REVIEW OF NON-OIL AND GAS RESEARCH ACTIVITIES IN THE HOUSTON-GALVESTON-GULF COAST AREA

FIELD HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED EIGHTH CONGRESS

FIRST SESSION

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December 4, 2003

REVIEW OF NON-OIL AND GAS RESEARCH IN THE HOUSTON-GALVESTON-GULF COAST AREA

THURSDAY, DECEMBER 4, 2003

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 1:30 p.m., in the Baker Institute Auditorium, Baker Hall, Rice University, Houston, Texas, Hon. Judy Biggert [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE
SUBCOMMITTEE ON ENERGY
U.S. HOUSE OF REPRESENTATIVES

"Review of Non Oil and Gas Research in the Houston-Galveston-Gulf Coast Area"

Thursday, December 4, 2003
1:30pm
Baker Institute
Baker Hall
Rice University
Houston, Texas

Witness List

Todd Mitchell
President
Houston Advanced Research Center
Accompanied by:
Dan Bullock, HARC Research Scientist
Greg Cook, HARC Air Quality Consultant and former EPA Region 6 Administrator

Dr. Richard Smalley
Director
Carbon Nanotechnology Laboratory
Rice University
Accompanied by:
Dr. Howard K. Schmidt, Executive Director, Carbon Nanotechnology Laboratory, Rice University
Dr. Robert H. Hauge, Technology Director, Carbon Nanotechnology Laboratory, Rice University

Mark Holtzapple
Department of Chemical Engineering
Texas A&M University

Robert (Bob) Hennekes
Vice President Technology Marketing
Shell Global Solutions

Franklin Chang-Diaz
NASA Astronaut and Director of the Advanced Space Propulsion Laboratory
Johnson Space Center

HEARING CHARTER

SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Review of Non-Oil and Gas Research Activities in the Houston-Galveston-Gulf Coast Area

THURSDAY, DECEMBER 4, 2003
1:30 P.M.
BAKER INSTITUTE
BAKER HALL, RICE UNIVERSITY
HOUSTON, TEXAS

1. Purpose of Hearing

On December 4, 2003 the Energy Subcommittee will hold a hearing to review the extensive non-oil and gas energy research that is being conducted in the Houston-Galveston-Gulf Coast area. This part of Texas hosts the highest concentration of the domestic oil and gas industry in the country. All of the multi-national oil companies also have extensive operations and facilities in the area. However, the area research community is very diversified and has extensive capabilities outside of the oil and gas sector. The hearing will take testimony on the scope of these activities and how current research being conducted in the areas is contributing to advances in energy conservation, efficiency and production.

2. Witnesses

The following persons are expected to testify:

- Mr. Todd Mitchell, President; Houston Advanced Research Center, The Woodlands, TX
- Dr. Richard Smalley, University Professor, Director of the Carbon Nanotechnology Lab., Rice University, Houston, TX
- Dr. Mark Holtzapple, Professor, Department of Chemical Engineering, Texas A&M University, College Station, TX
- Robert (Bob) Hennekes, Vice President, Technology Marketing, Shell Global Solutions, Houston, TX
- Dr. Franklin Chang-Dìaz, Johnson Space Center, Houston, TX

3. Background

For much of the 20th century Texas was the world leader in oil and gas production. In the 1920s discoveries of giant fields at Spindletop, east of Houston; The East Texas field, about 250 miles north of Houston and the beginning of the discoveries of oil and gas in West Texas put Texas on a course of transition of a largely agricultural economy to one heavily based on energy.

Oil production in Texas was so prolific that proration orders were put into effect in the 1930's to prevent waste and over-production that led to reservoir damage. During World War II, the Big Inch and Little Inch Pipelines were built to move oil safely from Texas to the East Coast over land and out of reach of German submarines. Much of it was refined in Pennsylvania and New Jersey and shipped to our armed forces and allies in Western Europe. After WWII markets for natural gas developed and the interstate natural gas pipeline system grew rapidly, generally spreading from Texas and Louisiana west, north and east to supply markets on the West Coast, Midwest and East Coast. However, by 1965 oil production had peaked and peak natural gas production followed about a decade later. Much oil and gas research was performed in Texas, primarily by the major oil companies, but almost all of those facilities have been closed as the industry has been squeezed the periodic downturns in the price of crude oil and natural gas and their production interests moved overseas.

The strong influence of the oil and gas industry has created a highly capable and adaptable research community in the area, characterized by a combination of universities, private research institutions and corporations. As oil and gas fortunes have changed the research community has moved into other energy areas and is among the leaders in a number of non-oil and gas areas. This hearing will demonstrate the diverse nature of the Houston-Galveston area research community and provide the Subcommittee new information on technologies being developed that may have a substantial impact on meeting the Nation's future energy needs.

Chairwoman BIGGERT. And I guess we have sound now.

Did Dr. Levy want to say anything? Dr. Levy, would you like to say anything? We thank you very much for——

Dr. LEVY. Thank you, Madame Chairman.

I am really please to welcome you this afternoon. My name is Eugene Levy. I'm the Provost of the University, and it's my pleasure to welcome you on behalf of the President Board of Trustees to the Rice Campus where we are very pleased to be hosting this gathering of participants from the scientific community and others who can share information with key policy makers from the United States Congress.

Today we are particularly honored by the presence of Congresswoman Judy Biggert from the Thirteenth Congressional District of Illinois and Chair of the Subcommittee on Energy of the House of Representatives Committee on Science.

In addition to chairing the Energy Subcommittee, Congresswoman Biggert is also a Member of Subcommittees of Environment, Technology, Standards, Education Reform and other committees.

Representative Biggert, we are really pleased you chose Rice as the venue for today's hearing.

Chairwoman BIGGERT. Thank you.

Dr. LEVY. Also honoring us with her presence today, we had expected the Chair of the Texas Delegation to the 108th Congress and a Member of the Research and the Space and Aeronautics Subcommittees of the House Committee on Science, The Honorable Sheila Jackson Lee, who I see is not yet with us, but I assume will join us soon.

And finally, it is my real pleasure to see again and to welcome Congressman Nick Lampson, the Ranking Minority Member of the House Science Committee's Energy Subcommittee and also a Member of the Space and Aeronautics Subcommittee in the House, an especially fitting assignment inasmuch as Congressman Lampson's District includes the NASA Johnson Space Center here in Houston.

Congressman Lampson, we are really delighted that you are here as well.

Mr. LAMPSON. Thank you.

Dr. LEVY. Houston is a world leader in the international fossil fuel industry which has been so crucial to the development of modern society and prosperity throughout the world. Probably it is fair to say that the easy, relatively easy availability of fossil fuel energy has been among the handful of the singularly important factors that enable modern life. But now several factors point us to contemplate the time, probably the not so distant time, when circumstances dictate the necessity of developing other approaches to the generation and distribution of energy. Not as smaller secondary adjuncts anymore, but as main supply massive primary sources of energy. The reasons for this necessary transformation are several, and I am sure you will be hearing about them this afternoon.

Meeting the need for new energy sources is a combined scientific engineering, economic and policy challenge. Houston scientific, engineering and policy community, and certainly Rice's community, is among those eager to take on that challenge. Meeting the new energy needs will entail marshalling capabilities and imagination and numerous spheres including nanotechnology, information technology, environmental technology and especially in the new and challenging areas that lie at the intersection of those fields including through Policy Studies Center here, at Rice's Baker Institute for Public Policy on the campus.

The Baker Institute, I should remark here, has established an especially important and prominent position in energy policy studies. So what's especially pleasing to us about having this hearing on the Rice campus is that it is potentially so forward looking a conversation. At Rice we have also been especially focused on looking forward to plot a future for the university that will realize it's potential for service to society in the highest possible way.

Altogether, our continuing aspiration for Rice is to define and occupy a position at the cutting edge of service to our society through research, education and outreach to the community, including importantly, outreach to the public schools with this entire crucial endeavor ultimately gets started. It is in that overall spirit that we welcome this hearing and Members of Congress, and the rest of you to the Rice campus. The spirit that animates this session needs to spread widely throughout our society.

So, again, I welcome you to Rice and trust that we all learn a great deal, and that that will help us move forward together into a very bright future.

Thank you, and welcome to the campus.

Chairwoman BIGGERT. Thank you very much, Dr. Levy.

And I would like to welcome everyone here to this field hearing of the Energy Subcommittee of the House Science Committee.

The purpose of the hearing today is to take a look at non-oil and gas research in the Houston area. That might be difficult because we always think from other states that this is the center of the oil and gas. But now granted, this is very broad but so too are the knowledge and research territory covered by the panel we will hear from today. Combining expertise from universities, private research institutes, corporations and federal science agencies like NASA, today's panel will cover a broad range of issues and technologies from high temperature plasmas to rotary combustion engines. And I'd like to thank our panelists for attending today, and I want to thank Rice University for graciously hosting us.

As Chairman of the Energy Subcommittee, I've enjoyed serving with Mr. Lampson in his role as Ranking Minority Member. And during the development of the R&D provisions in the Energy Bill, he and Representative Jackson Lee championed the development of the first comprehensive report on oil and gas resources off the shores of Texas and Louisiana. And Mr. Lampson made sure the bill included a project to demonstrate the benefits of fuel cells in local residential neighborhoods that are in close proximity to refiners that produce hydrogen. So we know northerners mostly know Texas for its history of oil and gas production, but the Lone Star State also supports a diverse portfolio of innovative energy research.

In addition to research on carbon sequestration and thermonuclear fusion, researchers throughout Texas are working to create a new engine that could displace the internal combustion engine, generate hydrogen from various carbon feed stocks such as biomass and municipal solid waste, harness the power of nanotechnology to improve all types of energy production and conversion, and reduce the energy use of buildings and vehicles.

So Members of our Energy Subcommittee, like so many in attendance today, understand the importance of developing energy alternatives and new energy technologies, particularly in light of our increasing dependence on foreign sources of oil. Combine that over-reliance with the environmental impact of fossil fuel emissions and the research we will discuss today becomes even more crucial.

What I like most about the National Energy Policy proposed by President Bush two years ago and the Energy Bill Conference report recently passed by the House is that both emphasize the use of advanced technology to expand and diversity our energy supply, meet growing demand and reduce the environmental impact of energy production and use.

Advanced energy technologies grow out of basic science and applied energy research like that supported by the Federal Government and our universities and national laboratories.

In numerous hearings before our committee, witnesses have testified that affordable energy and a clean and safe environment are not mutually exclusive. We can lessen our dependence on fossil fuels, reduce harmful emissions and improve our economic competitiveness by harnessing American ingenuity, putting technology to work and cutting through some of the red tape that has stifled the development of new energy supplies and infrastructure. That's why I think Texas is an appropriate place to hold this hearing today. There is a lot of cutting edge research underway here and you are taking full advantage of the alternative energy supplies available to you.

Now, it's true that I'm from the windy city, but it turns out that Texas is the windy State. For instance, renewable energy growth in Texas fueled primarily by wind has been remarkable. Texas has the second largest wind resource in the United States after North Dakota, and is expected to have more than 1200 megawatts of generating capacity on line by the end of this year. So, unfortunately or fortunately there's not wind everywhere in the United States like there is in Texas, not even in the windy city of Chicago, where I blew in from this morning. And that is why it is important that we continue researching solutions that will work in other parts of the country such as biomass for the northeast, energy from the ocean for coastal states, or even nuclear power which provides over 50 percent of emissions free electricity in my own State of Illinois.

As another example, Illinois has significant coal resources, which is why I am particularly interested in carbon sequestration research. Some day we may be able to combine carbon sequestration technologies with high tech coal fired power plants to make electricity and hydrogen for our fuel demands without emitting carbon dioxide.

America now has the motivation, perhaps like no other time since the oil crises of the '70's, to find newer and better ways to meet our energy needs. But American also has the ingenuity and the expertise to meet our future energy demands and promote energy conservation. And we can do environmentally responsible ways that set a standard for the world.

I look forward to the exciting new technologies that each of our distinguished panelists is working on. So, again, thank you for presenting testimony to the Committee today.

And before getting to the panel, I first recognize Mr. Lampson for his opening statement.

[The prepared statement of Chairman Biggert follows:]

PREPARED STATEMENT OF CHAIRMAN JUDY BIGGERT

The hearing will come to order.

I want to welcome everyone to this field hearing of the Energy Subcommittee of the House Science Committee. The purpose of this hearing today is to take a look at non-oil and gas research in the Houston Area. Now granted, this is very broad, but so too is the knowledge and research territory covered by the panel we will hear from today. Combining expertise from universities, private research institutions, corporations, and federal science agencies like NASA, today's panel will cover a broad range of issues and technologies, from high temperature plasmas to rotary combustion engines. I want to thank our panelists for attending today, and I want to thank Rice University for graciously hosting us.

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- create a new engine that could displace the internal combustion engine,
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Unfortunately or fortunately, there's not wind everywhere in the U.S. like there is in Texas, not even in the "windy city" of Chicago where I blew in from this morning. That is why it is important that we continue researching solutions that will work in other parts of the country, such as biomass for the Southeast, energy from the ocean for coastal states, or even nuclear power, which provides over 50 percent of emissions-free electricity in my own State of Illinois.

As another example, Illinois has significant coal resources, which is why I am particularly interested in carbon sequestration research. Some day we may be able to combine carbon sequestration technologies with high-tech coal-fired power plants to make electricity—and hydrogen for our fuel cell cars—without emitting carbon dioxide.

America now has the *motivation*—perhaps like no other time since the oil crisis of the '70's—to find newer and better ways to meet our energy needs. But America also has the *ingenuity* and the *expertise* to meet our future energy demands and promote energy conservation, and we can do so in environmentally responsible ways that set a standard for the world.

I look forward to hearing about the exciting new technologies that each of our distinguished panelists is working on. Thank you again for presenting testimony to the Committee today.

Before getting to the panel, I first want to recognize Mr. Lampson for his opening statement.

Mr. LAMPSON. Thank you, Madame Chair, and welcome to Texas.

Chairwoman BIGGERT. Thank you.

Mr. LAMPSON. Judy Biggert is a very good Member of Congress, and a wonderful woman to be able to work with on this committee. And I am very pleased that you were able to take the time to come down to Texas and participate in this thing, which I do indeed believe is a very important hearing for us.

She has been a Member of Congress since 1998. One of the things that I particularly found impressive about her, many of you who have followed me at all know that I am involved with some issues other than the ones that we are here to discuss today, particularly those that deal with missing children. And Chairwoman Biggert has been involved with legislation that dealt with the cyber tip line, making it easier to track and report computer based sex crimes against children. And doing some other things as far as trying to track down people who have ecstasy and all. So your good work goes way beyond the work that you do on science. And I am very pleased that you were able to come over today.

I also know that you have the Argonne National Laboratory located within your District, which is very important to you and, consequently, the work that you are doing on science can make a significant difference to the people that you represent.

She has been a leading champion of research in science programs in Congress. And she's a sponsor of the Energy and Science Research Investment Act which will provide additional resources to the Department of Energy's Office of Science and will make organizational changes that will enhance the accountability and oversight of energy research and science programs at the Department of Energy.

Also I want to thank the folks at Rice. This is a magnificent facility and it's always a pleasure to come here. You are always gracious hosts. And it is a thrill to be able to come and continue to learn about the activities that are going on by the bright men and women who work at this place and the research activities within which they are involved.

I also want to welcome this excellent group of witnesses. There is a tremendous level of non-oil and gas research and development activity in the Houston/Galveston area. And I wanted to make sure that the House Science Committee has the benefit of your testimony as we move forward to tackle these important issues. So I thank all of you for joining us today.

I have been talking for years about the need for us to make an orderly transition into what is going to be tomorrow's driving force within our economy. And those of us who think about it today and find out what it is that we can begin to do and move to replace those activities that we are involved with today, will be the leaders of tomorrow. And I hope that is us right here in Southeast Texas, particularly.

The Science Committee's Subcommittee on Energy is charged with overseeing research and development programs at the Department of Energy. Issues that the Subcommittee deals with range from alternative sources of energy, renewable energy, nanotechnology, nuclear energy, cutting edge science performed at DOE's national lab. And as a former science teacher I find the work that this committee does fascinating and extremely important to our future.

The Science Committee recently moved key aspects of the House Energy Bill, particularly in the areas of DOE research and development. And with a major portion of our current supply coming from overseas, it is essential that we make significant national investments in the Department of Energy Research and Development programs to give us greater control over our future national energy supply. Got to find ways to being to wean ourselves away from that and be dependent on ourselves.

Our efforts must be focused now only on fossil fuels, but across a broad spectrum of energy sources, including wind and solar, nuclear, hydroelectric and others.

I am proud of a project that we are looking at in Galveston that will cause the cruise ships that berth there to be plugged into a fuel cell, the energy of which will be generated from wind on that island. So it's very important.

Conversation and energy efficiency programs are also essential. And I supported the Energy Bill because I believe it provides us with a balanced approach to address our future energy needs, and we owe this to our future generations.

Now, I am going to take a personal privilege and ask Chairwoman Biggert to allow me to introduce someone who I noticed in the audience. He was a former Governor of Texas, Mark White. And I had a conversation with Governor White recently, and it was interesting because, part, when I told him about this particular meeting he made a comment that he was discussing these issues in 1983. And it is interesting that we are continuing to comment on the same kinds of things.

A company that he is involved with called Texoga is involved with some, I think very exciting oxygenating fuels technology called SAFuel. And it is ester based oxygenated fuel that's run in diesel engines with greatly reduced emissions and virtually no toxicity or flammability.

And I thought that it might be appropriate to take a few seconds and ask him if he would say a word. And I also would ask consent to enter some information about SAFuel into our record for today.

Chairwoman BIGGERT. Without objection.

[The information referred to appears in Appendix 1: Additional Material for the Record.]

Mr. LAMPSON. Governor White, would you like to make a comment?

[The prepared statement of Mr. Lampson follows:]

PREPARED STATEMENT OF REPRESENTATIVE NICK LAMPSON

I would like to welcome Madam Chairman Judy Biggert to Texas. She chairs the House Science Committee's Subcommittee on Energy and has represented her suburban Chicago constituents in the Thirteenth District of Illinois in Congress since 1998.

As a Member of the Science Committee we have worked together to strengthen our country's basic science research facilities. And I know this is of particular importance to the Chair—with Argonne National Laboratory located within her district.

Representative Biggert has been a leading champion of research and science programs in Congress. She is the sponsor of the *Energy and Science Research Investment Act,* which will provide additional resources to the Department of Energy's Office of Science, and make organizational changes that will enhance the accountability and oversight of energy research and science programs at the Department of Energy. It is a pleasure to have you here today.

I would like to thank Rice University for being such a gracious host. Rice is known around the world for their cutting edge science and technology programs. I couldn't think of a more appropriate venue for our hearing.

I would also like to welcome this excellent group of witnesses. There is a tremendous level of non-oil and gas research and development activity in the Houston-Galveston area and I wanted to make sure that the House Science Committee has the benefit of your testimony as we move forward to tackle these important issues. Thank you for joining us.

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Our efforts must be focused not only on fossil fuels, but across a broad spectrum of energy sources including wind, solar, nuclear, hydroelectric and others. Conservation and energy efficiency programs are also essential. I supported the Energy bill because I believe it provides us with a balanced approach to our address our future energy needs. We owe this to future generations.

STATEMENT OF MARK WHITE, FORMER GOVERNOR OF TEXAS

Mr. WHITE. Well, thank you very much, Congressman. I am certainly delighted that you selected Houston for this hearing, because I do not guess there is a more important place in our nation for the production of petrochemical fuels than Houston, Texas, this part of the country.

You have a distinguished panel here that is located Rice University, which is down the road from a place where I grew up. And the only way I could ever get into this campus is if I bought a ticket to the football game. But I gained admission to the school. I took science twice in college, and it was not because I liked it so much. So do not ask me any very deep science question. The chemistry underlying what I'm about say, and these are observations from a former public servant and an everyday citizen.

But just as we were talking the other day that 20 years ago we wee having some of these similar discussions and worried and concerned about what we were going to do for energy independence, what we were going to do about improved quality of our environment, at the same time retain our economic figure. And we are discussing that again here this year today.

I had the occasion, Madame Chairman, to call soybean producers in Illinois and ask a few questions this morning. It was not in anticipation in this hearing. But I want to say that there is some things going on in Illinois that all of us in this nation could benefit from in the way in which you all have gone about using soybean and producing bio-fuels for vehicles up there in your part of the country. It enhances the—gives fuller utilization to our agricultural produce. It improves the quality of the emissions from diesel engines dramatically. And with a little support from your State government and I'm sure the Federal Government it makes it economically viable.

I think that is something that should be considered in the fuels that we are talking about. I know many people will say "Well, it won't have a big enough impact." But it seems that every piece of advance that we make is a positive issue and can do a great deal of good in the totality if we look at it in that overview.

I wish the Committee would recall but for legislative action and governmental action, we would probably still be using leaded gasoline today in this country. It was a mandate that had to be done to make those changes.

I think that there are some things that have recurred and evidence again is what I have heard in the State of Illinois. Your soybean producers using that product from agriculture to produce a bidiesel that is very environmentally friendly and has very few downsides that I am aware of. It may be just that sort of thing that could be required and mandated by the Congress and say this is what we ought to be doing; let us go do it. It is not unlike what we see in the health care sciences in which they discovery some new chemical or some new pill and which can be applied immediately to change the outcome of disease, reverse it. They do not go forward with another 10 years of research. They stop the research and say the tests have gone so well, we just need to implement it.

I think we may get that studied in this particular area as far as bio-diesel concerns. It has been used throughout western Europe to good effect. It is something that can be blended into our fuels right now, causes very little change as far as I am aware. No change in the way in which the fuel settings are adjusted in a diesel engine. And will give very positive results from the environmental point of view. Good for farmers, good for environment, helps displace foreign imported oil and improves the outflow of funds or reverses the outflow of funds in our balance of payments.

I think it is something, Madame Chairman, that would be just fine that could be looked at more thoroughly and quickly with swift action hopefully following by your Committee.

Thank you, again, for letting me come back here today. I have enjoyed very much the opportunity to say a few words to you.

You could not have a more distinguished panel. And quite frankly, I think if we can combine the information you will have here with what you are doing in the great State of Illinois, we will combine the strong winds of both sources and make a much better country. Thank you.

Mr. LAMPSON. Thanks, Governor.

Chairwoman BIGGERT. And with that, we will turn on the panels.

I think that I will introduce all of you and then we will start.

Actually, Todd Mitchell is President of the Houston Advanced Research Center and he's accompanied by Dan Bullock, HARC Research scientist and Greg Cook, HARC Air Quality Consultant and former EPA Region 6 Administrator. Welcome.

Dr. Richard Smalley is the Director of the Carbon Nanotechnology Laboratory right here at Rice University, and he is accompanied by Dr. Howard K. Schmidt, Executive Director of the Carbon Nanotechnology Lab and Dr. Robert H. Hauge, the Technology Director of the Carbon Nanotechnology Lab.

And Mark Holtzapple, Department of Chemical Engineering, Texas A&M University. Welcome.

And Robert Hennekes, Vice President of Technology Marketing, Shell Global Solutions.

Franklin Chang-Dìaz, NASA Astronaut and Director of the Advanced Space Propulsion Laboratory at the Johnson Space Center.

So welcome to all of you.

Usually the way that our hearings are, it is a 5-minute limit on your testimony. We will have a little more leeway here today, but if you could keep it to about 10 minutes so we will have some time for questions.

And we will summarize your testimony, and then that will be incorporated into the record without objection.

We will start with Todd Mitchell.

STATEMENT OF TODD MITCHELL, PRESIDENT, HOUSTON ADVANCED RESEARCH CENTER; ACCOMPANIED BY DAN BULLOCK, HARC RESEARCH SCIENTIST; AND GREG COOK, HARC AIR QUALITY CONSULTANT AND FORMER EPA REGION 6 ADMINISTRATOR

Mr. MITCHELL. Thank you very much, Representative Biggert and Lampson for inviting us to be here today.

First, before I read some of my prepared comments, I am a geologist. I grew up in the oil business. I am a second generation oil and gas person and find myself at this stage of my career having decided that there has got to be a better way. And so Houston Advanced Search Center fully dedicated to looking at clean and renewable energy production and energy efficiency as a key component of the picture from the standpoint of how a non-profit organization can help advance some causes that are very important.

Houston Advance Research Center, it is a non-partisan research organization. Our mission statement says that we are dedicated to mobilizing the tools of science, policy and technology to improve people's lives and protect the environment in Texas. HARC serves as an unbiased, neutral organization that cooperates with universities, industry and governmental agencies to address complex and pressing issues related to how people interact with the natural environment on a regional scale. By applying an interdisciplinary approach to research and policy priorities, HARC seeks to improve decision-making and increase awareness of how science and technology can support and implement sustainability concepts.

HARC has been active in energy research since the 1980's, initially concentrating on oil and gas technologies. HARC managed consortium-based research programs funded by many of the world's largest E&P companies. Our primary research focus was on seismic, petrophysics and geochemistry. In the early 1990's the Geotechnology Research Institute was formed at HARC and designated as a state entity by the legislature of Texas with a mission to carry out research related to advanced hydrocarbon exploration techniques. But in the mid-1990's, the legislature expanded GTRI's mandate to include environmental geosciences.

In 2000 HARC narrowed its mission and dedicated itself to advancing the concepts of sustainable development in Texas. In the lexicon of sustainable development, protection of the natural environment is given a priority alongside social and economic development goals. With its new mission, HARC phased out our petroleum-related energy research programs and focused now entirely on clean and renewable energy.

While there are many reasons for our nation to develop clean and renewable energy resources, ranging from national security to minimizing the greenhouse affect on global

climate, HARC is particularly active in the link between energy generation and urban air quality.

Energy and air quality have become interlocking pieces in a critical technology and policy puzzle. Energy generated for residential, business, and transportation uses is a primary cause of air pollution in Texas cities, as well as cities around the world. There are four non-attainment areas in Texas for the 1-hour ozone standard, including Dallas/Ft. Worth, Houston/Galveston, Beaumont, Port Arthur, and El Paso. By remaining in a non-attainment status, the State of Texas stands to lose access to billions of dollars in federal transportation funds. We have seen estimates recently that the cost of Texas failing to come into compliance with the attainment standards could account for a loss of $24 to $26 billion net present value. So the costs are extremely serious.

The Houston region has the country's largest petrochemical infrastructure, which is a major source of point source pollution. But Houstonians drive further on average than residents of any other United States city. And if you add to that a hot and humid climate and other accidents of geography and meteorology, the result is an air shed that is capable of producing ozone at unprecedented rates. The health costs and lost productivity related to air pollution in Houston alone exceeds $3 billion annually.

The civic and business leadership in Houston has determined that Houston's poor air quality is having a detrimental impact on job creation and corporate relocations to the region.

To address the crisis, the State of Texas is actually doing some fairly progressive and unprecedented things. There is a program that is providing $150 million called the Texas Emissions Reduction Program. $150 million annually for the reduction of air emissions specifically looking at NO_X reductions with a large focus on diesel emissions.

Within that $150 million program, 9.5 percent of it will be focused on environmental technologies. There's an organization called the Texas Council on Environmental Technology, which will be funded to the tune of $12 to $15 a year to fund the development and deployment of air emissions technologies. And I am speaking about air quality, but ultimately most of these technologies link back to energy generation.

If I were to describe to HARC's role, I'd like to sort of divide it into sort of a energy generation and energy efficiency programs that we have at HARC.

In the energy supply side, one of the first programs that I'll mentioned is in the hydrogen powered automobiles. Hydrogen fuel cells will be the power trains of the future, but significant market penetration of hydrogen-powered vehicles is over a decade away. In the meantime, major auto companies will roll out prototype fuel cell vehicles, first in limited pilot programs and then later within fleets, and finally as a mass market.

Texas has the second and third largest truck and auto market in the country. We have got significant air quality problems and we have a fairly pro-business environment. And for those reasons, Texas has become an essential base of operations for the major auto companies that will be rolling out fuel cell vehicles. The market is too big here and the air quality challenges too significant for the fuel cell auto manufacturers to ignore the Texas market.

HARC is in discussions with two auto companies about providing support for fuel cell vehicle roll-outs, and we look to work in the following areas:

First of all, providing strategic expertise linking the science and policy of air quality and transportation in Texas;

Secondly, we would like to provide a physical site for pilot scale demonstration programs;

We would like to identify and coordinate fleet partners to help roll out these new technologies; and

We would like to be involved with data collection and analysis to support these auto companies as they manage and test these fuel cell vehicles.

Within the stationary fuel cell area, we believe that fuel cell powered vehicles are more than a decade away from being significantly penetrated into the market, but residential and commercial fuel cell applications can provide early markets to support industry development and technology advancements. Because stationary applications are less constrained by weight and size limitations and are easier to supply with hydrogen feedstock, they can be deployed in greater numbers within the next few years.

An area of need that precedes widespread adoption of this new technology is the creation of programs to test and evaluate early commercial products and to communicate this information to potential consumers. Since 2000, HARC has been engaged in such a program and is active in helping industry assess the market readiness of this technology. Our fuel cell applications consortium is supported by ChevronTexaco, BP, Shell Hydrogen, Southern Company, Disney, and other corporate and governmental entities. Texas A&M

University and University of Houston are active observers in the consortium.

HARC's fuel cell applications program is also active in deploying fuel cells in demonstration settings as a valuable precursor to more widespread commercial adoption. We are currently in discussion with the City of Houston and Bush Intercontinental Airport about a fuel cell program to reduce airport emissions

In the area of hydrogen generation, the main process for hydrogen generation today is Steam Methane Reformation or SMR. The SMR process is based on reacting steam with methane over a catalyst to form hydrogen. The cost of producing hydrogen through SMR is dependent on the price of natural gas; however, the price volatility of natural gas and the increasing demand for hydrogen create the need for a new reliable low cost source of supply. HARC has established a partnership to investigate a new approach to produce hydrogen at low cost. The key to the economics of this process, which is called the HydroMax technology, is the use of carbon feedstocks that have little or no value such as biomass, sewage sludge and municipal waste.

The process is a low risk adaptation of existing bath smelting technology that has been in commercial use for over 20 years. Conceptual engineering has been performed to develop estimates for a commercial plant. And a number of process simulations have shown that a wide range of carbon feedstocks is viable.

The operating cost of producing hydrogen via this process is less than zero if you take into account byproduct credits for electricity generation, steam and ammonium sulfate fertilizer. When carbon sources with a negative net cost are available, such as municipal waste or sewage sludge, it is possible to produce hydrogen at even lower costs.

In addition to what I've entered in the written testimony is that we have made it to a second round of DOE review for a proposal written to fund a pilot study for this program.

In the reduced energy demand side, we are working actively in the hybrid vehicle arena. We have a partnership right now with Environmental Defense and Federal Express. Federal Express has developed a delivery vehicle that has using a diesel-electric hybrid motor can reduce fuel use by 50 percent and NO_X emissions by 90 percent. This is a developed prototype. There will be six of these rolled out in the immediate coming months in Texas. With those vehicles, HARC is being hired to look at market penetration and to assess air emissions impacts over time. And having executed this project I think very well, we are now in discussions with other parties about helping entities who want to introduce these prototype technologies in Texas.

Energy efficient buildings is an area that we are hiring a nationally known expert. If you look at buildings nationwide, residences and commercial building account for approximately one-third of energy consumption and two-thirds of our electricity to man, as well as being a contributor to SO_X and NO_X emissions. There is a major certification programmed called LEEDs program which is gaining nationwide recognition as the primary certification for so called "green buildings." The problem with green buildings is that that is an undefined term until you put metrics onto it. The LEEDS program helps define.

Thank you very much.

[The prepared statement of Mr. Mitchell follows:]

PREPARED STATEMENT OF TODD MITCHELL

Introduction

Houston Advanced Research Center (HARC) is a non-partisan research organization dedicated to mobilizing the tools of science, policy and technology to improve people's lives and protect the environment in Texas. HARC serves as an unbiased, neutral organization that cooperates with universities, industry and governmental agencies to address complex and pressing issues relating to how people interact with the natural environment on a regional scale. By applying an interdisciplinary approach to research and policy priorities, HARC seeks to improve decision-making and increase awareness of how science and technology can support and implement sustainability concepts.

HARC has been active in energy research since the 1980s, initially concentrating on oil and gas technologies. HARC managed consortium-based research programs sponsored by many of the world's largest E&P companies. HARC's primary research focus was on seismic imaging of the subsurface, with ancillary programs in petrophysics and geochemistry. In the early 1990s the Geotechnology Research Institute (GTRI) was formed at HARC and designated as a state entity by the Texas legislature to carry out research related to advanced hydrocarbon exploration techniques. In the mid-1990s, the legislature expanded GTRI's mandate to include environmental geosciences.

In 2000 HARC narrowed its mission and dedicated itself to advancing the concepts of sustainable development in Texas. In the lexicon of sustainable development, protection of the natural environment is given a priority alongside social and economic development goals. With its new mission, HARC phased out petroleum-related energy research to focus entirely on clean and renewable energy.

While there are many reasons for our nation to develop clean and renewable energy resources—ranging from national security to minimizing the greenhouse affect on global climate—HARC is particularly active in the link between energy generation and urban air quality.

Energy and Air Quality—HARC's Role

Energy and air quality have become interlocking pieces in a critical technology and policy puzzle. Energy generated for residential, business, and transportation uses is a primary cause of air pollution in Texas cities.

There are four non-attainment areas in Texas for the one-hour ozone standard, including Dallas-Ft. Worth, Houston-Galveston, Beaumont, Port Arthur, and El Paso. The new eight-hour standard will expand the number of non-attainment areas substantially. Houston is consistently second in the U.S. only to the Los Angeles region in the number of days of ozone exceedances. By remaining in a non-attainment status, the State of Texas stands to lose access to billions of dollars in federal transportation funds, as well as potentially suffering other penalties and being subject to federally mandated measures. By failing to meet federal ozone standards, it has been estimated that Texas would experience economic losses of $24 to $36 billion over the next 10 years.

The Houston region has the country's largest petrochemical infrastructure—a major source of point source pollution—and Houstonians drive further on average than residents of any other U.S. city. Add to that a hot and humid climate and other accidents of geography and meteorology, and the result is an air shed that is capable of producing ozone at unprecedented rates. Health costs and lost productivity related to air pollution in Houston exceed $3 billion annually. Civic and business leadership in Houston has determined that Houston's poor air quality is having a detrimental impact on job creation and corporate relocations to the region.

To address the air crisis, a variety of measures, some demonstrating unprecedented leadership and cooperation, are emerging. The State of Texas, in its recent legislative session, authorized estimated revenues of $150 million annually for the Texas Emissions Reduction Program (TERP), an incentive-based program focusing on reducing vehicle emissions, and NO_X emission reductions in particular. A subset of the TERP funding, allocated to a program called the Texas Council on Environmental Technology (TCET), provides $14 million annually to promote the development, deployment, and validation of technology that will reduce air emissions, especially NO_X and VOCs.

The legislature also approved expenditure of an estimated $3 million for air research on the Dallas and Houston areas. This program, overseen by the Texas Environmental Research Consortium (TERC), will improve the reliability of input information and air shed models in East Texas. TERC has selected Houston Advanced Research Center as a Research Management Organization to oversee the expenditure of these funds and to work with regional stakeholders to translate the research for the benefit of public policy-makers.

Clean Energy Supply—HARC's Role

The federal regulations that require States to clean up the air also create opportunities and incentives to deploy new clean energy technologies. HARC is actively engaged in introducing energy technologies with direct impacts on air quality.

Hydrogen powered automobiles. Hydrogen fuel cells are the power trains of the future, but significant market penetration of hydrogen-powered vehicles is over a decade away. In the meantime, major auto companies will roll out prototype fuel cell vehicles, first in limited pilot programs, later within fleets, and finally to a mass market. Texas, with the second and third largest truck and auto market in the country, significant urban air quality challenges, and a pro-business environment, is an essential base of operations for auto companies wishing to roll out fuel cell powered vehicles. HARC is in discussions with two auto companies about providing support for fuel cell vehicle roll-outs in the following areas: (a) strategic expertise linking the science and policy of air quality and transportation in Texas; (b) a physical site for pilot scale demonstration programs; (c) identification and coordination of fleet partners; and (d) data collection and analysis support for operational fuel cells.

Stationary fuel cells for commercial and residential buildings. While fuel cell powered vehicles are more than a decade away from being significant in number, residential and commercial fuel cell applications could provide early markets to support industry development and technology advancements. Because stationary applications are less constrained by weight and size limitations and easier to supply with hydrogen feedstock, they can be deployed in greater numbers within the next few years. One area of need that precedes widespread adoption of this new technology is the creation of programs to test and evaluate early commercial products and to communicate this information to potential consumers. Since 2000, HARC has been engaged in such a program and is active in helping industry assess the market readiness of the technology. Our fuel cell applications consortium is supported by ChevronTexaco, BP, Shell Hydrogen, Southern Company, Disney, and other corporate and governmental entities. Texas A&M University and University of Houston are active observers in the consortium. HARC's fuel cell application program is also actively deploying fuel cells in demonstration settings as a valuable precursor to more widespread commercial adoption. HARC is currently in discussion with the City of Houston and Bush Intercontinental Airport regarding a fuel cell program to provide low emissions electricity to ground-support equipment.

Hydrogen generation. The main process for hydrogen generation today is Steam Methane Reformation (SMR). The SMR process is based on reacting steam with methane (natural gas) over a catalyst to form hydrogen. The cost of producing hydrogen through SMR is dependent on the price of natural gas; however, the price volatility of natural gas and the increasing demand for hydrogen create the need for a reliable low cost source of supply. HARC has established a partnership to investigate a new approach to produce hydrogen at a low cost. The key to the economics of the HydroMax technology is the use of carbon feedstocks that have little or no value such as biomass, sewage sludge and municipal waste. The process is a low risk adaptation of existing bath smelting technology that has been in commercial use for over 20 years. Conceptual engineering has been performed to develop estimates for a commercial plant. A number of process simulations have shown that a wide range of carbon feedstocks is viable. The operating cost of producing hydrogen via the HydroMax process is less than zero, −$0.03 per pound (−$0.066/kg), when the carbon source is petroleum coke priced at $10 per ton and byproduct credits are taken for electricity, steam and ammonium sulfate fertilizer. When carbon sources with a negative net cost are available, such as municipal waste or sewage sludge, it is possible to produce hydrogen at even lower costs.

Reduced Energy Demand—HARC's Role

HARC is actively involved on the other side of the energy equation, reducing energy demand. The following programs provide a snapshot of HARC's activities.

Hybrid vehicles. A promising trend is the rapid pace of technology development for hybrid engines (gas-electric and diesel-electric) in vehicles. Toyota's gas-electric Prius has exceeded expectations as a viable mass-market vehicle. Fleet operators are recognizing the life-cycle fuel cost savings associated with hybrid vehicles. HARC and Environmental Defense have teamed up to work with Federal Express to introduce diesel-electric hybrid delivery trucks in Texas. FedEx's design uses 50 percent less fuel and generates 90 percent less NO_X emissions than its conventional vehicle. HARC's role is to model market penetration scenarios and to predict the air emissions benefits of this technology. Having successfully managed the FedEx project, HARC is in discussion with other potential partners interested in introducing hybrid fleet vehicles in Texas.

Energy efficient buildings. Nationwide, residences and commercial buildings account for approximately one-third of our energy consumption and two-thirds of our electricity demand. From the perspective of national air quality, almost one-half of SO_X emissions, one-quarter of NO_X emissions, and one-third of greenhouse gas emissions are attributed to the energy consumed by buildings. The Department of Energy has established the target to have a net zero energy residential building system by 2020 and a net zero energy commercial building by 2025. The recent growth of the U.S. Green Building Council (USGBC, a Washington D.C.-based non-profit) is an important development. In 1995, USGBC created the LEED™ (Leadership in Energy & Environmental Design) Rating System in response to the U.S. market's demand for a definition of "green building." USGBC's membership is growing rapidly and the LEED™ standard is becoming the common measure of green design. We see a powerful convergence of clean and renewable energy generation technologies, energy efficiency technologies, and green building standards as forces that will propel a new era in energy efficient building design. Communities will be able to set well-defined goals for building efficiency that architects, builders, and occupants can understand. HARC has recently hired a national leader in green buildings to provide support for institutions in our region that look to implement green building concepts to reduce the energy demands of buildings.

Building Systems and Materials. Equipment and systems that provide thermal comfort and adequate indoor air quality for residential and commercial buildings consume 39 percent of the total energy used in buildings nationwide. In the greater Houston area, however, the cooling load can be much higher. A recent greater Houston area forecast predicts that 35,000 new homes will be added to the regional single-family home inventory annually for at least the next five years. HARC is working with others on a program designed to advance the state-of-the-art and overcome barriers associated with the use of desiccant dehumidification systems for residential applications. The team is in the process of designing and testing various options that incorporate a desiccant system for humidity control in a residential application. Humidity control is a large part of the air conditioning load. Incorporating desiccant dehumidification systems into residential HVAC systems can impact electrical usage and perhaps even decrease initial costs by reducing the size of the conventional HVAC system. Part of the project is to verify the energy usage related to desiccant systems, to educate the public and to identify the market potential for residential applications. Homes can be designed to reduce the costs of ownership by increasing energy-efficiency, conserving water and reducing maintenance costs through the use of more durable building materials. A key part of HARC's Building Systems program will be the integration of sensors, information technology, and modeling software to assess and diagnose energy performance in buildings.

Superconductivity. As the application of high temperature superconductivity slowly becomes a reality, incremental progress in the development of materials will be a key to success. Superconducting materials must be engineered to meet rigorous specifications, meeting both safety and quality standards. The design and use of low temperature and high temperature superconducting materials to store energy can greatly enhance power utilization. For 18 years HARC has worked with corporate and university partners in the design, construction and testing of various energy-storage devices. For example, HARC assembled a six-coil array micro-superconducting magnetic energy storage (micro-SMES) unit as part of a State contract to demonstrate the commercial feasibility of micro-SMES technology. University of Houston has been researching high temperature superconducting material for approximately 18 years. HARC and UH have teamed up to explore and exploit the recent advances in the development of high temperature superconducting wire. These advances may be the basis for development of coils that can be used in magnetic energy storage devices and energy transmission systems that reduce energy loss.

Power Sources. More than 800,000 small (less than 15kW) generators are sold in the U.S. each year. Principle uses for these small generators are as emergency back-up power units (principally residential) and for use as portable (off-grid) electric power in the construction industry. The potential to design micro-combined heating and power (micro-CHP) systems so that they also function as emergency back-up power systems for residential applications may represent a significant market opportunity. Residential scale micro-CHP systems may recover thermal energy for uses such as space heating, space cooling, dehumidification, domestic water heating, and other HVAC and indoor air quality (IAQ) functions. HARC is working with potential partners to demonstrate the value of micro-CHP technology as a way to reduce peak power demand and raise energy efficiency in residences.

Chairwoman BIGGERT. Thank you. That was excellent.
Dr. Smalley.

STATEMENT OF DR. RICHARD E. SMALLEY, DIRECTOR, CARBON NANOTECHNOLOGY LABORATORY, RICE UNIVERSITY; ACCOMPANIED BY DR. HOWARD K. SCHMIDT, EXECUTIVE DIRECTOR, CARBON NANOTECHNOLOGY LAB; AND DR. ROBERT H. HAUGE, TECHNOLOGY DIRECTOR, CARBON NANOTECHNOLOGY LAB

Dr. SMALLEY. Thank you, and welcome to Rice University. In fact, welcome to the home of the fullerenes. 1985, in a laboratory just a short distance from where we sit, my colleagues and I discovered C60, the buckyball, and what has turned out to be an infinite new class of geodesic materials, molecules made of carbon, which we call the fullerenes. It was fundamental research project carried out, in part, with support from federal grants from the U.S. Army Research Office, Basic Energy Sciences office of the Department of Energy, and the National Science Foundation.

The key graduate student involved in this discovery was a local Texas boy, Jim Heath, who is now a full professor at Cal Tech and is one of the very top stars worldwide in molecular electronics and nanotechnology. In a very important way, Jim Heath's graduate research based in the early '80's was part of the birth of what we now call nanotechnology.

Yesterday I was privileged to stand in the Oval Office behind the President as he signed the 21st Century Nanotechnology Research and Development Act which you on this committee did so much to make real. And I thank you for your efforts. I believe this will be a watershed event for the vitalization of science and technology in our country.

Energy is the single most important issue facing humanity today. Within this decade it is likely that world oil production will peak. Within another decade, unless we are incredibly lucky, worldwide natural gas production will also peak, and we will no longer be able to meet burgeoning worldwide demand for energy as China, India, and Africa develop. What will be our energy source then? What will fuel our cars, ships and planes? Will it be hydrogen? We must find an answer.

Through revolutionary breakthroughs in science, we must enable the development of new technologies which will be the basis for energy prosperity for ourselves and for the rest of the expected to be 10 billion people on this planet. It must be clean, and most importantly it must be cheap.

I am optimistic that this is possible. We can get there. But it will take a prodigious effort, and nanotechnology, I suspect, will be a big part of that effort.

We are engaged here at Rice University in a particular sort of nanotechnology research that will likely play a major role in future energy. A tube-shaped member of the fullerene family, molecularly precise objects we here at Rice lovingly call "buckytubes" are the current obsession of my research group and many others both here at Rice and around the world.

These structures are composed of a single sheet of carbon wrapped around to form a seamless tube, rather like a soda straw. But this soda straw is smaller than the diameter of a molecule of DNA. It is made of the strongest one-atom-thick membrane that can exit in this universe: the hexagonal "chicken wire" network of carbon atoms that you find in graphite. Capped at either end by a half of a buckyball, these single-walled carbon nanotubes are perfect fullerenes. They do deserve the name of tubes.

They have amazing properties. They are the strongest fibers that can be made, 30–100 times stronger than steel. They conduct heat along their length better than diamond, which hitherto was the all-time record holder for thermal conductivity. They are the best conductors of electricity of any molecule ever discovered.

We are engaged here at Rice in learning how to make these buckytubes, in discovering what makes them be what they are, and in developing applications. We like to think of them as a new miracle polymer, like Nylon was in its day, or Teflon, or polypropylene, or Kevlar. And we are convinced that ways can be found to make buckytubes on a large industrial scale much like these earlier, now well-established polymers.

These single walled carbon nanotubes are uniquely specified by two small integers, usually called n and m. The diameter is roughly proportional to the sum, $n+m$. The electronic properties, however, are determined by the difference of these two integers, $n-m$. If n and m are the same, then $n-m=0$ and the tube conducts electrons like a perfect metal. In the trade it is called and "arm-chair" tube. Electrons move down this tube as a coherent quantum particle, traveling down the tube much like a photon of light travels down a single mode optic fiber. Individual armchair tubes can conduct as much as 20 micro-amps of current. This doesn't sound like much until you realize that his little molecular wire is only one nanometer in diameter. So a half inch thick cable made of these tubes aligned parallel to one and packed side-by-side like pipes in a hardware store, would have over 120 trillion conductors packed side-by-side.

If each of these tubes carried only one micro-amp, only two percent of what has measured in the laboratory and many places as being its maximum of 25, only two, one on micro-amp, this half inch thick cable of carbon, amass a density of one-sixth of copper, would be carrying one hundred million amps of current. Fabricating such a cable, we call it the "armchair quantum wire," is a prime objective of our work.

There are two other types of buckytubes. One is a direct band-gap semiconductor in one dimension, with a band-gap very similar to silicon or actually much more similar gallium arsenide, a direct band-gap semiconductor. We have recently discovered that these buckytubes emit light, and have worked out exactly the band gap as a function of n and m.

The other type of buckytube is also a semiconductor, but has a tiny band-gap similar in energy to microwaves. This behavior occurs whenever $n-m$ is an exact multiple of three.

There are now four principal ways known for producing buckytubes. Three of these were discovered here at Rice University a few block away. Currently these tubes are being produced here at Rice, in fact right as we speak, by a process we call "HiPco" at a rate of about 25 grams per day in a research reactor here at Rice, and in pounds per day right now in a variety of related processes in a small nanotechnology start up company, Carbon Nanotechnologies, Inc., which was spun out of Rice about four years ago, and is located near here on the outskirts of Houston.

At Rice we are developing yet a new process for production of buckeytubes where we will grow the tubes from seeds, short lengths of previously selected buckytubes where we have attached nanocatalyst particles to the open ends. The process that we are developing produces long tubes which are exact clones of the tubes from which the seeds were made. This cloning process should give us control of n and m for the first time.

When we succeed, the impact on energy technologies may be immense. Running the cloning reactor with arm-chair seeds we should be able to make pounds of all armchair buckytubes. Using a process we have been developing for the past few years with support from the Office of Naval Research, we expect to be able to spin these nanotubes into continuous fibers. This process resembles the spinning of Kevlar. But here instead of forming a strong electrical insulator like Kevlar, the all-armchair buckytube fiber will be an electrical conductor. We expect the conductivity to be extremely high, both because of the quantum light-pipe behavior as the electrons traveling down the individual tubes, but also because of facile resonant quantum tunneling of the electron from tube to an adjacent tube.

To get a feeling for this bizarre quantum tunneling behavior, imagine that you are sitting on a subway train in New York City late at night. You're sleepy and for a moment you nod off. But there is another exactly identical train running parallel to you and when you wake up you wake up on this other train. So it is when electrons quantum tunnel from tube to tube in these arm-chair quantum wires. Welcome to the amazing world of nanotechnology!

Running a cloning buckytube reactor with seeds having a direct band-gap of, say, 1 eV, you make pounds of tubes that are just right for making single molecule buckytube transistors. Or, more interestingly for energy applications, you make the tubes so that they are optimized as nanoscale antenna for the use in the conversion of sunlight.

We have collaborated with the National Renewable Energy Laboratory and Air Products in a proposal to the DOE to establish a Virtual Center for Carbon-Based Hydrogen Storage. Our role in this collaboration, our role here at Rice, is to be the principal laboratory that develops single walled carbon nanotubes (buckytubes)——

Chairwoman BIGGERT. If you could close now.

Dr. SMALLEY. Stop? Okay. Optimized for storage of hydrogen.

Chairwoman BIGGERT. We will hear more about buckeytubes in the questions.

Dr. SMALLEY. We believe that this cloning process will provide the tubes that are going to be critical for this function.

Thank you.

[The prepared statement of Dr. Smalley follows:]

PREPARED STATEMENT OF RICHARD E. SMALLEY

Welcome to the home of the fullerenes. In 1985, in a laboratory just a short distance from where we meet today, my colleagues and I discovered C60, the buckyball, and what has turned out to be an infinite class of new geodesic molecules of carbon, the fullerenes. It was fundamental research carried with support from federal grants from the U.S. Army Research Office, the Basic Energy Sciences office of the Department of Energy, and the National Science Foundation. The key graduate student involved in this discovery was a local Texas boy, Jim Heath, who is now a full professor at Cal Tech and is one of the top stars worldwide in molecular electronics and nanotechnology. In a very important way, Jim Heath's graduate research was part of the birth of what we now call nanotechnology.

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Through revolutionary breakthroughs in science, we must enable the development of new technologies which will be the basis for energy prosperity for ourselves and the rest of what will likely be 10 billion people on this planet. It must be clean, and most importantly it must be cheap.

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We are engaged here at Rice University in a particular sort of nanotechnology research that will likely play a major role in future energy. A tube-shaped member of the fullerene family, molecularly precise objects we here at Rice lovingly call "buckytubes" are the current obsession of my research group and many others both here at Rice and around the world.

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They have amazing properties. They are the strongest fibers that can be made, 30–100 times stronger than steel. They conduct heat along their length better than diamond, which previously was the all-time record holder for thermal conductivity. They are the best conductors of electricity of any molecule ever discovered.

We are engaged here at Rice in learning how to make these buckytubes, in discovering just what makes them what they are, and in developing applications. We like to think of them as a new miracle polymer, like Nylon was in its day, or Teflon, or polypropylene, or Kevlar. And we are convinced that ways can be found to make buckytubes on a large industrial scale much like these earlier, now well-established polymers.

These single walled carbon nanotubes are uniquely specified by two small integers, n and m. The diameter is roughly proportional to the sum, $n + m$. The electronic properties, however, are determined by the difference, $n - m$. If n and m are the same, then $n - m = 0$ and the tube conducts electrons like a perfect metal. In the trade it is called and "arm-chair" tube. Electrons move down this tube as a coherent quantum particle, traveling down the tube much like a photon of light travels down a single mode optic fiber. Individual armchair tubes can conduct as much as 20 micro-amps of current. This doesn't sound like much until you realize that his little molecular wire is only one nanometer in diameter. A half inch thick cable made of these tubes aligned parallel to each other along the cable, would have over 100 trillion conductors packed side-by-side like pipes in a hardware store. If each of these tubes carried only one micro-amp, only two percent of its capacity, the half inch thick cable would be carrying one hundred millions amps of current. Fabricating such a cable—we call it the “armchair quantum wire”—is a prime objective of our work.

There are two other types of buckytubes. One is a direct band-gap semiconductor in one dimension, with a band-gap very similar to silicon or gallium arsenide. We have recently discovered that these buckytubes emit light, and have worked out exactly the band gap as a function of n and m. The other type of buckytube is also a semiconductor, but has a tiny band-gap similar in energy to microwaves. This behavior occurs whenever $n - m$ is an exact multiple of three.

There are now four principal ways known for producing buckytubes. Three of these were discovered here at Rice University. Currently these tubes are being produced using a process we call “HiPco” at a rate of about 25 grams per day in research reactor here at Rice, and in pounds per day by a variety of related processes in a small nanotechnology start up company, Carbon Nanotechnologies, Inc., spun out of Rice nearly four years ago, and located near here on the outskirts of Houston.

At Rice we are developing a new process for production where we will grow the tubes from seeds, short lengths of previously selected buckytubes where we have attached nanocatalyst particles to the open ends. The process then produces long tubes which are exact clones of the tubes from which the seeds were made. This cloning process should give us control of n and m for the first time.

When we succeed, the impact on energy technologies may be immense. Running the cloning reactor with arm-chair seeds we should be able to make pounds of all armchair buckytubes. Using a process we have been developing for the past few years with support from the Office of Naval Research, we expect to be able to spin these nanotubes into continuous fibers. This process resembles the spinning of Kevlar. But here instead of forming a strong electrical insulator like Kevlar, the all-armchair buckytube fiber will be an electrical conductor. We expect the conductivity to be extremely high, both because of the quantum light-pipe behavior of electrons traveling down individual arm chair buckytubes, and because of facile resonant quantum tunneling of the electron from tube to tube. To get a feeling for this bizarre quantum behavior, imagine you are traveling on a subway train in New York City late at night. You’re sleepy and for a moment you nod off. But there is another exactly identical train running parallel to you and when you wake up you are on this other train. So it is when electrons quantum tunnel from tube to tube in these armchair quantum wires. Welcome to the amazing world of nanotechnology!

Running a cloning buckytube reactor with seeds having a direct band-gap of 1 eV, you make pounds of tubes that are just right for making single molecule buckytube transistors. Or, more interestingly for energy applications, you make the tubes so they are optimized as nanoscale antenna for use in the conversion of sunlight.

We have collaborated with the National Renewable Energy Laboratory and Air Products in a proposal to the DOE to establish a Virtual Center for Carbon-Based Hydrogen Storage. Our role in this collaboration is to be the principal laboratory that develops single walled carbon nanotubes (buckytubes) optimized for storage of hydrogen. The challenge here is to control the diameter of the tube so that the absorption energy of hydrogen on the outside and inside of the tube is high enough to give the desired storage capacity at an acceptable pressure, without being so high that it takes too much energy to the hydrogen back off again. If the absorption behavior of the optimized tube is acceptable, then the challenge is to develop a process cable of producing this material at a cost of less than $10 per pound. We believe the new cloning process is the path to accomplish this goal.

Finding an answer to the storage problem for hydrogen-fueled cars and truck is a crucial challenge. If there exists a material, X, which we can put in our gas tanks that will act like a magic sponge and allow us to fill up on hydrogen with the same sort of experience we now have with gasoline, we need to find it. Single walled carbon nanotubes are the leading candidate for this material X.

However, we cannot change the laws of physics. Buckytubes, even with perfectly optimized n and m may not be good enough. And there may be no better material for the sponge. Material X may not be possible in our universe.

In that case, there can still be a hydrogen fueled vehicle, but the gas tank will have to be a pressurized tank for small vehicles, or a cryogenic liquid hydrogen tank for large vehicles, ships, and planes.

Buckytubes will be critically important to the hydrogen economy even then. They will be used in super-strong composites in the bodies of the vehicles to make them lighter. They will be used in the fuel cells, and batteries, and super capacitors of the electric drive system. If the arm-chair quantum wire turns out in practice to be as good a conductor as we imagine, it will be used to replace copper in the wiring harnesses of cars and airplanes.

The biggest challenge with hydrogen is not storage, it is production and transport to the place of use. Here too it may well be that single walled carbon nanotubes will play a pivotal role. Particularly important would be the use of armchair quantum wires in long distance electrical energy transmission. If we could efficiently transmit hundreds of gigawatts of electrical power over continental distances, and develop low cost local energy storage technologies, we could transform the electrical power grid and go a long way to solving our energy challenge. Local storage capable of 12 hour energy buffering would vastly lower the peak power demands, and enable solar and wind power to become a dominant provider. Long distance energy transmission via wire would allow vast solar farms in the great western deserts to play a big role in the Nation's energy needs. It would also allow power to be brought from clean coal plants in Wyoming, and nuclear power from remote sites where the necessary security is assured. Hydrogen would then be primarily produced locally at homes, businesses, and filling stations, and converted back into electrical power locally.

All these notions for transformation of the energy grid can only come into being through revolutionary advances in the underlying physical science and technology of materials. When after many decades this is all done and we look back to write the technological history of the 21st century, I suspect will find that nanotechnology (and buckytubes) played a central role.

BIOGRAPHY FOR RICHARD E. SMALLEY

Personal

Birth Date: June 6, 1943 U.S. Citizen

Children: Chad R. Smalley (born June 8, 1969), Preston C. Smalley (born August 8, 1997)

Education

Hope College, Holland, Michigan, 1961–1963

B.S. (Chem.), University of Michigan, Ann Arbor, Michigan, 1965

M.A., Princeton University, Princeton, New Jersey, 1971

Ph.D., Princeton University, Princeton, New Jersey, 1973

Industrial Positions

Research Chemist, Shell Chemical Company, 1965–1969

Chairman of the Board and Co-Founder of Carbon Nanotechnologies, Inc., 2000–present

Academic Positions

Graduate Research Assistant, Department of Chemistry, Princeton University (with E.R. Bernstein), 1969–1973

Postdoctoral Research Associate, The James Franck Institute, University of Chicago (with D.H. Levy), 1973–1976

Assistant Professor, Department of Chemistry, Rice University, 1976–1980

Associate Professor, Department of Chemistry, Rice University, 1980–1981

Professor, Department of Chemistry, Rice University, 1981–1982

Gene and Norman Hackerman Professor of Chemistry, Rice University, 1982–present

Professor of Physics, Rice University, 1990–present

University Professor, Rice University, 2002–present

Honorary Degrees

Doctor *honoris causa,* University of Liege, Liege, Belgium, 1991

Doctor of Science, University of Chicago, 1995

Doctor of Science, University of Michigan, 1997

Doctor of Science, University of Pennsylvania, 2002

Fellowships, Awards, and Prices

Harold W. Dodds Fellow, Princeton University, 1973

Alfred P. Sloan Fellow, 1978–1980, Fellow of the American Physical Society, 1987

Irving Langmuir Prize in Chemical Physics, 1991 (Awarded by American Physical Society)

Popular Science Magazine Grand Award in Science & Technology, 1991

APS International Prize for New Materials, 1992 (Joint with R.F. Curl and H.W. Kroto)

Jack S. Kilby Award, 1992 (North Dallas Chamber of Commerce)

Ernest O. Lawrence Memorial Award, 1992 (U.S. Department of Energy)

Welch Award in Chemistry, 1992 (Robert A. Welch Foundation)

Auburn-G.M. Kosolapoff Award, 1992 (Auburn Section of American Chemical Society)

Southwest Regional Award, 1992 (American Chemical Society)

William H. Nichols Medal, 1993 (New York Section of American Chemical Society)

The John Scott Award, 1993 (The City of Philadelphia)

Hewlett-Packard Europhysics Prize, 1994 (European Physical Society)

Harrison Howe Award, 1994 (Rochester Section of the American Chemical Society)

Madison Marshall Award, 1995 (North Alabama Section of the American Chemical Society)

The Franklin Medal, 1996 (The Committee on Science and the Arts of The Franklin Institute)

The Nobel Prize in Chemistry, 1996 (Royal Swedish Academy of Sciences)

Rice University Homecoming Queen, 1996 (Rice University Undergraduates)

Distinguished Civilian Public Service Award, 1997 (Department of the Navy)

American Carbon Society Medal, 1997

Top 75 Distinguished Contributors to the Chemical Enterprise, 1998 (Chemical & Engineering News)

Glen T. Seaborg Medal, 2002 (UCLA)

Memberships

American Chemical Society, Division of Physical Chemistry

American Physical Society, Division of Chemical Physics

American Institute of Physics, American Association for the Advancement of Science

Materials Research Society, Sigma Xi

National Academy of Sciences, 1990

American Academy of Arts and Sciences, 1991

Other

Chairman, Rice Quantum Institute, 1986–1996

Scientific Advisory Board, CSIXTY, Inc., 1995–present

Scientific Advisory Board, NanoSpectra Biosciences, 2002

Scientific Advisory Committee, Center for Nanophase Materials Sciences (CNMS), 2002

Scientific Advisory Committee, Center for Integrated Nanotechnologies' (CINT), 2002

Director, Rice Center for Nanoscale Science & Technology (CNST), 1996–2001

Director, Carbon Nanotechnology Laboratory, 2002–present

Chairwoman BIGGERT. Thank you.

Dr. Holtzapple.

STATEMENT OF DR. MARK HOLTZAPPLE, DEPARTMENT OF CHEMICAL ENGINEERING, TEXAS A&M UNIVERSITY

Dr. HOLTZAPPLE. Well, howdy y'all.

What I would like to talk about two patents that I have been working on for about 20 years. The first is biofuels and the other is a StarRotor Engine.

And first I am going to start with the biofuels. This is an ideal process, an imagine process that would volume as I've shown here as a tree, put it into some sort of a biodefinery and make fuels. Now, when you burn that biomass, you do make CO_2, but due to the process of photosynthesis, you fix that carbon dioxide and it simply cycles. So the idea is to have your cars run as solar powered cars.

Now currently you are driving solar powered cars, it is just old solar energy. It is about 100 million years old. The idea here is to drive new solar energy.

Now let's envision the ideal properties of such a process. The first thing I'd like to do is focus on the biomass itself. What we would like to do is be able to use all kinds of biomass such as trees, grass, agricultural resides, energy crops, garbage, sewage sludge and animal manure. And it turns out there is a lot of this stuff around, a lot of waste.

If we took all the biowaste in our states and converted to alcohol fuels, it is about 135 billion gallons. And to put that into perspective, U.S. gasoline consumption is about 130 billion gallons and diesel is 40 billion gallons. So it has the potential to supply a significant portion of our liquid transportation fuels.

We would also like to be able to use high productivity feedbacks. Like here I am showing the productivity of corn in dry times per acre per year. You see that it is only about 3.4. So if we were to go to something like sweet sorghum, it is 20. If we go to something called energy cane it is 30. So significantly more biomass being produced in the form of sorghum or energy cane.

To look at sweet sorghum, this is a single year's growth. It grows in about 35 states including Illinois, so it is a very prolific crop.

An energy cane, this is to me a phenomenal pictures. These are two full grown men standing next one year's growth of energy cane. This happens to be in Puerto Rico. It is a phenomenal productive crop. And to get some sense of how long it is, here they are standing next to it while it is cut. And that is a single stock that is stretching along the length of that truck.

The other thing we would like to do is get the farmer's a lot of income. I am going to talk of those corn grains, the lowest is about $340 per acre. But if they grew sweet sorghum, they could get $730 per acre. And if they energy cane, they could get over $1,000 per acre gross income. So we could really up the farmers using this kind of technology.

And if you look at the environment impact of growing various crops in terms of the water, fertilizer, pesticides, herbicides and sil erosion, what you see is that sweet sorghum and energy cane have a low environmental impact compared to growing corn grain.

Next I would like to talk about the process itself, what would be the idea properties of the process. And ideally you would like to have no sterility, because it costs money to have sterility.

It wouldn't bypass genetically modified organisms.

You want like to be adaptable to different kinds of feedstocks.

You do not want to have pure cultures.

You would like to be cheap.

You do not want to have enzymes.

You would like high product yields.

You do not want to have to add vitamins.

And you do not want to have co-products that carry the process.

And next I would like to focus on what are the ideal properties of the fuel itself. And what I am showing here is various features of fuels: The octane rating, volatility, the ability to ship through pipelines, energy content, heat of vaporization and damages to ground water. And you see that MTBE is very good on almost all of these, but there is a lot of concern about ground water damage. But if we go with mixed alcohols we see that it does not have any of the problems that are associated with the other fuels.

So we have these ideal properties. Is there a biofuel technology with those properties? And you probably know the answer to that question. The answer is yes. It is a process that I have been working on for 12 years now called the MexAlco process. And the way it works is you take your biomass and treat it with lime to make it digestible. And then you ferment that lime treated biomass with a mixed culture of organisms. They may call it carboxylate salts, such as calcic acetate, remove the water. When you heat those salts you get ketones such as acetones. And if you add hydrogen you get alcohol such as isopropanol.

So literally think about this. You could take manure and turn it into a salt with vinegar, nail polish remover and rubbing alcohol. So the acute alkamine is turning lead into gold can be done with this kind of process.

Another important point to be made is that hydrogen goes into process. The hydrogen could be made from coal, let us say where you sequester the carbon dioxide but the energy content of the coal shows up in hydrogen. And you can think if this biofuel as a hydrogen carrier that does not have a negative impact on the environment.

Just to point out how they do some of these steps. I am going to go into all the technology. The pretreatment and fermentation is done this way. You have a rubber lined pit with about three feet of gravel. You just pile up the biomass with line and calcium carboxylate. And for the first month you blow air up through the pile. That takes out the living make it digestible. And then you literally throw dirt onto the pile, in fact the best dirt is from Galveston that we have found so far. And at the bottom the pile just rots, and when it rots it turns into calcium acetate, which we harvest into liquid and send on for further processing.

The next step in the process is the dewatering. And here what you do is you put actmine on your salt solution with steam that comes out of the compressor, condenses and causes more water to vaporize.

And I just want to make as a side note, this could also be used to desalinate sea water economically.

And what are the economics of our process? What I'm showing here is the feedstock cost, there's that $40 per ton that I used before. And you see that if we paid the farmers $40 a ton, you could sell fuels for about .75 a gallon. So it's a very attractive process.

And notice I have some negative costs if you are using things like garbage or sewage sludge; people pay to get rid of that stuff.

The idea is to have an energy plantation. Here we have a central facility with 15 mile radius. It's 50 percent planted. It turns out that that factory has the capacity of half an oil refinery, and it can function forever as long as the sun is shining.

If we were to satisfy 100 percent of U.S. gasoline needs by growing energy cane in Brazil at current engine efficiency, that is the amount of land area required. If we double our engine efficiency, that's the amount required. And if we triple, that's the amount required.

And if we were to grow sweet sorghum in the United States, these are the analogous figures.

So what I would like you to envision is taking this amount of land area, assuming we can triple energy efficiency, and kind of stretch it along the coast. That means that the liquid fuels would be transported maybe 100 miles or so to the coast by barge. It would go to Houston and then through the pipelines to distribute the fuels. We could get it to the customer in an economical way.

Now how do we increase the efficiency of engines? It turns out that hydroelectrics are already on the market. They've doubled engine efficiency. And I think through better engines, we can double or even quadruple the efficiency of engines.

And so what I would like to so is show the StarRotor Engine which we have been working on now for about five or six years. The way it works is you take air out of one atmosphere. It compresses here to six atmospheres. You preheat it, and then you add your fuel. It expands in this region right here. And finally you do exhaust one atmosphere of gas. It is still fairly hot, so you capture the waste energy and cycle it back into the engine.

Now it so happens that I brought along here—at the end you are certainly welcome to come up and give it a crank and see how it goes.

And we have been doing this now for a while. And here is the prototype which we started testing in September. This happens this is just the compressor portion. There is an electric motor at the end. And here it is. You can see it rotating.

And one of the key points I wanted to make is that there is no physical contact between these rotating elements, so there's no tension and wear. It should have an extremely long life this engine.

The properties of this engine are very efficient. At full size power you should be able to get about 100 miles per gallon.

Almost no pollution with low maintenance,long life, low cost. Very high power density. No vibration to speak of and any fuel that you want. It does not care what the fuel.

And so the benefits of adopting these technologies are: That it could reduce waste such as garbage and sewage sludge; have cleaner air for cities like Houston; develop me markets for agriculture.; have energy security where we don't have to import over half our oil; improve our balance of payments. Currently we're spending $2 billion a week on import of oil. We could eliminate that.

We could address global warning; address the impending energy shortage; have more flexible international relations.

I ask why are we such good friends with Saudi Arabia? And everybody knows the answer to that question.

And then lastly, we can help developing nations pull themselves up by the bootstraps.

So what I would like to do is propose some legislative action to make all this happen. The first thing is that the Energy Bill has a tax credit for ethanol. What I would suggest is we simply erase the word ethanol and put biofuel there so that all biofuels could compete on an equal basis with the same amount of subsidy.

Also if we want to use things like garbage as a feedstock, I do not know of any chemical company or oil company that would touch it because they do not want the potential liability that comes along with handling these. If they could somehow be protected from liability of handling these wastes, then it is extremely attractive feedstock.

And lastly, since I am a professor, I have to say give more money for research.

[The prepared statement of Dr. Holtzapple follows:]

Biofuels
&
StarRotor Engine

Mark Holtzapple
Department of Chemical Engineering
Texas A&M University
College Station, TX

Setting the Stage

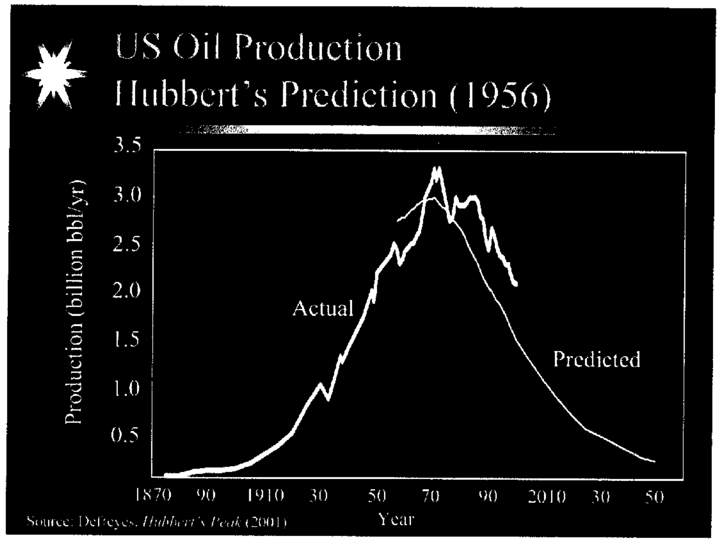
- Oil shortage
- Greenhouse Effect

M. King Hubbert (1903-89)

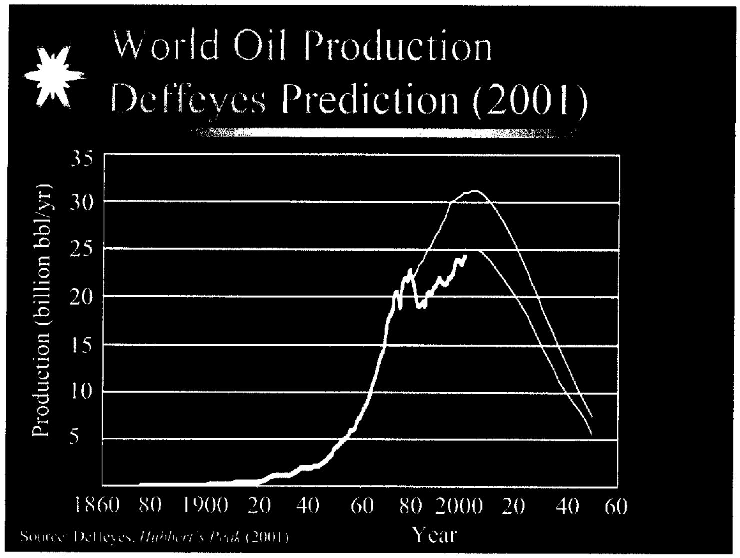
American geophysicist

Shell Oil research laboratory

Houston, TX



Hubbert assumed that oil production would be a bell-shaped curve. In 1956, he predicted U.S. oil production would peak in 1970, which it did.



Using techniques similar to Hubbert, Deffeyes predicts that world oil production will peak about 2004.

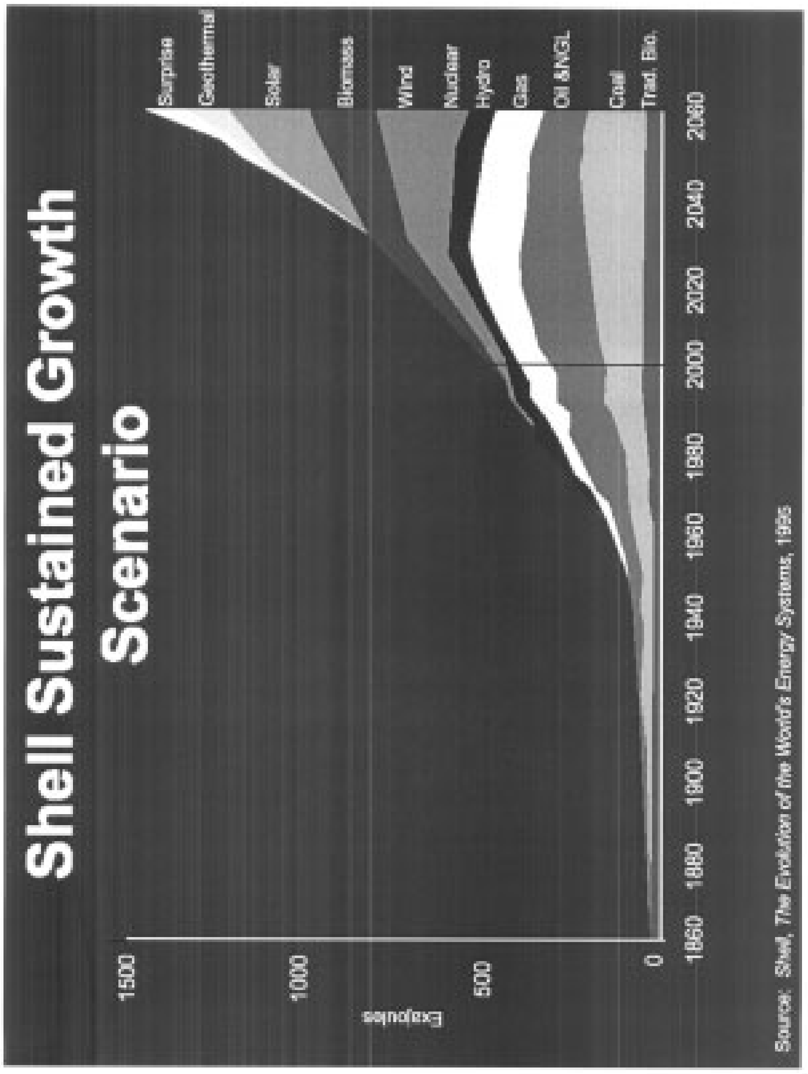
Where will we get our energy?

Study by Shell Group Planning

Georges Dupont-Roc
Alexon Khor
Chris Anastasi

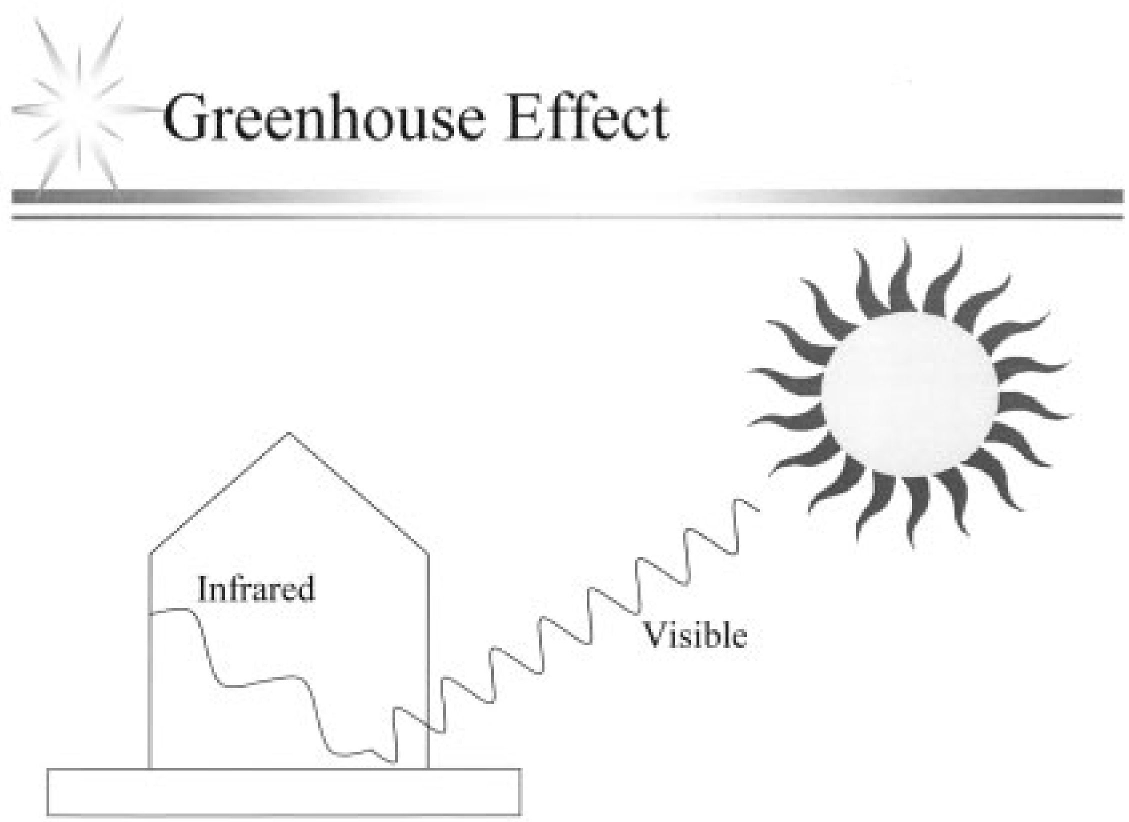
The Evolution of the World's Energy Systems

1996


Shell Sustained Growth Scenario
Exajoules
1500
1000
500
0
1860
1880
1900
1920
1940
1960
1980
2000
2020
2040
2060
Surprise
Geothermal
Solar
Biomass
Wind
Nuclear
Hydro
Gas
Oil &NGL
Coal
Trad. Bio.
Source: Shell, The Evolution of the World's Energy Systems, 1995

Setting the Stage

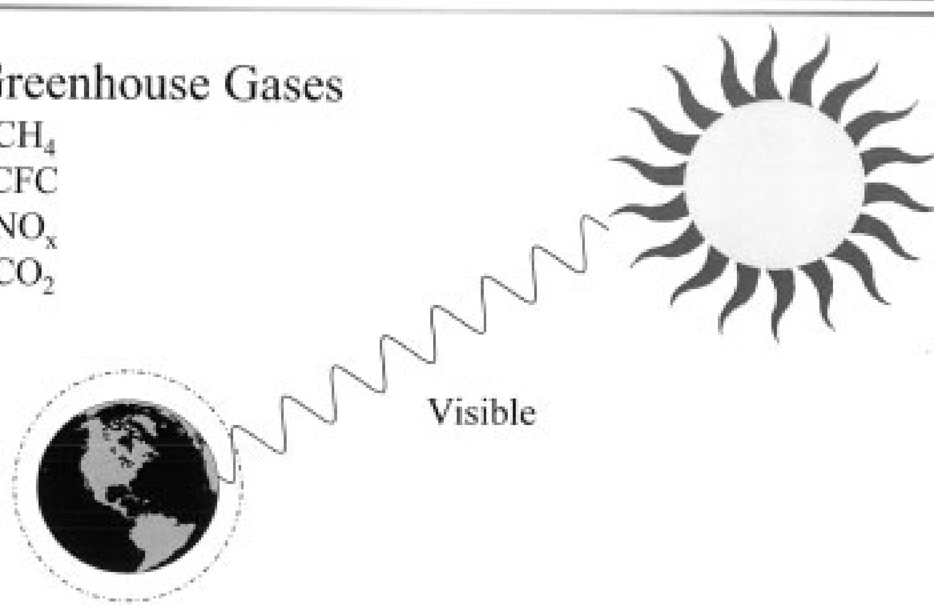
- Oil shortage
- Greenhouse Effect

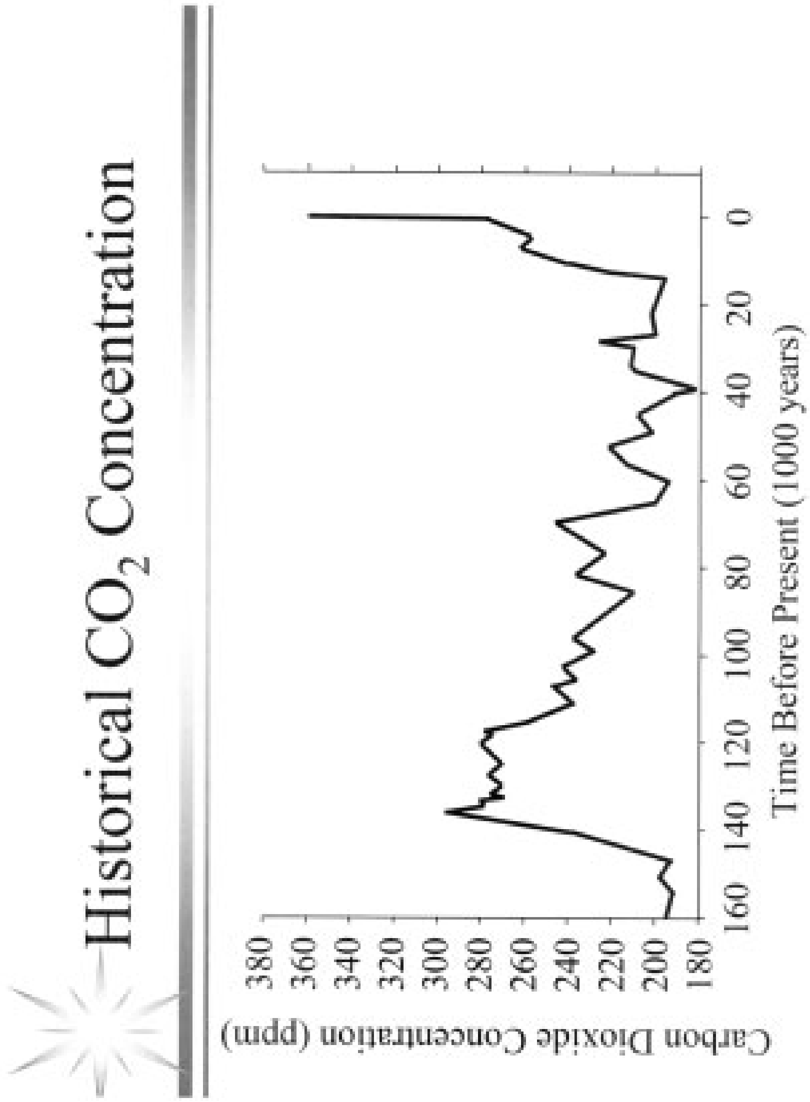

Greenhouse Effect
Infrared
Visible

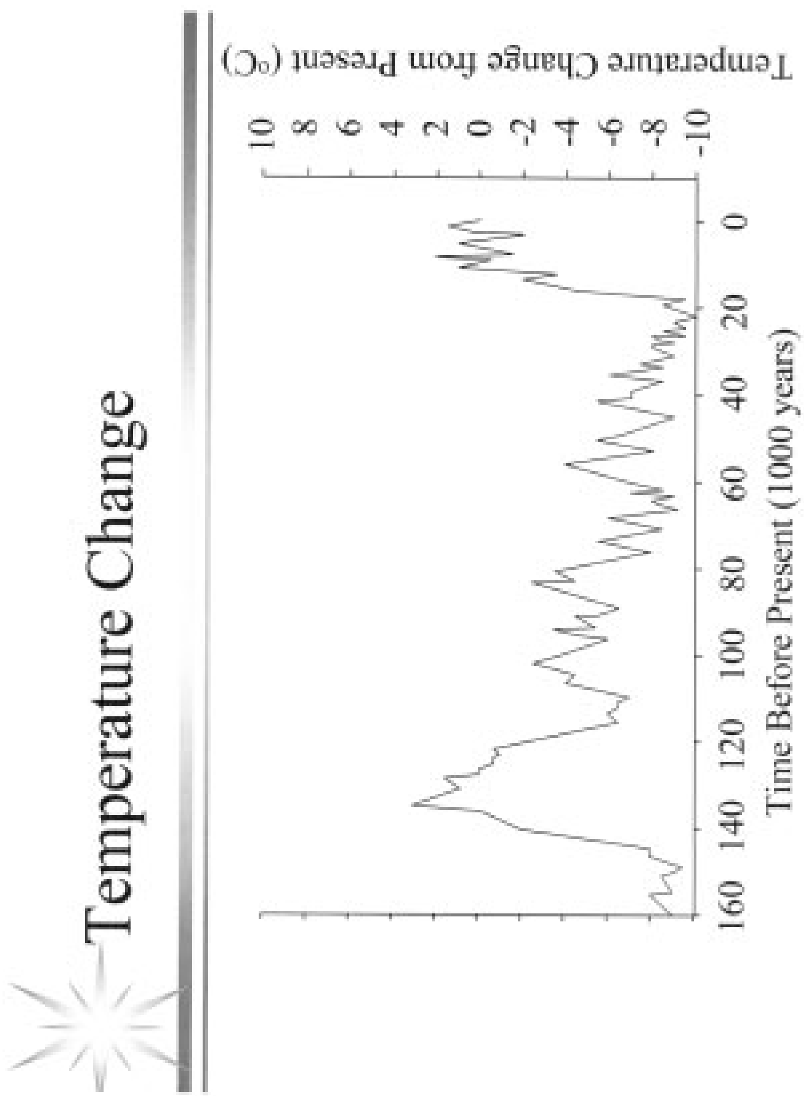
Greenhouse Gases

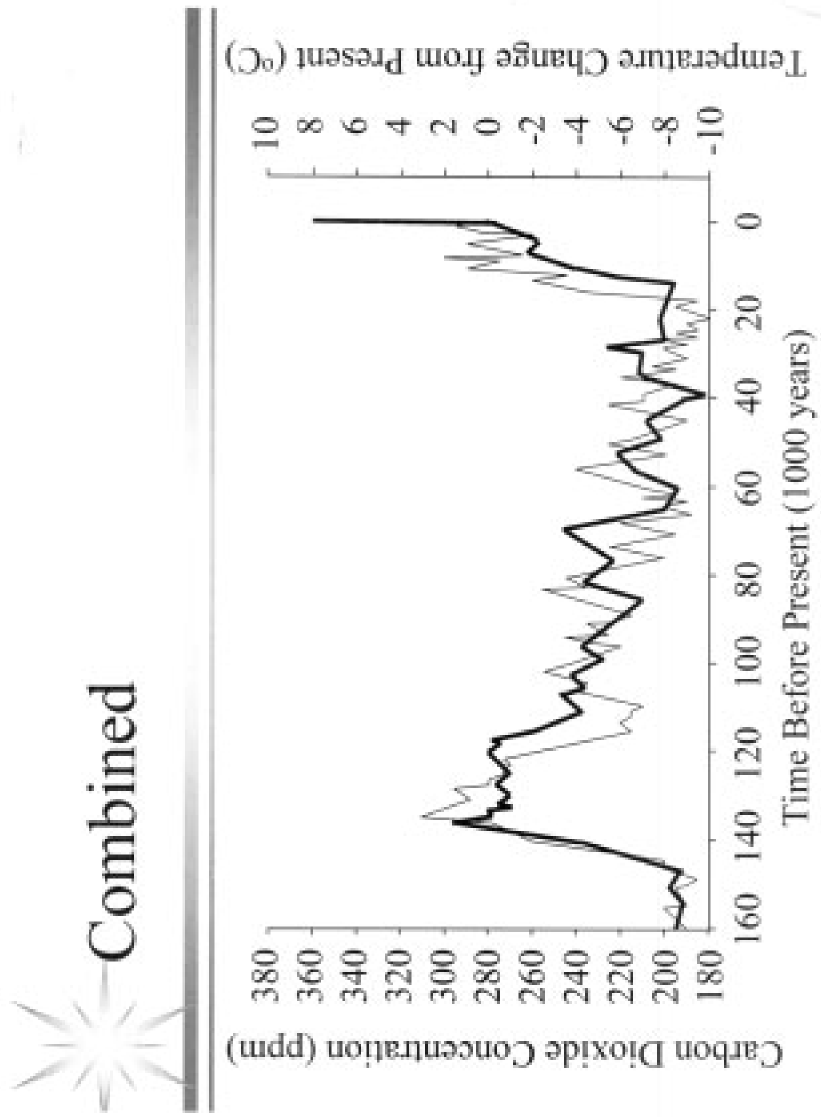
Greenhouse Gases

- CH_4
- CFC
- NO_x
- CO_2



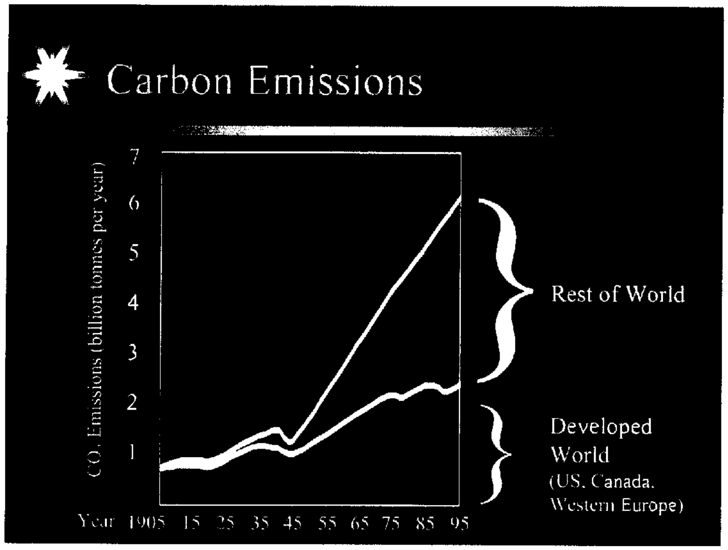

Historical CO_2 Concentration
Carbon Dioxide Concentration (ppm)
380 360 340 320 300 280 260 240 220 200 180
Time Before Present (1000 years)
160 140 120 100 80 60 40 20 0


Temperature Change
Temperature Change from Present (°C)
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
20
40
60
80
100
120
140
160
Time Before Present (1000 years)

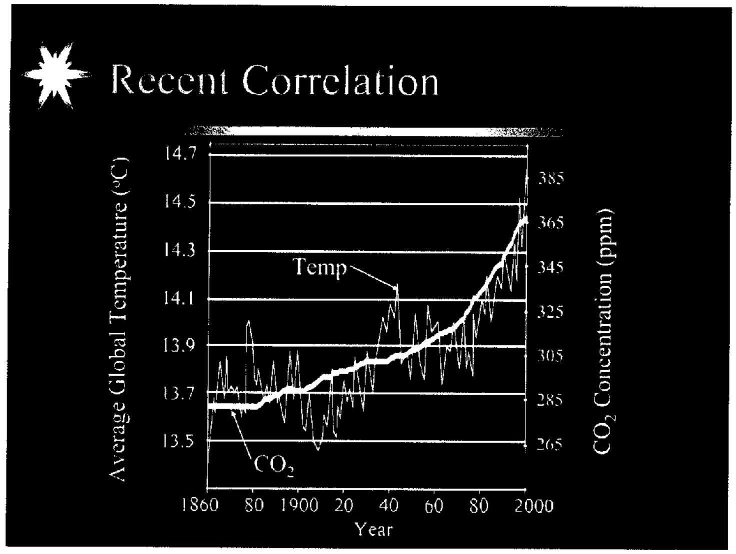

Combined
Carbon Dioxide Concentration (ppm)
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Time Before Present (1000 years)
10
8
6
4
2
0
-2
-4
-6
-8
-10
Temperature Change from Present (°C)

Correlation

Hypothesis	Independent	Dependent
1	Temp	CO_2
2	CO_2	Temp



We can determine which of the two hypotheses is correct by spiking the earth's atmosphere with carbon dioxide. This "experiment" was conducted during the 20th century – particularly after World War II – when fossil fuel combustion added a significant amount of carbon dioxide to the atmosphere.



The spike of carbon dioxide emissions has caused carbon dioxide concentrations to increase. The correlation between temperature and carbon dioxide concentration continues to hold.

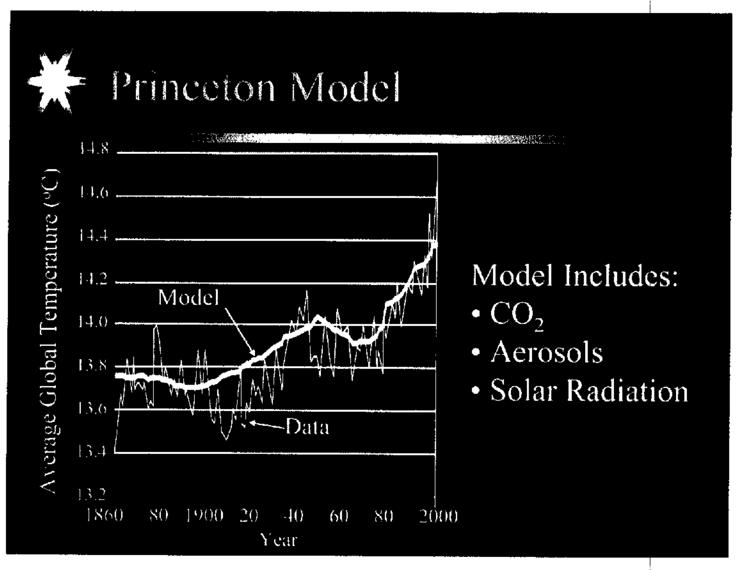
Conclusion

Hypothesis	Independent	Dependent
~~1~~	~~Temp~~	~~CO_2~~
2	CO_2	Temp

Conclusion

Hypothesis	Independent	Dependent
~~1~~	~~Temp~~	~~CO_2~~
2	CO_2	Temp

This is the Greenhouse Effect

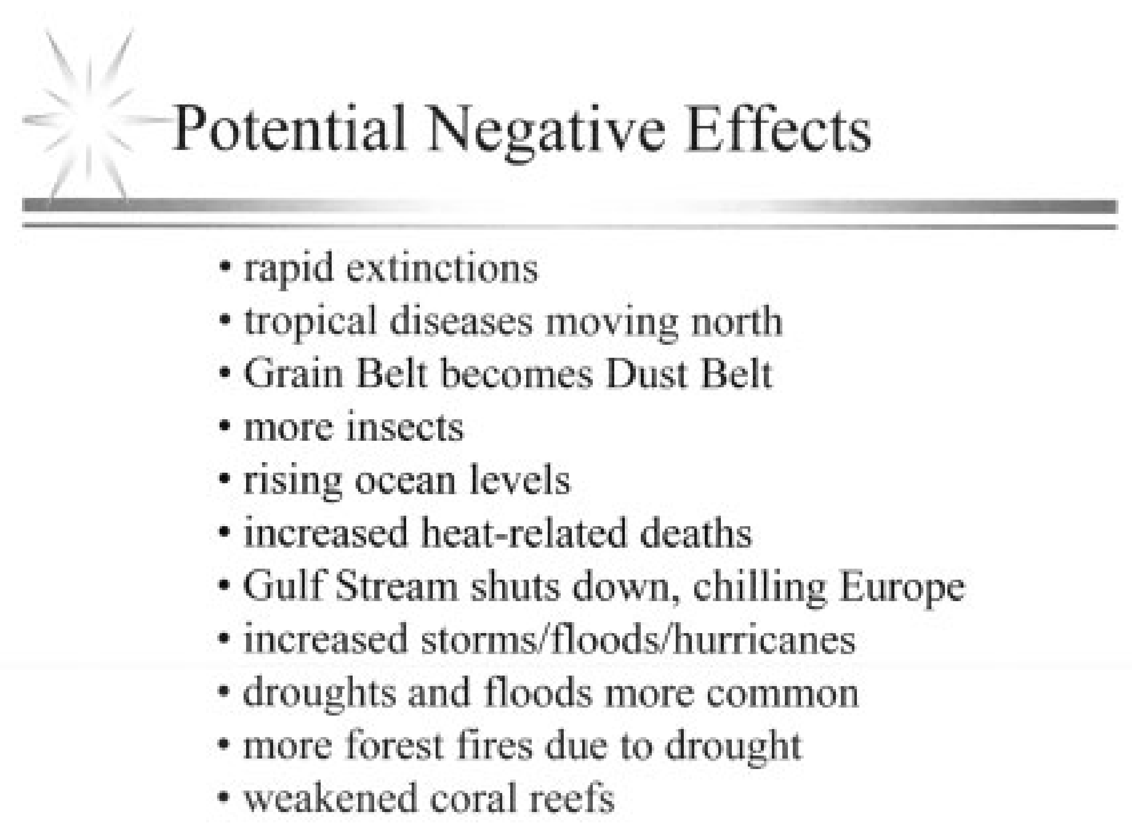


Recent mathematical models of global temperatures have included the effects of carbon dioxide concentration, sulfate aerosols (from coal combustion), and variations in solar radiation. The models agree well with the data. Apparently, the slight cooling trend experienced during the 1950s through 1970s resulted from sulfate aerosols. Starting in the 1970s, to address acid rain, sulfur scrubbers were installed at power plants which allowed the warming trend to continue.

Global Warming Conclusion

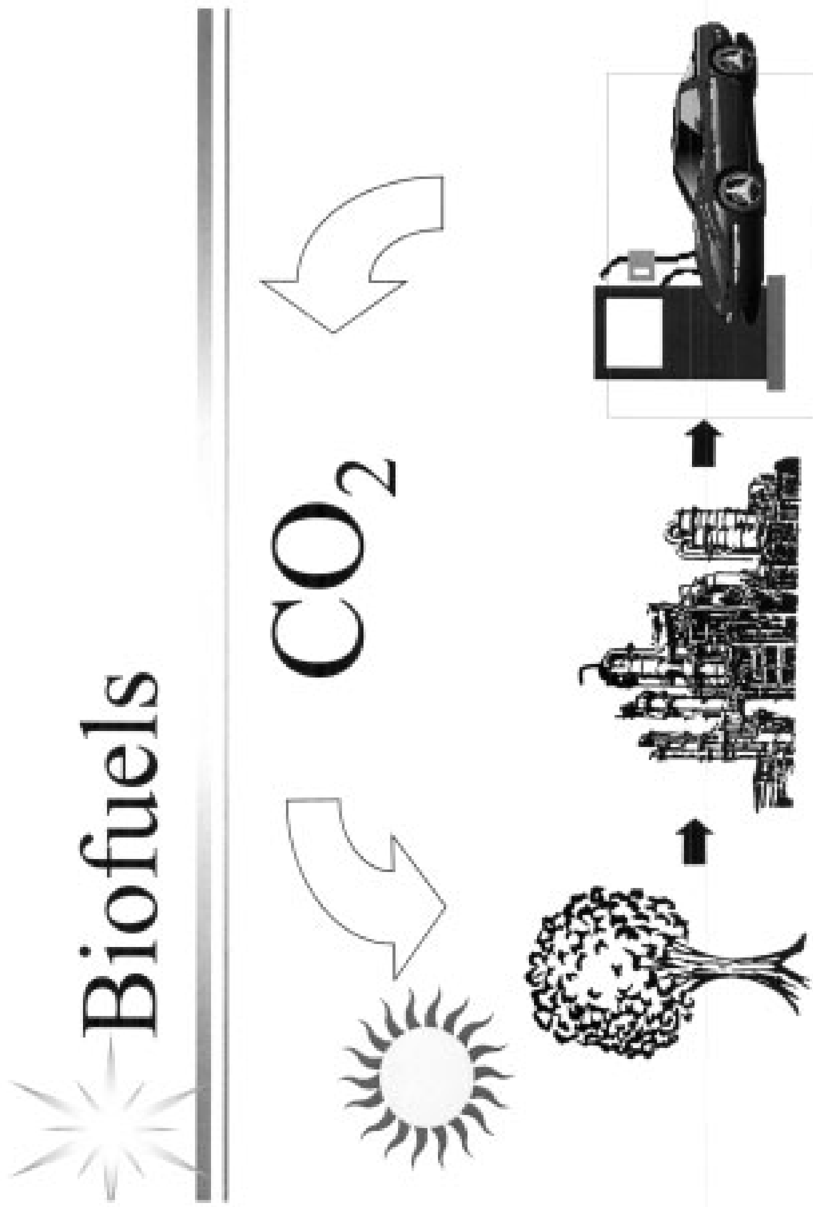
The evidence that human activities are causing climate change is as certain as science gets in almost any area.

Bette Hileman
C&E News
October 20, 2003

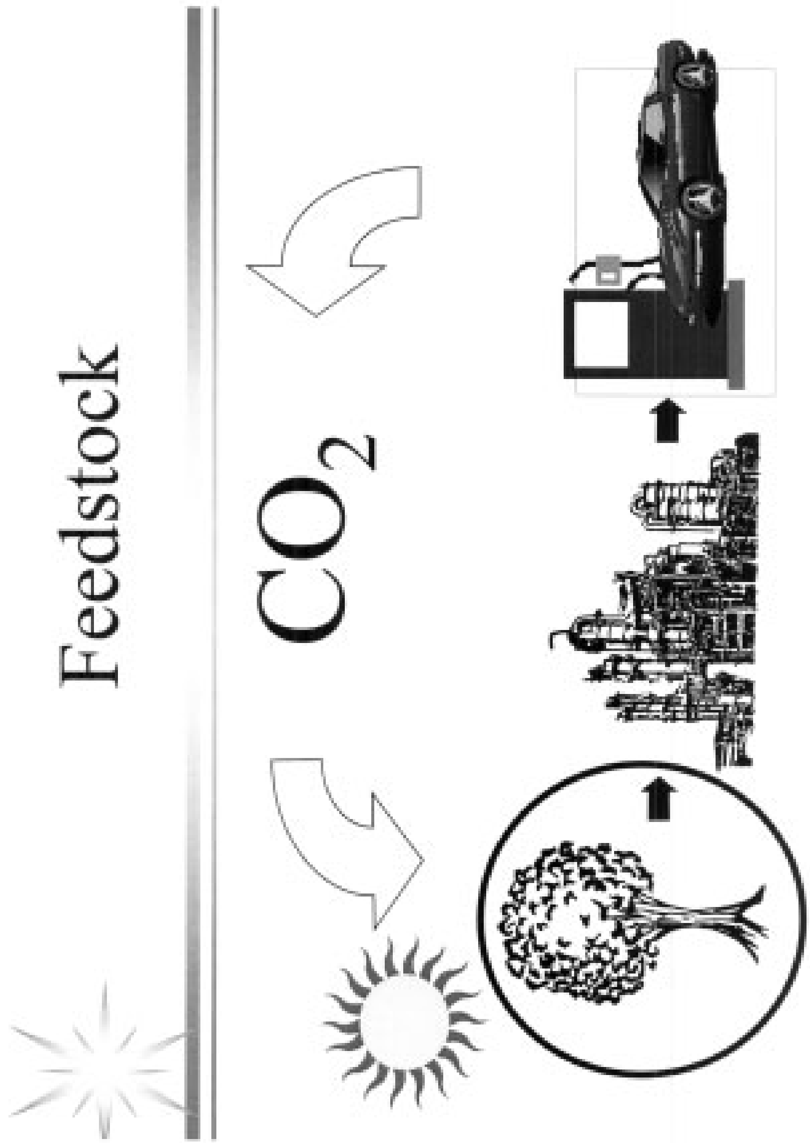

Potential Negative Effects
• rapid extinctions
• tropical diseases moving north
• Grain Belt becomes Dust Belt
• more insects
• rising ocean levels
• increased heat-related deaths
• Gulf Stream shuts down, chilling Europe
• increased storms/floods/hurricanes
• droughts and floods more common
• more forest fires due to drought
• weakened coral reefs

Exacerbating Effects

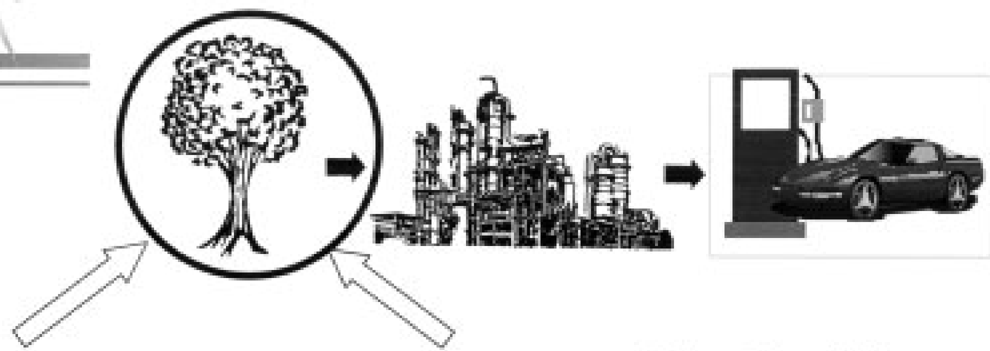
- extended thaw in tundra
- polar ice caps melt
- methane clathrates melt


Biofuels
CO_2

Let’s envision an ideal biofuel process


Feedstock
CO2

Multiple Feedstocks



- trees
- grass
- agricultural residues
- energy crops

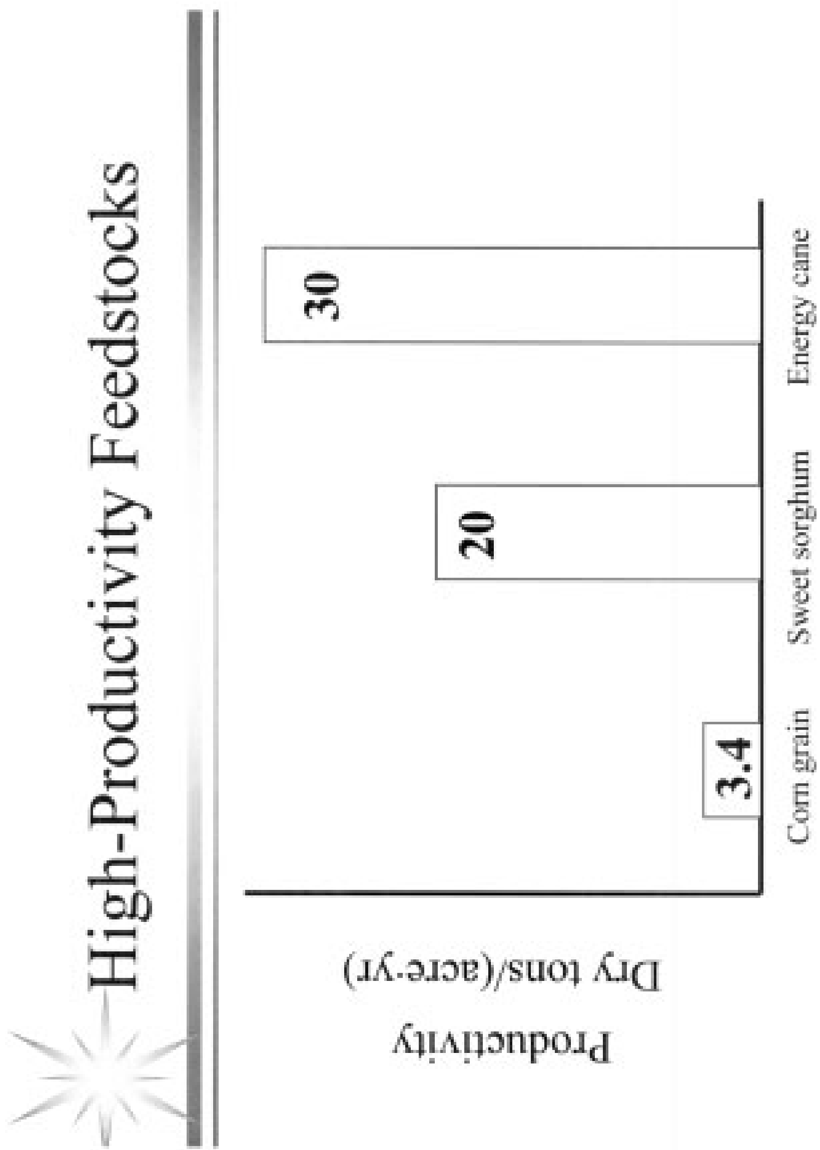
- municipal solid waste
- sewage sludge
- animal manure

U.S. Biodegradable Wastes

Waste	Amount (million tonne/year)	Alcohol Potential (billion gal/year)
Municipal Solid Waste	78	10
Sewage Sludge	10.9	1.4
Industrial Biosludge	3	0.4
Recycled Paper Fines	4.3	0.5
Agricultural Residues	400	52
Forestry Residues	330	43
Manure	220	28
Total	1,046	135

U.S. Gasoline Consumption = 130 billion gal/year

U.S. Diesel Consumption = 40 billion gal/year

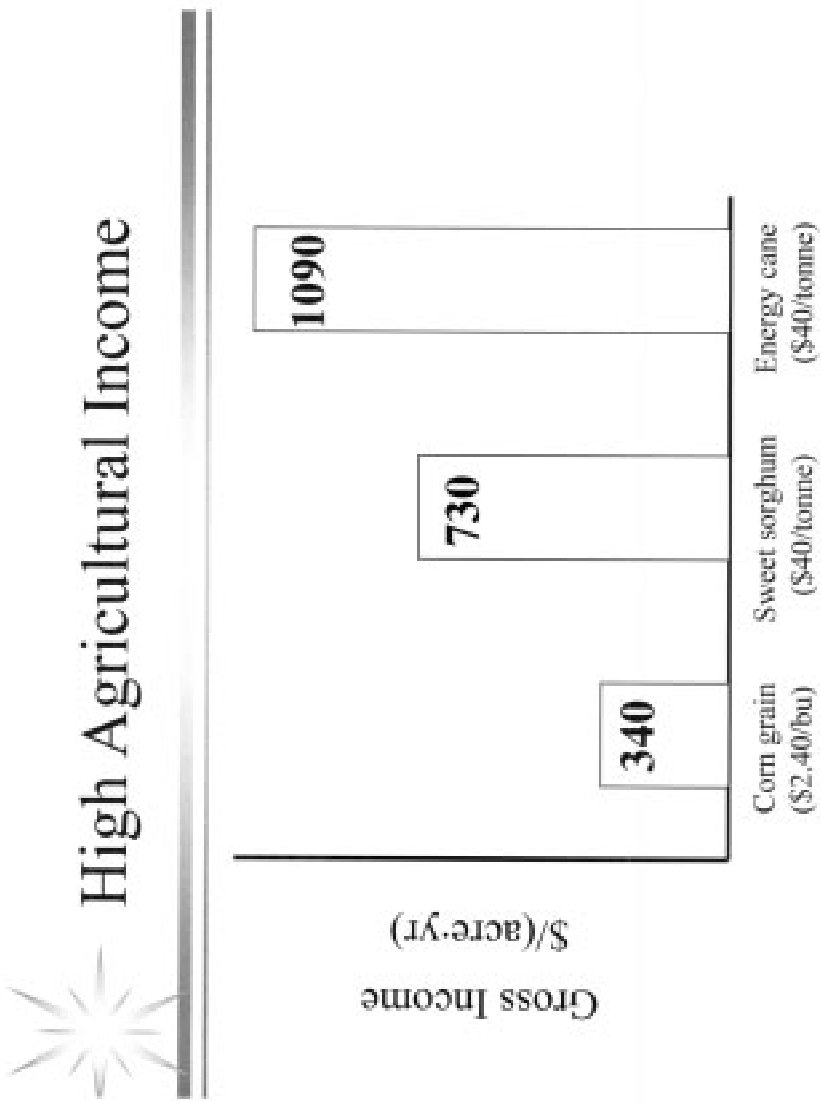

High-Productivity Feedstocks
Productivity
Dry tons/(acre·yr)
3.4
20
30
Corn grain
Sweet sorghum
Energy cane

Sweet Sorghum

Grows in ~35 US states

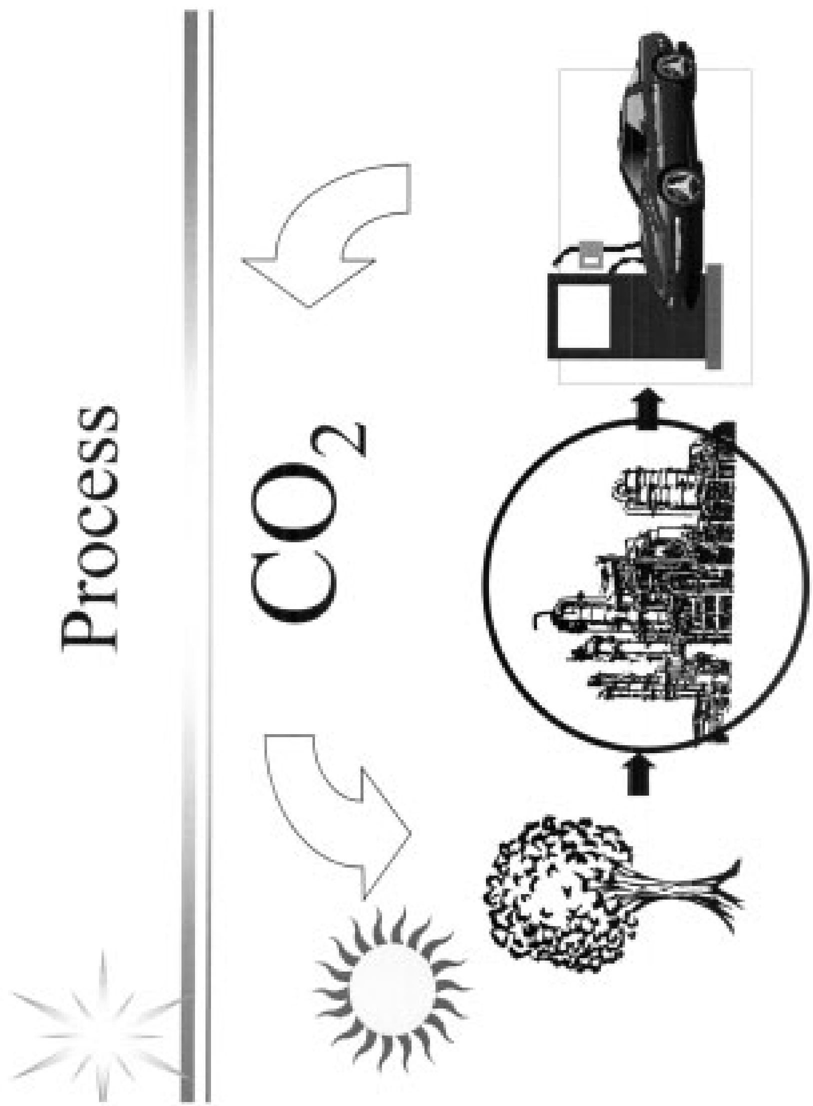
Energy Cane

Energy Cane


High Agricultural Income
Gross Income
$/(acre·yr)
340
730
1090
Corn grain
($2.40/bu)
Sweet sorghum
($40/tonne)
Energy cane
($40/tonne)

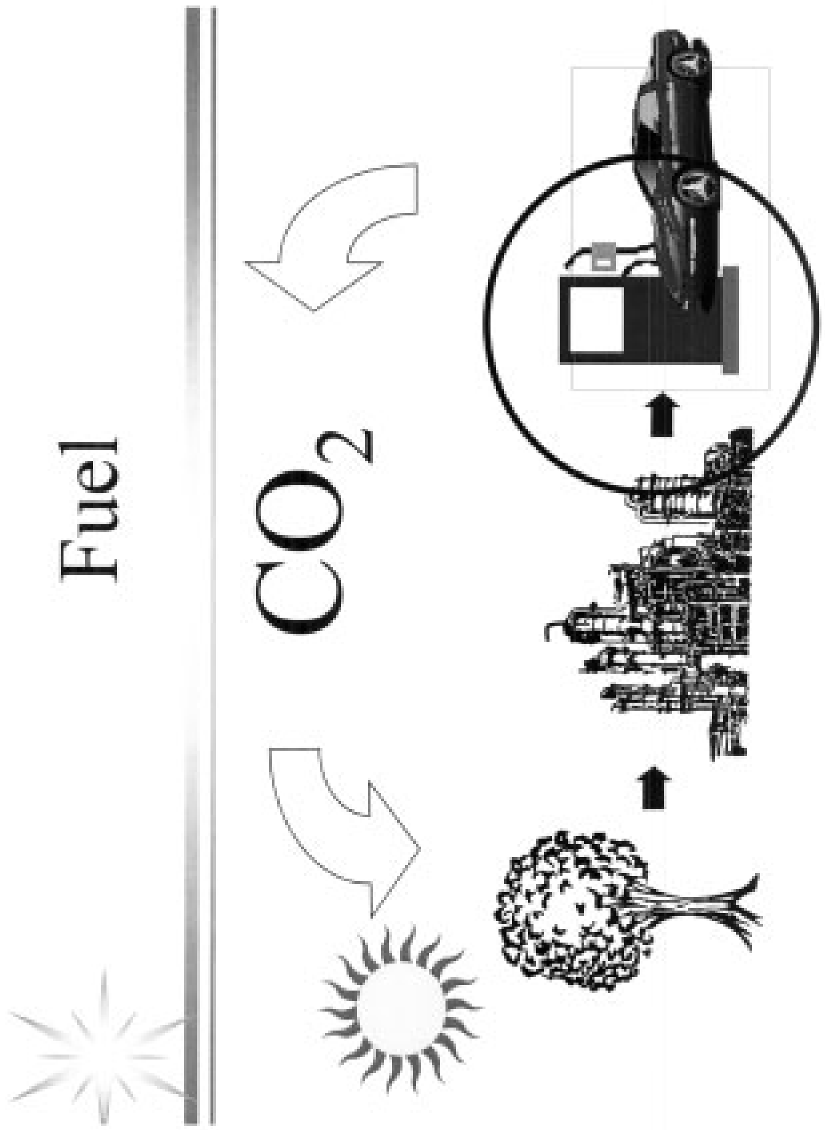
Low Environmental Impact

Environmental cost per unit of biomass	Corn Grain	Sweet Sorghum	Energy Cane
Water	High	Low	Low
Fertilizer	High	Low	Low
Pesticides	High	Low	Low
Herbicides	High	Low	Low
Soil erosion	High	Low	Low


Process
CO2

Ideal Process Properties

No sterility
No genetically modified organisms (GMOs)
Adaptable
No pure cultures
Low capital
No enzymes
High product yields
No vitamin addition
Co-products not required


Fuel
CO_2

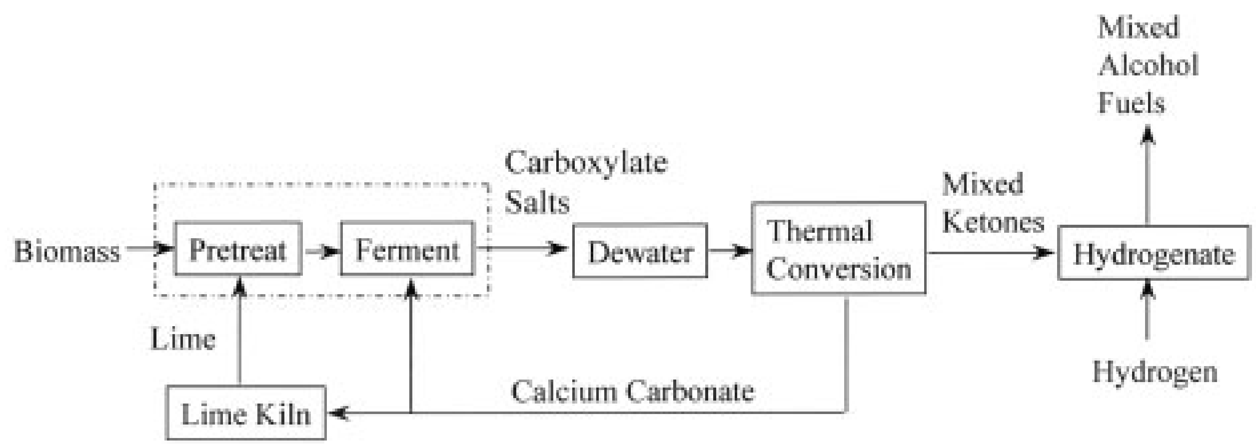
Fuel Properties

	Ethanol	MTBE	Mixed Alcohols
Octane	high	high	high
Volatility	high	low	low
Pipeline shipping	no	yes	yes
Energy content	low	high	high
Heat of vaporization	high	low	low
Ground water damage	no	yes	no

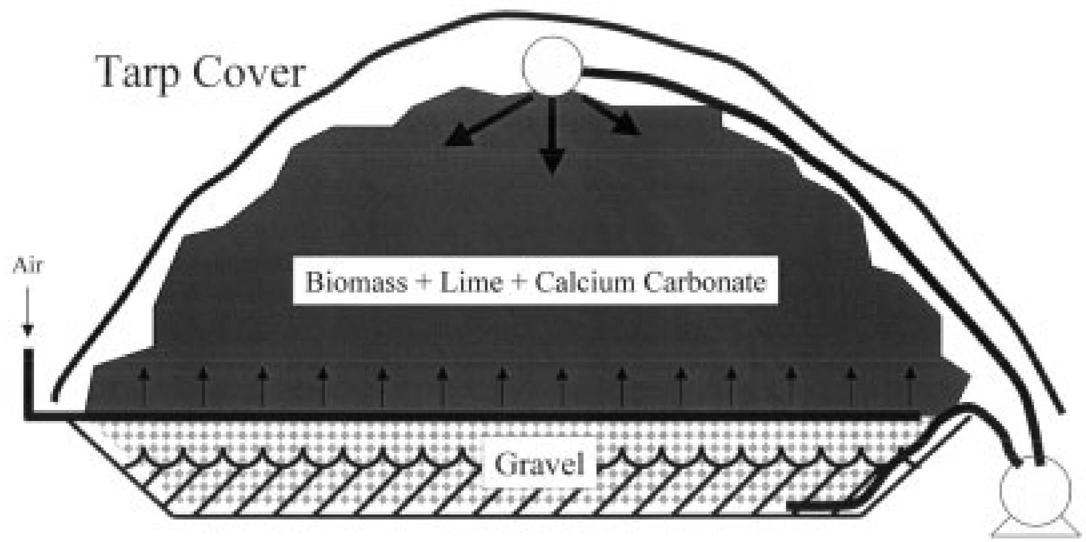
Is there a biofuel technology with the ideal properties?

- ✓ Feedstock
- ✓ Process
- ✓ Fuel

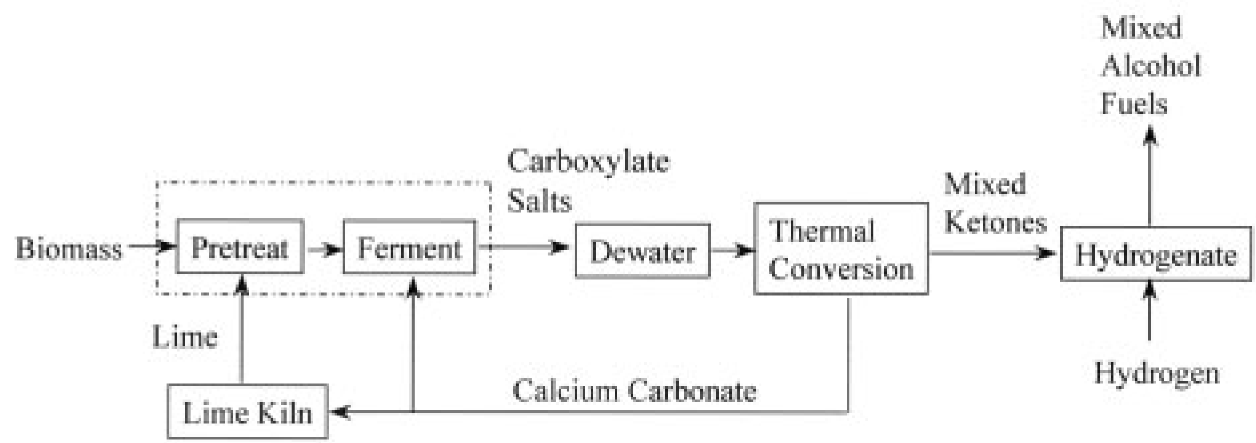
MixAlco Process



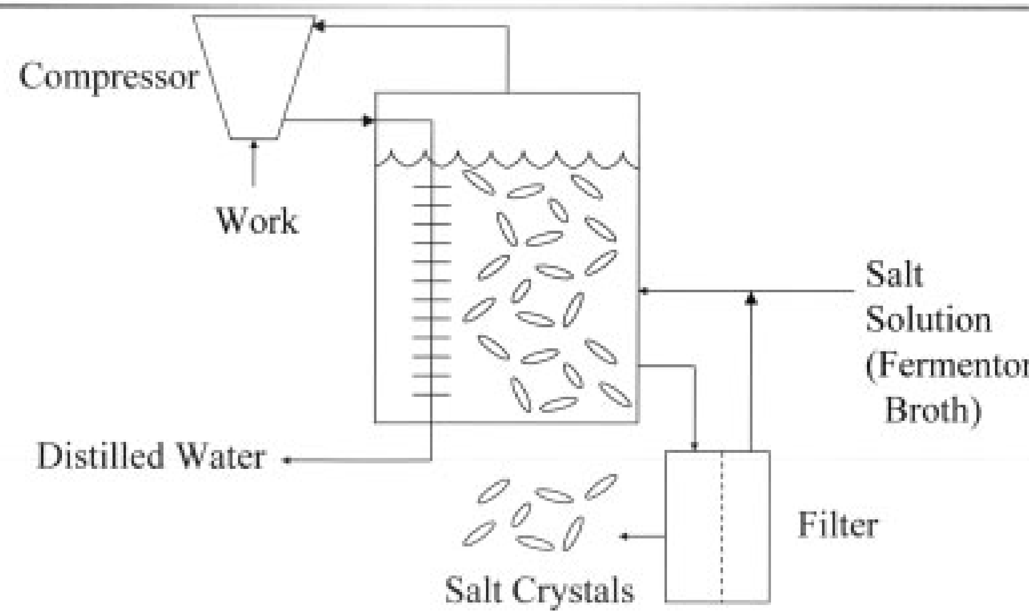
Storage + Pretreatment + Fermentation



Dewatering


Biomass
Pretreat
Ferment
Carboxylate Salts
Dewater
Thermal Conversion
Mixed Ketones
Hydrogenate
Mixed Alcohol Fuels
Hydrogen
Lime
Lime Kiln
Calcium Carbonate

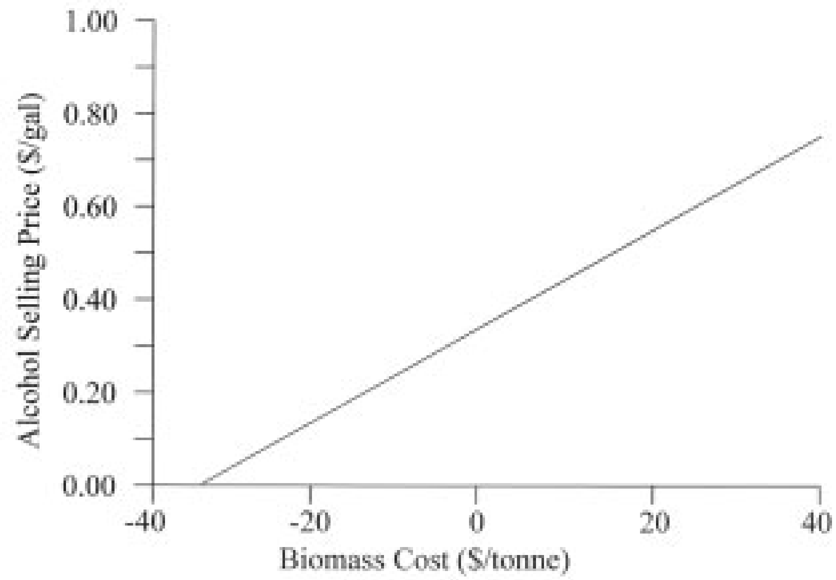
Vapor-Compression Dewatering

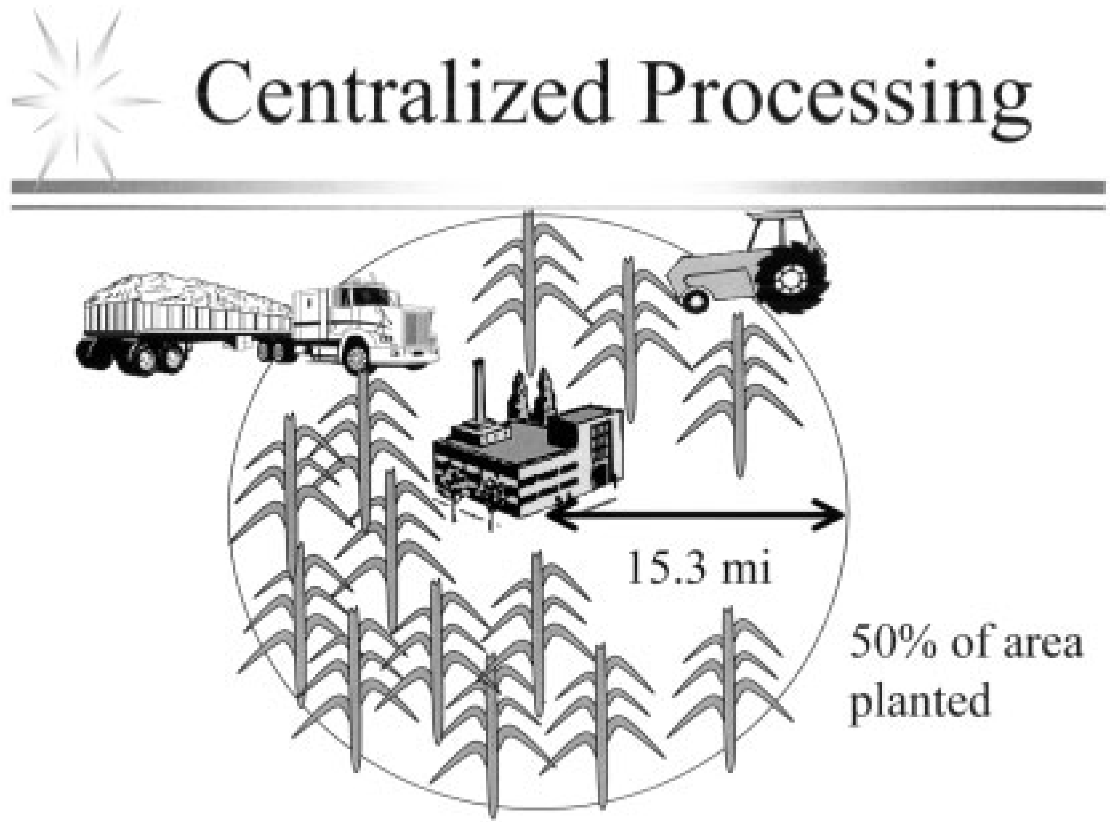


Economics

Effect of Feedstock Cost

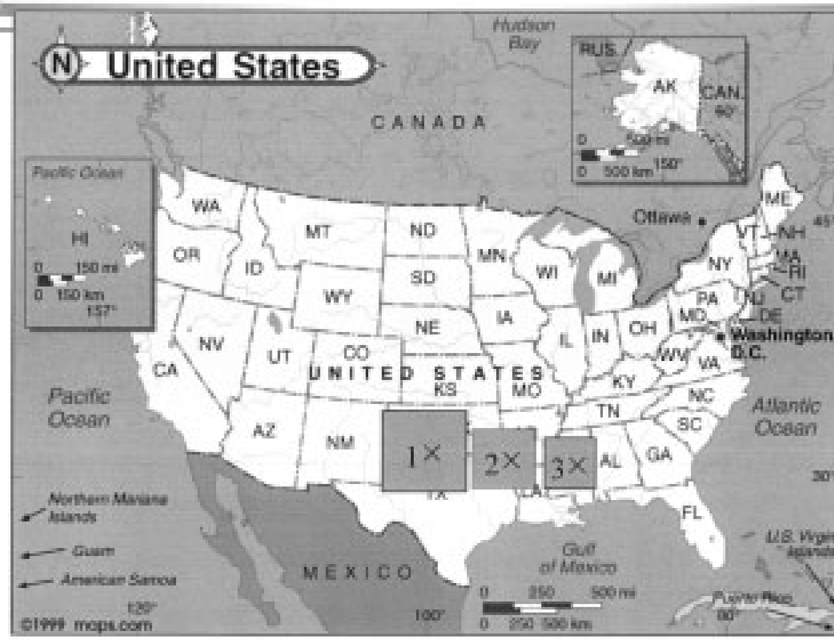
(800 tonne/h, 15% ROI)




Centralized Processing
15.3 mi
50% of area
planted

Meeting US gasoline needs by growing energy cane in Brazil

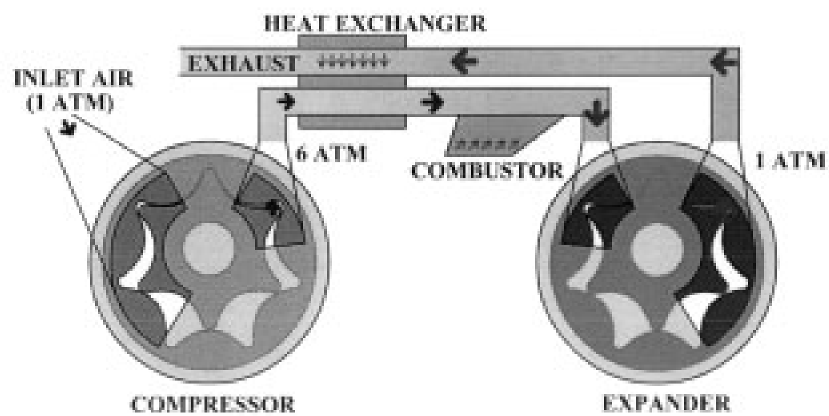
Meeting US gasoline needs by growing sweet sorghum in United States



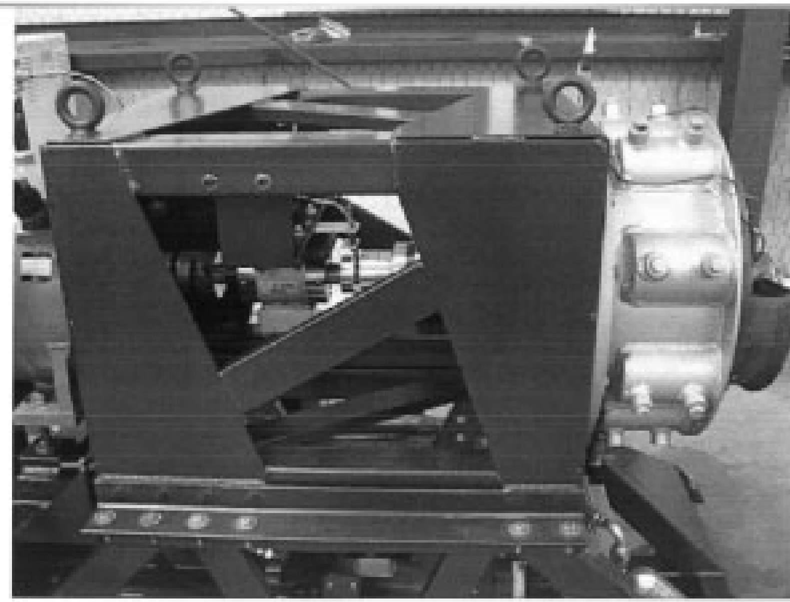
How do we increase engine efficiency?

- Electric hybrids (2 X)
- Better engines (2– 4 X)

StarRotor Engine



Prototype Testing



StarRotor Engine Properties

- High efficiency (~100 mpg)
- Low pollution
- Low maintenance
- Long life
- Low cost
- High power density
- Negligible vibration
- Multi-fuel

Benefits

- Reduce wastes
- Cleaner air
- New agricultural markets
- Energy security
- Improve balance of payments
- Address global warming
- Address energy shortage
- More flexible international relations
- Benefit developing nations

Legislative Action

- Give all biofuels same tax credit as ethanol
- Liability protection for companies that use biowastes (e.g., garbage)
- Support research in biofuels and high-efficiency engines

Mark Holtzapple

In 1978, Mark Holtzapple received his B.S. in chemical engineering from Cornell University. In 1981, he received his Ph.D. in chemical engineering from the University of Pennsylvania.

From 1981 to 1985, Mark served in the U.S. Army and rose to the rank of captain. While in the Army, he performed research on water desalination and microclimate cooling, a method for cooling soldiers encapsulated in chemical protective clothing.

In 1986, Mark became an assistant professor in the Department of Chemical Engineering at Texas A&M University, College Station, TX. He has been steadily promoted and now is a full professor. While a faculty member, Mark has been well recognized for his excellent teaching and has won the following teaching awards:

Corps of Cadets Teaching Award, 2002
Tenneco Meritorious Teaching Award, 2001
Who's Who Among America's Teachers, 1996
Who's Who in Science and Engineering, 2nd Edition
AIChE Student Chapter Award of Excellence, 1992
Tenneco Meritorious Teaching Award, 1991
Texas A&M Association of Former Students Distinguished Teaching Award for Texas A&M University, 1991
Dow Excellence in Teaching Award (Tenured Faculty), 1991
Texas A&M Association of Former Students Distinguished Teaching Award for the College of Engineering, 1990
General Dynamics Excellence in Teaching Award, 1990
AIChE Student Chapter Award of Excellence, 1989
AIChE Student Chapter Award of Excellence, 1988
Dow Excellence in Teaching Award (Untenured Faculty), 1988

In addition, Mark has been recognized with the following research awards:

Spirit of Innovation Award for Ingenuity, 2003
Halliburton Professor, 2002
Ford Fellow, 2001
Brockett Professor, 2000
TEES Senior Fellow, 1999
TEES Faculty Fellow, 1998
McGraw-Hill Environmental Champion Award, 1997
TEES Fellow, 1996
President's Green Chemistry Challenge Award, 1996
TEES Fellow, 1995

Mark has authored nearly 100 technical articles and reports, plus a widely used engineering textbook. Further, he has over 22 issued patents, numerous pending patents, and over 80 disclosures. His research interests include fuels and chemical from biomass, food and feed processing, water desalination, air conditioning, high-efficiency engines, jet engines, and vertical-lift aircraft.

Chairwoman BIGGERT. Mr. Hennekes.

STATEMENT OF ROBERT HENNEKES, VICE PRESIDENT, TECHNOLOGY MARKETING, SHELL GLOBAL SOLUTIONS

Mr. HENNEKES. Well, thank you for letting me speak today. I would like to give my appreciation to both of you for coming and giving Shell the chance to say a few words to Rice University and the rest of you ladies and gentlemen for giving us a few minutes.

What I would like to do is just take a couple of minutes to tell you about some of the things that we at Shell are doing in terms of research and development, and let you know about some of the ways that we are trying to help the environment and provide fuel and energy for the future.

When I was given the opportunity to speak, we first thought that because Shell happens to be a provider of things like gasoline and diesel. Hopefully, most of you have bought some of our product. Any who have not? Okay. That's a good sign.

And so we can talk a lot about oil and gas and fuels, but we were asked to talk about non-fuels, non-oil and gas. And so what I chose to talk a little bit about is those that are starred. First there's coal gasification. We'll talk a little bit about that and how it fits in with CO_2 sequestration.

Secondly, we are going to talk about metallurgy and innovation ways of looking at the metallurgy and trying to find any faults in that metallurgy and make sure that structural materials stay standing for as long as we desire them to stand.

I would be happy to talk about future fuels, lubricants, future catalysts, but that really wasn't what the intention of this was to do.

First of all, Shell Global Solutions, where I happen to work, maybe nobody's heard of that before. That is okay. We are a wholly owned subsidiary of Shell Oil Company. Hopefully, you have heard of Shell Oil. All the folks that are on this diagram you can see are the customers of Shell Global Solutions. To put it bluntly, we are the research service and development people for all of Shell. And so the oil products folks, the renewables, the exploration production all hire us to come in and do work and research and development for them.

Shell Global Solutions also happens to do work outside of the Shell companies. We started doing that about five years ago. So we can actually be hired out by other oil companies, by other research institutes in places such as that to do research and service for the rest of the world.First, let's talk about coal gasification. It's a shame that our former Governor is not here, because I was going to send him back to school for a third time and do a little bit of chemistry.

Everybody understand complete combustion. Complete combustion is when you burn wood, coal, gasoline or anything else you choose to burn. You have a lot of oxygen that's in the air and you go ahead and burn that and its makes CO_2 and water.

The idea is to take anything, biomass, coal from the great state of Illinois. We have worked on some projects there. And not burn it all the way, but partially oxidize it. So only add enough oxygen where the fuel is ready to be burned in a large turbine later one.

When you do that, you get a combination of carbon monoxide and hydrogen. You can then through the same shift reaction that you talked a little bit about previously, take some of that CO make additional hydrogen and you get a very pure stream of CO_2. You can take that CO_2 and sequester it. Currently for a company like Shell what we like to do is put it into a well some place where we're using CO_2 for tertiary recovery, those sort of things. You could even take the CO_2 and put it in Coca Cola or other products such as that. But if you do want to take the CO_2 and sequester it, Shell Global Solutions is working on a very large program with other industry folks to try and figure out how to sequester for reasonable price and minimize the amount of CO_2 going to the atmosphere. Okay.

Everybody understand the chemistry upon the board? Anybody who doesn't, raise their hand. Okay.

This is a gasification reactor. Just so you get a feel for it. Why is it so complex looking? Very simple. This process runs at about 2700 degrees Fahrenheit. 2700 degrees Fahrenheit is not something I have any concept of what it is. I've been by the reactors. I've seen them operate. But 2700 degrees is so high, it is absolutely phenomenal to me. So we have very talented metallurgist, people such as that to design this reactor so it is able to contain those reactions and give us the carbon monoxide and hydrogen that we need.

When we do the gasification of either the biomass, the municipal waste, the coal, those sort of things it is a very, very clean process. That is because it is still in a reduced state. We have not really oxidized it. It is in a reduced state. And we can clean up the sulphur almost completely. We can get rid of the NO_Xs. When a typical material burns, it will make NO_X of hundreds of parts per million. When you burn sin gas, it comes down to 10 to 20 PPM. We have almost no particulates because of the process at all.

The things that we are trying to do in terms of research still is how can we minimize the CO_2 and how can we sequester it? How can we grab the mercury out of the coal so that we do not pollute the lakes and streams? How do we make the burners, the gasifiers and the quench systems all more reliable. Those are all the kind of research that we are doing to try and make this process better. Okay.

I will take questions later on the gasification process.

For metallurgy, one of the things that is very important to a company like Shell is that our plants run and run as long as we desire them to run, and then shut down when we want them to shut down. So one of the devices we have developed is what is called a pulsed eddy current device. And we actually can use it outside of the refinery system.

This, for example, was a bridge and you could not tell where the cracks in the under carriage were occurring. But using this pulsed eddy current device you can actually find all of the cracks, okay. And that's the device. And that's a gentleman looking at the surface to determine the cracks, where they are and you can tell if that bridge or oil refinery or rig has corrosion and has problems and needs to be shut down.

What does this do? It allows us to avoid shutdowns when we do not want. It allows us to keep from flaring and putting hazards material into the atmosphere.

And what you see in front of you is simply a gentleman who is trying to find all the cracks that have already been found by the bridge company. So what they did is they gave us a challenge. They said we do not believe you Shell. We do not think you can do this. They went in, and all we were allowed to do was stay on the top and move our device and find the cracks. We found all of them. After we proved that out, we went back to the bridge that was in place, showed them where all the cracks were. Those were repaired, and we were back in shape. Okay.

That's the kind of research that Shell is doing. And we are more than happy to answer questions later on about that or any other item Shell might be asked about.

Thanks.

[The prepared statement of Mr. Hennekes follows:]

PREPARED STATEMENT OF ROBERT HENNEKES

Introduction

Madam Chair and Members of the Subcommittee, my name is Robert Hennekes. I am Market Development Manager, Gas & LNG, for Shell Global Solutions (U.S.) Inc. and a Vice President of Technology Marketing for Shell Global Solutions, a network of independent technology companies that specialize in cutting-edge technologies. I would like to talk a little more about some of those technologies and how they might contribute to meeting the Nation's energy needs in an efficient and environmentally responsible way.

Shell Global Solutions (U.S.) Inc., a wholly-owned subsidiary of Shell Oil Company, is located at the Westhollow Technology Center in Houston, Texas.

The Shell Global Solutions network is comprised of Shell Global Solutions (U.S.) Inc., Shell Global Solutions International B.V. (operating out of The Hague and Amsterdam (Netherlands), and with sister companies in Thornton (England), Petit Couronne (France), Hamburg (Germany), Kuala Lumpur (Malaysia) and Singapore). Each specializes in its own areas of expertise, and, through service agreements, support each other with research data, operational experience, technical know-how and staff who are top professionals in their own disciplines. When a client contacts any of the companies in Shell Global Solutions, it benefits from the resources of all of them.

Our Experience

I am delighted to have the opportunity to share a little of what we do here in Houston as a center of excellence for technical service in non-traditional energy issues. Shell Global Solutions (U.S.) Inc. provides technical services to third parties, Shell-owned companies and Shell joint ventures including gas transmission companies, chemical and LNG plants, hydrocarbon distribution companies and oil exploration and production facilities.

Shell Global Solutions (U.S.) Inc. provides services in three different areas:

First, we offer Shell technology and successful practices through comprehensive Technical Service Agreements (TSAs). This comprehensive set of services takes the Shell know how, experience, and successful practices and brings it to a company to help increase its margins and efficiencies and to lower its cost structure.

Second, we provide specific services designed to satisfy a companies' individual needs. One example would be providing assistance in a companies' review of its LNG facilities.

Finally, we license industry-leading technologies in gasification, and risk based pipeline assessment methodology.

Shell Licensed Gasification

Gasification is a very versatile process that converts a variety of carbon-containing feedstocks like coal, petroleum coke, lignite, oil distillates, residues and natural gas into synthesis gas by partial oxidation with air or oxygen. Shell has developed two dedicated gasification technologies, the Shell Gasification Process (SGP) for liquid and gaseous feedstocks and the Shell Coal Gasification Process (SCGP) for solid feedstocks, such as coal, lignite and petroleum coke. Both processes have been successfully applied commercially. Gasification projects select Shell technologies due to their high efficiency, versatile applicability, and performance, in addition to the technological know-how and operational experience of Shell Global Solutions.

Shell Gasification Process

Shell originally developed the Shell Gasification Process (SGP) to provide syngas for the chemical industry, e.g., for the production of fertilizer. The syngas can also be used for its combustion value. Feed flexibility, environmental performance, and the ability to use low cost feedstock are important drivers that support further application of this technology for power generation and hydrogen manufacturing in refineries.

In the early years, feeds were usually rather light distillates, but residues became more attractive due to their low cost. Adjustments to the process, such as the development of an improved Soot & Ash Removal Unit, extended the technology to the application for the manufacture of syngas from refinery-derived heavy residues such as those from vacuum distillation, visbreaking and solvent de-asphalting.

The main processes in a gasification system are the gasification, in which the feedstock is reacted with oxygen and steam to raw syngas, the syngas cooling, the sour syngas treatment, and the carbon handling system.

The non-catalytic partial oxidation of hydrocarbons by SGP takes place in the gasifier equipped with a specially designed burner. This design provides for more efficient gas-liquid mixing and a better flame temperature control.

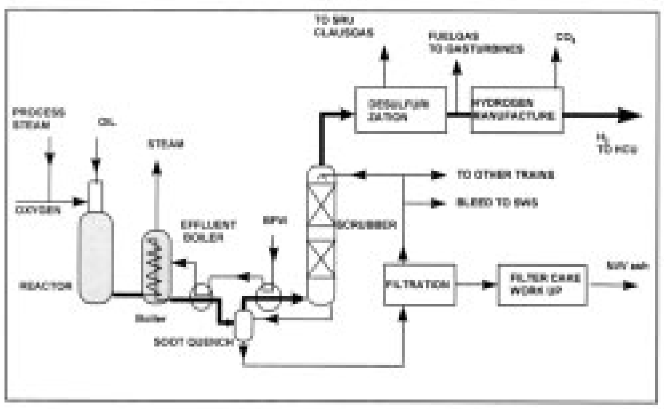


Figure 1 - A typical line-up of an SGP Gasification plant for hydrogen production

Figure 1 shows a typical structure of an SGP gasification plant for hydrogen production. Presently, 82 SGP reactors are producing about 62 million Nm3 syngas per day in 26 plants worldwide. This is equivalent to 23,000 tons of residue per day or nearly 8 million tons of residue per year.

Shell Coal Gasification Process

For gasification of solid feedstocks, a dedicated development program has resulted in the commercially marketed Shell Coal Gasification Process (SCGP). The process is characterized by the following features:

- Dry feed of pulverized coal,
- Compact gasified and other equipment due to the pressurized, entrained flow, oxygen blown concept,
- Slagging, membrane wall gasifier which allows high temperatures because of insulation and protection of wall by solid inert slag layer,
- Multiple, opposed burners resulting in good mixing of coal and blast, large turndown, and large scale-up potential.

The typical syngas product consists of 25–30 percent of hydrogen and 60–65 percent of carbon monoxide. High-pressure steam is produced in the gasification and heat recovery section and can be used, e.g., to generate electricity in the IGCC (Integrated Gasification Combined Cycle) application, thus increasing the efficiency of the whole process. Other by-products are inert slag, elemental sulfur, and relatively small amounts of clean water effluent. As an alternative to discharging the effluent water, it may be evaporated to give a zero water discharge and salts as byproducts. The slag and sulfur can readily be marketed.

The process can handle a wide variety of solid feedstocks, ranging from lignite, brown coal, sub-bituminous coal, bituminous coal, anthracite, to petroleum coke. Coal types can be switched during operation. Over the wide range of coal properties processed, the SCGP process has proven to be insensitive to the size, condition, or other physical properties of the raw coal.

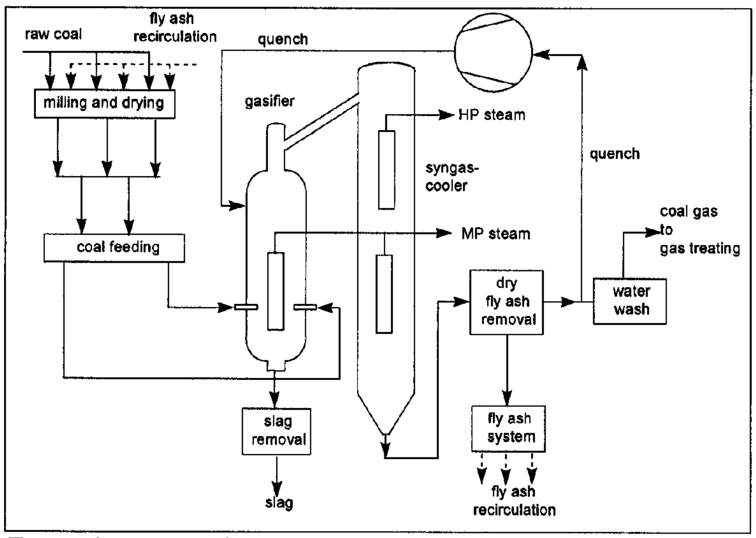


Figure 2 - A typical structure of an SCGP Gasification plant

Shell Global Solution's operational experience with coal gasification started with a 6 t/d pilot plant in Amsterdam, followed by a 150 t/d unit in Harburg, Germany. A third unit in Houston with a capacity of 250–400 t/d fully demonstrated the capability of the gasifier to process a wide range of solid fuels from lignite to anthracite and to petroleum coke. These experiences have led to the successful design, construction and operation of the 2000 t/d coal gasification unit of the Demkolec plant in The Netherlands. Various SCGP plants are at different stages of implementation.

ASSET

The ASSET technology was developed internally for Shell projects and evolved over a period of about 15 years to facilitate improved equipment engineering in the creation of a comprehensive information system for alloys that become corroded by contact with complex, high-temperature gases. ASSET finds wide applications for equipment used in thermal stimulation of heavy oil formations, oil refining, petrochemical processing, and coal gasification.

Joint industry programs are being developed and led by Shell Global Solutions to further advance the technology with the involvement of about 70 other companies, including energy companies, chemicals companies, metals producers, engineering companies, research establishments, and universities from both U.S. and non-U.S. organizations. Financial support and technological co-operation has been achieved from these companies and the U.S. Department of Energy—Office of Industrial Technologies, as summarized in the table here.

Project	Contribution by INDUSTRY AND US DOE – Office of Industrial Technologies	Time Period
ASSET	$3.8 million	2000 - 2003
Chemical Industry Corrosion Management	$2 million	2003-2005

Project Objectives

- Provide industry-enhanced use of technology in application of metals and equipment design for high temperature processes.
- Enhance/commercialize an information system which assists in predicting the rates of degradation of commercial alloys in complex, corrosive, high-temperature gases.
- Gather corrosion data with the participating companies and add to ASSET.
- Generate corrosion data and add to ASSET.
- Use new data to expand the envelope of corrosive conditions and alloys to more fully cover the diverse needs of equipment.
- Enhance thermochemical computations.
- Enhance the capability to predict corrosion behavior.
- Reduce energy consumption in various industrial processes.

Commercialization Plan

The potential users of the product of this project will be chemical process industries that operate processes which involve high-temperature gaseous environments that are capable of causing rapid degradation of the process equipment by oxidation, sulfidation, sulfidation/oxidation, or carburization attack, or by combinations of these modes. Examples can be found in base chemical production, sulfur removal process, and hydrogen production. Since the trend to increased efficiency typically involves the operation of chemical processes at higher temperatures and the creation of increasingly corrosive environments, the application of an advanced alloy selection and service life prediction system such as ASSET could be very wide.

The commercialization of the project's results will be a constant process over the life of the project. Each company participating in the project will have ready access to the most recent version of ASSET and will be trained in its use. Membership of MTI in the project allows more than 55 companies to access the software as it develops and after it is finished. The initial users of the ASSET technology will be the current ASSET member companies, as well as any other companies that join the project. Additional member companies will be sought throughout the life of the project.

Energy Saving Estimates

The estimated energy savings resulting from the successful implementation of the results of the ASSET project are as follows. One installed unit or unit production = an equivalent chemical facility utilizing in one year, one one-thousandth of the energy used by the entire U.S. chemical industry. A two percent improvement is assumed for the impact of the new technology.

Estimated Energy Savings Table

(a) Energy Source	(b) Current Technology (Energy Used per Installed or Production Unit Per Year)	Proposed Technology (Energy Used per Installed or Production Unit Per Year)
Electricity (kWh)	1.52 E-01	1.49 E-01
Natural Gas (cubic feet)	2.50 E+00	2.45 E+00
Petroleum (barrels)	4.20 E-01	4.11 E-01
Coal (short tons)	1.47 E-02	1.44 E-02

[(a)]Energy consumed with the current technology.
[(b)]Estimated energy consumed by the proposed technology.

Environmental Savings from Reduction in Noncombustion-related Emissions

(a) Waste Generated	(b) Current Technology (tons/unit/year)	Proposed Technology (tons/unit/year)
Other Waste Emissions (VOC (metric tons)	2.54 E+02	2.48 E+02

[(a)]Amount of wastes generated with the current technology.
[(b)]Amount of wastes generated by the proposed technology.

The technology to be developed may apply in many processes in the chemical industry in addition to the examples cited here. In order to estimate the impact throughout the chemical industry, an OIT GPRA spreadsheet was used. The project can significantly benefit the chemical industry, including improved energy efficiency, reduced cost and improved productivity, and enhanced environmental benefits in the U.S., which will result from the use of the ASSET computational software. The development and use of the ASSET information system will enable enhanced selection and use of optimal materials for utilization as materials of construction in chemical processes.

Chemical Industry Corrosion Management Project

Project Objectives:

- Improved accuracy in equipment lifetime predictions
- Energy savings of 18.5 trillion Btu by 2020
- Improved process safety and operations
- Reduced maintenance costs and expenses
- Reduced emissions of CO2 and other pollutants

Applications

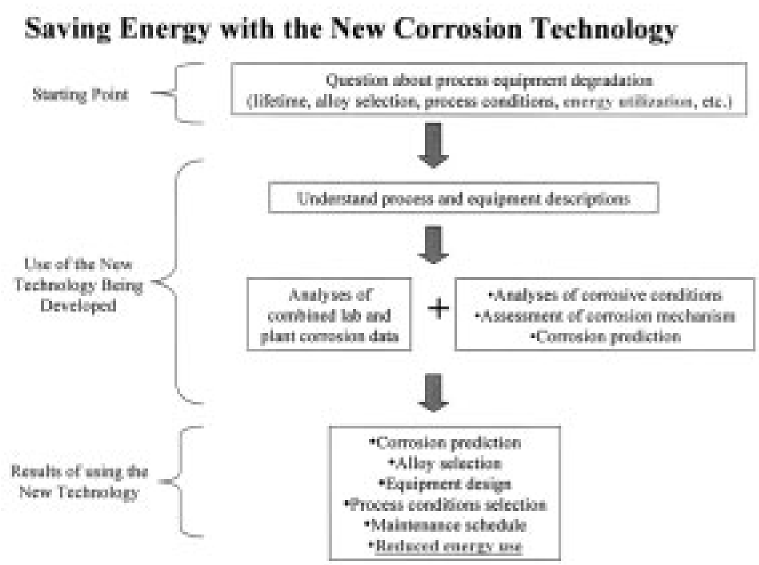
Data for corrosion by Cl_2 and HCl gases and corrosion prediction methods will benefit the forest products and chemicals industry, with applications in chemical processes, incinerators, burning chlorinated materials, and bleaching operations in paper manufacturing. Cyclic oxidation data will be applicable to the chemicals, steel, heat treating, and petroleum industries. Metal dusting data will be applicable to the steel, chemicals and petroleum industries.

Improved Corrosion Management Could Provide Significant Cost and Energy Savings for the Chemical Industry

In the chemical industry, corrosion is often responsible for significant shutdown and maintenance costs. Shutdowns are costly in terms of productivity losses, restart energy, and material costs. These shortcomings could be reduced by improving the capability of engineers to better predict corrosion of alloys under different conditions.

We have a significant opportunity to increase the accuracy used in predicting equipment lifetimes when this equipment is subject to corrosion in high-temperature gases. Researchers are developing corrosion data for commercial alloys, thermochemical models, and increased understanding, which will be delivered to plant designers and operators via an information system to allow industry to comprehensively and reliably predict corrosion. This includes an extensive list of commercial alloys exposed to complex and corrosive gases at temperatures ranging from 200°C to 1,200°C.

Anticipated benefits from improving corrosion management are extensive in the chemical industry, many other industries, and for the U.S. economy. Examples are improvements in process safety, reduction in maintenance costs of process operation, more cost-effective use of expensive alloys in equipment designs, reductions in energy use, moderation in the release of CO_2 and other pollutants to the atmosphere, and more confident use of alloys in progressively more extreme operating conditions. With improvements in corrosion management, equipment maintenance will be better scheduled, and unplanned outages due to unexpected corrosion will be reduced. The estimated annual energy savings by 2020 are 18.5 trillion Btu of CH_4.



Corrosion Project Description

The goal is to develop corrosion technology and to deliver it via an information system that will allow industries to better manage corrosion of metals and alloys used in high-temperature process equipment through improved prediction of corrosion-limited lifetimes and corrosion mechanisms. The project effort in corrosion technology combines comprehensive corrosion databases and thermochemical models and calculation programs to predict the dominant corrosion process. Metal losses by corrosion can then be calculated for commercial alloys over wide ranges of corrosive environments. The corrosion modes to be studied include corrosion by Cl_2/HCl gases, cyclic oxidation, and metal dusting.

The effort will generate several different types of corrosion data. Data for corrosion by Cl_2/HCl gases will be measured under conditions relevant for this mechanism, including temperature, time, gas composition, alloy composition, and mass transport characteristics as influenced by gas flow over metal surfaces. Thermal cycling generally influences oxidation behavior, but it can also promote additional forms of degradation, such as thermal fatigue. Generation of meaningful cyclic oxidation data poses a difficult challenge, due to the diversity of the many potential thermal challenges.

Researchers also intend to create a capability to compile all available data to help in assessments of the tendencies for alloys and metals towards metal dusting in commercial conditions. The aim is to predict metal dusting-limited lifetimes, as defined either by incubation times before onset of metal dusting or by metal loss rates once metal dusting begins.

Milestones

The four main tasks are as follows:

- Software development
- Thermochemical modeling
- Corrosion testing/corrosion technology development
- Commercialization

Commercialization

Developed technology will be transferred to industry through the project's member companies. The effort will be assisted with semi-annual meetings, electronic communication, software updates and presentations to industry conferences. The Materials Technology Institute (MTI) will distribute the technology to more than 50 chemical companies and their suppliers.

Pulsed Eddy Current Technology

Shell Global Solutions originally developed the Pulsed Eddy Current (PEC) technology as an assist for detecting corrosion under insulation (CUI) through insulation material and metal insulation covers. A number of 'spin-off' PEC applications were also identified over the past few years during this research effort.

The basic principle of operation of PEC is the induction of eddy currents in steel by a magnetic field in the sensor. The PEC probe acts both as magnetizer and detector of the induced eddy currents. A PEC probe is placed above a coated steel object. An electrical current is then introduced in the transmitter coil, which magnetizes the steel surface beneath the probe. Subsequently, the current is switched-off, causing the steel to de-magnetize. The sudden change in magnetic field strength generates eddy currents in the steel, which diffuse inwards from the steel, decaying in strength as they propagate. The induced magnetic field of these decaying eddy currents is detected by a set of receiver coils in the PEC probe, and the signal detected relates to the wall thickness.

PEC wall thickness is an average over the area of the probe's footprint, i.e., a roughly circular area where eddy currents flow. In practice, this means that PEC is well suited for measuring general wall loss. PEC is less suited to detect localized damage such as isolated pitting.

When is PEC suited for an inspection problem?

PEC is particularly suitable for the following situations:

No direct access to the metal surface, due to a layer of insulation, thick coatings, fireproofing, road surface or marine growth that is expensive or impossible to remove and for which removing would serve no other purpose.

Surface preparation: PEC does not require surface preparation, which is a crucial advantage in splash zone and underwater applications.

Access: Conventional methods are often not applicable if access is difficult or restricted. PEC is more suited than alternative techniques for deployment by remote access via jigs, suspension on cables, abseilers, ROVs and 'key hole probes.' This relates to the tolerance against misalignment of the PEC probes with respect to the steel surface.

Monitoring, especially at high temperature: PEC is uniquely suited for in-service monitoring of steel.

The technical feasibility of PEC relates to:

- Nature of the degradation PEC can detect and size general corrosion, but often fails to detect more localized corrosion.
- Complexity of the geometry: PEC is best suited for 'simple' geometries, i.e., straight sections of pipes without any nozzles and supports. It is possible, but more difficult, to apply PEC around more complex geometries.
- Thickness of the insulation: the thicker the insulation, fireproofing, etc., the more difficult it is to apply PEC.

Based on the utility and technical feasibility, the PEC applications can be categorized as follows:

Regular Applications

Corrosion monitoring
Splash zone inspection of coated risers and caissons
Under water inspections of caissons by remote operated vehicle (ROV)
Measurements through coatings and fireproofing
Well tubular inspections (offshore)
Key-hole inspections (e.g., annular rings storage tanks)
Measuring remaining wall thickness through corrosion products
Corrosion under insulation
High temperature inspections of a vessel (not corrosion monitoring)

Niche Applications

Delamination (few applications only)
Detection of cracks in welds (e.g., for inspection of orthotropic steel bridges)
Detection of geometrical anomalies (e.g., frame detection of sunken ships)

Technical Progress Over the Last Three Years

The Research and Development of the PEC team of Shell Global Solutions has led to a number of improvements to the PEC technology. This program also led to seven patent applications.

The main technical improvements are:

Patents have been filed for the focused probe design. This design reduces the footprint by about a factor of five with respect to other probe designs.

PEC profiling is being developed. PEC profiling further enhances the defect sensitivity for external corrosion.

Keyhole probes have been developed. These probes allow inspection in locations with restricted access.

A method has been developed to make PEC highly reproducible. A patent application has been filed on PEC corrosion monitoring.

Directional Pulsed Eddy Current is being developed for crack detection applications.

Portability

A unique feature of PEC is its portability. With PEC, a single sensor can be used to monitor many different locations. Positioning frames and center pop marks are used to ensure that the PEC probe is accurately located in the same monitor position each measurement.

The portability of PEC has important advantages over alternatives:

- Robustness. No fixed parts.
- Economical. Costs are saved by using just one set of equipment for many different locations.
- No problems with high temperature (tested up to 420°C).
- Installation: can be done while the equipment is running; no need for welding.

PEC probes are also available to monitor wall thickness at fixed positions. These are used to determine corrosion rates in areas where it is difficult to use the mobile PEC probe (e.g., in areas where scaffolding is required). The method is illustrated with Figures 3 and 4.

Figure 3- PEC monitoring

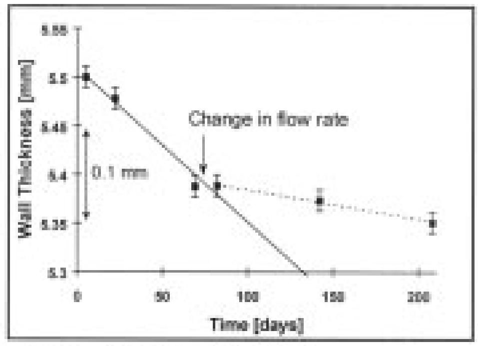


Figure 4 – Data collected over time

In the photo (Figure 3), data collection is shown in progress on an insulated pipe operated at 320°C. The operator places the PEC probe on a measurement position that is defined by a positioning frame or by center pop points on the pipe surface. The result of six such measurements recorded over a time span of 200 days is displayed in the accompanying graph (Figure 4). Note the expanded wall thickness scale.

PEC corrosion monitoring probes can also be fixed to pipes. For hot insulated pipes, the probes are strapped to the insulation; otherwise, probes are simply and directly strapped to the pipe.

Environment Remediation and Sustainability

Shell Global Solutions has active applied research underway in the Houston area for environmental remediation and sustainability. At the Shell Westhollow Technology Center, we continue to create more efficient and cost-effective site remediation methods for petroleum in the environment, including low-intensity biological remediation processes.

To promote sustainability concepts, Shell established Rice University's new Shell Center for Sustainability last fall through a $3.5 million endowment from the Shell Oil Company Foundation. Building on the Environmental and Energy Systems Institute's interdisciplinary program of education, research and outreach, the Shell Center focuses on the role of the private sector in implementing a sustainable future.

Royal Dutch/Shell Chairman Sir Philip Watts spearheaded the development of the center and also addressed the first conference held in March of this year. One of the primary goals of the new research center is to develop established methods or practices that industry can follow in order to foster sustainability.

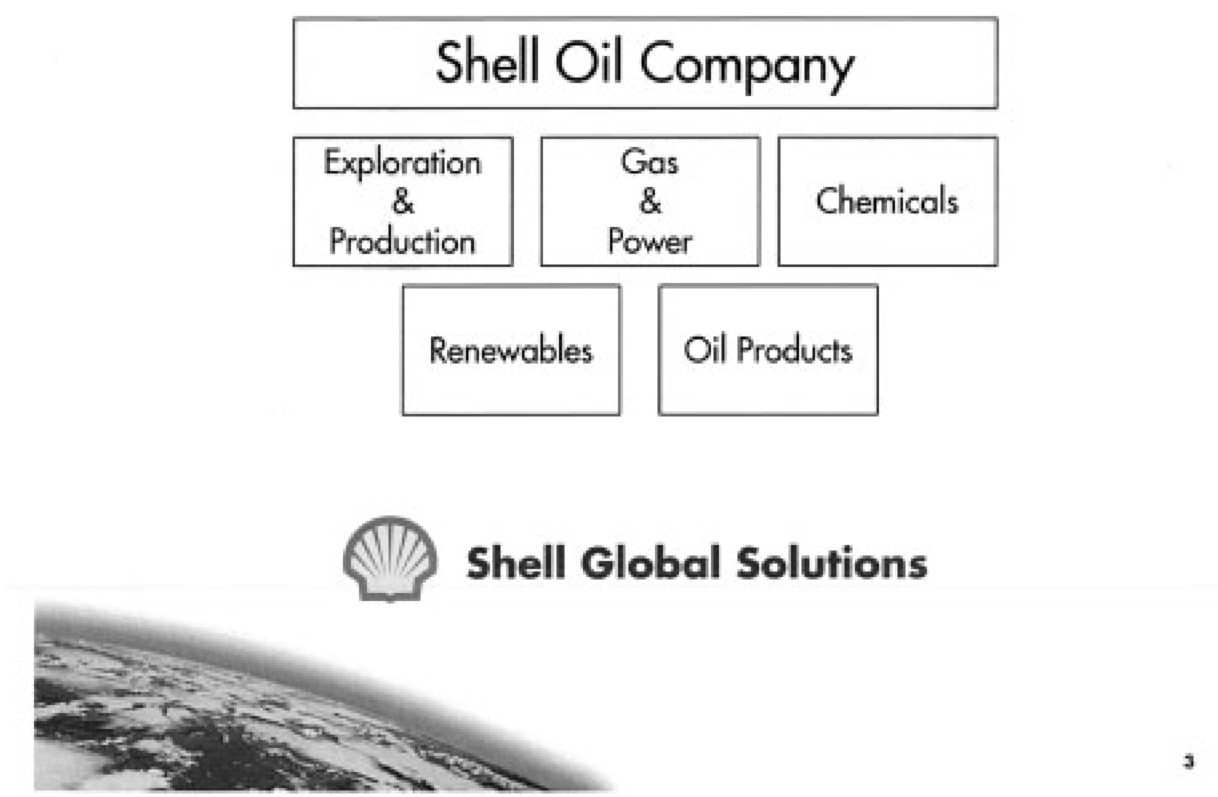
Shell Global Solutions

Presentation on Shell Technology to the House Science Committee

by Bob Hennekes

Research from Shell Global Solutions

Coal Gasification *
Metallurgy *
Future Fuels
Lubricants
Future Catalyst


Shell Oil Company
Exploration & Production
Gas & Power
Chemicals
Renewables
Oil Products
Shell Global Solutions
3

Shell Global Solutions

Coal Gasification

Shell Global Solutions

Gasification - Simplified

Complete Combustion

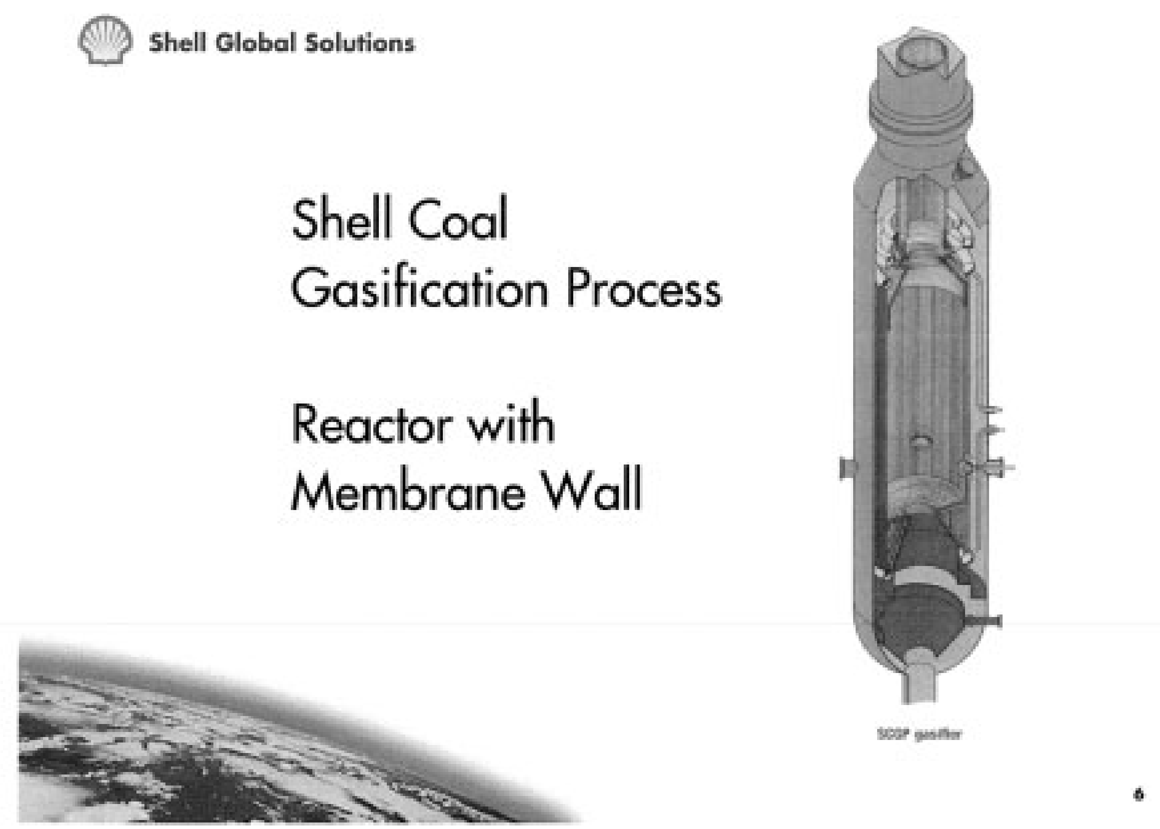
$$2(CH) + 2\tfrac{1}{2}\ O_2 \longrightarrow 2\ CO_2 + H_2O$$

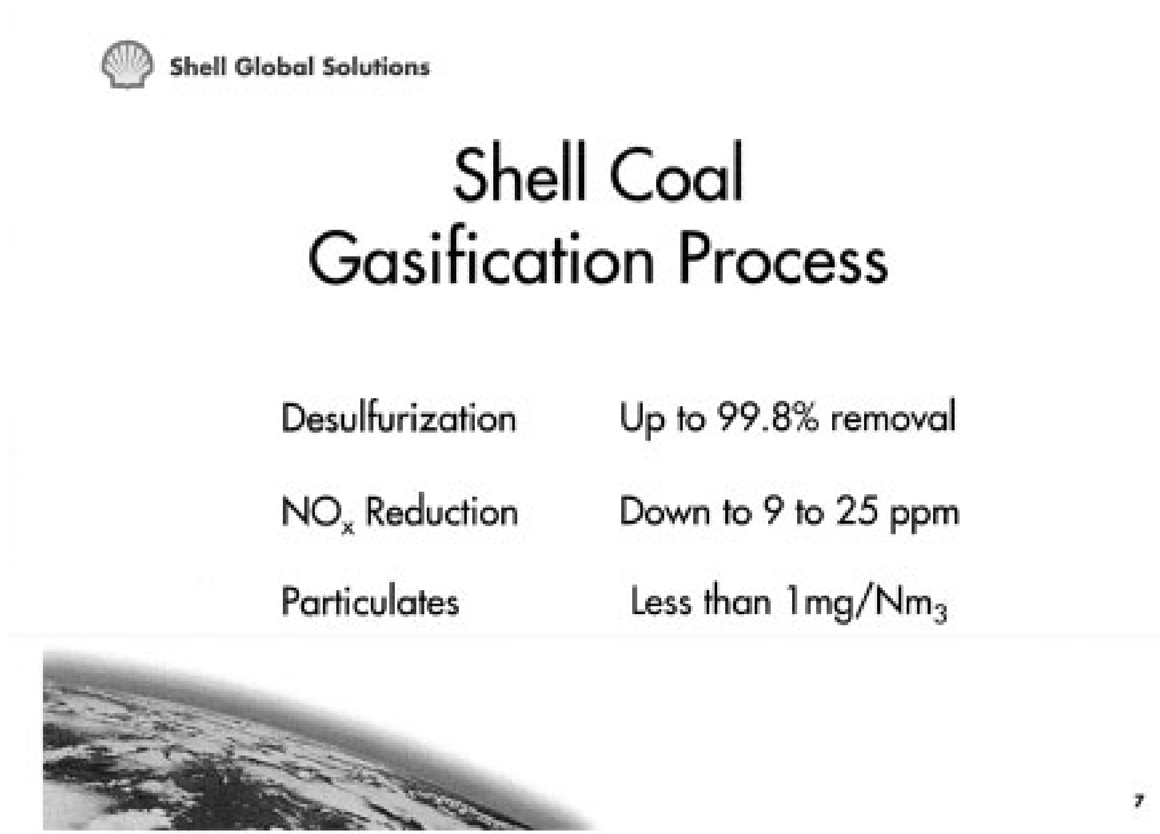
Partial Combustion

(Gasification)

$$2(CH) + O_2 \longrightarrow 2\ CO + H_2$$

5


Shell Global Solutions
Shell Coal
Gasification Process
Reactor with
Membrane Wall
SCGP gasifier
6


Shell Global Solutions
Shell Coal
Gasification Process
Desulfurization
Up to 99.8% removal
NOx Reduction
Down to 9 to 25 ppm
Particulates
Less than 1mg/Nm3
7

Shell Global Solutions

Shell Coal Gasification Process

Ongoing Research

- CO_2 minimization
- Mercury capture
- Burner reliability
- Gasifier reliability
- Quench reliability

8

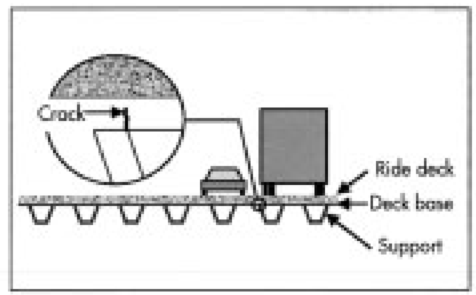
Shell Global Solutions

Metallurgy

Shell Global Solutions

The Problem

- Cracks in the deck base could cause the bridge to collapse
- Repairs are costly
- How to find the cracks without tearing up the ride deck?



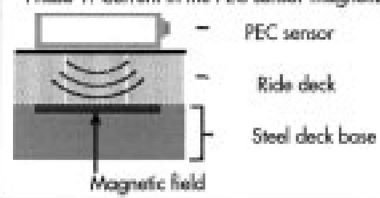
Shell Global Solutions

The Solution!

Pulsed eddy current (PEC)

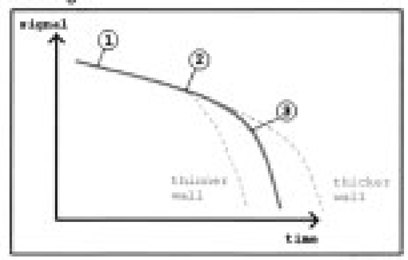
A technique to detect metallurgical defects without touching the metal

Phase 1: Current in the PEC sensor magnetizes the steel base

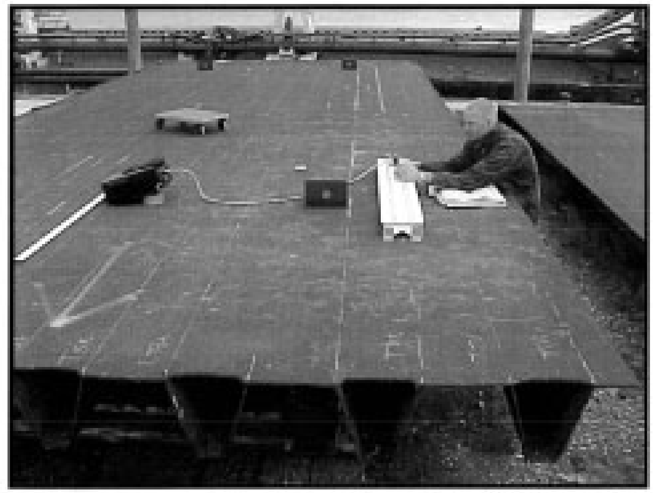


Phase 2: Shutting off the sensor current induces eddy currents in the steel base, that diffuse back and are detected by the sensor

PEC Signal



PEC Tool in Operation



BIOGRAPHY FOR ROBERT HENNEKES

Bob Hennekes is currently Vice President, Technology Marketing, for Shell Global Solutions (U.S.) Inc. Bob manages a group of sales professionals to gain technology business for Shell. Bob has a BS degree in Chemical Engineering from the University of California at Davis. Bob has a 22-plus year history in downstream (refining) for Shell and currently works with companies that need technology solutions in the midstream (Gas), namely LNG, Gasification, and Gas to Liquids.

Bob's prior work has been in technology, operations, project management, sales and marketing. Bob has worked in Gas, Refining, Pipeline and Distribution and Lubricants.

Bob is married to Kelley Hennekes for 18 years and has three adopted children: Bud, born in California, A.J., born in New Orleans, and Sammie Jo, born in Katmandu, Nepal.

Chairwoman BIGGERT. Thank you.

Last but not least, Dr. Chang-Dìaz.

STATEMENT OF DR. FRANKLIN CHANG-DÌAZ, NASA ASTRONAUT AND DIRECTOR OF THE ADVANCED SPACE PROPULSION LABORATORY, JOHNSON SPACE CENTER

Dr. CHANG-DÌAZ. Thank you very much.

Thank you for the opportunity to come and present this, and I'll go fast because I want to stay within your time.

As a way of introduction, I'd like to include some personal experiences that over many years have shaped my perspective on the subject of energy and space; my two most favorite subjects. I was fascinated by the topic of nuclear energy as a young boy. Since early childhood I remember an important event In Costa Rica as a boy in the late 1950's.

A traveling scientific exhibition was sponsored by the United States and was set up in a very large inflatable dome at the airport in San Jose. It was entitled "Atoms for Peace" and it was sent throughout the whole Latin America region to educate the public about atomic energy.

The exhibition spent several days in the country and, while it was there, every day after school I delighted myself in examining the new universe of atomic particles, their magical and amazing power for converting their mass into energy, according to Einstein's famous formula. The exhibitors talked about our growing energy needs and of the great future potential of this new power source. So it appeared halfway through the 20th century.

Like many children of my day, I was captivated by space and the flight of Sputnik; but, as a young child, nurturing dreams of space exploration, the relationship between space and atomic energy was the central notion that guided my chosen career. In my mind, the ships that would carry humans to the stars would be nuclear powered. The later news of the USS Nautilus opening a new sea route under the north polar cap was only a natural first early step.

This progression would eventually lead to similar ships traveling far and fast, not just through the ocean depths, but through the depths of space.

As a young high school student in Costa Rica I came across a NASA brochure written by Dr. Van Brown which was entitled *Should You Be A Rocket Scientist.* Immediately I sent in my response with a resounding yes. This NASA response that I got was a form letter, which you have in the testimony here. I have kept it over all these years, 36 years. In fact I have the whole envelope right here which has been with me since I came to this country.

[The letter referred to follows:]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35812

IN REPLY REFER TO:

PA

July 20, 1967

Mr. Franklin R. Chang D.
75 Vrs. oeste Bar La Primavera
San Rafael de Escazu
Costa Rica, Central America

Dear Franklin:

This is in reply to your recent inquiry concerning educational and career opportunities in rocketry and astronautics. Please know that we are very glad to hear of your interest in this challenging and fascinating field of activities. Your aspirations are commendable.

The enclosed material will help you in seriously planning such a career by providing an overall idea of the basic requirements and employment opportunities for future rocket engineers and space scientists. Of course, we are not in a position to give any individual advice on what specific college or university to attend or what courses of study to follow. Such a selection will depend entirely on your personal qualifications, talents, interests, and various other circumstances. Also, we are unable to foresee what job opportunities will be available in your own country. Careers with NASA are generally limited to United States citizens.

However, through NASA's Office of International Affairs, a number of cooperative space agreements with other nations have already been initiated. By inquiring with your Government, universities, or astronautical organizations in your area, you may be able to get expert advice on your country's participation in the exploration of space and obtain additional information geared to your particular needs.

NASA has an "International University Fellowships in Space Science" program which awards one-year fellowships for graduate or postdoctoral studies at U. S. universities to qualified applicants who are sponsored by their national or regional space research organizations, and who expect to continue space research work in their own countries afterwards. The sponsoring agency and the U. S. National Academy of Sciences, which administers the program for NASA, share each Fellow's expenses; if the sponsor and the university concur, a Fellowship may be extended for a second year.

2

Additional information may be obtained from the Office of Scientific Personnel, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D. C.

We certainly hope you will find it possible to realize your plans for a successful career in rocketry and astronautics and wish you the best of luck for the future.

Sincerely,

Bart J. Slattery, Jr.
Chief of Public Affairs

Enclosures

The message was very simple. To pursue a career in space I would have to come to the United States, and so I did. I had arrived in the United States in the fall of 1968 dreaming of NASA, space exploration and of working on the rockets that would carry us to the planets. Yet, while I watched landing on the moon as a college freshman, it was the energy crises of the 1970's that really provided the immediate imputes for my pursuit of a career in nuclear power, and ultimately the power of controlled fusion, the power of the stars.

It has been my belief since then that space exploration and fusion energy research are closely linked together and have a strong synergistic relationship which is embodied in the field of space propulsion. Controlled fusion power has been very elusive, but the pace of world research in this field has been steady, has been relentless.

It was during my graduate studies in plasma physics and nuclear power at MIT that I came to fully comprehend the awesome magnitude of the technical challenge. To heart a gas to temperatures of millions of degrees, greater than the interior of the sun and maintain this plasma in that container that wouldn't melt and the bear nuclei of the plasma would smash into each other fusing into heavier elements and releasing large quantities of energy. The energy would be captured, converted into electricity to power the engines of our civilization. The fuel would be hydrogen, the most abundant element in the university, and plentiful in our oceans.

The physics and engineering challenges to bring about controlled fusion conditions are daunting, yet such conditions are gradually be reached in multiple fusion experiments throughout the world today. The use of electromagnetic waves similar to those that we use everyday to heat our lunch as a quick meal are used to heat plasma to thermal nuclear conditions. Million degree plasma is suspended in strong force fields away from any physical structure so nothing can melt. Some of these magnetic bottles are just like gigantic donuts that have no holes and nothing can escape.

In this decade several major experiments in Europe, Asia and the Americans will be posed to demonstrate the conditions needed for a power producing reactor. The large world investment, investment in fusion research has spawned a host of new technology which can have immediate pay off. It is here that NASA through the development of plasma rock, it has come into the picture.

Through our research in plasma and controlled fusion, we can now consider rockets with exhaust temperatures in the millions of degrees, with a carefully shaped magnetic nozzles, the plasma accelerates, without melting anything, to velocities which are unthinkable with our present chemical rockets. The use of these plasmas for rocket propulsion has opened a new realm of technology within the existing field of electric propulsion.

We utilize the same plasma heating techniques and employ the same diagnostic sensors, which have been developed through years of difficult and expensive research in fusion. So, even before fusion becomes a reality, we can now reap a handsome benefit from the high investment.

Plasmas are the key to our future space transportation needs, but, as the name implies, electric propulsion depends on the availability of large amounts of electrical power in space. The synergism between power generation and space propulsion is again highlighted.

I often say that in space, power is life. As we reach the orbit of Mars and beyond, the rays of our Sun become too feeble to power human expeditions. At these distances, even our miniature robots rely on nuclear electric generators and heaters to stay alive. Future human expeditions will do so as well.

Recognizing this important technical requirement, NASA has embarked on the development of advanced nuclear power systems for these deep space exploration. These are extremely important for the development of a robust human and robotic exploration program. The cornerstone of this initiative is Project Prometheus, which is presently focusing on the definition of a very exciting mission: the radar exploration of three of the moons of Jupiter.

Propelled by nuclear electric rockets and equipped with much higher power instruments than the earlier Galileo probe, the robot will search for hidden oceans, and perhaps life, beneath the icy crusts of Jupiter's moons.

Our research group at the Johnson Space Center has been engaged in the development of the VASIMR engine, a new concept in high-power plasma propulsion, which embodies many of the concepts and techniques I have described. Our rapid progress has benefited greatly from a strong government inter-agency collaboration, involving the Oak Ridge and Los Alamos National Laboratories and three NASA centers. Several universities are also involved as well.

We are also stimulating the private sector, through small innovative research opportunities in superconductivity, advanced materials and other areas.

The synergistic relationship I describe between energy research and space propulsion plays in both directions. For example, a key component of the VASIMR rocket is a high-power plasma source known as a "helicon," which produces efficient high-density plasma. This plasma we then boost in energy to produce the propulsion that we need. This was invented by Australian physicist Dr. Roderick Boswell, and it was not addressed in a very large way in the early '60's, but it has now taken a much stronger effort.

Recent experiments have opened new applications of these devices for terrestrial use in plasma processing of advanced semiconductors and in the elimination of highly toxic waste. We are driving helicon discharges to ever higher plasma densities and power levels, consequently, knowledge of the physics of helicons continues to improve.

Let me just advance toward the end, because I wanted to point out to you that we believe we are also leaving a strong imprint in the development of fundamental plasma science at both the experimental and theoretical level. I know you are very interested in education, so doing so we are nurturing the education of our young and the training our future scientists. Since we began research operations at the Johnson Space Center in 1995, we have trained a total of 56 graduate and undergraduate students.

In strengthening our educational mission and in a matter reminiscent of that traveling science demonstration "Atoms for Peace"

I mentioned earlier, our team initiated an educational experiment with the Odyssey Academy, a predominately Hispanic middle school in Galveston, Texas. The project involves the teaching of an 11-week curriculum in plasma rockets to a class of 20 selected students from 6th to 8th grades. It has been a great success.

To end, I just want to say that humans began exploring space the day they chose to walk out of their caves in search for food. Space exploration is nothing less than human survival. You probably have heard us say that the first human being to set foot on Mars is alive today and living now somewhere on planet Earth, a young girl or boy sitting in one of our classrooms at this very moment. Will they be discouraged or encouraged by their elders?

I was blessed with the best parents anyone could ever have and perhaps fortunate to find a display on atomic power and a NASA brochure on rocket science to keep me going.

The opportunities we offer our young in these exciting fields of energy research and space exploration are key to our technological growth and the preservation of our way of life. I am indebted to this great nation for it has allowed me to partake in the greatest of human adventures. I hope we can continue to inspire our future generations to carry out our human legacy into the vastness of space.

I sincerely appreciate the opportunity to appear before the Subcommittee today, and I look forward to answering your questions. Thanks.

[The prepared statement of Dr. Chang-Dìaz follows:]

PREPARED STATEMENT OF FRANKLIN CHANG-DÌAZ

Madam Chair and Members of the Subcommittee, thank you for the opportunity to testify before you today regarding energy research and its relationship to our current activities in advanced propulsion at NASA's Johnson Space Center (JSC).

As a way of introduction, I would like to include some personal experiences that over many years have shaped my perspective on these subjects. I was fascinated by the topic of nuclear energy since early childhood. I remember an important event as a young Costa Rican boy in the late 1950s. A traveling scientific exhibition, sponsored by the United States, was set up in a large inflatable dome at the national airport in San Josè. It was entitled "Atoms for Peace" and was sent throughout Latin America to inform and educate the public about atomic energy. The exhibition spent several days in the country and, while it was there, every day after school I delighted myself in examining the new universe of atomic particles, their magical and amazing power for converting their mass into energy, as predicted by Einstein's famous formula. The exhibitors talked about our growing energy needs and of the great future potential of this new power source. So it appeared half way through the 20th century.

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As a young high school student in Costa Rica, I came across a NASA brochure, written by Dr. Werner Von Braun and entitled "Should You Be a Rocket Scientist?" I immediately sent him a letter with a resounding "yes." The NASA form letter response, which I have kept and enclose with this testimony, came months later and had a simple message: to pursue such a career I would have to come to the United States. So I did.

I had arrived in the United States in the fall of 1968, dreaming of NASA, space exploration and of working on the rockets that would carry us to other planets. Yet, while I watched the landing on the Moon as a college freshman it was the energy crisis of the 1970s that provided immediate impetus for my pursuit of a career in nuclear power and ultimately the promise of controlled fusion, the power of the stars.

It has been my belief since, that space exploration and fusion energy research are closely linked, and have a strong synergistic relationship, which is embodied in the field of space propulsion.

Controlled fusion power has been elusive, but the pace of world research in this field has been steady and relentless. It was during my graduate studies in plasma physics and nuclear power at MIT that I came to fully comprehend the awesome magnitude of the technical challenge:

> To heat a gas to temperatures of millions of degrees, greater than the interior of the Sun, and maintain this so-called "plasma" in a container that would not melt. In doing so, the bare nuclei of the plasma smash into each other, fusing into heavier elements and releasing large amounts of energy. The energy is captured and converted into the electricity that powers the engines of our civilization. The fuel is hydrogen, the most abundant element in the universe and plentiful in our oceans.

The physics and engineering challenges to bring about controlled fusion conditions are daunting, yet such conditions are gradually being reached in multiple fusion experiments throughout the world today. The use of electromagnetic waves, similar to those we now use to heat a quick meal, are used to heat plasmas to thermonuclear conditions. The million-degree plasma is suspended in strong force fields, away from any physical structure, so nothing can melt. Some of these magnetic "bottles" resemble gigantic doughnuts, with no openings for the plasma to escape. In this decade, several major experiments in Europe, Asia and the Americas will be poised to demonstrate the conditions needed for a power-producing reactor.

The large world investment in fusion research has spawned a host of new technologies, which can now have immediate payoff. It is here that NASA, through the development of plasma rockets, has come into the picture.

Rockets work by the ejection of high speed gases through a nozzle. The faster the exhaust, the better the rocket. To make the exhaust fast, we generally make it very hot. Our best chemical rockets of today produce exhaust temperatures of thousands of degrees, right at the limit of the melting point of the materials, which hold the rocket together.

Through our research in plasmas and controlled fusion, we can now consider rockets with exhaust temperatures in the millions of degrees, with a carefully shaped magnetic nozzle, the plasma accelerates, without melting anything, to velocities unthinkable with our present chemical rockets. The use of these plasmas for rocket propulsion has opened a new realm of technology within the existing field of electric propulsion. We utilize the same plasma heating techniques and employ the same diagnostic sensors, which have been developed through years of difficult and expensive research in fusion. So, even before fusion becomes a reality, we can now reap a handsome benefit from the high investment.

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The synergistic relationship I describe between energy research and space propulsion plays in both directions. For example, a key component of the VASIMR rocket is a high-power plasma source known as a "helicon." It efficiently produces high-density plasma, which we subsequently boost in the VASIMR to a much higher energy state suitable for propulsion. Australian physicist Dr. Roderick Boswell, and his team at the Australian National University, invented the helicon in the late 1960s. However, the technology of these devices did not develop beyond discrete low-power uses in the field of plasma processing of semiconductor chips.

Recent experiments have opened new application of these devices for terrestrial use in plasma processing of advanced semiconductors and in the elimination of highly toxic waste. We are driving helicon discharges to ever higher plasma densities and power levels, consequently, knowledge of the physics of helicons continues to improve today, driven partially by the renewed interest in plasma propulsion. A strong collaboration with Dr. Boswell's group in Australia is also developing and NASA is drafting a collaborative Space Act Agreement with the Australian team, to jointly continue the development of helicon physics. More recently, also in the experimental arena, our collaborators at the Oak Ridge National Laboratory, working under U.S. Department of Energy sponsorship, discovered an intriguing high-density helicon mode of operation, which would greatly enhance VASIMR performance. We are planning to utilize these advances in our high-power experiments next year.

Another important area where the NASA research component enhances the originally borrowed technology is in the field of superconductivity. Powerful superconducting magnets are used in fusion research to generate the strong fields required to contain the hot plasma. However, in their familiar fusion application, these magnets are generally heavy and bulky and not suitable for space flight. We are extending the technology to the new lightweight superconducting materials, which are now coming of age and incorporating cryocooler technologies developed for the Hubble Space Telescope. The end result is lightweight and compact superconducting magnets, which operate at higher temperatures. In this form, they become attractive for other terrestrial applications, such as transportation, medicine and energy storage and distribution.

We believe we are also leaving a strong imprint in the development of fundamental plasma science at both the experimental and theoretical levels. In doing so, we are nurturing the education of our young and the training our future scientists. Since we began research operations at the Johnson Space Center in 1995, we have trained a total of 56 graduate and undergraduate students.

One of our most recent Ph.D. graduates, Dr. Alexei Arefiev of the University of Texas at Austin, was awarded the prestigious Marshall Rosenbluth Outstanding Thesis award for 2003 by the American Physical Society. This is the first time this National award was given to a NASA project and the first time it was given in the field of propulsion research. Alexei's thesis described the fundamental physics responsible for the energy boost imparted to the plasma in the VASIMR engine. Our team at JSC has recently verified experimentally these theoretical predictions.

In strengthening our educational mission, and in a manner reminiscent of that traveling science demonstration "Atoms for Peace" I mentioned earlier, our team initiated an educational experiment with the Odyssey Academy, a strongly Hispanic middle school in Galveston, TX. The project involves the teaching of an 11-week curriculum in plasma rockets to a class of about 20 selected students from 6th to 8th grades. The pilot course involved our entire research group, in teams of two for each of the 11 classes. The investigators conducted lectures and experimental demonstrations at the school on the basic physics of energy production and plasma rockets. The pilot course was highly successful and we are now endeavoring to apply it to other schools in the local area.

Humans began exploring space the day they chose to walk out of their caves in search of food. Space exploration is nothing less than human survival. You probably have heard us say that the first human being to set foot on Mars is alive now somewhere on planet Earth, a young girl or boy sitting in one of our classrooms at this very moment. Will they be discouraged or encouraged by their elders? I was blessed with the best parents anyone could ever have and perhaps fortunate to find a traveling display on atomic power and a NASA brochure on rocket science to keep nudging me on.

The opportunities we offer our young in these exciting fields of energy research and space exploration are key to our technological growth and the preservation of our way of life. I am indebted to this great nation for it has allowed me to partake in the greatest of human adventures. I hope we can continue to inspire our future generations to carry our human legacy into the vastness of space.

I sincerely appreciate the opportunity to appear before the Subcommittee today, and I look forward to responding to any questions you may have.

BIOGRAPHY FOR FRANKLIN R. CHANG-DÌAZ

PERSONAL DATA:

Born April 5, 1950, in San Josè, Costa Rica, to the late Mr. Ramòn A. Chang-Morales and Mrs. Maria Eugenia Dìaz De Chang. Married to the former Peggy Marguerite Doncaster of Alexandria, Louisiana. Four children. He enjoys music, glider planes, soccer, scuba diving, and hiking. His mother, brothers, and sisters still reside in Costa Rica.

EDUCATION:

Graduated from Colegio De La Salle in San Josè, Costa Rica, in November 1967, and from Hartford High School in Hartford, Connecticut, in 1969; received a Bachelor of Science degree in mechanical engineering from the University of Connecticut in 1973 and a doctorate in applied plasma physics from the Massachusetts Institute of Technology (MIT) in 1977.

SPECIAL HONORS:

Recipient of the University of Connecticut's Outstanding Alumni Award (1980); 7 NASA Space Flight Medals (1986, 1989, 1992, 1994, 1996, 1998); 2 NASA Distinguished Service Medals (1995, 1997), and 3 NASA Exceptional Service Medals (1988, 1990, 1993). In 1986, he received the Liberty Medal from President Ronald Reagan at the Statue of Liberty Centennial Celebration in New York City, and in 1987 the Medal of Excellence from the Congressional Hispanic Caucus. He received the Cross of the Venezuelan Air Force from President Jaime Lusinchi during the 68th Anniversary of the Venezuelan Air Force in Caracas, Venezuela (1988), and the Flight Achievement Award from the American Astronautical Society (1989). Recipient of four Doctorates "Honoris Causa" (Doctor of Science from the Universidad Nacional de Costa Rica; Doctor of Science from the University of Connecticut, Doctor of Law from Babson College, and Doctor of Science from the Universidade de Santiago de Chile. He is Honorary faculty at the College of Engineering, University of Costa Rica. In April 1995, the government of Costa Rica conferred on him the title of "Honorary Citizen." This is the highest honor Costa Rica confers to a foreign citizen, making him the first such honoree who was actually born there. Recipient of the American Institute of Aeronautics and Astronautics 2001 Wyld Propulsion Award for his 21 years of research on the VASIMR engine.

EXPERIENCE:

While attending the University of Connecticut, he also worked as research assistant in the Physics Department and participated in the design and construction of high energy atomic collision experiments. Following graduation in 1973, he entered graduate school at MIT, becoming heavily involved in the United States' controlled fusion program and doing intensive research in the design and operation of fusion reactors. He obtained his doctorate in the field of applied plasma physics and fusion technology and, in that same year, joined the technical staff of the Charles Stark Draper Laboratory. His work at Draper was geared strongly toward the design and integration of control systems for fusion reactor concepts and experimental devices, in both inertial and magnetic confinement fusion. In 1979, he developed a novel concept to guide and target fuel pellets in an inertial fusion reactor chamber. More recently he has been engaged in the design of a new concept in rocket propulsion based on magnetically confined high temperature plasmas. As a visiting scientist with the M.I.T. Plasma Fusion Center from October 1983 to December 1993, he led the plasma propulsion program there to develop this technology for future human missions to Mars. In December 1993, Dr. Chang-Dìaz was appointed Director of the Advanced Space Propulsion Laboratory at the Johnson Space Center where he continues his research on plasma rockets. He is an Adjunct Professor of Physics at Rice University and the University of Houston and has presented numerous papers at technical conferences and in scientific journals.

In addition to his main fields of science and engineering, he worked for 2½ years as a house manager in an experimental community residence for de-institutionalizing chronic mental patients, and was heavily involved as an instructor/advisor with a rehabilitation program for hispanic drug abusers in Massachusetts.

NASA EXPERIENCE:

Selected by NASA in May 1980, Dr. Chang-Dìaz became an astronaut in August 1981. While undergoing astronaut training he was also involved in flight software checkout at the Shuttle Avionics Integration Laboratory (SAIL), and participated in the early Space Station design studies. In late 1982 he was designated as support crew for the first Spacelab mission and, in November 1983, served as on-orbit capsule communicator (CAPCOM) during that flight.

From October 1984 to August 1985 he was leader of the astronaut support team at the Kennedy Space Center. His duties included astronaut support during the processing of the various vehicles and payloads, as well as flight crew support during the final phases of the launch countdown. He has logged over 1,800 hours of flight time, including 1,500 hours in jet aircraft.

Dr. Chang-Dìaz was instrumental in implementing closer ties between the astronaut corps and the scientific community. In January 1987, he started the Astronaut Science Colloquium Program and later helped form the Astronaut Science Support Group, which he directed until January 1989.

A veteran of seven space flights, STS 61–C (1986), STS–34 (1989), STS–46 (1992), STS–60 (1994), STS–75 (1996), STS–91 (1998) and STS–111 (2002), he has logged over 1,601 hours in space, including 19 hours and 31 minutes in three space walks.

SPACE FLIGHT EXPERIENCE:

STS 61–C (January 12–18, 1986), was launched from the Kennedy Space Center, Florida, on the Space Shuttle *Columbia.* STS 61–C was a six-day flight during which Dr. Chang-Dìaz participated in the deployment of the SATCOM KU satellite, conducted experiments in astrophysics, and operated the materials processing laboratory MSL–2. Following 96 orbits of the Earth, *Columbia* and her crew made a successful night landing at Edwards Air Force Base, California. Mission duration was 146 hours, 3 minutes, 51 seconds.

On STS–34 (October 18–23, 1989), the crew aboard Space Shuttle Atlantis successfully deployed the Galileo spacecraft on its journey to explore Jupiter, operated the Shuttle Solar Backscatter Ultraviolet Instrument (SSBUV) to map atmospheric ozone, and performed numerous secondary experiments involving radiation measurements, polymer morphology, lightning research, microgravity effects on plants, and a student experiment on ice crystal growth in space. STS–34 launched from Kennedy Space Center, Florida, and landed at Edwards Air Force Base, California. Mission duration was 119 hours and 41 minutes and was accomplished in 79 orbits of the Earth.

STS–46 (July 31–August 8, 1992) was an 8-day mission during which crew member deployed the European Retrievable Carrier (EURECA) satellite, and conducted the first Tethered Satellite System (TSS) test flight. Mission duration was 191 hours, 16 minutes, 7 seconds. Space Shuttle Atlantis and her crew launched and landed at the Kennedy Space Center, Florida, after completing 126 orbits of the Earth in 3.35 million miles.

STS–60 (February 3–11, 1994) was the first flight of the Wake Shield Facility (WSF–1), the second flight of the Space Habitation Module–2 (Spacehab–2), and the first joint U.S./Russian Space Shuttle mission on which a Russian Cosmonaut was a crew member. During the 8-day flight, the crew aboard Space Shuttle Discovery conducted a wide variety of biological materials science, Earth observation, and life science experiments. STS–60 launched and landed at Kennedy Space Center, Florida. The mission achieved 130 orbits of Earth in 3,439,705 miles.

STS–75 (February 22 to March 9, 1996) was a 15-day mission with principal payloads being the reflight of the Tethered Satellite System (TSS) and the third flight of the United States Microgravity Payload (USMP–3). The TSS successfully demonstrated the ability of tethers to produce electricity. The TSS experiment produced a wealth of new information on the electrodynamics of tethers and plasma physics before the tether broke at 19.7 km, just shy of the 20.7 km goal. The crew also worked around the clock performing combustion experiments and research related to USMP–3 microgravity investigations used to improve production of medicines, metal alloys, and semiconductors. The mission was completed in 252 orbits covering 6.5 million miles in 377 hours and 40 minutes.

STS–91 Discovery (June 2–12, 1998) was the 9th and final Shuttle-Mir docking mission and marked the conclusion of the highly successful joint U.S./Russian Phase I Program. The crew, including a Russian cosmonaut, performed logistics and hardware resupply of the Mir during four docked days. They also conducted the Alpha Magnetic Spectrometer experiment, which involved the first of its kind research of antimatter in space. Mission duration was 235 hours, 54 minutes.

STS–111 Endeavour (June 5–19, 2002). The STS–111 mission delivered a new ISS resident crew and a Canadian-built mobile base for the orbiting outpost's robotic arm. The crew also performed late-notice repair of the station's robot arm by replacing one of the arm's joints. It was the second Space Shuttle mission dedicated to delivering research equipment to the space platform. Dr. Chang-Dìaz performed three EVAs (space walks) to help install the Canadian Mobile Base System to the station's robotic arm. STS–111 also brought home the Expedition-Four crew from their 6½ month stay aboard the station. Mission duration was 13 days, 20 hours arid 35 minutes. Unacceptable weather conditions in Florida necessitated a landing at Edwards Air Force Base, California.

DISCUSSION

Chairwoman BIGGERT. Thank you very much.

And thank you all for your excellent, excellent testimony. I really appreciate it.

And we have been joined by the gentlewoman from Texas, Ms. Sheila Jackson Lee.

Ms. JACKSON LEE. Thank you, Madame Chair. Thank you, Mr. Lampson.

Chairwoman BIGGERT. We will now proceed with our questions, and we will keep those to five minutes. And so if the answers do not stretch out too far, we can ask more questions. And I will start.

Let me just make a comment to Dr. Chang-Dìaz.

Thank you very much for all that you do. I think it is not rocket science that we need more scientists and engineers, and those in the field of research and for what you do. I hope that you carry your NASA brochures with you so that you can encourage more and more students to enter into these fields. It is very important for what you do, and really appreciate it.

I know I go into schools and talk about the Science Committee and how important it is for young people, and particularly young women I think. You know, once they get into a—and you do this for 6th through 8th grade. But about that age the girls say what? I am not supposed to do math. I am not supposed to do science. And so we could keep those minds active and I feel it is a very important. Thank you.

My first question is for Dr. Holtzapple. The StarRotor engine and your testimony sounds very promising, almost too good to be true, as they say. But what are the remaining barriers and why are not the auto companies not beating down your door to get a hold of this?

Dr. HOLTZAPPLE. It is interesting you mention that. I have had actual conversations with two automobile companies over the years. It is still early stage technology, so they are skeptical. I think their attitude is that we will be here in five or 10 years and when you have got a working engine, let us know. I think that is the basic attitude.

Chairwoman BIGGERT. Yes.

Dr. HOLTZAPPLE. But I think many companies are risk adverse and when you are just getting started, they do not feel it is their role to develop new technology. Their role is to commercialize things that have been brought to a semi-commercial state.

Chairwoman BIGGERT. Okay. Thank you.

Then Dr. Smalley, could you comment on the importance of energy storage and its challenges, and then the transmission of energy, how that is going to change and what you see as the challenges?

Dr. SMALLEY. If we were able through research, technological innovation to come up with technologies that would give the equivalent of an interpretable power supply that we could not just use for our computers, but use for our houses and our small businesses and not just for five to minutes, but in fact critically about 12 hours, that has a transforming effect on the electrical energy grid. Because now homes and businesses that really care about having guaranteed stable dependable power will go out and they will buy these units, and increasingly this will remove from the electrical energy grid a huge variation of between the low point of use in the middle of the night and the peak in the late afternoons which causes the energy industry to have to put in these peaking power supplies that take up a significant fraction of our total capital investment.

In addition, it gets you in a way that's gradual and innovated by small and big businesses year by year to a situation where you have an extremely robust electrical energy grid that is very hard to disrupt by terrorism or accidents.

And it also gives you the ability now to use energy, primary energy sources coming onto the electrical grid which are not dispatchable. Wind, for example. In Texas we have a lot of wind power. We have a hard time handling that much power on the grid because when the wind stops blowing we have to generate that power from some other source. If you have the storage, you can handle that.

Well given the two options of doing storage in vast amounts with big plants, the handling a gigowatt or more storage or in little places; it is much better to do it little because of all the innovation that can handle that and when you decide that, oops, I made a mistake and it was the wrong technology, so you cry and so forth but a year later you can buy the right answer and get rid of the old. Kind of like we drop off our computers these days.

Sounds great. We do not have that technology now. But it is a place I think that it would be very worthwhile for us to put effort, ten to 20 years. It seems to me there must be many technologies that are possible that would work on the small scale, that are out of the question on a large scale. And I think we ought to push them.

The final ingredient in the electrical energy grid is if we could have a transforming affect in our ability to at low cost transmit tens to hundreds of gigowatts of power over thousands of miles distance. That makes the whole thing work. Because now we can bring primary power into the grid from any source, no matter how remote. So nuclear power from not only in not your back yard, not your friend's back yard, but from someplace that you have not got a clue where it is.

Clean coal from places where we really have convinced ourselves we can stick the CO_2 and it is not going to come back at us for a 100 years.

Hydro power from northern British Columbia, stranded gas, solar from vast solar farms in the great western deserts. If we can bring them in at a net cost to the customer no more than a penny or two extra per kilowatt hour for having gotten your power from 2000 miles away, now it makes the whole thing work.

And so in fact you look at the plant and pretty much every continent has enough energy in it to handle it, to give you a very robust thing. And if you had to describe this energy system with one word, like for many years in the world we described energy as a one word "oil," what would that word be in this new technology? It would be electricity. It would not be so much hydrogen. It would certainly be hydrogen being used, but it is the electrical grid that I find so intriguing.

I think this is an area where we should direct major frontier research efforts to see if we can bring this about so in batteries in T-cells, anyway you could figure out to store energy. Something that looks kind of like your ashing machine in your house. Something that ultimately GE or Sears or Shell would sell. Be a very fertile area. There is a market for this right now and there will always be a market for it.

And then anything we can do to have a transforming affect on the cost of electrical transmission over very large distances, I think is a very fertile area for our research.

Chairwoman BIGGERT. Thank you for your premise.

Mr. Lampson.

Mr. LAMPSON. Thank you, Madame Chair.

Keep talking for just a minute, Dr. Smalley, about your C–60. I think you were telling me once how you could use it as a storage facility for hydrogen. Is that part of the plan or the hope, and can you talk for just a second about it and what—because we do not have the infrastructure that is necessary to use hydrogen if we do develop hydrogen powered vehicles. Is that the potential of something we can expect?

Dr. SMALLEY. Yes, we would love to find a material X that we can put in our gasoline tanks that allows us to go up to our friendly Shell stations, since we have Shell as our key concept today, and drive away five minutes or later with 300/400 miles of energy in our tank. But instead of having put gasoline in there or ethanol, we put in hydrogen gas. We would like that experience.

Well, you cannot do it just with an empty tank. You can do with a pressurized tank. Actually one can imagine using buckytubes to make these even stronger and lighter. But would it not be wonderful if we had some sort of magic sponge that we can put in there that would absorb the hydrogen, holding the hydrogen molecules close enough to the surface of whatever this material X is made out of that you can get enough density in there so we do not have to take that much larger volume of the car. But then be able to get it off reversibly as you drive the car.

So we and quite a number of people around the country since the President's announcement of his hydrogen fuel program have agonized over just what could that material X be, what would it look like? Having every atom of material X have an exposed surface, the maximum possible closed surface so that you can get as much hydrogen close to that atom of material X as possible, it sounds like the right answer. Sounds like a buckytube which has every atom with a surface on the top and the bottom on the inside. But in addition, the hydrogen has to have a reason to want to be there.

So in the absorption of hydrogen on carbon surfaces there is really two ways of doing it that we know about. There is fisabsorption, which is not enough, and there is chemisorption to make basically hydrocarbons, which is way too much. The challenge is to find some way to adjust the diameter of a buckytube and add electrons to it, do something that will get you to that magic place in the middle which is the sort of binding energy we need.

So we have together with Air Products and NREL, the laboratory, together with about 11 other universities, proposed to the DOE to set up a virtual center to explore the possibilities one can find an answer material X made out of carbon in the thought that we have buckytubes are the best single guess. But remember, we cannot change the laws of physics. So we will go and we will make the best possible buckytube and we will find out what gets——

Mr. LAMPSON. Are you making progress toward achieving that? Is that an expectation and if so, what kind of time period might you be looking at?

Dr. SMALLEY. I believe within three to five years we can give you a pretty firm answer whether or not the laws of physics will allow us to do it.

If it turns out the answer is yes, there is a good answer here with buckytubes or some other carbon thing, then we have to take on the next challenge of make that, you know, large amounts cheaply because there is a lot of volume in those gasoline tanks out there. We would need to be able to produce these optimized carbon nanotubes in the structure necessary for a cost of something like $10 a pound. And that means an innovation in the production scheme.

Well, it turns out we need an innovation in the production scheme anyway. So it is an area that we are very happy to pursue. But we cannot guarantee that there is a magic sponge. The advantage of the sponge would be so great, it would be foolish for us or the Nation to not look to see if the sponge can exist.

I will take that as my——

Mr. LAMPSON. No. But you will give me time now to squeeze a question to Dr. Chang-Dìaz before I give up my time. And you do not have much time to answer.

But you are going to be doing some experiments at Oak Ridge Laboratory next year. What do you expect to learn from them, and maybe you can give us some scenarios, if you would, that would describe how some of the work you are doing could be applied to solve problems on Earth?

Dr. CHANG-DÌAZ. Sure. The work at Oak Ridge centers on the production of plasma efficiently. And plasma has applications much beyond the propulsion application we have chosen. Obviously infusion, that is an application that we all know about. But plasmas are used today to etch, for example, microchips. You can make micro computer memories without using those very toxic chemicals that are used today to etch the little wafers. You use the plasma discharge and the plasma makes the microchip even better. So the waste is virtually eliminated. That is one area.

And now they are talking about plasma being used to separate the nuclear waste as well, to be able to take advantage of the plasma state to be able to separate the elements by weight. This is also a very interesting possibility.

So there is lots of applications that permeate I think all of our society.

Mr. LAMPSON. Thank you very much.

My time has expired. Thank you.

Chairwoman BIGGERT. Sheila Jackson Lee is recognized for five minutes.

Ms. JACKSON LEE. Thank you very much, Madame Chair. And let me, if I might, give a portion of my opening statement and then ask two questions. And I would simply like to ask that the statement in its entirety, ask unanimous consent that the statement in its entirety be submitted into the record.

Chairwoman BIGGERT. Without objection.

Ms. JACKSON LEE. Thank you very much.

First of all, allow me to welcome you to Houston. I know that you have been welcomed by my colleague and Ranking Member Congressman Lampson. And to say how pleased and proud I am to be able to participate with the House Science Committee that all of us are Members of, and to be able to cite the House Science Committee as having an excellent tradition of bipartisanship, first of all, but also tackling tough scientific and policy problems in an effective bipartisan manner. And so this is certainly a very prime example of that.

I thank the Chairman Biggert for her leadership. We have worked together on issues before. And I thank Congressman Lampson as the Ranking Member for his invitation, an invitation to Houston and as well, the kind of insightfulness and enthusiasm he brings to the Committee on the myriad of issues under his responsibility. And so thank you, Congressman Lampson for this hearing.

I believe this is an important historic hearing in what we call the oil capital of the world. And it begins to encourage us to look at the many options that we have, not only to balance our oil and gas needs in particular, and Congressman, you remember that one of our battles on the Energy Policy Act was to focus people on the Gulf and to do an ascertainment of what kind of oil and gas resources we had in the Gulf to be able to focus. Everyone was focused on ANWR and other places, but to focus on the clean technology that we had been utilizing. Shell, who is present here today, has utilized technology in the Gulf, and I think it has been very successful. And so we included that recognizing that we have to balance the use of oil and gas along with finding alternative needs.

I might also cite my colleagues to an amendment that I offered in the Science Committee that was passed that wanted to see a relationship develop between the Department of Energy and NASA to be able to find and use the technology that NASA has utilized, discovered to help the Department of Energy in their research on alternative fuels.

So I think we can work in cross pollenization.

[The prepared statement by Ms. Jackson Lee follows:]

PREPARED STATEMENT OF REPRESENTATIVE SHEILA JACKSON LEE

Thank you.

First, I would like to echo the remarks of my colleague Congressman Lampson in welcoming Chairwoman Biggert to Houston. The Science Committee has an excellent tradition of tackling tough scientific and policy problems in an effective bipartisan fashion. Today's hearing is a perfect example of that cooperation. How to lay the groundwork, so that America can continue to lead the world in energy research and development, is one of those tough problems that the Science Committee and the Energy Subcommittee are grappling with these days. I commend the Chairwoman for taking the time to come down to see the great talent and experience that Houston have to offer.

I would also like to commend Mr. Lampson for his great leadership on Energy issues, and for being such an excellent ambassador of Houston in the House of Representatives. The fact that Congressman Lampson is serving as the Ranking Member on the Energy Subcommittee while only in his 4th term in Congress, is truly a testament to just how much his work and his ideas on this subject are respected in the Science Committee. I look forward to working with both Chairwoman Biggert and Ranking Member Lampson in the New Year.

And a special thanks to our hosts here at Rice University. They have been great partners in the endeavor to secure the energy needs of this nation for generations to come.

Houston is often called the energy capital of the world—and when people think of Texas, they think of oil. Oil and fossil fuels deserve much credit for driving our economy and prosperity over the past centuries. I know that oil and natural gas will continue to play a large role over the next century at meeting our energy needs. However, we all know that fossil fuels are not the wave of the new millennium. We need to balance our use of fossil fuels with other fuels if we are ever going to clean up the air that our children are breathing, or if we hope to reverse the course of the climate change that is threatening to change life as we know it on this planet. Furthermore, we are overly dependent on foreign sources of oil, bought from people that we would prefer not be reliant on. For many reasons, we must be thinking ahead to a future less dependent on fossil fuels.

Of course moving away from oil and gas will have a large impact on Houston, but I believe that the transition will create wonderful opportunities for the people and the businesses in Houston. There is no city in the world with a greater depth of expertise on all things energy: production, transmission, trading, the policy, the politics, the needs, and the markets. Houston is poised to continue its leadership in the energy sector.

From our quality universities like Rice, to R&D facilities over at NASA Johnson Space Center, to our huge multi-national energy corporations, to dozens of small and medium-sized businesses on the cutting-edge of technology—Houston has much to offer. I think they will all benefit from the fact that Houston is such an energy hub. There is a synergy here, where these great minds feed off of each other, and do spectacular things. To promote that kind of fruitful activity, I authored one provision of the Energy bill that just passed that will create a cooperative effort between NASA and the Department of Energy, as well as several other agencies. The effort should spur on the development of alternative energy sources and industry from technologies that may already exist in federal labs.

We have an excellent cross-section of the Houston energy research community here today. It is always impressive to me to hear of the progress they are making in the field of energy. More importantly though, I am glad that we are getting their comments on the record so that our colleagues back in Washington can get a glimpse into the exciting developments here in Houston.

Again, I thank you all for taking the time to be here today. I look forward to the discussion.

Thank you.

Ms. JACKSON LEE. And with that, I would like to pose some questions along that line that here in Texas we do not want to talk about exclusion in totality, we want to talk about compromise and cooperation between the uses of fuel.

With respect to the question of NASA, if you would Dr. Chang-Dìaz, is the work that NASA does compatible with, among other things, I know it does great work in health research, but is it compatible in finding alternative fuels? And I certainly agree with the issue that space exploration equates to human survival. But do we have in NASA the amount of diversity and the amount of the ability to sort of change its mold to be able to be helpful in the research on alternative fuels?

Dr. CHANG-DÌAZ. I would say the answer is most definitely yes. We have now begun a very strong collaboration with Los Alamos and also with Oak Ridge in the field of plasma physics as it applies thermonuclear research, controlled thermonuclear research. That is a direct application.

Now the technology that has been developed over many years of United States investment in energy research it has immediate applications in many other areas. One of them is medicine, for example.

Here in Houston/Galveston we have very big medical centers. These super conducting magnets that are used to hardness, to hold together this high temperature plasmas are the same magnets where they put people inside to do an MRI. And these are the same technology. We are trying to make them less bulky, less expensive, easy to transport because all of this technology has to be sent up into space and it has to be light weight and it has to be very compact. This will allow people then to be able to have access to this technology all over the world.

So these are direct applications that I would say that the high investment the United States has made in energy research has already there is a handsome payoff.

Ms. JACKSON LEE. Excellent. I am not sure if my time has been far spent, but if there is anyone that would answer quickly how we can emphasize the public/private partnerships on this whole issue of alternative fuels. Anyone want to contribute to that?

Dr. HOLTZAPPLE. I would just like to reiterate that there is a lot of interest in subsidizing ethanol, for example, as a biofuel. And if you could generalize that to any biofuel, not just ethanol, I think that would be very helpful.

I would say that the government is not good at picking the winners. That is not really the role of the government. Industry is supposed to be smart at figuring out costs and so forth.

Ms. JACKSON LEE. That is a good point.

Dr. HOLTZAPPLE. So what the government should be doing is setting the goals.

Ms. JACKSON LEE. Yes.

Dr. HOLTZAPPLE. And putting the incentives in place, but let the industry figure out the details and how to get there.

Mr. MITCHELL. Could I also comment?

From the standpoint of institutions, one of the things I am comparing Houston Advanced Research Center to some of the either institutions or individuals here at the table. We intentionally position ourselves not to do the basic and theoretical work. We actually position ourselves in that sort of middle ground where technologies often fail, which is a wonderful laboratory concept not yet commercially scalable. And institutions like Houston Advance Research Center, a non-profit that works with both government resources and university resources and corporate resources we intentionally position ourselves to be sort of a bridging institution.

So I think it is important not just to think about individual technologies, but literally think in terms of the institutions that will help carry those forward. You cannot go to a venture capital company and always expect them to come in at the very seed levels of very first generation technologies. There is a role which is often not quite as well supported by our society for the institutions that will carry the technologies to the next step.

Ms. JACKSON LEE. Thank you very much.

Thank you, Madame Chair.

Dr. HOLTZAPPLE. Just I would like to add they call that the valley of death.

There is a lot of money out there for basic research on the order of $100,000 or so. And, of course, industry has money at the tens of millions of dollars to do things. But that in between area we do not do a very good job of bridging it. And among the scientific community it is called the valley death.

Ms. JACKSON LEE. I thank you for that. That has been very instructive. And I think we can find a very good balance.

And thank you very much for allowing me to share.

Chairwoman BIGGERT. We will do another round then.

Mr. Mitchell, you state in your testimony that Houston Advanced Research Center has been working for about 18 years?

Mr. MITCHELL. Yes.

Chairwoman BIGGERT. On various energy storage devices. Have any of these been successful, are they moving on or what has happened?

Mr. MITCHELL. Not so much exactly—I'm sorry. Are you talking the micro technologies, yes.

Chairwoman BIGGERT. Yes.

Mr. MITCHELL. We were funded by the State of Texas to work on significant energy storage technology. At that time we felt that our technology was among the leading technologies that had been developed. But, again, maybe it is the same valley of death like comment. It did not see a commercial market, but interestingly we turned that same technology and worked with a variety of partners, actually in magnetic resonant imaging. So there are transitions where technology may not have been ready for prime time. We successfully partner with others to take a technology into commercial product in MRI devices. Now what we are finding is that the world is kind of coming back to the timing is right for us again, so we are actually working very actively with University of Houston right now in looking at both superconductivity and energy storage. And it is that sort of a story that is still in progress.

Chairwoman BIGGERT. Are there obstacles that remain for the use of energy storage devices?

Mr. MITCHELL. I wish I were a physicist to be able to give you the details, and I am really not. But I do know that the superconductive materials, the big sort of holy grail and superconductivity is to get materials that are superconductive at higher and higher temperatures. And that is the basis of our project with University of Houston. It is a partnership with a U.S. Navy Research Lab and the initial results are very intriguing.

Chairwoman BIGGERT. Thank you.

Then Mr. Hennekes, in your testimony you mentioned the Shell gasification research program. And you talked about that it can produce extremes of carbon dioxide that could be sequestered. Is your company looking into carbon sequestration?

Mr. HENNEKES. Absolutely. We are not only trying to develop a gasification process in order to develop this very pure form of CO_2

that can be sequestered. More importantly used in tertiary recovery for wells or other as with CO_2, but we are in a joint agreement with several other oil companies to determine how CO_2 sequestration can be best done, how it can be kept for the 100 years that is needed so that it is not popping out, how can it be monitored for that length of time. And there is an industry group that is doing that.

So Shell is jointly spending research money with others to develop how that can best be done and kept properly for the very long period of time that this is envisioned.

Chairwoman BIGGERT. Thank you. Thank you.

We have reached 3:15, and I still do not have a way to beam myself up to the airport. I guess I could stay longer. But I am going to have to excuse myself and head for the airport. But certainly enjoyed this.

I am going to turn it over to Mr. Lampson. Now do not get too carried away.

Mr. LAMPSON.

Mr. LAMPSON [presiding]. Thank you. Thank you for your time.

Madame Chair, let me express my appreciation for you taking the time. It is not easy for you to come down here, I know that. And we really have had a good relation on that Committee, and I appreciate the effort you made to come here.

Chairwoman BIGGERT. And I am sorry I have to leave. Because this has been an excellent—I wish that it was in Washington so that there could be more people that would hear this from the Committee.

Mr. LAMPSON [presiding]. Which some of them might come up.

Chairwoman BIGGERT. I think that we will have to do that at some point. So thank you very much.

Mr. LAMPSON [presiding]. It is fascinating stuff, and I think that they have suggestions on which we can do to improve our policy.

Chairwoman BIGGERT. Thanks. Thank you.

Mr. LAMPSON [presiding]. Thank you very much. Have a safe trip home.

Chairwoman BIGGERT. Thank you.

Mr. LAMPSON [presiding]. My turn.

Let me start, I guess, with Mr. Hennekes, and maybe follow up a little bit with what she has asked about. I know that some of the work that is being done on that is at the West Hollow Technology Center.

Mr. HENNEKES. Yes. It is here in Houston.

Mr. LAMPSON [presiding]. So tell us a little bit about their work and how it relates to the research that is being done in both gasification and corrosion reduction.

Mr. HENNEKES. I'm sorry. I did not quite hear the last part. The gasification I understand.

Mr. LAMPSON [presiding]. And corrosion reduction.

Mr. HENNEKES. Okay. Actually, the corrosion reduction, let me separate that, is just a totally separate event. And I brought that to people's attention so they could understand the non-energy business that we deal with.

But when you do gasification you actually can make if you desire this very pure form of CO_2 in a gaseous state. It is usually at very,

very low pressure. So that it requires some pressurization through very standard types of compression devices, a compressor from GE or Westinghouse or Siemens. And then that material is taken and actually brought down, burrowed into the Earth where it is then closed in and allowed over a very long period of time to seep into the different structures of the Earth rather than going out into the atmosphere and rather than creating green house gases.

The work that we are doing is to understand how the CO_2 will react as it sits in the Earth for long periods of time, what will need to be done to keep it in? What kind of instrumentation do you use to monitor how that CO_2 is doing down in the Earth for that long period of time.

So it is all about what will it take and what is the most efficient way to capture and hold for that extended time. That is the work that we're doing at West Hollow.

And for those that do not know, West Hollow is a stone's throw, if I had a good arm, a little bit longer than that from here about 20 miles almost due west from here.

Mr. LAMPSON [presiding]. Okay. And while you are talking, let me ask you one other question. How much contribution would you expect full deployment of the Shell and the GTL fuels to make in reducing air emissions from mobile sources in the Houston/Galveston area?

Mr. HENNEKES. The gas to liquids materials, it will be very dependent on which type of pollutant you are talking about. But there is absolutely no sulphur whatsoever in gas to liquid materials. In fact, when you are running an engine, if you are an engineer that is worried about an engine and the long-term operation of it, you actually have to put lubricants back in. Because sulphur itself is a lubricant. We measure something called lubricity. And because the gas to liquids have absolutely no sulphur whatsoever, you actually lose lubricity and you have to put some sort of lubricant back into the fuel.

So when you talk about SO_X and those sort of things to the atmosphere, there is none. Okay. It is absolutely at a zero level. Not because of rocket science, but because of the fact that the catalyst that is required to make the gas to liquids will die if sulphur is present. So you have to do an absolute brilliant job of removing it.

In terms of other things, gas to liquids in all the other pollutants NO_X, and those sort of things, because of the material that is being burned it is a very impact energy type of material the gas to liquids is, it is lower in NO_X, it is lower in particulates. CO_2 in the end, from what I have seen and the research we are doing, is kind of marginal. It depends on how you measure, it depends on who is doing the measuring and it is a plus or minus. But for the other things, the sulphur, the NO_X, the particulates all are significantly lower with gas to liquid material.

Mr. LAMPSON [presiding]. Dr. Holtzapple, you talked some about MO_X. And one of the things that you mentioned, I believe you said that there was a dramatic reduction, it would go down to zero. How?

Dr. HOLTZAPPLE. Yes.

Mr. LAMPSON [presiding]. Because that is a problem, is it not?

Dr. HOLTZAPPLE. Absolutely.

Mr. LAMPSON [presiding]. All of these fuels.

Dr. HOLTZAPPLE. In the StarRotor engine the combustion is a continuous combuster rather than the batch-wise combustion that occurs in an internal combustion engine. So you design the combuster to do a really good job of combustion.

So one issue is that all the fuel has to go through a flame front. None of it slips by. So all the fuel gets burn. There is no hydrocarbon emissions at all.

And in this hypo-engine that we are using air is an excess whereas in an internal combustion engine it is on an exact balance. When you have air in excess, you do not get CO, you get CO_2, we do not get the carbon monoxide.

And then in terms of nitrogen oxides, the resonant time in the burner is so short there is not enough time to make very much nitrogen oxide. So you can almost pollution free transportation with the StarRoto engine.

Mr. LAMPSON [presiding]. That could be done. But maybe Todd or somebody else make some comments. What are we doing with the other fuels that are going to be burned in the engines that we have today? How do we go about reducing?

Dr. HOLTZAPPLE. Well, in terms of nitrogen oxides, if you can lower the flame combustion temperature that helps. So when you put alcohols into fuel, it has a higher latency to vaporization which cools the combustion process. So you can get the height and the maximum temperature in the combuster down a little bit, and that helps reduce some of the NO_X.

Mr. HENNEKES. We would agree also. When you burn a gasification product, you will find that the BTU content is something on the order of 10 ten 25 percent of that of natural gas. Again, exactly as he suggested, the flame temperature then is significantly lower and that is the big push in terms of NO_X. So you can end up with very, very low levels of NO_X.

If you clean up the sulphur, you can then actually go into selective catalyst reduction systems that again use a similar concept and you can be down into single digit NO_X from burning in large production turbines for many, many gigowatts. So if you put the right section together that has a low flame temperature, low sulphur, able to use another separate catalyst, you can get phenomenal low NO_X levels from those fuels.

Mr. MITCHELL. I will just a comment, which is that the role that our organization would play would not be so much to come up with a new approach or an approach similar to what they are doing, but to work with organizations or individuals like these to take those technologies, run through testing validation, field trials, demonstrations. But more importantly, put it into the context of the regional air sheds, air emissions and in a sense do forward modeling and projections to try to figure out what would be the impact. Because the role that we look to pay is sort of that link between science and policy. How do you take a technology that may be at the commercial stage, but then really to model over five years, over 10 years with certain adoption rates what are the impacts within the regional air shed. And that is not just sort of a model looking at, you know, so many devices times the air emissions reductions, but actually using the more sophisticated air shed modeling approaches to really try to make it useful for policy discussion.

Mr. LAMPSON [presiding]. I am not going to keep you all much longer, but I have a couple of areas of questioning that I want. I am going to ask everybody at the very end to again think about any suggestions that you would have for our subcommittee or committee about what we can do to further any of the activities that you are in that deals with legislation, changes of policy. Anything whatsoever. But before I get to that, you can be thinking about it.

But Dr. Holtzapple?

Dr. HOLTZAPPLE. Yes.

Mr. LAMPSON [presiding]. The area, this general area here has lost it is the process, I guess I should say, of losing an industry. And that is agriculture. We grew a huge amount of rice here. And over time the rice markets have gone away and a lot of the farming activity on rice has dried up.

We have looked at some alternative crops. We looked at producing sugar cane. We have looked at producing soybeans. We have looked at producing other kinds of things.

Would you talk a little bit about what capabilities we have to, we have already said significantly reduce our dependence on particularly foreign oil, but tell us more about that and maybe you can focus on some of the things that we can do to find the types of crops that may be specific to this area and make good cash crops?

Dr. HOLTZAPPLE. Absolutely. I have had some contact with the LCRA, the Lower Colorado River Authority. And they are actually worried about the loss of rice farming because they supply water to the rice farmers and they get money for that money. So they are also looking for alternative crops.

We could grow the sweet sorghum that I mentioned. And, in fact, one of my students has been growing energy cane in——

Mr. LAMPSON [presiding]. What is energy cane? Energy cane compares to sugar cane?

Dr. HOLTZAPPLE. Energy cane is a more of a wild type variety of sugar cane. You know, sugar cane is a wild plant, just like everything that we have is. But as mankind has grown these things, they select for certain properties.

For example, wild corn does not make a huge ear of corn. They are little tiny things. And we select for things that make more corn, in that case.

In the case of sugar cane, we've selected for high sugar concentrations but the plant has suffered and it is not growing as much. So the genes in the current commercial varieties of sugar cane enhance more sugar production, but not the fiber production.

And what energy cane is, is it going back more to the wind strains that just want to grow prolifically and take over. So it is just kind of a cross between a modern high sugar variety and the wild type variety.

Mr. LAMPSON [presiding]. And part of the problem that we found in this area to promote the production of sugar cane was its processing or as being able to process that into the energy that's necessary that you're proposing, what will it take, what kind of infrastructure would it take both in terms of cost and anything else that you can think of?

Dr. HOLTZAPPLE. Well, sugar is actually a very capital intensive process because you harvest only about three or four months out of the year and you have to process all of that sugar in a three or four month period. So the factory is very large in size for this maximum production rate. But a single squeezing mill that squeezes the sugar out of sugar cane is $2 million, and you need four of those. That is just to buy them. And then you have to install them and so forth.

So the problem is that there is a huge amount of capital required to take the sugar cane, squeeze out the juice and process it in that three to four month period.

In the case of our process, you are actually processing it over the course of a year so you do not have to have that very expensive capital that is sized for a short harvest season. But even having said that, it is still going to take a lot of capital.

That energy plantation that I showed where you have half an oil refinery. My estimate is the capital would be about $400 million to build that facility. But you would have to put that in perspective. I mean, a full oil refinery you could probably tell me more, but a full oil refinery is about a billion or two billion dollars I would think.

Mr. LAMPSON [presiding]. Certainly more than 400.

Dr. HOLTZAPPLE. Certainly more than 400. So it certainly takes a lot of capital, but in perspective of an oil refinery or a coal gasification or any of these things, it is actually fair low capital.

I think the major cost is this rubber lined pit with gravel on the bottom and a tarp on top of the biomass pile. So we purposely over the year engineered it to be really simple and low tech so that it can be implemented in the United States and all over the world.

Mr. LAMPSON [presiding]. Thanks.

That is all fascinating.

Dr. HOLTZAPPLE. You are welcome.

Mr. LAMPSON [presiding]. Everything that all of you are doing are absolutely fascinating things.

I will let you give your last comment to us as far as any legislation that you might want us to give consideration to, or any other thoughts that you might have and we will end this.

We will start with you, Todd.

Mr. MITCHELL. Sure. How long can I go on this topic?

Mr. LAMPSON [presiding]. Listen, I could listen to it forever. It truly it fascinating and there is a lot that we have to do to put this stuff into place.

Mr. MITCHELL. If I grant to sort of the summary or the highest concept level, I would say from a legislative standpoint from my perspective, the recognition of the role of organizations like Houston Advanced Research Center. If you look at the life cycle of technologies, there is never enough, as you can ask any of my colleagues to the left. There is never enough research money, but there is research money that we provide to institutes of higher education. And a great portion of that goes to the basic and theoretical research, and some component gets put into the applications.

At the other end of the cycle, you have venture capital dollars and eventually more mature investment capital going into these companies. It is that role in between that things tend to fall through. And Houston Advance Research Center, for example, has literally intentionally positioned itself in that middle ground where we can take technologies look at their applicability to energy and the relationships to other things, for instance air quality or other environmental unintended consequences and so forth. That is typically a sparsely funded sector, but my view it is no less important than the whole life cycle and the qualifications and skill of the people are no less—the qualifications are no less required to do that job well.

So I guess from what we would look for, you know, from the standpoint of the government recognizing—it's understanding that critical role and finding ways that organizations like HARC could partner with universities, with companies and with the government to be sort of the place where these technologies get picked. The winners should not be picked on Capitol Hill. The winners should be picked in a forum in which all these parties are working together where testing and evaluation and implementation are being done in a rigorous and scientific fashion.

Thanks.

Mr. LAMPSON [presiding]. Rick?

Dr. SMALLEY. Well, I have two answers to this. One just a broad issue is I believe that this challenge that we have of, well, basically finding a new oil; getting an answer for ourselves on this continent to energy prosperity as we get into the middle of the century. And since we are not disconnected in our business and dealings with the rest of the people in the world, the same time developing the technology that allows out continents, other peoples to find energy prosperity is a huge issue that is going to take, frankly, miraculous scientific discoveries before we can enable that.

At the rate that miraculous discoveries of that magnitude have occurred over the past 50 years, I do not think we are going to get there fast enough to avoid a pretty unpleasant future. So I think we need to take this much more seriously. I'm very concerned, as I know many of us are, with the health of the physical science as an engineering, the number of American boys and girls entering these critical fields that must be the areas out of which these miracles will come.

And I suspect that there is nothing short of Apollo level sort of program that happened in the '60's that will really address that issue. If we could recapture the magic of Apollo and get a new generation of scientists and engineers in the 2010 to 2020 region as we did the 1960, all sorts of things will work out just fine. But short of something involved with that, I do not think we are going to get there. So that is my concern.

The second point is more locally if I cannot have $10 billion a year for the next 20 years, which is what it is going to take to do this, let us focus on electrical energy storage and transmission. I believe we are going to have a big effect with some concentrated efforts in those directions.

Mr. LAMPSON [presiding]. Mark?

Dr. HOLTZAPPLE. What I would like to do is kind of give a history of how I tried to get my biomass technology out into the world.

It is always about investor confidence. You are trying to find a route that you can get the next level of funding, the next level of investment. So one of the roads that I thought was in New York City they are spending $125 a dry ton to get rid of garbage. And I said well I could use that garbage. I can turn it into fuels and chemicals and so forth. But then when I talked to the garbage companies, they do not know anything about running a chemical plant. They know how to haul garbage. And then I talked to oil companies, they do not want to garbage. So there is this huge resource there which for an institutional reason is not being tapped.

The reason the oil companies do not want to get involved is that there is this perception of liability that, you know, garbage is dirty and some of it is going to have be landfilled, and they are the last ones that touched it. And so if something bad is in there, they are going to be liable and they are risking the whole rest of their business for that.

So if somehow we could say it is actually for the Nation's better good to figure out how to use these waste materials and turn them into something useful, let us put those petty liabilities issues aside. Let us deal with those in some legislative way. That will be the instant way that we could get this technology moving.

The second road to getting the technology out of the laboratory is through subsidies. When I say I think I can make it for .75 a gallon, that is my best guess using standard engineering practices to estimate capital costs and so forth. But when I talk to big companies, they are very risk adverse. So what they intend to do is double all the costs. They say, you know, it is probably going to be twice what you are saying or three times what you are saying, so right now it looks like of marginal.

Well, if it we get the subsidy, then it can work. So what the subsidies do is get the comfort level there. It can get it started, people working with it and, you know, there is something called a learning curve. If you look at computers, what's happened with computers over the years; I mean the first computer I bought was in 1981 and I paid $3,000 for it. It had 65k of memory. And now for $3,000 you can get almost a super computer.

The reason we can do that is we are on the learning curve. You get a bunch of engineers around a process, they keep engineering the costs around. So one of the ways to get it kicked off is to have a subsidy. But the roadblock I ran into was the ethanol lobby has amassed these huge forces. You know, the Corn Growers Association, they have this massive effort to say give us our subsidy. Well, I am just one person. I cannot amass that effort and how can I make Congress people listen that, hey, you know ethanol is kind of neat but there is other ways to do it that I think are more economical if you give us a chance.

So if you could just broaden the horizon a little bit, say we reasonably want ethanol as the benefits of biofuel, just do not use the work ethanol, just broaden it.

And then third thing it relates to research, and I am in that valley of death. We have done research on this process now for 12 years. We have had laboratory studies and so forth. We are actually in the piloting stage of development. And, in fact, some of the people that have been supporting us in that piloting effort are here. A venture capital group that over the eight years they have been putting out maybe $2 million. And they deserve a medal for funding eight years without a penny return $2 million for us to keep developing the research. But they are kind of getting tired of this. And they need some help. And when we go to the government, the problem is their entrenched ways of doing things.

I mean, when people talk to me about making biofuels from cellulosics, they always say well ethanol. And what they want to do is use enzymes and genetically engineered organisms and so forth, and the cost come out to be like a $1.40 a gallon. And if only we had more research and more time, we could get that cost down. And what I am saying is I do not need any scientific breakthroughs; I just need to do it. And if we can somehow get the government to say let us open up the field to new ideas, let us not keep putting money into the same old thing where there is vested interests out there. The DOE has been around for a long time, the people that are working in it have their pet projects and so forth. I represent an outside process, out of the box thinking. And when we go to the government, I do not fit into their paradigm so I am denied. It is extremely frustrating and some way to break out of that would be very, very helpful.

Mr. LAMPSON [presiding]. Thank you.

Mr. HENNEKES. Just a couple comments for you. One, I very much appreciate your work on the Energy Bill and your colleagues. It was the House of Representative that was ready to pass it. It was your colleagues in the senior house, the Senate, that kept that from going here in the not too distant past.

I would put your arm around your buddies that are senators and say we really need this and see if we can put the partisan bickering aside and figure how to make this thing pass. And so I congratulate you and look for your help with your colleagues in the Senate.

The second thing is I'll agree most adamantly. I might take it a step forward. We talked about gas to liquid fuels. Rather than just saying ethanol has a credit or rather than biofuels, I would say synthetic fuels. So you take the gas to liquids and put them on the same level as the ethanol and all those sort of things. And, again, let every one of them compete to see which one can make the fuel and compete and allow them to work on their own merits with an even baseline.

The third item that I would like to put forward is gasification as a whole competes differently than combustion of coal in large burning plants. Because coal burns directly and you simply put it into the atmosphere, it has a set of standards that are conducive to a burner, to a furnace. Because we actually make a synthetic fuel and then burn it in a turbine, the gasification technology is held to the same level as natural gas. And so the coal burners can continue to pollute at one level, yet this very clean way to take our nation's very, very favorite asset. In fact, if you add up the United States, China and India, we have something on the order of 45 percent of the world's population in coal and it will take us many generations into the future. We have a technology that can bring us energy very quickly, but we are having to compete on a different environmental basis.

So if you put the coal burner on the same environmental basis as the gasification plants, you would have, I think, a very clean and very economic way to take our natural resource of coal and bring it to energy that can then be distributed through the grids, the electrical grids and that sort of thing.

Mr. LAMPSON [presiding]. Thank you.

Mr. HENNEKES. Thank you.

Mr. LAMPSON [presiding]. Franklin?

Dr. CHANG-DÌAZ. I just have one thing. What I would like to see happen is a much greater real collaboration across government agencies. You know, NASA and the DOE tend to be rather insular in the way they do business. And we have noticed that in our relationships that we struggle to build across the national lab and the research here at Johnson Space Center is something that is out of the ordinary. It is not the common process.

But I would like to see a more proactive action on the part of the government to integrate the various agencies that are working on projects that are of synergistic value together. And I think that certainly as a taxpayer, I think that we would get a lot bigger bang for the buck. So this would be my wish.

Mr. LAMPSON [presiding]. Thank you very much.

We are, I think, living in a funny time as far as government is concerned to accomplish some of what you said. It would be great if we could work in a truly bipartisan or maybe I should say nonpartisan way; that we put these things that we have been discussing here today up front as our drop priorities because of what it can do for all of our communities and all the people within our society, but we seem to get bogged down in our politics. And that seems to take the priority away from what we truly have the needs that Dr. Smalley said. If we do not address these things or find a miracle quickly, then we may be too late.

Hopefully we are not. I know that the work that you all are doing are pushing us to get there in time. We appreciate that. If there are things that—you have given us suggestions. I will try to follow through with those.

Now several of you mentioned money. You know, I certainly do not want to be known as a tax and spend liberal Democrat. Judy probably would not be known as a borrow and spend Republican.

We have got to make sure that we put things in the right kind of priority and understand that some of what we need in this country is going to cost us and we need to pay for those in this generation and not the next to make sure that we achieve those opportunities for the next generation to be able to survive, and to live the quality of life or aspire to the quality of life that we have.

So, thank you all for coming. Thank you for sharing your knowledge. Thank you for doing the work that you are doing. And I hope that we can do something that will strength that and make it happen quicker.

Thanks very much.

And for all the rest of you for taking the time to come out, thank you. And you all have a happy holiday.

Thanks for the staff.

We are adjourned.

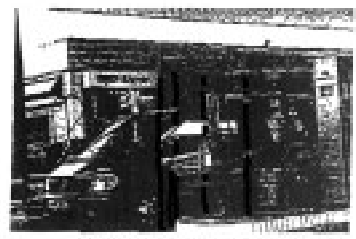
[Whereupon, at 3:40 p.m., the Subcommittee was adjourned.]

Appendix 1:

ADDITIONAL MATERIAL FOR THE RECORD

SAFuel Project

Texoga has followed research conducted by U.S. and NATO military laboratories for years on the development of fire resistant fuels that prevent explosions and flame propagation related to accidents and ballistic ignition sources. The most promising fire resistant fuels have involved biodiesel blends that have been used in Europe for decades.



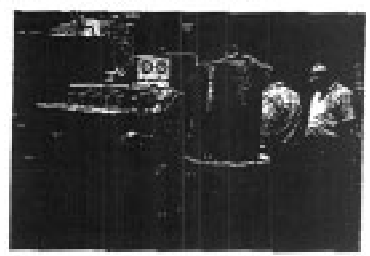
BIODIESEL STATION IN AUSTRIA

Biodiesel involves long carbon chain fuels made from vegetable oils instead of petroleum. Biodiesel can run in all types of diesel engines (including most aircraft and power plants) with higher lubricity, greatly reduced emissions and no toxicity. In addition, the biodiesel blends do not form flammable vapors and resist fire even in rigorous military live fire tests. Unfortunately, European biodiesel has been cost prohibitive by American standards. Since costly soybean or rapeseed oils are used for blending, the resultant fuels average $3.00-$4.50 per gallon. This is an acceptable consumer fuel in Europe, however, as this price is comparable to petroleum-based diesel and gasoline.

BIODIESEL PRICE OF $3.83/GALLON

Texoga's development of SAFuel involves a proprietary process of blending pure biodiesel from used vegetable oils that are offered under the heading of "yellow grease." This greatly lowers the cost and allows for marketing of this non-toxic environmental and fire-safe fuel at competitive prices to petrodiesel.

The development of biodiesel has involved decades of extensive testing in dozens of engine types. Test results confirm a reduction of 80% in CO^2 emissions, 90% reduction in unburned hydrocarbons and a complete elimination of sulphur dioxide. In addition, carbon monoxide and particulates are reduced. Performance monitoring also confirms that the higher lubricity of the SAFuel blend can extend the life of most engines without adversely affecting fuel consumption, ignition, power output and torque.

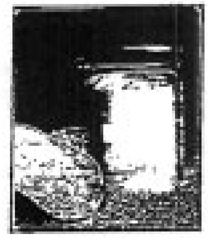


ENGINE TESTING AT FUELS LAB

The SAFuel blending process utilizes a series of measurement, mixing and separation systems that include proprietary injection flow meters, cyclonic blending units and low shear chemical pumps. The result is a continuous flow system that assures quality control fuel output with varying input mixtures. Consistent fuel quality is essential for the high performance engines for aircraft, military and fire/rescue vehicles.

WHAT IS SAFuel

SAFuel is the name for a variety of ester-based oxygenated fuels that run in diesel engines with greatly reduced emissions, virtually no toxicity or flammability.



Properties of SAFuel

Today's diesel engines require a clean-burning, stable fuel that performs well under a variety of operating conditions. SAFuel is the only alternative fuel that can be used directly in any existing, unmodified diesel engine. Because it has similar properties to petroleum diesel fuel, SAFuel can be blended in any ratio with petroleum diesel fuel. Many federal and state fleet vehicles in the USA are already using biodiesel blends in their existing diesel engines.

The low emissions of SAFuel make it an ideal fuel for use in marine areas, national parks and forests, and heavily polluted cities. SAFuel has many advantages as a transport fuel.

Key Advantages of SAFuel:

1. SAFuel (biodiesel) is the only alternative fuel in the US to complete EPA Tier I Health Effects Testing under section 211(b) of the Clean Air Act, which provide the most thorough inventory of environmental and human health effects attributes that current technology will allow.

2. SAFuel is the only alternative fuel that runs in any conventional, unmodified diesel engine. It can be stored anywhere that petroleum diesel fuel is stored.

3. SAFuel can be used alone or mixed in any ratio with petroleum diesel fuel. The most common blend is a mix of 20% SAFuel with 80% petroleum diesel, or "B20."

4. SAFuel produces approximately 80% less carbon dioxide emissions, and almost 100% less sulphur dioxide. Combustion of SAFuel alone provides over a 90% reduction in total unburned hydrocarbons, and a 75-90% reduction in aromatic hydrocarbons. SAFuel further provides significant reductions in particulates and carbon monoxide than petroleum diesel fuel.

5. SAFuel does not ignite unless exposed to the high pressures in the diesel engine. Therefore, it can greatly reduce fires from accidents, exposure to heat or ballistic penetration in military applications.

6. SAFuel is 11% oxygen by weight and contains no sulphur. The use of SAFuel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel, while fuel consumption, auto ignition, power output, and engine torque are relatively unaffected by SAFuel.

7. SAFuel is safe to handle and transport because it is as biodegradable as sugar, 10 times less toxic than table salt, and has a high flashpoint of about 125°C compared to petroleum diesel fuel, which has a flash point of 55°C.

8. Biodiesel is a proven fuel with over 30 million successful US road miles, and over 20 years of use in Europe.

9. Biodiesel has been determined by the Congressional Budget Office, and Department of Defense, US Department of Agriculture, and others to be a low cost alternative fuel option for fleets to meet requirements of the Energy Policy Act and is subject to Alternative Fuels Tax Credits currently proposed by Congress.

SAFUEL IMPACT

SAFuel has a positive impact on the US balance of trade. A 1998 Biodiesel lifecycle study jointly sponsored by the US Department of Energy and the US Department of Agriculture concluded that increased use of biodiesel and biodiesel blended fuels such as B20 would substantially benefit our economy. The report concluded that national spending to import petroleum sends significant amounts of dollars out of our domestic economy every year. Biodiesel offers the potential to shift this spending from foreign imports to domestically produced energy. The report notes: "With its ability to be used directly in existing diesel engines, biodiesel offers the immediate potential to reduce our demand for petroleum in the transportation sector."

SAFuel contributes jobs to the local economy. Economic work conducted at the University of Missouri estimated the benefits of producing biodiesel in a metropolitan region. This study concluded that 100 million gallons of biodiesel production could generate an estimated $8.34 million increase in personal income and over 6,000 additional temporary or permanent jobs for the metropolitan region.

SAFuel USAGE

Basic Terminology: **SAFuel** is the pure, or 100 percent, biodiesel.

It is referred to as B100 or "neat" fuel.

A **SAFuel blend** is pure SAFuel blended with petrodiesel. SAFuel blends are referred to as Bxx. The xx indicates the amount of SAFuel the blend (i.e., a B20 blend is 20 percent SAFuel and 80 percent petrodiesel).

Ensure the neat SAFuel fuel meets the SAFuel specification for pure SAFuel before blending with petrodiesel. The specification for SAFuel is designed to ensure that consumers will not experience operational problems from the fuel's use. Make sure that SAFuel meets this specification and that the fuel supplier will warrant this fact. Quality fuel will provide the consumer with improved air quality and enhanced operability. Poor quality fuel will create operability problems and increased maintenance activity.

Check fuel filters on the vehicles and in the delivery system frequently upon initial SAFuel use and change them as necessary. SAFuel and blends have excellent solvent properties. In some cases the use of petrodiesel, especially #2 petrodiesel (has not been observed with #1), leaves a deposit in the bottom of fueling lines, tanks, and delivery systems over time. The use of SAFuel can dissolve this sediment and result in the need to change filters more frequently when first using SAFuel until the whole system has been cleaned of the deposits left by the petrodiesel. This same phenomenon has been observed when switching from #2 to #1 petrodiesel.

Be aware of SAFuel's freezing properties and take precautions as with #2 petrodiesel use in cold weather. A 20 percent blend of SAFuel with petrodiesel raises the freezing properties approximately 3° to 5° F (pour point, cloud point, cold filter plugging point). In most cases, this has not been an issue. Twenty percent SAFuel blends have been used in the upper Wisconsin area and in Iowa during -25° F weather with no problems. Solutions to SAFuel winter operability problems are the same solutions used with conventional #2 petrodiesel (use a pour point depressant, blend with #1diesel, use engine block or fuel filter heaters on the engine, store the vehicles near or in a building, etc.). Neat SAFuel will begin to freeze at about 25° F and, if used or stored on site, will need to be kept in an area that will not get below that temperature. Most underground tanks are around 50° F and are not a problem.

Wipe painted surfaces immediately when using SAFuel. As mentioned earlier, SAFuel is a good solvent. SAFuel can, if left on a painted surface long enough, dissolve certain types of paints. Therefore it is recommended to wipe any SAFuel or SAFuel blend spills from painted surfaces immediately.

SAFUEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL		
Emission Type	**B100**	**B20**
Regulated		
Total Unburned Hydrocarbons	-93%	-30%
Carbon Monoxide	-50%	-20%
Particulate Matter	-30%	-22%
NOx	+13%	+2%
Non-Regulated		
Sulfates	-100%	-20%*
PAH (Polycyclic Aromatic Hydrocarbons)**	-80%	-13%
nPAH (nitrated PAH's)**	-90%	-50%***
Ozone potential of speciated HC	-50%	-10%
* Estimated from B100 result		
** Average reduction across all compounds measured		
*** 2-nitroflourine results were within test method variability		

The overall ozone (smog) forming potential of SAFuel is less than diesel fuel. The ozone forming potential of the speciated hydrocarbon emissions was nearly 50 percent less than that measured for diesel fuel.

Sulphur emissions are essentially eliminated with pure SAFuel. The exhaust emissions of sulphur oxides and sulfates (major components of acid rain) from SAFuel were essentially eliminated compared to sulphur oxides and sulphates from diesel.

Criteria pollutants are reduced with SAFuel use. The use of biodiesel in an unmodified Cummins N14 diesel engine resulted in substantial reductions of unburned hydrocarbons, carbon monoxide, and particulate matter. Emissions of nitrogen oxides were slightly increased.

> **Carbon Monoxide** -- The exhaust emissions of carbon monoxide (a poisonous gas) from biodiesel were 50 percent lower than carbon monoxide emissions from diesel.
>
> **Particulate Matter** -- Breathing particulate has been shown to be a human health hazard. The exhaust emissions of particulate matter from biodiesel were 30 percent lower than overall particulate matter emissions from diesel.
>
> **Hydrocarbons** -- The exhaust emissions of total hydrocarbons (a contributing factor in the localized formation of smog and ozone) were 93 percent lower for biodiesel than diesel fuel.
>
> **Nitrogen Oxides** -- NOx emissions from biodiesel increase or decrease depending on the engine family and testing procedures. NOx emissions (a contributing factor in the localized formation of smog and ozone) from pure (100%) biodiesel increased in this test by 13 percent. However, biodiesel's lack of sulphur allows the use of NOx control technologies that cannot be used with conventional diesel. So, biodiesel NOx emissions can be effectively managed and efficiently eliminated as a concern of the fuel's use.

SAFuel reduces the health risks associated with petroleum diesel. SAFuel emissions showed decreased levels of PAH and nitrited PAH compounds which have been identified as potential cancer causing compounds. In the recent testing, PAH compounds were reduced by 75 to 85 percent, with the exception of benzo(a)anthracene, which was reduced by roughly 50 percent. Targeted nPAH compounds were also reduced dramatically with SAFuel fuel, with 2-nitrofluorene and 1-nitropyrene reduced by 90 percent, and the rest of the nPAH compounds reduced to only trace levels.

Store SAFuel or SAFuel blend soaked rags in a safety can to avoid spontaneous combustion. SAFuel soaked rags should be stored in a safety can or dried individually to avoid the potential for spontaneous combustion. SAFuel is made from vegetable oils and animal fats that can oxidize and degrade over time. The oxidizing process can produce heat. In certain environments, for example, a pile of oil soaked rags can become concentrated enough to result in a spontaneous fire.

Use the SAFuel within one year. All fuels, including #2 and #1 petrodiesel, have a shelf life. This is also true with SAFuel and SAFuel blends. Industry experts recommend that SAFuel be used within one year to ensure that the quality of the fuel is maintained. Storage time does not impact SAFuel distribution given SAFuel's production logistics. SAFuel is generally not stored for long periods of time. Production levels and rates are established to meet demand (similar to "just in time" inventory methods). This is an advantage enjoyed by renewable fuels, like SAFuel, that cannot be shared by its fossil fuel counterparts.

EMISSIONS

SAFuel (biodiesel) is the first and only alternative fuel to have a complete evaluation of emission results and potential health effects submitted to the U.S. Environmental Protection Agency (EPA) under the Clean Air Act Section 211(b). These programs include the most stringent emissions testing protocols ever required by EPA for certification of fuels or fuel additives in the US. The data gathered through these tests complete the most thorough inventory of the environmental and human health effects attributes that current technology will allow. A survey of the results is provided in the table below.