposal of urban and industrial solid wastes has been delegated to the states, it is incumbent on the states to develop and exploit the most economical and practical approaches to solid waste disposal whether it is financed through local state taxes or federal funds now returned to the states through the Revenue Sharing Plan.

To date, the States' priority for the disposal of solid wastes has been and continues to be very low on the list, consequently the local communities receive little or no help from the state or Federal Government and must depend on local taxes. Since the least expensive method of disposing of solid wastes has been landfilling, local communities having access to landfill sites, generally bury their garbage and trash. It should be noted that the national average cost of collection and disposal of the solid wastes produced per capita per year is $14.54. The amount of Federal tax sharing of money allocated by the States for solid waste disposal is between $0.40 and $0.50 per capita per year or approximately 2.75 to 3.4% of the actual needs. This leaves the solid waste disposal problem in the hands of the various communities whose tax base generally can not consider solid waste resource recovery and management centers unless regional centers to handle a number of communities are established. Consequently, the solid waste disposal problem of the various communities is costly, inefficient, and generally ecologically unacceptable.

Whenever the Federal Government has assisted in the development, engineering and operation of processes to and through the demonstration plant capacity, the overall cost of solid waste disposal to the consumer has been reduced by 32 to 104%. These savings have been proved by the operation of the following systems:

System	Capacity (tons per day)	Savings (percent)
St. Louis, Mo	650	86.0
Wilmington, Del	745	32.0
Franklin, Ohio	150	43.0
San Diego, Calif	200	39.6
Baltimore, Md	1,000	41.4
Lowell, Mass	250	103.7

The results achieved by the above demonstrated systems prove conclusively, that properly engineered systems are economically and ecologically responsive to our needs. Moreover, since the development, engineering and operation of such processes are beyond the capability of any single community, the Federal Government must take action and assure the exploitation of new and or proved technologies to resolve this dilemma. To achieve this, it is recommended that the Federal Government require the various states to submit within 12 months, complete solid waste management plans whose implementation can be supported through Federal Tax Sharing Programs. Based on such plans, 25% of the funds now returned to the states should be earmarked for their implementation to and through demonstration size operations. Upon completion of satisfactory implementation of solid waste management plans, the funds earmarked for solid waste disposal will be reduced to reflect the operational cost of the systems.

Unless such action is taken at the Federal level, no single community or state will be in a position to allocate the priority and funds needed to develop and implement the most economical and ecological acceptable management and disposal plan for solid wastes.

Chairman PROXMIRE. Mr. Reed.

Mr. REED. If I may add an optimistic note, I do believe that although the Natick process is not as far along as some of the others, that in a general sense we are moving very rapidly. There are many plants on the board, on the drawing board, already completed which are using wastes. These may not be optimal for the long range, but they are already making good headway, and they are already using some of this kind of money which Mr. Spano mentions. We are in pretty good shape already. I hope that the Natick process will ultimately be even better.

Chairman PROXMIRE. Thank you very much, ladies and gentlemen. The subcommittee will stand in recess until tomorrow morning at 10 o'clock in room 1202 of the Dirksen Senate Office Building, to hear John Sawhill, Federal Energy Administration, and Russell Train, Environmental Protection Agency.

[Whereupon, at 12:35 p.m., the subcommittee recessed, to reconvene at 10 a.m., Tuesday, May 21, 1974.]

NATIONAL PRIORITIES AND FEDERAL RESEARCH AND DEVELOPMENT PROGRAMS

TUESDAY, MAY 21, 1974

Congress of the United States,
Subcommittee on Priorities and
Economy in Government of the
Joint Economic Committee,
Washington, D.C.

The subcommittee met, pursuant to recess, at 10:05 a.m., in room 1202, Dirksen Senate Office Building, Hon. William Proxmire (chairman of the subcommittee) presiding.

Present: Senator Proxmire.

Also present: Richard F. Kaufman, general counsel; Larry Yuspeh, professional staff member; Michael J. Runde, administrative assistant; George D. Krumbhaar, Jr., minority counsel; and Walter B. Laessig, minority counsel.

Opening Statement of Chairman Proxmire

Chairman Proxmire. The subcommittee will come to order. The President has given great emphasis to reducing our dependence on foreign sources of energy and for increasing food production.

In addition, of course, we have a very serious problem which has only been recognized in the last few years, but has been recognized with great concern by millions of Americans; that is the problem of what we do about our waste and the pollution of our environment through all of the products that we do not consume or recycle.

If we are to pursue these twin goals, however, we need more than periodic doses of rhetoric; we need action, coupled with imaginative explorations and inventions. The work of the Army's Natick Laboratory, where a method for producing low-cost glucose from waste materials has been developed and it is an example of government at its best.

There are a few good scientists working with little more than their minds and dedication, with a budget so low by most standards that it is almost laughable, have discovered a process which together with other related processes, has revolutionized traditional approaches to meeting energy and food requirements.

As was pointed out yesterday by expert scientists, glucose is a valuable storable raw material. There is an existing technology for manufacturing ethyl alcohol, single-cell protein, and other substances from glucose. Ethyl alcohol can be used as a fuel. Single-celled glucose is a food; it is already being used in other countries on a large scale as cattle feed. The possibilities are limitless.

One of the most striking benefits from the Natick process is that it employs waste products—not only municipal trash, which is very expensive for cities to collect and dispose of, but also animal waste that accumulates on feedlots, and agricultural wastes.

Incidentally, the agricultural wastes and the animal waste at feedlots provide a more substantial source than the municipal wastes. I will cite one impressive statistic.

As a byproduct of the corn crop, 180 million tons of agricultural waste is produced yearly—just corn. Using these wastes, the Natick process holds the potential of producing 90 million tons of glucose. The glucose can be used to produce 45 million tons of ethyl or about 12 percent of the National's total annual fuel demand for automobiles.

In other words, we are discussing the recycling of wastes and the elimination of solid pollutants, as well as alternative means of producing raw materials.

Today we want to discuss some of the public policy issues inherent in some of these approaches, whether it is economical to pursue this route to meet our energy or food needs, or both; and the appropriate roles of the Government and the private sector.

Some people say that the administration's spokesmen have been quicker to condone sky-high profits and record prices than to take positive steps to satisfy our requirements. If the Government is to serve the public interest, it has to be a good deal more decisive than it has been in recent months.

My own experience in trying to bring the implications of the work at Natick to the attention of various Government agencies has not been heartening. So far those agencies have moved with the alacrity of a wounded snail. We hope to get more encouraging signs this morning.

Three of our witnesses are distinguished public servants in the field of energy, pollution, and food. The fourth, Professor Aaron Altschul is a well-known former official in the Department of Agriculture.

We will first hear from John Sawhill, Administrator of the Federal Energy Office, followed by Russell Train, Administrator of the Environmental Protection Agency, and Lyle Schertz, Deputy Administrator, Economic Research Service, Department of Agriculture.

We are a little pressed for time. Mr. Sawhill has to leave at 11:30.

Mr. Train has accompanying him, Mr. Ronald Bradow of the National Environmental Research Center of EPA.

I would appreciate it, in the shortage of time, that each witness would summarize his prepared statement in the shortest of time, and that Mr. Train would give a summary of both his and his assistant's prepared statement.

Mr. Sawhill, please proceed.

STATEMENT OF HON. JOHN C. SAWHILL, ADMINISTRATOR, FEDERAL ENERGY OFFICE, ACCOMPANIED BY LISLE REED, DEPUTY DIRECTOR, OFFICE OF POLICY, PLANNING, AND REGULATION

Mr. SAWHILL. Thank you very much, Mr. Chairman. I will summarize my prepared statement, if that would be appropriate.

The prepared statement begins by talking about the supply and demand situation for gasoline and the increase in the demand for gasoline that we expect because of the growth in our economy.

We then talk about three ways of producing ethanol. First, from ethylene, which is produced from ethane, propane, gas, oil, and naphtha. And we find that to be—to significantly expand production of ethanol from petroleum-based products—to be uneconomic.

Then we discuss the production of alcohol from agricultural products. Of course, this is one of the oldest and best known chemical processes that man has developed. This process is accomplished by hydrolizing the starch and carbohydrate constituents in grains, by a process of fermentation, to ethanol or ethyl alcohol. The facilities required for large scale conversion of grain to alcohol would be batteries of commercial size cookers—reactors—a series of distillation and extraction towers, pipelines, and tanks. The plant would physically resemble a medium sized refinery or a large chemical plant.

Then, we assessed the economics of this process and also determined that at the current price of grain and because of the competing uses for grain, that it would not be an economic process either.

We conclude, for example, that on an equivalent Btu basis, the alcohol cost is probably in excess of 55 cents per gallon, assuming grain can be obtained for $1 per bushel. The cost of the alcohol will increase about 40 cents per gallon for every $1 per bushel increase in the cost of the grain.

The cereal grain that would provide the lowest cost alcohol at the present time is corn, but it is selling for about $2.50 per bushel—exclusive of tax, marketing, distribution, and profits. The equivalent prices of oil, therefore, would be about $40 per barrel. So, again, the economics of alcohol from grain does not appear to be competitive with present energy alternatives.

Finally, we discuss the process that you mentioned in your opening statement, that one that is being worked on at the Natick Laboratory.

Although agricultural residues and byproducts can also be a primary source of fuel or conversion to gas, at the present time these materals do not compete economically with fossil fuels such as coal and oil except under very favorable circumstances. Also, collection facilities and the powerplants for significant usage do not exist today. Although many research studies are in progress—and I hope they are proceeding faster than the snail—economically feasible solutions have not been found.

It is estimated that collection costs of agricultural residues and delivery costs to powerplant sites would normally vary from $10 to $15 per ton. If converted to gas, a raw material cost of $10 to $15 is equivalent to $1 to $1.50 per thousand cubic feet of gas with a heating value of 500 Btu's. With pyrolysis, the same raw material cost would be equivalent to $1.50 to $2.25 per thousand cubic feet of gas with a heating value of only 150 Btu's.

In response to the April 25 letter that you sent us, the process developed by the U.S. Army Laboratory at Natick was analyzed by our staff. Since the report furnished with our letter of May 8 is available to you, we will not present our analysis in detail at this time, except to note that the available information suggests that the process is only in the initial stage of development, and that additional work will be required before the process will be ready for commercial application.

As far as research and development is concerned, the manufacture of ethanol from petroleum is a well established process, and research in this area could not be expected to contribute any susbtantial payback. Production of ethanol from grain is also well established, and research would be of minimal value. Of course, this does not mean that we should close our eyes to the possibility of further development.

The Department of Agriculture has conducted preliminary research concerning fermentative conversion of gaseous fuels of animal wastes. We understand consideration is being given in that Department to conducting research concerning conversion of animal wastes and crop byproducts into liquid fuels by pyrolysis and hydrogenation. The U.S. Bureau of Mines Energy Research Center has also conducted preliminary studies. Other offices of the Department of Interior and the Atomic Energy Commission will conduct a number of basic research studies in this area.

The Federal Energy Administration plans to aggressively pursue the development of all energy resources. Although we will not necessarily conduct experimental studies, we will maintain an overview of all reasonable sources of energy. We intend to acquire the necessary economic and process yield data for an analysis of the various projects and to estimate the feasibility of the processes to the best of our ability.

There is possibly an enormous potential for all processes that can produce materials from organic wastes. The development of an ethanol manufacturing process by enzymatic action shares that potential and may also be an area in which research and development should be pursued.

You have asked that we assess the role of Government and private industry in the furthering and application of specific forms of new technology. In particular, you expressed an interest in the role of our Agency. In our view, the immediate action that can be taken by the Government is to expedite the preliminary work that has been done in evaluating the various processes to convert wastes to fuels. Only after this evaluation is completed can assessment be made of the research and development that should be undertaken for optimal results. Should any of the possibilities appear promising, the Congress could, of course, consider the funding of such research and encourage the construction of pilot plants.

We in the Federal Energy Office believe Congress has given us a clear mandate to promote the expansion of readily usable energy sources and to assist in developing policies and plans to meet the energy needs of the Nation. In implementing this directive, we see the Federal Energy Administration acting as a catalyst with the various Government agencies involved and with private industry. We are committed to the task of developing a comprehensive plan for achieving the objectives of Project Independence by November 1. This plan will describe our goals, discuss the need for any additional legislation required to achieve the Nation's objectives, and outline the budget requirements necessary to do the critical job that must be done to safeguard the economic life of the Nation. Certainly the possibility of using waste products to produce fuels will be considered—along with all other potential energy sources—in developing that program.

In summary, conversion of waste to fuel has the potential to provide an additional source of domestic energy. We look forward, therefore, to the completion of the initial studies now being developed. Any promising processes should be explored through research and development programs with the goal of developing commercial processes. We in the Federal Energy Office will also be studying waste conversion to fuel, including ethanol, as we develop the comprehensive energy program required by the Federal Energy Administration Act of 1974.

Again let me express my appreciation for the opportunity to discuss these matters with you and for the significant work by this committee in this area.

Chairman PROXMIRE. Thank you, Mr. Sawhill.

[The prepared statement of Mr. Sawhill follows:]

PREPARED STATEMENT OF HON. JOHN C. SAWHILL

Mr. Chairman and Members of the Committee, I welcome this opportunity to appear before you today to discuss the potential use of ethanol in automobile fuels. In my prepared comments, I plan to outline our broad objectives, to discuss the supply and demand for automotive fuels, and to present our views as to the part ethanol and other fuels converted from wastes may play.

THE MISSION OF THE FEDERAL ENERGY ADMINISTRATION

In the Federal Energy Administration Act of 1974, the Congress stated that positive and effective action was necessary to (1) conserve scarce energy supplies; (2) ensure fair and efficient energy distribution; (3) maintain fair and reasonable consumer prices; (4) promote the expansion of readily usable energy sources; and (5) develop and implement policies to meet the energy needs of the Nation.

In connection with the mandate from Congress to promote the expansion of readily usable energy sources, we in the Federal Energy Office are interested in developing any information concerning possible sources of fuels. These hearings will undoubtedly be useful in exploring the capability of ethanol to serve as a motor fuel, and we are pleased that you have decided to hold hearings on this subject. Since ethanol would be a factor primarily affecting the gasoline market, I should like first to discuss gasoline supply and demand, so as to place the availability and usefulness of ethanol in perspective.

GASOLINE SUPPLY AND DEMAND

The United States demand for petroleum products was about 18 million barrels per day in 1973. Of this amount, approximately 6.5 million barrels per day represented demand for motor gasoline. We anticipate that by 1980 total demand for petroleum products will approach 22 million barrels per day. We can further asume that gasoline demand will remain proportional. If this is the case, demand for motor gasoline by 1980 will be in the neighborhood of 7.5 million barrels per day.

There is, of course, no need to emphasize the importance of having an adequate supply of gasoline in an automobile-oriented society. The shortages in the early part of this year as a result of the Arab embargo underscored our dependence on gasoline, not only for the automobile but also for trucking essential goods around the Nation. To supply this demand, U. S. refineries, on the average, manufacture a higher percentage of gasoline from crude than any other refineries in the world. For example, U.S. average gasoline yield ranges from approximately 45% in the winter to a little over 50% during the summer months; European yield over the past two years has averaged 14 to 15%.

The high yield of gasoline production in a domestic refinery is a result of a very severe cracking operation which incorporates the use of catalytic cracking, hydrocracking and coking. Small amounts of ethylene are produced as a byproduct of the cracking operations. In some instances the ethylene is converted to synthetic ethyl alcohol or ethanol which is marketed as a petrochemical. This type of ethanol manufacture is sustained by the premium price derived from being a petrochemical. The entire manufacture of ethanol represents less than one percent of the crude barrel. Ethanol may also be produced from agricultural products.

ALCOHOL FROM PETROLEUM AS A CARBURANT

Synthetic ethyl alcohol is produced from ethylene which is produced from ethane, propane, gas oil or naptha. These materials are recovered either from natural gas or produced by refining crude oil.

There is presently no surplus of ethanol manufactured from petroleum. To obtain significant additional quantities of ethanol from petroleum, it would be necessary to construct additional facilities requiring a large capital investment.

In the short-term, any additional ethylene and ethanol must be obtained from imported feedstocks, as U.S. production of natural gas and U.S. refinery capacity is expected to be inadequate to supply current demand over the next few years.

If ethanol from petroleum were used as a carburant, it would be at the expense of other uses. Ethylene is one of the primary building blocks in the petrochemical industry, for example. This essential feedstock is used to produce commodities as diverse as anti-freeze, plastics, pharmaceutical products, and textiles.

On an energy content basis, or available BTU consideration, alcohol is less efficient than gasoline: however, alcohol is a prime blending component for increasing the octane of gasoline.

In short, we do not foresee ethanol produced from petroleum as significantly contributing to gasoline supply even if its higher cost were to be disregarded.

ALCOHOL FROM GRAIN AS A CARBURANT

Alcohol also can be made from agricultural products. The conversion of common grains to alcohol is one of the oldest and best known chemical processes studied by man. It is believed to have been developed several thousand years B.C. by the Egyptians. The process is accomplished by hydrolizing the starch and carbohydrate constituents in grains by a process of fermentation, to ethanol, or ethyl alcohol. The facilities required for large scale conversion of grain to alcohol would be batteries of commercial size cookers (reactors), a series of distillation and extraction towers, pipelines and tanks. The plant would physically resemble a medium sized refinery or a large chemical plant.

There are about 360 million acres of U. S. land under cultivation at the present time, which is about 60 percent of the land that could be made available if there was a strong incentive for maximum land utilization. By developing about 70 million acres, or about 30 percent of the potentially avaliable farm land, enough grain could be produced to manufacture a quantity of alcohol that could be used to supply 10 percent of our present gasoline demand.

The technology of producing alcohol from grain is well established; the feasibility of blending anhydrous alcohol with gasoline to obtain a suitable carburant exists; the quantity of land required to produce a significant quantity of grain exists; but the economics of the entire project simply do not make it competitive with other sources of energy at this time.

Recent studies indicate that the cost of converting grain alcohol in a commercial size plant is 10 to 13 cents per gallon, exclusive of the grain cost. If grain were priced at $1.00 per bushel, the total cost of the alcohol would be 47 to 50 cents per gallon. The amount of energy available from a gallon of alcohol is about 15 percent less than that available from gasoline. On an equivalent BTU basis, therefore, the alcohol cost is probably in excess of 55 cents per gallon assuming grain can be obtained for $1.00 per bushel. The cost of the alcohol will increase about 40 cents per gallon for every $1.00 per bushel increase in the cost of the grain.

The cereal grain that would provide the lowest cost alcohol at the present time is corn, but it is selling for about $2.50 per bushel. This price level is exclusive of tax, marketing, distribution, and profit costs. The equivalent prices of oil would be about $40 per barrel. The economics of alcohol from grain is thus not competitive with present energy alternatives.

If the price of grain decreases to at least $1.00 per bushel or there is reason to believe that there will be a finite demand for an alternate to petroleum at any cost, there may be economic justification for a grain to alcohol facility, but it would clearly be an extreme case.

Apart from the economic cost of alcohol from grain compared to gasoline, the use of alcohol from grain as a motor fuel would create competition with food and feed use of grain. The Department of Agriculture has estimated that a supply of ethyl alcohol equal to 10 percent of the gasoline used in 1973 would have required about 50 percent of the total feed grain supply of that year. In this time of high food prices and threatened world food shortages, use of alcohol from grain as a motor fuel could involve a tremendous social cost.

Agricultural residues and by-products also may provide a source of primary fuels or conversion to gas. At the present time these materials could not compete economically with fossil fuels such as coal and oil except under very favorable circumstances. Also, collection facilities and the power plants for significant usage do not exist. Although many research studies are in progress, economically feasible solutions have not been found.

It is estimated that collection costs of agricultural residues and delivery costs to power plant sites would normally vary from ten to fifteen dollars per ton. If converted to gas, a raw material cost of $10 to $15 is equivalent to $1.00 to $1.50 per thousand cubic feet of gas with a heating value of 500 BTU's. With pyrolysis, the same raw material cost would be equivalent to $1.50 to $2.25 per thousand cubic feet of gas with a heating value of only 150 BTU's.

In response to the April 25th letter from Senator Proxmire, the process developed by the U.S. Army laboratory at Natick, Massachusetts, was analyzed by our staff. Since the report furnished with our letter of May 8th is available to the Committee, we will not present our analysis in detail at this time, except to note that the available information suggests that the process is only in the initial stage of development, and that additional work will be required before the process will be ready for commercial application.

RESEARCH AND DEVELOPMENT

Manufacture of ethanol from petroleum is a well established process, and research in this area could not be expected to contribute any substantial payback. Production of ethanol from grain is also a well established process, and research would be of minimal value. Of course, this does not mean that we should close our eyes to the possibility of further development.

The Department of Agriculture has conducted preliminary research concerning fermentative conversion to gaseous fuels of animal wastes. We understand consideration is being given in that Department to conducting research concerning conversion of animal wastes and crop by-products into liquid fuels by pyrolysis and hydrogenation. The U.S. Bureau of Mines Energy Research Center has also conducted preliminary studies. Other offices of the Department of Interior and the Atomic Energy Commission will conduct a number of basic research studies.

The Federal Energy Administration plans to aggressively pursue the development of all energy resources. Although we will not necessarily conduct experimental studies, we will maintain an overview of all reasonable sources of energy. We intend to acquire the necessary economic and process yield data for an analysis of the various projects and to estimate the feasibility of the processes to the best of our ability.

There is possibly an enormous potential for all processes that can produce materials from organic wastes. The development of an ethanol manufacturing process by enzymatic action shares that potential and may also be an area in which research and development should be pursued.

GOVERNMENT ACTION

You have asked that we assess the role of Government and private industry in the furthering and application of specific forms of new technology. In particular, you expressed an interest in the role of our agency. In our view, the immediate action that can be taken by the Government is to expedite the preliminary work that has been done in evaluating the various processes to convert wastes to fuels. Only after this evaluation is completed can assessment be made of the research and development that should be undertaken for optimal results. Should any of the possibilities appear promising, the Congress could, of course, consider the funding of such research and encourage the construction of pilot plants.

We in the Federal Energy Office believe Congress has given us a clear mandate "to promote the expansion of readily usable energy sources, and to assist in developing policies and plans to meet the energy needs of the Nation." In implementing this directive we see the Federal Energy Administration acting as a catalyst with the various government agencies involved and with private industry. We are committed to the task of developing a comprehensive plan for achieving the objectives of Project Independence by November 1. This plan will describe our goals, discuss the need for any additional legislation required to achieve the Nation's objectives, and outline the budget requirements necessary to do the critical job that must be done to safeguard the economic life of the

Nation. Certainly, the possibility of using waste products to produce fuels will be considered—along with all other potential energy sources—in developing that program.

SUMMARY

Conversion of waste to fuel has the potential to provide an additional source of domestic energy. We look forward, threfore, to the completion of the initial studies now being developed. Any promising processes should be explored through research and development programs with the goal of developing commercial processes. We in the Federal Energy Office will also be studying waste conversion to fuel, including ethanol, as we develop the comprehensive energy program required by the Federal Energy Administration Act of 1974.

Again let me express my appreciation for the opportunity to discuss these matters with you and for the significant work by this Committee in this area.

Chairman PROXMIRE. Mr. Train, please proceed.

STATEMENT OF HON. RUSSELL E. TRAIN, ADMINISTRATOR, ENVIRONMENTAL PROTECTION AGENCY, ACCOMPANIED BY RONALD L. BRADOW, CHIEF, EMISSIONS TESTING AND CHARACTERIZATION SECTION, CHEMISTRY AND PHYSICS LABORATORY, NATIONAL ENVIRONMENTAL RESEARCH CENTER, ENVIRONMENTAL PROTECTION AGENCY, RALEIGH-DURHAM, N.C.

Mr. TRAIN. Thank you, Mr. Chairman.

To summarize, let me say first that the effective utilization of wastes in our society, both in terms of energy conversion and in terms of other uses, is a matter of the very highest priority. And for that reason in particular, we welcome the attention that the committee is addressing to this overall subject.

The need for the development of energy resources, both in terms of improving supply and in terms of reducing demand, is obviously also a very crucial concern to the country at this time. And the particular use of wastes in the production of energy is highly relevant to that concern.

We have looked into the possibility of using ethanol as a fuel additive or substitute in the context of motor vehicles. And, as you have mentioned, I have Mr. Ronald Bradow of our National Environmental Research Center, in Raleigh-Durham, N.C., with me. I would describe him as a combustion scientist. And if the committee has any technical questions in the field, I would suspect that he would be the best one to address those.

I would ask that his prepared statement be made a part of the record following mine; and rather than my attempting to summarize it, I would simply say that it represents a more technical development of the points included in my prepared statement.

With respect to the use of ethanol as an automotive fuel additive, as attractive as the prospect of such use might appear initially, we believe that its use as a motor fuel is not now practicable. And I emphasize the word "now." This stems from a number of technical and economic problems. At this moment it is not clear whether these can be resolved in a practical manner.

First, alcohols are less intensive sources of energy than gasoline. To obtain satisfactory performance from gasoline-alcohol blends in most of the present-day motor vehicles, carburetors would have to be modified to permit higher fuel flows. Once modified, the vehicle would perform satisfactorily only with fuels having a rather narrow range of alcohol concentrations. If such vehicle were then to be operated on conventional gasoline, for example, large increases in the emission of smog-forming hydrocarbons as well as needless fuel economy losses would certainly result.

Further, for this change in fuel technology to have appreciable impact, most cars now in use would have to be retrofitted in a short time. An additional grade of gasoline would have to be added to the present distribution system. Both changes, in the aggregate, represent major costs. We believe that such costs would outweigh any benefits that might be achieved.

Secondly, gasoline-alcohol blends can separate when contaminated with water, an inevitable occurrence when fuels pass through the present-day fuel distribution system. The two resulting liquids have vastly different combustion and antiknock properties. If this were to happen in an automobile gas tank, it could result in serious damage to the engine and would certainly result in very poor performance even if no damage were caused.

Finally, the vaporization of alcohols in gasoline blends is abnormally high. Handling such a fuel in presently available pumps and tanks may not be practical since large evaporation losses would be incurred.

I might interject at this point, Mr. Chairman, that evaporation losses from the present methods of handling gasoline, such as at filling stations, do represent in many urban areas a major source of hydrocarbons in the ambient atmosphere.

In view of those obstacles, it seems to us that the potential benefits in the use of ethanol as a motor vehicle fuel are outweighed by the obvious difficulties. Of course, this analysis is necessarily premised on automotive technology as we know it and can foresee it.

As to the potential uses of ethanol as a major fuel source, predictions are difficult and speculative at best. We try to anticipate technology as best we can. Barring some totally unforeseen technological breakthrough, we would anticipate major problems in an effort to obtain and use ethanol as a major energy source.

Ethyl alcohol is currently produced synthetically from petrochemical feedstock and from natural fermentation. Although the synthetic process produces ethanol more cheaply than the fermentation process, its dependence on petrochemicals eliminates its consideration as a possible solution to the energy shortage.

The fermentation process may use grain, molasses, sulfite liquors, and other fermentable sugar or starchbearing agricultural products as raw materials.

The use of cellulose from forest byproducts and municipal and agricultural wastes is currently under investigation, but is considered to be in a very embryonic state of development. Calculations show that only about 25 gallons of ethyl alcohol would be produced from municipal waste generated by one person over a year's time. The bulk of materials which would be necessary as an ethanol source is staggering. The cultivation of agricultural products for the purpose of ethanol extraction would require a radical restructuring of our agricultural and industrial makeup before ethanol could be a significant energy source. Nevertheless, we believe there may be potential in the use of ethanol as a power source for fuel cells and stationary power generators. It might also be used in very large mobile sources—such as ships—

where the fuel weight penalty associated with the fuel would have lesser impact.

The committee's suggestion that conversion of cellulose to ethanol might ultimately serve as a supplement to the Nation's energy has some fascinating long-range implications. In a technological sense, the suggestion means that perhaps the supply basis for energy may shift from mining fossilized plant stuffs to harness solar energy stored geological eons ago to a new basis: Agriculture. Thus, this year's solar energy might be stored in a highly efficient plant source of cellulose, then chemically harvested to produce liquid fuel. It is an interesting concept worthy of further long-range study.

Our belief that ethanol has limited immediate practical use as an energy source for vehicles at this time will not deter our continuing investigations into potential practical uses for the future.

I might add, Mr. Chairman, that we do have on the way, within EPA, some six demonstration projects, involving the conversion of municipal wastes to energy. These are of various kinds, including the mixing of organic waste, including cellulose, with coal. And one of these, the direct use of solid waste with coal, has been fully demonstrated and is now being applied in the city of St. Louis, with the St. Louis Gas & Electric Co. And it may well be that these uses of organic waste for the production of energy may be more efficient and more productive of energy in a net sense than the process that we are discussing here today.

I am not stating that as a conclusion, but simply raising it as a point that bears careful examination.

Thank you, Mr. Chairman.

Chairman PROXMIRE. Thank you.

[The prepared statements of Mr. Train and Mr. Bradow follow:]

PREPARED STATEMENT OF HON. RUSSELL E. TRAIN

Mr. Chairman and Members of the Joint Committee, I appreciate the opportunity to be here today to discuss with you new technologies and new energy sources in the context of our continuing energy needs.

I have with me Mr. Ron Bradow of our National Environmental Research Center at Raleigh-Durham, North Carolina.

This is the first opportunity I have had to appear before this distinguished Committee. It seems to me that this hearing today is further evidence of the far-reaching impact of inter-related energy and environmental concerns, which have been heightened by the energy problem.

It is clear that our energy needs offer an opportunity and an incentive for innovative development of new technology and a new awareness of the need for conservation of all our resources. The Committee is to be commended for addressing this most significant issue and in seeking ways to meet the challenge.

As you know, in his Energy Message of January 23rd, the President outlined the nation's energy program for the future—Project Independence. A key element in that program is the attainment of national energy self-sufficiency by 1980. That goal cannot be achieved unless we intensify our efforts to identify and use new energy sources. We are looking to the Outer Continental Shelf; we are examining the possibility of oil shale development. Beyond these sources we are examining the potential of expanded nuclear sources, solar and tidal energy. We of the Environmental Protection Agency are keenly aware of the necessity to develop these sources, but we must assure that this development is not achieved at the cost of a clean and healthy environment.

As a part of this search the Committee today is examining the feasibility of the extraction of energy from the earth's living environment—from plant and animal life. In particular, we are addressing the extraction of ethanol (ethyl alcohol) from waste products.

We have looked into the possibility of using ethanol as a fuel additive or substitute in the context of motor vehicles. Unfortunately, as attractive as the prospect of such use might appear initially, we believe that the use of ethanol as a motor vehicle fuel is not now practicable.

This stems from a number of technical and economic problems. At this moment it is not clear whether these problems can be resolved in a practical manner.

First, alcohols are less intensive sources of energy than gasoline. To obtain satisfactory performance from gasoline-alcohol blends in most of the present-day motor vehicles, carburetors would have to be modified to permit higher fuel flows. Once modified, the vehicle would perform satisfactorily only with fuels having a rather narrow range of alcohol concentrations. If such vehicle were then to be operated on conventional gasoline, for example, large increases in the emission of smog-forming hydrocarbons as well as needless fuel economy losses would certainly result.

Further, for this change in fuel technology to have appreciable impact, most cars now in use would have to be retrofitted in a short time. An additional grade of gasoline would have to be added to the present distribution system. Both changes, in the aggregate, represent major costs. We believe that such costs would outweigh any benefits that might be achieved.

Secondly, gasoline-alcohol blends can separate when contaminated with water, an inevitable occurrence when fuels pass through the present day fuel distribution system. The two resulting liquids have vastly different combustion and antiknock properties. If this were to happen in an automobile gas tank, it could result in serious damage to the engine and would certainly result in very poor performance even if no damage is caused.

Finally, the vaporization of alcohols in gasoline blends is abnormally high. Handling such a fuel in presently available pumps and tanks may not be practical since large evaporation losses would be incurred.

In view of those obstacles, it seems to us that the potential benefits in the use of ethanol as a motor vehicle fuel are outweighed by the obvious difficulties. Of course this analysis is necessarily premised on automotive technology as we know it and can foresee it.

As to the potential uses of ethanol as a major fuel source, predictions are difficult and speculative at best. We try to anticipate technology as best we can. Barring some totally unforeseen technological breakthrough, we would anticipate major problems in an effort to obtain and use ethanol as a major energy source.

Ethyl alcohol is currently produced synthetically from petrochemical feedstock and from natural fermentation. Although the synthetic process produces ethanol more cheaply than the fermentation process, its dependence on petrochemicals eliminates its consideration as a possible solution to the energy shortage.

The fermentation process may use grain, molasses, sulfite liquors, and other fermentable sugar or starch bearing agricultural products as raw materials.

The use of cellulose from forest by-products and municipal and agricultural wastes is currently under investigation but is considered to be in a very embryonic state of development. Calculations show that only about 25 gallons of ethyl alcohol would be produced from municipal waste generated by one person over a year's time. The bulk of materials which would be necessary as an ethanol source is staggering. The multivation of agricultural products for the purpose of ethanol extraction would require a radical restructuring of our agricultural and industrial make-up before ethanol could be a significant energy source. Nevertheless, we believe there may be potential in the use of ethanol as a power source for fuel cells and stationary power generators. It might also be used in very large mobile sources (such as ships) where the fuel weight penalty associated with the fuel would have lesser impact.

The Committee's suggestion that conversion of cellulose to ethanol might ultimately serve as a supplement to the nation's energy has some fascinating long-range implications. In a technological sense the suggestion means that perhaps the supply basis for energy may shift from mining fossilized plant stuffs to harness solar energy stored geological eons ago to a new basis, agriculture. Thus, this year's solar energy might be stored in a highly efficient plant source of cellulose then chemically harvested to produce liquid fuel. It is an interesting concept worthy of further long range study.

Our belief that ethanol has limited immediate practical use as an energy source for vehicles at this time will not deter our continuing investigations into potential practical uses for the future.

Thank you.

PREPARED STATEMENT OF RONALD L. BRADOW

Mr. Chairman, my name is Dr. Ronald L. Bradow. I am presently employed by the United States Environmental Protection Agency as Chief of the Emissions Testing and Characterization Section in the Chemistry and Physics Laboratory of the National Environmental Research Center at Raleigh-Durham, North Carolina. By way of introduction I hold a Ph.D. in Chemistry with a minor in Chemical Engineering. After receiving my degree I was employed for eleven years by Texaco, Incorporated, in the capacity of a research scientist. During that time I did basic combustion research related to the anti-knock quality of gasoline and to mechanisms of pollutant emissions from motor vehicles, as well as work on other fuel related problems. With a collaborator I won the Horning Memorial Award from the Society of Automotive Engineers in 1966 for my work in auto emissions.

During the past several years, the possibility of adding low molecular weight alcohols such as methanol, ethanol, and isopropanol to motor gasoline as a fuel component has been considered a number of times. Pure methanol was tested by our EPA laboratory as a possible fuel. A number of shortcomings were discovered which I will discuss later. At one time major oil companies commonly used isopropanol as an anti-icing additive in winter grade gasolines with good success at the 5 vol. percent level. This practice was later abandoned when cheaper anti-icing additives were found. With late model cars this anti-icing property is no longer needed since the intake air is heated to reduce cold start emissions.

Ethanol (grain alcohol) has also been added to gasoline as a legal requirement in grain-producing States, but this practice has been viewed by the energy industry as an aberration rather than a realistic source of large-scale combustion energy. If technology could be developed to convert cellulose rather than grain-derived starch to ethanol, then it might be feasible as a gasoline component. I will not discuss the problems associated with producing alcohol from plant-derived cellulose, rather, I will confine my remarks to problems in mutual adaptation of these potential fuel systems and the engines they must feed.

As I have indicated, all three of these alcohols, methanol, ethanol, and isopropanol, can be used as gasoline components. Unfortunately, of the three, methanol is the most difficult to adapt to fuel systems. Isopropanol, at concentrations up to 10 percent presents no fuel system problems. However, it is produced from petroleum sources and is therefore of no help from an energy standpoint. Although ethanol presents fewer combustion and handling problems than methanol, these problems are still severe.

There are many fuel properties which must be closely controlled in order to assure successful performance of a gasoline blend in present cars, even if minor modifications to existing automobiles were feasible. These would include: combustion properties such as heat of combustion, octane quality, and flame speed; storage and handling properties such as compatibility with fuel system plastics, corrosion properties, compatibility with water and other potential contaminants; carburetion properties such as vapor pressure, heat of vaporization, and stoichiometry and finally potential environmental impact of massive introduction of a new fuel system.

If we limit our attention to alcohol blends containing no more than about 30 vol. percent, then it can be safely stated that the combustion properties of all three alcohols are reasonably good. The octane quality is quite good especially in blends. However, the heat of combustion of alcohols is substantially below that of gasoline.

Thus, in the case of methanol, the available energy content per pound of fuel is about half that of gasoline and about two-thirds that of gasoline with ethanol. In order to achieve equivalent power levels, it is necessary to add more fuel to the engine when alcohol-bearing gasolines are burned. Thus, the gasoline mileage will be lower with such fuels. It is important that this factor be taken into account in the analysis of the cost-effectiveness of fuel alternatives. Other combustion-related properties are certainly compatible with conventional engines.

There are some rather severe storage and handling problems if alcohol blends were to be dispensed through the conventional gasoline distribution system. Gasoline normally contacts water in all tankage, in bulk storages facilities, in service stations, even in automobile gasoline tanks. Only relatively small amounts of water (less than 0.1 percent of the fuel volume with methanol, somewhat more with ethanol) cause a severe phase separation problem. In effect, a dense liquid layer separates from the gasoline and sinks to the bottom of the tank. This dense layer contains not only alcohol and water but also large amounts of high octane aromatic hydrocarbons. If this were to occur in an automobile gasoline tank, the dense phase could be burned first with decreased power due to the high alcohol content. When this dense phase is consumed, the remaining gasoline will be reduced in octane quality and the engine will begin to knock. The extent of this separation depends both on gasoline composition and the volume of contaminating water. It is conceivable that this octane extraction process could lead to complete destruction of the engine.

In addition to this problem, alcohol blends cause much more corrosion in the hydrocarbon phase than do present-day gasoline. There are potential problems of compatibility with fuel-system plastics as well. Thus, methanol blends deteriorate fuel pump diaphragms and power enrichment valves. Ethanol blends are probably less of a problem in this respect.

Perhaps the greatest difficulties are the problems associated with carburetion of the fuel. Carburetors are excellent mass metering devices. They maintain a constant ratio between the weight of fuel and the weight of air flowing into an engine. A portion of the weight of alcohol is, in one sense, chemically bound water and consequently cannot produce power. In order to successfully carburet such a mixture, the amount of this diluent and consequently the concentration of alcohol, must be held at a constant level. One could not burn gasoline, 10 percent alcohol-gasoline blends and 20 percent alcohol-gasoline blends using the same carburetor without suffering either a drastic loss of power, a drastic increase in exhaust emissions or both. Thus, a carburetor can be set up to operate on either gasoline or a single particular alcohol-in-gasoline blend, but once so tuned, it cannot be used on any other fuel without retuning. Considering the hard-won gains in exhaust emission controls due, in large measure, to careful control of carburetion, any short term gains in the availability of liquid combustibles should not be at the expense of emission controls.

Clearly a combined technical and legislative solution to this perplexing problem must be found if alcohols are to come into serious consideration as a gasoline supplement.

Since all the lower alcohols in the pure state have vapor pressures considerably lower than gasoline, it is somewhat surprising to find that blends of alcohols in conventional gasoline are too volatile for general summer-time use. This happens because internal molecular bonding forces—in this case hydrogen bonds—are partially disrupted in dilute hydrocarbon solution. I have seen methanol-gasoline blends boiling in carburetor float bowls with the air temperature in the 70's. This increased vapor pressure occurs with all alcohol blends to some extent. In order to achieve reasonable vapor pressures, gasoline blending practices and refinery balances would have to be adjusted to reject the more volatile components, chiefly normal butane, to non-gasoline uses. Butane is a low-cost high octane component and its replacement with alcohols would probably require some adjustment upward in gasoline price. The butane, of course, would not be lost as an energy source, but it should be noted in economic considerations that the quantity of liquid combustible available for transportation purposes will probably *not* increase linearly with alcohol production. Further, evaporative losses in handling are likely to be greater with alcohol blends than with conventional gasoline because of the exceptionally high effective vapor pressure of the alcohol. At present, the full impact of this volatility consideration is not clear. We may find that shipping of methanol-gasoline blends by conventional methods may be completely impractical.

The emissions problems associated with the use of methanol-gasoline blends are another concern. Alcohols in blends may increase aldehyde emissions somewhat. In experiments with pure methanol as a fuel, very substantial amounts of formaldehyde (an eye-irritant and serious smog contributor) were formed; however, with dilute solutions this may not be an important factor. The alcohols themselves are relatively inert in atmospheric smog-forming processes. Probably the most serious environmental hazards occur because of mechanical mismatches. Present evaporative control canisters are unlikely to be satisfactory if alcohols were the volatile fuel components. If new alcohol-controlling canisters were installed on cars, these would certainly not be effective with gasoline. As mentioned earlier, if alcohol-tuned cars are operated on gasoline, an excessively rich fuel air mixture would result, increasing exhaust emissions at an alarming rate.

In conclusion, the technical problems associated with the use of alcohols in gasoline blends are massive. It is likely that successful solutions to some of these problems could be found with research, but it is far from certain that all of them could be solved. In my professional opinion, the use of substantial quantities of alcohols as a gasoline supplement is not likely to be a realistic alternative in the near future.

Thank you.

Chairman PROXMIRE. Please proceed, Mr. Schertz.

STATEMENT OF HON. LYLE P. SCHERTZ, DEPUTY ADMINISTRATOR, ECONOMIC RESEARCH SERVICE, DEPARTMENT OF AGRICULTURE

Mr. SCHERTZ. Thank you, Mr. Chairman.

My prepared statement emphasizes five points. First, increases in food production in the developed countries have been approximately equal to the increases in production in the low-income countries.

Second, the diets for a very large proportion of the population in the low-income countries are inadequate.

Third, that incomes have an overriding influence on efforts to improve nutrition in these countries.

Fourth, it is appropriate that efforts to improve the nutritional levels in these countries proceed in a very broad front, including consideration of the topics that you are considering today.

And fifth, given the technological and income restraints that we visualize in these countries and in the world, the improvement of nutrition in the low-income countries will be a long-term process. For many years there is going to be a very large proportion of these people with inadequate incomes, and therefore, inadequate diets.

Let me elaborate on the first point that I made. Namely, that the increases of agricultural production in the low-income countries have been approximately equal to that in the developed countries. In the 10-year period from the early 1960's to the early years of the 1970's, production in both sets of countries increased approximately 30 percent. In contrast to the developed countries, in the LIC's, the population increases offset practically the entire increase so that the per capita availabilities from production in those countries is approximately equal to what it was in the 1960's—just slightly up.

In terms of the adequacy of diets, as you look at the figures around the world, Mr. Chairman, you find that the amount of cereals that the developed countries use for livestock is approximately equal to what the other two-thirds of the world depend on for their food. They, of course, use it directly as food. And this is, again, a reflection of their income restraints. The consumption figures vary: In the United States, it is almost equal to a ton of cereals; India, in contrast, consumes only about 400 pounds of cereal.

The role of income shows up in many ways. It shows up in trade. In 1972, the U.S.S.R. experienced a substantial cutback in their production. In years previous, when they have had shortfalls in their production, they have tightened their belts. In 1972, in contrast, they used their income and wealth, in the purchase on the international market, which in turn influenced the availability of food not only in their own country, but Japan, the United States, and the low-income countries.

The fundamental situation that comes out of the income situation of these countries is that the nutritional improvement will be a long process. The incomes, even if food were available, are such that without very substantial decreases in prices, the large amount of unemployment and the low incomes would prevent adequate nutrition.

When we come to implications, it strikes us that efforts should proceed in many ways. First, there should be continued efforts to increase yields of traditional agriculture; second, effort should continue to increase the protein content of traditional foods—such as maize and wheat; third, give high priority in policy considerations of these countries to traditional agriculture; and fourth, emphasize the nontraditional approaches, such as single-cell protein; and fifth, the very important emphasis on increasing employment in these countries.

In my prepared statement, I give some projections with respect to the capacity of U.S. agriculture to produce, and some projections with respect to the lower income countries. I will not go into detail on them, but I will just mention two or three conclusions.

One conclusion is that there is substantial capacity for U.S. agriculture to produce, assuming available fuel and energy and incentives for agriculture producers in this country.

The other main point that comes from those projections is that as we look forward to 1985, we see a substantial increased dependence of the lower income countries on the United States for their food supplies. We do not see famine conditions, although obviously there is that uncertainty as to what the weather will be and how much progress they will make. We see continual progress of their agriculture, slight increases in their per capita production; but with expected population growth and slow income growth, increased demand for imports is expected and in turn, demand for food from the United States.

I will make one other point that I think would be of interest to the discussions this morning, Mr. Chairman. Namely, it is important to keep in mind that traditional agricultural production—such as corn and soybeans—is the main source of nutrients throughout the world. Synthetic products that are used as agricultural substitutes at the present time occupy about 10 percent of the consumption.

In terms of protein specifically, one of the major competitive products, of course, with SCP is soybean meal. A few months ago soybean meal was selling for over $400 a ton. Today, it is selling for $110 to $120 a ton. At those prices there is a very serious consideration as to the competitive relationship with SCP protein. It does not say, in my mind, that there should not be substantial research and continued efforts to make those products economical. I am reminded that it was some 60 years ago that Haber was able to bring together nitrogen and hydrogen and make ammonia. And at that time, many thought it was hard to justify that effort because legumes were the accepted approach to bring nitrogen into the soil and to produce crops. Of course today we know we could not produce the food we do in the world if it had not been that that work had been undertaken and then brought to fruition.

Thank you, Mr. Chairman.

Chairman PROXMIRE. Thank you very much.

[The prepared statement of Mr. Schertz follows:]

PREPARED STATEMENT OF HON. LYLE P. SCHERTZ

This statement emphasizes the following major points: Increases of food production in the lower income countries has been roughly equal to those of the developed countries; diets in these lower income countries remain inadequate for large numbers of people; incomes have an overriding influence on efforts to improve nutrition; efforts to improve diets in the low income nations must proceed on a broad front.

Both technological and income restraints suggest that only modest nutritional gains can be expected in the lower income countries during the coming decade.

In general, the developed and the developing countries have generated agricultural increases almost in step with each other. In both, food production in 1972 was more than 50 percent above levels of the early 1960's. Unfortunately, the uptrend in developing nations has been almost totally eclipsed by population growth. For countries containing two-thirds of the world's population, then, per capita production of food in recent years is only slightly above what it was 2 decades earlier.

Today, people in the developing nations, two-thirds of the world's population, eat only one-fourth of the world's protein, and most of that is in the form of cereals. In countries such as India, people consume less than 400 pounds of cereals per capita each year. On the other hand, in the developed countries, where large quantities of cereals are converted to protein, per capita grain consumption is 1,435 pounds in the Soviet Union, about 1,800 pounds in West Germany and France, and 1,850 pounds in the United States. All told, the billion people in the rich nations, with Cadillac tastes for livestock products, use practically as much cereal as feed for livestock as the 2 billion people in the low-income nations use directly as food.

The price of food and the incomes to pay for it are inextricably bound up with the ability of poor people to eat right. This interrelationship was dramatically unveiled recently in connection with worldwide crop shortfalls, currency devaluation, and unusual grain purchases. In more normal years, the relationship still operates, but much less obviously.

For as long as there has been trade among nations, developed nations have commanded the food they wanted, when they wanted it. Wealth and high incomes have been the instruments of command. In times of abundance, this purchasing power has been subtle and has displayed a low profile; its impact has not quite achieved a critical mass which would earn the enmity of the have-nots. Only in times of food shortages and high prices does this power become shocking to its victims. Then, whether they be nations or citizens within, those with money have preempted what food they wanted; those without have tightened their belts.

High-quality protein, particularly from livestock products, is a consumer preference throughout the developed nations. This trend characterizes the wealthy nations of North America, Western Europe, and Japan. The Soviet Union and the East European countries have joined them.

Traditionally, when the Soviets came up short on production, they steeled themselves to wait out the shortage, sometimes to the point of accepting large-scale livestock slaughter, but not in 1972, when winterkill and dry midsummer weather disrupted the Soviets' cereal harvest expectations. They made massive grain purchases on the world market. The pace of their livestock development continued unabated.

The Soviet decision to protect diets was felt worldwide by both rich and poor. When the Soviets purchased practically one-fifth of the total U.S. wheat supply in the 1972/73 crop year, supplies normally available to others dropped sharply. Nations and people reacted by bidding up the price of the remaining wheat, the more aggressively because Japan and several other commercial importers of U.S. foodstuffs found their currencies worth substantially more in terms of dollars as a result of successive devaluations.

In contrast, the low levels of wealth and income of the poor countries determine how well they compete in the food-purchasing power game. So long as the overall production of cereals is relatively responsive to needs, effects on the poor are minimal, especially over time. But in times of severe dislocation of the balance of demand and supply through sharply increased demand or curtailed supplies, the impacts can be harsh—especially in those countries unable to insulate their poor from the market through concessional means such as the U.S. food stamp program. For example, the 1972/73 Indian food grain crop dropped from 105 million to 96 million tons. In the tug-of-war between maintaining diets and saving foreign exchange, diets lost and food prices were allowed to increase. Per capita calorie availability dropped toward the critical levels of the mid-1960's.

Thus, in a world having great affluence among only one-third of its population, the 2,300-year-old words of the Greek cynic Diogenes come back to haunt us. When asked for the proper time to eat, he responded, in his own practical manner: *"If a rich man, when you will; if a poor man, when you can."* Modern economists are reminded by an ancient philosopher of the simple, obvious relationship between incomes, wealth and diets.

The fundamental situation is that large numbers of people in the developing countries do not have the incomes to command the food which would give them adequate protein in their diets. This basic phenomenon overhangs all efforts to bring about nutrition improvements. And, this is the basic reason, barring a miracle, why nutrition improvement must be viewed as a long-term process. This assessment carries with it several important implications for policy makers, nutritionists, and agronomists.

1. Even if food were produced in amounts sufficient for adequate diets—and even if it were available in the low-income nations—many, many people would have insufficient income to pay for it.

2. Efforts to improve availabilities of food in the low-income nations must proceed on a broad front:

   Efforts to increase yields of cereals, forages, food legumes, and root crops such as casava must continue and be expanded especially in national research programs;

   The protein content of traditional crops must be improved through accelerated research efforts;

   Non-traditional approaches, such as food fortification and use of single cell protein substances, should be pursued aggressively;

   Low-income nations must place even high priorities on programs and policies to stimulate food production and improve its distribution.

3. Expansion of employment opportunities for the poor of these countries must not be overlooked, for the related income is basic to substantial improvements in the diets.

The recent world food crisis has again raised, in the public eye, the spectre of world famine. While I maintain that income and diet improvement in much of the world is a long-term process, I do not seriously anticipate a crisis of famine proportions.

For a number of years, the United States, on the basis of its large food stocks and operating through commercial and concessional programs, has been the food reserve of the world. Lately, through a complex series of events—including a new U.S. farm program aimed at reducing surpluses and placing U.S. markets into direct competition with world markets—U.S. exports skyrocketed, and precipitated a decilne in U.S. grain stocks. Important contributing factors have been successive devaluations of the dollar, making U.S. commodities more attractive to foreign buyers and added world demand emanating from widespread 1972 crop shortfalls. Such events have led to the recognition of a growing interdependency of the agricultural economies of the world.

Crop prospects for the coming year and for the next decade have important implications for how well developing nations will participate in the world market.

Nearby, the world food outlook is improved. The United States produced record soybean, wheat, and corn crops last year. And huge U.S. feed grain and wheat crops are projected for the coming harvest—wheat will jump to 2.1 billion bushels, 400 million more than last year. Feed grain production will also hit a new record.

Feed grain crops in 1973/74 or Australia, Argentina, and South Africa were up significantly as is the Australian wheat crop.

The Soviets had a record grain harvest of 222.5 million metric tons last year. This is 35.5 million tons more than their previous record in 1970. Soviet winter crops came through the winter in good condition. The size of this year's crop is not yet estimated by Soviet officials. However, they expect increased acreage.

Good monsoon rainfall and a fertilizer priority brought Indian rice output last fall back to the production plateau achieved in 1970/71. However, Indian wheat production this spring dipped below last year's crop and was almost 20 percent down from the record output of 26.4 million tons of two seasons ago. The world will anxiously watch during the coming weeks the start and progress of the monsoon in the Indian subcontinent.

In combination, the 1973/74 world grain crop was about 90 million tons more than the year before and the prospects for further production increases are promising but, of course, uncertain. Even with these increases, high demand and reduced stocks will likely hold prices at relatively high levels. Poor nations, with persistent food problems and limited foreign exchange, are increasingly worried about their ability to import their food needs. Availabilities of fertilizer and high costs of imported energy supplies for these countries have increased the anxiety over the eventual size of this year's crop production in the lower income countries.

When it comes to forecasting the future balance of food demand and supply, many factors must be taken into account: population and income changes, the availability and acceptability of substitutes for traditional foods, development and adoption of new technologies of production, potential changes in the use of water and land, prices of inputs such as fertilizers and fuels, and of course, weather. For most of these variables one can make assumptions for the future with fair confidence. Let us initially assume also that (1) fuel, fertilizers and pesticides will be available in adequate quantity and at prices consistent with trends up to October 1973, and (2) that weather will be not greatly different than it has been in the past.

Using the above approach, two points of overwhelming importance emerge in the projections of the U.S. Department of Agriculture. First, the role of the United States as the major supplier of food in international markets is expected to expand. Second, the dependence of the lower-income countries on food imports is expected, by 1985, to be nearly double the 1970 level. The two points add up to heavy dependence by the developing countries on the United States as a supplier of food.

The projections for the United States anticipate continued advancement of agricultural technology, as well as policy pressures to use exports of food to help pay for imports which underpin the American standard of living. Moreover, levels of production will depend substantially on returns to farmers and on government programs. If farm product profits remain at recent high levels, significant expansion of production is likely to occur as land not now in production is utilized to grow crops and forages, and new technologies are adopted more readily in order to capture these potential profits.

The expected expanding role for the United States also reflects anticipated developments in other countries. In Japan, for example, resource limitation coupled with a continuing drive to upgrade the diet as incomes increase should lead to a growing dependence on imports of food. On the other hand, the European Community has aggressively pursued policies promoting self-sufficiency in food production. These are expected to continue to be effective.

Developments in Canada would somewhat parallel those in the United States. For her size, Canada's role in world food is already extraordinary and steadily growing. However, Canada's production is only one-sixth that of the United States, and heavily focused on wheat.

The prospective import level of the U.S.S.R. is one of the major uncertainties which will affect the world market, and especially the price and availability of food to the developing world. In the intermediate and long-run future, the Soviets' capacity to import large amounts of agricultural products will be determined largely by their ability to obtain credit from and sell goods to the West. To a large extent, this may involve the Soviet Union's natural resources, such as petroleum.

In the poor countries, statistical increases in food production will likely keep up with population and perhaps gain on it. Some areas, such as Brazil, will be able to expand the area devoted to crops; others will develop their cropping capacity through irrigation, and one hopes most will have improved technology. However, nutritional improvement efforts and income growth—above all, the use of cereals to produce livestock products—are expected to push demand ahead of local production increases; hence the prospect that the poor countries will increase their dependence on imports of food, especially cereals and especially from the United States.

But what of the assumptions of normal weather and of adequate and historically priced energy components? Both, especially the latter, are open to serious question.

Unfortunately, man has not thus far been particularly successful in forecasting weather developments, or in modifying them. Various modern developments, to be sure, mitigate the effects of bad weather. Expansion of irrigation, improved drainage, soil and water conserving techniques such as ponds and terraces, shorter-growing, fertilizer-responsive plants, and mechanization—all soften the impact of weather.

Still, any farmer in India, Russia or America knows that if you don't get rain, you don't get grain. But sometimes professional economists forget; there is a great tendency even for experts to assume that recent weather will continue or will change to fit their image of the future. Such thinking generated much of the famine talk in the mid-1960's, and subsequently the abundance talk when the Green Revolution took hold. If the weather in 1970 had been poor instead of good, as it actually was, observers would not have been so confident about India's ability to feed her people, and forecasters of self-sufficiency would have been more cautious.

The potential effects of the scarcity and prices of energy are at best obscure. Effects on food production costs and income growth in both developed and developing countries are of concern. And too there is room for speculation whether the oil-rich countries will take major steps to ameliorate the impact of fuel and fertilizer availabilities and prices on the developing countries?

Could the Arab nations become, in effect, an international Robin Hood, favoring the poor over the rich? Over a period of years, the resulting impacts could drastically alter traditional production and trading patterns. For the short term, however, the energy crisis hangs over any prediction of both levels of supply and price.

In overall terms, the forecast for the decade would be a recovery of world food production and per capita supplies of food would increase slowly.

But, we visualize continued instability in U.S. and international prices as the low-income countries make only modest progress in improving nutrition of their people. Under any conceivable combination of increases in farm production and innovations of nontraditional foods, slowing of population growth, and increases of income, an overwhelming number of poor people in these countries will be inadequately fed for decades to come. The closing of the food gap between the rich and the poor is a long way off, despite the probable steady increases in production.

Chairman PROXMIRE. Our last witness is Mr. Altschul. Please proceed.

STATEMENT OF AARON M. ALTSCHUL, PROFESSOR, SCHOOL OF MEDICINE, GEORGETOWN UNIVERSITY

Mr. ALTSCHUL. Mr. Chairman, I am pleased to have the opportunity to testify at your hearing, and I would like to discuss the following four topics: One, some comments on the Natick process; two, the interrelationships of fuel and food; three, some comments on the world food problem; and four, some policy implications.

As Mr. Sawhill has pointed out, I think that this process is interesting, that is, the process of converting cellulose into glucose, but that much more work has to be done before we really know whether it is a practical process.

I do not know whether the committee has had brought to its attention analysis by Stanford University on the subject of synthetic carbohydrates, which deals in detail with the process of converting cellulose into glucose and the conversion of glucose into starch. This analysis came out at a price of glucose of 4½ cents a pound and at a manufacturing cost of starch from that glucose of 5.8 cents a pound. But I must emphasize that these are preliminary figures and that until there is a pilot plant operating and until the cost of collection of the cellulose, as Mr. Train pointed out, is put into the equation, we will not know exactly what this is going to mean.

I am convinced that the idea is sound, and that sooner or later the economics will be sound. There have been attempts for some years to grow microorganisms on a variety of substrates: Petroleum products, industrial wastes, animal production wastes, sewage wastes, et cetera. These continue. Microorganisms can be grown on these materials but the costs are still high, and the utilization is uncertain. Certain companies in Europe and Japan continue this effort; most expect that the first application will be in animal feeds. If this could work out and the price in animal feeds would be competitive with soybean meal, such a development could release larger quantities of soybean for direct human consumption. The price of the microorganism protein will depend on the cost of production and on the cost of purification or fractionation needed to make it suitable and safe as an animal feed.

But many had hoped that microorganism protein could be used directly for humans. There are several problems; I will speak of two: The need to fractionate and the problem of esthetics. The need to fractionate comes about from the fact that there are certain chemicals or biochemicals in the microorganisms which make it difficult to feed directly to humans and animals. I talk only of nucleic acids and perhaps cell wall material. Depending on the substrate, you can have an accumulation of toxins that have to be removed before the material could be fed directly to humans.

I would like to discuss an analogy, Mr. Chairman. No one really thinks of putting an animal into a blender and cutting up the whole animal and serving it up. One dissects the animal and calls this dissection "butchering," and serves up portions of the animal. Even the soybean, which is a much more simple material, is fractionated before it is used for humans. And I think that it probably was a very nice hope that you could use the microorganism directly. I think that a fractionation step will be required, and this, of course, will raise the cost.

Then there is the question of esthetics, I think that this is terribly important when you are dealing with materials that derive from waste materials. Microorganisms grown on wastes are esthetically undesirable, even though they may be perfectly wholesome and nutritious. The most driving force in determining food consumption with rising income is the search for more enjoyment in food, for more status foods. This has characterized every nation's food pattern as income has risen. This esthetic problem will eliminate the cheapest, the most direct conversion of waste substrate into food as a viable possibility for the near future, at least.

This means that anything directly derived from waste will have to deal with an esthetic problem. The interesting point about the conversion of cellulose to glucose is that you have converted a waste material into a chemical, a food chemical. but it is a chemical nonetheless, and when this has become a chemical, the compound has lost its history, and then you can go into many directions. You can make glucose by fermentation. You can make it from animal glycogen. You can make it by synthesis, or make it from cellulose.

So once you have glucose you have a material that can be made into a food. The interposition of a process for the isolation of a food chemical from waste is clearly an additional cost of recycling material into the human food chain, but, in my opinion, is a necessary one.

Therefore, this is another reason why the ability to form glucose from cellulose is an interesting ability which ought to be investigated.

You ask what should be done with the additional glucose? Should it be converted to ethyl alcohol for fuel or eaten for food energy, or converted to microorganisms for protein, or made into amino acids, or other purposes? At this point I think it is enough to know that these options exist. The deciding factor has to be the overriding national need at the moment. And this could change.

I do not think that this is a simple question of fuel or food, because these two are interrelated. The average American requires more energy from fuel for production, processing, and marketing his food than the food itself provides. The so-called "Green Revolution" in South Asia was the result of developing seeds that could utilize more inputs—fertilizer and water—than the traditional seed. This revolution stand or falls on the availability of nonrenewable energy, on imported fuel.

If I were to hazard a prediction about priorities, I would think that the first priority in food is to maximize agricultural production of the cereal grains and legumes, including soybeans. After all, the sun's energy is free: Maximum advantage should be derived from it. Therefore, if a shortage of food is threatened because of lack of fuel, the first priority would be to provide fuel for food production. Thereafter, I should think that glucose made available by this process would be converted by fermentation either to amino acids or to protein fractions thereby freeing more agricultural capacity for production of energy-rich foods—the cereal grains and roots.

The basic role of technology in this case is to increase the options for deriving fuel or food. The detailed decisions are time and place specific; the broader options are the determinantes of ability to solve problems.

I want to comment on the world food problem. We do not want to go into any detail, but I should mention three major trends that affect the world food problem: First, population growth; second, increasing demands for animal food products resulting from the higher income in the affluent countries; and third, the dramatic rise in the cost of energy.

These have been pointed out by Mr. Schertz.

One does not have to go to complex calculations to see the picture. It is only necessary to know the status of the poor countries as net importers of food. For a while in the 1960's there was a decrease in imports because of new technologies and food production. But the trend is changing and imports are increasing. And the cost of fuel is increasing. Without any compensatory increase in exports that would generate foreign exchange, these countries, which represent over a billion people or more, are headed for bankruptcy and famine.

Coupled with this is the continued trend to increase animal production in the developed countries. This has put a strain on world grain supplies so that reserves are down and stocks that could be available to avert famine are just not there. Affluent customers with cash are competing for our own grain supply with poor countries with no cash reserves. The affluent customer needs the grain to feed cattle; the poor customer eats the grain directly.

Mr. Schertz pointed out one way of showing the role of animal consumption and how much grain we need. Let me point out another way of putting it. If you add together the food energy that we eat directly and the food energy that our animals eat, which we then eat, it turns out that the average American eats daily 11,000 grain equivalent kilocalories. We actually eat 2,500 kilocalories. When you add together that and the grain that is used to feed the animals, it adds up to about 11,000. Developed society on the average eats about 8,000; the underdeveloped society, about 3,000. But most of the poor countries eat very close to their actual consumption; that is, in the range of 2,000 to 2,500 kilocalories.

One of the imperatives of my own professional life has been the certainty that classical agricultural procedures will fail to supply enough food. I have felt that animals will play a diminishing role in providing nutrition, esthetics, and status.

Mr. Chairman, this is with due regard to some of the animal products from your own State. I am thinking of more utilization of soy and and other oilseed protein directly for human consumption; the development of analogs from vegetable protein sources on the meat and milk model; of the addition of amino acids to plant proteins to improve their protein value; of production of new protein by fermentation. The hydrolysis of cellulose to glucose could be another example of nonagricultural inputs to food supply.

At this moment none of these with the exception of soy in the Orient contribute significantly to our food supply. But the situation is changing. Textured vegetable protein foods on the meat model either as extenders or as complete analog replacements are proliferating on the American scene. And they are moving into other developed societies. The school lunch authorities in the United States allow 30 percent replacement of the meat portion with textured vegetable protein. This remarkable development testifies that food science and nutrition have reached the stage where such major changes are possible. Other developments will follow as knowledge and technology improve.

One might have thought that these new developments would be achieved first in the poor societies where the need is the greatest. But this is not so. One of the properties of a developed and affluent society is the ease with which new ideas take hold and grow. The food pattern will change dramatically in the next several years in developed societies. The driving force will be a high level of technology, lower cost, functional advantages, and medical advantages. Thus, the affluent societies will be able to maintain a high level of consumption of foods on the meat model, but with less animals. Eventually, this also will be true of foods on the milk model. New nonagricultural sources of protein will arise and these will free land agricultural resources for more energy foods that can be eaten directly.

What does this do for the poor countries? Eventually, the technologies will of necessity be accepted. Their acceptance by the affluent societies will make it possible for them to divert grain from animal production to human consumption. And this may be the greatest benefit of all.

But no amount of technology can work miracles. Technology multiplies options or provides new options. Technology cannot overcome unrestrained population growth, nor the effects of poverty, or lack of education. Nor can technology substitute for proper distribution of wealth within and between countries. And technology cannot substitute for the ethical and moral quality that dictates how man should deal with man or nation with nation.

Let me conclude with some policy implications.

The idea of recycling waste into chemicals that can be transformed into food and fuel is an excellent one. Actually, the need for this kind of an operation becomes an absolute necessity both from the need to minimize ecological insults and the need for new sources of food and fuel. Natick ought to be encouraged and given the necessary resources to determine as quickly as possible the validity of this particular idea. Others should be encouraged to test alternative ideas.

But a new process for food besides cost considerations requires public acceptance and a regulatory climate that allows new ideas to develop yet protects the rights and needs of the consumer. This committee may wish to study the problems encountered when radically new ideas in food are introduced in American society.

Thank you, Mr. Chairman.

Chairman PROXMIRE. Thank you very much.

[The prepared statement of Mr. Altschul follows:]

PREPARED STATEMENT OF AARON M. ALTSCHUL

Mr. Chairman, members of Subcommittee on Priorities and Economy in Government, I am pleased at the opportunity to testify at your hearings. I will discuss the following topics: The Natick process for producing glucose from cellulose and its implications; The interrelationships of fuel and food; Some comments on the world food problem; Some policy implications.

THE ENZYMATIC HYDROLYSIS OF CELLULOSE WASTES

I thank you for the information that you sent to me describing the process for enzymatic hydrolysis of cellulosic wastes, and I have studied it. As I understand it, the process has passed the laboratory tests and now a pilot plant has been built to test it out on a larger scale. Real achievements have been made in the laboratory, among them production of a more active enzyme population and learning how to prepare the waste material so that hydrolysis proceeds most efficiently. The process, indeed, has promise.

But I should point out that much work needs to be done before there is a working process and before one can make responsible and accurate calculations of costs and price of final products. I would hope that Natick will move with all speed so that answers might be forthcoming in the next few years.

I am convinced that the idea is sound and that sooner or later, the economics will be sound. Among the determinants of practicality, aside from the specifics of the process, will be the cost of waste disposal, the cost of fuel, and the cost of agricultural calories and protein. The principle deserves further comment.

There have been attempts for some years to grow microorganisms on a variety of substrates: petroleum products, industrial wastes, animal production wastes, sewage wastes, etc. These continue. Microorganisms can be grown, the costs are still high, and utilization uncertain. Certain companies in Europe and Japan continue this effort; most expect that the first application will be in animal feeds. If this could work out and the price in animal feeds would be competitive with soybean meal, such a development could release larger quantities of soybean for direct human consumption. The price of the microganism protein will depend on the cost of production and on the cost of purification or fractionation needed to make it suitable and safe as an animal feed.

But many had hoped that microorganism protein could be used directly for humans. There are several problems: I will speak of two: the need to fractionate and the problem of esthetics. No one would think of putting an entire animal in a grinder and serving it as a food, although we do eat sardines and shell fish, and fish meal has been proposed. The more likely procedure is to dissect out the more useful portions of the animal for human consumption. Similarly, the soybean is not used for most purposes directly as food but is processed and fractionated first to make it suitable for human or animal consumption. It is a brave hope that microorganism protein with its complex composition, its nucleic acids, and its cell wall material will be uniformly suitable for repetitive, daily human consumption. A fractionation step will more than likely be necessary, and this will raise the cost above the cost of producing the microorganisms themselves.

Then there is the question of esthetics. Microorganisms grown on waste are esthetically undesirable even though they may be perfectly wholesome and nutritious. The most driving force in determining food consumption with rising income is the search for more enjoyment in food, for more status foods. This has characterized every nation's food pattern as income has risen. This esthetic problem will eliminate the cheapest, the most direct conversion of waste substrate into food as a viable possibility for the near future, at least.

That is why it is so interesting to learn of a process that produces a pure, clearly defined, chemical, and a food chemical at that, from waste materials. Glucose is a food but it is also a clearly defined chemical substance. This compound, once it is pure, has lost its history, so to speak. It is identical whether made from plant products, from animal glycogen, by synthesis, or from cellulose. Once it is pure the problem of esthetics disappears. And this glucose can be considered directly for human consumption; it is subject to analysis for contaminants; it can be clearly defined in specifications to protect its human consumer. The interposition of a process for isolation of a food chemical from waste is clearly an additional cost of recycling material into the human food chain, but, in my opinion, a necessary one.

THE INTERRELATIONSHIPS OF FUEL AND FOOD

What should be done with the additional glucose? Should it be converted to ethyl alcohol for fuel, or eaten for calories, or converted to microorganisms for protein, or made into amino acids, or other uses? At this point it is enough to know that these options exist. The deciding factor has to be the overriding national need of the moment. And this could change.

It is not really a simple question of fuel or food, because these two are interrelated. The average American requires more energy from fuel for production, processing, and marketing his food than the food itself provides. The so-called "Green Revolution" in South Asia was the result of developing seeds that could utilize more inputs—fertilizer and water—than the traditional seed. This revolution stands or fails on the availability of energy, on imported fuel.

If I were to hazard a prediction about priorities, I would think that the first priority in food is to maximize agricultural production of the cereal grains and legumes (including soybeans). After all, the sun's energy is free: maximum advantage should be derived from it. Therefore, if a shortage of food is threatened because of lack of fuel, the first priority would be to provide fuel for food production. Thereafter, I should think that glucose made available by this process would be converted by fermentation either to amino acids or to protein fractions thereby freeing more agricultural capacity for production of energy-rich foods—the cereal grains and roots.

The basic role of technology in this case is to increase the options for deriving fuel or food. The detailed decisions are time and place specific; the broader options are the determinants of ability to solve problems.

SOME COMMENTS ON WORLD FOOD PROBLEM

This is not the place to go into great detail on this subject. My own views are expressed in recent publications cited at the conclusion of this statement. Let me discuss some basic issues. The world food situation, particularly the problem of the poor countries, had been deteriorating in the last few years but other events have accelerated the deterioration. The three major factors are continued population growth, increasing demand for animal food products resulting from higher income in the affluent countries, and the dramatic rise in the cost of energy.

One doesn't have to go to complex calculations to see the picture: it is only necessary to note the status of the poor countries as net importers of food. For a while in the sixty's there was a decrease in imports, but the trend is changing and imports are increasing. And the cost of fuel is increasing. Without any compensatory increase in exports that would generate foreign exchange, these countries, which represent over a billion people or more, are headed for bankruptcy and famine.

Coupled with this is the continued trend to increase animal production in the developed countries. This has put a strain on world grain supplies so that reserves are down and stocks that could be available to avert famine are just not there. Affluent customers with cash are competing for our own grain supply with poor countries with no cash reserves. The affluent customer needs the grain to feed cattle; the poor customer eats the grain directly.

It costs about 11,000 grain equivalent kilocalories to feed the average American daily even though he eats directly only 2500 to 3000 kilocalories. The greater proportion of grain equivalent calories are required to feed the animals which he then eats. The average for the developed countries is about 8000 kilocalories and for the underdeveloped countries 3000 kilocalories. For the poorest countries the averages have to be lower and almost equal to the actual calories eaten.

There already is famine in some countries. The difference between survival and disaster for others hangs by a string. A bad harvest season is all that is needed to fulfill the Malthusian prediction.

One of the imperatives of my professional life has been the certainty that classical agricultural procedures will fail to supply enough food. I have felt that animals will play a diminishing role in providing nutrition, esthetics, and status; that legumes will fail to compete with cereals for scarce land resources. I am thinking of more utilization of soy and other oilseed protein directly for human consumption; the development of analogs from vegetable protein sources on the meat and milk model; of the addition of amino acids to plant proteins to improve their protein value; of production of new protein by fermentation. The hydrolysis of cellulose to glucose could be another example of non-agricultural inputs to food supply.

At this moment none of these with the exception of soy in the Orient contribute significantly to our food supply. But the situation is changing. Textured vegetable protein foods on the meat model either as extenders or as complete analog replacements are proliferating on the American scene. And they are moving into other developed societies. The school lunch authorities in the United States allow 30% replacement of the meat portion with textured vegetable protein. This remarkable development testifies that food science and nutrition have reached the stage where such major changes are possible. Other developments will follow as knowledge and technology improve.

One might have thought that these new developments would be achieved first in the poor societies where the need is the greatest. But this is not so. One of the properties of a developed and affluent society is the ease with which new ideas take hold and grow. The food pattern will change dramatically in the next several years in developed societies. The driving force will be a high level of technology, lower cost, functional advantages, and medical advantages. Thus, the affluent societies will be able to maintain a high level of consumption of foods on the meat model, but with less animals. Eventually, this also will be true of foods on the milk model. New non-agricultural sources of protein will arise and these will free land agriculture resources for more energy foods that can be eaten directly by now.

What does this do for the poor countries? Eventually, the technologies will of necessity be accepted. Their acceptance by the affluent societies will make it possible for them to divert grain from animal production to human consumption. And this may be the greatest benefit of all.

But no amount of technology can work miracles. Technology multiplies options or provides new options. Technology cannot overcome unrestrained population growth, nor the effects of poverty, or lack of education. Nor can technology substitute for proper distribution of wealth within and between countries. And technology cannot substitute for the ethical and moral quality that dictates how man should deal wih man or nation with nation.

SOME POLICY IMPLICATIONS

The idea of recycling waste into chemicals that can be transformed into food and fuel is an excellent one. Actually, the need for this kind of an operation becomes an absolute necessity both from the need to minimize ecological insults and the need for new sources of food and fuel. Natick ought to be encouraged and given the necessary resources to determine as quickly as possible the validity of this particular idea. Others should be encouraged to test alternative ideas.

But a new process for food besides cost considerations requires public acceptance and regulatory climate that allows new ideas to develop yet protects the rights and needs of the consumer. This Committee may wish to study the problems encountered when radically new ideas in food are introduced in American society.

It may be that I am unduly alarmed about the world food problem. I hope that I am wrong, and the Committee should seek views of others. Whatever the view that emerges, the public ought to know the realities of world food supply. The public ought to know the consequences of food habits in one country on food availability in another country. The interchangeability of fuel and food ought to be clearly depicted.

And when the time comes for all of us to face serious moral and ethical questions, we will, at least, be better prepared.

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Chairman PROXMIRE. I want to thank all of you gentlemen. The way this whole situation developed, we heard about this Natick breakthrough and we were impressed. It sounded interesting. We sent members of the staff, of this committee and my own staff, up to Natick to talk to the people up there. We were not satisfied with that, so we asked two distinguished scientists, Thomas Reed and David Wilson, both of the Massachusetts Institute of Technology, to visit the lab. They had no connection with it whatsoever. They went to the lab as objective, scientific observers and they gave us a report on it. On the basis of that we had hearings yesterday. Yesterday we had the man in charge of this, Leo Spano who testified before us, and two others, Mary Mandels and John Nystrom, who have been principally involved.

They testified that waste, including wastepaper, of which we have an enormous abundance as we know in our country, more than any other country has had by far, and it is getting bigger with newspaper production and other waste, animal waste, could be converted by using a mutated fungus method to glucose and the glucose, of course, by conventional methods into ethyl alcohol or ethanol, for about 20 cents per gallon.

Now the capital costs of building the conversion equipment was less than the cost of an incinerator, which is used to burn this excess anyway. So that seemed very promising. The estimate was $12 million in present dollars, with a conservative estimate of inflation, about $19 million in 1977 dollars, when they plan to build the regular plant and they plan to go ahead with the pilot plan. That would produce 1,000 tons a day as a result of having that kind of capital investment.

The potential national production, if we use the raw materials available fully, would be equivalent to about 14 percent of our present consumption and by a further process, about 20 percent of our gasoline. Now, if we can get additional energy resources that way, of course, it means, because of the much lower cost of ethyl alcohol or ethanol that is produced in this way, because of the fact of the increased amount that we anticipate for oil and gasoline purposes would be dropped somewhat, because 14 percent, of course, is an enormous additional source. We thought that this could result in moderating what otherwise would be a much higher cost for gasoline.

SAWHILL SEES ENORMOUS POTENTIAL FOR PROCESSES THAT PRODUCE FUEL FROM ORGANIC WASTE

Now, in view of all that I want to ask you, Mr. Sawhill, to begin with, about this. I wrote to you about the Natick process and the fuel implications on April 28. You wrote back an encouraging letter on

May 3 that said: "I agree that there is an enormous potential for all processes to produce fuels from organic wastes."

First of all, I want to know what positive steps you have taken other than sending me that letter? Have you had a chance to investigate this? Have your people investigated?

Mr. SAWHILL. Yes, we have had our people investigating and will continue to have them.

Of course, we would favor the continuation of this research project because there is nobody that would like more than I would to see the price of gasoline moderated and our supplies increased, particularly from an alternative source.

But this is just the kind of project that we in the Federal Energy Office or Administration are preparing now to begin work on.

Chairman PROXMIRE. What bothers me especially in your letter, you said that the primary responsibility for technical evaluations of biological processes for energy production is with the National Science Foundation.

I happen to be Chairman of the Appropriations Subcommittee that handles the budget for the National Science Foundation. They testified before us already on their 1975 budget. And my impression is that NSF sees as its primary response the awarding of grants to private persons who are using the money to conduct research. NSF does not have a very large in-house capability. As you know, it is a small agency. While it is accelerating its work in the energy field, it has not done very much so far.

We in Congress look to you, the FEA, the Federal Energy Administration, to evaluate new technologies that might have implications in the energy field.

Why can you not evaluate the Natick process and ethanol and other subjects for oil and gas? Why do you have to lean on NSF?

Mr. SAWHILL. Yes; we have had our people investigating and will will utilize NSF to let a contract to technically tell us whether that process is feasible or not.

I agree with you. It is our responsibility to ultimately make a determination and recommendation to Congress whether this is an economically viable process or not.

FEA TO CARRY ON A FEASIBILITY STUDY OF THE POSSIBILITIES OF THE NATICK PROCESS

Chairman PROXMIRE. Would it be possible for you to have your office do a study and present the results of that study to this committee?

Mr. SAWHILL. Yes.

Chairman PROXMIRE. Would you do that?

Mr. SAWHILL. Yes.

Chairman PROXMIRE. How long would that study take?

Mr. SAWHILL. It depends a little bit on the available data. I am not sure that we know that at this point, but we certainly could do it within 30 or 60 days.

Chairman PROXMIRE. I would appreciate that very much. It would be most helpful.

Mr. SAWHILL. We will present to you what a plant would look like using this process and give you our analysis of whether it would be appropriate to go ahead with a plant like that or not.

Chairman PROXMIRE. Very good. We are very anxious, as you are, as all of us are, every one of us. You gentlemen have a much bigger responsibility, specific responsibility, than any Senator has, and you have won the admiration for the work that you have done, both you and Mr. Train, for our Government, and you are recognized as among the most dedicated and enlightened public servants. I am not trying to criticize you personally at all. I do think that this does seem to have great promise, and I am very anxious to find out whether or not we should push it and to what extent.

I am very hopeful that we can.

Mr. SAWHILL. I think that this is very important. I am sure that it is somewhat frustrating that we have not done something like this sooner, but we built up this agency rapidly in a time of a very severe shortage. Now, and only now, are we beginning to put in place the real mandate that Congress has given us to develop a national energy policy for the country. It is just this kind of project that will contribute to the development of that policy.

USE OF ETHANOL AS A FUEL PRIOR TO WORLD WAR II

Chairman PROXMIRE. Mr. Sawhill, could you give the subcommittee an outline of the use of ethanol in gasoline? What was the extent of its use before World War II?

Mr. SAWHILL. Could I ask Mr. Reed to answer that question?

Chairman PROXMIRE. Yes, indeed.

Mr. LISLE REED. Would you repeat that?

Chairman PROXMIRE. Would you give the subcommittee an outline of the history of the use of ethanol in gasoline, the extent of its use before World War II, and why its use has been curtailed?

Mr. LISLE REED. I think it was used prior to World War II because of the shortage of petroleum supplies, and it was the only source of hydrocarbon that could be obtained in the countries that had petroleum.

Chairman PROXMIRE. I want to know where it was used and what percentages of gasoline as opposed to ethanol?

Mr. LISLE REED. I do not know.

Chairman PROXMIRE. Whether it was usable in Europe or elsewhere? Do you have any knowledge of that?

Mr. LISLE REED. No, sir. Only, I think, in airplane fuel, it was used.

Chairman PROXMIRE. Do you know the extent that it is being used anywhere in the world, any other countries as a gasoline additive?

Mr. LISLE REED. No, sir.

Mr. SAWHILL. I am sure we could develop that information for you.

My understanding is that the percentage of alcohol could vary between 10 and 40 percent, but for motor gasoline, once you get over 10 percent, the condensation problem makes it difficult to use. That is what Mr. Train was referring to when he talked about the requirement for carburetors.

Chairman PROXMIRE. We have such distinguished witnesses, and I know you have to leave fairly soon, but I would like to ask our witness, who I think is still here, Thomas Reed—would you step up, Mr. Reed?—to what extent ethanol has been used. It would be very helpful to us if you would give us that.

Mr. **Thomas Reed.** As was mentioned before, at times when gasoline becomes scarce people look for alternatives. Before World War II, the French—I also think the Germans—for a period of 4 or 5 years were adding ethanol to gasoline. They were doing it for national security. They were adding ethanol to their gasoline to the extent of about 10 percent.

I have had several people come back to me in the last few months from Brazil anl tell me there was actually a company down there, Petrobray, which is putting excess ethanol in gasoline, made from the sugar crop in Brazil. This is used as a method of balancing their balance of payment. They ship out sugar, or they can increase the price by making it into ethanol and using it in their own cars. They use between 10 and 30 percent.

Ethanol has been regularly used as an additive in South Africa. Cuba has also turned to ethyl alcohol and in its need for nonpetroleum base fuels, again, producing it from its excess sugar. But I have not met anyone lately who has been through Cuba and could give me a reliable report.

Chairman **Proxmire.** You said, Mr. Reed, that this was not economical, but it was used for national security purposes because of the limited supply, apparently, of petroleum.

Mr. **Thomas Reed.** France, in particular, being partly agricultural and being an expert in production of alcohol for consumption, was anticipating the need of alcohol for the production of munitions before World War II. So they wished to increase their alcohol production a factor of 10 or so. Yet they did not need it immediately. For this reason they added it to gasoline with a subsidy to keep the price down.

STATEMENT OF METHANOL FUEL PERFORMANCE

Chairman **Proxmire.** I want to develop one more point.

You said that it was not economical. However, you testified yesterday—and I wanted to have Mr. Train particularly aware of this—that you have used it yourself in your car, and you know of others at MIT that have used it to some extent. And you found in terms of performance, in terms of economy, and in many other areas, it is helpful with respect to gasoline, provided you use it up to a certain point.

After you get beyond about 15 percent, you found that the performance was not as good. You did, as I recall, indicate that under some circumstances, if the temperature was low, cold, zero to 20 degrees above zero, that you had some problems in performance. It started all right, but for a few minutes there was a coughing and so forth. That seemed to be a refutation to some extent of what Mr. Train told us this morning about the problems involved in the water problem and the other problems involved.

Is that correct?

Mr. **Thomas Reed.** Let me say that our experience has been with methanol, which I think, in my opinion, is already economically justified in this country.

I am saying that ethanol, as produced at the price that it is produced in this country, is not immediately parctical. Systems will have to be developed to lower the cost, such as the Natick system and others.

Chairman PROXMIRE. I just wanted a response if I stated the situation as you understood it correctly, as far as the performance of the automobile is concerned.

He said that with methanol there is an improvement, with ethanol, there is a variation, a little better, a little worse, but not significantly different; is that correct, Mr. Reed?

Mr. THOMAS REED. Yes. It is difficult to measure exactly, and it depends a great deal on the measurement, but we find increased fuel economy with methanol.

Professor Scheller at the University of Nebraska has been working with a number of cars using ethanol. It is a good ethanol State, because it produces wheat. He does not wish to say whether it is more or less economical because it is so close that it is difficult for him to say strictly on a miles-per-gallon basis that he does better.

HOW MUCH DOES ETHANOL IMPROVE PERFORMANCE?

Mr. SAWHILL. It is true, Mr. Chairman, that ethanol does have a very high antiknock value. To that extent, it would improve performance.

Chairman PROXMIRE. That testimony was not only on antiknock. I do not think that was discussed. He testified that it was more economical, he got more miles per gallon up to a certain point. He testified that you got greater acceleration. I think there was one other criterion.

Mr. SAWHILL. I cannot understand that, because there is about a third less energy in a gallon of ethanol than there is in a gallon of gasoline. To the extent that you are mixing them together, you are getting a composite fuel with less Btu component.

Mr. THOMAS REED. May I say when we first began to make these tests, we made a list on the blackboard of things which would be good and bad before we made the test. We anticipated exactly what you are saying, that it has less energy per gallon.

On the other hand, when you add methanol or ethanol to gasoline, you are effectively making a leaner mixture, therefore burning more of the rest of the gasoline.

When you get down to the nitty gritty, it is very difficult to make an exact statement. All I can say is, that on the basis of our tests, we did find better mileage, which was a great surprise to us, so we made some more tests to double check.

Chairman PROXMIRE. I understand that the American Petroleum Institute has indicated that they do not have any particular desire for ethanol. Of course, it is the American Petroleum Institute. They testified that it would be about a drop of one-tenth of 1 percent in the economy by using ethanol.

ETHANOL IS A VIABLE GASOLINE ADDITIVE IF PRODUCED BY THE NATICK PROCESS

Let me ask you this, Mr. Sawhill. You pointed out in your oral statement and in the FEO briefing book that you sent to my office, the reason that ethanol is not a common fuel in the United States is that the price of fermenting it, the cost of the grain from which it would be made, would make it prohibitive. But if these price obstacles were somehow removed, would not ethanol be a perfectly viable gasoline additive as far as its function is concerned?

Mr. Sawhill. Yes. I am surprised to hear the testimony that Mr. Thomas Reed just presented. That would even make it more desirable to the extent that you could add it and not decrease your miles per gallon. I think that would enhance its value, in my opinion. That is a very interesting point.

Chairman Proxmire. Mr. Train, there is a difference between the practical and economical. You have said that ethanol is not practical.

How do you justify this in view of the fact that ethanol is currently being used in Brazil and South Africa? The point is that ethanol must be practical because it is being used. What tests have been performed by EPA to support your conclusion?

Mr. Train. I am not really familiar with the practices either in Brazil or elsewhere. I think I had better ask Mr. Bradow to testify, if he would, at this point.

Chairman Proxmire. Mr. Bradow.

Mr. Bradow. Would you repeat the question?

Chairman Proxmire. I wanted to know how you justified the argument that ethanol is not practical, since it is being used in South Africa, it is being used in Brazil, as testified by Mr. Thomas Reed. What documentation do you have to support your conclusions that it is not practical?

Mr. Bradow. As far as documentation is concerned, of course, we did have reports available—I believe we have a copy of the API report on the subject of the use of alcohol.

Chairman Proxmire. The American Petroleum Institue?

Mr. Bradow. Yes.

ETHANOL HAS BEEN USED AS A FUEL ADDITIVE BY MANY COUNTRIES

Chairman Proxmire. I hope you are not relying on them. I think they are a fine group of people, but they do have an axe to grind.

Let me read what the report shows. It says:

> Since 1921, several well-known investigators and authors have published articles on the use of alcohol in motor fuel. Ethanol has been used in many foreign countries from time to time, including Austria, Brazil, Cuba, Czechoslovakia, England, France, Germany, Hungary, Ireland, Italy, Latvia, Poland, Spain, Sweden, and Yugoslavia. In general, however, economic considerations work against any widespread use of ethanol in motor fuel.

Mr. Bradow. There are a number of practical problems that arise from the use of either ethanol or methanol in motor gasoline.

For ethanol, the poblems are quite simply not as severe as they are in the case of methanol as a fuel, but they do occur. Methanol exerts a vapor pressure somewhat higher than would be expected, for example, from its normal boiling point considerations. There are good solid chemical reasons why this would be the case.

EPA KNOCKS METHANOL, NOT ETHANOL

Chairman Proxmire. Let me ask you about methanol.

It is puzzling to me that you, Mr. Train and Mr. Bradow, have spent so much time in your prepared statements describing the problems with methanol. Methanol is not ethanol. The Natick process does not involve methanol. We asked you to talk about ethanol. Why do you spend so much time with methanol? And do you not agree that the problems that you describe for it either do not exist or exist to a much lesser degree with ethanol?

Mr. Bradow. Certainly it exists to a much lesser degree with ethanol than the case with methanol. However, the production of ethanol from cellulose is in its infant stages at this time. For that reason, I spent more time discussing methanol. Its use is more feasible at this time from the standpoint of present production possibilities.

With respect to the problem of phase separation, that happens with either of the alcohol-bearing fuels. Methanol is particularly bad because only tiny amounts of water can cause such separation. In the case of ethanol, larger amounts are required. To be more specific, if water constitutes approximately one-quarter percent of the content of the fuel, this would be sufficient to cause the separation of the free component mixture of water, gasoline, and ethyl alcohol in two different phases, a dense phase that settles at the bottom of whatever receptacle the material is contained in, and a much lighter phase. These two phases have greatly different combustion properties. It would certainly be possible to run some sort of combustion system on either one of them at least temporarily.

But this would be very difficult, since modern day automobiles are trained to a particular component mixture.

Chairman Proxmire. May I ask that both you and Mr. Train, if you get a chance, we will make available to you to study, the testimony submitted yesterday by Mr. Thomas Reed that met this problem. He was concerned with it, too, and he admitted that it is a matter of concern. But I think he met it and indicated how it could be handled.

Mr. Bradow. I have actually operated automobiles as well for test purposes which were fueled by gasoline and alcohol. It is quite possible to modify automobiles so that they will run satisfactorily, at least for a short time on such a mixture of fuels. The question is whether or not, with the Nation's present fuel distribution system, this is reasonable and practical. In my view it is not.

TRAIN'S STATEMENT NOT RESPONSIVE TO THE COMMITTEE'S REQUEST

Chairman Proxmire. Of course, it has been used for 20 years in Europe, and is still being used. Mr. Train, I am a little puzzled by the prepared statement submitted by your aide and yourself. Although we appreciate your presence here this morning, I do not believe your statement is responsive to my request.

In my May 10 letter of invitation I briefly explained the Natick process. I said, I quote: "As you know, a technology already exists for manufacturing low-cost ethanol, chemicals, and food from glucose." I then added: "In your testimony I would like you to focus on the environmental implications of the new technology being developed by the Army laboratory."

I asked you to adjust the environmental implications of the Natick process and the use of ethanol.

You are, after all, the head of the Environmental Protection Agency. Nowhere in your prepared statement do you address the environmental issues. Am I correct or did I miss something in your oral or prepared statement?

Mr. TRAIN. Without reviewing the statement, I probably did not address it in any great detail. I do refer to some of the emission effects. I did refer to the importance of finding effective uses for wastes, and that, certainly, I would guess is the most significant environmental aspects of the issue.

Chairman PROXMIRE. Here is a way to convert garbage and wastes into storable raw material. A thousand tons of garbage can be converted to 500 tons of glucose. The glucose can be used to produce 250 tons of ethanol or 450 tons of single cell protein. This is not speculation, this is not theory, this is not a hoax; it is being done.

It is being done at Natick and other processes are being employed elsewhere. Waste materials are being successfully recycled, so that it would seem to me that this would represent a significant and serious possible way in which we could solve a very important environmental problem, which is the disposal of solid waste in our country.

Mr. TRAIN. As I pointed out in my statement, Mr. Chairman, I do not want to argue with the Natick project, certainly. We have not been up there to take a look at it, as far as I know, but we certainly will. And we will coordinate with the Federal Energy Office to insure that we do not duplicate or overlap in this respect.

We do have, as I pointed out, a great many projects in the Environmental Protection Agency at the present time. We are putting $35 million of Federal money into energy conversion projects from solid waste. This is simply on the energy side of the solid waste problem. Se we are very actively addressing these problems.

Chairman PROXMIRE. I appreciate that very, very much. As I say, I have great admiration for you. You have been in a most difficult position, and I have been proud and happy with the fine way you handled your task. I do not mean to be critical of you personally. I appreciate very much your statement that you will have competent people visit the Natick lab. I would appreciate it very much if you would make a study of any kind that you could make available to this committee based on that, giving the environmental implications of this ethanol operation.

Mr. SAWHILL. Maybe we could give a joint report to the committee.

Chairman PROXMIRE. Very helpful.

The figures that you cite in your statement and the facts that you use in your comments about ethanol seem to me to be possibly—and I do not mean, again, to indicate any bias—but they seem to present a case against this potential fuel, as if it is sort of an adversary additive.

You say that only 25 gallons of ethanol is recoverable from municipal waste from one person in a year. That seems like an awfully small amount. You then say: "The bulk of materials that would be necessary as an ethanol source is staggering."

Mr. Train, the bulk of wastes we generate each year is indeed staggering. We may not be able to produce much else, but we can certainly produce more garbage than any other country has ever produced in history, and it keeps expanding constantly. If you multiply the number of people in the country by 25 gallons or the number of residents in every city, see what you get. On the basis of a total national population of 200 million, we get an ethanol potential of 5 billion gallons; an average city of 500,000 would produce enough garbage to recover 12½ million gallons of ethanol.

Does it not make more sense to talk about municipal populations than individuals?

Mr. TRAIN. Very probably.

May I submit for the record, in case the committee would be interested, a summary of the amounts of waste in the country by category, that is municipal, farm, animal, industrial, that could be convertible to ethanol.

Chairman PROXMIRE. Fine.

Mr. TRAIN. I will submit that for the record.

[The following information was subsequently supplied for the record:]

ANNUAL GENERATION OF WASTES CONVERTIBLE TO ETHANOL

Category	Tons (million)	Remarks
Municipal (household and commercial)	90	See attached tables 1 and 2.
Farm (crop)	550	See attached table 3.
Animal	1,560	See attached table 4.
Industrial	30	See attached table 5.
Total	2,230	

TABLE I.—MUNICIPAL SOLID-WASTE GENERATION, BY MATERIAL AND SOURCE, 1971

Type of material	10^6 tons of waste, by product source category							Total			
								As generated		As disposed	
	Newspapers, books, and magazines	Containers and packaging	Major household appliances	Furniture and furnishings	Clothing and footwear	Food products	Other	10^6 tons	Percent	10^6 tons	Percent
Paper	10.3	20.4		(1)	(1)		8.4	39.1	31.3	47.3	37.8
Glass		11.1	(1)	(1)			1.0	12.1	9.7	12.5	10.0
Metal		6.1	1.9	.1	(1)		3.8	11.9	9.5	12.6	13.1
Ferrous		5.4	1.7	(1)			3.5	10.6	8.5		
Aluminum		.6	.1	(1)			.1	.8	.6		
Other nonferrous		.1	.1	(1)			.2	.4	.3		
Plastic	(1)	2.5	.1	.1	.2		1.3	4.2	3.4	4.7	3.8
Rubber and leather		(1)	.1	(1)	.5		2.7	3.3	2.6	3.4	2.7
Textiles	(1)	(1)		.6	.5		.7	1.8	1.4	2.0	1.6
Wood		1.8		2.3	(1)		.5	4.6	3.7	4.6	3.7
Food						22.0		22.0	17.6	17.7	14.2
Subtotal	10.3	41.9	2.1	3.2	1.2	22.0	18.4	99.1	79.3	104.9	83.9
Yard waste								24.1	19.3	18.2	14.6
Miscellaneous inorganics								1.8	1.4	1.9	1.5
Total								125.0	100.0	125.0	100.0
Percent product source composition	3.2	33.5	1.7	2.6	1.0	17.6	14.7		79.3		83.9

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[1] Trace.

TABLE 2.—MUNICIPAL WASTEPAPER GENERATION, 1971

	Tons (millions)
Newspaper	9.7
Corrugated	13.2
Mixed office papers	9.1
Others	7
Total	39

TABLE 3.—SOLID WASTE GENERATION FROM MAJOR AGRICULTURAL CROPS (1966)[1]

Crop	Acres harvested (thousands)	Field waste load: Tons per capita per year	Field waste load: Million tons per year	Nature of waste
Corn, for grain	56,888	4.5	255,996	Leaves, stalks.
Wheat, for grain	49,843	1.3	64,796	Stubble.
Oats, for grain	17,848	1.8	32,126	Do.
Barley, for grain	10,226	1.8	18,407	Do.
Rye, for grain	1,283	1.3	1,668	Do.
Mixed grains	1,000	1.3	1,300	Do.
Rice	1,967	3.0	5,901	Do.
Flaxseed	2,627	.8	2,102	Leaves, stalks.
Alfalfa-clover seed	1,312	.8	1,050	Do.
Sorghum, for grain	12,837	3.0	38,511	Do.
Cotton	9,595	2.0	19,190	Do.
Beans, dry	1,519	2.0	3,038	Do.
Peas, dry	344	2.0	.688	Do.
Soybeans, for beans	36,644	2.0	73.288	Do.
Peanuts, for nuts	1,436	3.0	4.308	Do.
Potatoes	1,479	3.0	4,437	Leaves, vines.
Sweet potatoes	187	3.0	.561	Do.
Tobacco	967	.5	.488	Do.
Sugar cane, for sugar	630	.5	.315	Leaves, stalks.
Sugar beets	1,161	3.0	3.483	Leaves.
Vegetables	3,636	3.0	10,908	Leaves, stalks, culls.
Fruits, nuts	4,699	2.0	9.398	Prunings, leaves, culls.
Total	218,137	(2)	551.959	

[1] Does not include nonwaste producing crops such as hay, silage, etc.
[2] Pounds per capita: per year—5,520; per day—15.1.

TABLE 4.—SOLID WASTE GENERATION BY MAJOR FARM ANIMALS (1966)

Animal	Number farms (thousands)	Waste load (manure): Tons per unit per year	Waste load (manure): Thousand tons per year
Cattle	108,862	10	1,088,620
Hogs	47,414	8	379,312
Sheep	21,456	3	64,368
Horses, mules	(1)		
Poultry:			
Broilers	2,568,338	.0045	11,557
Turkeys	115,507	.025	2,883
Layers	339,921	.047	15,976
Ducks, etc	(2)		
Total			[3] 1,562,721

[1] No estimate since 1960.
[2] No estimate.
[3] Tons per capita per year— 7,814; pounds per capita: per year— 15,627.2; per day— 42.8.

TABLE 5.—MANUFACTURING AND CONSTRUCTION INDUSTRY SECTOR COMBUSTIBLE SOLID WASTE GENERATION, 1967[1]

OMB standard industrial classification codes and industry groups	Dry weight		Heat content	
	Thousand tons	Percent	Trillion Btu	Percent
MANUFACTURING				
20—Food and kindred products	714	2.3	11.9	2.2
22—Textile mill products, and 23—Apparel and other textile products	291	1.0	5.2	.9
24—Lumber and wood products, except furniture	15,807	51.7	307.1	56.0
241—Logging camps and contractors, and 242—Sawmills and planning mills	13,609	44.5	272.2	49.6
All other, 2400	1,743	5.7	34.9	6.4
25—Furniture and fixtures	455	1.5	9.1	1.7
26—Paper and allied products	10,156	33.2	152.6	27.8
261—Pulp mills	1,262	4.1	19.0	3.5
262, 3—Paper and paperboard mills	8,223	26.9	123.4	22.5
All other, 2600 industries	671	2.2	10.3	1.9
27—Printing and publishing	404	1.3	6.1	1.1
30—Rubber and plastics products	152	.5	3.9	.7
31—Leather and leather products	59	.2	1.2	.2
19, 21, 28, 29, 32-39—All other manufacture	1,210	4.0	25.4	4.6
Total, manufacturing	29,248	95.7	522.5	95.3
15, 16, 17—Construction industries	1,300	4.3	25.9	4.7
Grand total, manufacturing and construction	30,548	100.0	548.4	100.0

[1] Waste defined in net terms after industrial recycling, byproduct material recovery and byproduct energy recovery from gross residuals generations. Includes industrial process waste only.

Source: Compiled by Frank A. Smith, Resource Recovery Division, EPA, from industry computer printout tabulation in appendix A of International Research and Technology, Problems and Opportunities in Management of Combustible Solid Wastes. EPA Contract No. 68-03-0060.

BUMPER CROPS AND FOOD PRICES

Chairman PROXMIRE. Mr. Schertz, I want to thank you for your constructive statement. I am particularly pleased about your optimistic forecast about U.S. feed grain and feed crops for this year.

Could you tell us how the bumper crops will affect food prices?

Mr. SCHERTZ. You probably have noticed from comments from, perhaps, farmers in your own State that farm prices have already declined rather significantly, in anticipation of increased production and expected demand.

Chairman PROXMIRE. Furthermore, I notice in this morning's release we got from the Bureau of Labor Statistics that consumer prices went up number 0.6 of 1 percent, which is unhappy, but much better than we had before. One good element is that food prices declined.

Mr. SCHERTZ. That is right. That is good or bad, depending on the point of view. Some farmers, as you know, are quite disturbed with respect to some of those declines in prices.

We do anticipate that the increased production for wheat and feed grains and other crops that we see coming on this summer will continue to have some moderating influence on prices.

There is still considerable uncertainty with respect to the prospects of crops in other countries. The U.S.S.R. has increased acreage. However, we do not have an estimate with respect to their production levels. Many of us will be watching the Indian monsoon rather closely. The course of that rainfall will be very significant.

SIZE OF THE SOVIET GRAIN CROP UNKNOWN

Chairman PROXMIRE. What do we really know about the Soviet crop?

Is that not kept very secret? Is it not very hard for us to judge that? Is that not one of the reasons why it is hard to plan our own actions with respect to our own reserves and so forth?

Mr. SCHERTZ. It is, and this is one of the very real reasons why there was an agreement between the U.S.S.R. and the United States with respect to exchange of information with respect to the agricultural developments of our countries. That agreement called for, among other things, the exchange of information on forward estimates of food production and trade.

Last week we held consultations with the Soviets with respect to these matters. We still have a considerable way to go. However, they were very cooperative in the exchange and the discussions. There is great uncertainty about what the Soviet crop will be and then their decision, whether they will enter or not enter the international markets.

Chairman PROXMIRE. One of the reasons that we asked you to testify with this distinguished panel—and we are happy to have you because you are a distinguished expert in this area—many of us have had the feeling that the shortage that we suffered so severely from last year is not to be a long-term development. World demand for food is bound to increase, probably more rapidly than production, however ingenious and productive we may be. We have done marvelously well in American agriculture. We hope to spread some of that abroad, so that this process of recycling waste for animal food purposes seems to me is of greatest importance if we are going to meet our population problem and meet it in a compassionate way.

NATICK PROCESS SIGNIFICANT POTENTIAL FOOD SOURCE

Mr. SCHERTZ. I embrace the concept that there should be considerable research on this. At the present time, it would strike me that the price relationship, at least for farm products, and to the extent that I have been able to ascertain prices and the costs associated with some of these other products that we referred to is such that the farm products have the edge at the present time.

Now, at the same time, let me repeat: I very much embrace the notion of continual research on these other nontraditional forms of food.

Chairman PROXMIRE. Mr. Altschul, you said that the Natick idea is sound and eventually you think that it would be economically sound, but as yet it is not.

Is that correct?

You said that there are two things we have to overcome. One is the fractionation step, and the other was the esthetic problem. It seems to me the esthetic problem is solved to some extent by concentrating for the time being, because of the need, at the time being, of feeding this to animals, there is no esthetic problem there. As long as it is wholesome and sound, they do not care, the animals. I do not know anybody that would be so supersensitive as not to eat a good steak because the cow had eaten something that had been prepared from animal waste. You would not go that far with estheticism.

PROBLEM WITH NUTRIENTS FROM WASTE MATERIAL

Mr. Altschul. Actually, you have to be careful about toxicology too. In Japan, for example, where they had announced the development of a large-scale process for producing micro organisms from petroleum, they had to back down because the consumers were opposed to animals produced from these products, because they were afraid of toxic residues.

Chairman Proxmire. That is a proper concern. Everybody should be concerned. And if this is a concern that we can answer, if there are toxic problems involved, that is a good reason for persons not to consume it, let alone make it available. If there are not, it would seem to me that most people would be satisfied to consume an animal, whether there was a prospect that the animal in turn had consumed something that had been waste at one point.

Mr. Altschul. I think that is correct. The point that I want to reemphasize is that the process of conversion of cellulose to glucose eliminates the esthetic problem, because now you have a chemical. Then it can go in either direction, whether it is animals or humans.

Chairman Proxmire. That leaves us with a fractionation problem.

How long does that take?

Mr. Altschul. It is not a question of time so much as a matter of cost. At the present time, I do not think that the cost of producing micro-organism food is competitive with soy.

Chairman Proxmire. You say that the esthetic problem was met by the Natick process.

Mr. Altschul. Yes.

Chairman Proxmire. How about the fractionation problem?

Does that remain?

Mr. Altschul. We were talking about several steps. Let us take the steps in order.

We start with cellulose. Then you have an enzyme that is produced from a micro-organism. That enzyme converts cellulose to glucose Then you can go in a number of directions. You can go glucose to alcohol, and we discussed that; glucose to starch; that has not been discussed, but it can be done. Or you can grow micro-organisms on glucose. That is where the fractionation step would take place.

Chairman Proxmire. No fractionation problem with respect to fuel?

Mr. Altschul. No, sir.

Chairman Proxmire. No fractionation problem with respect to starch?

Mr. Altschul. No, sir.

FRACTIONATION IS A PROBLEM WITH RESPECT TO PROTEIN

Chairman Proxmire. Strictly with respect to micro-organisms, which is protein. Is that correct?

Mr. Altschul. The micro-organism would contain the nucleic acids, the cell wall material, limiting what can be eaten by humans, certainly, and perhaps by animals. It is common experience that although people have been trying to feed yeast to animals for 40 or 50 years, they have only succeeded in feeding small amounts, 2 or 3 percent, maybe up to 5 percent. The reason is that there are physiological effects that limit the amount that the animal can tolerate; hence the need for fractionation.

Chairman PROXMIRE. Are you aware of a factory in France that is producing 20,000 tons a year for animal feed?

Mr. ALTSCHUL. Yes, sir.

Chairman PROXMIRE. Not this process, but similar; not as economical as this process, but it is working there, feeding the animals there.

Mr. ALTSCHUL. What I have not heard is the concentration of the material in the diets fed to the animals. I have yet to see hard data; maybe you have some, Mr. Chairman.

Chairman PROXMIRE. We are working on that and trying to get it. I want to thank Mr. Sawhill.

HOW TO PROCEED WITH THE NATICK EXPERIMENTS

Let me ask you one further question before you leave. We heard extensive testimony here yesterday concerning the many significant offshoots that may result from the Natick experiment. The possible payoff to the country of an imaginative research and development of this area, I think, is staggering. Yet the Army still only provides meager sums to reduce the Natick process into practice. Mr. Spano, from the Army labs, calculated that $20 million would be needed to construct and design a plant for urban use.

Is that correct, Mr. Spano, to design a plant for urban use?

Mr. SPANO. I talked yesterday with regard to building a demonstration unit to handle 200,000 pounds per month. That would be about $3 million.

Chairman PROXMIRE. Then you went on to say that a plant for urban use—I thought you said $12½ million in present dollars.

Mr. SPANO. I estimated, for a plant to handle 500 tons per day of trash.

Chairman PROXMIRE. About $20 million in 1977 dollars?

Mr. SPANO. Yes.

Chairman PROXMIRE. Considering, Mr. Sawhill, the probable high cost of the R. & D. and its far-reaching effects, it is essential that the most effective way to proceed with this R. & D. effort be determined. Therefore, what do you believe to be the most effective way to proceed with the research on the Natick process and reducing it to commercial practice?

Mr. SAWHILL. The first step should be a feasibility study which we will do and present it to the committee in connection with the Environmental Protection Agency. Some of the things that we will consider in that study will be the collection system itself and the amount of fuel used in the collection system, and the design of the plant, and the heat input in that plant, to assure ourselves that we look at the net energy gained from this process rather than the gross energy gained.

Once we can satisfy ourselves that it appears to be economically feasible and that, in fact, we do have net energy gain, which is a concept that, I think, would not only be in this plant but oil shale and the other things we are looking at, I think the next step would be to come to the Congress, perhaps with a request for a supplemental appropriation to move toward the pilot plant stage. It seems to me that this is something that we should do in a pilot plant and then a demonstration plant. I think that would be the procedure that we would follow.

Chairman PROXMIRE. The pilot plant would cost something like $2½ million, $3 million. That, of course, is a relatively modest amount. It is not a small amount by any means, but compared to the possible potential benefits, it seems to me it is highly feasible.

Thank you very, very much, Mr. Sawhill. I appreciate that very much.

Mr. Train, would you like to add anything to that, how we might proceed on that?

Mr. TRAIN. I think that Mr. Sawhill has set out a good progression for both of our agencies in working together to approach this project. We will coordinate closely with FEO and move ahead and provide a joint report to the committee as rapidly as we can.

The one uncertainty in my mind as to a timetable here is to what extent the data is available which will permit the kind of feasibility study that Mr. Sawhill discussed. I am personally not familiar with how far along the project is and to what extent we will be dealing with theoretical data or data actually based upon application.

Chairman PROXMIRE. I think the Natick study is most impressive. I will be very anxious to get your reaction. The study will be very helpful in ascertaining that.

In your prepared statement, Mr. Schertz, the nontraditional approaches with availability to food and single cell protein appears very far down on your list on the ways to proceed to meet our needs.

How familiar is the Department of Agriculture with the Natick process and its implications for single cell protein production, and what other methods of manufacturing these food substances and how significant do you feel this approach is?

Mr. SCHERTZ. As I mentioned to your staff, Mr. Chairman, I am not associated with the production research side of the Department of Agriculture. My area of expertise is in the economic area, and particularly with respect to the world's food situation and the relationships related thereto.

I do understand that the Agriculture Research Service has done some research with respect to the utilization of plant waste of agriculture, and, as one of the other speakers mentioned, they are giving further consideration to undertaking some activity with respect to animal waste. I frankly do not know how acquainted they are with the specifics of the Natick process.

DEPARTMENT OF AGRICULTURE VERY INTERESTED IN PROTEIN DERIVED FROM THE NATICK CELLULASE PROCESS

Chairman PROXMIRE. I want to get into that, because you work in the Department of Agriculture. I come from a State with a lot of farms. The Agriculture Department has traditionally viewed its role as one of supporting farm production and farm income. It is a proper role and continues to be proper and necessary.

I wonder if these nontraditional approaches to food production, such as making single cell proteins, may be viewed in your agency as somewhat alien, a potential threat to farm income, or somehow not very important because it is not the kind of activity that directly benefits farmers. Could you comment on this?

Mr. SCHERTZ. I would suggest, sir, that the Department's role has, as you outlined it, been very much in support of U.S. agriculture. At the same time, it is of extreme importance in that consideration to have full knowledge of alternative problems that are related to agriculture and substitutes for agriculture products. So consequently, the attitude in the Department has been of great interest and of great investigations regarding alternative products, because they are of importance to our primary clients, the farmers.

I would also want to mention, Mr. Chairman, that being third on that list of important things to do with respect to the world food situation, should not be interpreted to mean that it is not important. The fifth one is probably of primary importance in terms of food production in low-income countries because, quite frankly, we do service to the lower income countries when they recognize that 99 percent of the resources at their disposal are resources that they have. Assistance can only do very little, and how they use those resources with their policies and their programs will make the difference, whether they make it or whether they do not make it in terms of food production. So I would ask you not to infer priorities with respect to those five, as to one, two, three.

Chairman PROXMIRE. Mr. Train.

Mr. TRAIN. I would just like to add, Mr. Chairman, that EPA has had some projects in the area that you have referred to. I am not closely familiar with them; I know we can supply more information for the record.

We have had at least one project involving the production of single cell protein from bagasse, the sugarcane waste. I believe this was a project in Louisiana. And we also have had a number of projects involving utilization of animal waste, particularly feedlot waste, in the production of methanol and other fuels. Obviously, also, they are used for fertilizers. And we are also aware—I am not sure we have had any projects in this area—of the research being done in the utilization of animal waste for the production of protein feed for animals.

[The following information was subsequently supplied for the record:]

UTILIZATION OF FIBROUS WASTES AS SOURCE OF NUTRIENTS

Dr. James M. Leatherwood	Grant No.: EC 00274-03
Department of Animal Sciences	Funds Awarded: $80,555
North Carolina State University	Project Period: Feb. 1, 1968, to Jan. 31, 1972
Raleigh, North Carolina 27607	

Objectives: To develop a biologic technique for the conversion of natural cellulosic wastes to products that can be utilized as nutrients by animals.

Findings: Cellulose-utilizing bacteria were isolated from natural habitats of sewage, rumen, and soil and from cellulose enrichment cultures. The effects of pH, temperature, substrate composition and concentration, and other environmental factors on the effective level of cellulolytic activity was determined.

Small fermenters (700-ml Kelly infusion bottles) were used to study parameters of fermenter operation. Cotton linters were used as substrate and *Ruminococcus albus* was used as the hydrolytic agent in a semi-continuous operation with a cycle every 3 to 5 days. Fermenter effluents were analyzed for volatile fatty acids, bacterial protein, soluble carbohydrates, and total organic matter. Gas analysis from the fermenter showed considerable hydrogen production. Methanogenic bacteria were added to the system to remove the hydrogen, a possible inhibitor.

PHOTOSYNTHETIC RECLAMATION OF AGRICULTURAL SOLID AND LIQUID WASTES

Dr. William J. Oswald Sanitary Engineering Research Laboratory University of California-Berkeley Berkeley, California 94720	Grant No.: EC 00272–03 Funds Awarded: $93,838 Project Period: June 1, 1967 to May 31, 1970

Objectives: To study the application of an integrated system involving an anerobic digestion phase and an algae production phase to the disposal of agricultural wastes, especially animal manures, and to the reclamation of the plant nutrients and water contained in the waste.

Findings: A plant consisting of a digester, algae pond, equipment for harvesting algae, and necessary ancillary equipment was assembled at the University of California, Richmond Field Station. Animal wastes were fed to a 150-gal concrete anaerobic digester and fermented. The effects of solids content, pH of the waste, temperature, detention period, loading, and method of operation on the digestion process were determined with animal wastes. Wastes are characterized not only on the basis of origin but also on that of C/N ratio, nitrogen content, pH, and total and volatile solids content. The digester was operated both as a batch process and as a continuous process to determine digestion efficiencies under both conditions. Digester performance was judged on the basis of gas production, extent of volatile solids destruction, pH, volatile acid concentration of the sludge, and the physical characteristics of the sludge.

The effluent from the digester was fed directly into a 5,500-gal variable-depth algae pond. The effects of temperature, detention time, culture depth, mixing time, type of waste effluent, and CO_2 concentration on algae growth were determined. The performance of the pond was evaluated on its overall conversion efficiency and by its effluent quality after the algae had been removed.

An analysis of the integrated system indicated that biological activity in the sedimentation tank, digester, and algae pond decreased the total solids by 60 percent; the volatile solids by 62 percent; the total unoxidized nitrogen by 45 percent; and the energy input (exclusive of light) by 56 percent.

An economic evaluation based on an integrated system of 100,000 egg layers and the application of the *low loadings* and the *high cost* and *overdesigned* components used in the research indicated that the waste-handling costs of the system would be at the most 2 cents per dozen eggs. If the value of the algal crop were credited to the operation, the net waste-handling cost would be 1 cent or less per dozen eggs.

BIOLOGICAL CONVERSION OF ANIMAL WASTES TO NUTRIENTS

Dr. Byron F. Miller Department of Poultry Science Colorado State University Fort Collins, Colorado 80521	Grant No: EC 00262–02 Funds Awarded: $41,634 Project Period: June 1, 1968 to May 31, 1970

Objectives: To investigate the digestion of poultry manure by flies and establish husbandry procedures for caring for fly larvae on a manure medium. To measure changes accomplished in poultry manure by these organisms, and their efficiency. To determine the value of the protein material as a feed stuff for poultry.

Findings: Fresh raw poultry manure was "seeded" with fly eggs to convert the manure energy into useful animal protein. Samples of the manure were analyzed for composition and nutritive value before and after digestion with fly larvae. Environmental conditions such as temperature, moisture content of the manure, humidity, and ratio of eggs to manure conducive to optimum conversion of the manure to pupal protein were studied. The protein material was analyzed for nutritive content, metabolizable energy, and ability to support growth in young chickens.

The fly larvae effectively reduced the problem of manure disposal by eliminating 60 percent of the moisture and 80 percent of the organic matter during the digestion period. In addition, the wet, pasty, odoriferous manure was converted to a granular, stabilized, inoffensive product that was easily dried.

About 2 percent of fresh manure weight was harvested as dried fly pupae. These pupae contained 60 percent protein, comparable to fish meal as a protein supplement for starting chickens.

A poultry operation of 40,000 laying hens would produce 1,600 lb of dried fly pupae daily. At a price of 10 cents/lb, this would amount to $160/day. In addition, the manure residue could be used as fertilizer.

Feeding trials with growing broiler stock indicated that pupal protein could be used readily as the primary protein supplement in broiler diets.

RECLAMATION OF ENERGY FROM ORGANIC REFUSE

Dr. John T. Pfeffer	**Grant No: EC 00364-01 R 800776**
Department of Civil Engineering	**Funds Awarded: $74,000**
University of Illinois	**Project Period: Aug. 1, 1969 to Jan. 31, 1973**
Urbana, Illinois 61801	

Objectives: To determine the operating parameters for the biologic conversion of organic solid waste to methane by use of anaerobic digesters. To evaluate the potential operating problems associated with the proposed process and determine the potential for energy reclamation.

Findings: The effects of operating temperatures, retention times, and solids content were determined and related to the energy yield from the methane fermentation, the reduction in quantity of organic refuse, and the characteristics of the residue.

Shredded domestic refuse from which the inorganic fraction was separated was used as a substrate. Raw sewage sludge was added to the substrate in proportion to the rate at which it is produced by a population producing a given quantity of refuse. The quantity and quality of gas produced, the rate of gas production, the solids reduction, nutritional requirements and operating problems were evaluated in a laboratory system operating at temperatures ranging from 35°C to 60°C.

The results of the laboratory study together with published data on both capital and operating costs of refuse shredding, refuse separation, reactor volume, reactor mixing, reactor heating and residue dewatering were used to analyze the economics of the process. This analysis indicated that methane can be produced by anaerobic fermentation of organic refuse at a cost that would permit the sale of the gas at a competitive price.

The investigation is continuing under the support of the National Science Foundation. Allis-Chalmers, Inc., and Waste Management, Inc. have proposed a pilot-plant project (based on the laboratory work done by Dr. Pfeffer) to the City of Milwaukee, Illinois, that would generate 1500 ft^3/d of methane from one-half ton of municipal solid waste.

DEGRADATION OF WASTE PAPER TO PROTEIN

Dr. David M. Updegraff	Grant No: EC 00271-02
Denver Research Institute	Funds Awarded: $165.160
University of Denver	Project Period: June 1, 1967 to May 31, 1970
Denver, Colorado 80210	

Objectives: To evaluate a fermentation method of converting waste paper to a protein supplement for livestock feed, the specific objective being to obtain an extremely fast-growing, cellulose-digesting organism having a high nutritional/protein value.

Findings: The initial effort included isolation and screening of microbes to find suitable strains for rapid digestion of cellulose in a water medium enriched with hydrocarbons, oxygen, and nitrogen.

Myrothecium verrucaria gave the highest rates of protein synthesis of the fungi studied; therefore, scaled-up studies using 14-liter stirred-jar fermenters concentrated on this organism. Protein yield on ball-milled newspaper increased with substrate concentration up to the maximum used. A very simple medium containing dibasic ammonium phosphate, urea, and yeast autolysate proved optimal for protein synthesis and cellulose utilization. At a concentration of 4 g ball-milled newspaper per 100 ml medium, the maximum rate of cellulose consumption was 5.4 g per liter per day and the rate of protein systhesis was 0.3 g per liter per day. The maximum yield of protein obtained was 1.42 g/liter by a highly specific modified Biuret method, or 3.3 g/liter by the usual method of multiplying the total organic (Kjeldahl) nitrogen by 6.25. The amount of cellulose consumed under these conditions was 12.7 g/liter from an original 20.4 g/liter contained in 40 g/liter of ball-milled newspaper.

Chemical analysis of the dried final product indicates it may be a nutritious animal feed. The work accomplished was not sufficient to permit the design and construction of a pilot plant.

SINGLE-CELL PROTEINS FROM CELLULOSIC WASTES

Dr. Clayton D. Callihan
Department of Chemical Engineering
Louisiana State University
Baton Rouge, Louisiana 70803

Contract No: PH-86-68-152
Grant No: EC 00328-02
R 800696
Funds Awarded: $500,000
Project Period: March 1, 1969 to April 28, 1973

Objectives: To isolate and identify cellulose-digesting organisms, to study the growth of these organisms in the presence of cellulose, and to investigate the optimal conditions for enzyme production during growth of the various cellulosic wastes.

Findings: A continuous chemical-microbial plant was designed and constructed at NASA's Mississippi Test Facility for the production of single-cell protein. The process consists of an initial size reduction unit, a mixing area where the cellulosic wastes are pretreated with sodium hydroxide, an oxidation step whereby the lignin is deploymerized, a sterilization step, an acid neutralization step, and finally fermentation. The untreated whole cells, disrupted cells, and various protein fractions derived from the cell were evaluated both chemically and biologically.

When bagasse, the residue from sugar cane after the sugar is extracted, is used as the sole carbon source for the growth of *Cellulomonas*, a yield of 20 lb of cell product is obtained for each 100 lb of feed. About 50 percent of the bagasse is cellulose. Approximately 75 to 80 percent of this cellulose is solubilized by the microorganisms. Of this 37.5 to 40 lb of cellulose consumed from the initial 100 lb, about 50 percent is used to satisfy the metabolic requirements of the living cells. The remainder is converted to cell mass.

The harvested cells are about 50 percent protein. The amino acid analysis shows that this protein is high in lysine and other essential amino acids that are usually deficient in vegetable proteins. A favorable comparison of the amino acid pattern of *Cellulomonas* with the ideal amino acid profile recommended by FAO was obtained.

The economic feasibility of producing proteins from the cellulosic portion of urban solid waste appears comparable with argicultural wastes. An independent process cost analysis revealed that the final crude protein could be produced at a cost of about 13 cents a pound. The process is now under commercial development by the Bechtel Corporation.

Chairman PROXMIRE. Mr. Altschul, I want to thank you very much. I understand you interrupted your vacation to testify this morning. I am deeply appreciative of the sacrifice that represents and the value placed on the hearings, obviously, in the implication of your willingness to do that.

Would you describe for us some of the gains that have been made in the manufacture of protein substances, such as single cell protein, some of the problems particularly in the direct human consumption of these substances?

Can you tell us briefly what is being done here and abroad and whether you believe the state of technology has yet been reached so that large-scale production of these foods can begin?

May I ask whether you are familiar with that factory in France that I mentioned before of single cell proteins being produced on a large scale and being fed to cattle for protein?

PROBLEMS WITH FOOD FROM THE CELLULASE PROCESS

Mr. ALTSCHUL. Let me talk about two things. First, what can you do to find other sources of feed for animals? Of course, this has the biggest potential for microbial protein. The problem that is more challenging, perhaps, is what can you do to feed humans directly with new sources of food?

In that case, you have two problems. One, a nutritional problem: Is it possible to develop materials that are alternative to our conventional foods and have equal nutrition? And second, there is an esthetic problem of trying to put these in forms that people like.

I think it can be said that the nutritional problems that we know of have been solved: It is possible to develop, for example, completely nutritious materials from vegetable sources; these can be used to feed people from infants to the very aged.

The esthetic problem was a difficult one, and that has been solved in part. If I might take a second to tell you about it, Mr. Chairman, the problem was to make materials that had muscle-like properties, because that is the esthetic quality of meat. This was done by spinning and extrusion techniques that have been developed in the last 25 years, but the greatest spurt was within the last 5 years. It is possible to extrude vegetable materials such as soy protein to provide the chewiness in the mouth that one expects when one eats food on a meat model.

As I said in my testimony, these developments are making considerable progress. There has been one estimate that by 1980, 10 to 20 percent of the meat equivalent in the United States will be from these products. That is quite a lot of meat that is being displaced. In that connection, my own estimate has been that 50 percent of the processed meats including hamburgers would be of these materials. Another estimate was that where the vegetable protein sales were $100 million in 1973 in the United States, these will increase to $300 million by 1976, and $1½ billion by 1980. I am talking about products made from soy, primarily.

Chairman PROXMIRE. Those are interesting statistics economically. Obviously, you can meet the objections you might have from an agricultural vested interest, because you have such a vast market you are not going to be able to meet it anyway. This is simply going to supplement and make it possible to come up with some assistance of meeting a situation that goes from $100 million to $300 million to $1 billion in 5 years.

Mr. ALTSCHUL. When you talk about microbial proteins, we are not sure about the problems of nucleic acids, cell wall material, what the various fractions will be. There has been some progress in producing specific chemicals by fermentation. For example, you can make lysine, which is an amino acid, by fermentation. This might be a more practical thing than trying to sell the microbial protein. We have not solved the nutritional problem and the possibility for texturizing these materials to make them esthetically acceptable.

Chairman PROXMIRE. Let me read to you from a bulletin issued in 1972, 2 years ago. It said:

> In December of 1972, British Petroleum France's Capitavera plant began delivery of biosynthetic protein from petroleum and petroleum byproducts and mixed feed manufactured under the brand name Proteina. Although annual production from this pilot plant will not meet its full capacity.

This was 2 years ago; they have reached it by now.

> The decision purportedly has already been made to build a larger plant with an annual capacity of 100,000 tons. The synthetic product is a tasteless, odorless powder which contains about 70 percent protein, or about 1.6 times the 44 percent protein content in soybean meal, and 80 percent more protein than fish meal.

The source was a U.N. protein advisory group bulletin.

Then in addition, the protein advisory group of the United Nations system, dated June 8, 1973, reports as follows:

> The discussion of the ad hoc working group at the Cambridge meeting indicated two conclusions: (*a*) A variety of safe, palatable, nutritious and economically feasible SCP products can be developed for human consumption; (*b*) not all of the SCP products that meet all of the requirements were used in animal feeding will also be found suitable for human food use.

SCP, of course, is single cell protein.

Mr. ALTSCHUL. You are asking me to comment on those statements?

Chairman PROXMIRE. Yes.

Mr. ALTSCHUL. As I said earlier, I have not been able to find hard data on the percentage of these microbial protein products incorporated into animal feeds. Until we know those data, one would have to be a bit skeptical about the statements.

As far as human consumption, I have talked to the leading food manufacturers here and abroad. I have yet to find anyone that feels that microbial protein has reached anywhere near the stage of being considered for human consumption.

Chairman PROXMIRE. I think, again, that is right, but I think the human consumption is a marvelous possibility, but the animal consumption is something else. It is being sold; it is practical there. There is no question it is being used. The amount is very important. We do not have that.

I would like to ask Mr. Schertz if he could tell us whether the Department of Agriculture can get us that data?

Mr. SCHERTZ. We will inquire whether we can.

Chairman PROXMIRE. Will you let us know what the results are one way or the other?

Mr. SCHERTZ. I will.

There is one other point of information you may be interested in. Again, it is an activity on which we have very, very sketchy information. But the U.S.S.R. does have a plant on the Volga River using a process similar to the British Petroleum process. The amount of production, et cetera, that they are generating and the use of that product we do not know.

FOOD FROM THE NATICK PROCESS CAN BE FED TO ANIMALS

Mr. ALTSCHUL. I am convinced that ultimately this material will be fed to animals. My question is, how much will it cost for fractionation, to prepare it to be fed to animals?

Chairman PROXMIRE. Can you make an estimation of how long it will be before it is practical to have production for animals?

Mr. ALTSCHUL. Well, at the moment, the guess is that it will move slowest in the United States. The reasons are that it will take a long time for any of these to compete effectively with soy as a source of animal protein. The other countries are moving ahead much faster because they need alternate sources.

Chairman PROXMIRE. That is a proper observation up until now. But if the Natick breakthrough is what we think it is, based on the observation we have, might that not change the situation? The cost one-fifth of what it was—why would that not make it more possible, practical?

Mr. ALTSCHUL. I do not think the cost of the raw material is going to make proportionately that much difference in the ultimate cost of the final product.

Chairman PROXMIRE. The equipment for processing is very cheap, cheaper than building an incinerator to burn it.

Mr. ALTSCHUL. I do believe that when you have a negative price of raw material——

Chairman PROXMIRE. You are awfully close to that here.

Mr. ALTSCHUL. That is right. When we get to that point, I think it will become economical in the United States.

Chairman PROXMIRE. It is really a matter of conceiving these pilot plants.

Mr. ALTSCHUL. No question.

POLICY ADVICE TO AGENCIES INVOLVED WITH THE NATICK EXPERIMENTS

Chairman PROXMIRE. What policy or practical programs would you recommend for the Department, in connection with other agencies?

Mr. ALTSCHUL. First of all, I think it is quite obvious that we ought to know exactly what the problems are in going ahead with this process. Second, I mentioned it in my testimony, and that is, when you have a new product for human foods, there are a number of legal problems and regulatory problems that make it difficult to introduce these new human foods into the American market. The committee may wish to discuss the problems that have taken place up until now when new foods have been introduced.

Chairman PROXMIRE. Mr. Train, we are going to have a roll-call, so I will just take a short time with these two questions I have for you.

We discussed municipal waste. Now should we not also discuss other sources of waste? We learned yesterday that far more animal waste in feed lots and agricultural waste has accumulated than municipal waste. I cited some figures in my opening statement regarding agricultural waste from the corn crop alone.

As head of the Environmental Protection Agency, do you not view these sources of waste as significant parts of your responsibility, and does not the Natick recycling process appear to be a possible, partial solution to the problem?

Mr. TRAIN. As to the first, yes. As to the second part of the question, possibility. I am not sure. The answer would depend upon further feasibility studies.

Let me add that any conversion of waste to useful products tends to have very substantial environmental advantages in terms of the saving of national resources. The reduction of the municipal solid waste problem, the preservation of air and water quality and open space for landfill. I take that all for granted, although the actual benefits in this respect can vary from process to process. The real question comes down to the practicalities in terms of technology, and the economics of the particular process. That is the reason why my statement concentrated on technology and economic practicality, rather than more specifically on the environmental benefits, which would obviously be very real if the economic and technological questions can be resolved.

Chairman Proxmire. In your statement, you talk about the cultivation of agricultural products for the purpose of ethanol extraction. You said that would require radical restructuring of our agricultural and industrial makeup before ethanol could be a significant energy source. Of course, the phrase, radical restructuring, can be construed by some people as kind of scare language to frighten people away from considering the proposal. We are not talking about cultivating corn or any other crops so as to convert it into ethanol. We are talking about recycling waste. Do you believe that recycling waste, as envisioned by the Natick process, would require a radical restructuring of our agricultural and industrial makeup?

Mr. Train. No.

Chairman Proxmire. That is good to hear, because I think that is what we primarily have in mind. It has been helpful.

I want to thank you, Mr. Train, so much; Mr. Schertz, and Mr. Altschul, and Mr. Bradow, for your appearance. It was most helpful and useful, and I hope that my questioning and occasional adversary position can be regarded as simply a difference of opinion on some of the approaches, and not in any way any disrespect. I have the greatest admiration and respect for the marvelous job you are doing.

I want to thank you for a fine job today. The subcomittee will stand in recess until tomorrow, when we meet in room 1318 of this building, to hear Mr. Jerry Berger of the Shell Oil Company and Mr. Dayton Clewell of the Mobil Oil Company, and Ralph Nader and Clarence Ditlow of the public interest research group on the same topic.

[Whereupon, at 12 noon, the subcomittee recessed, to reconvene at 10 a.m., Wednesday, May 22, 1974.]

NATIONAL PRIORITIES AND FEDERAL RESEARCH AND DEVELOPMENT PROGRAMS

WEDNESDAY, MAY 22, 1974

Congress of the United States,
Subcommittee on Priorities and
Economy in Government of the
Joint Economic Committee,
Washington, D.C.

The subcommittee met, pursuant to recess, at 10:25 a.m., in room 1318, Dirksen Senate Office Building, Hon. William Proxmire (chairman of the subcommittee) presiding.

Present: Senator Proxmire.

Also present: Richard F. Kaufman, general counsel; Larry Yuspeh, professional staff member; Michael J. Runde, administrative assistant; George D. Krumbhaar, Jr., minority counsel; and Walter B. Laessig, minority counsel.

Opening Statement of Chairman Proxmire

Chairman Proxmire. The subcommittee will come to order. I want to apologize for being late. Unfortunately I had a speech scheduled from a week ago on the floor of the Senate, and I was hping that they would come in earlier so that I could get the speech out of the way and be here at 10 o'clock. But the Senate convened at 10, and there were earlier statements by the leadership before I appeared. So this has had to be delayed unfortunately. And I do apologize to the witnesses.

The scientific breakthrough made at the Army's Natick Laboratory is one of the most encouraging signs I have seen in the past several years. The successful enzymatic conversion of waste materials containing cellulose into glucose is an important discovery. The way this discovery was made demonstrates that significant progress can and is being made through the Federal Government's in-house research program. The Government is often criticized for spending the taxpayers' money in foolish ways. Often the criticism is deserved. Here is an outstanding example of the productive use of public resources.

The discovery itself, I am convinced, will, if properly implemented, have major consequences. The recycling of waste so as to produce storable raw materials which can be used to manufacture fuel, food, and other substances can contribute to the solution of several of the Nation's problems.

The question is, how to proceed from here? The scientists at Natick have so far performed their work on what can be fairly described, relative to other Government programs, as a shoestring. There is a question about how much more money the Army may be willing to invest in this project. I have brought the Natick work to the attention of several Government Agencies—the Federal Energy Administration, the Environmental Protection Agency, the Department of Agriculture, and the National Science Foundation, among others—and I intend to continue reminding them of their responsibilities to support worthwhile research in this area. I am hopeful that one of the results of these hearings will be a concerted effort on the part of one or more of the civilian agencies to build on the Natick efforts.

The Army, of course, is to be commended for what has been accomplished so far. I would like to see the Army continue to fund this project and to expand it. The Army has its own solid waste disposal and energy problems. In 1972, 500,000 tons of trash were accumulated at Army bases located in the United States. The Defense Department consumes about 650,000 barrels of oil each day.

I am writing to the Secretary of the Army and the Secretary of Defense to formally request that a pilot demonstration plant for the conversion of waste and the production of ethanol be constructed on an Army base. The funds required to build such a plant are modest by Federal standards. We were told that a pilot plant could be built for a few million dollars. The payoff could be enormous, worth many times the cost of the capital investment.

Our witnesses this morning include spokesmen for two of the major oil companies. We invited five companies to appear before us. Exxon at first agreed to testify then, 1 day after a group of Exxon officials visited the Natick lab and were briefed on the process, that company changed its mind and said it would file a written statement[1] rather than make a personal appearance. Texaco also agreed to file a written statement.[2] Gulf told us it had nothing to contribute.

We are very pleased that Shell Oil Co. and Mobil Oil Co. agreed to participate in our inquiry. As two of the principal energy producers for the Nation they undoubtedly have a deep interest in potential new sources of fuel.

We are also delighted that Ralph Nader and Clarence Ditlow have agreed to join us. Mr. Nader has testified many times before congressional committees and several times before this committee. He is one of the most versatile and insightful experts I have ever known and has been a great aid to our work and that of many other committees.

Mr. Berger of Shell will begin, followed by Mr. Clewell of Mobil, Mr. Nader and Mr. Ditlow, and then we will get into the questioning.

Gentlemen, I want to do everything I can to bring out all the facts. If you want to call on any experts that you have with you at anytime in any way, please feel free to do so.

If you want to supplement your responses to questions with any kind of a later submission of evidence, we will be delighted to have that. We want to get at the facts as thoroughly as we can. And you are among the top experts in the Nation, and capable of providing the facts. So go right ahead, Mr. Berger.

I might say that we hope that where you can do so, if you have detailed prepared statements, that you will summarize so that we can get to the questioning as rapidly as possible, and the entire prepared statement will be printed in full in the record.

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[1] See Exxon's statement, beginning on p. 225.

[2] See Texaco's statement, beginning on p. 229.

STATEMENT OF JERRY E. BERGER, RESEARCH AND DEVELOPMENT DEPARTMENT, SHELL OIL CO.

Mr. Berger. Thank you, Senator Proxmire.

My name is Jerry Berger. I work in the Research and Development Department of the Shell Oil Co. My responsibilities there are in the area of automotive fuels and automotive emissions.

I am very grateful for the opportunity to testify before this committee today on the subject of alcohols and gasolines. Earlier this week we submitted to the committee a prepared statement which I will try to summarize now in a few words. If appropriate, we request that this prepared statement be made a part of the record.

Chairman Proxmire. Yes, the prepared statement will be printed in full at the end of your oral statement.

Mr. Berger. In our prepared statement we considered both methyl alcohol and ethyl alcohol. We considered methyl alcohol because recent developments promise to make large quantities of this material available for fuel use.

We considered ethyl alcohol because some recent work at the Natick laboratory indicates that large volumes of this material may be available from cellulose.

During the next few minutes I would like to discuss briefly the following topics: the technology of blending and using alcohol and gasoline, and the technology of alcohol production and handling. And I would like to make a few comments about economic considerations. And finally, I would like to make some recommendations which we in Shell believe would help to alleviate the short-term energy dilemma.

With regard to the technology of blending and using alcohol and gasoline, this technology is known. Several countries in the world now blend ethyl alcohol and gasoline. And generally these are the countries that have a shortage of petroleum and an abundance of grain or sugarcane. Alcohols have been little used in this country because in the past they have been too expensive, and because there was no clear-cut technical advantage to warrant their inclusion in gasoline.

There are some theoretical advantages associated with blending alcohol and gasoline. The volume of the gasoline pool, of course, will enlarge to the degree that you add alcohol to it. Alcohols have high-octane numbers, and so blending alcohols into gasoline could provide higher octane fuel without additional refining investments. This could permit the engine manufacturers to return to higher compression ratios.

This engine design change in turn would recover some of the lost efficiency and the lost fuel economy which has resulted during our ongoing evolution toward the nonpolluting engine.

With regard to emissions from alcohol-gasoline blends, the data are rather ambiguous. Some recent findings from the EPA in March of this year indicate that with blends of methyl alcohol and gasoline, carbon monoxide emissions are reduced, nitrogen oxide emissions are reduced, but emissions of unburned hydrocarbons increase, as methyl alcohol is added to gasoline.

There are some disadvantages to blending alcohol and gasoline. These disadvantages depend to some extent on the alcohol selected, and its concentration in gasoline.

With regard to the methanol case, methanol is sparingly soluble in gasoline. Furthermore, blends of methyl alcohol in gasoline are sensitive to small amounts of water. Ordinarily there is no problem associated with the traces of water which are introduced either accidentally or unavoidably into our gasoline.

With blends of methyl alcohol and gasoline, however, small amounts of water cause the blend to become unmixed, and you get two liquid layers. We believe this sensitivity to water would cause many problems.

The ethyl alcohol case is different, because the ethyl alcohol-gasoline blends are more tractable. The solubility of ethyl alcohol in gasoline is greater. Furthermore, blends of ethyl alcohol and gasoline are more tolerant to traces of water. Probably no carburetor adjustments are required for automotive engine so long as the concentrations of ethyl alcohol in gasoline remain at a modest level. Hence we in Shell believe that ethyl alcohol could be used as a blending component for gasoline, and that the resulting blend could be distributed and used without undue problems.

Concerning the technology of producing and handling alcohols. I would like to mention that one of the promising new sources of methyl alcohol is the natural gas which is now burned in flares in the north African and Persian Gulf countries.

Initially it was proposed to liquefy this natural gas and transport it in cryogenic tankers to market in the United States, Europe, or Japan. The principal disadvantage with this strategy is the high cost of shipping since the shipping costs go up dramatically as distance increases. Hence it now appears more attractive to convert the natural gas to methanol at its source and transport the methanol in ordinary tankers to the market.

Coal also can be converted to methanol using known technology. This concept has general Government approval. The Bureau of Mines, for example, is seeking to have a 5,000-ton-per-day demonstration plant built, and they have urged that construction in this plant start at once, so that it can be on stream by 1978.

Grain fermentation has been mentioned from time to time as a source of alcohols. These suggestions have been made less frequently in recent years, because the grain surplus has diminished sharply. Shell would not support the construction of any new large-scale facilities for diverting large quantities of grain foodstuffs into fuel.

In the past, because of the costs that are involved, and because of a lack of clear-cut technical advantages, fuel related applications of ethyl alcohol have not received as much attention as those of methyl alcohol. The Natick research developments may change this.

I would like to say a few words about economic considerations. We believe that the motorist is not concerned so much with cents per gallon as with cents per mile of travel. Mileage depends on the heat of combustion per unit volume of fuel. The higher the heating volume, the higher the miles per gallon. Methyl alcohol, for example, has one-half the heating value of an equal volume of gasoline. Hence 1 gallon of methyl alcohol will propel a car about half the distance that a gallon of gasoline will. Therefore, as far as the motorist is concerned, the break-even point will occur when methyl alcohol is at half the price of gasoline.

Concerning the ethyl alcohol case, ethyl alcohol has two-thirds the heating value of gasoline for an equal volume. Hence a gallon of ethyl alcohol can propel a car about two-thirds the distance possible per gallon of gasoline.

For the motorist the break-even point will occur when the price of ethyl alcohol is about two-thirds the price of gasoline.

We believe that the costs of blended fuels in alcohol and gasoline should be adjusted to reflect this reduction in miles per gallon.

Finally, I would like to offer our suggestions. We believe the following: Energy self-sufficiency is the national goal to which we are committed. Hence we believe that all reasonably alternative energy sources should be scrutinized rigorously and quickly. For this reason we are gratified with the promising leads in cellulose hydrolysis which are being pursued by scientists at the U.S. Army Natick Laboratory.

In theory their work will force the opportunity to attain valuable energy form in a convenient form from a plentiful and renewable raw material. Simultaneously society's solid wastes disposal problem could be partially resolved.

The successful applications of this exciting new technology is not likely to be quick or easy, however. This opinion is not intended to detract in any way from the important progress the Natick research has achieved. We would be remiss in failing to point out, however, some practical considerations which undoubtedly have received a great deal of attention and thought from the Natick staff.

Materials handling and plant size were two factors which deserve brief mention. We have made some very rough estimates based on preliminary data, and these rough estimates are presented only to convey a quantitative concept of the magnitude of the venture involved.

The production of a large volume of ethyl alcohol—for example, the volume equivalent to 10 percent of our current gasoline supply—will require processing of about 220 million tons of cellulose wastes handling annually.

Furthermore, in producing this volume of ethyl alcohol, if a 5 percent glucose syrup emerges from the hydrolysis step, the volume of liquid handled will be twice that of the entire domestic petroleum refining industry.

These comparisons are made only to emphasize that cellulose hydrolysis is not likely to be a quick or easy solution to our energy dilemma. A whole new segment of the transportation industry must be organized, and very large plants will need to be built.

With regard to more immediate steps for our energy self-sufficiency, we believe that there are actions which should be taken simultaneously to the further development of cellulose-based ventures.

For example, we recommend the conversion of some stationary combustion installations to coal. This recommendation is based on our belief that technology exists for the removal of sulphur oxide in the stack gases for coal-fired boilers. The substitution of coal for the currently used liquid petroleum fuels will allow the displaced petroleum fuels to be diverted to refining operations for the production of such things as gasoline or home heating oil. This strategy will utilize the energy content of coal directly without the necessity of waiting for coal conversion plants to be built.

I would like to augment my prepared statement at this point by acknowledging that the long-term reliability of sulphur oxide removal processes has not been demonstrated. However, it is our belief that the technology for sulphur oxide removal will be reduced in practice, and that the time required to bring this about will be less than the time required for large scale ethanol production via cellulose hydrolysis.

Further in the future, we expect that methanol will become available from coal conversion. Such an energy supply will be an important and valuable source. But we recommend against its use in gasoline, because it is our considered judgment that such a move would result in diverse and widespread problems for motorists. Rather, we would recommend that supplies of methanol be utilized in stationary sources where the advantages of methanol can be exploited fully. This fuel switching could be brought about in such a manner to divert additional petroleum feedstocks to the manufacture of derivatives such as gasoline.

Ethanol, ethyl, alcohol, if available in large quantities, could be employed without undue problems in motor fuel. We believe that Shell will be ready to make whatever adjustments are required when that material becomes available for fuel applications.

Thank you for your kind attention and for the opportunity to address this point.

Chairman PROXMIRE. Thank you very much, Mr. Berger, for an excellent statement.

[The prepared statement of Mr. Berger follows:]

PREPARED STATEMENT OF JERRY E. BERGER

ALCOHOLS IN GASOLINE

TECHNOLOGY OF BLENDING MOTOR FUELS CONTAINING ALCOHOLS

The technology of preparing motor fuels composed of alcohols or gasoline/alcohol blends is a known process. Since the very early development period of the internal combustion engine, alcohol or alcohol-containing gasoline blends have been used to a limited extent as fuels. Despite the fact that gasoline/alcohol blends never have been employed to a significant extent in the U.S., some countries have relied on such blends to a major degree at various times in the past. In general, ethyl alcohol has been the preferred alcohol for inclusion in gasoline and its use has depended on special circumstances such as a shortage of domestic petroleum and an abundance of grain or sugar cane which served as raw material for ethanol production. Except for racing cars (which sometimes use "pure" methyl alcohol), alcohols have been little used as a fuel component in this country because historically the cost of alcohols has been relatively high and because clear technical advantages for alcohol blends were lacking.

Blending gasolines and alcohols for motor fuels has several advantages. Obviously, the volume of the total gasoline pool will grow to the extent that alcohols are added to current gasolines and this appears to be an attractive strategy for enhancing the supply of a fuel which now is projected to remain in short supply. In addition, alcohols have high octane numbers as shown in the following table:

Fuel:	*Research octane number*
Methyl alcohol	106.0
Ethyl alcohol	106.0
Premium gasoline[1]	99.3
Regular gasoline[1]	93.5
Unleaded gasoline[1]	91.7

[1] U.S. average values, summer 1973.

These data suggest that inclusion of alcohols in the unleaded grade of gasoline, for example, could provide higher octane numbers without additional capital investments in refining equipment. This change would permit automakers to build engines with higher compression ratios, a design change which would recover some of the efficiency and fuel economy losses which have accompanied the evolution toward non-polluting engines.

Another advantage of alcohols as a motor fuel concerns their latent heat of vaporization which is quite high in comparison to that of gasoline. The practical impact of this fact has to do with the degree of cooling which accompanies fuel evaporation in the carburetor and the induction system of an engine. This evaporative cooling is greater in the case of alcohols than with gasolines and as a consequence the volumetric efficiency of the engine improves when alcohol is present as a fuel component. Changes in exhaust gas composition also can accompany the use of alcohol as a gasoline blending component although the experimental results germane to this question depend to a significant degree on whether carburetor adjustments are made at the time alcohol is added to the gasoline. Some recent test results (March 1974) obtained by personnel at the EPA's Ann Arbor, Michigan facility are summarized as follows:[1]

Fuel	Emissions in grams per mile			MPG
	HC	CO	NO_x	
Unleaded gasoline	1.92	13.1	3.56	12.3
Unleaded gasoline plus 7 percent methanol	2.12	8.6	2.72	11.5
Unleaded gasoline plus 11 percent methanol	2.24	7.7	2.39	11.3

These data were obtained with a 1970 Chevrolet powered by a 350 CID engine operating under conditions of the 1975 Federal Test Procedure; the carburetor was not adjusted between tests of different fuels. Note that blending methyl alcohol into the gasoline produced significant reductions in exhaust emissions of carbon monoxide and nitrogen oxides but that hydrocarbon emissions increased. Fuel economy, as measured by miles-per-gallon, decreased as alcohol was added to the fuel in this test program.

Using methanol only as a fuel in a 1970 American Motors Gremlin equipped with a heated intake manifold, a modified carburetor with a heater, a catalytic muffler and air-injection, Adelman, Andrews and Devoto at Stanford University achieved exhaust emissions results which were very low.[2]

Experimental results for emissions produced by gasoline/ethanol blends are ambiguous and less complete than those relating to methanol as a blending component. Provided that appropriate carburetor adjustments are made when switching fuels, Lichty and Phelps showed that CO emissions were unchanged with gasoline blends containing up to 20 percent ethyl alcohol.[3] Morriss found no large differences in hydrocarbon or nitrogen oxide emissions with gasoline blends containing up to 30 percent ethyl alcohol.[4]

There are some practical disadvantages associated with using gasoline/alcohol blends and these disadvantages depend to some extent on the identity of the alcohol selected for use and on its concentration in the fuel blend.

Considerable attention has been devoted recently to the possible use of methyl alcohol as an ingredient in motor fuel. This attention has been due to the expectation that large volumes of methanol might soon become available as a derivative of coal or as a convenient liquid fuel synthesized from Mid-East flare gas. Despite the publicity that gasoline/methanol blends have commanded recently, there is one major drawback to the distribution and dispensing of such fuels. The disadvantage is related to the fact that methyl alcohol is sparingly soluble in gasoline. For example a saturated solution of anhydrous methyl alcohol in regular grade gasoline at 0° Fahrenheit contains only about 4 percent by volume

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[1] "Effects of Methanol-Gasoline Blends on Emissions', Test and Evaluation Branch, Emission Control Technology Division, EPA, Ann Arbor, Michigan, March, 1974.

[2] H. G. Adelman, D. G. Andrews and R. S. Devoto, "Exhaust Emissions From A Methanol-Fueled Automobile, Society of Automotive Engineers Paper No. 720693, August 21, 1972.

[3] L. C. Lichty and C. W. Phelps, "Carbon Monoxide in Engine Exhaust Using Alcohol Blends." Ind. Eng. Chem., 29, 495 (1937).

[4] F. V. Morriss, R. Modrell, G. Atkinson and C. Bolze, "The Exhaust Content of Automobiles Burning Ethanol-Gasoline Mixtures," ACS Meeting Preprint No. 77, September, 1955.

alcohol. At 60° Fahrenheit, about 13 percent by volume methanol can be dissolved in gasoline.

The presence of even small amounts of water in contact with a gasoline/methanol blend causes the blend to separate into two liquid layers. Small quantities of water can be introduced accidentally or unavoidably during distribution and marketing of motor fuel and while these quantities rarely cause problems today, the situation with gasoline/methanol blends is sufficiently delicate that we would anticipate many problems. Among the methods for coping with such a sensitive fuel blend are the following: (a) devise and implement an anhydrous distribution/marketing system, and (b) incorporate additives to improve the solubility of methanol in gasoline. Alternative (a) would entail additional costs which probably would far outweigh any potential savings accruing from the use of methyl alcohol; option (b) might also result in costs sufficient to erase whatever benefits might have been predicted.

Other adverse side effects have been observed in cars operating on gasoline/methanol fuel mixtures. These adverse effects include rusting of fuel tanks, corrosion of copper, aluminum or magnesium components and the deterioration of some elastomers.

A disadvantage of using "pure" methanol as automotive fuel is associated with the rather extensive carburetor and induction system modifications which would be required to enable a car to operate on this fuel. Additional segregated distribution facilities would be required if such cars come into widespread use by the public. These factors suggest that if "pure" methanol is deemed essential as a motor fuel, perhaps fleet operations (e.g. taxicabs) would offer the preferred mechanism for minimizing disruptions.

A minor disadvantage to the use of methanol as a single-component automotive fuel is that methyl alcohol has only about half the heating value for a given volume of fuel as does gasoline. Hence, the miles-per-gallon achieved with gasoline will be twice that obtained with methanol. Fuel-tank sizes could, of course, be enlarged to maintain constant cruise distance capabilities.

Blends of gasoline and ethyl alcohol are more tractable than gasoline/methanol mixtures. The solubility if ethyl alcohol in gasoline is greater and the resulting blends are more tolerant of traces of water. It seems likely that the distribution and marketing of motor fuels containing modest quantities of ethanol could be handled without undue difficulty; carburetor adjustments probably would not be required so long as the ethyl alcohol component remained at 10 percent volume or lower.

TECHNOLOGY OF PRODUCING AND HANDLING ALCOHOLS

The lower members of the alcohol family have been articles of commerce for many years and handling them entails no undue risks. Toxicity is a factor, but alcohols are less hazardous than many other common substances and the precautions required for safe operations involving alcohols are well known.

Among the promising "new" sources for methanol is the natural gas which is currently being burned in flares in North African and Persian Gulf countries. Initially it was proposed to liquefy this gas and transport it via cryogenic tankers to markets in Europe, North America or Japan. The principal disadvantage of this strategy is the high cost of shipping natural gas in the liquid form; shipping costs depend strongly on distance and these costs become the single most important factor for long trips (e.g. Persian Gulf to Europe or the U.S. via Cape of Good Hope). In a recent study of the available alternatives, Dutkiewicz concluded that importing methanol from the Persian Gulf to the U.S. will be more economic than liquefied natural gas.[5] This avenue would require the construction of methanol-producing plants at the source of the natural gas; shipping of the methyl alcohol could be accomplished using conventional tankers.

While the projected costs associated with ocean transport of liquefied natural gas cintinue to rise, the economics for methyl alcohol production have improved due to lower-pressure catalytic processes which are amendable to large-scale installations. Such a combination of circumstances may result in the availability of relatively large volumes of imported methanol which can be employed in a variety of applications. One possibility was tried successfully at a power generating facility in New Orleans.[6] In this experiment an impure form of

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[5] B. Dutkiewicz. "Methanol Competitive With LNG On Long Haul", Oil and Gas Journal, p. 166, April 30, 1973.

[6] "Methanol-Alcohol Fuel Gets New Orleans Tryout", Oil and Gas Journal, October 9, 1972.

methyl alcohol, dubbed "methyl fuel", was used as fuel and it proved to be a viable alternative to other conventional boiler fuels.

Due to the growing shortage of natural gas in the U.S., it is unlikely that domestic gas will be converted to methanol. On the other hand, our coal reserves are large and proven technology exists for the conversion of coal to "synthesis gas", the feedstock for methanol production. This general concept has government support, and the Bureau of Mines has stated that construction of a 5000 ton/day methanol demonstration plant should be started at once. If construction begins now, the demonstration plant could be operational in 1978. A successful demonstration project could lead to major construction programs in this area and this new manufacturing equipment could produce sufficiently large volumes of methanol to permit significant applications as fuel by the mid-1980's.

Large-scale fermentation of grain has been suggested from time to time as a mechanism for producing ethanol and simultaneously reducing grain surpluses. Such proposals have not been made frequently in recent years because the ethyl alcohol produced in this manner continues to be costly relative to gasoline and because the grain surpluses have diminished sharply in recent years. Shell would not support the construction of new, large-scale processes which would divert large quantities of grain foodstuffs into fuel. Furthermore, even if it is assumed that large quantities of ethyl alcohol were available, the inclusion of this material in motor fuel has offered no compelling technical or economic incentives or economic incentives in the past.

For these reasons, fuel-related applications for ethanol have not received the attention that methanol has in the past. Recent progress by scientists at the U.S. Army's Natick Laboratories may change these circumstances and focus attention on ethyl alcohol derived from cellulose. Should it prove feasible to reduce these developments to practice, it is Shell's opinion that we will be able to respond in a timely fashion in order to utilize additional ethanol supplies as they become available.

ECONOMIC CONSIDERATIONS INVOLVING ALCOHOL/GASOLINE BLENDS

In comparing the costs of various alcohols and gasoline/alcohol blends, it is important to keep in mind that the car owner is not concerned with cents-per-gallon per se, rather he is concerned with cents-per-mile-traveled. Mileage depends chiefly on the heat of combustion per unit volume of fuel: The higher the heating value of a fuel, the higher will be the observed MPG. Methyl alcohol, for example, has one-half the heating value of an equal volume of gasoline; hence, a gallon of methanol will propel a car about half the distance achieved with a gallon of gasoline. Under such circumstances and with other factors held constant, the "break-even" point for a motorist will occur when the price of methanol is half the price of gasoline. Ethyl alcohol has two-thirds the heating value as an equal volume of gasoline and hence gallon of ethanol will enable a car to travel two-thirds the distance obtained with a gallon of gasoline. Some illustrative examples of fuel economy for gasoline/ethanol blends are shown in the following table:[7]

Fuel:	*Relative MPG (road tests)*
100 percent gasoline	100.0
10 percent ethanol, 90 percent gasoline	98.3
20 percent ethanol, 80 percent gasoline	96.0
30 percent ethanol, 70 percent gasoline	93.3
100 percent ethanol	68.0

Costs of alcohol/gasoline fuels should be adjusted to reflect the reduction in heating value which accompanies blending. For example, Appendix I shows that a blend of 90% volume gasoline and 10% volume ethanol offers little saving to the consumer when ethanol is priced at 20 cents per gallon and gasoline is priced at 31 cents a gallon. Excluding taxes, the price of the blended fuel required to travel the same distance would be 30.9 cents compared to 31 cents for gasoline. This calculation simply verifies that ethanol and gasoline are at the "break-even" point (other factors being equal) when the price of a given volume of ethanol is two-thirds the price of an equal volume of gasoline. If gasoline prices rise, or if

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[7] "Use of Alcohol In Motor Gasoline—A Review", API Publication No. 4082, August, 1971.

ethanol prices fall, the economic incentive will favor the use of ethanol as motor fuel component.

In this connection, it is of interest to inquire briefly into the economics of imported methanol synthesized overseas from natural gas. In a paper delivered last year, Dutkiewicz[7a] made the following estimates (based on 1972 dollars) for methanol landed on the east coast of the U.S.:

Source:	*Landed costs (cents per gallon)*
Persian Gulf	8.0
North Africa	7.0
Venezuela	6.7

Soedjanto and Schaffert have published independent studies which are in close agreement with these values.[8] We wish to emphasize that these estimates depend strongly on raw material costs and shipping costs; we are unable to predict the extent to which these factors will change in the future.

It is of interest to note that similar projections have been made for methanol derived from domestic coal deposits.[9] These estimates envision a selling price of about 8 cents per gallon for the alcohol mixture emerging as the end product of coal gasification. This selling price does not include transportation or distribution charges. For comparison, the price of methanol got as low as 9 or 10 cpg for large quantities f.o.b. Gulf Coast sources in late 1971 and early 1972. The average price for methanol produced and sold in the U.S. during 1972 was 18.3 cpg.[10] Current prices for large contract purchases of methanol are around 26 cpg f.o.b. Gulf Coast plants, but spot purchases have, on occasion, involved prices three to five fold higher.

It is Shell's belief that future energy sources will tend to equilibrate at price levels determined chiefly by the energy content of that fuel (albeit with some degree of penalty or premium attached to fuels which are difficult to handle or especially clean, etc.). It is instructive to apply this concept to the methanol *vs* ethanol case in order to obtain a qualitative estimate of what ethanol price would be equivalent to 8 cent-a-gallon methanol which might become available from coal or foreign natural gas. Since the heating values per unit volume for methanol and ethanol are in the ratio of 1:1.33, it follows that ethanol at about 11 cpg is equivalent in price to methanol at 8 cpg. This cursory comparison assumes that all other factors are constant.

DISCUSSION AND RECOMMENDATIONS

Energy self-sufficiency is a national goal to which we are committed. Hence we believe that all reasonable alternate energy sources should be scrutinized vigorously and with a speed which is limited only by the prudence required to avoid serious errors. For this reason we are gratified with the promising leads in cellulose hydrolysis which are being pursued by scientists at the U.S. Army Natick Laboratories. In theory, their work affords the opportunity to obtain valuable energy supplies in a convenient form from a plentiful and renewable raw material. Simultaneously, society's solid-waste disposal problem could be partially resolved by this process.

The successful application of this exciting new technology is not likely to be quick or easy, however. This opinion is not intended to detract in any way from the important progress the Natick research has achieved. We would be remiss in failing to point out, however, some practical considerations which undoubtedly have received a great deal of attention and thought from the Natick Laboratory staff. Materials handling and plant size are two factors which deserve brief mention. Appendices II and III contain some rough estimates based on preliminary data which are presented only to convey a qualitative concept of the magnitude of the venture involved.

Note in Appendix II that the production of a large volume of ethanol (equivalent to 10 percent of our current gasoline supply) will require processing about 220-million tons of cellulosic waste annually. In terms of tons of mate-

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[7a] See footnote 5.

[8] P. Soedjanto and F. W. Schaffert, "Transporting Gas—LNG vs. Methanol", Oil and Gas Journal, June 11, 1973.

[9] "Outlook Bright for Methyl-Fuel", Environmental Science and Technology, 7, 1003 (1973).

[10] T. B. Reed and R. M. Lerner, "Methanol: A Versatile Fuel for Immediate Use", Science *182*, 1299 (1973).

rial handled, Appendix III reveals that this level of ethanol production would involve handling the same mass of material as that handled by 18 large petroleum refineries. If a five percent glucose syrup emerges from the enzyme hydrolysis step, the volume of liquid handled will be twice that of the entire domestic petroleum refining industry. These comparisons are made only to emphasize that cellulose hydrolysis is not likely to be a quick or easy solution to our energy dilemma: A whole new segment of the transportation industry must be organized and very large plants will need to be built. Capital requirements for a successful commercial venture remain unknown and we will look forward to learning of estimates based on the pilot plant project underway now.

With regard to more immediate steps toward energy self-sufficiency, we believe there are actions which should be taken simultaneously with the further development of cellulose-based ventures. For example, we recommend the conversion of some stationary combustion installations to coal. This recommendation is based on our belief that technology exists for removal of sulfur oxides from stack gases of coal-fired boilers. In this regard we agree with a January 1974 EPA report which concludes that the problems associated with flue gas cleanup have been solved and that reliable methods are available.[11] The substitution of coal for currently-used liquid petroleum fuels will allow the displaced petroleum fuels to be diverted to refining operations for the production of additional home-heating oil, gasoline, etc. This step utilizes the energy content of coal directly without the necessity of waiting for coal gasification plants to be built; capital investments will be minimized. It is our belief that time and capital needs will be smaller for installation of stack gas cleanup equipment than for coal conversion plants.

Further in the future, we expect that methanol will become available from coal conversion. Such an energy supply will be important and valuable but we recommend against its use in gasoline because it is our considered judgment that such a move would result in diverse and widespread problems from motorists. Rather, we recommend that supplies of methanol be utilized in stationary sources where the advantages of methanol can be exploited fully. This fuel switching could be conducted in such a manner to divert additional petroleum feedstocks to the manufacture of derivatives such as gasoline.

Ethanol, if available in large quantities, could be employed without undue problems in motor fuel. We believe that Shell will be ready to make whatever adjustments are required when that material becomes available for fuel applications.

APPENDIX I. COST COMPARISON: GASOLINE VERSUS GASOLINE/ETHANOL

Assumptions:

1. Ethanol at 20 cents per gallon at the refinery.
2. Gasoline at 31 cents per gallon at the refinery.[12]
3. Heating value of ethanol is 0.67 that of gasoline.
4. A fuel of 90% v gasoline and 10% v ethanol is desired.
5. Automobile fuel economy is proportional to heating value of the fuel.

Cost of gasoline/ethanol fuel:	*Cents*
0.9 gallon of gasoline	27.9
0.1 gallon of ethanol	2.0
Total	29.9

However, this gallon of fuel blend has a lower heating value than gasoline and hence an automobile will not travel as far on a given volume. To correct for lost MPG, it is necessary to divide by 0.967, viz: 29.9 cents over 0.967 equals 30.9 cents.

APPENDIX II. ORDER-OF-MAGNITUDE SIZE COMPARISONS

Assume: It is desired to blend all U.S. gasoline with 10% v ethanol. Ten percent of current gasoline volume is equivalent to about 10-billion gallons of gasoline annually; because of the lower heating value of ethanol, about 15-billion gallons of ethanol would be required annually in order to furnish equivalent energy.

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[11] "National Public Hearings on Power Plant Compliance With Sulfur Oxide Air Pollution Regulations", Report of the Hearing Panel, EPA, January, 1974.

[12] Based on recent spot purchases of regular and premium gasolines (Oil and Gas Journal, May 13, 1974).. Taxes not included.

Assume[13]: One ton of wastepaper produces 0.5 ton of glucose which will yield 68 gallons of ethanol.

Hence: The target ethanol production will require hydrolysis of 220-million tons of wastepaper per year, or about 1 ton per capita in the U.S. This is equal to the entire refuse production in the U.S.

APPENDIX III. MATERIALS HANDLING COMPARISONS

1. Consider a "large" refinery whose daily crude oil intake is 250,000 barrels. This volume is equivalent to about 12-million tons per year. Reference to Appendix II indicates that annual refuse-handling requirements are about 18-fold greater in order to produce ethanol equivalent to 10 percent of current gasoline volume.

2. Assume[14] : Hydrolysis of cellulose waste produces a 5% glucose syrup, and assume further that 15-billion gallons of ethanol is the desired annual production.

Hence: This level of alcohol production will require 220-billion pounds of glucose annually. With a 5% aqueous syrup, about 34- million barrels of syrup would require handling each day. For comparison, the U.S. petroleum refining capacity is somewhat less than half that volume.

Chairman PROXMIRE. Mr. Clewell, please proceed.

STATEMENT OF DAYTON H. CLEWELL, SENIOR VICE PRESIDENT, MOBIL OIL CORP., AND PRESIDENT, MOBIL RESEARCH AND DEVELOPMENT CORP., ACCOMPANIED BY DONALD P. HEATH, MANAGER, FUELS, ENERGY, AND AVIATION PRODUCTS

Mr. CLEWELL. Senator Proxmire, my name is Dayton Clewell. I am a senior vice president of Mobil Oil Corp., and president of Mobil Research & Development Corp.

My colleague with me today is Donald P. Heath of Mobil's Corporate Products Department. Mr. Heath is manager of fuels, energy, and aviation products.

We appreciate your calling our attention to the work being done at the Army laboratory at Natick, and we also appreciate this opportunity to comment on the potential of ethanol and other supplementary forms of energy. In these times of high prices and energy shortages, no promising lead or development should be overlooked.

Mobil research people have been familiar with the use of ethanol as a gasoline supplement for many years, because this use has often been suggested as a means of working off the country's surplus grain production. But the cost has been high, and the technical problems have been numerous.

Today we still have a number of technical problems. But gasoline prices have risen very steeply, and the Nation is running into tremendous balance-of-payments deficits. The supply of domestic crude oil cannot meet the demand.

With all these new forces at work, the oil companies would not be doing their job if they were not involved in developing supplemental or alternate sources of energy.

Mobil, for example, has spent several million dollars on tar-sands and oil-shale research over the past decade or more. In the early 1960's, we managed the operation of an experimental oil-shale retort near Anvil Points, Colo., using shale from a Mobil mine. The Depart-

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[13] M. Mandels, J. Nystrom, L. A. Spano, "Enzymatic Hydrogsis of Cellulosic Wastes", U.S. Army Natick Laboratories, Natick, Massachusetts, March, 1974.

[14] M. Mandels, J. Nystrom and L. A. Spano, "Enzymatic Hydrolysis of Cellulosic Waste", U.S. Army Natick Laboratories, Natick, Massachusetts, March, 1974.

ment of the Interior and five other oil companies cooperated in this pioneering program.

Today we are a member of another group which is supporting a company called Paraho, Inc., in testing an improved method for retorting shale.

Another area of particular interest to us is the liquefaction of coal. Our research people are working on a long-range project to develop a practical, economical method for converting coal into gasoline.

Large-scale production of gasoline from such alternate sources as shale and coal will take time to achieve. Shale technology is the most advanced, but our best estimate is that total U.S. production of shale oil may reach only about 500,000 barrels a day by 1985. That would meet perhaps 2 percent of our total oil needs in that year.

Under the best of conditions—the rapid completion of the Alaska pipeline, for example, and the accelerated leasing of offshore areas—the United States will continue to depend on foreign sources of conventional crude oil. We expect, in fact, to see imports increase during the years just ahead.

Thus, the United States has a great need to augment its domestic supplies of liquid hydrocarbons. Crude oil will continue to be the primary source for the foreseeable future. But unconventional sources, including solid waste as well as coal and shale, could yield substantial volumes. Transforming the organic content of solid waste into useful products would not only augment our supplies of fuels and chemical raw materials, but also would help solve the nationwide problem of waste disposal.

On May 8, four of our research people, including a microbiologist, visited the Army Laboratory at Natick. They were impressed with the work underway.

As you know, the Army research people have isolated a mutant of a type of fungus that was first found on a rotted cartridge belt in New Guinea. The fungus, in essence, changes the cellulose in organic wastes into glucose. The glucose could then be fermented into ethyl alcohol, or ethanol.

The new fungus is reported to work about four times as fast as older strains. Speed is essential in this type of process, since the faster the transformation, the smaller the size and cost of the processing facilities.

The Natick people have a pilot plant under construction, and believe they can reach an output of 2,000 pounds of glucose a month. This should give them enough experience to make a more thorough evaluation of the project.

We recommend this work be pursued. It appears that a promising start has been made, and that the results so far merit continuing development.

We believe that long-range research programs like this should be sponsored by the Government, whether the actual work is performed in Government, industry, or university laboratories. When the commercial stage is reached, private industry should assume the responsibility. If the commercial venture is high risk, and is considered to be in the national interest, some kind of further Government support may be needed.

Now for the economics of using ethanol as a motor fuel. It is too soon for detailed studies, we believe, but a look at current prices might be helpful.

First we need to make an adjustment for energy content. Since ethanol does not contain as much energy as gasoline, the motorist would have to buy 1.3 gallons of ethanol to equal the mileage of 1 gallon of gasoline. At the April retail gasoline price of about 52 cents, ethanol would have to sell for 40 cents to give the consumer the same energy value.

The retail price includes two elements which we could assume would apply to either fuel. These include an average of 12 cents a gallon for tax, and 10 cents for the service-station dealer's markup.

Deducting these elements from the retail price of 52 cents for gasoline gives us a price of 30 cents to the dealer. Deducting the same elements from the retail price of 40 cents for ethanol gives us a dealer price of 18 cents.

If the Federal and all the State Governments were to adjust their taxes to allow for the lower energy value of ethanol, the total tax would be about 9 cents for ethanol, and the dealer price would be 21 cents a gallon instead of 18 cents.

In sum, ethanol would have to be priced in the range of 20 cents a gallon or less to the dealer in order to equal today's retail gasoline price. This 20 cents would have to include manufacturing cost plus associated costs such as blending, storage, and transportation. And here I would like to add to the statement that these associated costs might be roughly offset by the value of the octane boost that can be gotten from methanol if in fact the boost can be utilized.

In considering the use of ethanol as a motor fuel, we must take its chemical properties into account. Ethanol differs from gasoline in a number of ways. Its lower energy content is one example. Carburetors would have to be modified to get the proper air-and-fuel mixture, since a greater volume of fuel would be entering the carburetor.

Years ago, gasoline blends with over 20-percent ethanol were used in some countries. But today's cars with their complex and delicate emission-control systems, have far less tolerance for ethanol and would need to be modified if more than about 5 to 10 percent ethanol were used. This would be expensive for existing cars.

New cars could be engineered to run on 100-percent ethanol, or on any specific blend. But we would then have at least two breeds of cars on the road—those that operate only on blends up to 10 percent and those that operate only at some higher blend.

Ethyl alcohol has a remarkable affinity for water. It would separate out of the gasoline and seek the water that is always found at the bottom of storage tanks. So unless we took unusual and expensive precautions, much of the ethanol would remain in the distribution system and never reach the customer.

Ethanol presents a number of other problems, but we believe they could be solved if necessary. Gasoline, for example, could be reformulated and engines modified to compensate for the hard starting and frequent stalling that could result from using ethanol blends.

It should be noted that adding 10-percent ethanol to gasoline would require more ethanol than could be made from solid waste in the foreseeable future.

According to a 1972 Bureau of Mines report, the Nation's readily recoverable urban refuse includes about 71 million tons of dry organic material per year.

Chairman PROXMIRE. Will you give us for the record the precise page that you are talking about, the page and so forth?

Mr. CLEWELL. Yes, sir.

I think that is in attachment 1 which we submitted with this statement.[1]

If all of the cellulose in this material were converted into glucose and then into ethanol, the yield of ethanol would be about 18 million tons. This equals about 4 percent of the current total gasoline demand. Other wastes which are readily recoverable, but at a cost, could double this year to about 8 percent. This would represent an important addition to fuel supplies.

Cellulose can, of course, be used for other purposes. One interesting alternate is to use the solid waste directly as fuel. In St. Louis, for example, Union Electric Co.—working with the city and with the EPA—has been operating a 300-ton per day plant since April 1972. Solid waste is shredded, separated from steel cans and other materials that can be recycled, and burned at a powerplant with pulverized coal.

The first plant has been so successful that Union Electric now plans to build a much larger facility, which is expected to be economically self-sufficient. The company then will be using virtually all of the solid waste in the St. Louis metropolitan area, and will receive a dumping fee for disposing of the waste. It will generate about 6 percent of its total power from energy recovered from solid waste.

Last week, the State of Connecticut announced plans to build 10 regional centers for processing all of the State's trash. The metal and glass will be recycled. The combustible material will be used for generating electricity.

Using trash directly as a fuel would be more efficient than first converting it into ethanol. That's because some of the energy content is consumed in each processing operation. Thus, the Nation's total energy picture would be improved more by direct burning of solid waste than by making ethanol. The tight supply of liquid hydrocarbons, however, might more than offset this consideration.

Trash also can be converted into a material similar to crude oil without going through the glucose process. The Bureau of Mines has had such a project underway in a laboratory near Pittsburgh for several years.

Another alternative would be to use the glucose generated in the Natick process as animal feed. As the research people at the Natick Lab have pointed out, the crude syrup can be concentrated to a molasses for feeding animals or adding to silage. The glucose also can be used as a base for processing into protein.

Still another alternative would be to utilize ethanol as a chemical building block. It already is in demand as an industrial solvent, and could be converted into many useful products, including gasoline components.

Solid waste is a renewable, domestic resource with many alternative uses. We feel that the best approach would be to continue an aggres-

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[1] See attachment 1, p. 195.

sive research program—including the project now underway at the Natick Laboratory—aimed at sorting out the alternatives that would be most economical and most useful to the Nation.

I am attaching for the record reports on the utilization of alcohol in motor gasoline and on the availability and alternate uses of waste materials.

Now, I would be glad to answer any questions.

Chairman Proxmire. Thank you, Mr. Clewell.

[The reports referred to follow:]

Use of Alcohol in Motor Gasoline— A Review

AUGUST, 1971

The Committee For Air and Water Conservation

AMERICAN PETROLEUM INSTITUTE

Publication No. 4082

Use of Alcohol in Motor Gasoline—A Review

At the request of the Committee for Air and Water Conservation the Engineering and Technical Research Committee commissioned a special task force to complete a state of the art study on the use of alcohol in motor gasoline. The task force members and authors of this report are:

Chairman: J. G. Keller - Humble Oil & Refining Co.
W. H. Douthit - Sun DX Oil Co.
W. C. Long - Chevron Research
H. R. Taliaferro - American Oil Co.

USE OF ALCOHOL IN MOTOR GASOLINE – A REVIEW

Abstract

Consideration of the use of ethyl alcohol in gasoline blending has been reviewed. It has been concluded that such usage would not be attractive today based on the effects on emissions, octane quality, engine performance, and unfavorable economics.

Ethyl alcohol has been reported to have high blending octane values when rated in the single cylinder laboratory ASTM Research and Motor engines. These high blending octane values have not been observed with alcohol blends in multicylinder engines. As with many high octane blending components, the benefits of alcohol diminish as the octane number of the base fuel increases. The addition of alcohol will not provide the octane improvement that can be obtained more economically from lead alkyls or processing.

The effect of alcohol blends on engine performance has been studied extensively and reported in the literature. The disadvantages documented in the past are still applicable today. Most important are the loss in mileage, poor warmup under cool temperature driving conditions, and a deterioration in driveability or engine response. This latter effect is particularly critical in the 1968 and later model vehicles which use lean carburetion as one of the principal means of reducing exhaust emissions. Extra handling care must also be exercised to prevent water contamination in alcohol-gasoline blends. Small concentrations of water cause the alcohol phase to separate, and this increases the adverse effects on engine performance.

The literature clearly shows that alcohol-hydrocarbon fuel blends have emission characteristics similar to pure hydrocarbon fuels when tested with the same percent theoretical oxygen. Under these test conditions the hydrocarbon, carbon monoxide, and nitrogen oxide contents of the exhaust emissions for conventional and alcohol fuels are the same, while the aldehyde and unburned alcohol content would be higher for the alcohol blends.

The economics of blending alcohol in gasoline remain very unfavorable. The current cost of producing a gallon of ethyl alcohol from grain is significantly greater than its value as a blending agent in gasoline. The total net cost of a 10 percent alcohol blending program to U.S. motorists would vary from about 2.7 to 5.8 billion dollars per year depending upon the price paid for grain, e.g. $1.00 to $1.50 per bushel, and upon the type of grain used, either corn or wheat. Reductions in crop storage expense and payments for diverted acres under the present farm support program would offset only a small part of this cost.

The blending of methyl alcohol in gasoline has also been reviewed to provide further information on the characteristics of alcohol-gasoline blends. Thus, some discussion of methyl alcohol appears in the report.

USE OF ALCOHOL IN MOTOR GASOLINE – A REVIEW

Table of Contents

Introduction

From time to time in the United States, proposals have been made, for various reasons, to use alcohols in motor gasoline as blending components. Primarily, the main interest has been on the part of the agriculture industry to promote the use of ethyl alcohol manufactured from grain. Once again, this interest has been evinced in Congress and in several of the large grain producing states, mainly because of the trend to the reduced use of lead compounds as antiknock agents and the purported beneficial effect of alcohol on automotive exhaust emissions.

Thus, this study treats of the available data on the use of grain alcohol - or ethyl alcohol - or ethanol - in motor fuel. However, because of closely allied studies, some attention will also be given to methanol. The study reviews available information on the history, antiknock quality, engine performance and fuel economy, emissions, economics, and several other important considerations.

History of Alcohol Blends in Motor Gasoline

There is considerable history of the study of the use of alcohols in motor gasoline either as an additive to impart special properties such as icing protection or as an octane improving agent. In fact, alcohols can be and have been used "straight" as motor fuels without any blending with other components.

Almost since the invention of the Otto cycle engine (the basic gasoline burning internal combustion engine as we know it today), alcohol has been considered as a fuel for this engine. A review of available literature and information indicates that, although perhaps not without some degree of difficulty, alcohol and alcohol blends can make very acceptable fuels. Most of these difficulties could probably be overcome, although not economically, with the application of modern technology.

Since 1921, several well-known investigators and authors (1) have published articles on use of alcohol in motor fuel. Ethanol has been used in many foreign countries from time to time, including Austria, Brazil, Cuba, Czechoslovakia, England, France, Germany, Hungary, Ireland, Italy, Latvia, Poland, Spain, Sweden and Yugoslavia. In general, however, economic considerations have worked against any wide-spread use of ethanol in motor fuel. And for the most part, in countries where it has been used, it has received special economic attention as an incentive to its use. In addition, in Europe, where there is little native crude oil, there was an incentive to conserve petroleum supplies in the event of a war which might cut off overseas' sources. In the long term, though, without price or tax supports or other economic incentive, ethanol (either from grain or from synthetics) has never been an economical substitute for motor fuel constitutents derived from petroleum refining.

In the United States, the first real incentive to the use of ethanol in motor fuel occurred with the passage in 1906 of the Industrial Denatured Alcohol Act, which freed ethanol from a tax whenever it was to be used for industrial purposes (1,2). Since that time, numerous government agencies and others have worked on the idea of using alcohol in motor fuel. These have included the U.S. Department of Agriculture, the Bureau of Mines, the National Bureau of Standards, engineers of the automotive industry, motor fuel chemists of the petroleum industry, and technical experts in universities, industries and scientific institutions. In 1940, an American Petroleum Institute Committee on Motor fuels (2) wrote, "All these have constantly been confronted by two obstacles of basic character, namely –

"(1) The excessive cost of alcohol compared with gasoline,

and

"(2) The absence of technical advantages in the use of alcohol justifying (the) higher cost."

Our current review (30 years later) can still be summarized completely accurately by this quotation. As late as November, 1969, the U.S. Department of Agriculture in a report by its Northern Regional Research Laboratory in Peoria, Illinois, summarized the situation as follows: "Use of ethyl alcohol from wheat as a required component of all automotive fuels would require National legislative action. The cost of the finished fuel would be higher than fuels now available from petroleum" (3)

The work and study by the numerous investigators since 1906 covered all the many facets of ethanol use, in addition to the economics. From a technical standpoint, these included antiknock (octane) quality, operation at lean mixtures, fuel economy (mileage), engine performance effects (e.g., power, corrosion, vapor lock, driveability, deposits and cleanliness), water tolerance, carburetor icing, and handling problems.

In addition, some of the investigators also examined the effect of its use on exhaust emissions, particularly carbon monoxide. Though the work may not have been as sophisticated as some of the analytical techniques permit us to be today, it was concluded that there would be no real beneficial reduction in carbon monoxide. "Broadly speaking, for engine conditions and adjustments giving comparable performance the carbon monoxide content of the exhaust gases will be about the same regardless of the fuel used." (4)

Antiknock Quality of Alcohols

There are numerous reports in the literature of the good antiknock quality of alcohols, either when blended with motor gasoline or when used alone.

Ethanol appears to have a much more beneficial octane improving effect on low octane base stocks than on high octane base stocks. (See Figure 1 and Tables I and II). The values in these tables have been extracted from several references (6,7,8,9,10,11,12,13,31.)

Its effect on Research octane number appears to be similar with leaded as well as unleaded fuel. However, its improving effect on Motor octane number does not seem to be as good with leaded fuels as with the unleaded product. In fact, several references (12, 13) show a depreciating effect on Motor octane number with leaded fuels.

For base fuels with antiknock quality comparable to today's typical gasolines, the blending octane values are about 107-110 Research octane number and 90-95 Motor octane number. The blending octane value (BOV) is defined as follows:

$$\text{BOV} = \frac{\text{O.N. (Blend)} - \text{O.N. (Base)} \cdot (1\text{-}x)}{x \text{ Alcohol}}$$

Where:

O.N. (Blend) = Octane number of the blend (Research or Motor Octane)

O.N. (Base) = Octane number of base gasoline or gasoline component (Research or Motor Octane)

x Alcohol = Volume fractional concentration of alcohol in blend

1-x = Volume fractional concentration of base gasoline or gasoline components in blend

The equation can be rearranged to calculate the octane number of the blend as shown below:

$\text{O.N. (Blend)} = \text{O.N. (Base)} \,.\, (1\text{-}x) + \text{BOV} \,.\, (x \text{ Alcohol})$

The curves in Figure 1 were developed from the data reported in the literature on gasoline blends having varying concentrations of ethyl alcohol ranging from 10-25% by volume. Detailed data will be found in Table I of this report. These curves illustrate that blending octane value varies widely with the initial Research and Motor octane numbers of the clear base gasoline.

Compared with some natural octane blending materials, ethanol seems to have a similar Research blending octane value to dimethyl butane, cyclopentane, diisobutylene, benzene, tolune and the xylenes (10). However, its Motor blending octane value is somewhat inferior to all of these materials, particularly in leaded fuels (10).

Compared with tetraethyllead, ten percent ethanol is decidedly inferior to 2.2 to 2.6 ml. TEL/gal. as an octane improver (4) on the basis of octane number alone. A 1938 API publication showed that 0.02% TEL (0.75 cc/gal.) was equivalent to 10% ethanol in octane improving capability (14). Another reference (11) has indicated 0.03% TEL (1.12 cc/gal.) to be equivalent to 10% ethanol.

Comparison on an equivalent cost basis with various octane improvement processes is made in Table III (10). It is obvious that at 110 blending octane value, ethanol must meet a maximum cost of 20¢ to 23¢/gal. at 10% volume concentration. This is true for any gasoline road octane number base of from 82 to 97.

A brief tabulation of antiknock quality of other alcohols is given in Table IV.

Engine Performance Effects

The use of alcohol as a fuel to improve engine power has long been known (16,17). Applications in this country, however, have been limited to racing events, manifold injection at heavy loads, or for high power output where fuel economy is not a major consideration. When considered as potential commercial fuel components, the methyl and ethyl alcohols must be evaluated on the basis of replacing conventional type gasoline blending stocks. For example, the reference engine performance level would be that which is attained with a straight hydrocarbon fuel. Power and economy comparisons are thus made by analyzing the following factors: (a) fuel energy contribution per unit volume of fuel-air mixture, i.e., BTU's/ft.^{3}, (b) the latent heat of vaporization which governs volumetric efficiency, i.e., charge density, (c) knock rating or octane blending value which indirectly relates to power output because of determining higher compression ratio and spark advance limits, and (d) the relative miles per gallon (mileage or fuel economy) as suggested by the heat of combustion per gallon of fuel – BTU's/gallon.

Other considerations which are a part of the engine performance critique are also discussed. These include driveability and pertinent data useful in ascertaining the "overall picture" of using alcohol-containing fuels in automobiles.

Power and Fuel Economy

The properties of methyl and ethyl alcohol are given in Table V, along with iso-octane which may be used as representative of a full boiling range fuel. Also shown are physical factors governing power and economy. Power is determined by the heat of combustion per unit of air consumed plus the effect of latent heat. (The cooling effect caused by a higher latent heat value decreases the compression work and tends to induct a greater mass of air, thus resulting in improved volumetric efficiency.) Mileage is based primarily upon the heat of combustion per unit volume of fuel, with higher latent heat being a secondary advantage.

As noted in the table, the relatively low heat content of the alcohols is a basic disadvantage to adoption as an engine fuel. The relative mileage compared with gasoline for a given power output shows an excessive loss in fuel economy for the alcohols. However, with actual alcohol-gasoline blends, the picture improves markedly. Many, and seemingly conflicting, reports appear in the literature concerning alcohol fuel economy, but a major part of the data is from tests on engines with compression ratios much lower than present day U.S. models. In these lower compression engines, alcohols and alcohol blends definitely gave much lower fuel economy for equivalent power output than did gasoline alone. The losses for ethanol blends vary widely and are reported ranging from zero to 36% on individual runs (18, 19, 20, 21, 22). As an example, economy and acceleration data concerning lower C. R. engines are shown in Table VI (11). These data agree quite well with theoretical calculations concerning only the relative heat content of the fuels. In contrast, the following is offered from a 1970 Union Oil Company memorandum (5):

"It was pointed out previously that methanol alone does not afford the mileage obtained with an equal volume of gasoline because of the lower heat content of methanol. Early British work showed that the addition of methanol to an ordinary gasoline (1932 in Britain) did not increase the rate of fuel consumption at mixture strengths slightly richer than theoretical, provided the methanol is kept below 15 to 20% by volume.

These findings from single-cylinder engine experiments were confirmed by actual road tests in automobiles of different types. All of the results showed that with normal carburetor settings a 10% methanol blend could be used with satisfaction, and that fuel consumptions remained almost exactly the same as with the gasoline alone.

It is interesting to note some similar performance findings in a more modern setting with a 25% by volume ethanol (200 proof) blend in gasoline used in a 1962, V8, 10.25:1 CR Oldsmobile "88" engine. The base fuel was a 60.6° API, 8.7 RVP, 92.5 RON (clear) gasoline. Performance data showed there was little difference between maximum bhp output with the blend and representative gasolines, with standard carburetor and specification timing, in spite of the fact that ethanol has a lower BTU content per unit weight than gasoline. Further, fuel consumption data showed the blend to be equal to gasoline in many instances, particularly on a volumetric basis."

The foregoing tends to point out that optimum alcohol blending for both power and economy is dependent on the characteristics of the engine. Noteworthy is the fact that greater engine efficiencies result with increased compression ratios and higher compression ratios require higher octane quality fuels. The antiknock quality of ethanol led Messrs. Rogowski and Taylor (23) to investigate whether higher compression ratio (CR) engines would overcome the poor economy shown at lower CR's. Table VII, summarizing this work, shows that alcohol blends would still show an increase in consumption. A better analogy by Rogowski and Taylor is given in Table VIII. Here, they calculated optimum engine design for each particular fuel so as to give all the advantage of high compression ratios into improved fuel economy, with the same power output for each engine. The data indicate that the consumption characteristics of alcohol-gasoline blends are better than low octane gasoline, but are still inferior to the higher octane leaded fuel. It should be pointed out that these data were published in 1941 and were obtained on low CR engines.

As noted, this review refers to alcohol as a fuel supplement or component, and touches only lightly on power gaining use. The power inducing objectives in an engine are quite complex and such use of alcohol normally involves blending with other high energy fuels, such as nitromethane, etc., and even water. Such use is unrelated to considerations of blending alcohol as an integral part of commercial gasoline and therefore is not covered in this report.

Starting, Warm-up and Vapor Lock

Bridgeman (24) gave comments on warm-up indicating that alcohol blends provide slightly better warm-up performance in warm weather and slightly poorer warm-up in cold weather. Bolt (1) gave the following account:

"A blend of 25% anhydrous ethanol and 75% regular gasoline was tried at the University of Michigan in 1963 and 1964 cars in March, when the temperature was near freezing. Starting and performance of the engines were quite normal. A hesitation could be felt following quick throttle opening during the warm-up period. With the carburetor set closer to the lean limit of satisfactory performance with gasoline, the 25% alcohol blend gave unsatisfactory acceleration, and lean surging in the cruise condition was evident. This is to be expected, since the alcohol blend had, in effect, a leaner mixture, as discussed in the section on Metering Characteristics."

This information indicates that when an alcohol-gasoline blend is substituted for straight gasoline, larger metering jets are required to maintain the same equivalence ratio, and thus prevent lean surging.

Pleeth (17) gives an interesting account of starting performance and vapor locking tendencies:

> *"Alcohol fuels have been attacked on the grounds that they provide poor startability at low temperatures and vapor lock at high. Neither of these statements is true, for they are based upon an error. In fact, alcohol in the proportions normally used has little effect upon startability and vapor lock, which are functions of the basis gasoline in the blend. The origin of the error is interesting. Vapor lock is measured by vapor pressure, and the normal method for the determination of this characteristic is by the Reid bomb. A standard volume of spirit is shaken with four times its volume of air at 100°F, and the final pressure, corrected for the water vapor present, is taken as the vapor pressure. But the method demands the presence of water in the initial stages, and this amount of water is sufficient to cause a normal alcohol blend to separate into two phases. As it happens, the vapor pressure of an alcohol/gasoline blend is higher than the sum of the partial pressures of the two phases, so that the unwary experimenter records a lower vapor pressure than the blend would give.*
>
> *When vapor-lock tests are made, and two fuels are compared, one a gasoline and the other an alcohol/gasoline blend of apparently similar vapor pressure, it follows that the latter shows a greater tendency to cause vapor locking, and it is on such grounds that the claim has been made. When the true vapor pressures are compared, however, the alcohol blend has a higher value, and could be expected to show a greater tendency to vapor lock. If now the tests are repeated using fuels of equal vapor pressure, no difference in vapor-locking tendency can be found. The effect is recognized in the standard method for the determination of vapor pressure, where the use of a dry bomb is recommended, thus preventing the separation of the alcohol blend into two layers."*

Probably the most basic premise is that no vapor lock difficulty would be encountered if the vapor pressure of the base gasoline is adjusted. For example, methanol has a very high blending Reid Vapor Pressure (RVP) in gasoline. And ethanol-gasoline blends are more prone to vapor lock than a gasoline used to prepare the blends. This is illustrated by the following data and comment from a discussion by H. R. Taliaferro of Lawrason's and Finigan's paper on "Ethyl Alcohol as a Modern Fuel" (25).

> *"Results of RVP and ASTM distillation tests on a typical Chicago summer season gasoline, and a blend of this gasoline with 25% (v) of 200° proof ethanol, are shown in the upper portion of Table D-2.*

TABLE D–2

RVP, DISTILLATION, AND VAPOR LIQUID RATIO TESTS ON GASOLINE AND AN ETHANOL-GASOLINE BLEND

	Gasoline	*Ethanol-(1) Gasoline Blend*
RVP, psi	9.3	9.7
ASTM Distillation		
10% Evaporation, °F	128	127
20%	148	140
30%	168	150
50%	206	161
Temperature, °F, for Vapor Liquid Ratio		
15	128	124
20	130	126
30	135	130

(1) 25% (v) of 200° Proof Ethanol

"The blend was 0.4 pounds higher in RVP and the temperatures for 20, 30, and 50 percent evaporated were markedly lower than from the gasoline. We compared the relative vapor-locking tendencies of the gasoline and the blend by determing the temperatures for several levels of vapor to liquid ratio in the Union Oil apparatus. At vapor to liquid ratios of 20 to 30 to 1, ratios at which car-fuel systems encounter vapor lock, the temperatures for the blend are four to five degrees lower than those for the gasoline indicating the blend would encounter incipient vapor lock at four to five degrees lower ambient temperature than the gasoline. Low-cost butane, and other light hydrocarbons, would have to be withdrawn from the enthanol-gasoline blend to provide vapor-lock protection equivalent to that provided by the gasoline."

Fuel System, Corrosion and Wear

Since alcohols are good solvents and loosening agents for such things as gum, resin and rust, some difficulty might be expected on initial use of such a blend in an automotive system which has previously been in contact with a 100% hydrocarbon fuel. The literature reports that there have been instances of blocking of fuel passages when such a blend was first used (17). These reports were made when gum was not held to as low a quantity in gasoline as it is today.

In the past, methanol in blends with water present increased the rate of corrosion of iron, lead coated iron, galvanized iron and aluminum. Fuel system corrosion problems should be minimized, however, with the use of organic corrosion inhibitors in most present day gasolines.

It was generally felt that alcohol blends increased cylinder and ring wear. A report of a test run on a fleet of trucks in England indicated a 60 percent increase in the corrosion rate for an alcohol blend compared with regular fuel. Some of the suggestions advanced for causing greater wear were (a) blends have a higher solvent power for oil, thus washing the oil film from the cylinder walls, (b) the higher heat of vaporization prolonged engine warm-up time, and (c) the general corrosive nature of combustion products attacked the metals. It is speculated that wear problems would be greatly reduced with modern engine oils.

Alcohol-Gasoline-Water Solubility

Methyl and ethyl alcohols are quite different in their degree of miscibility in gasoline and in gasoline containing some water bottoms. Consequently, the blending properties of each are discussed separately. All authorities agree that anhydrous alcohols must be used to minimize water problems in the fuel distribution systems. The difficulties encountered by phase separation in the automobile fuel tank include corrosion, rough engine operation, starting difficulties, and fuel line plugging.

Methanol suffers from the major disadvantage that there are very few fuels in which it is miscible in all proportions at ordinary temperatures, even when perfectly dry. The solubility of methanol in any hydrocarbon is a function of (a) the molecular configuration and physical properties of the hydrocarbon, (b) temperature, and (c) the presence of water. In general, the lower the temperature, the more narrow are the limits of miscibility between the two, while the presence of very small amounts of water greatly reduces miscibility. For example,

Union Oil (5) reported that dry methanol is miscible in all proportions in an aromatic gasoline at 60°F, but only about 13% would dissolve in a regular gasoline, and 4%in an all-straight run gasoline. At 0°F, the methanol solubility drops to 4% in regular gasoline and further to about 0.5% with the addition of 0.03% water.

Methanol is soluble to the least extent in the normal paraffins and to the greatest extent in the aromatics, and in most cases is more soluble in unsaturates than in naphthenes. This generalization is only true when comparing hydrocarbons of the same boiling point, for in all classes of hydrocarbons, the solubility of methanol decreases with rise in the hydrocarbon boiling point and molecular weight (26).

There are compounds, however, which are effective in promoting the miscibility of methanol and gasoline. Some are listed as follows:

Compound	*Vol. %in Gasoline*	*Vol. % Methanol Miscible above 32° F*
None	--	about 3
Iso-butanol	2.4	10
Iso-propanol	4	10
Ethanol	6	10
Benzene	13	10

of these iso-butanol has been shown to be the most effective solubilizer.

Since most storage facilities and supply depots contain some water contamination, an equilibrium phase diagram, Figure 2, for premium gasoline-methanol-water has been drafted. The positions of the equilibrium lines on the gasoline-rich side of the curves were determined by titrating known mixtures of gasoline and alcohol with water until the solution became cloudy. The water-rich side of the curves were determined by titrating known mixtures of water and alcohol with gasoline until hydrocarbon was observed on the surface of the solution. All samples were agitated vigorously between additions.

The tie-line data were obtained by mixing known volumes of the three components in a graduated cylinder. The volume of the water layer and the total volume of the mixture were then recorded. The position of the tie-lines was determined by applying the lever-rule based on the total volume of the mixture. From the attached phase diagram, a gasoline mixture of 25.0 volume % methanol will be required to keep 0.3%* water in the single phase region.

At methanol-gasoline concentrations of less than 25%, a water bottoms concentration of 0.3% will cause phase separation. When phase separation occurs, the methanol will drop out of the gasoline phase into the water phase until an equilibrium occurs. The phase diagram can give a good estimate of what this drop-out effect means in actual loss of methanol to the water phase. For example, a point can be picked in the two-phase region of the diagram, a tie-line drawn through it to connect the gasoline phase with the water phase, and finally an answer may be obtained by material balance.

Sample Calculation:

1. Point A, lies in two-phase region, 0.3% water, 10% methanol, 89.7% premium gasoline.
2. Point B, lies in the water phase, 83% methanol, 9.0% premium gasoline, 8.0% water.
3. Point C, lies in the gasoline phase, 7.7% methanol, 0.06% water, 92.24% premium gasoline.
4. Let x = volume of water phase, and y = volume of gasoline phase; x + y = 100.3 units
5. (a) .83 (x) + (.077) y = 10.00 units (methanol balance)
   (b) .83 (100.3-y) + (.077)y = 10.00 units
   (c) 83.249 - 83y + .077y = 10.00 units
   (d) .753y = 73.249 units
   (e) y = 97.28 units x = 100.3 - 97.28 = 3.02 units
   x = 100.3 - 97.28 = 3.02 units

6. *Check of Results*

   (a) Alcohol
   (3.02) (.83) + (97.28) (.077) = 10.00 units
   2.50 + 7.50 = 10.00 units

---

* On the average, most service station tanks do not exceed ¾" water bottoms. Therefore, a volume calculation will show that a half full 6-foot diameter tank with ¾" of water will have a maximum of 0.3% water bottoms.

(b) Water
(3.02) (.08) + (97.28) (.0006) = .30 units
0.24 + 0.06 = .30 units

(c) Gasoline
(3.02) (.09) + (97.28) (.9224) = 90.00 units
0.27 + 89.73 = 90.00 units

The above figures show that one-fourth of the methanol contained in the original gasoline mixture of 10% methanol will end up in the water phase, and the water phase will increase ten fold initially.

Anhydrous ethanol is miscible in all proportions with all but a very few gasolines. However, ethyl alcohol is hygroscopic and readily absorbs moisture from the air, thus limiting its miscibility in fuels. The rules governing the solubility of methanol also apply to the solubility of ethyl alcohol. And of utmost importance and similarly to methanol, the lower the temperature the lower the solubility, i.e., the smaller the water tolerance will be.

Egloff (27) in 1936 reported on the ability of ethanol-gasoline blends to carry moisture without separation. Figure 3 indicates that a 25% alcohol blend can tolerate about 1% water at 70°F. These data may not apply directly to modern-day gasolines, since pool octane composition has changed, but the curves can be used to extrapolate data obtained with present-day fuels. An extreme case of blending with a high aromatic premium fuel is illustrated on the attached 3-phase diagram, figure 4. For example, in continuity with the methanol information previously discussed, retention of 0.3% water in the gasoline phase would require about 8% alcohol. Ten percent ethanol in the premium fuel would retain about 0.5% water. As with methanol-gasoline blends, other stabilizers can be added to the ethanol-gasoline mixture to increase miscibility. But, the problem of normal water bottoms in storage tanks is not so severe as with methanol. Pleeth (17) suggests that the most likely place of blend separation is in the car fuel tank itself:

> *"Finally, to the car tank itself, the most rigorous test of all. Most car tanks contain water, obtained during delivery of normal petrol and by successive condensation. Usually this is held below the fuel-exit pipe and, except in violent swerving, does not reach the engine. At some stage, as the water increases in volume, some finds its way into the carburetor, causing spitting and erratic running. If the trouble persists, the only remedy is cleaning the tank.*
>
> *When an alcohol blend is introduced into such a tank, trouble might occur if the water content happens to be above a certain figure, corresponding to the water tolerance of the blend introduced. For example, suppose five gallons of alcohol blend were introduced into a tank containing water. With a typical water tolerance of 0.5 percent as little as 1 gill (0.25 pint) of water could cause separation on a cold day.*
>
> *It must be pointed out that this trouble is not a frequent occurrence. The writer has had much experience with 'broken blends' during the course of experimental road testing, and regards it as a minor nuisance. If the engine is warm, it will continue to operate on a separated blend, for the alcohol concentration in the water later is sufficient to keep the engine running, unless the water contamination is so gross that the engine would have failed in any case had petrol been the sole fuel. Of course, once the aqueous layer is exhausted, the engine will continue to function on the upper layer, which is mainly petrol.*
>
> *In starting, a separated blend is fatal. All that can be done is to drain away the aqueous layer, and continue on the upper, petrol layer.*
>
> *A final word about water: in general, trouble, if any, will be encountered on the initial use. Thereafter the capacity of an alcohol blend to absorb water will prevent the normal deposition of atmospheric moisture."*

The advantages of ethanol over methanol solubility can be noted by comparing the 3-component phase diagrams. At 50°F temperature conditions, an ethanol content of 10% in a premium fuel would tend to dry up a tank with less than 0.3% water on initial contact; whereas, a methanol content of about 25% would be required to absorb this same amount of water. At lower fuel temperatures, of course, or with water contamination during storage, the problems with both alcohols would increase markedly.

Exhaust Emissions of Ethyl Alcohol-Gasoline Blends

Long before automotive exhaust emissions became a matter of general concern, there was interest in the addition of ethyl alcohol to gasoline for the purpose of reducing the concentration of one particular noxious component of exhaust, namely, carbon monoxide. Several early studies indicated that carbon monoxide was lower when an engine was operating on an ethyl alcohol-gasoline blend than when it was running on straight gasoline. It was soon recognized, however, that this reduction was not due to any fundamental difference between combustion of ethyl alcohol and gasoline but was rather due to the leaning out of the air-fuel mixture when ethyl alcohol was added to gasoline (4). Air-fuel ratio is effectively leaned out because a given weight of ethyl alcohol requires less oxygen for complete combustion than the same weight of gasoline. Unless a carburetor which was originally set to run on gasoline is adjusted to compensate for this effect, an engine will be supplied with an excess amount of oxygen when running on a blend of ethyl alcohol and gasoline. Although this will reduce the concentration of some exhaust emissions, it will result in severe deterioration of performance, driveability, and fuel consumption.

It is, therefore, necessary to evaluate the exhaust emissions of gasoline versus ethyl alcohol-gasoline blends at the same *equivalent* air-fuel ratio or, in other words, the same percent theoretical oxygen. *The general consensus of published reports is that ethyl alcohol-gasoline blends give the same carbon monoxide, hydrocarbon, and oxides of nitrogen levels in exhaust as gasoline at the same equivalent air-fuel ratios* (5,6,28,29,30,31,32) More detailed data on these reports will be found in Table IX. This is true whether the emissions are measured on a mass basis or a concentration basis.

Carbon monoxide is well known for its toxicity. Unburned hydrocarbons and oxides of nitrogen react together in the presence of sunlight to give compounds known as oxidants. These compounds are the constituents of photochemical smog that cause eye and lung irritation to humans and damage to plants. Some oxidants are also produced directly during combustion.

Aldehydes are one class of eye irritants and there is some evidence from studies on ethyl alcohol-gasoline blends that the aldehyde concentration in the exhaust is higher with such blends than with gasoline (32). It is reasonable to expect this effect based on the combustion chemistry of ethyl alcohol, and this tendency is supported by more recent work on methyl alcohol-gasoline blends. This recent work also suggests that even unburned alcohol would also be present in the exhaust of an engine running on an ethyl alcohol-gasoline blend (33,34).

Some of the confusion on the effect of ethyl alcohol on exhaust emissions is attributable to reports which have been based on tests where the air-fuel ratio was not adjusted to compensate for the reduced oxygen requirement of ethyl alcohol-gasoline blends (6). Reduced exhaust emissions with ethyl alcohol-gasoline blends have been mistakenly attributed to an inherent advantage of these blends rather than to the effective leaning of the air-fuel mixture. In this connection, it should be pointed out that the same reduction in emissions can be obtained when operating on gasoline by adjusting the carburetor to deliver a leaner mixture. However, operation on leaner than designed air-fuel mixtures will result in a loss in performance and a possible loss in fuel economy. This can occur when a mechanical adjustment is made to the carbueretor while operating on conventional gasoline or when a lower per cent theoretical oxygen requirement results through the use of ethyl alcohol-gasoline blends.

Because ethyl alcohol has a fairly high octane number, the suggestion has been made that it could be used in place of lead in gasoline, thereby eliminating lead particulates from automotive exhausts and also reducing combustion chamber deposits which contribute to increased hydrocarbon emission as cars age. However, as indicated elsewhere in this report, ethyl alcohol at ten percent in gasoline is much less effective as an octane improver than lead at the level normally used. Ethyl alcohol therefore cannot be considered as a replacement for lead in gasoline.

In a paper presented to a session of the Society of Automotive Engineers dealing with the use of alcohol as motor fuel, Professor J. A. Bolt of the University of Michigan stated, "There is no published evidence that alcohols can appreciably reduce air pollution problems" (1). Nothing has come to light since that statement was made to alter this conclusion regarding the use of ethyl alcohol in gasoline.

Economics of Alcohol-Gasoline Blends

Cost of Producing Grain Alcohol

The Department of Agriculture, and other sources, have published estimates of the cost of producing ethanol from grain on several occasions since the 1930's. A recent paper presented at the Sixth National Wheat Utilization Research Conference, Oakland, California, November 5-7, 1969 (3), provides an up-to-date estimate of alcohol from wheat costs (Table X). These costs are for new plants with a daily capacity of 20,000 bushels of wheat. Earlier studies (35) have indicated this would be the most economical size plant to operate considering both conversion cost and cost of transporting grain to the plant site. Production of 190° proof alcohol would be about 17.2 million gallons per year from 6.6 million bushels of wheat. At current prices this plant was estimated to cost $12 million. The net conversion cost of 18.2¢ per gallon resulted from a base conversion cost of 26.8¢ per gallon, an added depreciation cost of 7.0¢ per gallon, and a credit for by-product feed of 15.6¢ per gallon. Table XI lists revised costs for alcohol from wheat for which a reasonable combined rate of 20% per year for depreciation and profit on investment has been taken. Provision for depreciation and profit results in a production cost of 28.3¢ per gallon. This cost for alcohol from wheat is exclusive of the cost of wheat, packaging, transportation, blending and sales expense.

If 8.8 billion gallons of alcohol were produced each year (volume necessary to provide a 10% by volume blend with gasoline), about 25 million tons per year of by-product feed would be produced. To quote from reference (3), "The significant effects of the 25 million tons of by-product feed produced on the markets for other grains and cereals have not been evaluated. These high protein by-product feeds would not fill the gap left by removal of a high proportion of feed grain from the market. These by-product feeds would also compete with such protein concentrates as soybean meal, cottonseed meal and other feed concentrates. Basically, there would be an excess of protein feeds but not enough carbohydrate energy." Such a large tonnage of by-product feed would be expected to have a substantial adverse effect on its price, thus further increasing the price of alcohol.

Table XI lists the effects of the price of wheat, in the present selling range of $1.00 to $1.50 per bushel, on the cost of ethyl alcohol. Including the wheat cost would result in alcohol costs of 67¢ to 86¢ per gallon.

Wheat has received more attention from farm-state legislators because wheat is in greater surplus than corn. Legislation providing for the blending of grain alcohol in gasoline would also have to specify the grains to be fermented. If this were not done, corn and sorghum would be used instead of wheat because alcohol from these two grains is cheaper than alcohol from wheat. Tables XIII and XIV list the costs associated with producing 200° proof alcohol from corn. These costs are based on reasonable adjustments to corn alcohol costs published by the Department of Agriculture in 1957 (36). Conversion costs for corn are lower than for wheat and the by-product feed value is about 150% of that assumed for wheat. As a result, alcohol from corn costs 57¢ to 75¢ per gallon as compared to alcohol from wheat costing 67¢ to 86¢ per gallon when both wheat and corn are valued at $1.00 to $1.50 per bushel. The comparable cost for ethyl alcohol manufactured from petroleum has been estimated at 30¢ to 40¢ per gallon (3).

As in the case with wheat, fermentation of sufficient corn to supply 10% alcohol in U.S. gasoline would yield more than 25 million tons of by-product feed. This is about equal to the current production of high protein feeds from soybeans, cottonseed, etc. The price of the by-product feed would be expected to decline resulting in a higher cost for alcohol.

Availability of Grain for Alcohol Production

Motor gasoline consumption in the U.S. in 1970 is estimated to be approximately 88 billion gallons. A 10% by volume blend of 200° proof ethanol and gasoline would require 8.8 billion gallons per year of alcohol. Production of this alcohol by grain fermentation would consume 3.3 billion bushels of grain annually. To place this tremendous demand for grain in perspective, the production of corn, wheat, and grain sorghum in 1969 was:

Grain, Millions of Bushels

Corn	*Wheat*	*Sorghum*	*Total*
4,640	1,450	719	6,809

Two methods, developed in discussions with members of the U.S. Department of Agriculture, were used to estimate U.S. capacity for producing corn, wheat, and grain sorghum if all-out production were undertaken. Results of estimating all-out grain production are listed in Table XV. Case A is based on 1967 acreage harvested to which the diverted acreage was added. Case B is based on a 30% acreage increase of 1964 acreage harvested and diverted. Both A and B use 1968 data for yields per harvested acre. The two estimates vary from 8.7 to 10.8 billion bushels. These estimates indicate that the approximately 10 billion bushels of grain to fill food and alcohol needs could be grown.

New Facilities for Ethanol Production from Grain

Excess capacity in existing fermentation plants, above that used to produce beverage alcohol, is only 15 to 20 million bushels of grain per year (3). (At present, about 130 million bushels of various grains are converted to beverage alcohol.) More than 500 new fermentation plants (each with a capacity of 6.6 million bushels of grain and 17.2 million gallons of alcohol per year) involving a capital investment of more than $6 billion would be required to meet additional demands for supplying 10% alcohol in gasoline. Costs of additional transportation facilities from the grain producing areas and alcohol plants to refineries, and costs of additional storage and blending facilities at the refineries have not been estimated but would represent a very significant investment.

Economic Aspects of Grain Alcohol-Gasoline Blends

Proponents of the use of grain alcohol in gasoline recognize the very unfavorable economics of grain alcohol costs in comparison with gasoline costs. However, they do maintain that certain "off-sets" from the elimination of farm price support payments and storage costs can make alcohol blends economically attractive. The following summarizes the economic aspects of these "off-sets."

The added costs to the public of a 10% alcohol in gasoline blending program using wheat for fermentation are estimated to range from 4.1 to 6.6¢/gal. In arriving at these estimates (Table XVI), it was assumed that alcohol in gasoline would have a value of 15¢/gal. Total cost of the alcohol plus wheat would range from $4.6 to $6.3 billion per year if wheat were made available at $1.00 to $1.50 per bushel. Since the cost of producing the alcohol is more than its value in gasoline, the total cost of the grain would have to be borne by the consumer or subsidized by the government. Thus, there is no "off-set" in terms of reduced price supports for grain. However, there would be "off-sets" in terms of payments for diverted acres and for grain storage costs. These "off-sets" have been "guesstimated" at $0.5 to $1.0 billion per year. Using this range for the "off-sets" results in an added net cost of $3.6 to $5.8 billion per year or 4.1¢ to 6.6¢ per gallon.

A similar series of calculations are made for corn as listed in Table XVII. The added net costs are 3.1¢ to 5.6¢/gallon.

Summary and Conclusions

The cost of alcohol made from wheat or corn is estimated to be at least 50¢ per gallon. The production cost alone of 20¢ per gallon, which does not include profit and raw material cost, is greater than the highest conceivable value of the ethyl alcohol as a blending stock in gasoline. There is probably sufficient acreage available to grow enough grain to put 10 percent ethanol in gasoline, but this would require a $6 billion investment and would cost the consumer at least $3 billion annually. This would be equivalent to over 3¢ a gallon. Economically, the use of ethyl alcohol as a gasoline component cannot compete with straight crude oil components.

At an equivalent air-fuel ratio, alcohol-gasoline blends give the same levels of carbon monoxide, hydrocarbons and oxides of nitrogen as conventional gasolines. The reduced exhaust emissions which have been reported for alcohol-gasoline blends are attributable to the effective leaning of the air-fuel mixture when alcohol is added to gasoline. However, if the air-fuel ratio is not adjusted to compensate for this leaning effect, driveability and performance will suffer.

No advantage in vehicle performance can be found by using alcohol as a fuel supplement or component. On the contrary, use of an alcohol-gasoline blend can result in a serious loss of driveability. Problems with alcohol-gasoline blends on current emission control vehicles would consist of "tip-in" or acceleration hesitation, poor throttle response during warm-ups, and loss of mileage. Certain alcohol-gasoline blends may provide equivalent power output with a small loss in fuel economy (compared to commercial gasoline); but in lower compression engines, fuel economy suffers significantly.

Initial use of an alcohol-gasoline blend by the motorist may bring on problems of cleanup and clogged fuel lines. In the longer range view, however, this should present no serious problems; corrosion inhibitors in present day gasolines and modern engine oils could alleviate reported difficulties.

Alcohol-gasoline-water solubility would present problems of increased handling and cost. Storage facilities would require measures to prevent water contamination because of the hygroscopic characteristic of ethanol. Water tolerance and control would require continuous monitoring to insure against motorists' problems during all weather conditions.

Ethyl alcohol by itself has good antiknock quality. It shows high blending octane values in low octane unleaded fuels when rated in the single cylinder laboratory ASTM Research and Motor engines. However, with leaded fuels, there is a depreciating effect on Motor octane number and thus these high blending values have not been observed with alcohol blends in modern multicylinder engines. The addition of ethyl alcohol will not provide the same octane improvement that can be obtained more economically from either refinery processing or the use of lead alkyls.

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TABLE I

ANTIKNOCK QUALITY OF ETHYL ALCOHOL, UNLEADED

BASE STOCK	*Alcohol Conc, %*	*Clear Blend Oct. No.*		*Blending Octane Value*		*Reference*
		Research	*Motor*	*Research*	*Motor*	
Ethanol	100	106	89	–	–	(7)
Ethanol	100	–	100	–	–	(8)
Ethanol	100	107.5	96	–	–	(10)
Cracked Aruba	0	70	68.5			
	5	72	70.5			
	10	76	72.5			
	20	85.6	77	142	111	(7)
Straight Run	0	40	40			
	10	53	57			
	25	70	70	160	160	(8)
Thermal Cracked	0	68	66			
	10	76	72			
	25	87	76	144	106	(8)
Cat. Cracked	0	84	75			
	10	88	80			
	25	91	84	112	111	(8)
Polymer	0	95	82			
	10	98	84			
	25	99	85	111	94	(8)
Cat. Cracked	0	92.5	–			
	25	97.5	–	112.5	–	(6)
Avg. Industry Regular	0	85.7	77.3			
	10	88.1	78.6	110	90	(9)
Avg. Industry Premium	0	92.9	84.5			
	10	94.6	85.1	109	90.5	(9)
Motor Gasoline	0	–	69.9			
	5	–	72.7			
	10	–	75.3			
	20	–	79.8	–	119	(11)

TABLE II

ANTIKNOCK QUALITY OF ETHYL ALCOHOL, LEADED

BASE STOCK	*Alcohol Conc, % (Vol)*	*Lead Tetraethyl TEL, cc/gal*	*Blend Oct. No.*		*Reference*
			Res.	*Motor*	
Avg. of 3 Reg. Grades	0	(2)	91	83	
	5		92.5	84	
	10		94.2	84.7	
	25		99	89	(12)
Avg. of 3 Prem. Grades	0	(2)	98.5	89	
	5		99.2	87.3	
	10		100.1	87.3	
	25		(102.3)	86.7	(12)
Cat. Cracked	0	0	92.5	–	
	25	0	97.5	–	
	0	3.0	98.0	–	(6)
Conventional Prem. Grade Base Fuel	0	0	N.A.	N.A.	
	30	0	+9.4 (1)	+4.7 (1)	
	0	2.84	+7.7 (1)	+8.2 (1)	(31)
Ethanol	100	0	–	90.7	
	100	0.15	–	87.3	
	100	0.60	–	85.4	
	100	1.0	–	85.0	
	100	2.0	–	85.0	
	100	3.0	–	85.0	(13)
Avg. Industry Regular	0	0	85.7	77.3	
	10	0	88.1	78.6	
	0	2.25	94.2	86.3	
	10	2.25	95.8	86.7	(9)
Avg. Industry Premium	0	0	92.9	84.5	
	10	0	94.6	85.1	
	0	2.25	100.0	92.1	
	10	2.25	101.0	91.9	(9)

(1) Increased octane number over base gasoline value (not reported).

(2) Not reported.

TABLE III

BREAK–EVEN VALUE OF GASOLINE BLENDING AGENTS

Break-Even Cost of Oxygenated Blending Agent at

10 Vol. % Concentration (¢/gal.)

Base Road Oct. No. Level		82			87			92			97	
Value of Base Gasoline, ¢/gal.		8¢			9¢			11¢			13¢	
Processing Cost, ¢/Oct. No. Bbl.	*8*	*15*	*22*	*8*	*15*	*22*	*8*	*15*	*22*	*8*	*15*	*22*
O. N. Blending Value of Blending Agent:												
100	11.3	14.5	17.9	11.5	13.6	15.8	12.5	13.9	15.2	13.6	14.1	14.6
110	13.4	18.5	22.7	13.4	17.2	21.0	14.4	17.4	20.4	15.5	17.6	19.8
120	15.3	22.1	29.0	15.2	20.7	26.2	16.3	21.0	25.7	17.4	21.2	25.1

TABLE IV

ANTIKNOCK QUALITY OF OTHER ALCOHOLS

Alcohol	*Alcohol Conc, %(Vol.)*	*Lead Tetraethyl TEL cc/gal.*	*Blend Octane No.*		*Reference*
			Research	*Motor*	
Methanol	100	0	106	92	(7)
Methanol	100	0	–	90.0	
		1.0	–	90.0	
		2.0	–	90.0	
		3.0	–	90.0	(13)
Methanol	100	0	115	88	
		3	115	98	(15)
Isopropanol	100	0	–	98.5	
		1.0	–	92.8	
		2.0	–	92.8	
		3.0	–	92.8	(13)
n-Butanol	100	0	–	85.0	
		1.0	–	81.5	
		2.0	–	81.5	
		3.0	–	81.8	(13)
Isopentanol	100	0	–	87.0	
		1.0	–	84.0	
		2.0	–	84.2	(13)

TABLE V

PROPERTIES OF OCTANE AND ALCOHOL

	Octane	*Methyl Alcohol*	*Ethyl Alcohol*
Chemical Formula	C_8H_{18}	CH_3OH	C_2H_5OH
Molecular Weight	114	32	46
Carbon %, by wt.	84.0	37.5	52.0
Hydrogen %, by wt.	16.0	12.5	13.0
Oxygen %, by wt.	Nil	50.0	35.0
Heating Value			
Higher, BTU/lb.	20,000	9,600	12,800
Lower, BTU/lb.	19,100	8,650	11,500
BTU's/gal	120,000	76,500	102,000
Latent Heat of Vaporization, BTU/lb.	141	474	361
Specific Gravity (60° F)	0.702	0.796	0.794
Stoich. Mass A/F Ratio	15.1	6.45	9.0
Boiling Temperature, F	258	149	172
Octane No., Research	100	106	106
Octane No., Motor	100	92	89

$$\frac{\text{Lb. Air}}{\text{Lb. Fuel}} = \frac{(a + \frac{b}{4} - \frac{c}{2})\,(28.97)}{.2095\ (\text{MW of fuel})}$$ from equation:

$$C_aH_bO_c + (a + \frac{b}{4} - \frac{c}{2})\ O_2 \longrightarrow a\,(CO_2) + \frac{b}{2}\,(H_2O)$$

Energy - BTU's/lb. air	1265	1340	1280
Relative Mileage (based on BTU's/gal.)	100% (ref.)	51%	68%

TABLE VI

FUEL CONSUMPTION

ALCOHOL-GASOLINE BLENDS

BIBLIOGRAPHY REFERENCE 11

Fuel	*Relative Miles per Gallon* *Road Test Data*	 *Laboratory Data*
100% gasoline	100.0	100.0
10% ethanol - 90% gasoline	98.3	98.5
20% ethanol - 80% gasoline	96.0	96.3
30% ethanol - 70% gasoline	93.3	93.8
100% ethanol	68.0	58.0

PERFORMANCE OF ETHANOL – GASOLINE BLENDS VERSUS 70 OCTANE BASE STOCK

(Average data for 5.5, 6.5, and 7.5 C. R. engines, spark advance adjusted for each fuel)

	% Increase in Max. Power			*% Increase in Fuel Consumption*		
Carburetor	*10% alc*	*25% alc*	*3 cc TEL*	*10% alc*	*25% alc*	*3 cc TEL*
Not adjusted	3.4	4.7	8.2	1.3	4.8	0
Adjusted for max. power	3.8	6.7	7.6	5.2	0.1	0

TABLE VII

COMPARATIVE PERFORMANCE OF BLENDS VERSUS 70 OCTANE BASE GASOLINE AT C.R. of 6

BIBLIOGRAPHY REFERENCE 23

(Spark, carburetor, and C.R. adjusted for each fuel)

% Increase in Maximum Power			*% Increase in Fuel Consumption*		
10% alc	**25% alc**	**3 cc TEL**	**10% alc**	**25% alc**	**3 cc TEL**
(7 C.R.)	(8 C.R.)	(7 C.R.)	(7 C.R.)	(8 C.R.)	(7 C.R.)
4.8	11.9	6.6	0.7	3.3	−4.1

TABLE VIII

EFFECT OF RE-DESIGNING ENGINE FOR EACH FUEL

BIBLIOGRAPHY REFERENCE 23

	C.R.	*Relative Engine Size*	*Relative Reduction in Fuel Consumption*
70 Octane Gasoline	6	100.0%	(base)
plus 10% ethanol	7	93.5%	2.5%
plus 25% ethanol	8	84.7%	1.2%
plus 3 cc TEL	7	91.0%	6.4%

TABLE IX

EMISSIONS FOR ETHANOL–GASOLINE BLENDS

SOURCE	DATE	BLENDS	TEST ENGINES	TEST MODES	MEASUREMENTS	FINDINGS ON BLENDS
Reference 31	1964	25% and 50%	Waukesha RDH–VCR	2000 rpm 18,25,29 In. Hg MAP	CO (Orsat) HC (FID)	At same A/F, 60-85% reduction in HC. At same ϕ, no effect on CO or HC.
Reference 6	1964	25%	1952 Chevrolet 1962 Olds GM ES-59	Idle, 1000, 2000 and 3000 rpm; Road load.	HC (IR) NO_x (PDSA)	10-30% reduction in HC. No difference in NO_x.
Reference 29	1964	25%	Single cylinder test engine	1200 rpm	HC (NDIR + FID) NO_x (PDSA)	At same A/F, HC 25% lower. NO_x higher if A/F $<$15.6. NO_x lower if A/F $>$15.6. HC and NO_x same as equal
Reference 30	1964	10%, 20%, and 30%	283 CID V-8	Simulated city driving; mixture adjusted for same performance	Not reported	If engine set rich, emissions decrease. If engine set lean, emissions increase. Blend has slightly higher reactivity
Reference 28	1964	25%	CFR engine	1500 rpm 15 In. Hg Vacuum	CO (NDIR) HC (NDIR + FID) NO_x (PDSA)	At same ϕ, no difference in CO, HC, or NO_x
Reference 32	1963	25%	1956 Olds V-8	Steady state and Calif. cycle	CO (NDIR) HC (NDIR + FID) NO_x (UV)	At same A/F CO and HC lower NO_x higher. Formaldehyde after irradiation higher
Reference 5	1956	–	–	–	–	Little effect on HC or NO_x Increased aldehydes

EMISSIONS FOR METHANOL–GASOLINE BLENDS

SOURCE	DATE	BLENDS	TEST ENGINES	TEST MODES	MEASUREMENTS	FINDINGS ON BLENDS
Reference 33	1970	Up to 25%	CLR engine	1500 rpm	HC (GC) CO and NO (IR) Aldehydes (MBTH)	At same ϕ, CO and NO_x same, formaldehyde increases and HC same (under lean conditions)
Reference 34	1967	12.5%, 25% and 37.5%	1965 V-8	Calif. cycle	HC, CO, CH_3OH by GC - NO_x by Saltzman	At same A/F, HC and CO conc. and mass reduced. NO_x and CH_3OH increased. At same ϕ, no difference.

$$\phi = \text{Equivalence Ratio} = \frac{(A/F)\ \text{actual}}{(A/F)\ \text{stoichiometric}}$$

A/F = Air to Fuel Ratio (Lb air/lb fuel)

TABLE X

FERMENTATIVE CONVERSION COST OF 190° PROOF ALCOHOL FROM WHEAT

(Exclusive of Cost of Wheat)

Item	*Cost, Cents/Gallon*
Base Conversion Cost	26.8
Depreciation ($1.2 milllion/yr., 10 yrs., 17.2 million gal.)	7.0
	33.8
By-Product Feed Credit (6 lbs./gal. alc. at $52/ton)	15.6
Net	18.2

Conversion Cost of 200° Proof Alcohol

Alcohol (1.048 gal. at 18.2 cents/gallon)	19.1
Cost of Dehydration	1.9
Total Cost (Exclusive of Wheat, Profit, Packaging, and Sales Expenses)	21.0

TABLE XI

REVISED FERMENTATIVE CONVERSION COST OF 190° PROOF ALCOHOL FROM WHEAT

(Exclusive of Cost of Wheat)

Item	*Cost, Cents/Gallon*
Base Conversion Cost	26.8
Depreciation and Profit ($2.4 million/yr., 10 yrs., 17.2 million gal.)	14.0
	40.8
By Product Feed Credit (6 lbs./gal. alc. at $52/ton)	15.6
Net	25.2

Conversion Cost of 200° Proof Alcohol

Alcohol (1.048 gal. at 25.2 cents/gallon)	26.4
Cost of Dehydration	1.9
Total Cost (Exclusive of Wheat, Packaging, Sales, Transportation, and Blending Expenses)	28.3

TABLE XII

EFFECT OF WHEAT COST ON ETHYL ALCOHOL COST

Basis: 2.6 gals. 200° Proof Alcohol per Bushel

Wheat, Dollars/bushel	*Alcohol Cost, Cents/Gallon*		
	Wheat	*Conversion*	*Total Base Cost (1)*
1.00	38.5	28.3	66.8
1.25	48.0	28.3	76.3
1.50	57.7	28.3	86.0

(1) These costs do not include sales, transportation and blending expense.

TABLE XIII

FERMENTATIVE CONVERSION COST OF 190° PROOF ALCOHOL FROM CORN

(Exclusive of Cost of Corn)

Item	*Cost, Cents/gallon*
Base Conversion Cost	25.0
Depreciation and Profit	14.0
	39.0
By-Product Feed Credit	22.0
Net	17.0
Conversion Cost of 200° Proof Alcohol	
Alcohol	17.8
Cost of Dehydration	1.9
Total Cost (Exclusive of Corn, Sales Expense, Transportation, and Blending at the Refinery)	19.7

TABLE XIV

EFFECT OF CORN COST ON ETHYL ALCOHOL COST

Basis: 2.7 gals. 200° Proof Alcohol per Bushel

Corn, Dollars/Bushel	*Alcohol Cost, Cents/Gallon*		
	Corn	*Conversion*	*Total Base Cost (1)*
1.00	37.2	19.7	56.9
1.25	46.3	19.7	66.0
1.50	55.6	19.7	75.3

(1) These costs do not include sales, transportation and blending expenses.

TABLE XV

All-Out Production of Corn, Wheat and Sorghum

Case A

	Corn	*Wheat*	*Sorghum*	*Total*
1967 Acreage Harvested (1)	60.5	58.7	14.9	
1967 Acreage Diverted (1)	*16.2*	*None*	*4.1*	
Total 1967 Acreage (1)	76.7	58.7	19.0	
1968 Yield Per Acre (Bushels)	78.5	28.4	52.9	
Estimated Production (10^9 Bushels)	6.02	1.66	1.00	8.7

Case B

	Corn	*Wheat*	*Sorghum*	*Total*
1964 Acreage Harvested (1)	53.7	47.9	11.1	
1964 Acreage Diverted (1)	*22.2*	*5.1*	*6.5*	
Total 1964 Acreage (1)	75.9	53.0	17.6	
30% Acreage Increase (1)	*22.7*	*15.9*	*5.3*	
Possible Available Acreage (1)	98.6	68.9	22.9	
1968 Yield Per Acre	78.5	28.4	52.9	
Estimated Production (10^9 Bushels)	7.7	1.9	1.2	10.8

(1) 10^6 Acres

TABLE XVI

COSTS OF AN ALCOHOL FROM WHEAT PROGRAM

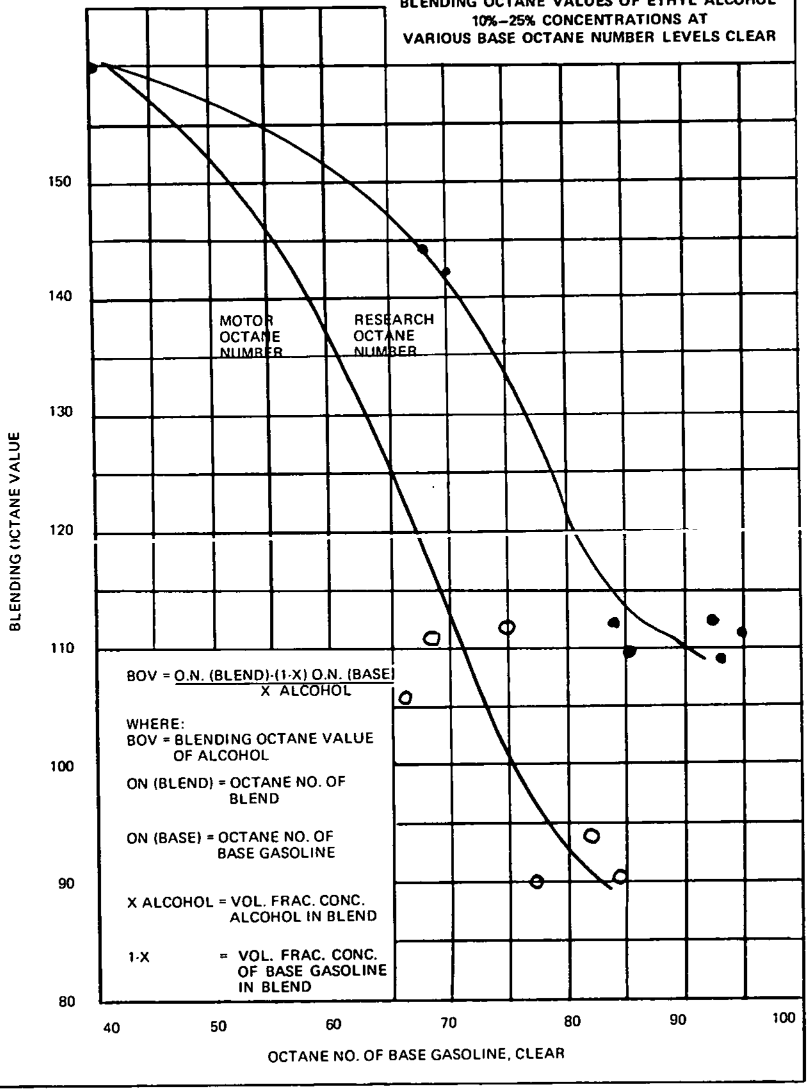
Value of Alcohol in gasoline	15¢/gallon
Differential between alcohol's value and its processing costs (28.3¢ - 15.0¢ = 13.3¢)	13.3¢/gallon
Added cost of alcohol in gasoline (8.8 billion gals. x 13.3¢ = $1.2 billion)	$1.2 billion/year
Added cost of wheat for fermentation	
(3.4 billion bushels x $1.00 = $3.4 billion)	$3.4 billion/year
(3.4 billion bushels x $1.50 = $5.1 billion)	$5.1 billion/year
Total of processing and wheat costs	
($3.4 billion + $1.2 billion = $4.6 billion)	$4.6 billion/year
($5.1 billion + $1.2 billion = $6.3 billion)	$6.3 billion/year
Net cost of alcohol in gasoline program	
($4.6 billion - $0.5 billion - $4.1 billion)	$4.1 billion/year
($4.6 billion - $1.0 billion = $3.6 billion)	$3.6 billion/year
($6.3 billion - $0.5 billion = $5.8 billion)	$5.8 billion/year
($6.3 billion - $1.0 billion = $5.3 billion)	$5.3 billion/year
Net added cost	4.1 to 6.6¢/gallon

TABLE XVII

COSTS OF AN ALCOHOL FROM CORN PROGRAM

Value of alcohol in gasoline	15¢/gallon
Differential between alcohol's value and its processing costs (19.7¢ - 15.0¢ = 4.7¢)	4.7¢/gallon
Added cost of alcohol in gasoline (8.8 billion gals. x 4.7¢ = $0.4 billion)	$0.4 billion/year
Added cost of corn for fermentation	
(3.3 billion bushels x $1.00 = $3.3 billion)	$3.3 billion/year
(3.3 billion bushels x $1.50 = $5.0 billion)	$5.0 billion/year
Total of processing and corn costs	
($3.3 billion + $0.4 billion = $3.7 billion)	$3.7 billion/year
($5.0 billion + $0.4 billion = $5.4 billion)	$5.4 billion/year
Net cost of alcohol in gasoline program	
($3.7 billion - $0.5 billion = $4.9 billion)	$3.2 billion/year
($3.7 billion - $1.0 billion = $2.7 billion)	$2.7 billion/year
($5.4 billion - $0.5 billion = $4.9 billion)	$4.9 billion/year
($5.4 billion - $1.0 billion = $4.4 billion)	$4.4 billion/year
Net added cost	3.1 to 5.6¢ gallon

FIGURE 1
BLENDING OCTANE VALUES OF ETHYL ALCOHOL
10%–25% CONCENTRATIONS AT
VARIOUS BASE OCTANE NUMBER LEVELS CLEAR



$$BOV = \frac{O.N.\ (BLEND) - (1-X)\ O.N.\ (BASE)}{X\ ALCOHOL}$$

WHERE:
BOV = BLENDING OCTANE VALUE OF ALCOHOL
ON (BLEND) = OCTANE NO. OF BLEND
ON (BASE) = OCTANE NO. OF BASE GASOLINE
X ALCOHOL = VOL. FRAC. CONC. ALCOHOL IN BLEND
1-X = VOL. FRAC. CONC. OF BASE GASOLINE IN BLEND

FIGURE 2–EQUILIBRIUM PHASE DIAGRAM FOR THE SYSTEM: METHANOL, WATER, AND GASOLINE (PREMIUM). DATA ARE GIVEN IN VOLUME PERCENT AT 76°F.

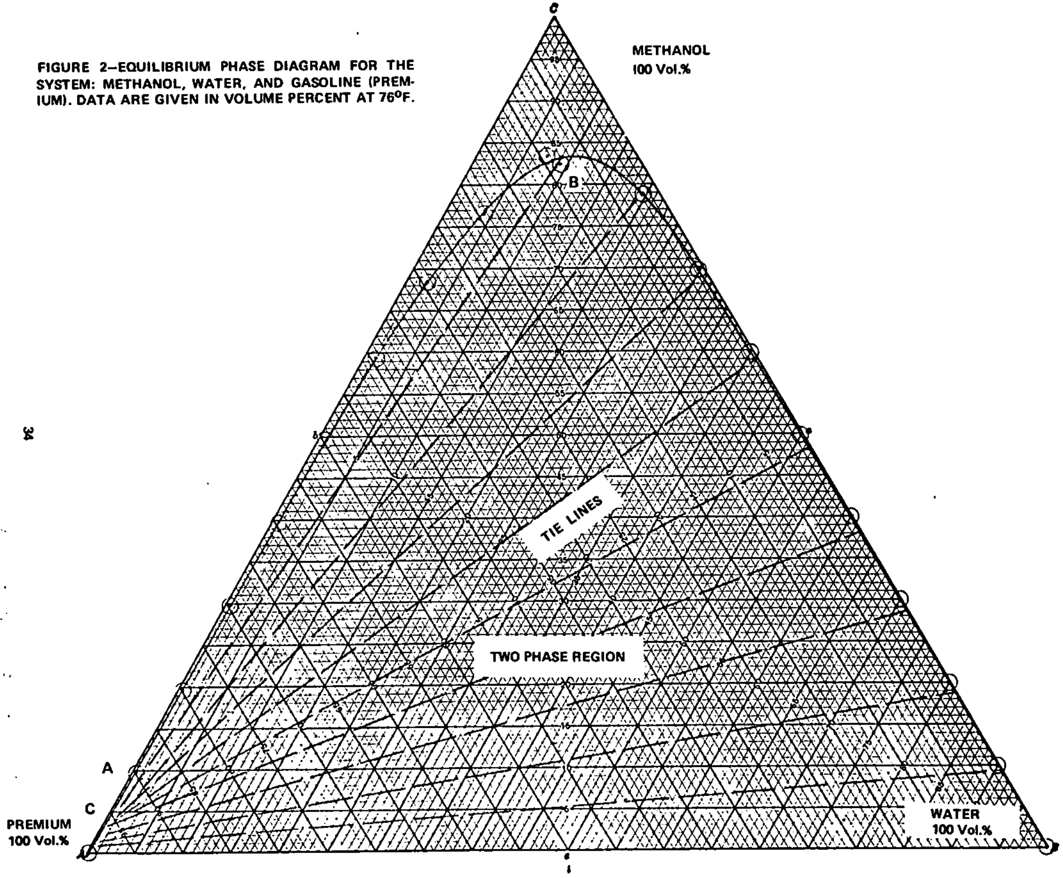
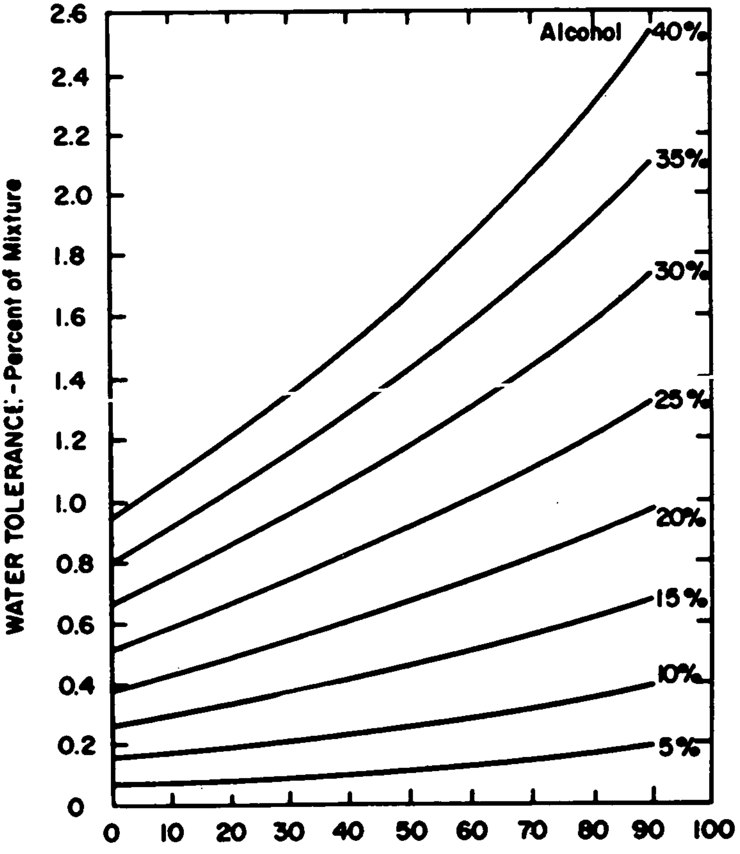
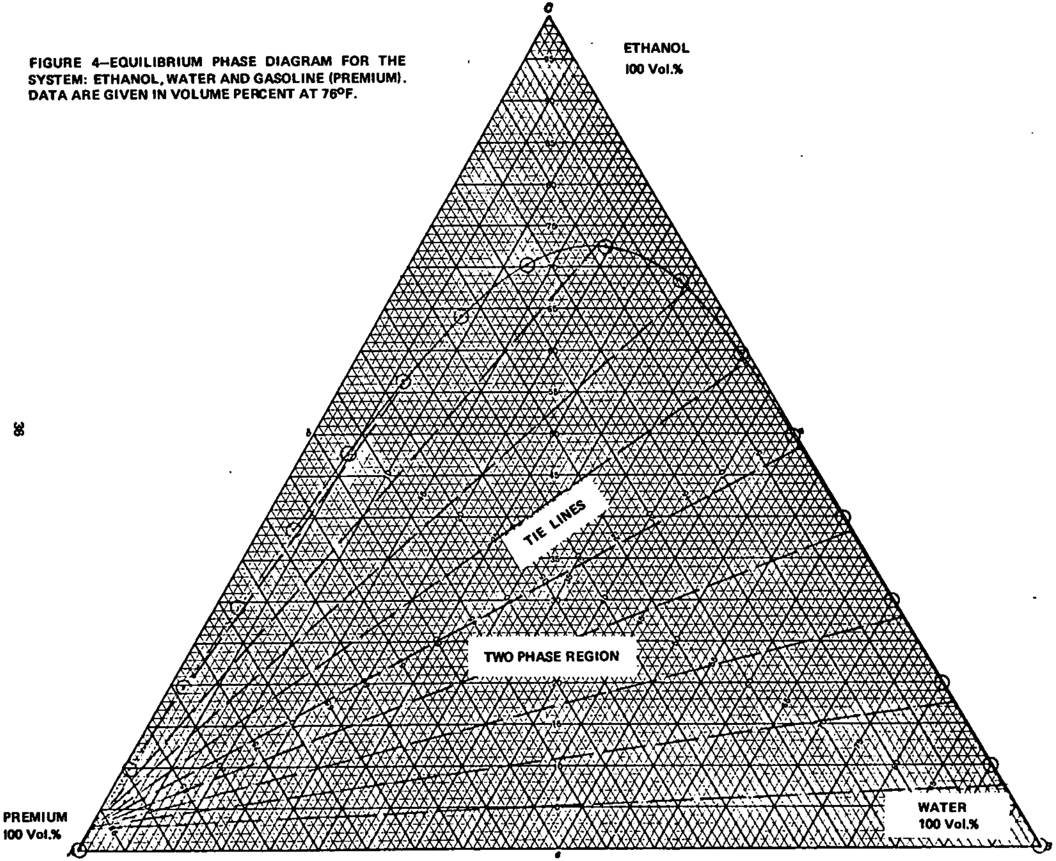


FIGURE 3—WATER TOLERANCE OF ETHYL ALCOHOL GASOLINE BLENDS



(Egloff)

FIGURE 4—EQUILIBRIUM PHASE DIAGRAM FOR THE SYSTEM: ETHANOL, WATER AND GASOLINE (PREMIUM). DATA ARE GIVEN IN VOLUME PERCENT AT 76°F.



MUNICIPAL TRASH AND ITS ENERGY POTENTIAL*

INTRODUCTION

The recovery of energy from the burning of municipal trash and other organic solid wastes has been considered in the U.S. for many years, but until recently was without any sizable applications. The present energy supply/demand balance problem has intensified interest in them as an energy source. These wastes are also being considered as sources of cellulosic material for fermentation into alcohols for fuel use. This memo summarizes information on the availability and composition of these wastes and their energy potential if burned as fuel. The experience with recent prototype plants and plans for other plants are also discussed.

QUANTITY AND COMPOSITION

Some 200 million tons of trash are collected yearly by towns and cities in the U.S.,[1] and this is growing at 4–5 percent per year. This collected municipal trash is presently disposed of as follows:[2]

Disposable method:	*Percent*
Dump	85
Incinerator (generally without heat recovery)	8
Sanitary landfill	5
Animal feed	2
Total	100

As shown below paper makes up a significant portion of municipal trash. If paper recycling programs are widely adopted, the energy content of these wastes would be considerably reduced.

Composition of Municipal Trash[1]

Component:	*Weight (percent)*
Paper and paperboard	50
Iron and steel	9
Aluminum	1
Glass, ceramics, rocks	10
Garbage, yard wastes	20
Plastics, textiles, miscellaneous	10
Total	100

[1] National Petroleum Council, U.S. Energy Outlook, New Energy Forms, 1973.

Note that about 70 percent of municipal trash is organic material in the form of paper, garbage and yard wastes. The organic portion would be the major source of fuel energy and would also be the source of material for fermentation processing. There are other large sources of organic solid wastes, in particular agricultural crops, food wastes and manure.

The amount of dry, ash-free organic solid wastes produced in the U.S. in 1971 is listed below as estimated by the Bureau of Mines.[3]

AMOUNTS OF DRY, ASH-FREE ORGANIC SOLID WASTES PRODUCED IN THE UNITED STATES IN 1971

Source	Million tons Wastes generated	Readily collectable
Municipal trash	129	71.0
Manure	200	26.0
Logging and wood manufacturing residues	55	5.0
Agricultural crops and food wastes	390	22.6
Industrial wastes	44	5.2
Municipal sewage solids	12	1.5
Miscellaneous	50	5.0
Total	880	13.63

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*Report by Mobil Oil Corp. Products Department, H. G. Grayson, May 17, 1974.

[1] National Petroleum Council, U.S. Energy Outlook, New Energy Forms, 1973.

[2] Engdahl & Drobny, Battelle Research Outlook, 1971.

[3] L. L. Anderson, Bureau of Mines Information Circular 8549, 1972.

The 200 million tons of municipal trash collected yearly in the U.S. is on a so-called wet basis. That means it includes the water normally associated with trash. About half of the total weight of solid organic waste is water. Therefore, the 140 million tons of organic material in collected municipal trash is equal to 71 million tons on a dry basis.

Note that urban refuse accounts for about half of the readily collectable organic solid wastes in the U.S., although urban refuse accounts for only about 15 percent of total organic solid wastes.

ENERGY EQUIVALENT

The heating value of municipal trash ranges from 3000 to 8000 Btu/lb., depending on its wetness and composition; with 4000 Btu-lb. an average figure. A rough rule of thumb is that one ton of refuse is equivalent to 1.4 barrels of fuel oil. The energy value of the 200 million tons of collected municipal trash if burned is equal to about 290 million barrels of fuel, about 800,000 bbls-day. This is about 4 percent of NPC's[4] forecast of 1980 total U.S. demand for petroleum products. Incidentally, municipal trash has a low sulfur content, therefore, this energy equivalent should be classified as a low sulfur fuel.

If the total municipal trash collected were converted into electricity at normal power efficiency, it could generate 14,000 megawatts of electricity. This is about 2 percent of the Federal Power Commission's 1980 projection for installed electrical generating capacity.

Converting the cellulose in organic wastes into ethanol is also being considered as a means of recovering energy from wastes. About 50 percent of organic waste is cellulose. If the cellulose in municipal trash were converted into ethanol, it would be equal to about 250,000 B/D of gasoline, about 4 percent of the present total U.S. motor gasoline demand. (See Attachment 1.) Burning of municipal trash will produce more energy than further processing of these wastes by fermentation and other secondary methods to produce synthetic fuels.

COSTS

Present costs for disposal of refuse in the New York metropolitan area were:[5]

$4.50 to $6 a ton for open dumping.

About $8.50 a ton for sanitary landfill.

$9 to $15 a ton for municipal incineration.

However, since municipal trash must be collected for whatever method is used for its disposal, collection costs should not be chargeable to the cost of the recovered energy. This assumes that the distance the trash must be carted will be the same for all disposal methods.

Municipal trash cannot be burned directly if efficient recovery of energy is desired. The trash must be shredded, the light and heavy materials separated, usually by air classification, and the ferrous materials magnetically removed.

The cost of shredding, separating and burning is expected to be in the range of $5–$15 per ton,[1] equal to 60¢ to $2 per million btu. By comparison, the price of low sulfur residual fuel to East Coast utilities is presently running about $1.5–2.00 per million Btu with a few purchases as high as $3.

EXAMPLES OF ENERGY RECOVERY FROM TRASH

Europe is much further advanced in the use of solid wastes for fuel as shown by the 150 plants of this type in operation.[6] In the U.S., Union Electric Co. in cooperation with the City of St. Louis and the EPA has been operating a 110,000 ton per year plant since April 1972. This demonstration plant operates as follows:

Raw residential solid waste is taken to a processing plant and shredded into small particles.

The light fractions of paper and other organic material are separated from the heavier metallic and glass particles by an air classifier process.

After air classification, the heavy fraction is magnetically processed to recover steel cans and other ferrous materials for recycling.

The shredded light waste is trucked to the power plant where it is burned with 85 to 90 percent of pulverized coal.

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[4] U.S. Energy Outlook, NPC, Dec. 1972.

[5] New York Times, Jan. 22, 1973

[6] New York Times, Dec 10, 1973.

It appears from the successful operation of this plant that almost all fossil fuel fired boilers can be adapted for burning processed municipal trash, provided they have ash handling capacity.

The Union Electric Co. recently[7] announced plans to generate power using essentially all of the solid waste in the St. Louis metropolitan area. (See Attachment 2) This plant will have capacity for 2.5 to 3 million tons/year of solid waste, will cost $70 million to build and $11 million/year to operate. The recovered energy from this waste will generate about 6% of the utilities' power. The plant is being built without government subsidy. The capital and operating cost recovery will come from the fuel value of the waste, sale of recyclable materials sorted from the waste, and from the normal dumping fees that the municipalities would have paid if they disposed of the trash by dumping. These fees are to be given to the utility.

The Connecticut Resources Recovery Authority very recently[8] announced agreement on construction of ten regional centers that will handle all of the state's refuse, about 3,600,000 tons per year. The first two plants in Hartford and Bridgeport will be similar to the St. Louis operation and will produce about 10% of the electricity needed in their regions. (See Attachment 3.)

Plants at Baltimore (365,000 tons per year) and San Diego (73,000 tons per year) are also under construction that will use a pyrolysis process for energy recovery from solid waste.[9]

Production of synthetic liquid fuel from organic wastes is another alternative to burning for energy recovery. The U.S. Bureau of Mines has done extensive work on conversion of cellulosic material to oil using hydrogen and carbon monoxide under high temperature and pressures to make the conversion. They are planning pilot plant operation this year to further test the process.[10]

In summary, the fuel energy content of the 200 million tons of municipal trash collected yearly in the United States is equal to about 800,000 B/D of fuel oil. Not all of this material can be economically burned for heat recovery, particularly trash collected in low population density areas. Burning of trash results in a larger energy recovery potential than further processing of the wastes by fermentation and other secondary methods to produce synthetic fuels.

Attachment 1

GASOLINE EQUIVALENT OF ETHANOL PRODUCED FROM ORGANIC WASTES

Assumptions:

1. Process; cellulose→glucose→ethanol
2. Dry, ash-free organic waste is 50 percent cellulose
3. No loss in cellulose→glucose conversion
4. glucose→ethanol stoichiometric, i.e. 1 lb. glucose produces 0.5 lb. ethanol

	Dry, ash-free organic wastes[1] (million tons per year)	Ethanol produced (million tons per year)	Gasoline[2] equivalent (MM barrels per day)	Percent of present motor gasoline demand
All wastes generated in United States	880	220	3.1	50
Collectable wastes	136	34	.48	8
Municipal trash readily collectable	71	18	.25	4

[1] Bureau of Mines Inf. Circ. 8549, 1972.
[2] Ethanol 13,200 Btu/lb, gasoline 5,100,000 Btu/bbl.

Attachment 2

[From the New York Times, Mar. 1, 1974]

ELECTRIC COMPANY WILL MAKE POWER FROM SOLID WASTE

ST. LOUIS, March 1 (UPI)—The Union Electric Company announced plans yesterday to generate electrical power using essentially all of the solid waste in the metropolitan area.

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[7] New York Times, March 2, 1974.
[8] New York Times, May 17, 1974.
[9] Fourth annual report of the Council on Environmental Quality, 1973.
[10] Energy Research Program, U.S. Department of Interior, March 1974.

The $70-million plant will generate about 6 per cent of its power from solid waste and will service St. Louis and six adjoining Missouri and Illinois counties.

The trash-to-electricity project, scheduled to be in operation by mid-1977, will be the first in the country to utilize all of a metropolitan area's solid waste as fuel.

The Union Electric president, Charles J. Dougherty, told a news conference that the proposed plant could handle 2.5 to 3 million tons of solid waste a year.

"It's a real first," Mr. Dougherty said. He explained that the $70-million worth of private capital for the plant and the $11-million annual operating costs would come from the heating value of the solid waste, sale of recyclable materials sorted from the waste before it is burned, and dumping fees.

Union Electric could save up to $10-million a year in fuel costs by mixing solid waste with coal to generate electricity, according to Mr. Dougherty. The utility will be built without governmental subsidy.

Under the plan, Union Electric will establish about half a dozen collection-transfer centers in the metropolitan area that will receive solid waste from private and public haulers and transfer it to closed containers for rail shipment to processing facilities at the company's power plant.

The company's decision follows its evaluation of an experimental prototype electrical generation system that has used about 250 tons of city garbage mixed with coal daily since mid-1972.

Union Electric's plan must be approved by the Environmental Protection agency. Mr. Dougherty said he did not "foresee any insurmountable contingencies" from the Government and did not expect opposition to the project from local environmental groups.

Attachment 3

[From the New York Times, May 17, 1974]

PLANTS TO MAKE FUEL OF GARBAGE

FACILITIES IN CONNECTICUT ALSO WILL SALVAGE METALS

(By Michael Knight)

BRIDGEPORT, Conn. May 16—Agreement was reached here today on the first steps toward construction of Connecticut's innovative $290-million system for converting all the state's household and commercial garbage into low-sulphur fuels for electric generating plants and commercially salable scrap iron, aluminum and glass.

The plan, described as the first of its type in the world, will funnel all 10,000 tons of refuse produced daily in the state's 169 towns and cities into 10 regional treatment centers by 1980, replacing hundreds of independently run, overtaxed and pollution-producing incinerators and dumps.

The Connecticut Resources Recovery Authority said today it expected to begin operations at the first two plants by mid 1976, with all 10 plants completed six years from now.

The first two plants, one here in the state's largest city and another near Hartford, are expected to process 3,600 tons of garbage a day and produce at a profit enough fuel to supply 10 per cent of the electricity needed in their respective regions. In addition, they are expected to recycle 80,000 tons of iron, 4,000 tons of aluminum and 40,000 tons of glass a year.

The authority's board of directors voted here today, and then announced at a news conference, that the Garrett Research and Development Company, a subsidy of Occidental Petroleum, has been selected as the over-all contractor for the Bridgeport plant, and that Combustion Equipment Associates, Inc., has been selected as contractor for the second plant, in Berlin, about 10 miles from Hartford.

"Every mayor and selectman in the state has been between a rock and a hard place when it comes to looking for a place to put the garbage," Malcolm W. Baldridge, chairman of the authority, said at the news conference. "It's exciting and glamorous to be the first state to set up a solution to the serious and growing problems of garbage. This is the first of its type in the world."

EVERYTHING WELCOME

The plants will handle "everything from old lawn furniture to tree trunks to bottles to chicken scraps," said Richard W. Chase, a former assistant commissioner in the state's Department of Environmental Protection who is now president of the authority.

Besides the scrap material, the first two plants will produce a dry confetti-like substance with a low sulphur content that will be burned along with fuel oil at Northeast Utilities Electric Generating plant in Milford, and at the municipal power plant in the city of Wallingford.

The other plants, modeled after a federally financed experimental station in St. Louis, will produce synthetic oil and gas for commercial sale.

The authority will charge $5 a ton for the disposal service, after rebating any profits from the scrap and fuel operations.

Mr. Chase said that, in addition to easing the problem of garbage disposal, the plants would ease local financing problems by paying property taxes.

The program is expected to save taxpayers $100-million by 1985, reduce air pollution from garbage disposal and reduce the need for new dump sites.

Chairman PROXMIRE. Mr. Nader, please proceed.

STATEMENT OF RALPH NADER, PUBLIC INTEREST RESEARCH GROUP, ACCOMPANIED BY CLARENCE M. DITLOW, ASSOCIATE

Mr. NADER. Thank you, Senator Proxmire.

Before discussing the specific focus of the committee's hearing on the Natick Lab development, I would like to suggest a number of frameworks by which this process and other innovations can be better understood.

First, in analyzing any alternative energy source there needs to be a strong emphasis on calculating the net energy value from that source. It is not simply the comparative Btu value of similar or dissimilar forms of energy. What is important is to analyze the broader framework to see how much energy does it take to produce, say, another alternative form of energy, and how much energy is saved or wasted as a result of the displacement effect of this new alternative form of energy.

Consequently we need the kind of analysis that would bring into much clearer perspective the facts of nuclear power from a net energy point of view. It takes a great deal of energy to produce nuclear power, which then is supposed to pay back society not only the energy it has absorbed, but a net energy component. If we consider an alternative form of energy, we have to ask ourselves, does it lead to less pollution. If it leads to less pollution, that means that not only will health and safety be advanced, but the energy that is necessary to clean up the pollution that would otherwise result is also saved. For instance, if animal manures or wastes could be cycled into usable forms of energy instead of dumped into our rivers and streams, that would reduce the burden of energy utilization to clean up the waters from the animal waste pollution.

The concept of net energy, I think, needs to be given much more serious consideration. Otherwise we will be choosing alternative energy sources that may put us on an energy treadmill where we are running fast only to stay still.

One of the most important contributions that the committee can make in its overall energy inquiry is to ascertain precisely what the net energy contribution historically and at the present time has been of nuclear power. I think certainly up to now it has been minus. And it would be interesting to note what the calculations are to be for 1978, 1985, and so forth.

In that respect we have to look very carefully at shale oil. There is a striking gap between the hundreds of millions of dollars which the oil industry now sees fit to commit to shale oil and the estimate by one of the witnesses here this morning that by 1985 there will be 500,000 barrels a day of oil, or 2 percent of our consumption, coming from oil shale. So when we talk about the investment necessary for methanol or ethanol production, we might also want to compare the investment necessary for oil shale, quite apart from its possible consumption of heavy amounts of water in water-starved areas of the United States.

This leads me to suggest that perhaps the committee could obtain the advice of economists who specialize in understanding the determinants of investment in one direction or another by industry.

One such economist is Professor Eisner, who is well known to this committee, on tax policy. For instance, given a choice of alternative energy investment opportunities, precisely what leads the oil industry or other energy industries, such as are still beyond the control of the oil industry, to invest. And I would suggest some criteria, for instance. The energy industry is more interested in investing in an energy source that it controls, or has title to. This is one reason for its marked disinterest in developing solar energy. It does not have title to the Sun.

The energy industry is also interested in developing the kind of energy source whose distribution it could control. It also is interested in developing the kind of energy source that its broader financial supporters are interested in developing, such as the banks. The Chase Manhattan Bank's oil expert is given a pedestal status by the oil industry which is quite remarkable. I think we have to pay attention to the role of the banks here.

There is also a factor which induces investment flow that could be characterized as a relatively finite exclusively possessible form of energy that is difficult for potential competitors or consumers to get at. Obviously oil, coal, uranium, and natural gas will fill those criteria. On the contrary, solar energy, if it can be developed for heating and cooling, can go directly to the consumer through a distribution system that could bypass the utilities and the energy companies.

So we have to probe this area, because it is important to understand the nontechnical barriers to innovation in developing alternative energy sources that may be cheaper or cleaner or more effective in deconcentrating the power of the energy industry as it is now organized.

One of the most interesting observations that can be made about the utilization of energy in this country is that the technology from the energy source to the consumption point that has developed in this country has been one that wastes scarce fuels instead of making abundant wastes convertible to usable energy.

Now, if we take the energy industry's word that it is proper to characterize the amount of oil and gas in this country as scarce fuels, although the recoverable oil reserves are much, much higher, given advanced technology and higher per barrel price, than the oil industry is willing to concede, we have to ask ourselves, what can we do to overcome the kind of technologies—and I am referring, for example, to the loss of waste heat from certain forms of technology, the internal combustion engine, air conditioning units, the design of buildings, the kind of technologies which are wasting enormous amounts of scarce fuels, instead of developing technologies that not only are more efficient in utilizing these fuels, but also work toward making scarce the abundant wastes that are now not converted to usable energy.

And so we come to the Natick situation from that standpoint.

If we develop an ethic in this country of encouraging the rapid development of technology that efficiently consumes energy, perhaps we can put into effect the Office of Energy Conservation's estimate that some 40 percent of the energy utilized in this country is wasted, and could be saved. If we look also at the effect of wasteful consumption of conventional fuels, we can point to the horror of proliferating nuclear powerplants which have got to be a prime incentive to developing alternative energy sources.

I am sure, Mr. Chairman, you have read the recent report of a plutonium leak in Ohio from a military weapons plant. It is still to be determined for how many days, months, or years this plutonium has been leaking from the plant into the mud outside. But one of the most startling aspects of that report was the statement by an Atomic Energy Commission spokesman, who said that, "The Commission had no idea how the plutonium leaked from the plant into the mud outside, that it was a total surprise to them." I think that if they are having difficulty controlling the leaking of plutonium from a weapons plant which has maximum security and maximum control by the Government, it is permissible to speculate as to the extent to which they are controlling radioactive leaks or will control radioactive leaks from civilian nuclear powerplants run by utilities around the country.

The Natick development illustrates the function of serendipity. It also illustrates how important it is to have nonindustry forums for technical research and development, because it is debatable to what extent this development would have been reported publicly and expeditiously if it was undertaken by an oil or coal company.

But what is also remarkable about the Natick development is the amount of money that was spent on it. For instance, in the past few weeks American Electric Power alone is spending $2.7 million on an advertising campaign to convince the public that burning coal without further pollution controls is the answer to energy problems. The U.S. Army Natick Laboratories have spent about $400,000 on enzymatic hydrolysis of cellulose waste as an energy and food source, $400,000. And these comparatively minute expenditures—minute especially by Army standards, of course—occurred as an unplanned offshoot of an Army program to prevent deterioration of cellulose materials. In contrast, the development of nuclear energy has received tens of billions of dollars in Federal subsidies. By comparison solar energy support has been less than $20 million, with the National Science Foundation providing $13.2 million this past fiscal year.

These are very important comparisons, because they reflect the impact of private corporate power on Government decisionmaking as to what areas of energy are to be developed.

Before we pooh-pooh a 10-percent contribution to gasoline fuel by ethanol production, it is wise to remember that after tens of billions of dollars of Federal research and development subsidies into nuclear power, at the present time nuclear power contributes less than 2 percent of our Nation's energy, and less than 6 percent of our Nation's electric output.

The Natick Laboratories are responsible for research for the prevention of deterioration of military clothing and equipment when exposed to the biological environment anywhere on Earth. As part of that research the laboratories have isolated 12,000 strains of fungi that biodegrade military supplies in order to prevent or control the degradation processes. One of these strains, *Trichoderma viride*, was discovered to rapidly convert cellulose to glucose for the production of the enzyme cellulose.

Available radiant solar energy in the United States—this does not include wind power, for example—is approximately 600 times our present annual energy consumption. The worldwide ratio is much higher due to the lower energy consumption in other countries. About 0.1 percent of the incident solar energy is fixed by green plants through photosynthesis. This process produces about 100 billion tons of cellulose per year, most of which is not utilized. Daily hydrolysis of only 1.5 to 3 million tons of waste cellulose could easily fill the largest industry-alleged oil shortfall of 2.5 to 5 million barrels per day during the height of the Arab oil embargo.

Unrecycled U.S. paper wastes alone were 48.1 million tons in 1969. Using the Natick process, this could be turned into 24 million tons of glucose or about 3.26×10^9 gallons of ethanol with an energy content of 3.34×10^{14} Btu's. Indeed, through hydrolysis of rumen fibers the Natick process holds great promise for reducing solid wastes from animal feedlots.

I think there needs to be agreat deal of attention given not just to paper wastes, but to the hundreds of millions of tons annually of animal organic wastes, particularly manure.

A 100,000-cattle feedlot annually produces 150,000 tons of dry organic wastes that can be hydrolyzed with almost the same efficiency as wastepaper to ultimately produce 7.14×10^6 gallons of ethanol with an energy content of 7.31×10^{11} Btu's. This is the energy equivalent of 6.1 million gallons of 100 ROM iso-octane gasoline.

Enzymatic hydrolysis of cellulose yields glucose which can be utilized into a number of other useful materials—single cell protein by microbial conversion; ethanol, acetone, and other chemicals including antibiotics by fermentation; and chemical feedstocks by chemical conversion. For the near term research and development should concentrate on production of ethanol—a fuel with an energy content of 102,000 Btu's per gallon as compared to 120,000 for gasoline and 76,500 for methanol.

According to the Natick Laboratories, 1 ton of wastepaper produces one-half ton of glucose which can be fermented to produce 68 gallons of ethanol. Other cellulose waste materials including pot-milled municipal wastes, papermill wastes, and animal wastes are about equally efficient in producing ethanol.

Depending upon the availability and price of gasoline, ethanol has had extensive use as automotive fuel and has been discussed before this committee. And during World Wars I and II ethanol was used extensively in Europe. But ethanol for fuel cells should be briefly discussed.

A fuel cell produces electricity directly from hydrogen or other clean fuels by electrochemical reaction. Contrary to most present electrical power sources, the fuel cell utilizes a clean fuel and air to produce electricity directly at the site of application without any intermediate transfer step. In essence, fuel cells have served as operational power sources for Gemini and Apollo spacecraft. The power output may vary from a single kilowatt to a 100 megawatt.

Ethanol can be used as a fuel for a fuel cell by reforming the ethanol into hydrogen and carbon dioxide. The hydrogen then reacts at the anode and oxygen at the cathode to produce electricity. The conversion efficiency of fuel cells is higher than that for any other present stationary or mobile power source. According to the National Academy of Sciences' Panel on Alternative Power Sources, the overall thermal efficiency—of vehicles powered by fuel cells—has clearly been proven to be at least twice as high as that of the gasoline engine in average use.

In addition to the energy efficiency of the fuel cell, the importance of the fuel cell may lie in curbing the monopolies of the oil industry and the utilities. Consumers could have their own electrical powerplants for home use. Motor vehicles would become less dependent on the oil companies for gasoline. As is usually the case, there has to be an economical optimism as a preface for developing the massive economies of scale. And it is important to focus on the technical feasibility and not confuse both the technical and the economic in deciding what the options are. They have to be taken individually, and obviously they work on one another, but they should not be confused in order to produce a pessimistic outlook.

The enzymatic hydrolysis of cellulose to glucose has been experimentally demonstrated by Ms. Mary Mandels and her associates at the U.S. Army Natick Laboratories over the past 10 years. Conversion of glucose to other useful products involves an application of known technological processes. The U.S. Army already holds two patents on the basic hydrolysis process. The Natick Laboratories are building a pilot plant for the basic process.

Beyond this point, there is no set Government policy or funding. Samples of the enzyme and royalty free licenses are freely given by the Army. Yet the private sector has shown little interest in applying this technology. In the alternative fuel area, the reason is clear; production of ethanol through enzymatic hydrolysis of cellulose is a displacement technology just as is the development of small fuel cells for automobiles and homes.

Such nontechnological barriers to innovation are more decisive than those technological barriers which can be resolved through research and development. Nontechnological barriers can only be resolved through changes in institutional structures such as breaking up of monopolies through strong enforcement of the antitrust laws or other Government policies to lower the artificial but powerful barriers to enterprise innovation. Put it another way, would Shell be willing to accept and develop an alternative energy source which cuts its profit rate of return by half, even though the cost of production is much smaller? That is, they could still justify it on a profit basis, but not as much as they could justify the profits from conventional fuel production. And this is the question that always has to be asked of the energy industries, that there may be, for example, developed much more abundant, lower cost technologies that produce less quantum profits, although they still produce a profit that would, say, attract a company.

But would they attract the oil companies who are making higher levels of profit on conventional fuels which they have a much stronger control over? That is the question that must be asked. And obviously, with the development of solar energy, and geothermal energy in other forms, it is not enough to say that at the present time there is no problem, because solar energy and geothermal energy, having hardly been developed, are higher cost technologies. The question is the future reduction of high cost forms of energy which might threaten the profit level of conventional sources of energy. It is known, for example, that the spreading control by the oil companies over other forms of energy beyond oil and gas, that is, uranium, coal, and geothermal, is designed to insure that alternative forms of energy do not displace or severely undercut their investments in oil and gas, and to also insure that the price of these alternative forms of energy are brought to levels comparable with conventional sources.

In the instant situation, significant Government research and development, not the few thousands of dollars spent thus far, are required to fully demonstrate the technology that is presently being worked on at the Natick Laboratories. If found viable, as all presently available evidence indicates, production and sale of ethanol and ethanol blend gasolines could be made in part, through a Federal corporation, such as the Federal Oil and Gas Corporation as proposed by S. 2506, which has the support of at least 22 Senators, until such time as competition can be assured roots secure from cartelized predations.

The production of glucose and glucose drivatives via enzymatic hydrolysis for human and animal consumption is faced with lesser institutional barriers. The primary problem is demonstrating that safe foodstuffs can be made. If this can be done economically then at the very least, beef producers who look for supplemental feeds should purchase the product. This is particularly true when soybean and feed grains prices are soaring.

This points out again the net energy concept, that is, assuming that this can be produced safely, it obviously has substitutive effects in terms of the demand level for forms of energy designed to produce more conventional foodstuffs. It obviously also has a very key relation to the number of people who will get food overseas from U.S. agricultural production.

Any patent licenses granted for use of the Natick processes should be on a nonexclusive basis. But licensing fees should be charged, perhaps with an initial royalty free period or volume to permit startup to an economical size. The funds from such licenses should be poured back into government research and development in extending the usefulness of this process. If the licenses process becomes a commercial success, all royalty fees should go to other clean alternative energy research and development.

But I think it is very important for the Government to sense early that if the private sector is going to block development due to the concentration of the energy industry on this process, that the development of this process can become one of the functions of the proposed Federal Oil and Gas Corporation as it perceives its role of promoting competition and breaking up monopolistic log jams in the production and distribution of all forms of energy that are now or about to be put into consumption channels.

We will be watching the Natick Laboratories work carefully. And we hope that they will be allowed to work with maximum support and cooperation from both governmental and private sectors.

Thank you.

Chairman PROXMIRE. Thank you very much, Mr. Nader.

[The prepared statement of Mr. Nader follows:]

PREPARED STATEMENT OF RALPH NADER

Mr. Chairman, distinguished members of the Joint Economic Committee, thank you for the invitation to express some comments on enzymatic hydrolysis of cellulose as an alternative energy and food source. My associate is Clarence M. Ditlow.

The past winter has seen an unprecedented propaganda campaign by the energy industry. American Electric Power alone is spending 2.7 million dollars on an advertising campaign to convince the public that burning coal without pollution controls is the answer to energy problems. The oil companies are spending tens of millions more dollars on slight variations of a simple message. They want to produce more and more of the same kinds of fuels—oil, coal, gas and nuclear—at higher prices via greater tax loopholes and weaker pollution controls.

Only by their way, they say, will there be enough energy to continue our economic growth. Their version of the so-called crisis is that Americans and their government are not letting Exxon, Peabody Coal, El Paso Natural Gas, American Electric Power and other companies get away completely with their plans. Whether it is their way of stripmining, their way of offshore drilling, their way of tankering, their way of refining, their way of combusting and their nuclearizing, the fuel companies and their corporate customers (such as the automobile industry) are plunging the nation toward technological suicide.

Human beings are not designed to withstand the torrent of chemical, gaseous and radioactive materials being released into their air, water, soil, food and themselves. All over the country, citizens are being jolted into action by disclosures of the catastrophic risks of nuclear power plants and their deadly wastes.

The question is not: Are we willing to pay the price to burn fuel safely? Rather, the question is: Can we afford to continue paying the price of human disease and resource destruction resulting from the energy companies' policies? Contrary to impressions made popular by industry advertisements, it is economically cheaper as well as safer to make dramatic changes than to continue disastrous practices.

To illustrate: For decades, the fuel companies promoted or condoned massively wasteful consumption of energy. The more waste fuel in inefficient auto engines and non-insulated homes there was, the more sales were chalked up by the companies. In just three ways— doubling the miles traveled per gallon (from the present average 13.5 miles per gallon to a highly feasible 27 miles per gallon already achieved by some medium sized imports), insulating homes and buildings and improving the efficiency of home and commercial furnaces—the consumption of energy could be cut by nearly 30 percent a year.

There are dozens of other examples ranging from over-illumination of office buildings to more efficient air conditioners which could reduce energy consumption and save money year after year with little or no investment over the next few years. These savings (along with more prudent industrial, commercial and consumer habits) require no new inventions.

The suppression of technological efficiency which would have benefited the consumer has taken on additional dimensions. The fuel industry wants to sell oil, gas, coal and uranium. Yet with reasonable research and development programs, this country could develop far more abundant, cleaner and safer energy sources such as waste cellulose, solar and geothermal energy. Such development would obviously revolutionize the price and profit structure of the fuel industry if not put fossil fuels out of business entirely in coming decades.

Up to now, the government has done almost nothing on solar energy and its renewable fixation in plants, prefering to take its cue from the fuel industry. Since the oil industry has not had title to the sun or the renewable derivative energy sources, the government displayed no interest in subsidizing the sun's development here on earth.

Along with direct utilization of solar energy, indirect utilization of solar energy through enzymatic hyrolysis of cellulose waste should receive government support. Development of nuclear energy has received tens of billions of dollars in federal subsidies. By comparison, solar energy support has been less than 20 million dollars with the National Science Foundation providing 13.2 million dollars this past fiscal year. The U.S. Army Natick Laboratories have spent less than $400,000 dollars on enzymatic hydrolysis of cellulose waste as an energy and food source. And these comparatively minute expenditures occurred as an unplanned offshoot of an Army program to prevent deterioration of cellulose materials.

The Natick Laboratories are responsible for research for the prevention of deterioration of military clothing and equipment when exposed to the biological environment anywhere on earth. As part of that research, the laboratories have isolated 12,000 strains of fungi that biodegrade military supplies in order to prevent or control the degradation process. One of these strains, *Trichoderma viride*, was discovered to rapidly convert cellulose into glucose through production of the enzyme cellulose.

Available radiant solar energy in the United States is approximately 600 times our present annual energy consumption. The world-wide ratio is much higher due to the lower energy consumption in other countries. About 0.1% of the incident solar energy is fixed by green plants through photosynthesis. This process produces about 100 billion tons of cellulose per year, most of which is not utilized. Daily hydrolysis of only 1.5 to 3.0 million tons of waste cellulose could easily fill the largest industry alleged oil shortfall of 2.5 to 5 million barrels per day during the height of the Arab oil embargo.

Unrecycled U.S. paper wastes alone were 48.1 million tons in 1969. Using the Natick process, this could be turned into 24 million tons of glucose or about 3.26×10^9 gallons of ethanol with an energy content of 3.3×10^{14} BTU's. Indeed, through hydrolysis of rumen fibers the Natick process holds great promise for reducing solid wastes from animal feedlots.

A 100,000 cattle feedlot annually produces 150,000 tons of dry organic wastes that can be hydrolyzed with almost the same efficiency as wastepaper to ultimately produce 7.14×10^6 gallons of ethanol with an energy content of 7.31×10^{11} BTU's. This is the energy equivalent of 6.1 million gallons of 100 RON iso-octane gasoline.

Enzymatic hydrolysis of cellulose yields glucose which can be utilized as an animal or human food. Glucose in turn can be converted into a number of other useful materials—single cell protein by microbial conversion; ethanol, acetone and other chemicals including antibiotics by fermentation; and chemical feedstocks by chemical conversion. For the near term research and development should concentrate on production of ethanol—a fuel with an energy content of 102,000 BTU's per gallon as compared to 120,000 for gasoline and 76,500 for methanol. Ethanol shows great promise as an automotive fuel and for use in fuel cells. Glucose and derivative compounds intended ultimately for human consumption must be carefully processed to ensure the elimination of potentially harmful impurities present in the cellulosic waste feedstock. There is no technical reason why impurities including lead, mercury and other heavy metals cannot be removed in an environmentally sound manner, but since such impurities have harmful health effects if allowed to enter the human cycle, additional care in research and development must be taken to ensure that this does not happen.

ETHANOL PRODUCTION

According to the Natick Laboratories, one ton of wastepaper produces ½ ton of glucose which can be fermented to produce 68 gallons of ethanol. Other cellulose waste materials including pot milled municipal wastes, paper mill wastes and animal wastes are about equally efficient in producing ethanol.

A. Ethanol as an automotive fuel

Depending upon the availability and price of gasoline, ethanol has had extensive use as automotive fuel. During World War I and II, ethanol was used extensively in Europe. Since World War II, Cuba has continued to use alcohol as a motor fuel due to the ready availability of sugar cane. In reviewing the use of alcohol as a fuel, even the American Petroleum Institute concludes that the cost of alcohol is the greatest obstacle to its use as an automotive fuel. The petroleum industry has now taken care of that objection itself with the recent drastic increases in gasoline prices.

If there is no water in the gasoline, ethanol can be added to the gasoline without problems. The most likely blends are 5 to 25% ethanol. Due to the leaning effect of alcohol on the air-fuel mixture, only the carburetor may have to be adjusted to utilize this fuel.

B. Ethanol for fuel cells

A fuel cell produces electricity directly from hydrogen or other clean fuels by electrochemical reaction. Contrary to most present electrical power sources, the fuel cell utilizes a clean fuel and air to produce electricity directly at the site of application without any intermediate transfer step. In essence, fuel cells have served as operational power sources for Gemini and Apollo spacecraft. The power output may vary from a single kilowatt to a 100 megawatt.

Ethanol can be used as a fuel for a fuel cell by reforming the ethanol into hydrogen and carbon dioxide. The hydrogen then reacts at the anode and oxygen at the cathode to produce electricity. The conversion efficiency of fuel cells is higher than that for any other present stationary or mobile power source. According to the National Academy of Sciences' Panel on Alternative Power Sources. The overall thermal efficiency (of vehicles powered by fuel cells) has clearly been proven to be at least twice as high as that of the gasoline engine in average use.

In addition to the energy efficiency of the fuel cell, the importance of the fuel cell may lie in curbing the monopolies of the oil industry and the utilities. Consumers could have their own electrical power plants for home use. Motor vehicles would become less dependent on the oil companies for gasoline.

GOVERNMENT POLICY

The enzymatic hydrolysis of cellulose to glucose has been experimentally demonstrated by Dr. Mary Mandels and her associates at the U.S. Army Natick Laboratories over the past ten years. Conversion of glucose to other useful products involves an application of known technological processes. The U.S. Army already holds two patents on the basic hydrolysis process. The Natick Laboratories are building a pilot plant for the basic process.

Beyond this point, there is no set government policy or funding. Samples of the enzyme and royalty free licenses are freely given by the Army. Yet the private sector has shown little interest in applying this technology. In the alternative fuel area, the reason is clear production of ethanol through enzymatic hydrolysis of cellulose is a displacement technology just as is the development of small fuel cells for automobiles and homes.

Such non-technological barrier to innovation are more decisive than those technological barriers which can be resolved through research and development. Non-technological barriers can only be resolved through changes in institutional structures such as breaking up of monopolies through strong enforcement of the antitrust laws or other government policies to lower the artificial but powerful barriers to enterprise innovation.

In the instant situation, significant government research and development, not the few thousands of dollars spent thus far, are required to fully demonstrate the technology. If found viable as all presetly available evidence indicates, production and sale of ethanol and ethanol blend gasolines could be made in part, through a federal corporation, such as the federal oil and gas corporation as proposed by S. 2506, until such time as competition can be assured roots secure from cartelized predations.

The production of glucose and glucose derivatives via enzymatic hydrolysis for human and animal consumption is faced with lesser institutional barriers. The primary problem is demonstrating that safe foodstuffs can be made. If this can be done economically, then at the very least, beef producers who look for supplemental feeds should purchase the product. This is particularly true when soybean and feed grains prices are soaring.

Any patent licenses granted for use of the Natick processes should be on a non-exclusive basis. But licensing fees should be charged, perhaps with an initial royalty free period or volume to permit startup to an economical size. The funds from such licenses should be poured back into government research and development in extending the usefulness of this process. If the licenses process becomes a commercial success, all royalty fees should go to other clean alternative energy research and development.

Chairman **Proxmire**. So far we have had testimony from the people responsible for this development of Natick, Mr. Spano and Mr. Nystrom and Ms. Mandels. And they set forth what the findings were. We asked two MIT experts to go up and check the findings, and they appeared at hearings and verified the validity of the process, and indicated that in their judgment there were some very real economic prospects for substantial development of several energy sources and food sources, too, from this process of converting wastes.

Yesterday we had testimony from the head of the Federal Energy Office, and the head of the Environmental Policy Administration, Mr. Sawhill and Mr. Train, and from an expert in the Department of Agriculture, Mr. Schertz, the Economic Research Service, and from another independent expert, Mr. Altschul, of the School of Medicine of Georgetown University. The Federal Administrators' response indicated an interest, but indicated very little real knowledge of this process. And I think that they were enlightened to some extent by the testimony that we had yesterday, and by the particiaption of Mr. Reed of MIT in the process of the testimony.

At any rate, there seems to be very little drive or enthusiasm for moving this process at all. And as I say, even a complete failure to understand on the part of Mr. Sawhill and Mr. Train of the fact that ethanol had been used for years in Europe in many countries for the mixing with gasoline, that there has been an economic, obviously an economic disadvantage in using ethanol in this country until recently, but they didn't even appreciate that fact.

At any rate, we now are at a point where we have very helpful testimony from the industry itself. And it is particularly useful, because both you gentlemen are undoubtedly highly competent, and you disagree on the realistic prospects for using this. And, of course, Mr. Nader provides a highly expert consumer and public interest view which is of greatest value, because it is so hard to find anybody who ever brings that to bear on anything in the Congress.

MOBIL IN FAVOR OF EXPLOITING ALL POSSIBLE USES OF ETHANOL

I would like to start out, Mr. Clewell, by asking you, you conclude in discussing this process that using trash directly as a fuel would be more efficient than converting it to glucose and then ethanol, although you qualify your conclusions somewhat by pointing out that the tight supplies of liquid hydrocarbons might offset the economic considerations.

In view of our recent experience with tight supplies of oil and gas and the likelihood that this situation will continue and possibly grow worse, especially if the Arab oil embargo is renewed, don't you agree that it would be foolhardy for us not to exploit all possible uses of ethanol and other alternatives to additional energy sources?

Mr. **Clewell**. I agree completely. And I tried to make that clear in our testimony, that we are certainly in favor of exploiting all alternative sources, and all sources of possible energy. And certainly this is one of them, because it is derived from a renewable source. It is derived from cellulose, which is being created all the time on the surface of the Earth. When we work with the fossil fuels, of course, we are working with living material which was formed many years ago, and luckily was stored for us until we learned how to use it.

And so I am greatly in favor of doing that.

I think the statement I made, that it would be more efficient to use the cellulose directly by burning is simply to point out that some of the energy is wasted in converting it from one form to another. If you can use it directly, all of the energy is usefully employed rather than wasting part of it in a conversion to something that may simply be more convenient.

Now, in the case of gasoline, there is a convenience that is necessary. It has to be in a liquid form, it has to be portable, it has to be concentrated. We have to pay for that convenience. And in the situation where we are short of liquid fuel for automobiles, even though we may waste some energy in converting trash into fuel, we still should do it. We lose some energy, but that is part of the cost of making it convenient.

Chairman PROXMIRE. That is very helpful. I am glad to hear you clarify that. Because what you are saying is that we have a realistic situation where we need fuel for transportation purposes. And obviously you put the trash right into the gas tank and drive off.

Mr. CLEWELL. Exactly.

FIGURES ON SUPPLY OF AVAILABLE SOLID WASTE SUBJECT TO CHANGE

Chairman PROXMIRE. You say in your statement that adding 10 percent ethanol to gasoline would require more ethanol than can be made from solid waste in the foreseeable future. You back that up with statistics derived from the U.S. Bureau of Mines publications showing the number of tons of readily collectible dry organic waste and material.

We have talked to—the staff has talked to the man who wrote that report, incidentally. And according to your calculations, the amount of wastes available can be used to produce only 8 percent of the current total gasoline demand.

Now, as you know, all estimates about solid wastes are at best rough and subject to change. And you show that 880 million tons of wastes generated yearly, and only 136.3 million tons readily collectible—that is the joker, I think, readily collectible.

Would it be fair to say that if those numbers were significantly increased the 8 percent figure would also have to be increased?

Mr. CLEWELL. Yes; I think that is right. If we took all the waste generated, the 880 million tons, if we could collect all that and convert it it would represent 50 percent of our present gasoline demand. Of course, as you go deeper and deeper in trying to collect every bit of waste, the cost goes up. But I am sure that there is some kind of a break-even point.

Chairman PROXMIRE. I asked the Environmental Protection Agency to provide me with its most current estimate of the annual generation of solid wastes convertible to ethanol. According to EPA, this country produces 2.230 billion tons—that is 2 billion 230 million tons of wastes—which can be converted to ethanol, more than the amount shown in your figures. Included in the total are 90 million tons of municipal wastes, and 550 million tons of farm or agricultural wastes, and 1,560 million tons—I should say 1½ million tons approximately—of animal wastes, and 30 million tons of industrial wastes. On the basis of these figures doesn't it appear that your 8 percent estimate needs to be revised upwards?

Mr. **Clewell**. It could if those figures are right, because ours are calculated directly from estimates of what the wastes amount to.

Chairman **Proxmire**. This table was given to us by EPA. I think we can make the assumption that it is reasonably accurate.

Mr. **Clewell**. I think the only assumptions we have made are that the organic waste is on a dry basis, and that half of it is cellulose.

Chairman **Proxmire**. You reduce the amount of wastes generated to the amount readily collectible in your table?

Mr. **Clewell**. Right.

Chairman **Proxmire**. What do you mean by readily collectible?

Mr. **Heath**. That is a Bureau of Mines definition. They provided that statistic.

Chairman **Proxmire**. Isn't it true that the Bureau of Mines defines readily collectible agricultural waste as the amount presently locatable at certain centers, such as food processing plants, and that it excludes all waste back on the farm and elsewhere?

Mr. **Heath**. I believe that is right.

Chairman **Proxmire**. And wouldn't it be fair to assume that a greater percentage of total farm wastes generated would be collected than shown in your figures if a program was established in which an effort was made to collect it, or if some kind of a premium were placed on its collection? For example, the experience we had with returnable bottles, if you put on a 5-cents-a-bottle premium you obviously collect a lot more than if you don't.

Mr. **Clewell**. There is no question about that. You mentioned it yourself, you said how much effort. And, of course, that usually means how many dollars are you willing to put into it.

SHELL IN FAVOR OF THE NATICK PROCESS—CONVERSION OF SOLID WASTES TO ETHANOL

Chairman **Proxmire**. Mr. Berger, you say that Shell favors the continuation of efforts to convert basic materials into ethanol, and you point out that if gasoline prices rise or ethanol prices fall, the economic incentive will favor the use of ethanol as a motor fuel component.

But if I understand your statement correctly, you are not saying that Shell would be willing to invest any of its own money into this effort at the present time.

Now, if this is true, at what stage would you expect Shell to spend significant amounts in this area? Or would they, at any point?

Mr. **Berger**. Senator Proxmire, first of all, I must say that I am not accustomed to making policy for my company.

Chairman **Proxmire**. I am not expecting you to make any kind of commitment at all. But you are an expert. And you understand far better than most of us how these things operate. And if you could just give us some notion of what in your judgment it might be.

Mr. **Berger**. The notion I would try to convey to you is that we do not consider ourselves to be very competent in the area of biochemistry. And so we feel it would probably be better to leave that to people who are experts, such as the people as Natick. When it gets to the point that we can apply our skills and our abilities, I think we would use our human resources in that area.

CORPORATIONS OFFER NO MONETARY SUPPORT FOR R. & D. AT NATICK

Chairman **Proxmire.** Let me say, the reason that I ask this question is that Mr. Clewell says in his remarks that long-range research programs like this should be supported with Government funds, and that private industry should come in only when the commercial stage is reached.

I wonder if you agree with that position?

Mr. **Berger.** In this case I believe I would agree with it, simply because we consider ourselves to be not competent in the area of biochemistry. And right now we are in biochemistry.

Chairman **Proxmire.** Let me ask Mr. Clewell.

I would like you to explain Mobil's position in regard to investing in the conversion of wastes into ethanol. You not only want the Government to support all the long-range research, but if a commercial venture is high risk and is in the national interest, you would expect further Government support.

Have I correctly stated your position?

Mr. **Clewell.** Yes.

I will give you an example of that, if you don't mind a few minutes for a prologue to it.

You have to remember that in the research we carry on in our company—and I am sure this is true in all companies—you are competing for money that is not unlimited. There are lots of places that a company can spend its money, and if you want to do some research work, you have to show that it is going to be a worthwhile expenditure as compared to many other expenditures the company could make.

This usually means that we have to be pretty selective on the research projects that we undertake. This also means——

Chairman **Proxmire.** You calculate your return so that your opportunity costs—the money goes wherever the return is the greatest, is that right?

Mr. **Clewell.** That is right.

The risk may be very high, but if successful, the return may be tremendous. So we would take that kind of a risk if we could. We have to measure the benefits alongside the risk. If a little bit of money, even though it is very risky, could give a big return, you go ahead and spend it.

Now, the thing I had in mind in saying that it may have reached the commercial stage and still have a high risk is exemplified by shale oil development, where investments in the public interests could result in high losses to private industry. It appears now from the studies that have been made that we are talking on the order of $900 million or $1 billion to put in a shale plant of economic size.

Chairman **Proxmire.** You are involved in that?

BUT MOBIL INVESTS IN HIGH-RISK OIL SHALE R. & D.

Mr. **Clewell.** Yes; we are involved in shale research and development, though we are not putting in a plant now.

But even with that kind of expenditure, plus the operating costs, and some undetermined ecological costs in disposing of the spent shale—those are costs that are really not well pinned down yet—shale oil recovery could be a profitable operation, if you were sure that the price would be around $10 or maybe $12 a barrel.

Now, it is true that some crude prices are that high today, and some are even higher. But it would take some 4 years to get the permits and build such a plant. And at that time, 4 years from now, who can say what will be happening in the Middle East, or whether somebody has found a lot of oil in Indonesia or somewhere else? So would the $10 or $12 price still be there? If it has dropped, we would have made a tremendous investment, and we would have to shut down the plant. In a situation like that we would expect maybe to have some Government help, particularly if operating the plant at a loss is in the public interest.

Chairman PROXMIRE. I have the greatest respect for the profit orientation of our society; I think it has enormous advantages, and that it has been the reason for our driving success in many areas. But at the same time I also have to recognize as a U.S. Senator that we have a situation here where we have a very serious pollution problem. We have literally billions of tons of waste, and we have a great problem of removing that, and a transportation problem, and a great shortage of energy. If we do anything to put these together maybe by Government policies, recognizing, of course, that we can expect a considerable amount of cooperation from industry, but there are limits, because your stockholders wouldn't stand still for your putting your money into less profitable areas—we are groping here for some kind of a public policy which will enable us to exploit these potential fuel resources in a vigorous, effective way, so that we can achieve what all of us would like to achieve, helping the environment, and also providing additional energy.

Mr. CLEWELL. I agree with you. I think this Natick process fits in very well in that sense. It is really needed.

PROBLEMS EXIST, BUT MOBIL DID NOT INTEND TO THROW COLD WATER ON THE EXPERIMENTS AT NATICK

Chairman PROXMIRE. But now it does not move—and I get the impression from you, and I got the impression yesterday—although we have to wait for these studies, and maybe the Government will take a new look at it—I got the impression that there is a tendency to throw cold water on it, and hope it will quietly go away, and that we stay with the energy sources we have.

Mr. CLEWELL. I did not intend to throw cold water on it. I did point out that a lot of problems still exist. It is long range, and some of these problems are going to be pretty severe. I suppose you are asking whether we, Mobil, are going to put money into developing this further.

Chairman PROXMIRE. I understand your viewpoint. But it seems to me that you could be construed as saying that Mobil expects the Government to spend money for research and assume any high risks, and expects the taxpayers to pay for the risks, while private industry gets the profit. Do you believe this is consistent with the principles of free enterprise? Is there some way that we can adopt this, or does the taxpayer have to take the risk in our society?

Mr. CLEWELL. The Government has one advantage over industry in evaluating research projects of any kind. If we are going to put money into a research project, we do have to see the possibility of a return on investments. On the other hand, the Government can justify research expenditures on grounds of improving national security, balance of payments, or the social welfare of the Nation.

MOBIL AGAINST A FEDERAL OIL COMPANY

Chairman PROXMIRE. What Mr. Nader suggested—and that is not just his suggestion, as he said—22 Senators are sponsoring a bill to provide for a Government corporation that would engage in energy production as a kind of a TVA yardstick or something of the kind—that is the option that I think industry would have in mind or would consider. Maybe you favor that. I am not one of those 22 Senators, but as I say, this is a very substantial group, bipartisan group of people, Republicans and Democrats.

Mr. CLEWELL. We are, of course, against the Federal oil company, because it would operate under tremendous advantages over a private company. They would get the choice leases, and they would get very cheap money, and so on, for all their developments. All I can say is, wherever we have competed with a national oil company in some other place than in their home country, we have always beaten them.

Chairman PROXMIRE. Let me ask Mr. Nader to comment.

Mr. NADER. Regarding what?

Chairman PROXMIRE. Regarding what we would do about this kind of a situation. We seem to be stalled in neutral with a program that seems to have a lot of possibility. We hope, but we cannot be sure yet that they will be able to produce in a big way. But on the assumption that we can move ahead, how do we meet the situation where industry understandably is very reluctant to move ahead because they cannot see the profit as compared with the risk involved? At the same time we have to recognize the political facts of life with Congress—as you said, you do have 22 Senators sponsoring the Stevenson yardstick approach, but that is not 51. You have to get it through the House and get it over a Presidential veto. And what are our options here? How can we move ahead?

NADER STRONGLY SUPPORTS THE FEDERAL OIL COMPANY CONCEPT

Mr. NADER. I think there are several points to be made. First of all, I was delighted to hear the gentleman from Mobil say that in competition with national oil companies abroad they have beaten these national oil companies, so that they certainly should not fear the establishment of a Federal oil and gas company.

Chairman PROXMIRE. He made the exception; he said, except in their own home territory.

Mr. CLEWELL. That is right. We have never beaten them in their own home territory, because they always have tremendous advantages of Government subsidization and protection.

Mr. NADER. I think the oil companies have tremendous welfare subsidy advantages in this country, too. The proposal to establish a Federal oil and gas company, first, of all, is designed to minimize strategically any continuing subsidy of that operation, particularly in terms of raising its money in the capital markets.

Second, we have the TVA, which arose out of a crisis in Appalachia, of lack of electric power in the thirties. And if we listen to the oil industry, there is a similar crisis nationwide or worldwide in the area of energy.

More to the point of your question, we are dealing here with a situation where most of the new oil and gas that is going to be found, or is being found in this country, is on Federal lands. And Federal lands mean just that, they mean lands belonging to the people of this country. And so there is a very strong argument that can be made that a portion of the energy found on those lands should be developed by a Federal company with the return going back to the public.

There is also a strong argument to be made that if there is going to be a spurt of competition, that this Federal oil and gas company could provide that spurt of competition. It could also make sure that there is an adequate supply in any national emergency or contingencies, whether real or fabricated, in terms of keeping alive small business distributors which have been going out of business in large numbers in recent months. And it could also provide the public with clear data relating to costs, such as drilling costs. And I think on all these grounds, particularly environmental, and the research and development that the company could undertake, it is a very, very attractive proposal.

NADER CALLS FOR RESEARCH ON SOLAR ENERGY

Now, as far as this subject is concerned, how long are we going to wait for industry to decide whether a potential alternate energy resource happens to fit its pattern of a controlled and absolute rate of profit return? I think it is quite significant that the major source of energy that this world will ever have, the Sun, has received very little investment development by these companies. You see, it is not just that an energy source has to work as far as the oil industry is concerned, it has got to work in the oil industry's way.

Just to take an extreme hypothesis, suppose some investor developed a capsule that would sell for $20, and you put it in your home and you could heat and cool your home for 20 years. It is obvious that the oil companies would not be interested in that if that was going to displace a much more cumbersome and much more investment laden and profit return technology.

INITIAL RESEARCH SUPPORT FOR NATICK SHOULD COME FROM THE FEDERAL GOVERNMENT

When we come to situations like ethanol, we have got to give these technologies a brief period, analogous to the infant industry argument, where they can develop on their own merits, without being encumbered by certain patterns of exclusivity that have been characteristic of the oil industry. And that is why I think it has got to get initial research and development support from the Federal Government.

Now, depending on the speed with which a competitive system can develop to produce and market ethanol will decide on the extent to which the Federal Government will stay in the business.

Chairman PROXMIRE. You recommend significant Government research to follow up the Natick work rather than the few thousand dollars spent so far? Which Government agency do you believe is best able to do the research, and how much would you spend?

RESEARCH SHOULD STAY AT NATICK

Mr. NADER. Well, as far as the first question is concerned, you know there have been proposals to set up a new agency, ERDA, Energy Research and Development Agency, which is now pending in Congress. It could come under that Agency. However, if that Agency is controlled by the nuclear power people out of the AEC, nuclear power may tend to be emphasized at the expense of other forms of energy like solar, geothermal, or ethanol. So for the time being, I think it should be kept at the laboratories where it arose—the Natick laboratories—and supported there.

There is a certain insularity—there is a certain isolation that surrounds these laboratories from political penetration by special-interest groups. The laboratories can justify their work on the ground that the Army consumes gasoline in considerable quantities. And they already have the scientists who have been working on it. So I think it would be important to let it stay there and give it greater support. I certainly could not suggest at this point how much greater support is needed.

Chairman PROXMIRE. Let me get back to your recommending the production and sale of ethanol through a Federal corporation. Could you explain the rationale for this proposal, and of the details, and whether you would assign any role to private industry?

Mr. NADER. Yes. I would suggest that this not be monopolized by a Federal oil and gas company, but that it be simply a competitor. We have not traditionally thought of public enterprises in our country as competitors with private enterprise. It is usually thought of as either one or the other, You usually have a Federal monopoly, for example, the Post Office Department until recently, or you have full control by private enterprise. And I think the whole proposal of the Federal oil and gas corporation is not to make it exclusive, but to make it competitive, and not to make it able to endlessly draw on the U.S. Treasury, for once it gets its initial capital, it has to make it on its own. So I think in the area of ethanol, there are two stages: one, the research and development stage, which would have a heavy Federal involvement; and second, the production and distribution stage, which would occur out of a Federal oil and gas corporation as long as there was not a competitive process in industry to produce it.

Chairman PROXMIRE. Meanwhile, you would make the process—I guess right now they are completely available, but I guess there could be further advances—you would make those, as I understand your statement, available to a private industry, not on a free basis, but on the basis of a realistic and limited royalty?

Mr. NADER. That is correct.

Chairman PROXMIRE. Mr. Berger, would you comment on the practicality of this, as you see it? What happens if the Federal Government as a corporation has developed something of this kind, and you are free to move in, and the Federal Government's purpose, as I understand Mr. Nader, would not be necessarily to stay in business and monopolize it, in fact it would be quite the contrary, it would be to encourage private industry to take it over as soon as they could; in fact, they would take it over.

Mr. BERGER. It is my belief that if the products of that industry, of that venture, were available in sufficient quantity and at a price level which allowed that product to compete with alternates, we would certainly be most interested in it. One of the things I tried to bring out in my prepared statement was that if we consider ethanol as a fuel, we must consider it in the light of what other alcohols are likely to appear. And methyl alcohol is likely to appear. The published predictions for its price are quite low, and, therefore, I think we need to think of ethanol competing against methyl alcohol. It is these tradeoffs that will allow one to make a decision.

Chairman PROXMIRE. Do you think this is the best way to move along with this process? We are very interested in getting it moving. As I pointed out again and again, we have a great interest in seeing that we have this constructive use of our wastes. What do you think would be the way to do it, from your standpoint as a representative of an outstanding oil company?

BERGER, SHELL OIL'S REPRESENTATIVE, FEELS NATICK SHOULD RECEIVE GREATER MONETARY SUPPORT

Mr. BERGER. I really could not comment on that, Senator. I came here prepared to talk about the gasoline and alcohol blend.

Chairman PROXMIRE. I am simply asking, what do you think would be the best way, putting yourself, say, in the position of a Senator or Congressman, what do you think would be the best way for us to help move this along?

Mr. BERGER. I think that if I were a Senator or a Congressman considering this question, I would be inclined to look with favor on the Natick request for sufficient money for a pilot plant and a demonstration plant.

Chairman PROXMIRE. Would you go beyond that to Mr. Nader's suggestion of a Federal corporation?

Mr. BERGER. I would not want to go beyond that now. I think I would want to see the result from the pilot plant.

Chairman PROXMIRE. In the event that private industry does not step in and take advantage of the Natick process, then would you say there might be the basis for a Federal corporation?

Mr. BERGER. I would prefer not to comment on that.

Chairman PROXMIRE. Mr. Clewell, what is your reaction?

CLEWELL OF MOBILE SAYS NATICK SHOULD GET MORE MONEY

Mr. CLEWELL. My reaction is that this project is a very interesting one in its early phases. I think by far the best thing to do would be to give this particular laboratory more money to pursue the idea that they have. They need to have that pilot plant, and I would say as soon as possible. Down the road I am sure that we will find that Mobil will be looking at it, and I am sure a lot of other companies will be looking at it, whether they are oil or otherwise. Once it looks like some of these problems are being solved, I am sure that we are going to be very much interested in seeing how we can take advantage of something that is coming along here that is new. I like this particularly—because it uses a renewable resource and helps to solve a disposal problem.

Chairman PROXMIRE. Will you give us the benefit of that as time goes on? We are expecting within 60 or 90 days at the most, a feasibility report that is going to be joined in by EPA and the Federal Energy Office, they promised us that yesterday. And I did request in my letter—this is specifically what I wrote you on May 10 when I asked you to appear, I said:

> I would like you to help me evaluate the new technology and its potential use, and I would also like you to address the policy issues inherent in the new technologies. Those issues, as I see them, include the rôle of the Government and private industry in furthering the application of the new technology and the plans your company has for it.

So I realize again that we would like to have this feasibility study first from these two agencies, but we would like you to give us that advice on a continuing basis as we move along.

Mr. Nader.

SOME ADDITIONAL POINTS ON WASTEFUL POLICIES BY THE OIL COMPANIES

Mr. NADER. Senator, I think a couple of additional points might be made here.

First of all, the Government does monopolize the enrichment of uranium, so in terms of the enrichment of uranium to supply the nuclear powerplants, there is a precedent there, although it does have security aspects and problems.

Second, Consolidated Edison in New York, has just pushed through the State legislature in New York a law which compels the New York State Power Authority to buy two of its plants which are now under construction.

And three, as I understand the oil company's inference in recent weeks, it is that if the price of foreign oil goes down substantially below the price in this country, they are going to want the imposition of oil import quotas reestablished by the Federal Government.

The oil companies have also been receiving subsidies in the form of tax preferences for many decades. So that the theme behind these examples illustrates that when it benefits the policies of these private companies, they are all too willing and demanding of Federal participation, Federal protection of Federal subsidy. So that when we talk about a Federal oil and gas company, we are not breaking any new ground in terms of the entry of the Federal Government in energy policy, except for the direction of that entry. This direction presumably by a federally owned gas company would be for consumer protection and the protection of small business freedom to compete in a fair economy.

For years the Federal Government has been deeply involved in terms of protecting the oil companies, and putting them on a form of welfare through tax preferences, import quotas, and most recently, on a State level—and it is a serious trend—the passage of State laws which require the purchase by State authorities of private utility plants, such as the Consolidated Edison example, which some sources in New York think may not be a lone one in the coming years throughout the country.

The second point I want to make is that the waste of energy in our economy is not a waste from the point of view of the sellers of energy. If they can sell energy in a wasteful manner, they sell more energy and they make more sales and they make more profits. For instance, obviously the oil companies are selling more gasoline, because of the inefficiency of the internal combustion engines. Obviously, the electric utilities have been selling more electricity over the years with their inverted rate structure and their promotion of electrically heated homes, and so forth. So, although waste has a pejorative connotation from a consumer point of view, it is a way of sales maximumization from a producer's and seller's point of view.

Furthermore, I think the committee could benefit by obtaining data as to the range of waste of natural gas which is flared off in the North African and Mideast fields. The reason why I think this is important is that if the process of converting this natural gas to methanol can be developed, it opens up much greater opportunity for the shipment of an energy source to the United States and other European countries that is now being completely wasted. One estimate I heard is that the amount of natural gas being flared in Saudi Arabia in 1 year is equivalent to 16 percent of the U.S. consumption of natural gas. And I think it would be important to get some sort of estimate from the oil companies as to the amount of natural gas that is flared off in the Mideast and North Africa and Venezuela and Nigeria, and other oil fields, in order to see what the potential is of converting a 100-percent waste factor via methanol into usable energy for the world's needs.

And the other point on waste, I would like to refer to Mr. Ditlow on the octane situation.

Mr. Ditlow. There is another example of the oil industry not elimianting waste. And that is in octane posting. In 1970 the Department of Commerce indicated that consumers, through octane overbuying, that is, purchasing a 100 or 94 RON gasoline instead of 91, when the vehicles could run on 91 RON, cost $300 million a year. In 1974 the octane overbuying amounts to a billion dollars a year, and it amounts to a waste of at least 8,000 barrels per day of gasoline. Now, this is one situation that can be corrected by matching up the octane sold to the vehicle in use. In 1974. 40 percent of the vehicles could run on a 91 RON fuel. And yet, only 5 percent of the gasoline sold is 91 RON. This is a waste of energy which the oil companies do not correct by posting the octane numbers in a compatible manner with the octane listed in the owner's manual which is the RON basis.

Chairman Proxmire. That is a very good point. I have been trying to push that for a long time.

Mr. Clewell is very anxious to comment. But before I get to that I would like to say, Mr. Nader, the difficulty with a Federal corporation has been viewed in several ways. Some of them, I suppose, are wrong because they are contradictory. One is that such a corporation would be kind of a step toward socialism, and it would be a tremendous governmental monster that would compete with great force and power against private industry. And the other is that it would become a creature of the industry itself, which has happened to Government regulatory agencies, so that the people affected would get closer to it, lobby it, and get appointed to run, and tend to dominate it, and that it would be something that would tend to be a drain on the taxpayer, because it would be run not from the standpoint that those who conceived the corporation to begin with had in mind, but from the standpoint of those who had the most continuous and persistent economic interest. And in either event, great as our hope might be for it, it would be unlikely to flower as we would like it to.

Mr. NADER. As far as the ideological point, I just refer to the prior comments which I made about the activity of Consolidated Edison and the TVA example, and the many policies which the oil companies have posted here in Washington which have led toward the nationalization of consumers by the oil companies rather than the reverse.

As far as the second point, that is a real problem. It could become a creature of the industry, and it could display attributes that are certainly not in accordance with the purpose of protecting the consumer and fostering competition. And that is why I think the most important effort in structuring this corporation should be to make sure that it is democratically responsive to those whom it is supposed to be helping. And in concrete terms, that would mean establishing a kind of Federal cooperative form of oil and gas corporation where citizens would have a share in it. To the extent that Federal lands were being exploited, these resources belong to the people.

If a Federal company is going to exploit these lands, the people should benefit. And they should also have a very strong role in deciding policy. So it does not fall under the control of a few Presidential appointees which come from the oil companies or the coal companies and run it accordingly. We do not want the parallel of the U.S. Postal Service, where a system was designed by businessmen to replace the old Post Office Department, and now it is staffed by businessmen, and not running in accordance with the critical postal needs of the ordinary citizen. And it is also being undermined by companies that are taking off the more profitable top of the postal business, leaving the most heavily subsidized area to the U.S. Postal Service. I think we have got to structure it in such a way so that it is controlled not by bureaucrats or political appointees, but it is controlled on a consumer cooperative-type basis.

Now, we have in the Midwest in particular plenty of precedents dealing with consumer co-ops. They do not deal with energy except for rural electric cooperatives, of course, but with other areas of the economy, particularly with food. But I think it is time to resurrect the old idea of a cooperative economic enterprise, and apply it to new technologies.

Chairman PROXMIRE. I wish you would give us as much documentation on that as you can. I think that those Midwestern consumer cooperatives by and large, are not governmentally oriented, except that there is a governmental mission in which they function, and this might not be appropriate. We would be very interested in the kind of legislation which would provide the protection on that.

Mr. Clewell.

WASTE FROM THE LOSS OF FLARED GAS

Mr. CLEWELL. This goes back quite a few minutes to something Mr. Nader said.

This flared gas in the Middle East and other places around the world is something the oil companies have been very much concerned about for a number of years, especially right now, because here is energy being wasted. There are several ways to correct that. In the first place, we can put a lot of it back in the ground to keep pressures up in the reservoirs and assure greater ultimate recovery of oil. Hopefully, by the time the gas comes back again, we will know what to do with it.

Another thing being done is to liquefy it, because the basic problem is how to get the gas from there to here. You cannot build a pipeline across the ocean. So we are looking into liquefaction processes, and some are going ahead. However, competing with that is converting the gas to methanol. There are also very serious studies on that. We have made some ourselves. And I think there are some commercial operations very close to being started to bring methanol made from gas in the Middle East into this country and burn it directly as a fuel.

Chairman PROXMIRE. Would you agree with Mr. Nader's estimate that the gas wasted is about 16 percent of the total gas consumed in this country?

Mr. CLEWELL. I do not know the number. That may be it.

Chairman PROXMIRE. What was it, 16 percent of our consumption in this country?

Mr. NADER. This was an estimate made about 3 years ago, that the amount of natural gas flared in Saudi Arabia would be the equivalent of 16 percent of our natural gas consumption in this country. It would be nice to nail it down more specifically.

Mr. CLEWELL. We can get an estimate if you want it, a good one.

Chairman PROXMIRE. We would like to have it.

Mr. CLEWELL. I would like to say one other thing.

There have been a lot of comments here that we are only interested in selling our fuels, and the more inefficient our customers are in using it, the better it is for us. And that is just not the truth. In our business, we compete with all the other oil companies. Mobil competes with Shell and Exxon and all the others. For many, many years, we have been doing everything we can to show a customer that if he will buy one of our products, one of our lubes, or even one of our fuels, he can save money. By doing that, we get more business. And we find that our rates of return and the viability of our own company are increased by giving the customer just as much benefit as we possibly can.

Chairman PROXMIRE. I do not see how that necessarily contradicts Mr. Nader's position, which is, as I understand it, that you have a situation in this country where you have enormous automobiles, unnecessarily big, and at long last we are beginning to recognize that, where we have a great advertising campaign to encourage people to use electricity in all kinds of ways, and where we have people build so that the more they use the less they are charged on their electricity. I am not saying Mobil is responsible or Shell is responsible, but I say that this is something which has greatly expanded your market. And it is an element in your profitability. I am not saying you did it, but it is there.

Mr. CLEWELL. Well, the individual actions of our company have always been—and I am sure this is true of most of the other oil companies—in the direction of trying to give the consumer more for his money than he gets from some other company, because those are the things that do him more good.

NO ADDITIONAL INVESTMENT IN REFINING FACILITIES FOR ETHANOL AS A FUEL

Chairman PROXMIRE. Mr. Berger, you indicate in your prepared statement that alcohol could be added to gasoline "without additional capital investments in refining equipment." Do you mean to say that the process of blending ethanol with gasoline would not require any capital costs to Shell?

Mr. BERGER. It would not require any capital costs for refining equipment. It might take some blending facilities.

Chairman PROXMIRE. Would you agree with that, Mr. Clewell?

Mr. CLEWELL. Yes.

Mr. BERGER. The comment I wish to make, Senator Proxmire, had to do with gas consumption. And the statistical abstracts from 1972 reveal that in 1971, the U.S. consumption of natural gas was 24 trillion cubic feet. That same volume indicates that the flare of gas burning in Mideast countries, not just Saudi Arabia, was 4 trillion feet, which turns out to be 16 percent.

Chairman PROXMIRE. So that confirms the figure that Mr. Nader gave.

Mr. Clewell, you pointed out that ethanol has less energy content than gasoline——

Mr. CLEWELL. Per gallon.

Chairman PROXMIRE [continuing]. And you used this to make your price calculations. Mr. Berger makes a similar assumption, saying that a gallon of ethanol will enable a car to travel two-thirds of the distance obtained with a gallon of gasoline. Now, we have the testimony based on experience with alcohol blends that there is in fact no loss of energy, and that the mileage per gallon appears to actually increase with a 10-percent mix. In addition, I received Exxon's statement for the record[1] of these hearings last night, and Exxon says the following, and I quote:

> MORE FUEL ECONOMY IN ALCOHOL-GASOLINE BLENDS
>
> Most of the available data show that alcohol-gasoline blends give a slightly better fuel economy than predicted from their Btu content. This is not due to this combustion characteristic per se, but rather to the fact that they change the air-fuel ratio.

Will you comment on that?

Mr. CLEWELL. I have an expert here on that.

Mr. HEATH. I would like to talk first about the statement that you get more mileage, the Exxon statement.

No two automobiles are the same. In our business we frequently test a number of cars off the same assembly line for different purposes.

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[1] See Exxon's statement, beginning on p. 225.

If you take 25 Chevrolets of the same make and model and test them all for octane requirement, for example, you will find a range of maybe 10 numbers in octain requirements between the lowest and the highest. Now, similar things apply to the rest of the automobile. No two of them are the same. In the design of carburetors, the builder compromises between emission standards and the driveability of the car in establishing how the carburetor is set. But still no two of them come off the assembly line exactly alike. If economy tests are made and by chance you get a carburetor that is a little bit rich, the mere substitution of an alcohol blend will, in effect, lean out the carburetor, which will improve the fuel economy. Thus, in some of those cars you will get slightly better economy, but many of them will suffer some loss in driveability; that is, they will perform poorly. If these cars had been designed for alcohol blends with the same compromises between economy and performance that were made when they were designed for gasoline, the fuel economy would have been the same, as expected from the energy content of the blend.

Chairman PROXMIRE. May I just interrupt to say, Mr. Heath, that the day before yesterday we had very fine testimony from Mr. Thomas Reed, who is here, who said that he conducted these tests over a period of time, and that he had found over a period of time that this economy factor was better with ethanol. I would like to ask you if you or any other oil company, petroleum company to your knowledge, has conducted any comprehensive testing in your laboratories or elsewhere, and whether you can give us the results of it or document any findings that would contradict the testimony of Mr. Reed using ethanol, not methanol.

Mr. HEATH. Mr. Reed was using methanol, I believe.

Chairman PROXMIRE. That is right.

But either one would be fine.

Mr. HEATH. One of the reports attached to our statement was a 1971 study by the API trying to summarize all the information that was available on using alcohols in motor vehicles. API has reconstituted a group to make a new study to update the ethanol booklet and put out a new one on methanol. These should be available in the fall.

The testwork that Mr. Reed did, if I read his testimony correctly—I was not here when he gave it, but I read it—said that he was testing his personal cars. And I assumed this was a few cars. We are also testing a few cars on methanol mixtures at the present time.

Chairman PROXMIRE. As I understand it, API has said that they did no tests to come to the conclusions that they came to in what they believe so far, and that they furthermore do not contemplate any actual tests in the release that they expect to make this fall, simply a compilation of the literature in the area, but no actual testing; is that right?

Mr. HEATH. This would be right. The companies that participate in this, if they have test information available, will probably contribute it. We have been solicited for any test information we would have to contribute to that study. So they will be able to gather any information that is currently available in the industry.

Chairman PROXMIRE. Now, Mr. Clewell, you suggest that to apply a fair tax, the tax on ethanol should be somewhat higher than the tax on gasoline because of the lower energy value of ethanol. In addition to what was just pointed out by the performance with alcohol blends, ethanol burns much cleaner than gasoline and produces less pollution. Mr. Berger has a table in his prepared statement showing that carbon monoxide and nitrogen oxide emissions are reduced with methanol blends. Why should not taxes be less for alcohol blends than for gasoline, or entirely removed to give an incentive to pollution-free fuels?

Mr. CLEWELL. In my testimony, I said the tax should be less. And that would permit a higher cost for ethanol.

Chairman PROXMIRE. The tax is less. And that would increase the likelihood of it becoming more economic.

Mr. CLEWELL. Right. That is in my testimony. The tax would be less for the very reason you are saying.

Mr. HEATH. We said it should be, but we cannot control the State governments or the Federal Government.

Mr. CLEWELL. But as far as the emissions——

Chairman PROXMIRE. We appreciate the suggestion. We can do something about that.

Mr. CLEWELL. Our suggestion in the testimony was that the tax should represent this different energy content of ethanol versus gasoline. And therefore, the tax per gallon could be less.

Chairman PROXMIRE. Why should it not be much less based on a pollution-free content?

Mr. CLEWELL. But we are not sure that there is any advantage on pollution——

Chairman PROXMIRE. Mr. Berger said there was.

Mr. CLEWELL. I know. We just do not understand it. We have to talk to him.

Chairman PROXMIRE. Did you want to say something, Mr. Berger?

Mr. BERGER. I would like to back up to this question of mileage, because I still have the feeling that there is some confusion on this point. And at the risk of boring you, I would like to say that aerodynamically, you cannot make a car go further when you use a fuel with a lower energy content. Now, when Mr. Reed observed results to the contrary, it means that an artifact had appeared. And if he had taken his carburetor and adjusted it to the same equivalence ratio that it would be if he were running it on gasoline, he would have received the same increase in miles per gallon that he achieved for his alcohol gasoline blend. In running his car on the blend, he went to a leaner mixture. So the comparison in this instance fails to take into account the difference in leanness. It is this factor that is causing the confusion with regard to miles per gallon.

Chairman PROXMIRE. Exxon came up with the same conclusion that Mr. Reed did. And they based it on their tests. I will read their conclusion:

> Most of the available data shows that alcohol-gasoline blends give a slightly better fuel economy than predicted from their Btu content. It is not due to this combustion characteristic per se, but rather the fact that they change the air-fuel ratio. The predicted change in fuel economy is exactly borne out in recent tests that Esso research conducted on three cars, using a 15 percent methanol blend, one rich, one lean, and one in between, and equipped with a catalytic converter for exhaust emission controls.

And then they give the data in the testing.

Mr. BERGER. Without saying that, I think that that is virtually identical with what I have said. We are talking about predicted miles per gallon. The predicted miles are derived from Btu's per gallon.

Chairman PROXMIRE. They say it is better than that.

Mr. BERGER. They say it is slightly better.

ARMY PATENT POLICY AND THE NATICK PROCESS

Chairman PROXMIRE. I will have to find out how much that is.

Mr. Nader, the Army has never charged royalties on a nonexclusive license. It is not clear whether the armed service procurement regulations would even allow royalty charges on them. What do you suggest be done about this?

Mr. NADER. If it requires new statutory authority, then that will be needed.

Chairman PROXMIRE. Now, considering the poor record of the Army in creating even minimal interest in its patents, and also its inability to charge royalties on nonexclusive licenses, do you think it would be wise to move the R. & D. effort on the Natick process from the Army to another Government agency or department?

Mr. NADER. As I said, I do not think at the present time—there tends to be a disruption of a research team's effort when a move is made like that. And until we see whether the new ERDA bill is going to be outside the control of the Atomic Energy Commission people, it is best to keep it where it is. If in 3 or 4 years the ERDA is established and it gives equitable attention to all alternative forms of energy, and is not dominated by one school of thought such as the nuclear school of thought, then perhaps the work can be shifted over or extended under ERDA.

Chairman PROXMIRE. At the present time, you should know that there are few takers for the Natick patents, although there is no royalty charge on them. If royalties are charged, might not that just postpone the day when this process is going to be used?

Mr. NADER. No. I think, first of all, royalties do not have to be very stiff. But if someone is willing to pay royalties, it is likely that they are more willing to develop it, whereas if it is without royalties it might be just show.

Chairman PROXMIRE. When they pay the royalty it is reflected in the price of what they sell, so the taxpayers get it both ways, they have to pay in the first place for the research, and then I guess they get it back, but they seem to have to pay again when they buy the gasoline. You argue, however, that there would be an offset.

Mr. NADER. Yes. And it could be a very modest royalty, that is, it could be a royalty set by the policy considerations that you are referring to. For instance, you would not want to have a very stiff royalty that would preclude a smaller business firm from developing the technology further.

Also, if the royalty funds go back to research and development and alternative energy sources, that is a good channel of use for the taxpayer's fund once removed.

Chairman PROXMIRE. Now, it is customary for income from the licensing of Federal Government patents to go directly to the Treasury and not to be earmarked for any particular purpose. To earmark the royalty from royalty payments, a statutory regulation may be needed. Can you suggest for the record what type of legislation we should have?

Mr. Nader. The problem in focusing on ethanol, for example, is that you are just assuming that it is developing as an isolated alternative form. If we look at what is going on in Congress now in terms of all the alternative bills, the overriding question is, should there be an energy R. & D. trust fund? No; if the Congress is willing to fund ERDA sufficiently—there is a bill which passed the Senate, which is $20 billion over a period of years, R. & D. bill—if the Congress is willing to fund energy research sufficiently, maybe there should not be a trust fund concept inserted. But if we look at the past, it would have been nice to have a trust fund over the last 10 years. Things might have changed. We have to wait and see what Congress comes up with this year in terms of both Senator Jackson's bill and the ERDA bill, in terms of (*a*) its funding, and (*b*) its independence from one type of technological school of thought, such as nuclear power.

Chairman Proxmire. I would like to ask both Mr. Berger and Mr. Clewell to respond. Both Mobil and Shell are fairly large defense contractors. Mobile defense contract awards totaled $98 million in fiscal 1973, and Shell's defense contracts were $36 million. Can you tell us whether any of this money went for research, or whether Mobil or Shell uses defense or other Government funds in its program, and whether either company receives what is known as independent R. & D. from the Defense Department?

First, Mr. Berger.

Mr. Berger. I would assume that funds from sales to the military are to be mixed with funds from other operations.

Chairman Proxmire. You do not know of any specific research and development contracts or R. & D. contracts, or independent R. & D.?

Mr. Berger. No, I do not.

Chairman Proxmire. To your knowledge was this primarily the sale of petroleum to the Navy.

Mr. Berger. My assumption would be that all or virtually all would be the sale of products.

Chairman Proxmire. And I understand the Navy buys all of the oil for all of the services.

Mr. Berger. I cannot comment. I do not know.

Chairman Proxmire. Will you check with your company and let us know?

Mr. Berger. We would be happy to.

Chairman Proxmire. Mr. Clewell.

Mr. Clewell. At this moment we do not have any contracts of a research nature with the Government. And this income which you are talking about is derived entirely from the sales of fuels and lubricants. We have had some small research projects in the past on the order of a $100,000 or something like that. But at the moment we have none.

Chairman Proxmire. Is any Federal R. & D. money of any kind used in your research program? Do you get any Federal money at all?

Mr. Clewell. No. Not at this time. We have in the past a few projects. We had one with the Air Force on mist lubrication or something like that, I forget what it was.

Chairman PROXMIRE. Mr. Berger, would you check and see if there have been? We would just like to know. Because I think that might be appropriate for this process at some point, or at least ought to be considered.

Well, gentlemen, I want to thank all of you very, very much. This has been most helpful. I want to give the oil companies their due, they were more optimistic and encouraging than the Government witnesses. And I think that is to your great credit. I am delighted and surprised and pleased—I should not be surprised. But maybe I had better take a new look.

Mr. Nader, I want to thank you very much. You have been extremely helpful.

The subcommittee will stand adjourned.

[Whereupon, at 12:30 p.m., the subcommittee adjourned, subject to the call of the Chair.]

APPENDIX

Esso Research and Engineering Company,
Linden, N.J., May 21, 1974.

Senator William Proxmire,
Chairman, Joint Economic Committee, Subcommittee on Priorities and Economy in Government, Dirksen Office Building, Washington, D.C.

Dear Senator Proxmire: Exxon Corporation is glad to have the opportunity to respond to your request for technical information on the subject of using alcohols or alcohol-gasoline blends as fuels for motor vehicles. Most of our comments will deal with alcohol/gasoline blends, for it is here that we have most of our experience.

Although alcohols (particularly ethyl alcohol) have been used in gasoline in some countries in the past, we feel this experience is not complete enough nor reliable enough to indicate that such blends will not cause serious problems in the U.S. Considerable development and test work would be necessary to overcome known technical problems and to insure the compatibility of alcohol blends with today's types of vehicles and today's gasoline distribution systems. We therefore believe it would be premature to draw firm conclusions about using alcohol gasoline blends prior to the availability of such data. Both the Bureau of Mines and the AEC have ongoing programs to develop this kind of information.

The scientific basis for our conclusion is presented in the attached memorandum and may be summarized as follows:

A gasoline/alcohol blend will separate into two layers in the presence of trace amounts of water; with methanol this is 0.1% with ethanol about 0.4%. Inasmuch as almost all storage tanks in the gasoline distribution system have a water bottom, separation of the alcohol is very likely to occur.

Alcohols increase the volatility of fuels disproportionately. Such blends may not meet the volatility requirements set by the legislatures of several states, and they will undoubtedly contribute to serious vapor lock problems in some customer automobiles.

Fuel economy of alcohol/gasoline blends on the average would decrease on a mile per gallon basis, although older (pre-1968) vehicles would show a benefit on a mile per BTU basis and would also have slightly lower emissions. This advantage, in our judgment, is not enough to counterbalance the problems mentioned above.

In addition, while we have focussed on the technical features of alcohol-gasoline blends, we should note that consideration must also be given to comparative costs of ethyl alcohol, methyl alcohol, and other synthetic fuels; to the use of these fuels in other outlets; and to the consequent modifications necessary in petroleum refining and marketing.

Unmixed alcohols have certain desirable features as prospective fuels—they are easy to handle and store, and can be burned cleanly and with low emissions. These features of unmixed alcohols need to be taken into account in any serious attempt to decide whether to undertake large volume alcohol fuel production and to determine the optimum utilization of this supplementary fuel in view of national energy needs. For example, alcohols (and particularly methyl alcohol) make a very desirable fuel for land-based gas turbines for electric power generation. They not only are free of sulfur, nitrogen and ash, but they also greatly reduce nitrogen oxides emissions. This use of gas turbines is a rapidly growing field that will require considerable quantities of petroleum or natural gas. The substitution of alcohols will free petroleum for other uses, e.g. to make additional gasoline, thus helping solve the problem by indirect means.

We would also like to bring to the attention of the Subcommittee two related developments:

(1) A forthcoming conference on Methanol Fuel sponsored by the Engineering Foundation and scheduled for July 7–12, 1974 at New England College in Henniker, N.H. This will bring together a well-balanced group of technical experts from government, industry, and universities in order to examine the manufacture and uses of methanol from a variety of perspectives. Ideally this in-depth examination will establish a sound basis for appraising the merits of methanol fuel as an element of the United States energy economy.

(2) An ongoing study, sponsored by API, to assess all available information on the use of alcohols as fuels. This study will summarize many as-yet-unpublished findings and should be completed this fall.

We believe that a careful study of the material presented at the conference and in the API study will be helpful in making any decisions regarding alcohols.

We hope that our comments and the attached technical memorandum will be helpful to the Subcommittee. We would be happy to provide additional details on any aspect of this material, if the Subcommittee so desires.

Very truly yours,

R. R. CECIL.

Attachment.

EXXON EXPERIENCE WITH ALCOHOLS IN MOTOR GASOLINE

(Prepared by Esso Research and Engineering Co., Linden, N.J.)

Exxon Corporation, through its research affiliates, Esso Research & Eng. Co., has done research on alcohols as motor fuels, dating back to 1955. Both ethanol and methanol have been evaluated, and this research has been up-dated from time to time. Because these two alcohols are roughly similar in their behavior, both will be discussed here.

Alcohols are quite different chemically from the hydrocarbons found in gasoline and therefore impart a different behavior, partly good, partly bad. Among the advantages are somewhat better fuel economy on an energy basis and lower exhaust emissions for some cars. Among the disadvantages are a tendency to separate into two phases when even a trace of water is present, and an increase in volatility that would increase vapor lock. These four properties will be discussed at some length.

Alcohols as Motor Fuel—Advantages

Alcohol blends have two advantages over conventional gasoline: they give somewhat better fuel economy and somewhat lower exhaust emissions. Only the first of these is really important however, because as will be shown later, the decrease in emissions is not enough to obviate the use of catalytic converters; and if catalytic converters are used, the emission levels are already so low that the use of alcohols does not give any further improvement.

FUEL ECONOMY

In discussing fuel economy, it is better to talk in terms of miles/BTU rather than miles/gallon. Otherwise, alcohols are penalized unduly. This is because the heat content of alcohols is much lower than gasoline. Alcohols may be considered as compounds that are already partly burned. Methanol, for example, has only half the heat content of gasoline, and would require a gasoline tank twice the present size to get the same miles between fill-ups. However, the proper basis for comparison is mileage for an equivalent amount of energy.

Most of the available data show that alcohol/gasoline blends give a slightly better fuel economy than predicted from their BTU content. This is not due to their combustion characteristics per se, but rather to the fact that they change the air/fuel ratio. Because alcohol contains less energy (for the reasons stated above), when it displaces gasoline the effect is that of supplying less fuel to the carburetor, so the air/fuel ratio is leaned out. If the car was originally set slightly rich (i.e., slightly more fuel than can be burned completely) this leaning-out effect will improve fuel economy. This rich setting was typical for cars made before 1968. Present-day cars are set lean to reduce emissions; they would not be expected to show this improvement in fuel economy. By the time alcohols could be present in any significant quantity (1978) less than 15% of the cars on the road would be pre-1968.

The predicted change in fuel economy is exactly borne out in recent tests at Esso Research on three cars using a 15% methanol blend: one rich, one lean, and one in between and equipped with a catalytic converter for exhaust emissions control.

Fuel	Car		
	1967 (rich)	1973 (lean)	1975 (catalyst equipped)
Gasoline (miles per gallon)	14.3	11.2	11.4
Gasoline plus 15 percent methanol (miles per gallon)	14.4	10.6	10.9
Percent change (miles per gallon)	+1.0	−6.0	−4.0
Percent change (miles per Btu)	+8.0	+1.0	+3.0

These are single tests, but are in agreement with similar results from other researchers. It appears that the main effect of alcohol is in its effect on air/fuel ratio. Presumably the same effect could have been obtained with gasoline by adjusting the carburetor to run slightly leaner. Nevertheless, the overall effect of adding methanol is a positive one, giving more miles per BTU on the average, at least in the present car population.

Alcohols can also improve efficiency due to their higher octane number. Higher octane number does not give more miles per gallon directly, but it does allow the automotive manufacturers to increase the compression ratio of their future engines somewhat, and this increase could improve fuel economy by 3–5%. Cars already on the road would not be affected, so the octane effect on fuel economy would be observed only after several years of new car manufacture.

EMISSIONS

Alcohols also have an effect on exhaust emissions, and again this is almost entirely due to the effect of alcohols in leaning out the air/fuel mixture. The effects are somewhat complex; so, suffice it to say that alcohols uniformly decrease CO and unburned hydrocarbons in today's cars, while their effect on NO_x is either to increase it or decrease it, depending on whether the car was originally set rich or lean. This effect was predicted by existing references in the literature and was reconfirmed by recent Esso Research data:

	Exhaust emissions, grams per mile, Federal test procedure			
	Hydrocarbons	CO	NO_4	Formaldehyde
1967 car:				
Gasoline	5.2	83.0	6.4	0.13
Gasoline and 15 percent methanol	3.8	41.0	8.1	.20
1973 car:				
Gasoline	1.2	23.0	2.7	.07
Gasoline and 15 percent methanol	1.1	8.0	1.9	.10
1975 car:				
Gasoline	.07	.3	2.6	.002
Gasoline and 15 percent methanol	.10	.4	2.3	.004
1977 Federal standards	.4	3.4	1.5	

In the above table the "1975 Car" has a catalytic converter of the type expected on many 1975 vehicles. It reduced emissions to such a low level that the methanol had substantially no effect. Note also that methanol increased the formaldehye emissions. Formaldehyde is a potent eye irritant, but again in catalyst-equipped cars the formaldehyde level was so low as to be negligible.

The overall effect of alcohols on emissions is to give some improvement, but not enough to preclude the use of catalysts. With catalysts, the effect of alcohols is extremely small.

Disadvantages

PHASE SEPARATION

Alcohols are only marginally soluble in gasoline. The lower the temperature the less soluble they become. In present-day gasolines (which have a high aromatic content) both methanol and ethanol are soluble up to 10–15% if the gasoline is dry. However, even a trace of water is enough to cause all the alcohol to separate out. If this occurs, the alcohol layer does not have enough heat content to allow the engine to run. For this reason, the gasoline supplier would have to provide absolutely dry conditions whenever alcohol is present. In the usual distribution system—tankers, depots, tank trucks, service-stations—water is normally found in all tank bottoms. This does not cause any trouble with pure gasoline because water and gasoline do not mix. However, with an alcohol/gasoline blend, the existing water would cause almost complete separation of the alcohol. With current equipment and procedures, it is not possible to guarantee that water will be kept out of the distribution system. To use alcohols it would probably be necessary to have a separate alcohol tank at each service station and to blend the alcohol with the gasoline in a special proportionating gasoline pump. The required modification at stations is feasible, but expensive.

It is our opinion that once a dry alcohol/gasoline blend is delivered into the automobile, the chance of phase separation is fairly remote. We have not noted any instances in which such a separation occurred in our own tests, though it is reported occasionally in the literature. Concerns like this point to the need for extensive field testing before we would want to supply customers with an alcohol/gasoline blend. Even more, we would need to get field experience on the ability of our distributors to provide delivery of dry methanol to the service station, and that the methanol does not pick up water in the service station tank.

The addition of higher alcohols as mutual solvents to increase water tolerance does not appear to be an economic solution. One of the most effective of the higher alcohols is isopropyl alcohol. As shown in the table below, the addition of 6% isopropyl alcohol increases the water tolerance by a factor of 4, but even so, less than 0.5% water still causes separation.

PERCENT ISOPROPANOL IN 10 PERCENT METHANOL/GASOLINE BLEND	PERCENT WATER CAUSING PHASE SEPARATION AT 32° F.
0	0.08
3	0.20
6	0.36

This amount of isopropyl alcohol would greatly increase the cost.

VOLATILITY

Alcohols and gasoline are dissimilar materials as has been already noted. One of the well-known effects of blending alcohol and gasoline is a disproportionate increase in vapor pressure. As little as 2% of methanol, for example, can increase the Reid vapor pressure by 3 psi. Alcohols also tend to increase the evaporation of gasoline by forming low-boiling azeotropes.

The combined effect of these phenomena is to cause vapor lock. Vapor lock is a situation that causes difficult engine starting when hot, frequent stalling, hesitation, poor acceleration and sometimes complete failure to start. In several states, gasolines are limited by law in their volatility characteristics. An increase of 3 psi in Reid vapor pressure would cause the gasoline to fail to meet legal requirements in these states. Apart from the legal aspects, our current *predictive* equations would forecast a serious driveability problem for a substantial fraction of the cars on the road when using alcohol/gasoline fuels.

The driveability problem may not be as acute as predicted, because alcohol/gasoline blends may not behave exactly like gasoline alone. However, a priori, there is no reason to suspect that the situation would be different. Again a very substantial field test, involving several hundred cars, would be necessary to assess the severity of this problem.

It is important to note that the volatility problem cannot be solved by reformulating the gasoline. If the volatile components of present-day gasoline are backed out, two adverse effects occur. First, the low volatility alcohol blend will probably be very hard to start when cold (and will have very high exhaust emissions under these conditions) ; second, the light ends that are backed out will be downgraded in value. It appears that the most probable use for these compounds will be as boiler fuel. If this is true, it would be better to use the alcohol as boiler fuel directly, and thus obviate the many difficulties of using alcohol/gasoline blends.

Other considerations

In other respects, alcohol/gasoline blends do not appear to cause serious problems. In 1957 Esso Research conducted a small field test on 12 cars using 10% methanol in gasoline. The methanol was added separately (dry) to each car, and the gasoline was balanced in vapor pressure by backing out butane. No serious difficulties were found, although low-speed acceleration was poor (probably because of the lack of butane). There was no phase separation, odor, paint damage, or deterioration of fuel pump gaskets or diaphragms.

Methanol as the Sole Fuel

Racing cars frequently are designed to use methanol as the sole fuel. This is because methanol gives a slight "supercharging" effect. In passenger cars this advantage would be negligible. An experimental methanol-fueled Gremlin was entered in the 1970 Clean Air Car Race (and won), but we understand it had problems in startability, and formaldehyde emissions. Exxon does not have any first-hand data on such cars. It is our understanding from discussions with automobile manufacturers that there are many formidable problems to be worked out to design a methanol-fueled car that has as good all-around performance as today's cars. Ethanol would have a place intermediate to methanol and gasoline.

Other Uses for Alcohols

Lastly, it should be noted that it is possible to increase gasoline supplies indirectly. If alcohol can replace a petroleum fuel in another sector (for example, in place of distillate fuel oil for space heating), the fuel thus replaced can be, in effect, converted into gasoline. Alcohols have the potential of being used in place of virtually any other fuel except in aircraft (weight penalty) and diesel engines (low cetane number). Their only drawback is their relatively high cost.

One particularly advantageous use for methanol is as a fuel for land-based gas turbines. This is a very rapidly growing field and is expected to require a substantial amount of clean-burning low-ash fuel. Gas turbines have a potentially serious emissions problem with NO_x (nitrogen oxides) when used in large numbers. Methanol has been shown to give an 80% reduction in NO_x, and is thus a doubly-favorable fuel. It appears to us that such a use will solve a serious emissions problem, provide an additional fuel source, and avoid the problems already known to exist with the use of alcohol/gasoline blends in automobiles.

Summary

Thus, from Exxon's data there appears to be a slight advantage for alcohol in fuel economy, but two potentially serious problems with phase separation and volatility. These latter two problems will have to be investigated in much more depth than heretofore, before considering the use of alcohol in gasoline.

TEXACO, INC.,
1001 CONNECTICUT AVE., N.W.,
Washington, D.C., June 3, 1974.

Hon. WILLIAM PROXMIRE,
Chairman, Joint Economic Subcommittee on Priorities and Economy in Government, 5241 Dirksen Building, Washington, D.C.

DEAR SENATOR: With respect to the hearings on the use of ethanol as a motor fuel held by the Joint Economic Subcommittee on Priorities and Economy in Government, attached hereto is Texaco's statement. It would be appreciated if this statement would be made an official part of the record.

Very truly yours,

WILLIAM K. TELL, JR.

Enclosure.

STATEMENT BY TEXACO, INC.

Texaco appreciates the opportunity to present this statement to the Subcommittee on Priorities and Economy in Government of the Joint Economic Committee regarding the use of ethanol as a motor fuel.

Enzymes are capable of accelerating chemical reactions under mild conditions compatible with life faster than man-made catalysts. Most enzymes are very specific and catalyze only one reaction. Chemical reactions can be carried out very rapidly by enzyme systems without harsh reagents, high energy input or high temperature/high pressure vessels. Therefore, Texaco views with interest the reported U.S. Army Research Laboratory enzyme breakthrough which would allow ethanol to be inexpensively made from common organic wastes (cellulose).

The ability to use alcohol as a fuel in internal combustion engines has been well known for many years. Further, it has been used in foreign countries where gasoline is in short supply and has frequently been employed in the U.S. in certain restricted applications, such as racing, where its unique properties have made it attractive.

However, in the past, the high cost of ethanol, coupled with its inherent poor engine performance and water solubility disadvantages compared to gasoline, has negated the normal use of ethanol in motor fuels. The disadvantages and problems associated with ethanol as a motor fuel have been well documented in the literature. Without going into extensive detail, these include the following:

High latent heat of vaporization which contributes to poor starting and warm-up characteristics of vehicles.

Lower energy content per gallon which at a given equivalence ratio provides lower fuel economy in terms of miles per gallon.

Non-linear blending characteristics with respect to volatility which present problems in blending requirements as well as in tailoring blends to ensure satisfactory vehicle starting, warm-up, driveability and freedom from vapor lock.

Poor water/gasoline solubility characteristics which necessitate special complex and expensive handling facilities in the distribution of fuels.

Possible inability to use ethanol in significant gasoline blend proportions in current automobiles without expensive modification to the engines and meet stringent emission requirements.

All of the foregoing mitigate against the use of ethanol as an automotive fuel. Nevertheless, it is felt that should a process be developed which would allow the economic manufacture of ethanol for use in gasolines, petroleum companies would utilize such technology to expand the supply of motor gasoline.

We understand that the engineering aspects, and hence the economics for the Army's proposed process, are not yet firm, but that pilot unit and demonstration plant programs will develop the process and economic information necessary to consider building larger plants. In evaluating the manufacture of ethanol from cellulose, the numerous steps involved in the overall process must be considered: e.g., (1) producing, transporting, and protecting the enzyme, (2) collecting, storing, and preparing the cellulose raw materials, (3) converting the cellulose into glucose, (4) fermenting the glucose and recovering the ethanol, and (5) disposing of the waste products. Therefore, it is felt the cost figures for ethanol from this process presented thus far (20¢ per gallon) are highly optimistic.

Texaco plans to closely follow the results from the Army Research Laboratory Program regarding the production of ethanol from cellulose.

NATIONAL SCIENCE FOUNDATION,
Washington, D.C., July 9, 1974.

Hon. WILLIAM PROXMIRE,
U.S. Senate,
Washington, D.C.

DEAR SENATOR PROXMIRE. This is in response to your letter of June 20, 1974, to Dr. Holt Ashley of the National Science Foundation. Since responding to your letter concerning the "Natick" process for converting organic wastes to glucose and ethanol, a seminar on "Cellulose as a Chemical and Energy Resource" was held at Berkeley on June 25–27. Dr. Mary Mandels of the U.S. Army Natick Laboratories and Dr. Charles R. Wilke were organizers of the seminar. The discussions were frank and spirited and included all technical aspects of the research as well as of the economics of converting cellulose to glucose. Mr. Lewis G. Mayfield, Deputy Director for the Division of Advanced Technology Application in the RANN program, briefed a group from the Federal Energy Agency on the seminar and gave them a copy of the key paper on the economics of this process. It was quite clear that the process is feasible; however, much more research is necessary to refine the economic estimates and to improve the process. In the future it will be desirable to extend the research to include a variety of cellulosic materials in addition to newspaper.

I am pleased to note your interest in the enzyme technology program. The program has been in existence for four years. The two important program goals are to develop new and improved processes utilizing enzymes and to advance general enzyme technology. Over the last several years many products have been investigated by RANN grantees, with a number of them reaching the stage of proof-of-concept experiments. For instance, our interdisciplinary group at the Massachusetts Institute of Technology (MIT) has successfully synthesized the complex antibiotic material, Gramicidin S. Grantees at the University of Pennsylvania completed their work on glucose oxidation, which has been used as the basis of a new class of glucose analyzers recently introduced into the market by Leeds and Northrup Corporation. An enzyme reactor of a capacity of 1,000 lb/day has been in continuous operation at Iowa State University for two months producing glucose from starch. This project provides engineering design information and also has proven the long term stability of the immobilized enzyme system. Researchers at the University of Virginia have been successful in showing that viruses may be eliminated from an air stream using an enzymatic system. Industry is now examining this concept for the development of several new commercial processes for environment control. RANN grantees are investigating new enzymatic methods for fixation of nitrogen for fertilizer, for producing sweet syrups from liquid wastes like whey, and the enzymatic synthesis of chenodeoxycholic acid, a drug that can remove gallstones by nonsurgical means.

We believe that these successes confirm the great potential of enzyme technology in meeting national needs of increased industrial productivity, cleaner environment, better health and new food sources.

Onset of the "energy crisis" and the increase of food prices make all the more imperative the full and efficient utilization of renewable resources. The application of enzymes in the production of new foods and alternative fuels from such things as cellulose, hemicellulose and lignin in agricultural, forest, municipal and industrial wastes and in materials harvested from "energy farms" are increasingly important research problems. Nitrogen fixation by biochemical and enzymatic means, hydrogen generation by biophotolysis and others are all important research topics involving enzymes.

For your information I have enclosed copies of the Enzyme Digest which keeps interested scientists and engineers appraised of the program and enzyme technology development.[1] I have also enclosed Scientific Information Exchange summaries of projects in order to present a picture of the scope of the program.

Should members of your staff desire further information on the cellulose conference or on the enzyme technology program, I would urge them to contact Mr. Lewis G. Mayfield, Deputy Director for Advanced Technology Applications in the RANN program.

Thank you for your interest in the National Science Foundation's Research Applied to National Needs program.

Sincerely yours,

ALFRED J. EGGERS, Jr.
Assistant Director for Research Applications.

Enclosures.

[EDITORIAL NOTE

[The most abundant material in municipal solid waste is paper. It comprises about half the waste collected and deposited as landfill, or burned. In the manufacture of paper, for every 100 pounds of wood that is pulped, between 30 and 40 pounds of a waste material called "lignin" is removed at the paper mill. This waste amounts to some 12 million tons of lignin generated annually.

[The quantity of all wood harvested in the United States in 1970 for all purposes amounted to 12 billion cubic feet, containing some 75 million tons of lignin, more or less.

[The point of these figures is that an enormous quantity of lignin is produced in the United States as a useless byproduct of paper making and much of it pollutes surface waters. Non-polluting disposal of lignin is a burden on paper mills.

[If a commercially valuable use could be found for lignin in large volume, very large quantities could be made available.

[A letter is presented here that explores this theme. It is a proposal to mount a new kind of scientific attack on the problem of finding massive uses for lignin.

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[1] The enclosure referred to may be found in the subcommittee files.

The idea emanates from the Federation of American Societies for Experimental Biology. It proposes to develop a scientific campaign to manipulate the lignin molecule by enzymic decomposition, to produce a variety of hydrocarbon materials useful as gasoline supplements and plastic feedstocks.

[With the United States faced by rising prices for petroleum and demanding elimination of stream pollution, two economic trends are combining to encourage a new look at the old problem of finding a use for lignin. Undoubtedly there are other possible approaches than the one advanced by FASEB. However, it is presented here to demonstrate that the resources of science and technology offer untapped possibilities for improving our uses of the resources of nature.]

OUTLINE OF STUDY PROPOSAL

In view of the expanding human requirements for food and sources of energy, lignin is an available waste product of potential utility. At present, the vast quantity of lignin produced in the pulp and paper industry is a troublesome waste product. However, lignin and lignin degradation products can be used as substrates for microbial growth and can be converted to useful hydrocarbon products such as benzene, toluene, and other derivatives of phenylpyruvanate. Destructive distillation is currently used to produce benzene and related substances from lignin but recent advances in biochemistry suggest alternative methods may be more efficient.

Microbial enzyme systems already exist which are capable of degrading lignin or modifying native or sulfite lignin into several potentially useful degradation products. Similarly, bacterial protein, produced from wood wastes, represents a new source of protein for animal and human foods. The development of biochemical technology associated with the use of boundenzyme systems provides new impetus for re-examination of utilization of our huge reserve of solid and liquid forest wastes. For example, for every ton of paper pulp produced, there is approximately one ton of lignin waste which is produced as a waste product. In pilot plant studies, investigators have succeeded in producing liquid fuel from sulfite liquor. Using pulping fines, a paper waste, bacterial growth with protein yields up to 30 percent have been achieved.

There are no recent reviews of the opportunities to apply this new biochemical technology to efficient utilization of lignin and related industrial wastes. The Federation, through its Life Sciences Research Office, proposes to conduct an *ad hoc* review of the opportunities to apply new biochemical technology to the production of useful products from lignin wastes. This will involve an *ad hoc* group meeting of approximately 20 to 30 scientists representing several disciplines including microbial biochemistry, microbial genetics, bound-enzyme technology, petroleum engineering, and wood products utilization. These scientists would be asked to apply their collective expertise to issues associated with the utility of and impediments to efficient and economic degradation of lignin by new and novel techniques involving bound-enzyme systems. Based upon the discussions of the *ad hoc* review group, and an analysis of pertinent literature, a definitive report will be prepared by the Life Sciences Research Office.

Attachment.

FEDERATION OF AMERICAN SOCIETIES FOR EXPERIMENTAL BIOLOGY,
Bethesda, Md., December 17, 1973.

Dr. ARLEY BEVER,
Deputy Director, Office of Experimental R. & D. Incentives, National Science Foundation, Washington, D.C.

DEAR ARLEY: Outlined below is a statement of a problem of major importance to the nation, along with the suggestion that FASEB thru its Life Sciences Research Office undertake an initial assessment of feasibility and state of the art.

The United States consumed about 4500 million cu. ft. of pulp wood in 1970 of which 3925 million cu. ft. were produced domestically. The 4500 million cu. ft. converts to about 40 million tons. Approximately 30–40% by weight of pulp wood consists of a substance called lignin. The production of lignin therefore amounts to more than 12 million tons, i.e., 24 billion pounds.

Lignin consists largely of a polymer of phenylpropylene chemically known as polyphenylpropylene, although it is not quite so simple a substance as the name suggests. Lignin is not useful in preparing paper because it discolors and has other adverse qualities. The current practice in the paper industry is to separate cellulose from lignin, discarding the lignin waste into streams and rivers. In theory it is possible to convert 65% of lignin into a valuable aromatic hydrocarbon called toluene.

Lignins have relatively high caloric values; for example, the black liquor residue from the Kraft process has a heat content of 6000 BTU per pound. Attempts to create an industry based on spent liquors has been partially successful, not that chemicals are difficult to extract from lignin, but it has been difficult to meet the economic competition of the same chemicals produced from other sources because of the energy required to separate them from spent liquor.

In the United States in 1968, 27 million tons of Kraft black liquor solids were produced. Of this total, approximately 10,800,000 tons were inorganic salts used for the recovery of pulping chemicals and approximately 16,200,000 tons were organic material. Except for limited production of organic materials, practically all of this material is burned to provide heat for evaporation of liquor and to recover the inorganic chemicals. The estimated energy involved in burning the organic material includes the requirement for 2.6 x 10^{14} BTU on an annual basis to evaporate the black liquors with the subsequent release of 3.2 x 10^{14} BTU of heat energy released.

The wastes from the processes are discharged into streams. The lignin waste products contaminate and pollute and in the process of being oxidized, the oxygen in the streams is depleted killing fish and marine life. Lignin waste is a major source of pollution of the rivers. The Androscoggin in Maine, for example, is hardly more than a discharge pipe for refuse from paper mills.

Relevant and of interest is another factor. Petroleum companies in the manufacture of gasoline add aromatic hydrocarbons to improve the octane rating. Lead tetraethyl is used also for this purpose. Because of the potential hazards of lead tetraethyl, petroleum companies are now being required to reduce lead content in gasoline and totally eliminate the use of lead tetraethyl in pproximately 5 years. An increasing quantity of aromatic structures will be needed as additives to the aliphatic hydrocarbons in gasoline in order to obtain desired octane rating. An ideal additive is toluene.

Aromatics in the form benzene, toluene, phenylethane, and phenylpropane can be obtained from the hydrolysis of the lignin. Naturally occurring enzymes found in fungi present in rotting wood are capable of hydrolyzing lignin.

Enzymic decomposition of lignin is not only potentially feasible, but has the added advantage of not requiring a high expenditure of energy. NSF is already embarked on an enzymic technology program under the RANN operations. The use of lignin as raw material for gasoline additives would be a constructive use of a natural resource now largely wasted and would at the same time alleviate a major source of pollutants in many rivers and streams.

Until recently, production costs and other economic factors were not particularly favorable for producing benzene, toluene and other derivatives from lignin. It cost more to produce benzene and toluene from lignin than from coal and crude petroleum. The economic factors have been dramatically altered within the past year, as you are well aware.

The January 1, 1973 issue of Chemical and Engineering News had an article on page 9 indicating a tight supply and a higher price for benzene and its byproduct ethylbenzene which is used in the production of styrene—a further indication of the usefulness of the hydrolysis of lignin. I am confident that lignin available in large amounts, now discarded and a source of pollution, can be converted to a valuable raw material useful to the chemical and petroleum industry.

An initial step requires that knowledgeable people from the (1) paper industry, (2) the petroleum industry, (3) academic scientists expert in enzymology, and (4) forest product or agricultural economists be assembled in conference to examine the state of the art, technical feasibility and cost factors.

The Federation is capable of undertaking the task of evaluation and assessment and recommending appropriate action.

The Federation Board, recognizing that scientists have a special obligation not only to inform society about what is being done in the laboratories, but also about the possible opportunities and consequences associated with discovery, both positive and negative, in 1962 established a Life Sciences Research Office. The LSRO serves as an operational tool to mobilize special knowledge existing within the membership of the constituent Societies and scattered throughout the worldwide community of biomedical scientists. Upon request, and at cost, the Office has convened *ad hoc* review panels to evaluate and assess specific problems in biology and medicine. These discussions which frequently extend over several days are used to prepare reports for the sponsoring organizations.

Since 1962, the Life Sciences Research Office has prepared approximately 25 reports for various agencies within the Federal Government. These reports are available and can be ordered from the National Technical Information Agency of the U.S. Department of Commerce.

In summary, a problem of major significance to the nation is in need of attention and action.

Dr. Carr, Director of LSRO, and I would be pleased to lunch with you at your convenience to discuss the matter in greater detail.

With best wishes.

Sincerely yours,

EUGENE L. HESS,
Executive Director.

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