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FUELS/ENGINE INTERFACE RESEARCH: EDITED WORKSHOP PROCEEDINGS

September 22-23, 1981
Bartlesville, Oklahoma

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MEMORANDUM FOR Harry Johnson
Director, Bartlesville Energy
Technology Center

SUBJECT: Fuels/Engines Workshop Proceedings

It is our pleasure to submit to you the completed proceedings from the workshop on Fuels/Engines Interface Research held September, 1981. We believe you will find this to be an excellent discussion of the subject which fulfills our objective of identifying a rational research agenda in which industry, universities, and government could cooperate constructively.

This conference record is organized to reflect the actual events which took place over two and a half days. After the opening address, the members were divided into four small groups, each charged with a specific topic to discuss. The most important part of these proceedings are the reports received from these small groups and the resulting open discussion from the audience. Even on paper, these discussions reflect the insight brought to the various topics by the distinguished scientists present. The manuscript closes with a summary compiled after the workshop to present the conclusions in the most useful format possible.

The most obvious general conclusion was that there are important roles for both government and industry in this critical area of research. Only by working together can the full potential of emerging fuel/engine systems be realized. One result of the discussions was an attempt at providing a specific delineation of roles, as reported in the abstract and conclusions.

We believe the result of the workshop and our subsequent distillation of the discussions represents a significant and useful document. As much as anything else, this reflects the quality and quantity of work by those who led and participated in the small group sessions and open discussions. We were pleased to have had roles in organizing this effort and trust that this final product will be useful not only to the Department of Energy but also to all those involved in any way with research at the fuels/engines interface.

Ed V. de Palma

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Dennis W. Brinkman

Attachment

DISCLAIMER

ABSTRACT

Over 60 representatives of industry, universities, and government were invited to a two-day workshop focusing on the research needs at the interface between the fuels and engines industries as new fuels and new engine systems emerge. As a result of the many small group and plenary discussions, the following areas of research were designated as needing additional research and development. The areas are separated according to who should take the lead role in organizing the research.

Industry -

- Electronics and Microprocessor Technology
- Materials Development
- Market Strategy for Introduction of New Fuels
- Trade-offs of Fuel Quality
- Applied Combustion Kinetics
- Engine Life Cycle Costs

Government -

- Fundamental Combustion Kinetics
- Health, Safety, and Environmental Protection
- Physical and Chemical Characterization of Products from New Resources
- Severity of Processing vs. Fuel Cost
- Generation of Test Fuels
- Examination of Optimum Utilization of Resources
- Fostering Cooperative Research
- Emerging/Contingency Planning for the Fuels/Engine Interface
- Military Applications of New Fuels and Engines

Industry and/or Government -

- Reevaluation and/or Revision of Fuel Tests and Specifications
- Multifueled Engines
- Examination of Vehicle Fleets as a Mechanism for Introducing New Fuels

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INTRODUCTION

A workshop entitled "Fuels/Engines Interface Research" took place at the Bartlesville Energy Technology Center (BETC) of the U.S. Department of Energy (DOE) on September 22 and 23, 1981. The proceedings of this workshop are summarized in this report. Two days of discussions were focused on what research is the most critical for fuels and engines as both areas are expected to undergo significant changes over the next two decades.

Over sixty participants attended the workshop and included representatives of the major fossil fuels resource companies, as well as of a large number of engine manufacturers. This group was supplemented by personnel from commercial, government and university organizations conducting research in both fuels and engines technology. A complete list of attendees may be found in Appendix A.

BACKGROUND

The workshop grew out of the perception of DOE and BETC senior management that research needs at the fuels/engines interface were not well defined. In addition, contact with personnel from both industries indicated a need for and support for such a workshop. The requirement to better define research needs was heightened by the increasingly limited government resources that could be devoted to this area. Hence, it was especially important to understand the research needs, their proper priority, and the logical parties to sponsor and perform the needed work.

Thus, the purpose of this workshop was to identify and assemble a rational research agenda. Special attention was given to the needs for inter-industry and/or government cooperative projects. These efforts would include those projects clearly having benefits for all parties, while not being practical for each to carry out individually.

Data and information needs of both the fuels and engines industries seem to be increasing and may accelerate over the next 10 to 20 years. Already there is a trend toward the production of fuels from the refining of heavier crude oils which are more difficult to process. From these feedstock changes, fuels can evolve with characteristics that are different from past experience. Properties that are expected to change include a higher specific gravity, a higher viscosity, higher levels of sulfur, vanadium, and trace metals, as well as poorer ignition and combustion characteristics. These changes will accelerate as feedstocks from alternative sources are brought into commercial production.

Some types of engine combustion systems, by the nature of their basic design, are more able to use poor quality, minimally-refined fuels. For example, continuous combustion systems, both internal and external, do not require the strict specifications that the intermittent spark and compression ignition systems need. Some modifications can be made to increase adaptability, but, if fuels change greatly in quality or composition, engine designs must also change significantly. Proposed alternative fuels cover the entire spectrum from gases to solids.

Because of these potential changes, engine manufacturers and fuel suppliers are individually pursuing the development of their respective products. Each development program is driven by market forces and the probability of reward. However, there should be opportunities for these individual activities to exchange information and better coordinate their respective research programs to utilize our energy resources most efficiently. In this way, the development of future fuels can be guided by knowledge of the most probable new engine designs and engine manufacturers can allocate their development efforts so as to make engines available that can best use the new fuels.

However, the fuels/engines interface is very complex and the organizations which produce both products vary greatly in size. The largest of these enterprises are probably capable of doing much of their own development work and supporting research especially if directly related to commercializing a product. However, many of the smaller organizations with more specialized markets (especially for engines) depend more heavily on results from cooperative and government-supported research. Hence, the workshop was an opportunity for industry to communicate directly among themselves and with government about common research needs.

WORKSHOP ORGANIZATION

The discussion of R&D needs was broken down into four major areas, so that it could be addressed by specialists in each area. These areas were:

- Refining current fuels from new resources
- New fuel types
- Improvements to current engines
- New engine technologies

The main topic, of course, remained the fuels/engines interface. The choice of subtopics was made to illustrate the different perspectives from which this interface could be examined. These subtopics were initially defined as follows:

- Refining current fuels from new resources - What major new resources may become available from which to refine current specification fuels? How must refinery designs be modified and what changes might be made in product specifications and costs? What are the potential impacts on engines and emissions control technology?

- New fuel types - What new fuels are likely to emerge from the changes in available resources? What new process technology is needed? What are the likely costs and characteristics of these new fuels? How can these new fuels be utilized in current and future engine technologies?

- Improvements to current engines - How can current gasoline and diesel engines be made more flexible and tolerant of fuel variations? What role will microprocessor control systems play? What are the costs and implications of new materials (i.e., ceramics) or new engine configurations (i.e., turbo-compound diesel)?

- New engine technologies - What is the eventual role of new engine technologies?. What are the desired fuel characteristics for these engines and how can they best utilize the new fuel types? Where are technology advancements expected to be concentrated concerning new engine types?

In addition to assembling a research agenda, the meeting was set up to provide the attendees with an opportunity for unique discussions not normally available within their organizations. This was accomplished by assembling a wide spectrum of representatives of processing and utilization viewpoints and by allowing them to talk about their problems, followed by discussion of potential solutions. It is anticipated that publication and dissemination of these workshop proceedings will spread the benefits to these discussions beyond those who attended.

The workshop agenda (Appendix B) can be viewed in four parts. An introductory session familiarized the participants with the purpose of the meeting and provided detailed instructions in preparation for the small working group sessions. In the second part, four small groups addressed the four perspectives of the fuels/engines interface mentioned above. Each group had almost six hours to identify problems or research needs and organize recommendations.

The second day of the workshop was devoted to reporting the results of the small group sessions and generating a research agenda. Thus, the third part occurred during the second morning session, in which each small group leader reported on the discussions and conclusions reached in his group. After each discussion there was an opportunity for all participants to comment or ask questions.

The final session began the afternoon of the second day by reviewing common themes of several of the morning presentations. Discussion then focused on the overall research agenda itself. The body of the discussion revolved around what was to be done, as well as who should do it. Some of the discussion also addressed the relative priority and time scale for these activities.

The organization of this report parallels the organization of the workshop. Although edited somewhat for readability, the following sections retain much of the informal tone and the variety of viewpoints expressed in the workshop.

WELCOME

Harry R. Johnson, Director, DOE/BETC
(Read by Ted de Palma)

Good morning and welcome to Bartlesville, Oklahoma. We appreciate your willingness to come and participate in our workshop on fuels/engines interface research. We hope to make the next two days as useful and enjoyable as possible. We are sensitive to the fact that most of us attend too many meetings and conferences every year. That is one reason we have restricted invitations to a relatively small number of people we feel most qualified to contribute.

First, I will give those who are unfamiliar with BETC some background. We are the descendant of a Bureau of Mines Experimental Research Station which was established in 1918. The construction that some of you see across the street at the south end is where the original building was constructed, and it was razed just about five weeks ago. A new wing is now being built there. Our current organization includes three research divisions. The first is Production Research, which focuses primarily in enhanced oil recovery. The second is Processing and Thermodynamics Research, which includes active groups in the thermodynamics of gases, liquids, and solids related to fossil fuels, in chemical characterization of these materials, and in the processing of these materials. Finally, we have the third division of Utilization Research, which, of course, concerns itself with both fuels and engines.

Fuel Utilization, in conjunction with Processing, is sponsoring this workshop for the next two days. As you can see, we follow the fuels all the way from exploration and production through characterization, processing and utilization. We feel this combination of interests, the ability to study fossil energy sources from cradle to grave, is unique and holds a potential for significant research contributions. It's through workshops such as this that we identify the most needed and the most appropriate research we should be doing.

There is a totally new atmosphere in energy research as a result of the new Administration. We fully recognize that industry has been given the principal responsibility of syncrude and synfuels development. The new National Energy Plan prepared by the Department of Energy states that companies have the financial and technical resources to commercialize synthetic fuels technology. Thus, we feel it is crucial for industry and government to sit down at this time to discuss the research needs and the appropriate roles under these new guidelines. While we hope you leave here believing it was a worthwhile two days, we also want to spread the benefits to those not invited. Thus, all preliminary sessions will be transcribed, then edited and published as a government report; of which you will all be a recipient. Your small group sessions and all the informal discussions will not be recorded, so that you can feel comfortable and free to speak your mind. We feel that is critical if we're going to obtain anything useful. However, summaries of the results of your efforts will be presented tomorrow morning by the group leaders. And they will, of course, be included in the final proceedings.

WORKSHOP PURPOSE AND OBJECTIVES

Ted de Palma, DOE/BETC

I would like to add my welcome to Harry's and express my pleasure that so many of you have chosen to participate. For the next few minutes, would like to talk about why we decided to organize a workshop, what tasks we hope to accomplish, and how we hope to approach these tasks. That sounds like a lot of work, and I think it is; but we certainly appreciate your efforts. We intend to provide an occasional diversion or two.

Over the past year or two, we've been receiving an increasing number of inquiries concerning future fuels and engines. For example, we have several very specific requests from engine manufacturers for fuels from coal and shale liquids, which they would like to use for their development research. As we at BETC and the Department of Energy attempted to deal with these individual requests, it became obvious that a more organized approach and assessment of the research needs at the fuels/engines interface was needed.

With the arrival of the new administration and its strong view that industry should do as much as possible on its own and that government should not provide the extensive commercialization support originally projected for future fuels and engines, it became even more important to get a group like this together to step back and to look and see where we are and to assess the situation. Of course, we in DOE are interested in obtaining a reading from both industries involved as to the appropriate government role, if indeed there is one. However, we want to make it very clear right at the onset that we are not presupposing anything about the role we or any other government sponsored entity should play in the fuels/engines research, or even in information and data transfer. This is something that we hope to resolve in the next couple of days in the workshop.

I would like to talk to you a little bit about the scope and objectives of the workshop at this time. I'll speak on four different areas. The first is our perception of the forces that are bringing about these changes in fuel and engine research. The second will be the interactions at the interface, focusing on those of fuels and engines. Third, why we want to talk about the R&D needs; and fourth, just a few thoughts on assigning research roles and priorities.

There are a large number of strong forces that will, in all likelihood, cause significant changes in fuels and engines and are therefore of concern to both industries. Let me suggest a few. On the fuel side of the ledger, for example, we can expect in the long run that the cost of the conventional liquid fuels will increase. Now this may or may not eventually make synfuels rather attractive. It certainly would seem to put more pressure on engine and fuel processors to be more efficient or to find ways of utilizing less-refined fuels than we now use. The petroleum feedstocks are becoming heavier, causing current specification fuel production to become more complex and certainly more expensive. Sulphur, nitrogen, and mineral content have also become important considerations.

Synfuels will become a reality in the near future. In spite of the withdrawal of much government financial support, the Department of Energy, in its National Energy Plan which was just issued in July, projects a synfuels volume of 500,000 barrels per day in 1999.

Also, there's been continuing interest in ethanol and methanol from coal, gas, and biomass, both as neat fuels and as blends into more conventional fuels.

Of course, gaseous fuels from LNG, LPG, and perhaps even hydrogen sources will be used increasingly in certain applications.

Continued research will expand our understanding of additives and fuel characteristics and their interactions.

Now, over on the engine side we know that for reasons of efficiency and economy, since about 1970, engines for almost all applications have become smaller and lighter through various means, including the use of lighter materials. So far, this has been a fairly evolutionary change, but it's entirely possible that new technology, really in a revolutionary category, may be forthcoming.

The use of microprocessors has been a fairly evolutionary change, but new technology is developing very rapidly. The use of microprocessors started in 1978 to control air/fuel ratio. Their use will probably be extended to mitigate the cost situation to which we as a nation have been harshly exposed in the past several years.

Improved lubricant technology may permit engine operation even under the most severe conditions. Since changing refinery feedstocks also affects lubricants produced, additional research in lube-additive characteristics and responses will be necessary.

There will also be an increasing demand for engines with multiple fuel capability, able to adapt to changing supply and cost situations.

As I mentioned before, I began this list with the idea of giving our perception. So, the first objective is that by the end of this workshop we will have a pretty good understanding of what you people feel who represent these two massive, sophisticated, well-oriented industries; and your comments could change the whole picture.

Identifying these changes is the first step, but the prime importance of the workshop is to focus on the interactions of the fuel and engines developments.

Some examples are the increased potential for reactions of fuels with engine materials, as the composition, quality, and style of either change. More specifically we're all aware of the use of alcohols, gasohol being the most recent, which presumably cause some problems with fuel filters, gasket materials, and the like. These are not unsolvable problems.

We know that it's merely a matter of economics. As we attempt to squeeze more and more efficiency out of our engines, combustion kinetics and overall thermodynamics must be increasingly better understood and defined. Even

after we understand the thermodynamics, we must somehow find a mechanism for implementing the best pathways from production and refining of a resource through its final utilization. This is true particularly in light of the new synfuels and, of course, the new refinery feedstocks. Similarly, the microprocessor controls on engines may allow purposeful changes in fuels, rather than just permitting flexibility.

On the other hand, it's just as likely that new engines will place new restrictions on certain fuel properties, and, of course, new fuels will place new restrictions on engine design. This is nothing new. We've experienced this many times in the past. We must also be certain that mandated emission and efficiency levels be mutually compatible. Many of us feel this probably has not been the case since the promulgation of the Clean Air Act of 1970.

You have been invited here because you are all knowledgeable experts in the various facets of the two industries and the interactions of the fuels and engines. Our second objective, therefore, it to elaborate on these potential interface problems. There's no question about the fact that both fuel and engine developers are well established, forward looking, and technologically sophisticated. Both are conducting R&D relative to the interface between future fuels and future engines, which is evidenced by the correspondence we have had with many of your firms. Here at the center, several large diesel engine producers are working with us on testing crude coal and shale liquids which we have provided as part of our stationary diesel study. Further, we have recently received approval for a long-term, high-risk program for developing coal slurries in various carriers -- water, methanol, diesel fuel -- for use in slow and perhaps medium-speed diesel engines continuing toward the development, adoption, and selection of engines, burners, and other end-use technologies that are compatible with nonconventional fuels.

Many proposals have been submitted to us attesting to the high interest and the large number of possibilities and unknowns at this time. There are some types of research which really don't fit any single company or any single industry. Therefore, a third objective would be that the workshop is to discuss what R&D is being done and to identify what else has to be done.

Finally, the last objective is to define the roles and priorities. Clearly, the primary responsibility for commercialization and the near-term R&D leading to commercialization rests with the private sector. Industry knows how to do it; how to do it better; how to do it more efficiently. Therefore, it makes sense that you should do it. The federal government has stated that it will decrease dramatically its role in assisting and accelerating the steps leading to commercialization. However, the administration's policy recognizes that there are, indeed, appropriate roles for the government to take in energy research and development. And of particular relevance is "the long-term, high-risk research". Providing basic research data such as chemistry and thermodynamics of fuel species, the generic engine characteristics; data of this type is something that, perhaps, we would be prone to do and more likely be asked to do.

Other roles might include making available syncrudes and synfuels which are generated either at government pilot plants or at private facilities which have received government assistance, as opposed to each of you individually trying to get a few barrels of this, that, or the other. Where appropriate,

and not already covered by other organization such as the CRC, the SAE, the National Petroleum Refinery Association, and others, we could probably provide enhanced technology and information transfer, as well as some coordination of research and development, or conduct more of this type of workshop where we bring all of you from the two industries together to talk.

The choice of new fuels and engine technologies involves substantial investments in resource development, refineries, distribution capacity, and in engine manufacturing and maintenance facilities. Therefore, it's prudent for these industries to be extremely cautious and well-informed before committing themselves to major long-term changes. It is really in this area of generating data and information, which is pretty risky, which might take a lot of the front-end capital money when the "pot at the end of the rainbow" doesn't look so pretty and shiny. It is in these areas where the government should probably be collecting data, which in turn prepares you to do more on your own, at a lesser risk.

Once we've identified what needs to be done and who should do it, then the question of priority also needs to be addressed. That, therefore, is the fourth objective.

Now the fuels/engine interface problem is not something unique. All of us here in the audience have seen this for many many years. We could go back to the introduction of thermal cracking processes many years ago, followed by cat-cracking. Those gave us some problems. We used more of the barrel, true; but it gave us problems with gum, varnish, sludge, and corrosion. Catalytic cracking and reforming added problems of combustion chamber deposits and excessive aromatic contents. Some of us remember detergents which were put in the advanced lubricants in the late 1940's and the limited slip differential additives; all of which created problems. The introduction of unleaded fuel, gasohol, and now, fuels from coal, shale, tar sands and biomass, all led and are leading to questions needing resolution at the fuel/engine interface.

For example, in the mid-1950's some vehicle octane requirements were above 100. The fuel industry increased processing severity a bit and added a trifle more of the BTX tower bottoms. The engine people retarded the spark a degree or two and tweaked compression ratio down 0.1 to 0.2 units. Reformers then came in, which were not too good for diesels and not too good for pre-ignition manifolds; one result was that deposits increased. Clear fuel caused problems with octane requirements and valve seat recession. More recently gasohol has appeared on the market with its attendant problems. Right now we are addressing the present: coal, shale, tar sands, biomass, all kinds of new sources of energy.

The reason I mentioned all of these is that in the past these problems were attacked by the fuel industries and by the engine industries in a more or less iterative fashion. There has been the luxury of time. We don't have that now. At that time the market forces were the significant controls. What we're trying to do is to solve these problems in a more timely fashion, primarily because this is a critical national need. We all know about the export of our dollars, what it's doing to our pocketbooks, our paychecks, and our national economy. It's a very serious problem, so we want to treat it accordingly. The presidential edict was to become independent of foreign energy, and this is one way of doing it. We want to displace foreign

petroleum with some of our own energy sources. I don't pretend that this two-day workshop is going to solve all these problems, but it can be a step in the right direction.

So, fundamentally, we need to identify the problems. Who is doing what? If they're all covered, great. If not, who ought to be doing them? Finally, let's try to assign priorities. That is what we want to do in this workshop. I welcome all of you. There's a lot of talent in this room. If any of these objectives are not obtained in the next two days it certainly is not because we have a lack of talent.

Now, I would like to introduce the people who have been responsible for bringing the workshop into being. I would like to ask them to stand and be recognized: Dennis Brinkman of Bartlesville; Dan Gurney of Bartlesville; Larry Perrine, a consultant in Bartlesville with his two pretty assistants, Sandra and Debbie; and then finally two technical consultants, Ken Heitner, TRW, and Matt Reilly, Environmental Research and Technology. These gentlemen and ladies have helped immeasurably. Thank you very much, all of you.

DISCUSSION GROUP PREVIEWS
Dan Gurney, Moderator

My name is Dan Gurney. I'm the project manager for fuel utilization here at Bartlesville. As Ted mentioned before the break, there are several driving forces that will accelerate the normal response in fuels and engines. We're here today to look at those forces and to examine our roles in responding to them. To do this, we coordinated this two day workshop as you have seen on your outline in your briefing packet.

The next thing on the agenda is to hear from each of the small-group leaders, and the first one we'll hear from is Walter Douthit. He's going to be the group leader for Refining Current Fuels From New Resources. He's currently involved in fuel research of various kinds, alternative fuels, emissions, processing, and other related areas. Without any further delay I'll turn it over to him.

REFINING CURRENT FUELS FROM NEW RESOURCES
Walter Douthit, Suntech

Thank you, Dan. On behalf of Suntech I would like to say that we're really pleased to participate in this workshop. I might add that Sun Company defines itself as an energy company, not as an oil company, and, of course, we're concerned about future energy needs.

We look to a workshop of this nature to surface new ideas and help solve problems. As energy prices soar, conservation has become one of the more immediate concerns in the marketplace. This is helping to reduce our dependency on foreign oil, since the energy problem, itself, is equally related to conservation as well as to sources of supply. What we really need is a reliable and adequate liquid fuel supply. Conservation has proved to be part of the answer, but we still look to new domestic sources, including shale and coal conversion, to make up the difference.

By now you've probably looked at this handout on Refining Current Fuels From New Resources, plus you have the names of people that are in the group. Some of the points to be considered are listed in the pamphlet, so I'm not going to read these out. But I do have a discussion outline that includes various other considerations. Of course, if you or members of the group have additional input, please let me know. Let me run through this proposed outline quickly.

We look at the charge of this particular group to: (1) assess the development of essentially current specification liquid fuels from new resources, (2) determine possible research needs in utilizing such fuels, and (3) earmark roles for industry, government, academia, et cetera, in getting these supplementary fuels to the commercial stage. The scope, here, is to increase the liquid fuel for transportation and stationary engines from sources other than what we call common crude oil.

Norm Sefer has agreed to assist in taking notes and outlining the discussion. As I see it, the topics for discussion fall under these categories: Number one - "What's the current fuel definition?" Should we, for example, look to EPA's concept of "substantially similar" as the definition of a current fuel?

The next topic we're going to have to consider is the resource candidates, including shale oil, tar sands, methanol, biomass, coal liquids, coal-oil slurries, gaseous fuel, et cetera.

Beyond that might be a perspective on product demand. Are these going to be fuels that are consumed in their natural state? How are we going to utilize these in the marketplace? We've got to make an assessment of the technical problem areas arising from the different properties of these candidates. Moreover, we've got to consider environmental concerns such as contaminates, processing and distribution. We may want to talk about time frame, economics, priorities, and significant market impact.

The final item is research needs. We must look at current efforts, examine future needs, and assess who should carry out the research industry, government, universities? More specifically, how can we best utilize new materials from a particular new resource? What kind of research are we going to need?

I think by the time we cover some of these questions we can come up with suggestions on the role of the government in the areas of cooperative research. As Ted mentioned, Government may have a role relative to high-risks, long-term specific research projects, national security needs, central data bank for the general distribution of data, etc.

What I'd like for this team or group to do is to think of other considerations which aren't listed in your packet, and then determine how we should organize our group discussion. This outline is strictly a suggested method of organizing ourselves and is subject to change. If there's anything that's consistent, its change.

DAN GURNEY:

At the end of each of all of the short presentations, or previews by these leaders, we'll have a short period for questions and answers. So we would ask that you hold any questions or comments that you have until that time. We want you to hear each of them first.

The next small-group leader is Robert Jackson of Conoco Coal. He's the director for marketing development with Conoco, served as mechanical engineer with Shell for several years, and since '72 with Conoco. He's looking at alternative fuels, and one of those is methanol-sources and uses.

NEW FUEL TYPES

Robert Jackson, Conoco Coal

One of the first problems I had when I saw the outline paper sent to me was the definition of new fuel types and identification of fuels. None of them were really new: methanol, oil shale, tar sands, oil from coal, and electricity and everything else. Until I came to live in the United States, my milk was delivered every morning in an electrical vehicle; so it's difficult to see the angle of the new fuels.

What we do have is a new philosophy on fuels, so that some of us call them alternative fuels. That means we're trying to makes fuels other than from crude oil. But when we do this, we get involved in arguments as to whether we really want to make a new fuel. This is because the system that exists is so used to being the way it is, that that system will have to be changed in many cases. Therefore, you will get some people coming and saying, "Well, if you extract fuel from shale or tar sand or maybe oil from coal, then you should process it severely and convert it into a fuel that is just like ones we already have. Then we don't have to change the system." Maybe that's good. Maybe that is a means to become more or less independent of imported oil. There's a lot of energy in the United States in the form of coal and shale that can keep the country going for a long time without changing a thing.

But I think a few years ago the United States decided it would not accept inefficient use of fuel in automobiles anymore, and the government decided to mandate that. Prices rose fast enough that efficiency didn't need to be mandated. The people realized that. So they wanted to use the car more efficiently, and the automobile manufacturers produced more efficient cars to match. So the circumstances maybe always overcome use. The point we all have to face, when we look at engines or fuels, is whether we have to dedicate ourselves to the system. Can we move forward? Is it possible to move towards a new system where a new generation of fuels appear which are not the same as the ones we have now? They might be slightly dissimilar, and they may be very dissimilar.

Maybe the greatest problem one has to face in solving that is what does it cost? If we take methanol as an example, there are many of us who believe that we can make methanol fuel from coal. This may enable us to run an automobile which is 50 percent more efficient than the typical gasoline automobile. That means we're going to use a lot less energy than if we, for instance, converted that fuel to gasoline. But there isn't any system of distribution for methanol. Therefore, we would involve ourselves in a very serious problem trying to distribute this methanol, and it's something we have to consider very carefully.

We all realize that nobody is going to create overnight either the production capacity or distribution system to enable all the cars in the United States to run on methanol. One of the things I often say when talk to students at universities is that alcohol fuels are the fuels of the 21st Century. Because if you have a lot of cheap electricity, which is the basis of the hydrogen economy, you can just as easily make methanol from CO_2 and water; and you can grow things to make methanol; and thus you can justify going to a methanol system. On that basis methanol could go on forever, and someday we have to start.