

ENVIRONMENTAL PROTECTION AGENCY

SYMPOSIUM-WORKSHOP ON ALTERNATIVE FUELS

OCTOBER 15, 1974

HILTON INN

ANN ARBOR, MICHIGAN

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ALTERNATIVE AUTOMOTIVE FUELS

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Ann Arbor, Michigan

October 15, 1974

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MR. HAGEY: I'm very pleased that you are here today with us for this Conference on Alternative Fuels and Fundamental Combustion Research.

We are hosting this Conference with the National Science Foundation. Dr. John Belding is here with us from the Science Foundation today. The Conference, again, sponsored by the Alternative Automotive Power System Division of the Environmental Protection Agency and the National Science Foundation, Advanced Energy and Research Technology Division. The primary purpose of the Conference is to inform you of directions we in the Federal Government intend to take in developing technologies needed to utilize new fuels in motor vehicles which are not derived from petroleum resources, but rather fuels which can be made from more abundant natural resources in the U.S.

Our role is not to develop production-related technologies for these fuels, but rather to look at these fuels from the viewpoint of the user -- in this case, motor vehicles.

To place the present and planned federal

program in perspective, we are today reviewing ongoing private-sector and federally-supported R & D programs on alternative fuels.

In particular, we are reviewing research principally on methanol -- not because we are singularly interested in methanol, but rather because this fuel has received principal attention as a near-term alternative fuel. Industry has conducted considerable research on methanol, and the present federal program is emphasizing methanol research at the present time.

Finally, the Conference seeks to provide a focal point of coordination for the numerous federally-supported programs on alternative fuels and related combustion research.

In 1973, the Alternative Automotive Power System Division initiated a program of study in applied research on alternative automotive fuel, Chart 1.

The goal of the program is to evaluate the application on non-petroleum based fuels and energy sources as partial and complete substitutes to gasoline and distillates from petroleum for use in motor vehicle systems.

The program, by study and research, provides for evaluation and assessment of the following fuels

which have been determined to be the most promising future alternatives: gasoline-like fuels from non-petroleum energy resources; for example, gasoline distillates from coal and oil shale. Secondly, unconventional fuels from non-petroleum energy resources; namely, methanol from coal and organic waste. Finally, hydrogen for nuclear energy.

Chart 2 identifies the program elements planned from the research on these fuels.

The evaluation and assessment will provide a relative ranking of the fuels and will, in the conduct of the evaluation, provide information on the characterization and future automotive utilization aspects of the fuels and their combinations. Thus, the program will provide appropriate information on the future fuels for automotive transportation, such that rational public policy and technical choices can be made for the future introduction and use of these fuels.

The federal program will address the research and utility aspects of the fuels. The Conference today will provide you with an overview of the program, and although we have singled out for review the areas of basic combustion and methanol research, I wish to emphasize that our future research will be broad-based and will address all of

the above fuels.

The initial feasibility study of alternative fuels was conducted by Exxon Research and the Institute of Gas Technology. Final reports on these studies will be distributed shortly.

As a follow-on to the feasibility study, research was initiated in early 1974 at the Bureau of Mines for the characterization of methanol and methanol-gasoline blends in conventional internal combustion engines.

Principal focus of the 1974 research is on emissions, performance, and fuel economy of 5, 10 and 15 percent methanol-gasoline blends. Additional research will be conducted in 1975 at the Bureau of Mines for the characterization of pure methanol and gasoline-like fuel from coal and oil shale. The methanol research program is described by Chart No. 3. We anticipate the research on gasoline-like fuels will be structured similarly.

In 1974, we initiated research on hydrogen storage for automobiles. Although the feasibility study indicated that hydrogen is a speculative automotive fuel and its use would not occur before the year 2000, we believe that limited research is warranted on the principal automotive hydrogen-technology gap, namely on-board vehicle

storage: Chart No. 4.

It is anticipated that research will be sponsored in 1975 with government, industry and universities to investigate health effects, materials, fuel blend stability and atmospheric effects as well as continued engine combustion research on these alternative fuels.

As a follow-on to the Exxon and IGT studies feasibility of alternative fuels, Stanford Research Institute is conducting a study of the impacts associated with the future use of these fuels. This study will develop scenarios for the introduction of alternative fuels where there are competing uses for sources and fuels and will identify the critical factors and impacts for these resource-fuel shifts which are believed to be most promising.

In summary, today's Conference provides an overview of a recent and in-progress research on combustion and methanol fuels. It is my desire that this review will encourage the experts assembled here today to provide us in government with information on methanol-technology gap, since we are actively researching this fuel at the present time.

More importantly, however, Dr. Belding and I will seek to draw conclusions in the workshops on the future directions which the NSF combustion program and the

federal Alternative Fuels program should be directed in the alternative fuels area.

For the combustion workshops scheduled from 3:30 to 4:00, Dr. Belding will present his views of the priority future combustion research needs, and these are ten priority areas. He will then ask, through a three-member panel, for a discussion of these priorities, and in particular we are seeking your expert opinions to the combustion research needs in alternative fuels.

In a similar manner, I will, in the alternative fuels workshop scheduled from 4:00 to 5:00 P.M., solicit your expert recommendations with regard to the directions and emphasis of the Federal Alternative Fuels Program.

Can I have the lights up just a little bit, please?

So much for the so-called formal introduction. A few housekeeping chores. We are breaking at 12 o'clock for dinner, lunch. We reconvene at 1:30. I think the Hilton can take care of all of us for lunch. If we do get a situation that's overcrowded, I hope we don't, but if we do, there is a shopping center right adjacent to the Hilton and there are lots of restaurants in there. We have a very tight schedule today. I'm going to -- Dr. Belding and I

will insist upon keeping to the schedule, even though we have already dropped 15 minutes in starting, but we will -- we will break at 12 o'clock. We will reconvene at 1:30.

I am adding two items to the agenda that don't show on the letter that went out.

Mr. Jerome Hinkle will, at 11 o'clock -- and if I can't schedule it then, it will be at 1:30 -- a short, five-, ten-minute discussion -- not discussion so much as a presentation, just summary of what the Stanford Research study is doing. This is the impact study on the alternative fuels.

Also, some people from the City of Seattle are with us today. They have a proposed program to -- Dave, how should I describe it? -- to take all of their garbage and to make synthesis gas which would be converted to methanol and/or ammonia, a combination, perhaps, of ammonia and methanol, and they are interested in converting their city fleet of cars to run on methanol. So they are with us today and I understand they have a slide presentation which they would like to present, and so they will make this available at five o'clock. If any of you are interested in staying, please stay. I intend to stay. I think it's a very interesting program and I think those of you that are interested in methanol will find this a very fascinating subject.

One last thing: We are being recorded. What I hope to do, when we close, or not today but subsequently, we will put out a summary of the Conference. We will have the tape. The girls will go through the tape and we'll put out a summary on the Conference and make this available to each of you attending today. We are not -- as you know, people presenting today are not giving papers; there are no proceedings, as such, from the Conference. So this will be the record and our secretaries will transcribe and prepare a synopsis summary of the Conference and we'll make this available to all of you.

Now, I think we are ready. John?

Dr. John Belding of the National Science Foundation.

DR. BELDING: Well, I would like to discuss just for a minute what the NSF objectives are and some of you who are not familiar with the new role of NSF, the applied role, may wonder why we can set objectives.

The old NSF just gave grants for doing basic research, and if -- the researcher comes in with a gem, that's great.

The applied side of NSF is called RANN, Research Applied to National Needs, and we are very definitely mission-oriented. I'm in the Energy Division and we are trying to conserve or find new methods of producing

energy.

The program that we are going to talk about today is just the automotive combustion area. We are also interested in new materials, although we do not have any funding in that area at this point.

Well, what are the objectives of the NSF automotive program? Basically, the objectives are to understand better the combustion of internal combustion engines. We are not at this point working turbines. We are working spark ignition and diesel, and we don't have any plans particularly for going into turbines. We have another part of the NSF program which deals with turbine combustion.

So we are trying to understand, then, the basic combustion phenomena to make the automotive engine more efficient and, in doing this, we are looking at various things like lean combustion, stratified charge, alternative fuels as part of that, and we are trying to then infuse this understanding into the people who use that type of engine, namely the industry.

Our funding last year was \$900,000, and this year it's 900,000 and next year -- knows? With the new Energy Administration opening up, we may go out of existence; we may continue to have a less significant role, or more

significant role. At this point, the head of NSF and the heads of lots of other agencies are in a little conference, trying to decide who does what to who, and I'm sure we'll all come out on the short end of it.

Well, for the time being, we are going to have to assume we are going to stay in business. I have been in Washington for eight years and I assume I'll be there for the rest of my career, with some agency, whether it be NSF or anybody else, and I assume that we are going to still do automotive combustion. Those are the real facts of what's going on.

How do we propose to get these kinds of studies done? Well, if you will look at today's program, we have one industrial contract and the rest of them are with universities. That was not planned that way. It's not that we don't like universities or we don't like industrial contractors. What we want to do is get the best research for the amount of dollars that we have, and if that can be done in industry, then we go to industry. If it can be done in a teaming arrangement, we go to a team, and we are pursuing some team arrangements now between the automotive companies and universities.

Well, what we are going to do this

morning is, we are going to review the ongoing contracts that NSF has, and there are seven of those.

The first one will be given by -- the first overview will be given by Dr. Toru Iura, of Aerospace Corporation. He is looking at: Where Do We Go from Here? Exactly what this Conference is looking at. The only difference is, he's being paid for it. His results will be in in June, right? May? And he is going to give you a quick overview today, this morning, of what he has come up with so far, namely state of the art and a little bit of generalities on where we go.

This afternoon, then, we'll take all this knowledge that we have accumulated all day and try to come up with a matrix of where we go in the combustion and alternative fuels area, as Graham has indicated.

So if there are any quick questions, I'll be glad to answer them. If not, we'll go ahead and listen to the speakers who know what their technical areas are all about.

Okay? Toru?

MR. IURA: What I'm going to talk about is the grant that we have at National Science Foundation, which is a research planning study for achieving reduced automotive energy

consumption. The end objective is to delineate a research plan in this area. This grant activity was initiated in May 1974, and as mentioned, it is scheduled to be completed in May 1975. The grant budget is \$139,000 and the grant project officer is Dr. Tom Anderson of the National Science Foundation. We have advisory panels for this study to assure that we get maximum inputs and review comments from a cross-section of industry, university, and government personnel, and to be sure that there is proper coordination between the various organizations that have a stake in the automotive combustion or drivetrain area.

The objective of this study is to systematically assess meaningful internal combustion engine, component, and powertrain alternatives to determine which approaches offer potentials for improvements in automotive fuel consumption, and also to assess the impacts of alternative fuels on these approaches. The eventual objective is to define a time-phased research program in the combustion, materials, carburetion and controls, transmission, and powertrain areas, or any research associated with the drivetrain, from the engine to the tires. We will not be examining the vehicles or bodies during this study. Also, we will attempt in our study to assess those social, economic, or legislative policy factors that might impact on the type of research that we might suggest in the plan, and will also attempt to identify research in these areas.

It should be noted that the study is limited to the internal combustion engine. This includes conventional engines, variations of the stratified charge engine, lean burn concepts, and the diesel engine. We will be also evaluating research related to alternative fuels as they were defined today. We are not evaluating gas turbines or Rankine cycles research needs, since the AAPS program is pursuing these developments.

The study will address fuel economy factors, primarily for passenger cars. Although the emphasis is on passenger cars, we will also be examining buses and trucks in order to determine the type of research that can be done to improve fuel economy in that area. I think I have mentioned before that we were examining several engine variations; in that regard we are also looking at the rotary engine and whether research should be performed in that area.

A block diagram giving the various study tasks will furnish an idea of what we are doing in the study. The initial task involves a state-of-the-art survey. A key input to this task, so far as data sources are concerned, will be information obtained from government and industry liaison. We will be making maximum use of the studies that have been sponsored by government agencies such as the DOT/EPA-sponsored studies sponsored by EPA. There are, of course, many other studies that have been going on that will be used in our evaluation. We have been examining the information from all of these studies with respect to identifying where the payoffs are in fuel economy. We have visited many people and we plan to visit many more who are actively involved in automotive research, so as to determine what technology gaps exist, what work is going on, and how this relates to the research gaps. The end objective is to delineate a time-phased research plan which will be valuable to the National Science Foundation as well as other government agencies, such as EPA and DOT, who have roles in the automotive fuel economy area.

Approximately fifty organizations (research laboratories, universities, and government agencies) have been visited or contacted thus far on this study to discuss their research activities and suggestions for further efforts. We are essentially half-way through our contacts at this point. Members of the automotive research community, your inputs are vital to our study. I will try to discuss this subject with those of you with whom I

have not previously met personally. If, by some chance, I am unable to meet with you today, I will try to see you at a later date.

Are there any questions?

In this research, does this investigation include operator aspects of energy conservation?

Are you talking about driver aids, that type of thing? No. We are not considering that type of concept in our study, but it does consider similar things that have been covered by other studies. This study is basically oriented to fundamental research.

DR. BELDING: Anybody else?

Thank you, Toru.

The next speaker will be Dr. Bob Sawyer from California, and he is going to talk about automotive engine combustion with excess air, better known as lean combustion

DR. SAWYER: I have a few copies of an outline of my comments. Maybe if I just sort of pass those out, I won't have to carry them back to California

It is always difficult to come to describe a research program which is only three months old, because you end up speaking about things that you intend to do rather than things that you have done, and that is always

a little empty, I believe. But I would like to describe our program and what we have accomplished to date.

First of all, please note that I am just one of five faculty investigators on this program, so it's a large effort in terms of people. We will eventually have about ten graduate research assistants working on this program and two professional research staff members as well.

Combustion research at the University of California has been a substantial effort within the Department of Mechanical Engineering for a long period of time, certainly since before I arrived at Berkeley. At the present time, we have about eight faculty and 30 graduate students working in this area, with an annual funding of about six-tenths of a million dollars per year from a variety of sources, including several NSF programs, AFOSR, UPRI, NBS, NASA, and some smaller programs as well.

Berkeley had, up until a few years ago, a substantial engine research program which was associated with the name of Professor Ernest Starkman now known as Mr. Starkman at General Motors. Unfortunately, with his departure and the decrease of funding in that area, our work in the field of engine combustion was decreased.

It never went to zero and we are pleased to be back

in the engine research business again with this substantial program from the National Science Foundation.

We, too, have an advisory panel, including participants primarily from industry and also from government, which we look to to help us in guiding our research.

The words "combustion with excess air" include an awful lot. Our objective is simply to understand from a fundamental standpoint how combustion occurs in systems in which there is an excess of air and this has application, of course, to a number of different engine types which are of increased interest now. The lean burn engines, the torch ignited engines, the divided chamber stratified charge engines, the direct injection stratified charge engines, and even the diesel engines fall in this general category. We simply want to find out what limits the combustion process with an excess of air and the research is focused upon a single pulse, high-pressure compression-expansion device, an extension of similar work done other places, particularly at MIT.

The diagram here is in too much detail to be seen, but perhaps the material which we have handed out to you will explain what this device is.

It is different from other similar experiments in that it provides for both compression and

expansion. Those of you who are concerned with the intake and exhaust stroke of the engine realize that this device does not cover that part of it. It's not because we don't think that part is important, but simply because we wish to focus on the combustion process itself.

The important experimental aspects are that the test section has full optical access over the entire open volume in one transverse direction to the piston motion and ported access for optical and mechanical access for sampling and pressure instruments in the other axis normal to the piston motion.

The combustion process will be observed optically, using high-speed laser schlieren and high speed sheer interferometry techniques which have been used previously at the University of California by Professor Oppenheim in his detonation research work.

In support of this focus experiment, we also have initiated several fundamental research tasks and several applied or engine research tasks. We believe that the fundamental topics dealing with such areas as low-pressure combustion and chemical kinetics are important to give us a firm scientific foundation for the single pulse experiment and that the engine studies are important to keep us on the right

track of real problems and also to assist in formulating our results in a manner which will be useful to engine designers.

Some of these other tasks and the responsible personnel are indicated here. First of all, the pulse high-pressure experiments are under the direction of Professor Oppenheim. We have initiated steady low-pressure experiments in an attempt to understand the chemistry primarily of the lean combustion process, which I am directing, and we are working on spectroscopic techniques for time-resolved quantitative spectroscopy for the single pulse experiment and this work comes under the direction of Professor Greif. This is not a sophisticated approach, but simply the use of emission and absorption spectroscopy for composition measuring.

To back up the experimental work, we have several theoretical and modeling programs which have been initiated and we hope to draw heavily upon the work of other investigators in the NSF program in this area.

We have also initiated several engine studies and particularly work on homogeneous lean combustion and upon a divided chamber engine, with the last two tasks

delayed for a later part of our research program. But over the first three months' period, we have been in the phase of final design and fabrication of the single pulse

experiment; that is in the assembly phase now and initial check-out will occur during the month of November.

In the material which was handed out, I have indicated in somewhat more detail the staffing and the particular areas in which we are working. This shows the interrelationship of the various tasks, simply with the focus upon the pulse-type pressure experiment with both fundamental and applied topics feeding into and from that particular program. We do have some interesting results from a single-cylinder divided chamber study based upon a Waukasha CFR cetane engine, similar to the Newhall work, in which we have been studying pure gasoline and gasoline-methanol blends. The system is such that the 25 percent volume free chamber is injected while the 75 percent volume main chamber is carbureted. The results are preliminary but interesting, nonetheless. It's indicated here in terms of the hydrocarbons and nitric oxide level. We notice, under similar operating conditions, substantial differences between the methanol-gasoline blends and pure gasoline, which we find somewhat surprising. We do not expect to see such substantial differences from what we have learned from the literature. This work is continuing. There is much more experimental data than I am showing here that has not been analyzed in detail yet.

We have also recently completed a study of atmospheric pressure, turbulent diffusion flames, in which we have been surprised by the appearance of high concentrations of nitrogen dioxide as immediate combustion products. We think this has application to other turbulent diffusion combustion processes, perhaps to diesel engine combustion process, which it is also known to produce anomalously high nitrogen dioxide concentrations.

Other research tasks which I will not describe in detail but will merely mention by name which have been initiated include lean combustion in a rotary engine, a part of which involves also hydrogen addition fundamental measurements of quench distance, obviously related to trying to understand the formation of hydrocarbons better, some rather basic work in cycle analysis which we thought was essential to build up for our own background information. We have initiated analytical modeling of the single pulse experiment to be able to better analyze the data from that when it is obtained, and also our work on spectroscopic observation techniques has been initiated by, in this case (inaudible) awaiting the construction of the single pulse experiment.

Very briefly, then, that's mostly what

we intend to do and a little bit of what we have accomplished in the first few months.

DR. BELDING: Any questions? Yes, sir?

MR. LETZ: My name is Sam Letz, from Penn State.

Bob, what, under your engine category there, what experiments to you plan to do or are planned in the engine itself that are not already documented?

DR. SAWYER: The engine experiments are primarily single-cylinder engine experiments and we are attempting to conduct the same type of experiments in the engines that will be conducted in the single pulse experiment. The initial single pulse experiment will be homogeneous, fully vaporized, spark-ignited experiments. We will have backed that up with single-cylinder work of exactly the same type, the same fuel composition, same pressurized rate and same mixture composition. We don't mean to imply that this hasn't been done extensively and reported extensively in the literature. We are certainly aware of the vast background of work in the area. We simply wanted our own laboratory to be able to have these comparison experiments, to make sure that our single pulse experiment is not too far off base from actual engine work.

DR. BELDING: Any other questions?

You will notice that both Tora and Bob have mentioned that they have no results yet. They are new programs.

There is a reason for this. The NSF Program is almost nine months old now. It started in December of last year, and we were given \$900,000 and told to move, and we moved, and we have seven contracts. Hopefully, we are going to move a little slower from now on and we are going to -- we are going to do a little more planning than we had a chance to do last year.

I think that we were very fortunate, however, in getting the kinds of people that we got under contract, and I think you will see that as the morning goes on.

The next speaker is Professor Sorensen from Illinois, and he is going to talk about improving the performance of fuel and fuel consumption of dual chamber stratified charge spark-ignition engines.

PROFESSOR SORENSEN: I don't have any slides, so you don't have to (inaudible).

Bob has already indicated one of our problems also. We are -- I think we are a month less on experience than they are. We have only been in operation

about two months in this contract.

As was indicated, the title is Improving the Performance of Fuel Economy of Dual Chamber Stratified Charge Spark-Ignition Engines. Our basic interest there is on the performance of fuel economy considerations. We are interested in emissions. Of course, we don't want to let emissions get too far out of sight, but that's not our primary objective.

To do this, we have a program which has a double thrust to it. One is an experimental program; the other is an analytical program, which I will describe. At least our plans -- as I say, we have only been in operation roughly two months, so obviously we don't have any results.

The experimental study will be performed on single-cylinder engines and we hope to use experimental work or we plan to use experimental work in conjunction with our computer simulations.

What we are going to do is take two single-cylinder air-cooled engines, which are smaller than a CFR engine; about three inch bore, three and a half inch stroke, and modify them. We have two engines which are identical. One, we will take and put on a dual chamber head which we can -- which will have provision for modifying the location,

geometry and size of the prechamber. We plan to run our basic performance data on this engine.

The second engine will be set up for taking high-speed combustion movies in an overhead valve setup. It will be similar to the setup or the operation which was done by Dr. Goldrich at GM and by researchers at Southwest Research Institute. We have put in a quartz piston in a mirror arrangement which enables you to look up from the bottom into the combustion chamber, and what we'll be doing is taking high-speed movies in order to get some more information on the basic combustion process, evaluate the mixing which occurs, the kind of combustion, the richness and the leanness. We should have some information on that from the luminosity of the flames and other things like that.

So what we plan to do is to experimentally run performance tests on one engine and use the other engine with the same head mounted on our movie arrangement in order to compare the two results and try to explain what effects that we do see.

At the present time, we have the engines on hand. We are working on installing them. Installation is pretty well along. We will design the heads and the arrangement for the high-speed movies.

I might mention -- I forgot to mention at the start that I am working with Professor William L. Hull of the Internal Combustion Engine Laboratory at the University of Illinois, who has had considerable experience in the area of engine development and taking high-speed movies, and we currently routinely take high-speed movies of diesel combustion.

For high-speed movies we have facilities to run up to 22,000 frames per second. We don't know if we will need that high a framing rate. We can run anywhere from about a thousand to 22,000 frames per second, so we should be able to cover things reasonably well.

So we plan to take the experimental data, as I say, and use that in conjunction with a computer modeling program cycle simulation, which we are going to develop these two things concurrently, take data from the experimental portion and use that to help develop our model, and then hopefully, if we get things done, we'll use these in a program, to try to improve the performance, and see what we can establish as the limiting factors for performance and operation of the engine.

As I say, we have the engines. The installation is in process. We hope to have the first

engine running, one which does not have the high-speed movies, hope to have that running somewhere around the first of the year, if things go reasonably well.

The high-speed movie engine thing will take longer. That's a lot more work to that. We have to do substantially more modifications to the engine in order to make that occur and we are basically about complete with our literature on the process. We are just starting to get together our thoughts and ideas on the computer models. We are not very far along, so it's hard to be terribly specific about things we are going to do and I apologize for that, but, as I say, we are only about two months along into the project and any comments in terms of directions and things like that are, of course, welcome. But, as I say, our main goal is to look at performance and fuel economy, try to improve these through the stratified charge concept, develop its ultimate feasibility (inaudible).

I think that's about all I can say about the project at this time.

DR. BELDING: Any questions?

VOICE: Did you say 22,000 frames per second?

PROFESSOR SORENSEN: It's half frame.

It's on a high-cam.

VOICE: I beg your pardon?

PROFESSOR SORENSEN: It's 22,000.

It's on -- if you do it -- it's on a high-cam camera, at a half frame, you get 22,000 pictures per second. We have a Fastex also.

MR. BLUMER: Paul Blumer, Ford Motor Company. What specific experimental inputs from your high-speed photograph do you envision going into your cycle analysis?

PROFESSOR SORENSEN: We are looking into mixing rates, depending on the size of the chamber. If you have a bigger chamber, the mixing may be important between the rich chamber and the lean chamber. We haven't set any specific limits on exactly what chambers we are going to look at. We hope to make our heads adaptable enough so that we can vary that, the size ratio, and look at what that effect is on the combustion process, the burning rate, the mixing rate, the structure of the flame, what we can see about the surface of the flame itself, those sort of parameters, to see if they need to be incorporated into the program and, if so, to develop ways to do so.

DR. BELDING: Way in back of the room.

Mr. Stahman: Ralph Stahman of EPA.

Is this a three-valve (inaudible) concept or --

PROFESSOR SORENSEN: Yes. I'm sorry, I didn't mention that. It's three-valve. We were planning to run all free mix. We don't plan on using any injection at this time. We could, but we don't plan on it right now.

DR. BELDING: All right, thank you.

Well, the next speaker will be from the University of Michigan. Jay Bolt is principal investigator on the problem, but Steve Burgen is going to give the talk today and the talk is entitled "Lean Mixture Combustion and Combustion Bomb Studies."

Steven?

MR. BURGIN: Thank you, John.

We have got a lot to cover here in a short time, so I would like to get right into the slides, please, if I could have the first one.

This shows that we have two distinct stratified charge combustion programs that are ongoing at the University of Michigan and we believe that these fit well into our fairly long history of combustion research at the Automotive Laboratory. The first, the open chamber study, has been in progress for almost two years and it was funded

initially by Mechanical Engineering Departmental funds and a grant from the Outboard Marine Corporation. As of September 1 of this year, we have the National Science Foundation funding.

Now, I would like to go through the open chamber bomb study at some length, since we do have quite a little bit more to say about it, and then come back and say a few things about the divided chamber study which we have just started recently.

I might add that the reason for using bomb studies to obtain the kind of information that we are after is that hopefully bomb studies allow wide, independent variation of parameters and are somewhat less complicated than engines, although we are finding that bomb studies can be quite complex in their experimental setup also.

I might add that we have had, over many years, a long contact with people in the industry, always having in mind the way the information we generate can be used.

Could I have the next one, please?

Now, this shows the objective of the open chamber bomb study. We believe that others have already demonstrated that open chamber stratified charge engines can produce low emissions, excellent fuel economy, and a wide fuel tolerance. So our

interest is not specifically in emissions or these other matters, but in obtaining a better understanding of the combustion process, because we believe that this is what's needed to advance the development of these engines.

Next slide, please. These are specific objectives in this program. We want to learn what essentially you have to do to get the fuel to burn and that really is a problem. We are interested in flame initiation and flame development. Of course, we want to minimize the amount of unburned fuel.

Next one, please. This shows briefly our experimental approach and I'll have a little more to say on each of these three points. Essentially, what we do is set up in our open chamber bomb the kind of conditions that you would expect in an engine at the end of compression. Then we inject fuel and spark-ignite it and see what happens over a period of a few milliseconds and then we are able to analyze the combustion gases to try to determine what has happened. I might add that under No. 2 there we take high-speed motion pictures of what goes on and hopefully that will give us -- hopefully ~~that~~ will answer quite a few ~~questions~~ about mixture formation and flame development.

Next one, please. Now, this shows a

plane view of combustion in our open chamber bomb or in an open chamber stratified charge engine. It is shown to scale -- the bore is four inches in this case. Now, in order for this experiment to work, three basic systems are required.

First, we need a way to generate an air swirl. Second, we have to inject fuel into that air swirl, and then we need a system to fire the spark plug at the right time.

Now, we have developed systems at the University of Michigan to achieve all these things, and I'll have some data later on the development of the fuel injection system. I might add that sealing this chamber for -- we start out at essential combustion chamber density, sealing that pressure, combustion pressure, and having a shaft come into the bomb to drive the fan to generate the swirl was quite a formidable problem, but we have overcome that.

Now, you might recognize that the configuration that is indicated in this slide looks more like one particular version of open chamber stratified charge engine than any of the others. We do not mean by this slide to imply that any one type of configuration is better or more suitable than the others, but we do believe that this is a pretty good place for us to start because it's a fairly

straightforward concept in which mixture is formed and burned essentially immediately. This is not to say that the other kinds of stratified charge engines are less desirable or won't work or any of that kind of thing. We just believe this is a good place to start. I might point out one thing that's required in this kind of an engine is excellent control of fuel injection, probably a better level of control than is required in diesel engines. Certainly, after-injection or secondary injection and dribbling flow are very undesirable in this kind of a system.

Could I have the next one, please?

This is an elevation view of the bomb that you have seen in the previous slide. It shows the fan which we used to generate a high-velocity swirl. The fuel injector is also shown.

One thing you will notice is we are trying to simulate here the -- essentially, the clearance volume of an engine and certainly the depth of this bomb is much greater than what you would have in an engine at the end of compression.

Well, the reasons that we had to make the bomb so deep were to fit the fan in to get a good sized quartz window in on the side. I might add that we have a quartz window up above, too, and we wanted to have some flexibility

in positioning the fuel injector. So we accepted this large volume and with it a large amount of excess air, since we do achieve essentially clearance volume density, so we do have a large excess of air.

Now, even though we have about six times as much air in this bomb as you would expect in an engine of a four-inch bore by four-inch stroke, we are injecting the quantities of fuel that you would expect in an engine of that size. So the bomb is way lean under all conditions.

Okay. Now, the next two slides or next three slides, I show some pictures of equipment. This is the bomb itself. You notice that its construction is quite heavy. The reason for that is that we took the position that we would design it for reasons of safety so that if we got (inaudible) mixture in there, which we don't expect to ever have, but which could occur if the fuel injection system malfunctioned, and then we waited long enough for that mixture to become, for the fuel to become completely vaporized, and then we got spark, we wanted the structure to be able to withstand the pressure rise, and, for safety reasons, we decided to go this way rather than to use any kind of a relief valve system. So it looks awful heavy, but there is a reason for that.

I might point out that the tank you see in the lower right is the accumulator tank for the fuel injector system. That is capable of being charged up to 20,000 psi in order to drive the fuel injection system.

Next slide, please. Okay. This shows the fan which is used to drive the air swirl. We have an air turbine system mounted below the bomb which drives it. I have another slide showing some of the specifications, but this can be run up to many thousands of rpm. The air turbine is rated at 30,000 rpm, but we find that it's not possible to provide enough power to drive the fan at that speed. We can get to about 25,000 rpm with it, and the next slide is an exploded view of the bomb. This shows the two quartz windows and the balls in which the fuel injector and spark plug are mounted. The reason for using balls is that it makes the geometry easily variable, and the fuel injector and spark plug can be positioned essentially anywhere within the bomb.

Next slide. Now, this shows the limitations of our study to the early phases of combustion. We are simply not able to simulate the late things that happened late in the cycle, but we are able, I believe, to simulate quite well what happens during the time that mixture is being formed and ignited. Our excess air, of course,

limits us in the sense that if we wait too long after injection, we lose the fuel to -- a lot to diffusion in all the excess air. We believe that the swirl we set up is an excellent approximation to what you get in an engine and we have some recent research results -- well, not our own, but from other people -- that the kind of swirl we set up is approximately equal to what you get in an engine and then, of course, since there is no expansion, we cannot simulate what happens late in the cycle.

Now, going back to the experimental approach, the next slide, this, as you remember, was Point 1 of the experimental approach. This gives some of the numbers involved and the conditions that we set up in the bomb before combustion. I think that's pretty much self-explanatory.

The next one, the next slide, shows the things that we measure during the few milliseconds after fuel is injected. Now, fuel injection line pressure is an indicator of how, how consistent the rate of injection is during the time that the fuel injection system is in operation or that the needle is open. Of course, the needle lift and spark timing are fundamental to the timing of this whole combustion process. The gas pressure gives an indication of the rate of energy release and hopefully our high-speed

movies will tell us a lot about mixture formation, where the flame goes, that kind of thing.

And the next slide is Step 3 of our experimental approach, which is the step in which we can analyze the products of combustion.

Okay. Now, I would like to briefly show you some of our results. I am sorry to report we don't have any combustion results at this point, but we have done quite a bit in the development of our accumulator-type fuel injector system and that may be of interest.

The next slide, please. This shows three cycles, three consecutive cycles of the accumulator-type fuel injector system, and you can see that the repeatability is excellent. Actually -- well, we get a little bit of a thick line in a few places, but for all practical purposes, the performance is constant. The conditions are shown here.

Now, in an actual test run, we would have an additional piece of information on a photograph like this. We have a blip in time where we take a small piece out of the pressure trace and at the right time, at the time that the spark fires, we get a blip on the screen, showing the timing of the spark. We do this by essentially adding a spike voltage to the line pressure, fuel line pressure trace.

Now, we have a second scope for recording of chamber pressure and also we have run that chamber pressure signal through an operational amplifier to obtain rate of pressure rise. The reason for using a second oscilloscope is that we would probably -- we feel sure we would want a different sweep rate for the pressure measurements.

Okay. If we could go to the next one, please. The point I wanted to make here, very briefly, in the interests of time, is that the air swirl rate determines the rate at which mass of air flows into the flame zone. In other words, the total mass of air that's trapped in the cylinder -- this is in reference to an engine now -- is pretty well constant regardless of speed and load, if we assume that the engine is on throttle. So that the air swirl rate determines the mass rate of air flow into the flame zone. Therefore, the mass swirl rate and correspondingly the engine speed determine what kind of a fuel injection rate that we need.

So if we go to the next slide now, we'll see that for a 4 by 4 unthrottled engine, naturally aspirated engine, that for each fuel injection rate, there is a corresponding swirl rpm. It turns out that for a 4 by 4 engine, you need approximately 60 milligrams of fuel at full load and you will find that if you multiply the fuel injection

rate times the time for one air swirl, in all cases this will turn out to be 60 milligrams.

The thing that's important about this slide is that it shows that, in order to cover this fairly modest range of swirl speeds or correspondingly engine speeds with a single nozzle or a single-hole nozzle, a constant area, a great difference in injection pressure is required over the range that we need and this is, as I pointed out earlier, one of the reasons that we say that extremely accurate control of fuel injection will probably be needed for open chamber stratified charge engines of the type that burn the mixture substantially as soon as it is formed. We see this as a very difficult problem, since dribbling type of flow and secondary injection probably cannot be tolerated in this kind of an engine. This slide also shows some of our data for the rate of injection as a function of pressure, and it conforms pretty well to what the theory says it should.

Okay. If I could have the next slide, please. This is simply another injection condition of shorter duration. The reason that this is included in here is we do have a high-speed movie of fuel injection into the bomb under conditions where the air is swirling, the bomb pressure is -- well, it's over a hundred psi, but we are at room temperature.

Now, we are not going to be able to show that as part of the presentation this morning, but if there is an interest in seeing the fact that we have our experiments set up and seeing where the fuel goes in the bomb, we can show this at lunchtime, if there is some interest.

I would like to go now to slide No. 19, which is the next, the one after this, and talk briefly about our divided chamber study. These slides are pretty much self-explanatory, and I think you will notice that there are quite a few areas of similarity between the two bomb studies, the open chamber and the divided chamber.

Go on to the next one, please, and the next one shows a schematic of what the divided chamber bomb looks like. I think you will notice here that it is quite similar in concept to our (inaudible) chamber bomb and there are several areas of similarity.

And the next slide -- okay, these show the variables that can be studied in the divided chamber experiment. Geometric variables include the ratio of the two volumes of the chambers, include the ratio of the throat area between the chambers to the volumes. Stoichiometry is of considerable importance, since there are two chambers and two different fuel ratios involved in this thing, and their

ratio is probably quite important to the combustion phenomena, and the next slide shows that there is an engine study planned -- that's somewhat further down the road -- to correlate what's learned in this divided chamber experiment.

As I say, we do have a high-speed movie of -- not of combustion, but of fuel injection into our open chamber bomb and we'll be happy to show that possibly during lunch, if there is any interest in that.

VOICE: How long does it last?

MR. BURGEN: Well, we are not set up to do it right at the moment.

VOICE: Oh, okay.

MR. BURGEN: But we can show this if there is some interest.

Thank you.

DR. BELDING: Are there any questions?
I don't see any hands. I don't see any people.

VOICE: I have a question, Steve. How do you propose to characterize the turbulence?

MR. BURGEN: Well, we do plan some hot wire anemometer measurements. That's one of the nice things about the high-speed movie of supply injection. It shows pretty well where the fuel goes and it shows that we

do have essentially solid-body rotation in the bomb, but we do plan some hot wire anemometry to back that up.

There is a possibility that some time in the future we might use some laser techniques to determine velocity and species concentration, but these are things that are not developed at this time. Actually, developing them would be a project in itself, but having the two quartz windows, it might be possible to do that at some time in the future.

MR. MOSES: Clint Moses from Southwest Research. Two things: one, did you say you had not done any combustion?

MR. BURGEN: Well, we have achieved combustion in the bomb but not reliably and not on film. We are -- I think that demonstrates pretty well what we need to learn in this case: How do you burn a spray?

MR. MOSES: The other question is: Are you taking into any consideration either toroidal swirl or the small-scale turbulence --

MR. BURGEN: Well --

MR. MOSES: -- which is known to be quite important in the air field (inaudible) rates?

MR. BURGEN: We believe that, frankly,

that the toroidal motion simply does not exist in engines. The recent data pretty confirms this. I'm referring specifically to a 1974 Institution of Mechanical Engineers paper which has looked into this quite extensively, using hot wire anemometers in a motored engine. So there are some disclaimers, I guess I have to add, to that, but, no, we are not considering any kind of toroidal motion because we don't think it's there in an engine.

Secondary flow -- certainly, there is some in an engine and there is some in the bomb. Whether or not they are comparable, we are not in too good a position to say, but you are right. This is one of the places where our experiment may deviate from what happens in reality.

We just don't know about secondary flow.

DR. BELDING: In the back.

VOICE: (inaudible) How do you --
how, where and when do you intend to do your chemical sampling?

MR. BURGEN: Well, the only chemical sampling we plan at this time is hydrocarbons, homogeneous hydrocarbons, after combustion. After the combustion event, the fan keeps going, so we assume that we get essentially a homogeneous mixture in the bomb. Now, there may be some reaction of hydrocarbons after combustion. We are not really

looking too much into emission formation at this time. We are interested more in the combustion process for the -- how you initiate combustion, how you can get combustion to occur reliably. We think that hydrocarbon emissions or hydrocarbon concentration in the bomb will tell us whether or not we have burned all the fuel, but we are just going to pump it out and measure it. I mean, we are not -- we recognize that this isn't a real sophisticated way to look at hydrocarbon formation, but that's our plan at the moment.

VOICE: (inaudible), Cornell University.
How do you plan to interpret your data you obtain with the ion probes?

MR. BURGEN: That, I will have to defer to -- is there someone else here who would want to handle that one? I'm not in a position to handle that one. You are talking now about the divided chamber study, which -- I might add that this is really only at the consideration stage. There is no equipment built for this. I suppose that the ion probe will tell you where the flame is, as a function of time, but I honestly don't know what's envisioned for that data.

Anybody else in the audience from Michigan want to try to handle that one?

VOICE: What was the specific question?

I didn't get the question.

VOICE: The question was: How do you plan to interpret the data you obtain through the ion probes?

MR. BURGEN: This is in the divided chamber bomb.

VOICE: Is Patterson here?

VOICE: Yes. Say as best we can.

VOICE: We are in a thinking stage on much of this and we have not thought this all through.

MR. MOYER: Dave Moyer from Ford. What ignition system did you use with this and have you any provision for alteration from a standard ignition system?

MR. BURGEN: Yes. We developed a capacitor discharge type of system within our laboratory that allows us to vary the total energy, the duration of spark, the number of spark strikes. I can't really give you specifications on this system, but we believe that it is -- it does provide very variable spark characteristics. I can send you some more information on that if you like, but I don't have it right here.

VOICE: Is it realistic to keep the fan going all through the combustion process, or do you turn it off before you start an injection?

MR. BURGEN: Well, we can't really stop it. Its inertia would be great enough that -- I suppose we could put a brake on it or something, but -- well, see, the thing to consider is that the entire combustion process occurs in one revolution of the fan or less, and we don't believe that the fan, as such, has much to do with combustion. It just gets the air going and we hope it stays out of the way. As far as stopping it before combustion, I don't see what advantage that would have, really.

VOICE: Is the entire combustion process in one revolution of the fan, 25,000 rpm?

MR. BURGEN: Right, right. Well, of course, it varies depending on what load and speed you are simulating, but in an open chamber engine of this type, the combustion always occurs in one revolution or less.

Well, that -- now, in terms of crankshaft revolutions, that's -- you know, that's only a few degrees of crankshaft revolution, but it's about one swirl of the air.

DR. BELDING: One additional little tidbit that I might throw in is that when we accept proposals, whether they be solicited or unsolicited, we try to plan for multi-year contracts. However, we only fund one year at a time

and at the end of that first year we reconsider and sometimes a contract hasn't performed the way we want it to and we don't continue it. We are a hard-nosed organization. We are not like the old NSF. We try to industrialize universities, is the best way I think I can put it.

The next speaker is from Princeton University, the "eastern combustion world," and Dr. Fred Bracco will present his story on Multi-Fuel Optimal Stratification in Spark-Ignition Engines.

Fred?

MR. BRACCO Well, I come from the Gugenheim Laboratories of Princeton University, and this laboratory has been involved in the combustion research for over 20 years and there are some rather well-known graduates from this course. Sawyer is one of them, Miller, others and so forth, and in early 1970 (inaudible) got very puzzled by the difficulty of the combustion problem or the combustion processes in the engines that we are talking about today, stratified charge engines, and any other type of engines. We saw, for example, in direct injection of stratified charge engines, we saw a process of formation of a spray, which is called condensation. We saw process of (inaudible) of a thick spray, a droplet; the process of

turbulent mixing and reacting with chemical kinetics and heat transfer, all of which being unsteady and three dimensional, and we thought a challenge to optimize or even to make sense out of this very complex process was almost overwhelming, and we couldn't understand how one could optimize or even evaluate a given engine just by trial and error procedures. It looked to me like some guidelines, some detail models were necessary in order to have some idea of where to go in (inaudible) so we stopped using these models and we made some progress since then. I have some documents here if you want to take a look at them.

The main goal of these efforts in modeling, detailed modeling, that is (inaudible) was twofold. On one hand, it was to come up with ways of evaluating designs before long trial and error procedures are undertaken and, second, and very important, was to complement our regular work with the development work of specific engines.

I am very pleased to say that for two years now, at the end of the second year, I have been working with Curtiss-Wright Corporation of New Jersey, in helping them develop their direct injection stratified charge engine. They have paid for this research directly from Curtiss-Wright money so they must be getting something. Otherwise, they

wouldn't keep paying for it.

Essentially, what we do, we have detailed models for the engine that they are working on. We studied their results. They take flame measurements data, pressure measurements data, besides the usual, specific fuel consumption, and all of this and we analyzed this data and we come back with interpretation of why, for example, the engine was misfiring and very lean or why it was not operating on the very rich side and we come out with specific suggestions on how to modify the injection system, the timing, in order to improve the engine, and we have gone through this process for two years with some degree of success. Otherwise, we still wouldn't be in the business.

Now, more recently we at -- by the way, the previous speaker mentioned that he thinks that probably the injection system in direct injection stratified charge engine has to be controlled more precisely than in the diesel engine. Well, one result of all these efforts that I mentioned is that I know exactly why. I have two specific reasons that I can discuss with some of you why it probably takes better control of the fuel injection. It definitely takes better control of the fuel injection for two very specific reasons, and when you hear them you will recognize

them as being obvious. Now, these causes are not found in a trial and error procedure, but by detailed studies of the processes.

Now, more recently I have had the pleasure of getting some support from NSF to apply the same theoretical experimental effort to a reciprocating engine. I selected the open chamber stratified charge engine because I think the open chamber is potentially a better engine because it has less surface-to-volume ratio than the divided chamber, potentially. On the other hand, it requires a more accurate control because in the divided chamber you rely on the division of the chambers to separate the rich from the lean mixtures. In the open chamber, you must rely on the control of the injection and the combustion process to obtain that, but ultimately there is a lower surface-to-volume ratio and is a potentially better engine. So we concentrate on the direct injection stratified charge engine and we have the single-cylinder engine and the goal is to run this engine, take the same type of measurements that Curtiss-Wright has been taking, produce the model and (inaudible) from the engine data and the model.

Now, the first item of selection was the -- I mention various processes that influence the

combustion. The first one was the condensation. I am very glad to see that my research, my thinking is going along the same thinking of the previous speakers, without having any communication with them. Due to the fact that the control of the injection system has to be so precise in the direct injection stratified charge engine, one cannot put up with the irregularity of the (inaudible) bomb or the diesel system injection which is often used in development of direct injection stratified charge engine systems like (inaudible) and even Curtiss-Wright engine.

So the first thing to do was to generate, to build a system which produces high hydrostatic pressure with no hydraulic waves whatsoever. We have built a system which has some similarity to this system discussed previously, whereby we generate up to 20,000 psi of hydrostatic pressure. There is no motion of anything, just static pressure, whereby the injection system is completely under control.

The second element is to study each and all the possible ways of atomizing the fuel. Most of the atomizers that are used are (inaudible) atomizers, coming again from the diesel engine, but these are not the only one.

Well, the (inaudible) jets are other

forms of atomizers which present specific advantage in direct application to the direct injection stratified charge engine, but one must have models (inaudible) to evaluate (inaudible).

So the next step is to be the selection of various type of injection systems, and the third step I mentioned, mixing and turbulence. The shape of the chamber -- swirl is part of it -- has a lot to do with the mixing and the turbulence level, so the third step to select the design of chamber. One can have the team chamber like the Texaco style or one can have the (inaudible) system like the (inaudible).

We are going to investigate both because we don't have enough information to select (inaudible).

So, in conclusion, we have already developed the high-pressure system with the needle up to 20,000 of static pressure. We have selected several formal injection systems. We have selected two chamber configurations, both of which are open chamber, but one is a team and the other is (inaudible).

We have some criterion to distinguish between importance, for example, of swirl and turbulence in injection. The criterion is you must compare the velocity of injection with the velocity of swirl, with the velocity produced by the flame -- that was not mentioned -- in

combustion itself, and this is the velocity in the flame, which is the same amount ~~that~~ is the velocity of the turbine or the swirl, and it is the same order of the injection velocity. Depending on which one of these velocities is greater will determine which one of the three processes control (inaudible).

So we have selected various ranges within this broad field of choice and the goal is to optimize by (inaudible) experimental problems similar to the one we have been engaged with at Curtiss-Wright for two years.

Do you have to put emphasis on the injection system? Do you have to put emphasis on the swirl system? Do you have to put emphasis on the turbulence system? Do you have to put emphasis on chemical kinetics and (inaudible)?

Well, there is no answer to this and I don't think trial and error is going to deliver the answer at this point. So that's the type of research we are in now.

DR. BELDING: Any questions? Yes?

DR. MIRSKY: Bill Mirsky, EPA and University of Michigan. In your model, you have taken into account the characteristics of the spray with regard to drop size, drop size distribution.

DR. BRACCO: Yes, as well as we can.

DR. MIRSKY: Do you have any way of experimentally verifying your model with regard to this effect?

DR. BRACCO: Yes, there are two ways. One way is to verify (inaudible) outside the combustion chamber. In other words, you spray into a bomb type with high pressure, if you want, gas and you compare the characteristic of this spray under this conditions. You have some evidence (inaudible) may not be (inaudible). Okay?

DR. MIRSKY: Do you make a measurement of drop size or do you just look at the envelope of the spray?

DR. BRACCO: We make very careful measurements of the drop size, velocity and distribution, as well as spray distribution, but this is another phase of the project which I will rarely mention at all here.

The fact is that atomization, chemical atomization (inaudible), turbulent mixing and chemical kinetics are each one fields of their own, which is (inaudible) and is the type of phenomena that is essential (inaudible) and anytime models can be produced to make best use of what is available (inaudible).

DR. BELDING: I think that this is a very sensitive and critical process in the combustion process

that very few people are looking at, detailed --

DR. BRACCO: That¹ was the point I was trying to convey this morning, that while trial and error procedure of specific designs are most welcome and imaginative thinkers can come to very clever solutions, somebody has to take a slower, if you will, methodical look at all these processes as well as can be possibly done today.

DR. BELDING: Anybody else?

Well, the next speaker happens to be from a not so well known university, Princeton again. Irv Glassman is the principal investigator. However, Irv had some family problems and couldn't be here, but his able stand-in is Fred Dryer and he is going to talk about Fundamental Combustion Studies of Emulsified Fuels.

DR. DRYER: I might mention that there are three people associated with the program that John has mentioned, the combustion of emulsified fuels, and we are looking primarily at their application in terms of diesel combustion. However, there are some very interesting potential benefits that can be obtained from the possible use of emulsions in other systems such as (inaudible) and also possibly in the spark ignition engine. The other two people associated with the program besides myself, as John mentioned,

is Irv Glassman and another research staff member, Dave Negli.

I would also mention a number of other programs in which our section of the Guggenheim Laboratory is involved which really contribute all to this fundamental regime that Fred Bracco spoke of earlier, this idea of spray formation vaporization, mixing and chemical kinetics, as fundamental building blocks that are necessary really to produce analytical models that do not give you finite details of the process, but guidelines in your experimental development or prototype development of these devices.

Let me first address myself to the problem of emulsified fuel combustion. We had a fortunate circumstance this summer to participate in a summer study sponsored by the American Physical Society, which was held at Princeton during July, and I show you a draft of the report of that summer workshop which is presently in review at Sandia. It was under the direction of -- a third of that study was under the direction of Daniel Hartley at Sandia Research, and our part of the study investigated the role of physics in combustion and it was addressed primarily to the physics community, trying to point out to them areas in which they could not contribute to the combustion area, using our own presently available expertise.

One of the areas of that report was to do a survey of present understanding of the combustion of emulsified fuels. I am sure all of you have seen some recent articles that have appeared in a number of popular journals, such as Science or Popular Mechanics, as such, to the effect that a man by the name of Mr. Walter, Professor Walter Eubank at the University of Oklahoma, has been involved in trying to develop an emulsion of gasoline and water or alcohol and water which would be stable and could be used in prototype combustion carburetion systems.

There is another fellow by the name of Mr. Cottell at Tymponic Corporation, which is trying to -- who is trying to develop ultrasonic types of emulsified systems.

There is a basic difference between these two types of systems and it has to do with the quality of emulsions produced and this quality of emulsions produced has a lot to do with what emulsions do for you in terms of potential benefits and their uses.

Now, Mr. Eubank would point out to you that the injection of water into the internal combustion engine is not a new field by any means. It's been investigated since the middle 1930's, first as a successful approach to anti-knock and secondly as an internal coolant.

Now, the third reason for using an emulsion has nothing to do with those two areas. It has to do with enhanced vaporization. It's a process that has been coined by the Russians as microexplosions and the Russians, at present, are the only ones that have done any fundamental research on the problem whatsoever. It was done in late 1959 and reported and translated by NASA in 1965. The workers involved were fellows by the name of Ivanov and Nefedov, and they did studies of suspended single droplets of emulsified fuels. They dealt mainly with mazute, which is a crude oil of the same constituency as Bunker C, kerosene and benzene. These investigators showed that they could significantly change the ignition and vaporization characteristics of single suspended droplets by first emulsifying these fuels with water. They explained this process by the fact that the water internal to the primary droplet, which was a microdroplet in suspension, went through a vaporization process long before the fuel reached an ignition occurrence, and, therefore, produced either surface distortion or actual rupture and secondary vaporization of the primary droplet.

Why would this process be of interest? In diesel combustion, there are really two approaches to the present problem of NO_x smoke and performance problems in that

system. They all have to do with the heterogeneity of the combustion and the heterogeneity can either exist as possible gaseous pocket distributions in the chamber or it may be even heterogeneity in the liquid phase.

Now, the question is: What can be done about that? The present approaches are to do things in terms of adding circulation to the systems or to do things in terms of the injection. The question arises of what happens if one does something in terms of abusing emulsions as the material to produce a secondary vaporization to reduce the heterogeneity? Now, that question has been approached by two investigators at Cummins Engine Company, and they did one prototype study on diesels and came to the conclusion that emulsions were actually detractive in their interest as far as diesels are concerned and this is why I say there is a basic difference between using emulsions which are used for storage and emulsions which are produced ultrasonically and has to do with the quality of emulsion. If the quality of emulsion is such that you do not produce the microdispersion that I referred to earlier, you are not going to get the enhanced vaporization and you are going to get some ignition problems and this is exactly what Wulfhorst and Valdemanis found on the Cummins Engine studies.

We have proposed to back off and we want to look at just the fundamental combustion properties of emulsions. Does the enhanced vaporization process actually occur? And there isn't really more than limited data available from the Russian work. If it does occur, what quality of emulsions are necessary for its occurrence?

We proposed a number of studies to investigate this fundamental problem and the first study has to do with repeating the initial Russian work, suspending-filament work, but at pressures that are more similar to those occurring in the internal combustion systems, both in internal compression ignition engines and we also want to look at the characteristics that will be available at pressures such as those observed in gas turbines.

Secondly, we want to do some pre-droplet studies, ala the Keston approach, which is presently being developed to produce free droplets in a 20 to 80 micron area, which can be studied by cinematography, and this program is under the direction of Art Keston at UARL, United Research Laboratories.

We want to apply this approach to emulsified fuels and again make a comparison of the vaporization and combustion characteristics of fuel and emulsified

fuels.

Obviously there can be no direct extension of droplet observations to diesel spray combustion such as that which occurs in diesels, so comparative fundamental spray studies on multi-component and emulsified fuels are of importance. Finally, to complete this study, single cylinder diesel work will be necessary to evaluate performance and emission characteristics.

As with most of John's programs described here today, this work was only very recently funded (July 1, 1974). At present we have completed a literature survey of available technology of emulsified fuel combustion and have found that which exists is poorly documented and in most cases inadequate to develop any clear understanding. To our knowledge there are at present no current programs on diesel applications and only very limited programs on spark ignition engines (Ewbank, Cottell). Most interest is presently directed toward furnace applications (Cottell) where some evidence exists that particulate production and excess air requirements are substantially improved. Dr. Hall at EPA Research Triangle Park is currently evaluating both a French mechanical system and the Cottell device on residential size furnaces. The fundamental research area is even more scant with the Russian and our proposed work representing the entire area.

Since attendees of this conference are greatly concerned in methanol and its use as an alternative fuel, let me mention in passing that methanol is a very good alternative to water for forming emulsions with typical hydrocarbon fuels. Additions of small amounts of water to methanol renders it insoluble in conventional fuels, and this has been a major difficulty in developing high concentration methanol fuel solutions. Methanol fuel emulsions should also produce the secondary vaporization process described earlier.

There has been considerable research effort devoted to the development of methanol as an alternative fuel. Yet I do not know of any current or past studies using methanol emulsions rather than solutions. In fact while much systems research on neat and methyl fuel blends is underway, I know of no basic chemical information on what happens when methanol combustion occurs.

There are no data on the rate of methanol pyrolysis and oxidation, the rate of formation of intermediate products or what those intermediate products might be. There are some interesting results which are observed in spark ignition combustion that suggest the intermediate species, the emissions formed are much more complex than one would suspect from the simplicity of the compound. We are presently studying these fundamental aspects of methanol pyrolysis and oxidation in a unique type of research instrument called a turbulent flow reactor. It allows us to measure chemical concentration, and concentration time gradients of stable reactants products and intermediates as functions of reaction time. The temperature range 1000-1200K and reaction times we can observe are incompatible with other chemical kinetic methods such as static reactors or shock tubes. It should be pointed out that this range of variables is of great interest in terms of hydrocarbon emissions in internal combustion engines.

Using this same research tool we have also been studying the high temperature chemical kinetics of hydrocarbon fuels in the alkane series. There are very limited high temperature data on the reactions of alkanes more complex than methane and ethane, and most experimental work has attempted to measure "ignition delay" parameters rather than actual chemistry. The presently accepted theory of how these hydrocarbons are oxidized suggests that hydroxyl radicals are of major importance to the kinetic mechanisms, and that energy release is proportional to initial fuel disappearance. We

are presently involved in experimental studies of paraffin species through hexane, and cursory results suggest that at flow reactor temperatures these postulates are incorrect. We are attempting to formulate semi-global models which are commensurate with these more detailed experimental data. Such models are of importance to predicting energy release rate and emission trends in system analytical models.

In summary, our laboratory is primarily involved in fundamental combustion research in several areas where more understanding is needed to improve energy conversion efficiency and emissions from combustion devices using conventional and alternative liquid hydrocarbon fuels. Thank you.

DR. BELDING: Questions? My goodness. Everybody must be getting tired. Okay.

Well, the last speaker this morning, by alphabet only, is Dr. Naeim Henein from Wayne State University and he is going to talk about flame propagation and auto ignition of alcohol-petroleum air mixtures.

DR. HENEIN: I am not going to take a long time in my presentation because everybody is kind of tired now.

As John mentioned, our purpose in this study is to study the flame propagation (inaudible) methanol,

petroleum, benzol mixtures.

This work started at Wayne State University in January of '74 and the original idea of using methanol was made by Dean Stynes. He is a chemical engineer and he said, "You fellows, you are wasting petroleum products. You shouldn't use petroleum in engines, but you should be keyed to petroleum products for petro-chemical industry and try to find something else which is less expensive to produce."

The work started in January and it was funded by the School and, as of July 1st, this work has been sponsored by the National Science Foundation.

Professor Simbles here and myself and three graduate and two undergraduate students are working on this project at the present time. The work includes both theoretical and experimental parts. Let me start with the experimental.

The experimental part is on a CFR spark-ignited engine. This engine is completely instrumented. We measure the air flow, fuel flow, pressure (inaudible) power output, different emissions, including CO, CO₂, O₂, NO, NO₂, hydrocarbons, by using both heated f.i.d. and unheated f.i.d.

In addition, we measure the flame speed

in the combustion chamber by using ionization probes. At present, all the equipment and the instruments are debugged, operating, and we are starting to get some experiments. The electronic circuits for the ionization probes are complete now and we are trying to put many of these probes in the cylinder head in order to measure the location of flame at different parts of the cycle.

The third report, in addition to the standard studies on chemical equilibrium, electric field temperatures, we are -- we would try to correlate the flame speed as a function of the mixture pressure and its (inaudible) temperature and also we get into the correlation, the fuel-air ratio or equivalency ratio and flame speed. Hopefully, instead of engine speed, if we can put in parameters which would indicate the velocity, for example (inaudible) number, or something like this, but at present we can't put the engine speed as one of the parameters.

The work would be done on mixtures of methanol and indolene, which is the standard fuel for EPA emission tests. Different ratios would be used from zero methanol up to 100 percent. For this, we have to change the carburetion of the engine to allow the use of hundred percent methanol. Hopefully, we would produce some equations which

can give the flame velocity in an engine under different, varied conditions of pressures, temperatures and speeds, and we feel that this basic data is needed for any computer simulation in the future.

You find many models published about NO formation in spark-ignition engines and if you look at these folders you will find that there is one basic piece of information which is missing and that is the flame speed.

I can say that the accuracy of these models depends on the accuracy of the flame speed (inaudible) under the engine-running condition. If you look into the literature, unfortunately, you won't find this basic piece of information which we are (inaudible).

In addition to this program, we have other programs which are supporting this activity and which will be of interest to some of you based on what I heard from the previous speakers. At present, we have an extensive program sponsored by the U.S. Army Tank Command, to study the properties of different injection systems.

Here we have the jet air pump and we have been studying the system for about three years now and we know all its pitfalls, all of its drawbacks.

We have another program which is on the

unit injector, and this is a really challenging piece of equipment on (inaudible) and finding what's going on in the air injector. We spent about one year trying to understand the processes which are (inaudible) in this injector.

We also have a program on the Cummins PT system. The purpose of this injection system studies is for diagnostic purposes, but before you diagnose a (inaudible), you have to understand the processes which are taking place in the (inaudible) system very well.

In addition to this injection system program, we have another program on the auto ignition properties of fuels and this is done on two types of engines. The first one is the CFR compression ignition engine, which is (inaudible) engine used to study the cetane (inaudible) fuel.

The other engine is an Army single-cylinder research engine (inaudible) engine, and these two programs are running simultaneously and we are relating simple numbers of fuels to the ignition delay of these fuels and we are trying to find out what is the meaning of a cetane number. Does it really mean anything? Particularly if you extrapolate the cetane scale, you find that nonlinear at low cetane -- when you use low cetane number fuels (inaudible)

you will find that in many cases you have to use low cetane fuels in diesel engines. For example, in many cases, you may need to use gasoline in a diesel engine. Gasoline is a very low cetane number fuel.

Now we are trying to find out what's wrong with the cetane scale at its low edge or at the low part of the scale. From zero up to about 30 or 35 this scale is nonlinear. So the problem on auto ignition properties of fuels would help us in the future, hopefully, to study the auto ignition properties of future fuels.

In addition to these activities on single combustion engines, whether spark ignition or compression ignition engines, we have a program on continuous combustion systems which we started about a year ago and hopefully which will use in the future alcohol-petroleum mixtures, to study their combustion characteristics in continuous combustion systems at different pressures and temperatures.

This concludes my presentation.

DR. BELDING: Any questions?

MR. BARR: Fred Barr, Princeton University. I would like to comment on the addition of methanol to other petroleums, the petroleums other than

gasoline, and even to the mixture of methanol and gasoline above 15 percent.

The first thing one realizes when one adds methanol to something like a general kerosene product is that it is insoluble to about a half a percent and you find the same thing when you add methanol to gasoline in concentrations slightly above 15 percent and you find also that if there are small concentrations of water in the methanol, it becomes insoluble at much lower percentages.

I would like to offer to you the possibility of using methanol as an additive to these fuels in emulsion form. I would also like to suggest to you that the same characteristics of using water-fuel emulsions can be realized with methanol-fuel emulsions with some benefits possibly in the chemistry. Methanol has a boiling point -- it's about half that of water -- heat of vaporization is about half that of water and, therefore, consumes less energy in its vaporization and also vaporizes at lower temperature. Therefore, it should produce the same enhanced vaporization as much more -- at much better characteristics.

We find that in this form you can also probably produce dispersions of methanol in the petroleum with much smaller microdropping because of the differential

in surface tension.

MR. HENEIN: Let me add here we are not concerned with mixing of methanol and petroleum. In fact, we mixed them fresh for experiment, so we don't get into this separation problem where you have a mixture of alcohols and petroleums sitting there for some time. So we always use a fresh mixture. In fact, we made an experiment, in order to study the separation problem. We have two glass containers in which we put different percentages of alcohols and petroleum. If you keep these closed, you won't find the separation and we have been studying in the lab, because we have many objections from -- about -- and we were scared about the separation, of course. Separation would cause misfiring and then we may find that this is misfiring from methanol and it is from water, you see.

MR. BARR: I would like to point out to you that a static test of mixing these things is probably not very, very good in the sense of how you are using these things. You are putting these things under tremendous dynamic sheer forces in the pumping process into the compression ignition engine or into a spark ignition -- even in an injection system on a spark ignition, fuel injection, and you will find out that those dynamic sheer forces produce separation

in these mixtures. That has been also shown in terms of high internal phase emulsions which the Army studied at Catell Research.

MR. HENEIN: Let me add, all our studies now are related to gasoline engine or spark ignition, so we pre-mix them without imposing them to any sheer stress, so maybe later on, if we study auto ignition properties in diesel engines, we get into the scope and hopefully by then we'll have a solution for it that we can use it.

DR. BELDING: Fred?

VOICE: In your presentation, you say that all available models need flame speed data. That is incorrect. Models have been available since 1970 which do not need flame speed data (inaudible). It's true that flame speed data are always useful. We take them, too, but they are not needed.

MR. HENEIN: Let me ask, are these models for engines with which there is a flame propagating --

VOICE: (inaudible)

MR. HENEIN: How will you determine the maximal pressure and temperature in the cycle without knowing the flame speed?

VOICE: By solving the conservation

equation.

MR. HENEIN: Well --

VOICE: (inaudible)

MR. HENEIN: Conservation equation
is an (inaudible) equation or is a lock system --

VOICE: (inaudible) If you go back
to the (inaudible) conservation, you can solve for the
composition, the (inaudible) in space and time.

MR. HENEIN: How will you get the rate
of heat released by flame propagation without knowing the
flame speed?

VOICE: Well, can you think of your
conservation equations?

MR. HENEIN: Oh, yes.

VOICE: (inaudible) are part of the
input which, when coupled with everything else, the scale of
intensity of the difference, the heat transfer, okay, the
(inaudible), all these functions --

VOICE: I, for one, would like to
support your work and I think it is important to measure the
flame speeds because we are about to report some work, burning
methanol-gasoline blends up to 30 percent in an Exxon engine
and we found this was the one piece of information we would

like to have, and I would like to talk to you later to show you that we have some indications of what does happen to flame speed.

DR. BELDING: Is there one more quick question and then -- Fred, you and Naeim can talk --

VOICE: (inaudible). I didn't say that flame data are not useful. We take them. They are very useful.

MR. HENEIN: Well, this is the impression I got, that flame speeds are --

VOICE: No, you made a statement that flame propagation data (inaudible).

DR. BELDING: Let's take a ten-minute break and be back --

The session from 11 o'clock to 12 o'clock, is on University Research on Methanol, Methanol-Gasoline Blends. Before we get to our three speakers, Dr. Adt Mr. Pefley and Dr. Johnson, I would like to have Mr. Jerome Hinkle from the Environmental Protection Agency give a very brief, five-minute overview of the study which we are sponsoring at Stanford Research Institute on the Impact of Alternative Automotive Fuels.

Following that, Dr. Adt will describe

a grant research program which he has with the Environmental Protection Agency on methanol-gasoline blend research.

Mr. Richard Pefley from the University of Santa Clara will describe previous work which he has done on methanol, and Dr. Richard Johnson from the University of Missouri will describe a methanol-gasoline blend university grant research program which he has with the Department of Transportation.

Briefly, Dr. Adt is at the University of Miami. He has his Ph.D., has a Doctor of Science from the Massachusetts Institute of Technology. Currently, he is Assistant Professor of Mechanical Engineering at the University of Miami.

Mr. Richard Pefley, from the University of Santa Clara, has his Bachelor's degree from Case Institute of Technology, his Master's degree from Stanford University. He is Professor and Department Chairman of the Mechanical Engineering Department at the University of Santa Clara.

Dr. Richard Johnson, from the University of Missouri, Rolla, has his B.A. from the University of Missouri, his M.A. from the University of Missouri, and his Ph.D. from the University of Iowa.

Mr. Hinkle?

I guess he is on at 1:30 pm.

DR. ATT: We have just started, like a number of other people, on a program for the Environmental Protection Agency and we have a four-task program which is involved with characterizing methanol-gasoline blends as an automotive fuel, and I'll describe each of the tasks first and then in a little more detail into what we are going to do in each of these tasks.

The first task is in three parts and the first part is an assessment of the past and current studies of performance, emissions and practical use characteristics of methanol and methanol-gasoline blends. The second part of the first task is identification of performance, emission and practical use characteristics which are missing from the current technology, and also included will be a program we will carry out at the University of Miami to answer some of these questions which I will go into in a few moments.

We are also going to have, as a part of our first task, a review of the various methods for measuring the problematic emission components in methanol-gasoline blends, namely methanol and the aldehydes.

Task 2 will be experimental in nature

and it's a determination of base line performance and emission characteristics of a gasoline-fueled engine. I'll describe that in a few moments.

Task 3 is determination of performance and emission characteristics for methanol-gasoline blends and some neat methanol tests and the fourth task is a materials compatibility study.

Now, I would like to go over each one of those tasks in a little more detail. The assessment we'll carry out will cover only performance, emission and practical use considerations that are related to on-the-vehicle. We will not be concerned with off-vehicle problems, such as production, off-vehicle distribution of the methanol, off-vehicle storage of methanol-gasoline blends and so forth. It will be strictly on the vehicle, and we feel that there is a definite need for such an assessment because it's been about ten years since Professor Bolt did his very comprehensive alcohol review.

I just hope that we come somewhere near to what he did in his review, The review in the past was concerned mostly with ethanol rather than methanol and consideration was for pre-emission controlled engines.

In our updated assessment, we'll focus

our attention on methyl alcohol and also blends of methyl alcohol and gasoline and we'll be giving considerations to the power plant of today with the various emission control equipment, the effect of catalytic reactors, exhaust gas recirculation, and so forth. And we'll also look into applications in more advanced power plants such as the stratified charge engine and we'll also include the recent data regarding exhaust emissions, including unburned methanol, aldehydes and polynuclear aromatics found in the exhaust.

The second part of Task 1, once we have this assessment done, we will be in a position to identify, as I said before, performance, emissions and practical use considerations that are deemed important and lacking in the current technology and also to identify a program that we'll carry out at the University.

In this assessment, we'll also review the various methods for measuring exhaust gas constituents. Some of them are somewhat of a problem. For example, unburned methanol, if you go, use a flame ionization detector, it turns out that the response of the detector is quite a bit lower for the methanol molecule than the other hydrocarbon molecules and also if you use an unheated flame ionization detector, you lose your methanol in the condenser

trap.

Aldehydes are somewhat of a problem in that they are quite tedious with chemical methods that are used now, and another one that may be a problem, we're not sure, is NO_2 . A lot of people report that most of the nitric oxides are NO in the exhaust gases, but some of the work by Adelman, for example, show that there are substantial amounts of NO_2 in the exhaust. If this is the case, we are just not sure what happens when you use a cold trap. I know in some of the hydrogen research, where they find significant amounts of NO_2 , care must be taken or they have taken care not to use a cold trap for fear of using the NO_2 in the condensed water phase. We just don't know whether this is a problem or not, but it's something that has to be looked into, and so that's the type of thing we'll be looking at in that portion of the research.

After we finish that, we'll be for base line performance and emission characteristics of a gasoline-fueled engine. We have rather long-range plans on what we would like to do, looking at alternate fuels. We have looked at hydrogen in the past and now we are looking at methanol, but in order to do this we feel we have to have a good engine, that we have got some very good base line data

from gasoline-type fuels against which we can make our comparisons. So what we have done is, we are going to be using a multi-cylinder engine. It's a four-cylinder Pontiac engine, but we'll be using today's cylinder head. You can change the cylinder heads on the engine and also we'll be using today's cam profile, so we simulate the modern engine.

As far as the fuel goes, we'll be using unleaded indolene as our reference gasoline and the type of tests we'll be doing are steady-state engine dynamometer testing and we'll be taking raw exhaust sampling, we'll be using the carbon balance method to arrive at mass emissions.

After we get our basic data from the gasoline engine, then we'll proceed, looking at the blends of methanol and gasoline, and it looks like, from the literature that, the most optimum blend is somewhere around 15 percent. So we'll probably be doing most of our testing around there and we'll also do some testing with neat methanol.

The fourth task is a materials compatibility study. In the literature there are reports on problems when you use methanol-gasoline blends as far as, for example, corrosion in the gas tanks, like the turn plating, for example, has been found to present

somewhat of a problem. So one of the things we want to do is take different metals that come into contact with the fuel from the carburetor, type of metals, problems have been found there from the fuel tank, and so forth, and do some carefully controlled tests, carefully control the temperature, the water content and the blend compositions so we can determine what type of corrosion to look out for.

Also, there has been quite a bit of published problems with regard to use of non-metals with compatibility with the methanol and that's basically what we'll be doing in our first year's work, and in the future we hope to, after that's done, look at more advanced power plants. Once we have the basic data from today's engine,

then we'll go off into more advanced power plants such as the stratified charge engine and then we'll have something against which to compare changing engines,

Finally, after that, we would like to then test some of the synthetic fuels -- maybe from coal and so forth. Instead of using indolene, take a look and see what effect a synthetic fuel will have on these different aspects that we'll be studying in the first year.

So that's basically our program. Any questions?

VOICE: I would like to make a comment concerning your methods for determining methanol concentrations and aldehyde concentrations in emissions.

There is an approach to using flame ionization which is detailed in the Environmental Science and Technology article in the February issue 1973 which we developed along the lines of the nickel catalyst approach for analyzing carbon monoxide on flame ionization. If one uses ruthenium as a base catalyst for that system, one finds that you get a complete conversion of oxygenated compounds, such as aldehydes and methanol to a saturate material which produces a response similar to that of a paraffin. You get a 1 to 1 correspondence between the carbon number and the response in the item, and we have found that it works very well for alcohol. It works very well for aldehydes above formaldehyde; however, formaldehyde is probably the aldehyde you are going to find is the major aldehyde in emissions. It turns out that the conversion works very well with formaldehyde. However, to find a gas chromatographic column that can separate formaldehyde from other items without some hangup on the column is quite difficult. Sapulco Corporation of Bellefont, Pennsylvania, claim that they have a material that does that now.

I would also like to suggest to some of the other people in the audience that this may be a much better way to evaluate what the coal hydrocarbon emissions are from an engine. If one is able to get a total carbon number in terms of emissions, that might be much more realistic in terms of hydrocarbon emissions than to (inaudible).

DR. ADT: There are other ways that we -- for example, you can strip out -- in an f.i.d., you can strip out the methanol and measure, you know, the stripped sample and then the unstripped sample and determine your response of the f.i.d. and that will tell you what you have.

VOICE: This is a very effective way to use this sort of approach for hydrocarbon emissions. You strip out the CO and CO₂ in the emissions and look at just what the total hydrocarbon emission is on a backflush and, in fact, you can compare that with what your total hydrocarbon reading is in hexane calibration and you will find you have got a number that's associated with the oxygenates and cyclo compounds that don't have paraffin response.

DR. ADT: We're also interested in the distribution amongst the different hydrocarbons. That's another --

VOICE: You can characterize some of

that.

DR. ADT: Yes, that's right. Thank you.

DR. BELDING: Thank you, Bob.

Our next speaker is Mr. Richard Pefley from the University of Santa Clara.

MR. PEFLEY: Good morning.

I think some of my remarks here go back to BEC. I'm not saying "BC" now; I'm saying BEC, which means "Before Energy Crisis" to me and one wonders if that may not be an important date in times to come.

If you want to hold that slide off for just a minute -- our early work was supported by NAPCA and it involved the CFR engine and we'll have a little bit more to say about it in a slide here in a few minutes, but the main interest was using disassociated methanol. As many of you recognize, if you disassociate the methanol, it absorbs energy and you are burning then, in the engine, you are burning CO and hydrogen and that's very attractive.

Our initial interest was in a clean-burning fuel and so our earlier work -- and it's published in the literature -- addressed that issue and we ran a CFR engine on all blend mixtures of disassociated methanol and pure methanol and in many senses it is attractive in an emissions

sense as a fuel.

One of the big problems, of course, that still is unresolved is how do you effectively disassociate the methanol? But the idea is so attractive that it needs further pursuit and it's part of our interest.

In addition to that early work with the CFR engine, we started in the fall of 1971 a project with the City of Santa Clara where we engaged them to buy cars to our specification and matched an engine to those cars in our laboratory and they were Plymouth Valiants, 1972, slant 6 engines, and one of them actually ran for some time on straight gasoline and currently we are running it on blends.

The other vehicle has never been on anything but pure methanol. It's over two years now, 30 months, over 20,000 miles in operation, and it has never had anything but pure methanol in it and if I may have that first slide, we'll talk a little bit about the -- I think you can all hear me, can you not, and will the recorder work all right if I stand over here?

What you are looking at here is the blend vehicle, and if you look at the upper photograph, this represents the ordinate. Everything is normalized in comparison to gasoline, and the abscissa represents the blends of

methanol and the upper graph represents the miles per BTU. If you look at the energy conversion efficiency of the car, you see in this particular vehicle up to 20 percent we found a slowly rising efficiency. Each point there, unless noted otherwise, represents four points and the average of four test points, so we think they are reasonably well anchored. The curve just below that shows the miles per gallon and, of course, because the methanol is about half the energy of gasoline, you see that it does not hold up and so if we are going to talk about methanol to the public, certainly we have to talk about energy or miles per unit of energy per million BTU's or whatever and not miles per gallon.

The lower three curves represent emissions and I'll not take a great deal of time to discuss these because this is documented in the publication, the Methanol Conference at Henneker this summer. We presented this material. It's discussed in detail, but the general evidence for the hydrocarbon, CO and oxides of nitrogen are all generally downward as you increase the percent methanol.

Now, basically what is happening, you are leaning out the engine. The one anomaly is, you would expect the oxides of nitrogen to rise.

Henry is going to have some more to say

about that shortly here, but even taking into account the fairly complex curve shape, the general trend is downward in all three emission species and so we think that methanol is attractive in this sense.

Let me have the next transparency.

This is the vehicle that's never had anything but methanol in it. It's still on the streets. It's operated by meter readers, typical operators in the City of Santa Clara, and you can see some, briefly, some comparative data between California federal emission standards in the lower pair of tabulations and in the upper, the first was done by the Los Angeles Air Resources Board and then we tested it in our own labs and, as you see, the emissions from this car -- it's equipped with a catalytic muffler, hydrocarbon catalytic muffler, and, as you see, the emissions levels are pretty attractive.

However, it's important to report that at those conditions, this was in a clean air car competition a couple of years ago, at those conditions, the operators did not care for the car. It was sluggish in operation and we have indicated that. In addition, other problems associated with the pure methanol are that there is a cold start problem and there is some -- we have encountered some fuel

systems materials incompatibilities in the operation.

May I have the next one? This little Gremlin is now four years on methanol, never had any part of the fuel system changed except the fuel pump, so far as I know, and Henry can probably verify that because Henry started out with this thing at Stanford in a student clean air car race back in 1970, and what is of interest here is the progressive improvement in emissions performance and also efficiency.

This last year, it won three of the four first places in the student clean air car competition and the fascinating thing is that this vehicle doesn't have, I doubt, over \$100 worth of modifications on it, and so -- well, actually, neither of these vehicles, the pure methanol vehicle nor this vehicle -- basically what we have done is change the jets in the carburetor, modify the spark timing, and provide a heat source in the intake manifold in these vehicles and this car actually has four years now and is still in very good operational shape.

Well, just to be brief, our conclusions from this early work are that methanol vehicles give reasonably good performance, even when you only spend a modest amount of money in converting them.

There are some problem areas, however,

and others have identified these as well as ourselves. Cold start on methanol -- cold start is a serious problem, even at 45 degrees ambient temperature. When we say "cold start," why, with methanol, you find trouble at that temperature.

We also believe that the fuel -- there is more stratification. The methanol-air mixture in the standard carburetor manifold system has greater difficulties than the gasoline-air mixture in being homogeneous as it enters the cylinder, and so fuel nebulization and fuel-air distribution are problems of concern.

I previously mentioned earlier materials incompatibility. We are concerned with the aldehydes particularly, and as one of the elements of proposal for ongoing work, particularly are we concerned in the maladjusted engine. It looks very satisfactory. At least what evidence we have is that it is competitive with gasoline if the engine is well-adjusted, but if you have burned valves, problems like this, we are concerned and we like to look at that kind of situation in greater detail before we harness the public with such an idea.

Then, of course, the phase separation in a blend vehicle -- we have encountered some problems. You do have to watch water presence. Unless you are going to

resort to special fuel preparations, why, you do have to watch for the presence of water to avoid phase separations in the gasoline-methanol blends.

Well, where do we go from here is where I would like to wind up my comments. What we would like to do is take a conventional engine today, a '75, '74, '75 engine, and get a basic performance characterization of it on gasoline. Then we would like to use our low-cost modification, best low-cost modification based on what we now understand, and get methanol performance with that low-cost modification for the fuel induction system and then, thirdly, we would like to really optimize the induction system. We have been working for some time with a pressure wave carburetion system that we think is far superior to conventional manifold carburetion systems and that or something equivalent to it, we would really like to optimize the induction system for methanol because, as you go back to my earlier slides here on the Gremlin, if students and \$100 modifications can produce that kind of change, it's interesting to ask the question: What is possible if people really turn their engineering talents to this problem?

So we would like to do that, try to optimize an induction system as well as an ignition system and see what kind of performance map we would get in comparison

to gasoline, using a stock engine, so to speak.

Well, I would like to just briefly describe one last transparency and then I would like to introduce Henry Adelman, who will make a few comments.

This goes back to our -- before our energy crisis data. It was the CFR engine. In this case, Henry and one of the other fellows in our laboratory wanted to look at the disassociated methanol in the very lean region and notice now the equivalence ratio across the abscissa and so we are getting down here in the very lean region, particularly as it relates to the oxides of nitrogen. You can see as we come very lean, the engine continued to develop power clear out in this region, although there was a power fade. Notice that an equivalence ratio of about .35, the carbon monoxide started to take off and what we have is a homogeneous mixture in the cylinder and what we think is happening is that the temperature dropped low enough that we are no longer reacting the carbon monoxide and -- but in this region, notice the NO_x production has dropped well below an order of magnitude below its peak, and we think this is an attractive region that should be explored further, recognizing the power fade, the trade-off in terms of reduced NO_x production is really attractive when you run the engine on this disassociated

methanol form, and now I would like to turn -- I assume we have a few more minutes and I would like to turn the podium over to Henry Adelman, who has been doing some computer studies. We also think that, as has been suggested earlier here, that just brute force and awkwardness in terms of modifications are not necessarily the only route to go. We should couple this with the sophistication of analysis that are available to us and Henry has been doing some work on computer models and I would like to turn it over to him to discuss that just briefly.

MR. ADELMAN: Thank you.

I would like to talk about some work that we are doing for NASA-AMES Research Center. It's a small grant we started about a month ago, and it involves a combustor model for a gas turbine engine that we will be using dissociated methanol, methanol, perhaps blends of these fuels, and comparing them with hydrocarbon fuels, probably methane and isooctane and if we can get thermodynamic data on, say, jet fuel, we'll compare it to jet fuel. This computer model that we are using was developed by Roger Craig at NASA-AMES. He has been working on this for several years, and if I could have the first slide, we have a schematic of the combustor. We have to make several idealizations here.

First, we assume that the fuel is in

gaseous form. We also assume that if there is recirculation of the burned gases into the unburned mixture, that this is complete and instantaneous. We have taken the Pratt & Whitney JT-8-D engine as the model. This is a schematic of that engine.

The primary zone is roughly 7 1/2 centimeters long; the second zone is 35 centimeters long. There are four stations, I believe, where secondary air is introduced along the zone. We assume that that secondary air is also mixed instantaneously and uniformly in each plane.

If I could have the next slide. The major input through this program, since it deals with the reactions in a flowing system, are, of course, the combustion reactions for the fuel that you are considering. Now, our first cases are for disassociated methanol; that is, two molecules of hydrogen to one molecule of carbon monoxide. Here you see the 33 reactions that describe the combustion of the hydrogen CO system and the formation of oxides of nitrogen. These have to be input into the program.

One of the difficulties is coming up with the correct reaction scheme. Other information that has to be put into the program are the former great constants for each reaction. The program has thermodynamic data to calculate the reverse reactions from the equilibrium constants. That,

of course, is another area of uncertainty.

A lot of these reactions have an uncertainty of plus or minus 50 percent. However, Roger Craig has done considerable work on the use of hydrogen diluted with argon. He has compared his results with work that NASA-Lewis has done on hydrogen fuel turbine combustors and is very confident in the operations program.

If I could have the next slide, here we see -- this is a case where the primary zone is operated fuel lean, .8. The overall air-fuel or equivalence ratio for the turbine is .25 for all cases I'll consider here.

What we see here is, for this case, from zero to 1 centimeters there is what you might call induction period, where some of the free radicals are being formed. I should mention that there is a recirculation of burned products and this is necessary because the air leaves the compressor at 700 degrees K. In actuality, before combustion starts in the Pratt & Whitney turbine, the air-fuel is raised to a thousand degrees K, which means that some of the burned products must be recirculated through heat, the incoming mixture. What we found is that if you recirculate inert products to bring the incoming mixture up to a thousand degrees K, that it generally has an induction time that is so

long that it won't even burn in the primary zone. Now, if you also include the free radicals, then the induction time is shortened and, indeed, compares very well with the experiment. So what we have here, and it unfortunately doesn't show up too well, is that some of the free radicals, such as O, H, and OH, are recirculated at levels of about 10 to the minus 4 and they don't show up here but they drop very, very rapidly to 10 to the minus 7 levels. Then, of course, they rise, overshoot equilibrium considerably in the flame region, and then come back down to post-flame equilibrium values.

So there is quite a flurry of activity that at 1 centimeter, which represents the flame zone. However, a few curves stand out here. For example, this and this, and even this one, but these two in particular have time constants, of course, that are orders of magnitude longer than the time constants for the HO reactions and, of course, these are the oxides of nitrogen. This is NO_2 and this is NO and if we can have the next slide we'll see, in a little more detail, the combustion zone. We'll see again the overshoot of some of these free radicals here at the center, OH -- I have to apologize for this transparency; it's not too clear.

You can also see carbon monoxide

starting to be oxidized in the flame zone, NO_2 .

One interesting thing is that before the flame, there is essentially no NO . It starts to form right here. This is what a lot of people call (inaudible) NO , and if we could see the next slide, we see that happens to these gases once they reach the secondary zone.

Now, here the mixture is being diluted with nitrogen and oxygen, essentially air, and again we see the fuel, the hydrogen, and even the CO , which, I can find it here, when it started, in this case was a fairly substantial amount (inaudible) a negligible amount. NO is just -- the rate of production of NO is being slowed because the temperature is decreasing and after that it's essentially frozen and you are simply seeing a dilution.

Interestingly enough, though NO_2 is still forming and here we have a case of about 20 parts per million and that compares to about 500 parts per million for NO .

I also have a few runs for the case of the primary zone was burned with the equivalence ratio of 1 and show them for comparison.

VOICE: I think we are about out of time.

MR. ADELMAN: The main feature here is, of course, the induction time was a lot quicker for stoichiometric mixture. Aside from that, there is not a whole lot of difference. Again, the combustion details -- that's okay. We will get another slide.

Finally, the secondary zone, where the emissions of NO in this case are about three times higher than the case where we had .8 equivalence ratio, I think we have about 2000 parts per million NO and, again, about 20 parts per million of NO₂, but I think this is a very interesting program.

Our next step will be to obtain a reasonable reaction scheme for methanol. I say "reasonable" because there hasn't been much work done on this since 1934, although Dr. Craig Bowman at United Aircraft is still working on studies for methanol reaction schemes. So we intend to, then, compare methanol with disassociated methanol and jet fuels and try to use this program to design a low-emission turbine burner.

Do we have any questions?

DR. BELDING: Henry, thank you very much.

Our last speaker for this morning,

Dr. Richard Johnson from the University of Missouri.

MR. HAGEY: I think I am going to make a light adjustment in the schedule. I indicated when we started this morning that we would try and get the City of Seattle program presentation which originally was not scheduled, but which we would like to schedule today. Originally, we had thought of running it at five o'clock, but I think -- there are a number of people who want to hear this and five o'clock is a conflict with some people on airline scheduling, so I'm going to schedule at one o'clock, from 1:00 to 1:30, the City of Seattle personnel will present an overview of their program plans and then our regularly scheduled agenda will start at 1:30. Those of you that are interested in sitting in on the Seattle presentation, I would invite you to be here at one o'clock.

DR. JOHNSON: I would like to talk a little bit about the methanol fuel studies that we are doing at the University of Missouri at Rolla, and I will be the first to admit that we are relative novices to the field of engine and fuels research, having gotten into the field within the last two to three years, and we got into it kind of in looking at alternative fuels and energy forms that led us to the conclusion that independent data was necessary and needed in

terms of the use of possible alternate fuels and, in examining the fuels that are likely to come on line and be viable in the relatively near future, methanol certainly stands out in this area and that existing technology can produce it. In addition to that, it can be manufactured from a variety of sources, coal, garbage; of course, petroleum as well.

Now, our initial concept was to consider methanol as an extender for petroleum fuels, particularly gasoline to do a characterization study to examine the emission and fuel economy and other characteristics of methanol-gasoline blends. We wanted to limit our study to small displacement engines and the kinds of vehicles that they are likely to be in because we felt that many factors will force a reduction in vehicle size, weight and so forth by the time methanol is available in any kind of quantity for fuel use.

The current work we are involved in is supported by the Department of Transportation, and right now we are working on two programs. One program is to characterize emission fuel economy and so forth for the small displacement engine, using what we call simulation of the federal test procedure with the urban driving cycle.

If I could have the first slide. Now, this is kind of a shoestring-rubber band operation, and

we couldn't afford a vehicle, so what we have got is the engine and drive train that we can mount on a chassis dynamometer. We have gone to a mobile analysis technique to determine the concentrations of pollutants, fuel flow, and so forth as a function of time. We sample data every half second and from this do a carbon balance across the system and develop from that the emission characteristics. This is the general apparatus you see here.

Let me move to the next slide. This is a fair view of the engine package. You will notice that there is no vehicle around it.

Next slide, please. We have a separate driver console with the driver's aid and other parameters needed for the driver to operate the "vehicle."

Next slide, please. Our emission measurement system consists of standard instruments for measuring hydro -- unburned hydrocarbons, carbon monoxide, carbon dioxide, and oxides of nitrogen. We have made every effort to obtain instruments with fast response and have, indeed, included in our computer analysis of the data from the system the corrections for the time response, concentration characteristics, and so forth of each of these instruments.

Next slide, please. This doesn't

look very fancy, but this is our data acquisition system. It consists of a 16-channel sampling system. We can sample 16 channels every half second, which is stored in (inaudible) form on magnetic tape and then we hand carry the magnetic tape to our local computer center and essentially play it to the computer and, from that point, analyze the data.

Now, a second program that we are involved in at this point, in parallel with this one, is a parameter study, using a CFR engine, and we are trying to characterize the effect of spark on fuel consumption, emissions and so forth, in addition to the methanol concentrations. We are also doing a wet chemistry analysis of aldehydes and trying to look at the, let us say, the in and out characteristics of catalytic converter, particularly with respect to aldehyde concentrations.

If I can have the next slide. For those of you who are familiar with CFR engines, this is a very old edition; however, it nevertheless has been brought up to current state of operation and is, indeed, (inaudible) and calibrated.

Our concept here is to move from this parameter study and try to develop some important parameters that can be varied, particularly ones that are easy to vary, like

spark advance and perhaps fuel-air ratio, and incorporate these changes into our engine drive package on the chassis dynamometer and get results in terms of the federal test procedure.

Now, we have completed some initial studies, using the CFR engine in terms of developing octane characteristics for methanol blends into unleaded gasolines, and we ran into some rather peculiar characteristics. I'm going to have to qualify my results a little bit here so you can understand how these octane characteristics were determined.

If I can have the next slide. Those of you who are familiar with knock testing, and forgive the slide; two inexperienced operators tried to put these things together Friday night and we didn't do too well, but those of you who are familiar with knock testing, this is a representation of the knock characteristic. This is an isooctane, the standard reference fuel, and, indeed, you see a sharp spike here near the top of the pressure time diagram. This represents knock. Actually, there would be a ringing process here, but this measurement is made after a filter in the knock instrumentation, so this ring is removed.

Now, if we can move to the next slide.

Under standard operating conditions for the knock test procedure, if you run a hundred percent methanol, you will get standard knock under certain conditions. However, if you are listening to the engine, you will notice that it is not knocking audibly and if you look at a pressure time trace, you will see something like this. This is, indeed, a fairly sharp pressure rise, but no sharp spike that indicates actual engine knock. It turns out this is really kind of a problem with the instrumentation in that it looks at only the area above the line CD there and essentially integrates that area and gives you a meter reading.

If we could go back to the previous slide -- I don't know whether we can go backwards here -- you will notice that for isooctane, the standard fuel, the area above AB is controlled primarily by the spike area there. Now, if we can move forward, for straight methanol there is no spike, but the area could be equivalent, so you could get standard knock even when the engine isn't knocking.

By slightly modifying the standard test procedure and using an oscilloscope to determine when the engine was knocking, we got traces similar to the next slide here.

The upper slide is for methanol and

the lower slide is for isooctane, plus tetraethyllead, in order to bring the octane number up. These are at approximately the same octane number. Note there is still a slight difference in the knock characteristics; however, there is no question at this point that the methanol is knocking and, under these kind of conditions, we consistently determine an octane rating for research octane of 109 1/2 for methanol.

We used this procedure henceforth throughout the testing, particularly for high concentrations of methanol.

We can move on to the next slide. Here we are talking about the characteristics of four unleaded fuels. Now, we have blended methanol with fuels ranging from 81 research octane to 98 research octane and this is the first of those fuels, a low-octane fuel. You will note that the octane increase of the research octane rating is fairly substantial. This is the kind of thing that people note when they talk about the octane-improving characteristics of methanol.

However, the motor research number, which is probably a better indicator of how a modern engine with automatic transmission is going to behave, doesn't show

nearly so substantial an increase. You will notice there is a couple of parameters defined here that you are probably not familiar with. One is delta N and the other is K.

Essentially, we developed a description or, I should say, fitted a description equation to the data we developed and tried to come up with parameters that have some physical meaning in terms of the octane characteristics.

Delta N is a characteristic we have called the octane improvement index, or increment, and essentially it gives an indication of the maximum possible effect that methanol will have on a given base fuel. You cannot possibly reach that kind of octane increase. In other words, you can't increase the octane number by 30, but it gives an indication of what the maximum effect could conceivably be.

K is a parameter we have called the octane response, and it kind of indicates how sensitive the fuel is or the octane of the fuel is to small amounts of methanol. The larger the K is, the more significant the octane increase you will achieve by adding small amounts of methanol.

If we could move on to the next slide, we'll go through these fairly quickly. This is for increasing

basic octanes of the fuel. This is at 89 research octane fuel. Again, you will notice a substantial increase in the research octane; in the motor octane there is very little increase.

Next slide, please. This is again a higher octane fuel. In fact, this happens to be equivalent to a premium, unleaded fuel that you could buy at the pump. Again, there is an increase in the research rating. The motor rating, however, at increasing concentrations of methanol, even goes down and the next slide here, this is base fuel D which happens to be indolene clear and, again, we see there is some improvement in the research octane but very little in the motor. In fact, it does even go downhill.

Now, one parameter that has been used to describe what's happening here is the blending octane value and if I could have the next slide, we looked at blending octane value for the first fuel and blending octane value is, we feel, very misleading, particularly for low concentrations of methanol and this is the range we expect to be looking at for a couple of reasons. One is it's not independent of the concentration, and we felt that any parameter that was going to describe the effect of methanol on a given base fuel ought to be independent of the concentratio

of the methanol.

The second thing is, when you get to very low concentrations, because of the method of calculation of blending octane value, any slight errors in your readings are going to cause giant variations in the blending octane value, and you can see this from the data presented here. So that at very low levels of methanol concentration, which are probably the most realistic ones, the blending octane value doesn't have a very good, very stable meaning.

So we move to these other parameters that we describe, the delta N characteristics which kind of indicate the maximum increase you might be able to anticipate, and this K factor which indicates how sensitive a fuel is to small amounts of methanol.

Now, the last slide here represents the results of correlations we tried to make between these two parameters we have defined and the base fuel octane number. Now, there is a piece of information missing off this figure. $N(f)$ is the octane number of the base fuel. These are the results of the correlation we did for delta N and you will notice that there is a pretty strong correlation between the delta N factor and the research octane and, as well, the motor octane number of the fuel and, in fact, they were

well-described by a simple linear relationship. Although we don't have sufficient data to draw any firm conclusions, we could speculate from this information that this delta N factor is apparently dependent only on the base fuel octane number and not the composition, because the composition of these unleaded fuels was quite variable as far as the hydrocarbon distribution.

Well, this represents the current status of our project. We are right now about to begin taking data from our federal test procedure simulation and hope to be able to report within the next few months at least the beginnings of that study and are now converting our CFR engine into the engine parameter studies. However, this octane information has been valuable to us in the sense that we have decided that compression ratio is probably not going to be as significant a parameter as we had originally thought in the sense that in actual vehicle operation, since it operates more like the motor number, we see that the motor octane isn't going to change very dramatically by adding methanol. The sensitivity of the fuel mixture will increase, but basically the motor characteristic doesn't appear to change enough to justify a large program, examining changes in compression ratio. So this data has been important to us

in trying to shape some of our planning as far as our engine parameter studies.

That's all I have.

DR. BELDING: Thank you, Rich. Do we have any questions? Yes, sir?

VOICE: Your observation on the research engine indicated a region which is defined as knock on the basis of pressure and yet you don't hear the knock.

DR. JOHNSON: That's correct.

VOICE: There is a question: Isn't the audible knock which you hear with this present engine, which we must avoid at all costs, or is the excess pressure rise on smaller -- is that same pressure rise over a longer period of time?

DR. JOHNSON: I think the real criteria is the spike that we saw, the pressure time trace. This actually represents the detonation of the remaining charge of fuel in the cylinder. When you have -- even though it's a more rapid burning rate and you get a higher pressure, it's spread over a larger period of time and you don't have essentially an explosion occurring in the chamber, which this is the thing that tends to --

VOICE: Isn't it true that -- is that

a usable increase in pressure which works for you as ordinary pressure increase does, or is that one to be avoided?

And so the whole question of the meaning of (inaudible) has to be re-examined (inaudible). What would you like to have and what becomes dangerous? So I don't know how to answer that. You have opened up a very important observation, a very important area. I hope a lot of people will look at it, think about it and not just stick exactly what you already know for gasoline. Gasoline has its own properties.

DR. JOHNSON: Well, I agree with you in the sense that we feel the real criteria is going to come in road octane and we are not equipped to do that. The real value that the car develops hopefully lies somewhere between the motor and the research and the question now is where. Does it lie closer to the motor or does it lie somewhere more toward research when you burn alcohol, and we don't know the answer to that.

VOICE: How much of that pressure increase can you (inaudible)?

VOICE: I noticed in some of the diagrams of knocking cycle that the knock normally occurs at the end of combustion. Was the total time -- did you analyze the cycle to indicate what the total time of flame propagation

really was with (inaudible)? In other words, was the flame speed, overall flame speed (inaudible)? Was that higher or was that lower with methanol?

DR. JOHNSON: I would have to be honest and say we did not analyze the --

VOICE: Usually, you can determine this very simply with knocking cycles because the knock occurs right at the end and it occurred to me, from the flame diagrams that you showed for comparable octane fuels, that, in fact, the methanol knock occurred later in the cycle than it did in the case of the isooctane.

DR. JOHNSON: There is definitely a difference in the knock characteristic. This is not only visual, but it's audible as well.

VOICE: Of course, you could analyze a (inaudible) diagram to try to determine the total time of flame propagation to determine whether, in fact, that is higher or lower and I guess my impression, in fact, is it is longer with methanol.

DR. JOHNSON: As far as the total flame. The onset appears to be more rapid.



Seattle Presentation:

MR. ROBERT SHEEHAN: Bear in mind a couple of things here. This show is straight out of the photo lab. I haven't even seen it, gone through it myself, so -- and it's also made for our City Council, which we intend to approach next week.

As if that isn't complicated enough, why, it was intended to be a double-screen presentation. You are going to see them all on one, so I will do the best I can with it.

I see some friends out here that really helped us. Without the Tillmans and the Reeds

our progress even this far would have been impossible, so thanks to all those that helped us.

I wonder if we can dim the lights a bit.

In December of '73 and commencing right after the first of the year, the Mayor of the City of Seattle instructed the Department of Lighting, the electric utility of Seattle, and the Department of Engineering to undertake a study for the utilization of solid waste for energy for salvage, the goal being to get out of the landfill business, if possible, before 1980. It was pretty obvious, as we began our study, that we weren't just dealing with garbage or solid waste, as it's called in more sophisticated circles. We were really talking about a resource which was being dumped on our city hands, in fact, in large quantities and, of course, it has a chemical characteristic and it's essentially a shame to bury it.

With that kind of beginning, of course, being with the lighting utility, our assumption was that we would ultimately see its use in a steam power plant of one kind or another, either for the generation and marketing of steam in the urban area or more likely for the generation of electricity. So we looked at a lot of concepts, including some involving gasification by pyrolysis. As a result of looking at these various alternatives, we catalogued over a dozen of them that looked to be practical from a technological standpoint and we compared them on the basis

of ultimate disposal cost, which is the number on the far right.

Now, bear in mind that landfill essentially is about \$4 to \$5 a ton, projected to grow as labor costs rise, as fuel costs for hauling rise, and as we move farther and farther out to more environmentally acceptable sites, if there are any.

Essentially, the name of the game was to come up with something better than landfill. In our early study, why, we looked at coal-fired plants, combination coal and solid waste, pyrolysis and so on, and along the way we began to realize that the gas stream coming from a pyrolysis system was potentially a feed stock for the manufacture of methanol and so, having identified alternatives K-2 -- K-1 and K-2, that is the pyrolysis for the production of methanol, having identified those as potentially very attractive economically, we realized there were other benefits as well, which I will cover as we go on.

Well, of course, there has been an awful lot of reports written on the subject. The one on the right was our summary of alternatives which we published in May of this year. The one on the left has recently been completed by Mathematical Sciences, Northwest, whom we have

retained as a consultant during the period May through September for an intense look at this methanol concept. Along the way, they identified the possibility, potentially more attractive economically, of making ammonia from the off-gas or conceivably a plant combining products. Of course, along the way we have had an interesting inter-departmental group and try to think a little bit as though you are in city government and grasp some of the problems. Our interests were across ordinary organizational boundaries. We had a man from our office of Management and Budget looking at it from a management standpoint, myself from the Lighting Department, Dave Gordon, who is down here -- raise your hand, Dave -- who is Manager of our total city fleet of some 2500 vehicles. In addition, we had Mass Sciences and we had, of course, our Solid Waste Manager, so we had a cross section of people attacking a problem. It was pretty obvious that methanol held some intriguing possibilities for us: City energy and fuel independence for our fleet, reduction in air pollution to the extent that our own fleet would reduce air pollution in the urban core, and, of course, comparable costs or better relative to landfill. With these incentives, why, Mass Sciences proceeded.

Along the way, we briefed the Mayor

and the Chairman of the City Council Utilities Committee and appropriate department heads in many sessions, receiving their endorsement and encouragement consistently all the way along. Within city government you can see the cross section of people that we had, from various departments on the executive as well as the nut and bolts level like Dave Gordon and myself and the Solid Waste Manager. The team that Mathematical Sciences, Northwest, put together was a pretty impressive team with strong representation from the Department of Chemical Engineering at the University of Washington, plus the inclusion of an industrial representative. We retained or they retained Foster Wheeler to provide a certain practical nut and bolt flavor and their mission was to essentially review the total concept of methanol relative to technical feasibility, economics, marketing the products, benefits to the City, and the environmental impact. Of course, it was in the course of their efforts -- this is the structure of their organization -- in the course of their efforts, some very competent chemical engineering people, a team led by Dr. Haltman, the University of Washington, identified ammonia as another possibility with some very interesting market advantages in terms of dollars, but we are still fascinated at the concept of methanol for vehicles.

In any case, the study that Mass Sciences has done confirmed our belief in the technical feasibility of the processes for either methanol or ammonia from solid waste so that put the problem to bed.

The process that we have considered, of course, is the preparation of solid waste with some material salvage, then gasification, some waste from that, mostly a granular type of material, and then a gas shift reaction to get the carbon monoxide and hydrogen into the proper relationship, and finally the manufacture of our end product, another ammonia or methanol.

So the first step, of course, is to prepare the solid waste and one way to do it is, of course, to try to use it raw. One system we are looking at would allow the use of raw solid waste. It seems more likely, though, that we would go to a grinding operation and here the photo lab let me down. They cropped out a photo and cropped out the bottom, which is what I wanted. Essentially, I was trying to show a simple grinding operation. A more sophisticated route is to go through grinding and air classification until you get a material that's essentially nearly all cellulose. I doubt that we will go that far. I think it's more likely that we will go the simple grind route. But

that's the upstream fuel preparation.

The second step is gasification, essentially destructive distillation, converting the cellulose to usable gas products, and so many of you are intimately familiar with this kind of chemistry, we end up with carbon monoxide and hydrogen but, unfortunately, they are in the wrong mix.

The system we are most interested in at this point, because we feel it's well-developed or near commercialization, is Union Carbide's Purox System. Schematically, we see it here. Essentially, it's a vertical furnace not unlike in appearance a blast furnace, and the solid waste comes in the top. The heat for the process is at the bottom, where char, which is all that's remaining at the bottom, is partially oxidized to form CO, which is hot, which then permeates upward through the solid waste, performing a pyrolysis reaction and also drying the solid waste at the top and -- voila, out comes mostly carbon monoxide, a considerable amount of hydrogen, some methane, some CO₂ and whatever else happens to get swept on out, which requires cleanup.

The next step following cleanup, which, of course, will involve some sophisticated system

to keep the sulfur under control and anything that might poison catalysts, the next step in any case is to get the carbon monoxide and the hydrogen to the right relationship, for example, for the production of methanol or for the sake of ammonia, to get that hydrogen out. So we go through a shift reaction, which many of you are again far more familiar with than I, so that we get the right gas mix so that we can go into a product manufacture and that, of course, then, is the fourth step, involving carbon monoxide, hydrogen, pressure, temperature, catalyst and, depending on what we are doing and the process, why, we either end up with methanol or ammonia.

Now, the first one is probably a little more straightforward from a plumbing standpoint. That is, we are going to methanol. The other alternative, ammonia, of course, would involve using nitrogen and that's quite practical in this kind of a scheme because, in order to run the pyrolysis plant upstream, Step 2, we had to use oxygen and so in the process of making the oxygen, we have some nitrogen available which lends itself, then, to this kind of a process. However, it's a little more costly and complex from a plant standpoint.

The question then is: What are the

yields? On methanol, we conclude that this is the actual yield. In our earlier studies, we figured about 25 percent more than this, but under the test of actual mass balances, by some competent chemical engineering people, these are the kinds of yields we looked for from the City of Seattle with 550,000 tons of solid waste a year. If we go to ammonia, we get a little more in the way of tonnage and it looks like 120,000 tons a year. The big question, of course, is markets, among other things. Obviously, the methanol could be marketed, potentially marketable in the chemical market, but our preliminary studies indicate that we would saturate the Northwest market. We could displace about 80 percent of what's currently being marketed as chemical methanol. So that doesn't look too good, unless it was by way of substitution through appropriate companies that are now hauling it up from the Gulf Coast, so that's kind of iffy.

It's also a very cyclical market. The automotive fuel market is pretty obviously an attractive market because, first of all, we have a captive fleet of our own which could consume about 1/6 of our methanol output if we went 100 percent methanol. That's an attractive alternative for us because of the energy independence and

because of reduced air pollution.

We could also dump it on the utility market, and I do mean "dump" because the price would not be as attractive.

When we look at ammonia, it, too, has some interesting possibilities from a marketing standpoint, but it doesn't look like we can even slightly dent the fertilizer market, for example, and Eastern Washington, as many of you know, is heavy on wheat growing, so it looks to us like there is a very large ammonia market and the question is: What are the economics of the various alternatives? We can see some benefits to the methanol to the City directly, but the production of fertilizer in this day and age is not exactly un-American, if you know what I mean.

In any case, these are the kinds of crises as we see them right now. I think that probably the chemical is a little on the conservative side. Spot prices are higher and considerably higher in some cases. Automotive fuel -- we are saying it's got half the heating value of gasoline and, of course, you get into the argument -- do you or don't you include the cost of road tax? One of the things that I think that anyone who goes into the

methanol business is going to have to address is whether or not it should, through appropriate legislative changes, be given a break in terms of road tax. I think in the case of Project Independence, I think there is a good arguing point for this.

As far as utility fuel, it's got to compare on a BTU basis with distillate. It's got half the heating value, a little less than half the heating value of distillates, in the low 30's, so you are at 15 cents a gallon. So it's pretty obvious, if you go methanol you have got to look at the chemical market which is a relatively limited market, and automotive fuel which is not limited, so we are looking at, first of all, a fleet demonstration and potentially wider use if that turns out to be the most desirable scheme.

In terms of prices for ammonia, this looks pretty attractive. Of course, it's been an upsey-downsey market as many of you know. These kinds of things we are going to analyze in the several months ahead.

In looking at the historic crisis of the these products, you can see that there have been some good times and some bad times, and I think there has been a dip farther than that on methanol that we haven't plotted up

Similarly, ammonia has been a rather -- well, I guess I could say erratic market. At the moment, it looks like a bonanza, but who knows what lies ahead?

These are the kinds of things we are going to address in a coming study. In terms of the economics, taking a look at the methanol, we are a little short of time, I won't dwell on it, but essentially what we see is that for methanol we can about compete with landfill right now and to the solid waste people that's very attractive.

In terms of a 15-year writeoff, which is what we are using here, in a 15-year plant life, we figure that we could save \$2 million relative to the cost of continued landfill and, of course, we would have then realized benefits in terms of fleet fuel independence, reduction of air pollution, in a small amount at least, and very significant environmental benefits.

So this one looks like a winner, even with the short, what we consider to be a short plant writeoff time for a city, that's a 15-year writeoff. This assumes 8 percent money.

Now, when we look at ammonia, we practically dance and do a jig here because, if you look

at bottom line, if these numbers are correct and these actual markets and revenues for ammonia can really be realized, this thing is really a bonanza. We can actually end up with better than free disposal of solid waste and so looking at it from the City's standpoint, this could be very attractive economically but, again, the market really has to be tested and this does not afford us in-city benefits; that is, fuel independence.

So what we are looking at with greatest interest right now is a plant that has a mix in terms of product output, enough fuel output in methanol for our own fleet uses and then ammonia to make money. We are looking at specific sites. We are getting down to actual specifics on this project.

We had very preliminary appraisal of the environmental impact and how we put it together on property which we and the county own. Looking at a real place, a real time, we are getting very interested in the thing. We look at the problems associated with the various products. We view methanol as something that's quite easily handled in conventional tankage, for example. Of course, there are some tradeoffs when you get into ammonia now. It gets a little more complicated to store the product.

These are some of the things we have to evaluate along the way.

In terms of transportation, of course, with methanol it's pretty easy. When we get into ammonia, why, we have to talk about pressurized carriers or progenic carriers.

So we are into a little different ball park here. These are all factors that we'll have to somehow evaluate, hopefully in a fairly analytical and not political context.

In terms of safety, of course, you are all familiar with the safety aspects. I am inclined to think that it's pretty much a tradeoff between methanol and ammonia. They are not orders of magnitude apart. There are problems with each, but then people don't go around drinking gasoline out of fuel tanks either. So these are some of the matters that we will be exposing to our legislative body in Seattle and, of course, we will have to address environmental impact, esthetics. It's very difficult to make a refinery look like anything other than a plant. That's mainly what we are talking about. We are talking about some sewer waste, some air waste, no doubt, from various venting portions in the cycles, some heat reduction, but small

compared to a power plant and, of course, there will be noise. About the same thing holds true for an ammonia facility. I think environmentally it's about a 1 for 1.

When we get into regional planning, which, of course, is the end thing in most regions, the question is: What does it do to regional planning? Well, for one thing, if you start locating plants of this kind near the source of your solid waste, you can now start saving fuel, reducing haul cost, cutting noise and so on. So there are some real advantages to this. We are looking at the possibility and will be looking at the possibility of some other strategically located sites in the area to be handled by other agencies. These are some of the political problems we have to put together in working on a concept like this.

Our conclusion is that Seattle's concept can be duplicated elsewhere in our region. We have yet to convince some other political entities of this, but there is no reason why it can't also be duplicated elsewhere.

In terms of what it looks like, this is the only picture I could get and I gleaned that from a Davey Power Gas booklet. If there is anybody here from Davey Power Gas, thank you. I didn't have time to get your permission to use it, but I gave you credit.

I wanted to let our City Council know that we are not talking about a thing of beauty here. It's a piece of plumbing and it's functional and that's what it looks like. Maybe we can get some hippie painter to do an exotic paint job on it. I'm not sure what.

We are looking at a non-action plan for our City Council and essentially this is the pitch: We want four months. In that four months, what we want to do is, we want to looking at marketing of our product. We want to look at the possibility of participation by other agencies or industries in our program. It's a demonstration program, and we are looking at the beginnings of a fleet program, and at the end of that we'll pretty well know whether it's go or no go.

If we can actually put together some pretty hard numbers on product prices, potentially long-term contracts, we feel that at that point we could justify funding of a project on revenue bonds, which is the real way to go, make it pay its own way. That's our goal.

In terms of product marketing, we will be looking for long-range contracts, either for product or potentially for a joint ownership of the facility. For example, where we own the gasifiers that produce gas and then

we had an across-the-fence type agreement, take or pay on gas to a firm that wanted to make either ammonia or methanol, with a cut of the methanol reserved for us. There are a lot of possibilities here and we are open to any kind of propositions at this point.

Of course, the markets we are looking at are those. We are definitely and perhaps tactlessly very interested in participation. We are looking at state, at federal, and we are sure interested in industry. If there are any entrepreneurial types that want to walk into Seattle and make a proposition on joint construction of a plant, great. We are open to propositions and we'll be looking for them.

We will also be rapping on doors, but we don't know what door to knock on at this point in time. I think with (inaudible) having been formed, why, there is some problems but I'm sure we'll live through them.

Our vehicle test plan -- I think Dave Gordon can address that subject, but it will be -- the first phase will be a limited test. We actually got approval of policemen, to the Police Department. They can run police cars in actual working circumstances.

As far as general-use cars, that's a

little more -- a little easier we can convince people of. Similarly with trucks. But if we go to a hundred percent methanol and a hundred percent of our now gasoline-powered fleet, that will be a first.

So you fellows out there in the scientific end, really doing the exploration work and pioneering, we're the settlers. We are going to come in and try to use this technology. You guys prove that you can do things; we're going to put it to work and, of course, in the context of being settlers, I guess we will be the first settlers out there, but you guys are ahead of us and we appreciate that support.

There is a picture of the Mayor and a couple of other dignitaries actually looking at the kinds of cars we are going to try converting, so it's for real and this little dolly with the smile, which some of you remember from Henniker, is Dick Pefley's daughter in disguise. She really isn't that cute any more. She, with her smile, portrays our general attitude about methanol.

I'm running out of time. I'll skim over this.

You see Dick Pefley's data and, Dick, I was hoping to plagiarize your work by showing this

to the City Council. It is data that you developed, with appropriate credits, I hope. Yes, you are on the bottom there.

So, essentially, solid waste can be made into methanol or ammonia. Processes are definitely feasible. The economics are favorable, and the City can realize significant benefits, either in fuel independence or reduced air pollution or just plain money in savings to the people who have to pay have their garbage hauled away. In terms of conservation and Project Independence, it's a crime to see scenes like this, where we are burying fuel that can be put to work and it's really surprising that all of these forces have come together at the same time -- environmental problems, the fuel problems, resource problems, and a general awareness that we just can't continue on with that kind of thing. So there are the benefits in methanol, benefits from ammonia, and it's time for our City Council to move.

If you were the City Council, I will say, "Well, fellows --"

Excuse me, I wouldn't say "fellows." I would be a lot more tactful than that, but essentially the ball is in your court. We want them to give us a resolution

that assures us that the City is behind this program, and we can then go to people in industry and look for markets. That will be subject to its demonstrated economic feasibility. We will also be asking them for a modest budget and hopefully, when we get to the bitter end, we will be able to say, "The Seattle City Council recommends Go."

I can't yet report that, but I hope to in two weeks. That's all I've got.

Dave, do you want to add anything on the --

MR. HAGEY: Thank you very much. I think it's a very fine presentation and, on the surface, a very fine program.

Mr. Jerome Hinkle from EPA will briefly describe a study which we have underway with Stanford Research Institute on the Impact of Alternative Automotive Fuels.

Jerry?

MR. HINKLE: (inaudible) counterpoint to this morning's laboratory thing, so let me ask you to extend your imaginations beyond the individual laboratory suggestions. We are conducting at Exxon Research and Engineering and at the Institute of Gas Technology, a pair of studies checking out

the feasibility of large-scale production of alternative fuels, and this study looks at the impacts of that across several dimensions. It's a technology assessment that's been contracted out, the basic part of it has been contracted out to Stanford Research Institute who has put together a multi-disciplinary team of -- a group of economists, a sociologist, a couple of environmental effects people, some technology people, people who are looking at some of the chemical engineering parts of it, these kinds of process portions.

Let me sort of read down some definitive things here. We want to look at an assessment of the impacts that resource extraction, alternative fuels production, distribution and utilization would have upon the environment, domestic energy resources, production distribution industries, urban and rural regions, and finally consumptive sectors.

There are three basic tasks we define here and we will just sort of -- we are just sort of completing the first task and we are partially -- we are getting well into the second task.

Task 1 is to identify and assess critical impacts of major national and regional shifts to alternative fuels.

Under this, we start by developing a base line fuel demand forecast which will guide scenario construction which then these scenarios will represent major shifts to different resource fuel combinations and, from this, we expect or along with this we expect to develop impactor rays associated with differential levels of development, as different levels of maturity and differential rates of development. Each scenario will include a systems analysis, showing inflows and outflows of capital, labor, natural resources and energy. Critical environmental, economic and social impacts will then be identified and a sensitivity analysis done to isolate critical effects.

Okay. That work is largely completed at this time, although unreported.

Task 2, which we are working on presently, is to determine which, if any, among the alternative are serious substitution candidates and estimate timing and extent of penetration of the auto transport sector. Under this, we'll be identifying competing uses of specified resource fuel combinations by developing criteria and methods for allocating between fuel demand sectors, develop priorities for uses on the basis of Task 1 results with respect to including locality and sensitivity analyses that have followed

from the Task 1.

The Task 1 things are a necessary kind of preparation for the Task 2.

Task 3, evaluate the relative attractiveness of alternative resource fuel combinations for auto transportation during the 1975-2000 time frame and beyond; to develop comparative criteria applying to ranking for net feasibility, using Task 1 and Task 2 results; perform another sensitivity analysis to develop some policy options for this.

It's a very conscious effort to do some looping feedback kinds of things with some of the things being accomplished in the first stages, and we expect then to evaluate and estimate some costs of some of these policy options with regard to shifts to major substitutions of fuel.

The products of this research are tailored to the need of a wide base of the potential users, especially policy planning in government and industry. Much of the basic data, systems, description and scenarios could be utilized by themselves, but their primary value lies in the large-scale systems analysis that they complete. Specific policy options for fuel alternatives will be laid out with

all supporting analyses that influence those choices as well as for alternative options that seem less feasible, considering environmental, social and economic factors.

In this, we were visualizing alternative fuels introduction as a problem in the management of technological innovation where optimizing a cross regional and national levels must be (inaudible).

Total funding in this regard is \$309,000. We have got some follow-on technical consulting work that Exxon and IGT are doing with us and the Office of Research and Development, EPA,

has a supplementary grant that looks at the identification of future pollution control system requirements.

I got about a minute and a half.

Any questions? You have got a handout -- if any of you are interested at other levels of detail, we have -- I have some copies of scope of work back here, if you are interested in carrying them along to people who you think in your organizations may be particularly interested in this or may perhaps give us a hand, some advice at some time or another.

Thank you.

MR. HAGEY: Any questions? Thank you, Jerry.

We are now turn to the portion of our Conference dealing with government and industry research. Again, this is principally a discussion on methanol, methanol-gasoline blend research progress.

Our first speaker is Mr. Jack Freeman from Sun Oil Company. Mr. Freeman has an M.E. from Cornell University and his Bachelor's degree from Northwestern University. He is a senior environmental engineer with responsibility in the area of product quality. He has worked at Sun Oil for nine years in automotive-environmental affairs, technical services products planning and forecasting for applied research and development.

MR. FREEMAN: Thank you, Graham.

The program mentions me in connection with Sun Oil Company. Actually, that's a gracious of recognizing the people that sent me here today, but what I will have to talk to you about is a little API program that we have ongoing at the time.

About a year ago, when the Project Independence concept was first identified, the American Petroleum Institute looked at its position on non-hydrocarbon fuels and found that it had really only one technical assessment, a report that had been published in 1970 and

was hardly really comprehensive even in terms of a literature search and tended to emphasize ethanol, which was the alcohol of interest at the time the study was put together. So we put together, the NAPI, a little task group to determine what we ought to do really. Would it be acceptable and useful to update that 1970 report, or should we really start from scratch and look at the thing again and decide what we ought to do? So we put together a group of people, one of whom is here on the program this afternoon, and looked at the general question and thought, yes, it would be time to look at the whole subject of alcohol fuels again, not try to update the report that we already had, but we felt that at that time, and I think it's still true, we felt that we could make a useful contribution by looking critically at the literature, much of which exists in the technical arms of our own member companies, and producing an appropriate study that hopefully would be a base, a technical base, for policy makers.

The API, of course, is a trade association, but since the member companies had a great deal of technical expertise, it's also a research arm. Our task force decided, rather than to try to do this assessment in-house, since we were looking for a critical evaluation of

the literature, that we would hire contractors and we did hire a contractor for this program. William F. Miller is our contractor and, working with our task force, he has outlined the program, a critical evaluation, and he has outlined his literature search. He has that pretty well in hand by now. He has made interviews with most of the sources of information on alcohol fuels as they exist at the present time, and I thought the most useful thing that I could do at this point would to be review with you, I suppose, the table of contents, if you will, of what this effort hopefully will bring about, and if you turn on the first chart, please, because I think that you might agree that this has general application. Perhaps it's just as well that I give this little talk first in the program this afternoon.

You would probably agree that you would want to look at these factors whether you were looking at alcohol fuels or any other alternative fuels that might be considered, and we start, really, with the properties of alcohols and blends, applications -- I can hardly read my own chart -- applications in automotive fuel. That really is going to amount to be the centerpiece of the whole effort. It certainly will be the largest chapter that we'll have in this thing and it's developing.

Other fuel uses, non-fuel uses, of course.

Manufacture of alcohols. Distribution in the market. Economic considerations. Health and safety considerations, and then some conclusionary points.

Now, I think it will be useful to go into some of these chapters in some detail to show you how we see this thing at the moment.

Now, if I could have the second chart, please. I don't want to pre-empt what you are going to hear later. You are going to get some of this as we go through the afternoon, so perhaps this will serve as a bit of a preview.

Properties of alcohols and of alcohol blends. The general physical properties. Combustion characteristics, vapor-pressure relationships. The water tolerance situation, the corrosion aspects.

Now, Item 4, I'll talk about separately. That's our automotive fuels application section, and I think that's probably one of the most controversial and complex areas of the whole methanol fuels subject, and I keep saying "methanol fuels," but we are talking about ethanol as well as methanol in this study.

Our fuel uses, we haven't talked about the utilities, for example. At the Henneker Engineering Foundation Conference, this was discussed in great detail.

Boiler operation, dual fuel turbine operation. The alcohols look very attractive in the turbine fuel, indeed, as they might be if they were to be used as a fuel perhaps in other stationary power applications.

We have to be considered -- we have to be concerned with gasoline appliances, not because they are large users of fuel, but because gasoline gets into them. Small engines, the same thing as well.

Now, the next chart will focus in on the automotive applications that concern us. You had a pretty good summary of that already, I think, with Dr. Johnson's remarks on the anti-knock situation this morning. He mentions that he still needs road octane data. Certainly, we think in terms of the laboratory octane effects and the road octane effects. From what I have seen of Miller's work to date, it looks as though what Dr. Johnson had to say this morning about the octane characteristics of methanol should give you a pretty good picture.

The engine performance, power and economy. We have had a lot of allegations here. We think

that if you really look at the fuel consumption and thermal efficiency curves for homogeneous charged spark ignition engines that you could predict many of the power and output effects that have been demonstrated with methanol and, of course, again you look at these things on the laboratory scale and then you look at them in terms of full-scale multi-cylinder engines, vehicle studies. Again, I -- this is a preview of what you are going to hear later from Joe Calluci, much of the same material.

Also, in vehicle operability, drivability and lean mixture effects. Do you have a different situation with methanol than you have with hydrocarbon fuels? There is some indication that you do. So we'll be covering that in this section.

Starting warm-up vapor lock. Some very peculiar situations occur. In vapor lock, the methanol blends are hardly linear as far as vapor pressure blending is concerned and probably Bob Lindquist will have something to say about that in his presentation.

Then, of course, the problem of how you handle blends, the problem of water tolerance and phase separation. I think we continue that on the next chart.

Air-polluting emissions. Laboratory

engine studies, carbon monoxide and other exhaust constituents. What are they? How do we look at these things? Do we look at them on a mass basis? Do we look at them on a volume basis? We have volume -- methanol blends don't blend linearly on a volume basis. How do you handle this? How about the nitrogen oxide situation, vis-a-vis stoichiometry and the range of flammability that can be -- we are looking at what the literature has to say in these areas.

Unburned fuel and its decomposition products, and then emissions from motor vehicles themselves, and then studies with the modified methanol fuels.

Then the effect on the fuel system, fuels and lubricants.

The corrosion effects -- you will hear more about that from Bob Lindquist.

Solvent effects, other material effects that one would encounter in the vehicle fuel system, and effects on the lubricant as well.

May I have the next chart, please. Non-fuel uses -- we mentioned this a little bit earlier in the first overview.

Industrial chemical production, of course.

that's where methanol is used today. Production of proteins, beverage alcohol brings in the grain alcohol situation again. Municipal waste treatment we just heard about. Manufacture of alcohols, methyl and ethyl, historical, bringing us through to date, to the production of coal from waste.

Coal, the same for methanol.

The distribution problems in the marketplace, transportation. How do we handle a fuel that has such a different water tolerance than do our hydrocarbon fuels? Can we handle such fuels successfully in gasoline distribution systems? Must we go to different -- if we use methanol as an automotive fuel, do we consider blending it at point of sale, for example, to minimize the water problem? We'll be getting into these aspects and those questions and then, of course, the economic considerations. I don't really how much we can actually treat the economics in this kind of a report. They become so inextricably intertwined with public policy that perhaps this report is not going to be definitive in those areas at all.

Then, of course, the OSHA, the health and safety effects, handling regulations and so on.

I think that it's inappropriate at this time to say anything really conclusionary. It's obvious

that methyl alcohol can be used in vehicles and in automobiles. That's already been demonstrated. I suppose the question is: Do you really want to use methyl alcohol that way? I guess we have a limited amount of hydrocarbons,, and how we use them depends on how we deal with cars, really, and we hope that this report will shed some light on coming public policies in that area.

Now, I don't want to take any more time at this point, Graham. I think that gives you an overview. If there are any questions, we could perhaps entertain them.

VOICE: One factor in emissions control that methanol fuels is probably, I would say, gotten short shrift, people haven't discussed it very much at this point, the vapor composition above a methanol-gasoline flame has a very substantial amount of methanol. This certainly has to have some impact on how one goes about designing a vapor loss entraining device or possibly might have an effect on the functioning of the present gasoline vapor loss systems. You know, from basic principles, one would think that a canister would load with methanol rather more timely than it does with (inaudible). It could conceivably, for example, kill off an evaporative loss package that way.

MR. FREEMAN: Yes, I think that's a very interesting point. That whole question of evaporative emissions and the degree of control needed needs to be looked at.

VOICE: (inaudible)

MR. FREEMAN: Dick, I had hoped -- when I told Graham that I would come to this meeting, I had hoped that I could give you more than just a rundown through our table of contents. I had hoped that we would have it well in hand by now. This has proved to be a much bigger task, I think, than any of us really thought when we began, and our objective is to try to come up with something that is useful not just today or tomorrow, but can still be referred to five years from now. So it's been a pretty big job and I'm hopeful that we will get this dog-gone thing out by the first of the year.

As I say, I had hoped to have had it by now.

VOICE: How will the report be distributed?

MR. FREEMAN: It will be available through the API. I have been taking names of people who have a particular interest in getting a copy of it, but it will

be available on request through API.

MR. HAGEY: Thank you very much, Dick.

Our second speaker on the agenda was Mr. Richard Hurn from the Bureau of Mines in Bartletsville, Oklahoma. Dick is not with us today.

Mr. Jerry Alsup from the Bureau of Mines will be representing Mr. Hurn. Mr. Alsup has a Bachelor's degree from the University of Tulsa. He is a mechanical engineer and project leader for the Bureau of Mines.

MR. ALSUP: Our work at the Bureau of Mines could be divided into two major groups. The first effort will be in fuels. We will be preparing a number of different fuel stocks at varied aromatic concentration, different octane levels, and we will prepare from this an inventory of the physical characteristics of the fuel, including water tolerance levels, hopefully maybe as a function of aromatics, and the nonsolubility of the methanol in the fuel also.

The second major part of the program -- also, with the fuels, we will be determining the octane requirements and the octane susceptibility of the various fuels.

The second major part will be the actual automotive testing, and in this we will have all late-model equipment. We will be using a 350 cubic inch engine on a stationary dynamometer and with this engine we will be first looking at the lean limit using blends up to 15 percent and also 100 percent methanol. This will also be done at different compression ratios, 8 to 1 and 9 1/4 to 1, and also 10 to 1, and also with this engine we will do some emissions and fuel economy maps. The majority of the work will be done at steady-state conditions, but hopefully some will be with the transient conditions. This will be dependent on the development of a decent fuel handling system, air-fuel induction system.

Right now we're looking at going two different ways. One is using a completely vaporized mixture in the engine and get some ignition measurements this way and also using either a fuel injection system or some type of a carburetion system that will provide decent distribution in the cylinders, but not completely vaporized fuels.

Also, in addition, six vehicles will be used for studies with blends. This will be with the methanol as a fuel extender, standard carburetion system, standard adjustments.

We will be looking at '75 model catalyst and non-catalyst equipped vehicles. Also, we will be making measurements before the catalyst and after the catalyst on some vehicles.

In addition, we will be doing work at 20 degrees Fahrenheit as well as 100 degrees to see if there is any, or to see the dependence on temperature when using these blends. The vehicle work will just be done with the blends, not the pure methanol.

Also with this, we will be making economy measurements, aldehyde determinations, hydrocarbon distribution for some of the tests, and also we will be measuring the unburned methanol in the majority of the tests.

I think this is a pretty good summary of what we're doing.

MR. HAGEY: Thank you, Jerry.

Do we have any questions?

VOICE: Jerry, how are you -- are you going to shoot for control of vapor pressure, consistent control of the Reid vapor pressure in fuel set? If so, how do you approach this problem, varying the methanol content?

MR. ALSUP: Well, first, we will determine the vaporization characteristics of the fuel before

we start and we will compare this with what we get. Controlling it, as such, we will not make any other effort than that, using different peaks.

We have already seen, done a few tests, and might shed some light on the previous question about the vaporization part of it, and in the '75 test procedure, our Bag 3, after the hot soak, is just about twice as high as the first cold bag, which does suggest that the -- a lot of vaporization in the carburetor.

VOICE: It depends on control of the Reed vapor pressure. If you blend, say, 20 percent methanol into a convention gasoline base stock at, say, 75 degrees ambient temperature, the material is boiling. (inaudible)

You have to do something to control the Reed vapor pressure.

VOICE: How long have you been burning the unburned methanol and aldehyde?

MR. ALSUP: We are working on that right now, trying to develop some methods. Right now we're looking at a GC, the type that was discussed here earlier, backflush.

MR. HAGEY: Fine. Thank you, Jerry.

Our next speaker is Mr. Joseph Colucci from the General Motors Corporation. Mr. Colucci has a Bachelor's degree in mechanical engineering from Michigan State University and his Master's degree from Cal Tech in mechanical engineering.

He has worked at General Motors since 1959 in the research laboratories, Fuels and Lubricants Department, on atmospheric pollution, auto emissions and fuel-related projects. He has been head of the Department since 1972.

MR. COLUCCI Thank you, Graham.

I would like to say that I thank Graham for the opportunity to speak once again before what must be about the fifth or sixth meeting of the Methanol Marching and Chowder Society, and I'm sure we will have additional meetings of this group as we try and further define what to do with methanol.

The talk I'm going to give you this afternoon is a shortened version of the talk we presented at the Methanol Conference at Henniker last summer. That talk was presumably entitled "An Automotive Manufacturer's Outlook on Methanol," but I think a much better title would be "Does Methanol Give Your Car a Kick in the Gas?"

I would like to get on to the first slide if I -- this is a brief outline of what I would like to discuss today. We have programs at the General Motors Research Laboratories relating to single-cylinder engine studies with pure methanol, mimical studies with methanol-gasoline blends, and some work looking at the octane quality of methanol-gasoline blends.

Then I'll try to give you some explanation of the results and some concluding comments.

I might mention that our vehicle studies are going to be reported at the S.A.E. meeting next February at Detroit. I'm sure you are all familiar with these physical properties and I will only show three of them because they are very important in looking at the results that you obtain with methanol.

The first one is the stoichiometric air-flow ratio, which, as I am sure you recognize, is considerably different from that for gasoline. It's about $6 \frac{1}{2}$ to 1 for methanol as opposed to $14 \frac{1}{2}$ -- 14.7 to 1 for gasoline. The density of the two fluids is quite similar; however, methanol is slightly heavier than gasoline.

There is separation. Methanol will go to the bottom.

The final one is the heating value of the two fuels. As has been discussed, methanol is about half that of gasoline.

First, we would like to get single-cylinder engine studies with pure methanol. I'm going to have here cells slotted for various parameters versus equivalence ratios, where greater than 1 is rich, less than 1 is lean.

Regarding our results (inaudible) for power and thermal efficiency -- you can see the methanol stuff, which is the dotted lines in all the cases, for methanol the power was slightly higher than for gasoline and the efficiency was also slightly higher.

The other interesting point, you will see it on all these curves, is that methanol will operate considerably leaner than gasoline. This engine was out to about .6 and gasoline was out to about .85.

This is a curve for nitric oxide emissions with indolene and methanol and, once again, there are two significant points. The first, as I have already mentioned, is that the methanol operates considerably leaner and, second, as that equivalence ratio shows, the NOx emissions for methanol are considerably less than those for

indolene.

If you want to run real lean with methanol, you can get very low nitric oxide emissions compared to what you can get from a hydrocarbon fuel.

This graph shows the carbon monoxide emissions obtained with methanol and with indolene, and you can see there is essentially no difference. I might mention that all this data was obtained at the test emission shown in the upper right-hand corner. This was with a CFR test engine.

This is one that addresses itself to the unburned fuel emissions with either methanol or with indolene. There has been considerable discussion on how you should report unburned fuel. You have got methanol, we learned, from some studies with the gas chromatograph -- most of the emissions from pure methanol are methanol. However, there is some hydrocarbon emissions also. We are looking at the emissions from methanol, using gas chromatographic techniques and with heated and nonheated flame ionization detectors.

We have come to the conclusion that a nonheated flame ionization detector just doesn't give you the right answers because we lose too much of the

methanol in the system. It falls out of every nook and cranny that has a low temperature, especially in the water cracks.

You look at this one. The results shown here in terms of unburned fuel -- there is considerably more methanol than there is -- considerably more unburned fuel in the exhaust with methanol than there is from indolene. However, that fact, per se, should not be very upsetting. The key issue is: What is the effect of methanol when it gets into the atmosphere? What is its reactivity? Most of the information that I have seen indicates that methanol is not a very reactive species once it gets into the atmosphere. So even though it is shown here that methanol provides a lot more unburned fuel than a hydrocarbon fuel, the result, when it gets into the atmosphere, might not be as bad as pointed out by this figure.

This contains a summary of our results with methanol in the single-cylinder engine. You can see at the same equivalence ratio carbon monoxide emissions are about the same. Nitric oxide emissions are considerably less with methanol than with endolene. The hydrocarbon -- really, this should be unburned fuel emissions -- are considerably greater with methanol. The power was slightly

greater with methanol. The thermal efficiency was comparable.

If you go to operation at the lean limit, methanol and indolene were equivalent. Nitric oxide was considerably less with methanol than with indolene. Unburned fuel was considerably greater with methanol than with indolene. Power was slightly less with methanol than with indolene. The thermal efficiency was greater with methanol than with indolene.

Now I would like to get into our vehicle studies with methanol-gasoline blends. This indicates our program. I'm only going to discuss certain items that I show here. We are evaluating methanol-gasoline blends in production vehicles with the current emission control systems. The data I'm going to report today are with existing carburetion. We have also taken the same vehicle and adjusted carburetion to what it would be in terms of equivalence ratio with the methanol blends and we have also adjusted it rich to get a comparison.

We are also carrying out a study of methanol use, methanol-gasoline blends, their use, in a cross-section of existing vehicles. We have gone through about 15 vehicles so far and I'm not going to report that data today, but if anyone is interested, they can see me

and I'll let them see the slide.

Finally, we have evaluated methanol in a vehicle with a catalytic emission control system and I will show you that information. The factors that we have evaluated are emissions, fuel economy, drivability, performance and, where we have seen operational problems, we have made a note of these.

This is results of emissions from a 1973 Oldsmobile with a 455 V-8 engine. The methanol was 10 percent methanol in unleaded gasoline. These are the results on a 1975 federal test procedure. You can see carbon monoxide was reduced by about 48 percent; nitric oxide was reduced by about 14 percent, and there was essentially no change in the hydrocarbon emissions as measured on the federal test procedure.

In this case, it is a nonheated flame ionization detector. As I am sure you recognize, under federal test procedure, the exhaust is highly diluted. There is very little likelihood of any material falling out in the traps.

These are results for fuel economy measured on two different bases, one on a volume basis, the second on an energy basis. The volume basis is miles per

gallon on top, and, on the bottom is fuel economy in miles per million BTU.

We have got results shown here for four different schedules, a business district schedule that we use at our proving grounds, 1975 federal test procedure, a suburban schedule, and a highway schedule.

You can see on a volume basis in general with this vehicle the fuel economy in miles per gallon was anywhere from about 4 to 11 percent less with methanol blend than it was with gasoline.

On the energy basis, the results were different; it was almost a standoff. On the business district, a standoff to about a 5 percent loss on the highway schedule.

If one wants to extrapolate, it appears that methanol did slightly worse the greater the average speed of the test vehicle.

Here are results on drivability, comparing various blends of methanol and gasoline with 100 percent gasoline. These were carried out at two different temperatures. The first set was at 30 to 40 degrees Fahrenheit. The second set was at between 50 and 60 degrees.

We have here plotted drivability in terms of total weighted demerits. As you can see, as more methanol is added to the gasoline, the drivability was further impaired. This drivability measurement was carried out in a fashion very similar to the CRC standard drivability measuring procedures. The result here, as most of the results with the methanol, is primarily attributed to the leaning effect of the methanol on the carburetion. The more methanol you are adding, in essence, the leaner the carburetion and we all know that leaner carburetion leads to worse drivability. You can also see from this chart that the drivability, with 10 percent methanol, the lower temperature was worse than it was at the higher temperature. We all know that drivability gets worse as the temperature gets lower.

Here are some results on vehicle performance with 10 percent methanol and gasoline compared to gasoline, and on the far left we have a wide open throttle acceleration. You can see under those conditions it was essentially no change in the acceleration time from zero to 60 miles per hour with gasoline and with 10 percent methanol and gas. However, when we go to some part-throttle acceleration, in this case constant manifold vacuum acceleration

from 25 to 60 miles per hour, there was a penalty with the methanol blend. This penalty got worse as the vacuum increased.

Here are results with a car with a catalytic converter. This was a prototype system in a 1974 vehicle. You can see here the emissions on the left-hand side on the federal test procedure. The CO, even with the converter system, was reduced by about 40 percent. NOx was reduced by about 15 percent, and the hydrocarbons, once again, were essentially unchanged.

I think results with catalytic converter systems with any vehicle representing a 1975 and future model car are the ones that we should really pay much attention to. As I'll point out later in the talk, by the time we get around to using methanol as an automotive fuel, if we ever do get there, the vehicle population will exist mainly of vehicles which are being produced this year and which have not yet been produced. So the effects with methanol should be dependent on how methanol reacts in those vehicles and not those vehicles that make up the population as it exists today.

As far as fuel economy is concerned, you see the results for two different schedules, a 1975

federal test procedure and a suburban cycle. In both cases on a miles per gallon basis, the results of methanol were lowered by about 5 percent, which is essentially what you would expect based on a decrease in the heating content of the fuel when you add 10 percent methanol.

Here are a summary of the results of the vehicle studies. These also relate to some of the studies which I haven't recorded on the cross-section of existing vehicles, but in all cases carbon monoxide is reduced. This is due to the leaning effect of the methanol. On some of the cars that we tested, hydrocarbons was increased. In some cases, it was decreased. The same thing is true with oxides of nitrogen. This is, once again, explainable due to the methanol effects on air-fuel ratio.

If you have a car which is initially carbureted quite rich, you add methanol, you lean it somewhat, you can be going up the nitric oxide curve; therefore, get increased nitric oxide measurements. If it is carbureted lean and you are going down the nitric oxide curve as you add methanol, you are going to get lower NOx emissions.

The same thing is true with hydrocarbons. It depends on where the car was initially carbureted, what the effect of adding methanol would be.

Basic fuel economy was generally reduced in proportion to the energy content in the blend and the reductions appear to be greater as the average driving speed increases. This may just be due to the effect that as the average speed and load on the vehicle increase, you get back into more of the power enrichment circuit in the carburetor and, therefore, you are going to a richer operation more frequently with methanol blends than you would with pure gasoline.

As far as drivability is concerned, it was impaired in essentially all the vehicles we tested and it was impaired greater with '73 and '74 model vehicles than with previous years' vehicles. This is generally because those vehicles were carbureted leaner than older vehicles. As far as performance is concerned, the full-throttle acceleration was unaffected and part-throttle accelerations were slightly impaired.

Now, let's get back to a question which has been addressed by some of the previous speakers. That's the octane quality of methanol and methanol-gasoline blends. Published numbers on research octane are generally about 106. In the published information on the motor octane number as given in one of the previous API publications, it was 92.

But I show that there with a question mark because you can't measure the motor octane quality of methanol using the standard ASTM techniques because of methanol's very high heat of vaporization.

With the standard technique, you cannot get enough fuel into the methanol to vaporize it. So you have to go to a different technique and what that number means as compared back to gasoline or another fuel, I really don't know.

The thing that really counts, we'll get to that, is how methanol reacts in an automobile. Here is data on the research and motor octane quality of various methanol blends and gasoline, going from zero percent, which is pure gasoline, to 30 percent, and these are for two different commercial 91 and 94 research octane unleaded gasoline. You can see with both of these gasolines the research octane number depreciated much more than the motor octane number.

Recent model vehicles especially like the taste of motor octane number much more than they do the research octane number. I think you have to consider the motor octane results much more than the research octane results in evaluating the octane improvement with methanol.

The real issue lies -- these are measurements made in a CFR engine, using the standard ASTM technique. They are not measurements made in an auto dealer. What counts is how methanol reacts when it's used in an automobile and, in this case, it's the road octane number of the fuel for use in a vehicle that will tell.

I have added information on the road octane number with methanol blends to the information on research and octane -- motor octane number from the previous slide. You can see with this vehicle, which was the 1973 Oldsmobile that we mentioned in the previous results, the motor octane number only went up about one and a half numbers and it would appear to maximize at about 10 percent methanol and gasoline. I must caution you that this is a result from one vehicle only and we need considerably more information on many other vehicles to come up with a final determination on how much methanol will help octane quality. But based on this information, there does not appear to be a very significant effect when adding methanol to gasoline as in terms of the vehicle's response to that fuel.

This is a quick summary of the octane studies with methanol. As I mentioned, the motor octane number of methanol is not well defined. Methanol addition

increases research octane number much more than motor octane number. Based on this one car we ran, the road octane number may be maximized at about 10 percent methanol in gasoline.

Here are the overall conclusions from our vehicle work to date. As you recognized, this is all with 10 percent methanol in gasoline. The effects are mainly attributable to the leaning of the air-fuel ratio. CO is reduced. Hydrocarbon and NOx effects uncertain because they depend on the base carburetion of the vehicle. There do not appear to be any fuel economy benefits. Drivability is impaired and octane benefits are questionable.

There are also some potential vehicle operational problems that have to be addressed. I think maybe Bob Lindquist is going to address some of these: the cold weather operation, especially if water gets into the fuel; could lead to problems. If there is separation, the first fuel picked up by the system is pure methanol. There are also material compatibility problems which have to be addressed in terms of corrosion of the fuel system components and problems with some of the elastomers used in the fuel system.

Finally, one problem that the petroleum

is demonstrated by this curve shown here, which plots the (inaudible) fraction of the total car population versus vehicle age. You can see that approximately 55 percent of the vehicles are five years of age or younger and 90 percent are ten years of age or younger.

Really, even more important than this is if you plot cumulative miles driven versus vehicle age. Newer vehicles drive more miles per year than older vehicles, and for vehicles five years of age or younger on a vehicle miles driven basis, it comes out about 65 or 70 percent of the total miles driven are driven by vehicles less than five years of age.

So I say this gets back, once again, to the point that the vehicles of real concern are those that are being produced now and which will be produced in the future.

In conclusion, I think at this stage of the game we should not decide whether or not to use methanol-gasoline blends. We need considerably more work before the proper use of methanol is decided. We may decide that it is much better off to use methanol as a fuel for stationary power systems, where a hundred percent methanol in vehicles may turn out to be a better fuel.

In the interim, work on methanol generation from all sources should continue, as well as work on hydrocarbons from coal and oil shale. Uses will be found of all these fuels. The final results, economic and environmental conditions, will decide which fuel will be favored.

If anyone has any questions, I will be glad to try to answer them.

Yes, sir?

VOICE: (inaudible), Ford Motor Company.

I noticed in your engine study that you have been very careful to match up equivalence ratios with blends and run (inaudible) and when you came to vehicle studies, it seemed like you just took an existing distributor calibration and (inaudible) carburetor and there was no attempt to bring up the methanol blend to what you would call a more optimal tuning of that particular vehicle, and I think that presents somewhat of a distorted picture.

First of all, your thermal efficiency data on your engine (inaudible) showed a better thermal efficiency than the two comparables and you have got a detriment in fuel economy, even on an energy basis. So there is really no reason for suspecting that would be the case

unless you slacken the blend to an existing calibration and say, "Here, look at the results."

So many different attempts have been made to compare apples to apples rather than --

MR. COLUCCI: As I mentioned, we are also running tests -- we have run tests to readjust carburetion and the timing with methanol to what it should optimize it, but I think in the real world you cannot expect that to happen because you cannot expect a hundred million vehicles to be readjusted. That's one hell of a job.

VOICE: I don't think we are talking about a hundred million vehicles readjusted. I mean, I think what we are talking about is phasing in something --

MR. COLUCCI: You are phasing in --

VOICE: We are looking at the potential of it, not for retrofitting. I mean, it's like the cars that are being produced today that take only nonleaded gasoline. You know, you are not talking about --

MR. COLUCCI: You are phasing in -- you can do this in many ways and I am sure the SLI study is going to concentrate on this, but you could phase in a pure methanol system.

What we have got there in the single-

cylinder engine data was all a hundred percent methanol. The vehicle data with 10 percent methanol and gasoline, those are two different kinds of systems. That's why they were run that way.

VOICE: Well, I guess my basic comment is I think that the vehicle comparison I don't think really is valid. I'm not a proponent for or against methanol, one way or another. I just don't think there is a valid vehicle comparison, although I can't knock your basic premise or going in hypothesis about existing vehicle population, but I think, you know, if you had run a different calibration, a more optimal one, that would be a little more worthwhile.

MR. COLUCCI: I am sure if you run, if you optimize the vehicle for the 10 percent methanol and gasoline blends, you would get different results.

MR. PASTERNAK: Al Pasternak (inaudible)

Jerry, you showed some data comparing emissions with the catalyst, comparing methanol and gasoline and, if I remember correctly, the CO was low with methanol and unburned hydrocarbons was up and octane was up, and NOx was about the same.

Suppose you were to compare unburned

hydrocarbons from just gasoline and look at the different components of gasoline? How much is known about the relative ease of oxidizing saturated hydrocarbons, olefins, aromatics? Is the catalyst as effective with one as with another, or does some slip through?

VOICE: (inaudible).

VOICE: Maybe I can speak (inaudible).

We have done quite a bit of work -- (inaudible) from Exxon.

We have done quite a bit of work with compositional relationship with respect to fuel (inaudible) in a variety of different systems, but it appears that the catalyst selectively removes the (inaudible), aromatics and the olefins are also essentially removed. We end up with a predominance of methane (inaudible) from gasoline.

We have also done some studies in methanol-gasoline blends. In this case, you don't see that much of an effect between the methanol-gasoline blends and gasoline. The catalyst does selectively remove the (inaudible)

VOICE: (inaudible) Joe, I always worry when my results differ from GM Research, but one point in particular on your unburned fuel emissions on your single-cylinder work. You show consistently higher unburned fuel

emissions with methanol and in most cylinder work we get the reversal of this effect. Now, is there anything about the quench zone in this single-cylinder or anything that would lead you to believe that you might be measuring an anomaly here on the unburned fuel?

MR. COLUCCI: Does anyone have any feel for this on using the single-cylinder engine for unburned hydrocarbon emissions? Has anyone had any experience with it?

VOICE: I would support your position. We used gas chromatograph analysis and we did find lower hydrocarbons with methanol --

VOICE: You find it consistently lower with methanol.

VOICE: Are you accounting for the unburned methanol also? That was grams of unburned fuel; it wasn't grams of hydrocarbon that I have plotted. That's unburned hydrocarbons and unburned methanol.

VOICE: It includes methanol.

VOICE: I think this is one area that deserves a lot more attention because I don't think anyone is on firm footing with respect to determining the emissions of unburned fuel from methanol and methanol blends.

MR. HAGEY: I agree. As many of you here know, Dick Hurn the Bureau of Mines, sponsored a Conference in Denver, the 17th of September, where the subject was strictly the measurement, the methodologies for methanol, methanol-gasoline blends, and there is a great deal of uncertainty as to the optimum ways to go about measuring the products of combustion.

Are there any more questions? Yes?

VOICE: Here is another comment.

Due to the fact that the combustion characteristics of methanol -- hydrocarbons we are familiar with -- it is also possible that the design of the engine and the time, location of the spark and entire carburetion system might have to be redesigned and re-evaluated for that particular fuel.

I am directly responsible for developing (inaudible) and switched to methanol and draw a conclusion exclusively on that basis because the combustion characteristic of methanol is so much different than it is of octane. That, on top of the uncertainties on the measurements and the various conclusions reached by different (inaudible), I think it points out to the difficulty in making decisions on this point. I think there is much more to be done (inaudible).

MR. HAGEY: Thank you. Do we have

any more questions or comments? Yes, Al?

VOICE: I have one comment on the question of measurement. I'm not an instrumentalist, so you went into detail a little over my head. Livermoore has a small contract with the EPA for the development of a microwave technique. I think it was specifically directed toward hydrogen and formaldehyde (inaudible) and the people at Livermoore, Larry Rubin of the College believed that it's also immediately applicable not only to formaldehyde but to methanol molecule (inaudible).

MR. HAGEY: Any further questions?

Yes, Bob?

MR. DUNN: Bob Dunn. Is the Bureau of Mines work something you measured on '75 cars?

VOICE: Yes.

VOICE: (inaudible).

VOICE: Getting some of the answer, the unanswered -- answering some of the unanswered questions that were alluded to by Joe?

VOICE: Yes, yes, that's correct.

MR. HAGEY: Let's move along.

Our next speaker is Dr. Robert Lindquist from Chevron Research.

Dr. Lindquist has his Master's degree from the University of Minnesota, his Ph.D. from the University of Berkeley, California.

DR. LINDQUIST: I would like to run over briefly with you this afternoon the work we did at Chevron Research starting in 1971 for about three years, at which time, as you recall, 1971, lead was being phased out of fuels and we were looking for an alternative method to up the octane level of the gasoline fuel without lead.

At that time, it looked like a possibility of very cheap methanol from the Persian Gulf flare gas and that was one of the impetuses to look at where methanol could fit in in place of tetraethyllead for high octane fuel.

Of course, since then the economic situation has changed quite a bit and we are at a situation where we are looking at rather high-cost materials to make methanol, with the exception of garbage, which Bob Sheehan described very well. That's a case of really high-grading

something that's negative value.

I think one thing, one number that's worthwhile keeping in mind is what happens if you start out with coal and you want to make (inaudible). You really have two routes, two general routes. You can make a distillate and that consumes about 35 percent of the BTU value of a ton of coal, producing a distillate, and then you can go ahead and process that in the automotive fuel or you can make CO and hydrogen and then make methanol. That consumes 60 percent of the BTU value in a ton of coal. So methanol is really a very high-cost material to make from coal, both in terms of our natural resources and cost, and I think Bob Sheehan had an excellent presentation. I will differ with him on one point, and that is the value of methanol per gallon. Gasoline right now at our refinery gate, the average price is 28 cents a gallon. Methanol is equivalent -- one gallon of methanol, two gallons -- excuse me. One gallon of gasoline equals two gallons of methanol. We are really talking about 14 cents a gallon for the value of methanol and you can have some tax adjustments, but you still have to transport twice the bulk to get the same BTU value.

Well, let's look at the first slide.

I think we can leave the lights about halfway up.

This is some of the same deal that you have seen about three different ways. We have some degrees in centigrade for people who like that instead of Fahrenheit. It's been well pointed out that the density of methanol is slightly more dense than gasoline and, of course, in the water separation problem in your carburetor, you do have a water separation problem. In a methanol-gasoline blend, the first thing that's going to go into the engine will be methanol and that's where you get the stall-out due to water separation in the carburetor.

The lower heating value in calories per gram is about half that of gasoline. Then we come to latent heat of vaporization. We have this factor of a little over approximately $3 \frac{1}{2}$, so you have to have extra heat in the induction system to get the methanol into the cylinders on a cold day.

The next one, the boiling point of methanol, 64 degrees centigrade, 65. That brings up the problem, you really have a single component system rather than a widespread system in terms of the boiling point and we'll see that when we come to the Reid vapor pressure problem. The Reid vapor pressure, for those of you who aren't applied

engineologists, it's an arbitrary vapor pressure measurement at approximately 100 degrees Fahrenheit in a certain type of container to visualize the vaporization of gasoline in the carburetor. The Reid vapor pressure of methanol is about a third of that of gasoline or a third to equal it. I will show you how that happens when you start blending it in another car.

Then we come down to the research and motor octane ratings, which we have heard quite a bit about. We can pass that slide.

What we have here is the distillation temperature, plotted as the abscissa and the ordinate here is the percent recovered on a standard ASTM distillation curve. The smooth curve with triangles is an unleaded gasoline; the dotted curve is the same gasoline containing 10 percent methanol, and you notice the large amount that boils off at a much lower temperature, which is principally the methanol coming off.

Methanol, of course, being one of the most hydrogen-bonded of organic liquids, very close to water, when it's dissolved in gasoline those hydrogen bonds are broken up and you get a much higher vapor pressure than you would predict from Raoult's law.

The next slide shows the calculation for Raoult's law for methanol and gasoline mixtures. It's effectively the sum of the mole fracture of two components would give us the Reed vapor pressure as shown by that line labeled Raoult's law. Up above, we have the actual Reed vapor pressure. So in blending methanol with gasoline, the refinery would effectively have to back out the high volatility propane and butane and use the methanol vapor pressure as the like fraction and then you have consideration on the distribution system, that engine, to be sure you get the methanol to the, the distribution to the cylinders, unless you are using something like a fuel injection system.

We used a series of 1967 and 1971 cars and here we compare methanol, a 10 percent blend with no methanol and research motor and road octane. As you can see, the road octane is much closer to the motor octane. We get some blending values which perhaps can be disregarded as too significant since it varies significantly as to the aromatic character of the gasoline.

We had cars in a fuel economy operation for about six months, put on about 5000 miles, and we looked at the fuel economy with 10 percent methanol. The overall number here, we got about a 3 1/2 percent drop

in fuel economy, whereas at 10 percent methanol it was strictly on the BTU basis, we would get about 5 percent. So very close to what Joe Colucci is showing. We get a slightly better fuel economy than predicted on the average, and we attribute most of that to a leaning out of the carburetors.

Once again, these were 1971 cars which are quite a bit richer than current 1974 cars.

We ran a drivability test where -- these are now the reverse of what Joe had. These are drivability demerits and we found that operating at 70 degrees -- 40 to 70 degrees Fahrenheit, that we just about doubled the drivability demerits with 10 percent methanol, and when we cool it down to 25 Fahrenheit, the demerits jumped up as much as a factor of 8. So these cars, once again, we're looking at the problem of putting methanol in existing gasoline fuel, where you had to take what you came. You didn't have the option, as Seattle is talking about, of using a hundred percent methanol fleet.

Here is some more exhaust emission test data, and I think, in light of Joe's comments, you might look at the lower half. We had air injection in a catalytic reactor. Our unburned fuel, which we are using

GC for determining the grams of methanol, it looked about a standoff of gasoline. G stands for gasoline up there and M for methanol. This is a hundred percent methanol compared to a hundred percent gasoline. Our main drop is -- we got a very significant drop in hydrogen oxides. That was the impressive one with methanol.

The major problems we saw which led us to a hundred percent methanol when we looked at these blends and convinced us that we couldn't put methanol as a blend in gasoline and as a fuel supplier, stand the problems the motorist would have, were in the water separation problems. What we have as the abscissa here is the parts per million of water to what I call haze versus methanol in volume (inaudible).

What we did was took varying concentrations of methanol and gasoline, used this in little sealed vials with a rubber septum and titrated with water. As the technician shot in microliters of water, he would shake it and would observe a haze point which, in about a half of hour, you would get the haze separation. And you really have to get up to about 30 or 40 percent methanol before you get to what we consider a safe level of water tolerance, namely about 2000 parts per million.

Now, we take this 2000 parts per million based on some experiments where we observed the breathing of a gas tank about a quarter full in the humidity of Berkeley, California, over a period of a week. We figured some guy might let his car set out over a week and we would see the diurnal breathing of the gasoline tank wherein the engine heated up and you expelled some fumes and brought some more in and we figured that if it could get up to 2000 parts per million, we would be in good shape. Well, that blend of methanol, of course, was inoperable without carburetor adjustment, so we decided to take a look and see if we could find an emulsifier. The clothing industry has had a lot of experience with emulsifiers for dry cleaning stores where detergents are ionic and they are carried in an emulsifier to clean the clothes and in oil well drilling areas, so I talked to my acquaintances in the company in this area and we screened about 80 different emulsifiers, trying to find one that would do it economically to hold 30, 40 percent methanol in gasoline, and we couldn't. Our upper criterion was that we didn't want to use over a third of the amount of methanol as emulsifier and I guess if I had done a little more thinking before I had started, I would have realized that effectively you are asking an

emulsifier, which in these dry cleaning fluids, you put in a mole for mole basis with water, you do the same thing for water and methanol and the methanol molecule appears like water molecules in emulsifier, so we were just soaking up the emulsifier in handling the methanol and we couldn't handle the water. It turns out the cheapest way we could see was to blend higher alcohol. As we got up to tertiary butyl alcohol and have about a third of total alcohol, you can easily handle those 2000 parts per million of water with the total alcohol concentration of 15 percent. Unfortunately, tertiary butyl alcohol is a rather expensive alcohol.

Our next problem, we said, well, we can shift to a hundred percent methanol and we have been running all our fleet tests out of things like outboard motor cans and 5-gallon cans that were galvanized, tin-lined.

We started using a fuel injection Volvo and put the methanol in the gasoline tank and in a week or less we found we couldn't operate the vehicle. What happened is the turn plates, the 90 percent lead, 10 percent tin of this fuel tank was attacked and it was attacked particularly rapidly in this fuel injected Volvo

because it has an in-line electric fuel pump. So we were getting about 10 microamps leakage current which accentuated the attack and we effectively dissolved all the turn plate. This is a view of the iron magnified by about a factor of -- this was about 200 here -- where we have gone through the white lead oxide and we are down, chewing away at the steel.

The principal corrosion problems we saw were, as I say, in the turn plate. We checked our gasoline tanks. We had about 10 percent corrosion after six months' exposure in a year-old vehicle and we found, we started testing parts of metal. The aluminum magnesium is particularly susceptible. This shot is a fuel tank of a chain saw, and it was used up in the upper Northwest where an individual put our methanol in the gasoline to prevent, keep the gasoline from freezing in the fuel line, and he ate his way through the magnesium aluminum alloy in about 12 months of use. So there is some engines that are using magnesium aluminum parts in the fuel pumps and this would have to be looked at.

Now, this wouldn't be a problem if we designed the vehicle to use a hundred percent methanol. You would take precautions to set them up, but as a fuel supplier you can't watch a fuel without assuming some liability

and if even there is only one vehicle out of a hundred,
that's rather expensive to replace their fuel system.

That's it.

MR. HAGEY: Do we have any questions?

VOICE: (inaudible). I would like to
go back to your comment on the (inaudible). It turns up
that this is really a production problem that can be easily
overcome with the tailoring of methanol production catalyst
(inaudible) so that its unavailability or high cost of
higher alcohol can be overcome within the (inaudible) and
this is really a tailored product, depending on how you want
to use it. (inaudible).

DR. LINDQUIST: I have heard some
discussion of that and I would sure like to see some costs
from Vulcan-Cincinnati

DR. LINDQUIST: I have talked to
Ted Wentworth several times on this, and he never has pro-
duced the numbers for me, but I would like to see it.

VOICE: You were saying T butyl
is a good blending agent.

DR. LINDQUIST: Yes.

VOICE: And, secondly, that it's expensive. I think this depends on who you are and what you are making. Arco is now putting -- 5 percent T butyl? -- I believe in some of their gasoline some places just to get rid of it. So one man's feast is another man's famine.

Have you heard any reports on how they like it, how does it go?

DR. LINDQUIST: Gentlemen, I don't --

VOICE: Because that's really sort of a foot in the door of alcohol, to see how it goes.

DR. CASSIDY: Phil Cassidy, with the City of Seattle. I was interested in the pure fuel, pure methanol emissions data you had. The car without the catalytic converter was operated stoichiometrically and also lean, but the one with the catalytic converter was operated stoichiometrically and rich, and I wondered why you have chosen that. Specifically, why you have chosen the rich operation, because that's, as we know, the methanol will burn considerably leaner than gasoline and I would think you would look at the lean side. I --

DR. LINDQUIST: Well, on the catalytic converters, generally you run rich so you have enough to heat

your catalyst up and that's -- we used the same setup for both gasoline and methanol.

VOICE: It's not too fair, I don't think, again in the sense of the Ford question, it's not too fair, especially when you are looking at pure fuel vehicles where you know you have got to make adjustments anyway. I can see the argument for a planned vehicle, compare two vehicles. Not -- no adjustments made, but in a pure fuel vehicle, I -- it's not too fair.

MR. HAGEY: Mr. Adelman?

MR. ADELMAN: Henry Adelman, from the University of Santa Clara. Have you actually observed a separation in any of your vehicles?

DR. LINDQUIST: Yes. In the six-car blends right there, we had three separations when we had to go out and haul the guy in. We had provisions so we could easily open up and get at the carburetor and one particular failure that sticks in my mind, because I had the President of Chevron Research putting around there and he called me up and said, "Come on over and get me. I'm in San Francisco." So that sort of stuck in my mind. I had to go --

VOICE: Do you have any exhaust

emission data from your blend vehicles?

DR. LINDQUIST: Yes, we do. We should be presenting that at the S.A.E. meeting and this information I presented and some more will be in Chem Tech in a couple of months.

VOICE: Well, in general, what have been your findings?

DR. LINDQUIST: In general, we get a reduction of NOx, almost proportionate to the amount of methanol we have in there.

VOICE: In the emissions data again, was the Reid vapor pressure controlled in any of these experiments?

DR. LINDQUIST: Yes, they were comparable.

VOICE: That seems to be a very critical -- in order to get reasonable comparability to the gasoline and methanol.

DR. LINDQUIST: Right, we had to back off the butane and bring it up.

I think Dr. Wigg will say a little bit about that.

VOICE: Bob, what was the aromatic

content (inaudible) you were mixing with?

DR. LINDQUIST: It was about 35, 40 percent.

VOICE: We could have really put the -- very high on benzine. We get a lot with methanol.

VOICE: You did.

DR. LINDQUIST: Yes.

MR. HAGEY: Thank you, Bob.

Our next speaker is Dr. Eric Wigg from Exxon Research Corporation. I apologize to Dr. Wigg. When we sent out the announcement of the agenda, we called him "John" Wigg. I told him we would make the correction today.

Dr. Wigg has his Bachelor's degree and his Ph.D. from McMaster University in Hamilton, Ontario. He has been with Exxon for the last, I believe it's, seven years. Is that correct, Eric? And has been involved in a number of projects dealing with auto emissions, one of which has led to -- excuse me -- one of which involved methanol-gasoline blends. The current project he is involved in is sulfate emissions from catalyst-equipped cars.

DR. WIGG: Thank you, Jack.

I would like to briefly cover some of

the work we have done at Exxon in the area of methanol-gasoline blends. If I could come to the first slide, please -- somebody take it on themselves to -- we were interested in obtaining information in the three areas shown here: fuel economy, exhaust emissions and product quality.

I'll say at the outset that the fuel economy and emissions data are in good agreement with what Joe Colucci presented a few moments ago. Some of our data will be appearing in the Science article which will be published in the near future, and we are also planning to present a paper on this subject at the S.A.E. meeting in Toronto next week. So today I would like to just touch briefly on some of the highlights of our work.

Part of our studies, looking at the fuel economy and emissions program, involved comparison of two fuels, a base blend which was a typical unleaded gasoline, and a 15 percent methanol blend. This methanol blend was adjusted to give the same Reid vapor pressure as the base blend and, as has been mentioned here a couple of times, from a fuel economy and emissions point of view, it's important to match vapor pressure because differing vapor pressure can influence emissions presumably as well as fuel economy.

The program that we followed involved the use of three different cars. We chose a '67, a '73 and a catalyst-equipped '73. The selection was based on a desire to cover the span of carburetion normally found on the road today. The air-fuel ratio considerations are important with respect to determining the effects of methanol on the fuel economy and emissions.

Why don't we turn down that amplifier a little bit? I seem to be getting feedback here.

Thank you. I'll just speak a little louder.

The data shown here, the fuel economy measurements, and these were obtained using the 1975 federal test procedure, I have given the effect of methanol in terms of -- on a volume basis as well as on an energy basis and as far as an energy basis is concerned, you can see the 1967 car, which is with its relatively rich carburetion, gave about an 8 percent increase; the 1973 car and the catalyst-equipped car showed very little change.

Now, these results are in excellent agreement with theory, if we assume that the change or lack of change is due to methanol's influence on the stoichiometry.

This slide shows the general

relationship between fuel economy and air-fuel ratio. You can see that the maximum fuel economy with respect to air-fuel ratios occurs slightly on the net lean side. The arrows there refer to the average air-fuel ratio observed with the 1967 car and the 1973 car. Because of the air injection on the catalyst-equipped car, we weren't, we didn't make comparable measurements with that system, but it was adjusted to run slightly richer than the 1973 car. So its position on that curve would be just slightly to the left of the '73 car.

Now, adding 15 percent methanol to gasoline causes about a one number increase in the air-fuel ratio, effective increase in the air-fuel ratio. So the 1967 car would be expected to slide up the curve somewhat. The '73 vehicle would move along, but because of its starting position, you would not expect to see much change in the fuel economy.

The catalyst-equipped car would also be about the same as the '73 car.

Now, the results that we found were in excellent agreement with this treatment, with the '67 car, on an energy basis, giving an improvement. The other two cars showed very little effect.

Methanol's effect on emissions, in general, also followed the expected trend based on air-fuel ratio considerations. This plot shows generalized relationships between CO, hydrocarbons and NOx and the air-fuel ratio. So the 1967 car, with its rich carburetion, again with the addition of methanol, the CO would be expected to drop sharply. Hydrocarbons would be expected to drop somewhat, and NOx would be expected to increase because it's on the left of the maximum.

The '73 car would be expected to give lesser decreases in CO and hydrocarbons on an absolute basis, and NOx emissions would probably not be expected to change too much. I'll just quickly go through the data that we observed.

With the '67 car, it was definitely a big drop in CO emissions. Percentage-wise, a fairly big drop in the '73 (inaudible) also. However, on an absolute basis, it was smaller than that.

The catalyst-equipped car we observed to show a slight increase in CO emissions and this we attributed to somewhat poorer drivability during the cold-start portion of the test. This gave somewhat higher emissions in the first bag before the catalyst warmed up.

However, you can see the levels are extremely low and I am sure this difference wouldn't be environmentally significant.

As far as hydrocarbons are concerned, again a significant decrease in the 1967 car. The '73 car showed no change, and again a small increase with the catalyst-equipped car.

NOx emissions -- as predicted, the '67 car showed an increase, while the two newer cars showed a decrease. Now, this decrease is somewhat bigger than we would have expected based on the relationship of the NOx curve. It's possible that the effect may be due to latent heat of the vaporization of the methanol, a somewhat lower heat flame temperature.

We looked at aldehyde emissions during this study, and we did see a significant increase in aldehydes, particularly with the older car. The methanol, one of the oxidation products of methanol is formaldehyde, and we did a study to determine the relative proportions of individual aldehydes in the aldehyde fraction and, indeed, the increase could be essentially all accounted for on the basis of increased formaldehyde yields. So this is to be expected.

So from a -- both from a fuel economy and an emissions point of view, it appears that any

benefits in the area, in these two areas, would be pretty well limited to the older, rich-operating cars and, in the case of emissions, the benefits in the CO and hydrocarbon area would be counterbalanced by an increase in the NOx emissions and aldehyde emissions.

Turning now to look at the product quality aspects, we would be particularly interested in three areas.

Phase separation is probably the most critical problem that one could face in the field. There being a considerable amount of comment on that already this afternoon, I don't plan to go into it any further.

The question of volatility. It's been mentioned that blending methanol into gasoline gives very substantial increases in Reid vapor pressure as well as the percent distilled at 158 degrees, which is the front end portion of the gasoline. So the question arises: What would the sharply increased volatility of these blends, what effect would this have on vapor locking tendencies in the field? Now, I want to give you some data that we have obtained in this area in a moment.

The other area is drivability, and.

Joe Colucci touched with this with the excessively lean carburetion in some cases due to the methanol, creating problems of hesitation and what's known as stretchiness, lack of expected response to throttle movement. I won't be touching on any data in this area.

As far as the volatility question is concerned, we carried out a study where we looked at two different ambient temperatures, 70 degrees Fahrenheit and 100 degrees Fahrenheit, in our controlled-temperature facility. The program utilized eight different fuels. Four were run at the lower temperature and four at the higher temperature. Each group of four fuels consisted of a base blend and three 15 percent methanol blends. One of these was vapor lock index matched. In other words, the vapor lock index of the fuel was matched to that of the base blend.

Now, vapor lock index is defined as Reid vapor pressure, plus .13 times the percent distilled at 158. So by adding methanol to the gasoline, you get a very large increase in the vapor lock index, because Reid vapor pressure increases sharply and the percent off from 158 also increases sharply.

So in order to match the vapor lock

index of this first fuel in the methanol blends, it was necessary to back out a considerable portion of the front end hydrocarbons.

The second methanol blend was matched with respect to Reid vapor pressure. This required a less drastic tailoring of the fuel as far as backing out front end hydrocarbons is concerned, and finally we looked at a blend where there were no vapor pressure constraints, just adding the methanol directly to the base blend.

This part of the program utilized 13 cars, model year varying from 1967 through 1974.

This slide shows the tendency to vapor lock or the incidence of vapor lock problems with the four different fuels at the two test temperatures. You can see that there is a very large increase in the number of problems observed with the fuel where the methanol is just added directly to the gasoline, and this was particularly severe at the 100 degree Fahrenheit test temperature, as you would expect.

The vapor lock problems were defined as stalling during acceleration, or a hesitation and a backfire, which caused a 25, greater than 25 percent increase in acceleration time from 15 miles per hour to 70 miles per

hour under full throttle conditions.

So there is a very significant increase in vapor lock tendencies and this suggests that if methanol were to be used in gasoline, there would have to be some adjustments made to the volatility to derive some semblance of customer satisfaction.

Now, this would have a marked negative impact on methanol's role as a gasoline extender because if you have to take something out in order to put it in, then this will detract from its role as such.

I have illustrated here what we have had to do to obtain the test fuels that we used in this study. In each case, of course, we are adding the equivalent - on a hydrocarbon equivalent basis, we are adding 7 percent by adding 15 percent methanol because methanol is about half the energy content of gasoline.

In the case of the VLI matched blend, we had to take out 12 percent of the hydrocarbons, the butanes and most of the pentanes, giving us a debit, actually, in the available energy for gasoline fuel of 5 percent.

The RVP match, because of the less severe change in the hydrocarbon composition, ended up with a 2 percent debit and, of course, no constraints will give

you the full 7 percent debit.

Now, these blends, of course, were just two -- actually, an average of two blends in each case, the 70 degree Fahrenheit blends and the 100 degree Fahrenheit blends, and this gives you some idea of the magnitude of the attack. We do, indeed, have to make some alterations to the volatility of the fuel.

Now, the misplaced hydrocarbons, of course, could be used in alternate applications, but if the name of the game is to extend the gasoline supply, this wouldn't be realized if we had to take these hydrocarbons and use them for refinery fuel or for some other application.

By way of conclusion, then, we feel that as far as fuel economy and emissions are concerned, the data strongly support the fact that it does, indeed, follow the stoichiometry. The results are interpretable in terms of the leaning effect of methanol, and it appears that significant benefits would only be realized for older cars.

As far as product quality is concerned, in addition to the phase separation and drivability problems, this volatility factor could create a problem with respect to methanol's role as an extender.

Thank you.

MR. HAGEY: Do you have any questions?

VOICE: You said that your vapor lock tests were run at full throttle acceleration, is that right?

DR. WIGG: Yes.

VOICE: And that you noticed an increase in acceleration time.

DR. WIGG: Right.

VOICE: Well, why did you (inaudible) to the lean (inaudible)?

DR. WIGG: It could be probably just attributed to that, yes. We did part-throttle accelerations also. I didn't give you those data.

VOICE: I can't separate the two.

DR. WIGG: Between vapor locking and lean.

VOICE: Yes, not on that test.

DR. WIGG: Yes, there is a probability that the leaning effect would contribute to the problem.

VOICE: You speak of this butane that you are having to back off as being a problem, that you could burn it as refinery fuel, but isn't this also one of the components of LPG? Aren't we very short on LPG?

It brings a high price, doesn't it?

DR. WIGG: Yes, there's a possibility
of --

VOICE: The people who are dependent
on LPG in rural districts would be very glad to have it backed
out, I think.

DR. WIGG: Yes.

VOICE: But don't print it in the
finding paper.

DR. WIGG: Okay.

Yes?

VOICE: (inaudible). I have a
comment on it also. We often think that there are two routes
introducing methanol to the transportation system, one the
blend route and the other the neat methanol route, and the
problem has been identified with each, the problem of
excessive vapor pressure, vapor lock in the blend route,
and the neat methanol route, the problem of cold start.

One way to get around cold start
is to add butane. It's not very often that the juxtaposition
of two (inaudible) suggests the obvious solution, but when
alternate (inaudible) with the butane, you have got to back
out a blend, put it into the neat cars, cars that are running

on neat methanol, and maybe you can try both routes at the same time when methanol becomes available.

DR. WIGG: It sounds kind of complicated, but, yes, I guess there would be some merit to that.

Yes?

VOICE: Another one that Vulcan-Cincinnati is talking about, and again this is one of these -- solve two problems at once or you don't solve either, and that is that it's very expensive to ship from the Far East, very expensive to ship the liquid petroleum fractions, at \$25 a ton for shipping costs, but if you are shipping a lot of methanol, with 10 percent butane and pentane with it, take it back out in this country and still ship it in standard tankers rather than LPG tankers.

VOICE: I would suggest you examine your vapor pressure data on those.

VOICE: Well, as I say, it depends on which ones you are putting in and how much, but he says 5 or 10 percent methanol.

Do you think that's too much?

VOICE: I noticed (inaudible) the vapor pressure curves, it is.

VOICE: Well, it's not my figures.
It's (inaudible).

VOICE: This energy consideration that you mentioned at the end, I think you consider that to be a detraction by the use of methanol, but it appears to me, from the other data you presented, where you had, say, for the catalytic converter-equipped car, a 2 percent increase in energy consumption or a 2 percent decrease in energy consumption. You are 2 percent better off there and then you point out later on, when you balance the Reid vapor pressure, which I assume you did NAP test the fuel --

DR. WIGG: Yes.

VOICE: -- you said you did, and you got another 2 percent that you saved from the light end that you took off. So there's a total of 4 percent energy you are saving by putting, by blending methanol with the gasoline.

DR. WIGG: Well, you are still using the methanol.

VOICE: No, that's already in there. You got the 7 percent energy added and 9 percent hydrocarbon energy removed.

DR. WIGG: Yes.

VOICE: So that's the 2 percent that

you gain there.

DR. WIGG: No, no. You show that the car ran 2 percent better with the blend. I mean, you are right. You have lost the overall fuel pool, but the car ran 2 percent better with the blend, so there is a total 4 percent energy savings. Two percent shows up the stuff that you save, the butane or whatever you took off. The 2 percent shows up from the fact that your car runs a little more smoothly. So there is a net 4 percent energy saving.

VOICE: (Inaudible).

DR. WIGG: Well, I can't argue with that.

VOICE: I don't know whether adding butane to methanol is going to work. Generally speaking, the only reason why you put methanol in gasoline in the first place is substantially aromatic time gap and it's very insoluble (inaudible). It may not be a reasonable thing to do, to add butane to methanol.

VOICE: I think Al was pointing to some of our work on that and we have looked at butane concentrations in methanol up to 10 percent and if you look at the plot, if you look at the phase diagram of methanol, you will find that as you get above 90 percent methanol, you

have a great deal of problems (inaudible) and water, and this is the way we have attempted to get by with our cold-start problem, by adding 2 or 3 percent butane which is necessary to about 14 pound RVP, and we have had no compatibility problems at all. We have (inaudible).

DR. WIGG: Yes, Max?

VOICE: You could also use pentane for the same purpose and you could use some of the nitric quantities there successfully.

MR. HAGEY: I think we are about out of time, but I'm going to try to stick to the schedule. So on to our last speaker, Mr. Richard Tillman from Continental Oil Company. Dick has his Bachelor's and his Master's degrees from Southern Methodist in Dallas, Texas. He has been with Continental Oil Company for the past 21 years and he is presently Associate Manager of Petroleum Products Research, R & D.

Dick?

MR. TILLMAN: Thank you.

Rather than rehash some of the data which some of you have heard at Henniker and which we have submitted for an S.A.E. paper to be held at Congress in Detroit in February, I thought I would give you some

up-to-the-minute work we have been doing and so I'll apologize for the quality of the slides and the incompleteness of this report, but I thought you might be more interested in a little up-to-date picture than what we looked at before. Part of the problem is the fact that there was a little misunderstanding between Graham and myself as to what an opaque projector consisted of, but I do appreciate the help of his girls in getting my opaque slides reduced to a transparency slide, but the quality isn't what I would like it to be.

Sorry about that, Graham.

Okay. I'm going to describe today the experience we have had with two different automobiles, plus some engine test results on the -- tests and dynamometer that we have been running recently.

The first one is a conversion of a '72 Volkswagen 412 sedan. This vehicle was selected because it is a fuel-injected engine and the work that was done at Stanford on one of the author's recommendation was that somebody ought to look at a fuel-injected automobile. Well, this may be the only one left if Bob Lindquist has gotten rid of his Volvo.

Have you still got that, Bob, or --

DR. LINDQUIST: No.

MR. TILLMAN: We don't have the only one left, but there aren't very many of these fuel-injected methanol vehicles around.

This one is interesting from a couple of standpoints. One, it's been in service on methanol for over two years and we have had no fuel system component deterioration, except for some elastomers. We have recently noticed a slight drip at the bottom of the pan and traced it to the elastomers that had gotten brittle on us and it actually started cracking, but no corrosion of the fuel pump or the fuel tank.

The other interesting thing about this vehicle is that it is our dual-fuel automobile. The conversion -- we inserted an extra set of fuel injectors per cylinder so that we have two injectors per cylinder which we can actuate either one or two sets. If we are operating on gasoline, we inject the bottom set. When we are working with methanol, we energize both sets. So this vehicle, with no more than a flick of a switch, can operate interchangeably between gasoline and methanol.

That's the good things about it.

Now, the bad thing to date has been our lack of ability to control the electronic ignition.

circuitry that this vehicle is blessed with, and I have a little preliminary data. This was developed in conjunction with the Bureau of Mines, Bartlettville. They have been kind enough to run our CBS test for us and if I could have the first slide, please, this shows the vehicle is running -- well, the vehicle, take my word for it, is running very rich, as you can see from the CO and hydrocarbon with no catalyst. It is very rich. It's particularly rich on the transients. We did the best we could, trying to bypass this black box, installed a pair of PTH catalysts, took it back over to Bartlettville, and our steady-state operating conditions at this time were pretty good, but we didn't have any way of really examining speed transients. So we gave it back to Bartlettville and they obligingly ran it for us again and again we were -- the speed transients have completely licked us on this thing and it's a function of the accelerator pump on this particular system. I think the interesting thing from my standpoint is the very low NOx values that have been achieved with this.

Well, let me have the next one because it shows the steady-state conditions. These are steady-state conditions that show that we do get excellent control of CO and hydrocarbon with these catalysts on. These

are approximate. We haven't reduced these to mass emissions. This is just to give you a comparison of parts per million concentrations. We get good control of these emissions through a catalyst as long as we don't get these spikes. Now, when we get a very rich spike, as we do on transients, this stuff just scoots right on through the catalyst without having a chance to get converted.

The next slide, then. We have talked about some of the performance. This particular vehicle performed very well on straight methanol. I think you can see. The top table is the acceleration with gasoline versus the acceleration with methanol and the various loads. These are full throttle, not part throttle, and constant manifold, but the differences in acceleration are almost negligible between methanol and gasoline in this vehicle. We are operating reasonably lean overall, though. If you will look at the economy down there, the bottom table, looking at the economy and BTU's per mile, you will see that we are showing a considerable improvement in economy with methanol on this vehicle, even in this fairly rich condition. We do have hopes for this vehicle -- the reason I haven't gotten rid of it yet is, we have been working with the Robert Bosch Corporation and they have very graciously

converted our black box control circuit to a controllable circuit and if it's in the mail now, I hope it will be in (inaudible) City by the time I get back, and they have put us in a number of variable potentiometers in this circuitry so that we can vary air-fuel ratio and particularly we can bypass this accelerator pump that is giving us the speed transient problems. We hope, after our brief experience with this, to put our catalyst back on, drive back over to Bartletttsville and demonstrate that this vehicle will, indeed, meet the original '75 specifications. That's the Clean Air Act.

Okay, so much for the fuel injection vehicle. This one, we think, has promise because certainly we don't have the maldistribution problem that people recognize as being existent with the carbureted automobile.

Since we didn't have a whole lot of experience with the carbureted automobile, we decided we would get our feet wet with a '74 Pinto. We chose the Pinto, the 2.3 liter engine, which, from one standpoint, was a mistake. When you start redesigning the other systems for the Pinto, you find that the distributor is not in the most opportune place to get the pipes exactly where you would like them to be, but we started out on this and the next

slide will show the air-fuel distribution we got with the stock carburetor, the stock in the system that -- after it was adjusted simply to give us fairly lean methanol operation. It's kind of hard to see. I apologize again. This is the distribution between cylinders, cylinders 1, 2, 3 and 4, air-fuel ratio along this axis.

At 30, we are running rich, but we are running pretty uniform. At 40, we are getting up to about where we would like to be and still getting uniform, and then when we get into the high speed, 50 and 60 miles per hour for operation, we get the characteristic mal-distribution pattern.

Well, if you look at this particular inlet system, you will see that the primary barrel is towards the back and as long as you are operating below where the secondary barrel kicks in, you are getting good distribution. When the secondary barrel kicks in on the 50 and 60, it's dumping right in the center of the 2 and 3 inlets and the 1 and 4's don't have a chance to pick this methanol up. Consequently, we get this big variation in air-fuel ratio.

A big variation in air-fuel ratio in methanol is considerably more serious problem when, one, you are trying to make it operate as lean as practical, in

order to minimize emissions and maximize economy and, secondly, when you consider that the air-fuel equivalence ratio with methanol is 6.45, as has been pointed out, versus gasoline, about 15 to 1, a change of 1 to 1 1/2 air-fuel ratios makes a much different, a much bigger difference in equivalence ratios with methanol than it does gasoline. Simple arithmetic shows you that.

What happens in a practical sense, then, on this particular automobile or on a V-8, it behaves about the same way, that you will have some of the cylinders running essentially at lean misfire limit when you lean this out as far as you can take it, and these cylinders then contribute just (inaudible) to the carbon monoxide and hydrocarbon emissions.

On the other hand, you have a couple of cylinders or more that are operating in the rich regime which contribute disproportionately to the NOx emissions.

If we could get the distribution pattern we would like, we think we could get both the hydrocarbon-carbon monoxide and nitrogen oxide emissions down to the point that we would like them.

Okay. That -- we have looked at a number of different inlet systems on this Pinto to try to

optimize that and, unfortunately, with all the wiring and the double carburetor systems and the two and four-barrel and everything else you can think of, we haven't significantly improved on the Ford design. My congratulations to Ford. They did a much better job than I had at first anticipated.

I thought, hell, we could do better than that. We haven't to date.

The one that we are using has some promise and the one which we are checking out now is -- we are putting a larger single-barrel on the back burner there, which will, we hope, give us a better distribution pattern. Our objective on this car -- the reason we are striving to lean it out is to, one, we want to demonstrate the emission potential with this car with a lean thermal reactor (inaudible) and also we want to do the same thing with a catalytic converter.

Now, we think methanol has some potential for maybe being controlled not with a catalytic converter but with a lean reactor as well. So when we get this leaned down to our satisfaction, we'll slap on a lean thermal reactor, call it (inaudible) catalytic converter and see what we can't do on emissions.

We have got about five more minutes.

Now, I'll raise the spectre of some problems, some serious problems that we have run into in the last month in our engine tests. We wiped out four -- three engines in the last five weeks on methanol, using straight methanol, and it is a concern to me, and I think it should be a concern to all of us, since we are involved in this work, and I would like to raise the problem so that some other people besides ourselves can be thinking on possible solutions to it

The first one I mentioned out at the Denver meeting, for those of you who were there, we decided, capriciously, I guess, to run a 5-C engine test. Those of you who are in the oil business, this is a -- know what I'm talking about; others may not. This is a standard ASTM lubricating oil type test. It's run on Ford 350 cubic inch V-8 engine and we have a lot of emissions and performance data on this engine, so we decided to run a standard 5-C test on it. The engine that we ran our performance and emissions on has over 300 hours on methanol, some of it under very hard service, at 70 mile per hour equivalent, full throttle -- I mean maximum power, run it just as hard as we could run it, and when we tore this engine down we had no problems whatsoever.

Well, when we tried to run the first

5-C sequence test, which -- I think a 5-C, it's either 168 or 172 hours, one or the other, and I have forgotten the exact length of time, it's -- you just simulate stop and go driving. So it's not a real tough test from operation. It's really kind of a sludge test for oils, sludge and lacquer test.

Well, we ratioed this on the air-fuel ratio, gasoline to methanol, and we got the engine running pretty rich, richer than we would for minimum emissions. Well, this test aborted -- well, it started to abort about halfway through by oil consumption. We were outside the limits on oil consumption. We decided to, as someone stated this morning, through brute force and awkwardness, we were going to force it through. Finally, we were up to about a gallon of oil every 12 hours on this engine before we could finish the test. We took the engine down; we had excessive wear in the piston rings. We had just worn out a set of piston rings in less than -- well, right at 172 hours. This particular test calls for a soft ring and we thought, well, maybe something is amiss here, so we ran the second 5-C test, using the standard Ford rings, which are somewhat, quite harder than the recommended rings for the 5-C test. This one -- same type of phenomena. Oil consumption

went up very rapidly after about midway in the test. We did get through. We were again using about a gallon per 12 hours. This time we had dished out the top of the cylinder. The rings themselves didn't show any wear, but we had a nice little wear pattern at the top of the cylinder. It was severe enough to allow excessive oil loss.

Well, as if this wasn't bad enough, just before I left, our little Pinto engine started getting noisy on us, particularly on the No. 2 valve, and we were pulling it down for another manifold change. So we decided we would look at the head while we had it down and we had cut out the exhaust valve guides on 2 and 3 to the point that we couldn't even get an air gauge measurement on them. So we now replaced it with another gauge. I have a Piston from the No. 3, incidentally. This shows the extensive scoring in case -- a lot of pounding that I don't understand. So those are the three engines we wiped out in the very brief history. This Pinto engine had about 1500 miles on methanol after first breaking it in with 2000 miles of gasoline operation.

So that is a problem, fellows, and we sure solicit any and everybody's help on it.

Yes, sir?

VOICE: This is a question that I was going to raise as soon as you finished, and that is the effect of the methanol on the lubricant, oil, the additive packages, various additive packages that are used by companies and as a base stock that is used.

MR. TILLMAN: Okay. Well, the oil -- this is one thing we haven't varied from. The oil we have been using on this is a proprietary oil. It's our highest quality of oil that we feel is equal to anything on the market in terms of S.A.E. quality, which means nothing probably as far as methanol is concerned. It is a lubricity problem and it is apparently associated with richness.

Do you remember, on the Pinto, the two cylinders that were rich were 2 and 3; those are the two that cut out. I feel strongly that it's a lubricant problem and I feel also strongly that is associated with rich operation of methanol, but I don't propose a solution because I don't know one.

VOICE: On the engine that -- you said it had 300 hours of full throttle or full power use, was that on your methanol or (inaudible)?

MR. TILLMAN: That's on pure methanol. It was interchangeable. We ran base lines with gasoline and

we ran with methanol so there was a lot of -- both types of operation.

VOICE: Would you expect more blowby to be occurring in the accelerating cycle than on just a steady-speed cycle?

MR. TILLMAN: Yes.

VOICE: And so that type of testing would probably accelerate the problem?

MR. TILLMAN: That's another point that I didn't mention in the 5-C. Maybe you are familiar with it. In the 5-C you do intentionally cut out the piston rings a little bit to give you much more blowby than you would on a stock engine to accelerate the test, so these 5-C engines do have quite a bit of blowby on them by design. The Pinto engine, I don't know.

Fred?

VOICE: You said you ran the Volkswagen for two years and the fuel system was clean after two years? Do you know (inaudible) the turn plate, too?

MR. TILLMAN: I don't know. We got a spare tank to put on this thing. We took it down and looked at it and we couldn't detect any corrosion whatsoever. Since we have to drop the engine to put this new tank on,

we decided just to hold onto the tank until we got ready to get rid of the automobile. Then we'll put it on.

VOICE: That could be an important point, what people use for this gasoline (inaudible).

MR. TILLMAN: We are going to visit Volkswagen later this month. I won't, but Bob Jackson, I believe you know, is going over there and this is one of the questions we are going to pose to them: What have you folks done on your tank that makes it work so well?

VOICE: Did you put any intake heat in your Pinto manifold?

MR. TILLMAN: No. We are trying to avoid -- we are trying to get mechanical rather than putting the heat in. Yes, putting inlet heat would, of course, might help, but we were trying to do this mechanically.

VOICE: Volkswagen, Graham, you said (inaudible). I thought you said a thousand Fahrenheit, and they said they had been doing a lot of work with all their engines on methanol and -- but they definitely put in intake heat, manifold heat. I think the factory says it's necessary, so maybe it's necessary.

VOICE: It probably -- well, it may be.

VOICE: We were trying to avoid it.

MR. HAGEY Something we would like
to avoid, if we could.

Do we have any additional questions?
If not, I would like to proceed to the workshop. Before we
go to that, does anybody have any requirements for typing
or anything that we can have our secretaries perform? If
not, I think we'll let the secretaries go. They have been
very patient and very helpful to us.

Ladies, I thank you very much, but
I think that should suffice.

If anybody has anything, now is your
last chance.

John? What we are going to do with
the workshops is try to run them in series so that -- John
is going to take the first crack at it and he and I will
split it up and try to be through by five o'clock.

For my workshop, I'm going to have
three panel members, Tom Reed, MIT; Dick Tillman who you
have just heard, and Joe Colucci in the front and, quite
frankly, we want your recommendations, opinions, bitches,
whatever, as to what -- not only in methanol, because we
have heard principally about methanol and methanol-gasoline

blends today, but recommendations, suggestions, where should the federal alternative fuels program be directed? I'll turn it over to John and I think he has the same objectives in terms of the Combustion Research Program.

DR. BELDING: Thank you, Graham.

Toru Iura and Bob Sawyer and Fred Bracco are my three panelists and they are going to start off the conversation, because what I'm going to do is suggest my priorities and then they are going to probably chop me apart and I hope that you will chime in then and have at it with them.

So why don't you three grab a chair up here in front so you can face the jury.

Well, by necessity, I think my objectives have to be somewhat broad. I could give you specifics on what I think needs to be done, but let me just give you the top three items that I think ought to be done and then I'll back those up with some kind of service areas.

My feeling is that, regardless of the type of fuel that we run, we need to understand combustion generally. I think once we understand combustion generally, we can then apply the type of fuel and I think the program that I will outline here will allow us to do that.

I think the No. 1 objective of the combustion program is go to ultra lean combustion and, in order to do that, I think that, first, we have to look at the stratified charge, and by "stratified charge," I mean all types, the Honda, the Texaco, et cetera.

The No. 2 area, then, would have to be the diesel engine, and I think there are lots of areas in diesel that can be looked at, open and closed chamber, or open and dual chamber included, but you also have to look at things like the odor, the noise, cold-start problems and things like that.

So those two areas, then, stratified charge and diesel, are really two different types of combustion that I think we ought to attack and the ultimate, of course, is lean combustion. So that's the third area.

Now, in order to support those three areas, I think that we need some very serious work in characterization of fuels. We have mentioned that earlier today. What are we talking about with the methanol fuel or other types? What are the law of limits and stuff like that?

I think also, in order to understand that, we need to look at droplet combustion, and we need to

include in that mixtures, sprays, emulsions, et cetera, and then we need to understand better the catalyst that would aid us in combustion. I am thinking more in terms of continuous combustion and the long-range goal, of course, for the whole program is to be able to model these machines on the computer so that we can cut out some of this testing.

Okay? Those are my objectives.

I hope the panel will disagree with me or agree with me or whatever. So I open that up to the panel.

VOICE: Obviously, I tend to agree for the need for the lean combustion work and the limitations there. I think there is at least one very fundamental area which really isn't a combustion problem in itself which has been overlooked and needs a considerable amount of work, and that's mixture preparation, just the general problem of carburetion or fuel injection, and, with that, the mixture distribution problem as well. I know that's one of the things that's bothered us, the Academy study I have been involved with. We haven't seen that much work going on anywhere, really, in the field of mixture preparation. It seems surprising because it comes up over and over again. The maldistribution of the mixture ratio at the cylinders and failure to vaporize well or to atomize well seems to affect

the performance both in terms of emissions and fuel economy, and I simply put that at the top of my list. It's not even a combustion problem, as such, but I think it's an extremely important one. I'll just throw that one out and save some other ones.

VOICE: Okay. Well, I think I want to add another thing with regards to lean combustion and whether you are talking ultra lean or stratified charge or its variants and that is, I don't think it's been brought up clear that there is a -- talking to a number of the investigators, and I think the thing that seemed to come out the most was the fact that there is a lack of understanding or a need for a greater understanding of hydrocarbon control, how it's formed and what its fate is, what happens in the cylinder walls, and I think this is an area that, if you want to take advantage of lean production, work can be done. I would certainly agree with you on that mixture preparation.

Another thing, John mentioned about diesel engines. It seems that if one is to consider diesel engines for automotive use, essentially what I think we are talking about -- free combustion chamber, free chamber diesels rather than the open-chamber that might be used for

heavy-duty applications, and perhaps the work might stand orientation in that area insofar as understanding and developing an understanding of the odor problem or the noise problem, which really are the inhibiting factors, aside from power and weight ratio.

VOICE: First of all, I agree completely, really, with the list that John gave, in that order, too. He started with the stratified charge engines and went to diesel, lean combustion, characterization of the fuels, droplet combustion and as the long-range goal, he is hoping for some detailed models which could shorten the development times of real engines. So I agree completely with that list.

As far as the suggestion from Sawyer that the fuel distribution, the nature of how uniform a charge is for a carbureted engine is concerned, I think it's a very valid point, but it depends on what the goals, the final goals of the programs are. I think the future, utilizing direct injection, whether it is intake manifold or whether it is directly into the cylinder, in particular stratified charge engines, I think they are going to be directly injection, either intake manifold or in the cylinder, the beginning of the compression stroke or at the top of the

compression stroke. If for no other reason because that eliminates pre-ignition and cuts down the knock if you design it properly and, therefore, I think in long terms -- well, perhaps (inaudible) carburetor is not of great interest to me. If you are interested, on the other hand, in the 5 percent, perhaps, improvement that you may get and in the present cars -- from the present cars, then I think perhaps one of the easiest place to look at is, indeed, the carburetion and, indeed, the uniformity of the charge.

Now, another point which is dear to me, as some of you know, is this business of the models. I believe that -- well, first of all, we all know that Ford, for example, has a 10 year old or 15 or 20 year old program to develop stratified charge engine. Texaco has a similar program. Curtis-Wright has another program, and many other corporations, too, that I am not even aware of. I think models are available now that could shorten the development times of these engines. I have a couple of years of experience to back that statement up, and I think I would recommend a joint effort of industry and university, perhaps under the sponsorship of NSF or any other way.

One immediate result that I can see from that is rapid evaluation of certain power plants; to

debate, for example, is (inaudible) better than the Texaco system or vice versa? It has been offered for -- how many years? I think it would be offered that many more years, unless some specific testing and understanding of the details of the two combustion processes are undertaken, which would reveal which one of the two is basically, has basically more potential, but, as I started saying, I think I agree with the list that John gave, in that order.

VOICE: Does anybody out there have any differences? If you do, you can leave the room.

MR. ASHBY: I have a few comments on scattered subjects. I'm Tony Ashby with the EPA.

The first that Professor Sawyer, the point that he reminded me of in terms of fuel induction systems and to be considered are the people who are going to be doing the investigations. Have you considered Sine-Venturi carburetor systems, such as Besser Industries have developed, which they claim and have data to back it up they operate at an overall ratio, air-fuel, of 18.5 to 1 over a wide range of engine operating conditions and they are on the right side of the NOx versus air-fuel ratio curve, and so they have very low NOx and hydrocarbon and CO and fuel economy.

You might want to talk to those people. In thinking about diesel, many of you may know that the Emission Control Technology Division of EPA in Ann Arbor have just recently finished a study done for them by Riccardo on the diesel as a likely power plant, in which a lot of the problems were identified and potential solutions. Toru mentioned that he thought odor and noise and some other things might be important. I -- my personal opinion is that noise is relatively unimportant. You can build a car to isolate the passenger compartment from the engine noise, but odor -- define odor and measuring it objectively is a big mystery right now and there should be a lot of attention paid to those considerations.

Finally, Professor Bracco talking about the years of development on the Ford and Texaco stratified charge processes, can be compared with what I understand to be a relatively short development time in the case of the Honda CVCC engine, and as far as an engine such as the Proco coming to the marketplace or having a viable place in the market, I think that -- and again this is just my opinion -- that the manufacturing costs rather than any basic understanding of the combustion will be the determining factor. I think that probably the cost of

high-pressure injection systems may mitigate against such engines.

VOICE: Any response?

VOICE: I certainly agree with that last point, that although I see the advantages that Fred is pointing out on going over to fuel injection systems, Proke type or even diesel, that it's going to take a long time, if that's a desirable thing to do, to convert the carburetor production capacity over to fuel injection production capacity, and, in the meantime, we can certainly use some other solutions.

I think in a diesel, the other area which really needs to be pinned down at the particulate characteristic, and I think that, in general, is a problem of the fuel injection systems, whether it be stratified charge or diesel. Everybody is talking about particle size and particle composition, but I still don't see the good, careful work being even initiated to give a thorough characterization of what the particles are that are produced in these engines and what is causing them to be produced, what the important parameters are. That, of course, is another area which needs to be worked on.

As a second-order requirement and as

a researcher in the combustion field, I think the area of diagnostic techniques needs a lot of work and I think the people who do that work should not necessarily be the same people who are trying to do the combustion research because there isn't that much manpower in our program, for example, to do it. There are two areas. The first is the laser (inaudible) measurements of turbulence and velocities inside the combustion chamber. These techniques are ready to be applied, but I don't know of anybody who is doing it. It's something that should be initiated and it should be initiated rapidly, to find out what the flow field patterns are in the engine while it's running and what the turbulence levels are and whether the turbulence is dominated by the intake process or whether it's stamped out by the motion of the piston, for example. These questions are not understood, and I don't think that the hot wire anemometry is quite strong enough or flexible enough to give the answers to that.

The other area one keeps hearing about is the time and space resolved spectroscopy which the laser-Raman techniques are supposed to provide some real possibilities there. Again, these are huge, major efforts to be undertaken with application not only to automotive engine combustion, but many other fields and one

should not underestimate the difficulty of proving out these techniques. They are major programs, probably beyond the scope of the National Science Foundation automotive engine combustion field, but I think they are well worth resolving and getting after.

VOICE: I would like to answer some of the indirect questions and to add my support to what Sawyer said.

First of all, the Honda, indeed, has come to a high degree of development in a short time as far as we can tell, because I have never really seen a complete set of data as far as that particular engine is concerned. The main reason is that they are using the divided chamber approach and, in essence, they are stratifying the charge forcibly by having two chambers. The main problem with the open chamber, which is the Texaco and the Proco approach, is that you are trying to divide the rich and the lean charge by some (inaudible) way and, of course, the second approach is much more difficult than the first one, even intuitively. However, the second one has a much lower surface to volume ratio. So, if achieved, it will have a better efficiency.

Okay. Now, as far as the high-pressure

injection, that is something coming over from the diesel combustion. What happens, when they start the development of the stratified engine, they say, "How will you inject the fuel?"

Well, look at the diesel people and they use the jet-type pump. Well, first of all, you can obtain atomization with much lower ΔP if, instead of using the shower head injection you use a different injection system like a vibrating (inaudible), for example, or (inaudible) jets.

So the ΔP is not now the order of tens of thousands of psi, but of the order of hundreds of psi. So you don't have to use a high-pressure injection system to stratify a charge. In fact, you don't even have to use it in a diesel engine.

There is the problem also of penetration (inaudible) which, again, will bring you back to the model and let us leave that alone for the time being.

As far as the carburetion is concerned I think that even makers have already realized that the carburetion isn't exactly the best way you meter the fuels. The Volkswagen, the Porsche, are already using intake manifold injection. It's a low-pressure injection system

electronically, and the feeding of the fuel is related to the temperature and flow rate of air, so that you get the precise metering of the fuel and they are already doing it. So I think the days of the carburetor, to a large extent, are over, no matter what.

VOICE: I don't think I agree with that.

VOICE: But it is true that Porsche and Volkswagen are already using it in their engines.

VOICE: Yes, but they are using it because of the fuel distribution problem, not so much as a fuel metering problem, and I think those are quite different.

I also think that there are opportunities in the Dresser-type and other types of (inaudible) flow carburetors which have not been fully explored and that, with a good carbureted system, you can get excellent fuel-air control. It's just that the systems we have now are really pretty crude and not flexible over the entire operating range.

VOICE: There is a slight difference here. I prefer the low-pressure injection system, but that's okay. You mentioned something about cost associated with the stratified charge system injection. It is my information

directly with discussion with the auto makers that cost is not a major element in their consideration. The (inaudible) cost with the low-pressure injection system would be of the order of perhaps hundreds of dollars, most, and you know cars went up 50, 40 percent in price over the last two years. A hundred dollars would not make much difference.

VOICE: Let's get another question from the audience.

MR. LESS: My name is Sam Less from Penn State. I certainly agree with you on lean combustion which we have been working on for quite some time, but I would like to make a few points here.

First of all, it depends on our time scale whether we are looking at long-range or short-range. I think the short range problems are very practical in nature and there is lots of areas that have been neglected and we should pay attention to them right now, from both an emissions and an energy standpoint.

One that pops right into my mind is the idea of warmup. That's been neglected and something should be done about it right now, both from an energy and an emissions standpoint. But if you are looking further down the tube to what's ultimately going to happen, we are

going to be burning fuels that can't be carbureted. I feel that coming, or at least some fuels that can't be carbureted. What do you do with these? You got to get them insomewhere else, into the engine some other way, and for this reason I think it's very important to get on the ball with the injection research.

Also, as opposed to open and closed chamber, all of us know the advantages and disadvantages of both types of operation. I think the prime goal for our research down the tube, the very first and prime goal should be that we should come up with a device that is capable of handling multi-fuels. It should have multi-fuel capability, because we don't know what we are going to be burning 10 years from now or 15 years from now, and this should be the No. 1 goal. Whatever we do, we don't know what the engine is going to look like, but, by God, it better be able to burn anything from olive oil to -- who knows what? And I think this is what we should set for our long-range goal.

The immediate goals should be the more practical types of things that we have heard mentioned here by Professor Sawyer, the distribution -- certainly, if we knew more about the distribution, we would be able to do more with our lean combustion.

The diesel problem, the particulate matter, and the smoke are important problems with the diesel engine; but we have got to keep our eye on the ball. Short-range, very practical-type problems. Long-range, we better be prepared for what's coming.

VOICE: I wish we would get a good resolution of whether the multi-fuel capability is something we want to go for or not. My impression is that the premium fuel will be reserved for the automobile and the power industries and others will have to get by with the lower grade fuels. It sounds good to me, Sam, but I -- the people that deal with fuel supplies don't seem to think that's necessarily the case.

Let me throw out another long-range item which looks very attractive, and that is the feedback control systems for the combustion process. The work that's been done on the three-way catalyst has shown that there is some very interesting returns from this type of system. There is not a good sensor for a lean combustion feedback control system and this is the system which would control such things as air to fuel ratio obviously, spark advance and perhaps other parameters to either optimize fuel economy or power or minimize emissions. This, again, is

not really a combustion area but it's tied very closely to combustion.

VOICE: I take it you are familiar with the work that Schwitzer has been doing --

VOICE: Right.

VOICE: -- and the one thing that -- the one open question in that is really what do you use for the feedback signal? For any optimizations system to work, you need to have something that either goes through a minimum or a maximum. You can't -- you can't feed back -- you can't -- you need an error signal that can dither and home in on either a minimum or a maximum and this is what we are busily trying to find.

It seems to me that the people at Sheffield over in England are using temperature feedback and it's working real well. I think that's what they are using, I'm pretty sure.

Graham Hagey wanted to say something.
Graham?

MR. HAGEY: Well, I just -- I had an item on the side here with Fred Kant. I asked Fred to respond to the multi-fuel question because he has done some work for us in this regard and --

VOICE: Well, I would just make a broad comment. I think people always wishfully think about putting together a car that will burn things from soup to nuts or olive oil to tar, but I think, when you really get down to it, it makes -- you can optimize a car for one fuel but you will find that when you do that, how it performs on Fuel B is going to suffer greatly and, furthermore, if you superimposed on that, you have to have a variety of distribution networks for each fuel. You just can't possibly, in my opinion anyway, conceive of a fellow driving on one tankful of fuel A and pulling into a gas station, and, without doing things, pulling out with fuel B and back to A and C.

We have, at best, the possibility of perhaps two grades which we now have, or three for the time being, but a two-grade system makes sense in the long run, perhaps, but to have like the Texaco system which has been promoted in the past on the basis that it is really a wide-range fuel machine, I don't really think, when you really get down to it, or, for that matter get there, would really work out that way and I think we are putting our focus on real --

VOICE: Well, I have to agree because the other area that I work in is base load power stations

and we are working on the same problem and it is a very long-term kind of goal.

VOICE: John, too, when you talk about heavy fuels, you are talking about dirty fuels and it takes fairly sophisticated processing to clean them up and the trend is to get cleaner and cleaner fuels and I don't think that we are going to see devices on cars to clean up. I think this can be done in central processing units where you can specify the quality and something they can monitor.

VOICE: I have a couple of comments that relate both, I think, to the multi-fuel question that Sam brought up and another area that I would like to suggest. My name is Clif (inaudible) from Southwest Research Institute and, in particular, I am with the Army Fuels and Lubricants Research Laboratory which is located there.

I think, in the multi-fuel question, the Army probably is the only one that is really concerned with it as being meaningful because they have a security problem in that quite often they have to live off the land and in a combat situation. Whether that occurs or not in the future, that's a question, but still that is a problem that they have to concern themselves with.

I think that an area, though -- that

this brings in another area of interest and that is the effect of real fuels on heterogeneous combustion. We have seen a lot of work done in the past, both the single drop and spray combustion, using pure hydrocarbons (inaudible) whatever, because of simplicity and understanding the vaporization of the droplet, but when you get into a real fuel with a broad-bottom boiling range or a narrow-cut boiling range or something like with the methanol added to it where it really bastardizes the normal, smooth (inaudible) curve (inaudible).

These can affect the modeling concepts for ignition and ignition delay periods that are needed for the diesel combustion. All -- of course, the fuel components affect (inaudible) production, the stable aromatics, the pyrolysis of ambients; that's pretty well accepted, but there may be some work along those lines that can help. I forgot the other point that I was going to say.

Well, anyway, I think that's another area that's worthwhile.

Oh, for instance, we are not really even sure how a droplet vaporizes. If -- does a droplet distill or are mechanisms involved in the diffusion of -- once you equate the outer surface of the light ends, is there a diffusion mechanism from the interior of the droplet to the

surface so that you deplete all of the light ends and then go through to the heavier ends, or do you strip off the entire boiling range from the outer surface and just go (inaudible) the droplet? This all affects what's going to be in the vapor phase.

VOICE: I think Fred (inaudible) has a comment that he can make on that.

VOICE: (inaudible), Princeton University. I would like to add a couple of comments, one first in the diagnostics area to which Dr. Sawyer referred.

There is one other diagnostic tool that really has come to quite advancement in recent years and could be of great aid in much of the heterogeneous sort of combustion processes that we are investigating and that's holography. There is an area in terms of spray distribution (inaudible) that we really don't understand in terms of droplet distribution, and distribution and even the spray (inaudible) distribution in the chamber that can successfully, hopefully, investigated through the use of holography. This is an area that really, as well, needs to be advanced.

There is another area that was identified in addition to both the laser-Raman approach and

the (inaudible) approach, and this APS summer study to which I referred earlier.

I would also like to add some, what I think will consider very fundamental combustion research aspects that I think lead into the support sort of areas that John mentioned earlier. The area of characterization of fuels. We have gone to great extents (inaudible) octane number and cetane number and, to some extent, even the ignition delay sort of characteristics of fuels, but we have not, as the fellow from Southwest Research Institute pointed out, considered very often the multi-component character of most of the practical types of fuels we use. Indeed, I think it might be this multi-component character that adds to the smoke formation problem in many of these systems.

There is one early work on the burning of multi-component droplets. It was done by Lysatole in about 1951 and it's in the NASA data value, and you will find there that they do observe what is called fractional distillation pattern for the droplet itself in its combustion and, therefore, what you end up with is the heavy end product in the final droplet that's being combusted. These are very conducive to soot formation for these heavy end products.

It may well be that adding materials that don't come out as a fractional distillation pattern could be very important to this smoke formation, particularly in diesels and this is why we think the use of water-fuel emulsions in such heavy fuels may well be of importance in terms of breaking up these final droplets that are left of heavy distillates.

There are a couple of other areas in terms of modeling which I might mention which, again, are very fundamental things that are needed in progressing further in the model area. We really don't understand the droplet formation problem in terms of sprays. Now, we really don't understand at this point, even in simple terms of trying to specify global mechanism, the chemistry and energy release that must go in as terms and expressions in even the simplest of models, where we are trying to replace this idea of using flame velocities as a (inaudible). These are measurements that really have to come, I think, in the long range before we can push these models to the point of having some sort of real confidence in our (inaudible).

I would add one other area that I think has come up more than once in this problem of using methanol-gasoline blends and that's the area of even evaluating

what the hydrocarbon emissions are from these blends. We have talked about developing a specific engine for a specific fuel and what we found we are doing, we are also developing specific emission characteristic tests for specific fuels, if you will. We haven't really considered the chance of having a major something, such as an alcohol in emissions, and, as I have reiterated earlier, there are techniques, I think, that are presently available that we can put to use.

VOICE: I think Dr. Neke can address that specific problem with emissions because he is doing that on his contract.

VOICE: This methanol-gasoline blends, we are studying both the (inaudible). I can't say (inaudible) because I don't think many people understand what's going on (inaudible) and, by the way, this is a very important thing that needs to be studied, ultra (inaudible) combustion of heavy molecules.

I feel that before we go to blends and mixtures of fuels, we need to understand at least the combustion of the heavy molecule like octane. I haven't seen in the literature any published data that show a growing mechanism for the combustion of a heavy molecule because here you are talking about processes of decomposition,

partial distillation (inaudible).

I think we need a good model for combustion of these heavy molecules and then we can proceed to combustion of mixtures of heavy molecules and light molecules. This is an area which I propose some of the combustion specialists to work on. This is not my area.

The area which we are talking about, our work, is the flame propagation inside of engines (inaudible).

Meanwhile, we are studying the emission characteristics of these mixtures in the single-cylinder engine. We have the whole emissions (inaudible).

We will be able to measure the CO, hydrocarbons, NOx (inaudible) with different mixtures of methanol and gasoline in single-cylinder under different conditions (inaudible) and so on, and we hope to extend this to the auto emission of these mixtures. For example, the behavior of these mixtures in diesel engines, for example (inaudible) and we hope to come up with something in the future about this and we will be very careful in watching this (inaudible), the methanol and gasoline under pressure.

VOICE: The thing that I was really addressing was the fact that you have a testing device from

an unnamed company at this point and it essentially wipes out all the heavy hydrocarbons (inaudible), so what he has done is, he set up a special measuring device because he realized that prior to the test, and that measuring device will, in fact, pick up those heavy hydrocarbons.

VOICE: (inaudible).

VOICE: The EPA standards make you go through an ice bath first that washes out all the heavy hydrocarbons and so we bypass that particular aspect of it.

VOICE: We are measuring by using (inaudible).

DR. BELDING: Right. Why don't we get some comments from the panel here and then we'll go back to the audience again and then I have got to turn it over to Graham.

VOICE: Well, going to an area which came up earlier today but hasn't been mentioned now and that's the whole subject, once again, all over, of knock, octane number and fuel additives. Is that worth trying to understand and push the octane rating up, or do you push the octane requirement of engines down? It seems to me that we have got to go back and work on that one again, unfortunately, and I think also related to that is probably work in combustion

chamber heat transfer because there should be fuel economy savings where you reduce heat transfer loss in the chamber which you are going to run into octane knock problems. There are certainly emission advantages to keeping the exhaust temperature up and one way to do it is to cut down on the heat transfer of the wall.

VOICE: I was just going to add another thing, was this octane rating increase that you experience is another thing that probably is worth looking at, and Sam mentioned earlier about this warmup problem. I think this whole area of -- we are at a loss, since so much of our driving occurs in the city and are of very short duration, there is no question about where the losses occur. It's not clear that it's all in the engine or much of it is the engine alone, especially if we have emission control systems and faster chokes, that how much of the loss is going into the drive line and how much might be going to the tire and perhaps can't do anything about. I think there's an area here that perhaps information is available. If it is, I would sure like to hear about it, but it's a very fruitful area.

VOICE: I would like to comment farther on these suggestions that multi-fuel capability of

engines are important. I don't think that anybody is advocating or predicting that 10 or 15 years from now there will be various kinds of fuels that one can choose from. I think what we are saying is that, in particular, the National Science Foundation should, at this point, see to it that knowledge is accumulated about any possible fuel which may be found available or to which society may switch in 10 or 15 years, and that could be lower octane, just as simple as that; just lower octane. Fuel -- it could be methanol, it could be hydrogen -- you name it.

The fact is that one thing we want to make sure is that 10 years from now, okay, we are not going to be faced with the problem of what to do with the new fuels which are available then, and we now spend time on the carburetor. The National Science Foundation should look ahead and look at the multi-fuel capability of an engine, not because an engine will burn ten different fuels, but because we may be called to operate on any number of fuels.

VOICE: Well, we are, in fact, trying to get fuels from the Navy. They are probably the front runners as far as making up new fuels, and we are trying to get fuels from them and we will pass those out to the various people and see if we can (inaudible).

There was a question over there in the back.

VOICE: Yes, I have a comment. I think that one of the basic areas of research that I haven't heard mentioned here (inaudible) was that someone has to first understand gas phase reactions. I think that even these stratified charge engine experiments should be done with the gaseous fuel first, because what we found in our turbine work is that there are important parameters like heat transfer and also the presence of free radicals that determine, you know, how long is it going to take for combustion to occur, how lean you can run, things like that, and you also, in the area of pollutant formation, you have got to be able to separate the effects of gas phase reactions from those of droplet burn.

You might take methanol for example, has been cited as producing a lot of formaldehyde and right now I don't think anyone can say, well, that's a gas phase reaction problem unique to methanol or it's a droplet burning problem, and I think until we have models and experiments that correlate these models with gaseous fuels, gas phase reactions, a lot of this is just a shot in the dark.

VOICE: One question right here.

VOICE: It wasn't a question. I would just like to reinforce Dr. Sawyer's goal or whatever that we look at the induction or the mixture thing. I think we need both a near-term look at this and a long-term.

VOICE: Just talking about knock for a second, we some time ago came up with a method where we documented emissions in a single-cylinder study versus knock intensity and this appears in the S.A.E. literature, but the important thing is to come up with a method. If you really want to make comparisons, you got to come up with a method that permits you to do this, and what we did was, we used something called knock intensity, which was based on the rate of pressure change, which is more sensitive to knock, by the way, than just the pressure itself, and we were able to get a good correlation --

VOICE: -- also work on gasoline and distillate fuels from coal and shale and hydrogen.

I would like to have any general comments that you might have in this regard as to where we conduct our research and our studies.

Yes?

MR. BURNHART: Phil Burnhart, EPA

(inaudible).

I think in the previous session, in -- I don't think enough emphasis was placed on emissions and I'm not speaking of conventional CO and hydrocarbons and NOx emissions, but (inaudible) new species from either an alternative fuel or, say, substitutes for tetraethyllead which we are involved with now or, say, the catalyst with a side effect of the sulfate emissions. If you only can measure CO, hydrocarbon and NOx, then you are not going to pick up these things. So I think we need to identify early in the game with an eye towards environmental and health concerns the new species that would be identified.

For instance, the City of Seattle considering the use of methanol, and we can't even measure some of the species that are in the emissions. So I think we have to identify them more closely.

VOICE: I thank you very much for the comment because I think it's a very appropriate comment. I don't think we want to get into another situation such as EPA has recently gotten themselves into with the sulfate problem. I think that's an unfortunate situation, and I would hope that as we investigate these alternative -- other fuels, that we would very carefully investigate the products

of combustion so that we don't get into a similar kind of a situation in the future.

Yes?

MR. CAMPBELL: I'm Fred Campbell, also with the Toxicology Lab (inaudible) EPA. I would like to carry what (inaudible) said a little bit further. I apologize for being an outsider here. I'm probably the only toxicologist in the group, so I'm a wee, small voice, but I would like to acknowledge that I think what I've heard today by virtue of roundabout invitation, I appreciate very much all this technological language. It's gone somewhat over my head today, but I would like to acknowledge it for what it is and for why it is and say that, to the toxicologist who is ultimately going to have to evaluate these alternatives in terms of public health hazard, perhaps, that we need all of this information that we can before we launch into our section of the program. Not only from the standpoint of developing engine or model atmospheric generator systems for testing (inaudible), but also the chemistry involved in defining these atmospheres so that we can at least get some leads of what it is that would be out in the environment as a result of using some of these alternative systems.

We can't possibly test -- for example,

someone earlier mentioned today that if you take methanol, there are probably over a hundred possible chemical reaction times and possible species that might result from the combustion of this under various conditions. Well, we can't possibly start out testing all hundreds of those and to the extent that we don't have to do that, obviously, the better off we are in evaluating the health impact aspects of these things (inaudible).

VOICE: Joe, any comment on that?

I tend to support that.

VOICE: One of the things I was going to point out I think we need a little bit more work on with respect to methanol is with respect to the effect of methanol emissions on the atmosphere. If there is appreciable unburned methanol that gets into the atmosphere, we should know what the effect will be. I mentioned in my talk that information at hand indicates that methanol is not very reactive, but I'm still not certain that when it gets there with the rest of the (inaudible) that there are in the atmosphere that there might not be a (inaudible).

I don't think it is going to occur, but I think we ought to check into this and find out. We need some good smog chamber studies with methanol, both from

the pure state and exhaust from methanol-fueled vehicles.

VOICE: I was going to say the same thing, but one thing a little less sophisticated. Supposing you have a car with this fuel mix stuck in a cold garage space for a week or two? How much EPPN do you build up in this material? What is the long-term effect of having somebody breathe this? And these are things that we really can start now. I mean, we know pretty well what the alternative fuels are going to be in the next 10 or 15 years -- methanol, coal, shale-derived material. You won't go far wrong if you bet on those, so I think there is certain work that can be done in this field while we do more of this combustion work or field testing and so on, because I know that kind of work is very time-consuming and it would be unfortunate to then have to wait for the important things to be done after all the other information is gathered. So I think we can save a little time by (inaudible).

VOICE: Good, Fred.

I had a comment -- excuse me. I'll get to your turn.

VOICE: I would like to comment in terms of the toxicity problems with methanol and even its grouping problems. As far as emissions from methanol, neat

methanol combustion, the one that is probably of the most importance as far as photochemical smog reactions are concerned, is formaldehyde, and the reason is because formaldehyde can be photochemically decomposed by wave lengths very close to those of typical sunlight.

As far as products other than that that are dangerous in terms of emissions, I doubt that there are any that are really as serious as those we are already facing with gasoline, and the reason is the following: we have done some pyrolysis tests on methanol, on methanol itself, at temperatures around a thousand Kelvin (inaudible).

It turns out formaldehyde is the only product that we see that's not a paraffinol but an etheline, and if you see products that are of higher hydrocarbon content than, let's say, C_2 , it's probably occurring from droplet combustion in your cylinders and it's very possible you may have droplet combustion within your cylinders because of the high heat of vaporization mechanism and the fact that it is not able to vaporize anywhere near as well as gasoline (inaudible).

VOICE: I wonder if Mr. Campbell could describe, does EPA have a program on these possible toxicological things?

VOICE: Well, I think it might be appropriate. The question was: What was the EPA program on toxicology with these fuels?

VOICE: Rather large. We have a program that's coordinated out of Washington and involves a great deal of effort in (inaudible), but also (inaudible) from research efforts at both RTP and Cincinnati, and I think that probably the notable name in coordinating within EPA research in this area is John Moran at RTP as a program element manager, as we call him, but these things are programmed into EPA research and I would just like to try and promote that some of the health aspects of this kind of research, have the knowledge or the crystal ball feature that you people are able to come up with in time for us to be at least not very far behind, at least in testing some of the more critical aspects of the possible emissions impact from a new material, but there is a program in EPA. I'm sure that the new ERTA is going to have an interest in finding out what these health aspects things are and it's going to have to be some inter-agency coordination here. This, I guess, will have to be developed yet, but I'm sure it's possible and I trust and hope that it will work, but it will take a lot of mutual cooperation by us, government and so on.

VOICE: Thank you.

VOICE: I would like to follow that with a comment. As Joe Colucci pointed out, there is a need for smog chamber work to determine the reactivities of the species, engines running on methanol.

At Livermore, we do have a group which does atmospheric modeling and over the course of the next year they will be applying that model, Livermore Regional Air Quality Model, try to do these tabulations, make some intelligent guesses, where guesses are needed, where the data is not available, in which perhaps some of these (inaudible) will be treated as parameters and (inaudible)

VOICE: I would like to perhaps steer the conversation just a little bit.

Does anybody have any comments on our hydrogen program? It's a very small program and it's primarily concerned with the onboard vehicle storage of hydrogen. Does anybody have any feelings about -- I know one gentleman does -- with respect to other aspects of hydrogen work? Combustion, perhaps.

VOICE: Well, it is a little concern, a problem that I have. Let me tell you what I'm driving to. I'm driving to that a little bit of money should be put in

the utilization of hydrogen in engines.

Now, you are putting whatever money you have in the storage problem. Suppose that you solve this storage problem and now that you look at utilization of hydrogen in engines and you find out that you have problems utilizing in engines, that you get a lot of nitric oxide when you use it (inaudible). Then what is all this, having solved the problem 1 good for?

On the other hand, if you could (inaudible) utilize hydrogen in engines and you convince yourself that it can be utilized, that the nitric oxide emissions are that low, but you cannot carry the ball, then what good is that information?

It seems to me that the problems cannot really be uncoupled, that if there is to be any effort at all in the hydrogen area -- I'm not saying there should be any -- but if there is going to be any, okay, it looks to me like the two problems cannot be uncoupled. Then, of course, I can say frankly that although work has been done at (inaudible) in the internal combustion engine, all that work doesn't amount to much in the way of quality and conclusiveness.

VOICE: I think that's right.

Yes, John?

VOICE: (inaudible) two points.

One, I think we have all ignored one little problem I think needs to be clarified (inaudible) methanol and it comes back to the lubricant. What is the -- how does this get out? I want you to tell me that. In some of the diesel work, there is some instance maybe this can be a problem and if you put water in fuel such as hydrogen, I'm sure this is going to be a major problem.

The other one is the analytical training, as I mentioned many times. They will be normally available in your chemistry department, engineering department.

VOICE: (inaudible), Cornell University. I would like to stress a problem that was brought up before but hasn't been discussed in much detail and that's the (inaudible) when you run on pure methanol. There are interesting numbers that one can cite about that. It's already been cited that you need about twice the amount of heat to heat the mixture because of the high rate of vaporization and also because you have relatively less air present in this stoichiometric mixture. Now, if you don't have that heat, the temperature drops 300 degrees Fahrenheit. That compares to 40 degrees Fahrenheit when you have a

gasoline-air mixture stoichiometric. The temperature drop would be less when you have a leaner mixture, but even then it is quite considerable. If you have a mixture at 55 degrees, then the vapor pressure is just barely enough to get a chemical mixture. So if you start at 55 degrees, you are way off. You have to start higher than that, and apparently 70 or 80 degrees you have easy starting, but below that already there are difficulties.

So it seems to me, from a practical point of view, that problem really needs to be stressed. There are a number of possible solutions. One is to add acetone or ether as a starting fluid. That's not very pleasant and not an easy thing to do.

Another possibility would be to add heat while you are starting, but you have to add a lot of heat and it isn't -- as long as you don't have the exhaust available (inaudible), and the third possibility which we are preparing to study under contract with the Department of Transportation is direct fuel injection into the cylinder.

Now, hopefully -- at least you get the fluid in the cylinder, but one of the difficulties, of course, is when it vaporizes you cannot transport the fuel. If you direct the injection to the cylinder, at least it's

there. If you do it early enough during the stroke, hopefully you can -- and certainly at the end of the compression stroke the temperatures are high enough. That's not a problem any more. There comes the problem of how rapidly can you evaporate the mixture. It seems a possible way for starting even at very low temperatures and we are all set up. We are working in hydrogen and that's a second comment I would like to make, if I may.

At the moment we have received (inaudible) direct fuel injection so certainly we can convert that to the methanol. In working with hydrogen, I would like to emphasize what you said. There are many points that need to be studied and the more -- the deeper you get into it, the more points you see that need to be studied before you -- because it becomes clear that hydrogen engines are not very well documented in the literature and there are a number of points that remain to be resolved.

One of them we are studying right now is possibility of using compression ignition with hydrogen. Jet propulsion laboratory is very interested in that. They are considering using their hydrogen to run their diesel engines to become energy self-sufficient, but there is no documentation in the literature at the moment that you

can run hydrogen on compression ignition. At least no technical documentation. There are somewhat nontechnical references.

So there are many other points like that for hydrogen, so I would like the point made that hydrogen engine research is very much needed also.

VOICE: Have you any comments to make on the question, the subject -- you know, what I'm really searching and I'm not getting it from the audience and maybe I have a preconceived notion of what I'm hunting for, but the comments really on the program that we presented -- you see deficiencies. Emphasis -- you know, should we be spending five times as much effort in this area as we are spending in -- I'm looking for fundamental, not so much whether we solve a cold-start problem with methanol, although I'm not knocking that comment, but you see what I'm trying to strive for here, Andy?

VOICE: Well, I see what you are trying to strive for, but I'm not going to answer your question.

It is fundamental, what I will like to bring up. As a reader, I find it very confusing, trying to compare results from research and industry communities

which are reported on supposedly the same types of information. It would seem like the fundamental issue, some accepted test standardization procedure or format or something should be developed so that everybody is doing their reporting on the same basis.

VOICE: That's a toughy because you know how long it took to get just a federal test procedure for gasoline. You know, the emission test procedure for gasoline.

VOICE: But you always listen to --

VOICE: I agree with you.

VOICE: You read papers and you hear reports. As a nonresearcher, it's very difficult when you are reading something that is unrelatable to another issue.

VOICE: I agree. It's something a great deal of work could be done on this area, but I think it's going to be a long time coming. I don't think it's going to be overnight.

Dick?

VOICE: Yes. I would like to raise a little different issue. I certainly appreciate the work that needs to be done, the basic type of work that D&SF is approaching, but I guess because I'm kind of a brute force

type anyway, the work that we are doing, it's going to come to an end very soon, but I think practical vehicle experience with these alternate fuels and particularly as far as I'm concerned with methanol is an area that is kind of getting overlooked and guess this is where you are going to find that you have a number of problems that you don't even recognize yet.

Now, I certainly would like to see you pick up more EPA work in this area for, as I recall hearing the Bureau of Mines gentleman saying today, their vehicle testing program didn't include straight methanol. It was only in blends.

VOICE: I'm sorry. Say that again?

VOICE: The Bureau of Mines program in Bartlettville does not include vehicle testing on straight methanol. It only includes vehicle tests, fleet tests on alcohol blends. That's what I wrote down. Is that correct, Jack?

VOICE: That's what he said.

VOICE: Jerry?

VOICE: Sorry you got that impression. The vehicles will only be run on the blends. Along with that, we have a stationary engine, Chevrolet, that will --

VOICE: That doesn't answer the question of fuel tank compatibility, elastic compatibility, a lot of these other problems that I (inaudible). That's where I think you are weak.

VOICE: I think you are probably right. Well, maybe it's an appropriate time to just make the comment and I think everybody is aware that, and we have had some discussion on it today, that there is a new energy research and development administration and our activity is being transferred out of EPA and into ERDA and we expect that the alternative fuels program, as well as the alternative engine power plant programs are going to move into ERDA. So the details of the program, our current program and our future program, are somewhat up in the air and will depend on what monies are made available within ERDA and what the program priorities are and so -- I can't really respond to your question or your comment but to accept it and hope that, with an expanded program and a new agency, that we will have a great deal more flexibility in this regard.

VOICE: There is one other area that hasn't been addressed that I would like to see somebody cover and I hate to suggest replowing this ground again, but if we are considering methanol as a viable alternate fuel, I think

catalyst life studies and catalyst-type studies might be re-examined because, from what data we have, it would appear that methanol is much less tough on catalyst life and, indeed, some of the non precious metal catalysts might be substituted if you are going to go to methanol operation which would (inaudible).

The other thing is catalyst life on the precious metals, I think from what we have seen you can get a lot longer catalyst life (inaudible).

VOICE: You just triggered a process in my thinking, that I wanted to state, and I should have stated earlier, in all of this research that we are sponsoring, we are not promoting any of the fuels. Our real-- our objective here is to document, characterize the fuels in engines and in vehicles. We are not promoting hydrogen or methanol or any other fuel, but it is to put the data, the information in the public domain, and -- Allen, I guess you have your hand up back there.

VOICE: I would like to try to respond to the question of (inaudible) by saying that whatever research is published, quoted, I would hope that it is sufficient (inaudible), starting from the resource, winding up with the vehicle on the road.

you to provide practical information from which a decision can be made, but one information is the fleet approach. The other information is a fundamental approach, and that's why the two agencies should cooperate. Otherwise, it can come up with a very disleading picture.

VOICE: Yes, I think that's a good comment. Thank you.

Andy?

VOICE: I tend to support what the last two gentlemen said, and I wonder if Joe Colucci would mind commenting on the same issue relative to the advantages and disadvantages of (inaudible).

VOICE: I tried to imply that by saying that you have to phase it into a given system, but the new vehicles that are produced can be designed for the new fuels that will be available and they will be designed based on a lot of information that will be generated from all of these four basic, four fundamental studies, not from vehicle studies with existing vehicles. We are intending to do more of these studies ourselves.

There are two ways to look at it: the existing vehicles and those that are yet to be produced, and the ones that are yet to be produced can build on the

information that we are going to generate. The ones out there have a hard time building on that information.

VOICE: Does a lot of (inaudible) with the ones out there just tend to end up being confusing, giving results that are almost impossible to understand?

VOICE: No, I don't think so. I think if you are doing tests now with the vehicles, '75 model vehicles, the biggest change that has occurred in the automobile industry in many years, going to catalytic converters, and the catalytic converter itself is going to be around for quite a few years yet. So testing with those vehicles is going to represent, is going to count with respect to vehicles that will not be produced for at least the next five years, maybe even much longer than that. Testing -- a lot of testing with the '68, '69, '70, those vehicles, is not going to help much.

MR. TEAGUE: Max Teague of Chrysler. Talking about things from a rather more immediate and practical standpoint, if we, indeed, expect to meet the standards which have been proposed for 1978, which are extremely difficult on all three components, we have a real problem. Not only do we have anticipated difficulty meeting the hydrocarbon and CO standards without a dual bed system,

I don't think it is adequate to look at either end of the fuel-to-road spectrum. Bob Lindquist reported some figures comparing the thermal efficiency for very cold methanol with very cold (inaudible).

Maybe (inaudible) from that point of view would have an advantage. I would be a little bit surprised if it's as big an advantage as he claimed, but granted there may be an advantage in the fuel production end.

Then the question comes up: Well, which is really a better fuel in the car? You get better efficiency in the car with methanol than you do with whatever gasoline (inaudible). When you look at the overall system, which is giving you the greatest passenger miles (inaudible) or whatever other, and certainly if you make your contracts with SRI --

VOICE: Yes, it is addressing.

VOICE: All these factors -- (inaudible) just mentioned that question of catalyst life, environmental impact. All those factors do have to be evaluated in order to make a rational decision. Given the resource, what is the best route to go?

VOICE: Yes. Of course, there are