OIL AND GAS TECHNOLOGY INNOVATION

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

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May 3, 2017

OIL AND GAS TECHNOLOGY INNOVATION

WEDNESDAY, MAY 3, 2017

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:06 a.m., in Room 2318, Rayburn House Office Building, Hon. Randy Weber [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

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House of Representatives
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Subcommittee on Energy

Oil and Gas Technology Innovation

Wednesday, May 3, 2017
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Mr. Edward Johnston, Senior Vice President for Research and Development, Gas Technology Institute

Mr. David Brower, Founder and President, Astro Technology

Mr. Walker Dimmig, Principal, 8 Rivers Capital, LLC

Dr. Ramanan Krishnamoorti, Interim Vice President and Interim Vice Chancellor for Research and Technology Transfer, University of Houston & University of Houston System; Chief Energy Officer, University of Houston

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

Wednesday, April 26, 2017

TO: Members, Subcommittee on Energy

FROM: Majority Staff, Committee on Science, Space, and Technology

SUBJECT: Subcommittee hearing: "Oil and Gas Technology Innovation"

The Subcommittee on Energy will hold a hearing titled *Oil and Gas Technology Innovation* on Wednesday, May 3, 2017, at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

The purpose of this hearing is to explore innovation in oil and gas technology, focused on research led by the private sector. This hearing will also examine opportunities for collaboration between industry, universities, and the national labs in oil and gas technology development, and the appropriate roles for the Department of Energy and industry in this area of applied research.

Witness List

- **Mr. Edward Johnston,** *Senior Vice President for Research and Development, Gas Technology Institute*
- **Dr. Dave Brower,** *Founder and President, Astro Technology*
- **Mr. Walker Dimmig,** *Principal, 8 Rivers Capital, LLC*
- **Dr. Ramanan Krishnamoorti,** *Interim VP/VC for Research and Technology Transfer, Univ. of Houston & Univ. of Houston System; and Chief Energy Officer University of Houston*

Staff Contact

For questions related to the hearing, please contact Emily Domenech of the Majority Staff at 202-226-2179.

Chairman WEBER. The Subcommittee on Energy will come to order. Without objection, the Chair is authorized to declare recesses of the Subcommittee at any time.

Welcome to today's hearing entitled "Oil and Gas Technology Innovation." I recognize myself for five minutes for an opening statement.

Today, we will have the opportunity to hear about exciting new research and developments in oil and gas. Fossil fuels continue to be America's dominant energy source and provide over 80 percent of the energy around the world. It's no surprise that we have a robust industry here at home investing in developing the next generation of technologies to help produce American fossil fuels more efficiently, more safely, and at a lower cost for American consumers.

Our hearing today will highlight individuals and private sector organizations taking a leading role in oil and gas technology innovation. Much like our Committee roster, we see a lot of our Texas innovators on our panel today.

As we worked to put together today's hearing, I quickly learned we could fill this room with innovators from across Texas and the country who are exploring new ways to improve a broad range of technologies that can help revolutionize this industry. My staff and I have had the opportunity to talk to researchers from the University of Texas, Texas A&M, University of Houston, Rice University, and the DOE national labs, all of whom are conducting research that is driven by industry needs.

We heard about research in materials science, to develop materials resistant to the high temperature and pressure environments that occur particularly in offshore drilling. We even learned about the unique applications of nanotechnology to monitor the subsurface, and basic research in geology and computing that allows industry to make better decisions about when and where they drill.

I want to thank Dr. Ramanan Krishnamoorti—am I saying that right? Close enough, huh? Okay. You're very kind—from the University of Houston for testifying today and representing the incredible research going on in my home State. I'm a graduate of U of H myself, Doctor, by the way, so thank you for being here. I look forward to hearing—the Cougars, yes. I look forward to hearing your insight on the nexus between this basic and fundamental research and how it applies in the oil and gas industry.

This brings us to the appropriate role for the Department of Energy. The Department has contributed valuable research in this field for decades. Congress first funded DOE's unconventional oil and gas research programs beginning in 1976, and collaboration with industry has indeed been a core part of DOE's research efforts. Historically, the Department has conducted basic and early-stage research, collecting long-term data and maintaining expertise to provide industry with the tools necessary to achieve technology breakthroughs.

Industry then led the next step, building on DOE research, to commercialize oil and gas technology. Using this collaborative approach, DOE research conducted by the national labs contributed to the development of key technology for hydraulic fracturing and revolutionized the American economy in the process.

Today, DOE continues to make targeted investments in early-stage unconventional oil and gas research, while efforts to deploy new technology are consistently led by the private sector. The Department also contributes funding to larger, industry-led projects measuring seismic data and analyzing geological formations like the Gas Technology Institute's research to maximize the efficiency of hydraulic fracturing in the Permian basin, which we're going to hear more about in testimony today.

As we approach the budget season, it is our job as an authorizing committee to make sure that we have a clear picture of what federal research investments provide the most bang for our buck.

We know that industry has the skills and resources to fund technology commercialization, but they often don't have the tools to conduct early-stage research and maintain that historical data like the DOE national labs can. With that in mind, DOE should prioritize the basic and early-stage research that provides data and analytical tools to researchers and allows the private sector to commercialize groundbreaking technology.

I want to thank our witnesses for testifying today, and I look forward to hearing more about your innovative research.

[The prepared statement of Chairman Weber follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
May 03, 2017

Media Contact: Kristina Baum
(202) 225-6371

Statement of Energy Subcommittee Chairman Randy Weber (R-Texas)
Oil and Gas Technology Innovation

Chairman Weber: Today, we will have the opportunity to hear about exciting new research and development in oil and gas.

Fossil fuels continue to be America's dominant energy source, and provide over 80% of energy around the world. So it's no surprise that we have a robust industry here at home investing in developing the next generation of technologies to produce American fossil fuels more efficiently, more safely, and at a lower cost for American consumers.

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As we worked to put together today's hearing, I quickly learned we could fill this room with innovators from across Texas, and the country, who are exploring new ways to improve a broad range of technologies that can revolutionize this industry. My staff and I had the opportunity to talk to researchers from the University of Texas, Texas A&M, University of Houston, Rice University, and the DOE national labs – all of whom are conducting research that is driven by industry needs.

We heard about research in materials science, to develop materials resistant to the high temperature and pressure environments that occur particularly in offshore drilling. We learned about unique applications of nanotechnology to monitor the subsurface, and basic research in geology and computing that allows industry to make better decisions about when and where they drill.

I want to thank Dr. Ramanan Krishnamoorti from the University of Houston for testifying today and representing the incredible research going on in my home state. I look forward to hearing your insight on the nexus between this basic and fundamental research and how it applies in the oil and gas industry.

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With that in mind, DOE should prioritize the basic and early stage research that provides data and analytical tools to researchers, and allows the private sector to commercialize ground breaking technology.

I want to thank our witnesses for testifying today, and I look forward to hearing more about your innovative research.

###

Chairman WEBER. And with that, I will recognize my good friend from Texas, Mr. Veasey.

Mr. VEASEY. Thank you, Mr. Chairman. I would like to thank you for holding this hearing and thank you for having the witnesses here today. It looks like we have a really—a good distinguished panel, glad that there are two Texans leading this discussion on energy and oil production technology, and it really is amazing how that technology has played such a major part in the world changing just in the last two years. It really is very, very miraculous.

And as you know, the State of Texas represents the largest share of the U.S. oil and gas industry. And everyone here knows that we produce more crude oil and we also produce a lot of natural gas. And this industry has been a major economic driver for our State for a long time, employing hundreds and thousands of Texans. In order to continue this economic success, it is necessary for our State to lead the way in making oil and gas cleaner and safer for the environment and public health.

I'm happy to see that everyone on the panel today can speak to the crucial importance of the environmental mitigation in the extraction production and consumption of oil and gas. I look forward to hearing everyone's insights and ideas. Because—even though there has been some disagreement, we all know for certain that human activity has contributed to the warming of the climate, and the scientific community has made clear that we all need to take some sort of action on climate change.

And so what does this mean for the oil and gas industry? The shale gas boom can take credit for much of the U.S. emissions reductions over the last five years. Much of the power generation sector has switched to natural gas, and we've enjoyed the benefits of this cleaner-burning resource.

However, this is not a sufficient long-term solution to lowering our emissions. Methane, the largest component of natural gas, has 84 times the heat-trapping capacity of carbon dioxide over a 20-year span. Aging infrastructure, greater storage demand, and a growing pipeline network present a number of challenges in monitoring and preventing these leaks.

The most notable leak since the shale gas boom occurred in 2015 at the Aliso Canyon storage facility in California. The leak resulted in the release of 109,000 metric tons of methane into the atmosphere. While methane is colorless and odorless, we know the impact it can have on the environment and the health of our own communities, as evidenced by this incident that we saw in California.

Methane leaks are unique in that the environmental incentives align with the profit incentives of the industry, but it also can mean a loss of profit for industry. But working together, we can provide the incentives and research necessary to drastically reduce methane leaks by closely aligning the industry's bottom line with our urgent need to protect the environment.

The increased reliance on natural gas also highlights another long-term challenge, and that is the deployment of carbon capture technologies. The use of this resource still pumps out greenhouse gases at an unsustainable rate, and that is why we must accelerate the deployment of carbon capture technologies not only for coal-fired plants but also for natural gas power generation.

According to the International Energy Agency, carbon capture and storage technologies are vital to enabling a robust global response in addressing the threat of climate change. The necessity is reflected in the Paris climate negotiations, and we are not short on innovative concepts.

I particularly look forward to hearing from Mr. Dimmig on NET Power's unique zero-emissions design that they are trying to commercialize in Texas in the next few years.

And before I finish, I would also like to note that during today's dialogue, we may hear a few inaccurate or misleading statements comparing incentives for fossil fuel versus those for various forms of renewable energy and energy efficiency. The most obvious inaccuracy in this criticism is the presumption that all renewable energy is the same. It's not, as if solar, wind, geothermal, and hydropower are not all unique forms of energy generation.

Claiming a lack of parity in research and development funding by comparing fossil energy research budget lines to budgets for efficiency and all of these renewable sources lumped together is not only misleading, it ignores the basic fact of how our energy markets work. Fossil energy has enjoyed strong government support for the past century, including tax incentives, subsidies, research, development funding. In fact the current boom in natural gas production can be traced back to research on horizontal drilling and hydraulic fracturing pioneered by the Department of Energy in the 1970s.

Moreover, fossil energy commands strong control over the electric generation and transportation markets, and yet some of my Republican colleagues cry foul when the biggest energy companies in the world do not receive the same dollar-for-dollar government support as all other energy industries combined.

I strongly support government research and development to advance energy efficiency, the wide range of renewable energy technologies, and nuclear power. However, this does not mean that the Department of Energy can't or shouldn't support a robust portfolio of fossil energy research and development as well. This area of research requires a strong partnership between government and industry focused on mitigating the environmental impacts of fossil energy generation.

The Department of Energy's work in this space is vital to our environmental priorities. I hope we have the opportunity this Congress to collaborate with our colleagues on the majority in examining how we can prioritize and expand the Department's R&D in this critical area.

Mr. Chairman, thank you for your patience. I know I went over my time there, and I yield back the balance of my time, and again want to thank the panel for being here.

[The prepared statement of Mr. Veasey follows:]

OPENING STATEMENT
Ranking Member Marc Veasey (D-TX)
of the Subcommittee on Energy

House Committee on Science, Space, and Technology
Subcommittee on Energy
"Oil and Gas Technology Innovation"
May 3, 2017

Mr. Chairman, I'd like to thank you for holding this hearing and thank you to the witnesses for being here today. It seems fitting to have two Texans leading today's discussion.

The state of Texas represents the largest share of the U.S. oil and gas industry. As everyone here likely knows, Texas is the leading crude oil producing state and the largest natural gas producer. This industry has been a major economic driver for our state, employing hundreds of thousands of Texans.

In order to continue this economic success, it is necessary for our state to lead the way in making oil and gas cleaner and safer for the environment and public health. I am happy to say that everyone on the panel today can speak to the crucial importance of environmental mitigation in the extraction, production, and consumption of oil and gas. I look forward to hearing your insights and ideas.

Since the industrial revolution and the birth of the fossil fuel-based economy, the world has seen a sharp increase in atmospheric greenhouse gases and a warming climate due directly to human activity. As the scientific community has made clear, action on climate change cannot wait. So what does this mean for the oil and gas industry?

The shale gas boom can take credit for much of the U.S. emissions reductions over the past five years. As the power generation sector switched from coal-fired power plants to natural gas, we have enjoyed the benefits of this cleaner-burning resource. However, this is not a sufficient long-term solution to lowering our emissions.

As the use of natural gas increased, so too has the potential for methane leaks. Methane, the largest component of natural gas, has 84 times the heat trapping capacity of carbon dioxide over a twenty year span. Aging infrastructure, greater storage demand, and a growing pipeline network present a number of challenges in monitoring and preventing these leaks. The most notable leak since the shale gas boom occurred in 2015 at the Aliso Canyon storage facility in California. The leak resulted in the release of 109,000 metric tons of methane into the atmosphere. While methane is colorless and odorless, the impact it can have on the environment and the health of our own communities is evident as demonstrated by the incident in California.

However, this problem presents an opportunity. Methane leaks are unique in that the environmental incentives align with the profit incentives of industry. Every methane leak represents additional warming for Earth's climate, but it also means a loss of profit for industry. Working together, we can provide the incentives and research necessary to drastically reduce methane leaks by closely aligning the industry's bottom line with our urgent need to protect our environment.

The increased reliance on natural gas also highlights another long-term challenge: the deployment of carbon capture technologies. Even though natural gas is an improvement over coal when it comes to emissions, use of this resource still pumps out greenhouse gases at an unsustainable rate. That is why we must accelerate the deployment of carbon capture technologies, not only for coal-fired power plants, but also for natural gas power generation.

According to the International Energy Agency, carbon capture and storage technologies are vital to enabling a robust global response in addressing the threat of climate change. This necessity is reflected in the Paris climate negotiations, and we are not short on innovative concepts. In particular, I look forward to hearing from Mr. Dimmig on NET Power's unique zero-emission design that they are trying to commercialize in Texas in the next few years.

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Fossil energy has enjoyed strong government support for the past century, including tax incentives, subsidies, research and development funding, and the unaccounted-for military resources marshalled to defend oil shipments around the world. In fact, the current boom in natural gas production can be traced back to research on horizontal drilling and hydraulic fracturing pioneered by the Department of Energy in the 1970s. Moreover, fossil energy commands strong control over the electricity generation and transportation markets. Yet, some of my Republican colleagues cry foul when the biggest energy companies in the world do not receive the same dollar-for-dollar government support as all other energy industries combined.

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I hope we have the opportunity this Congress to collaborate with our colleagues in the Majority to examine how we can prioritize and expand the Department's R&D in this critical area.

Thank you again, Mr. Chairman and I yield back the balance of my time.

Chairman WEBER. Thank you, Mr. Veasey.

I now recognize the Chairman of the Full Committee, Mr. Smith.

Chairman SMITH. Thank you, Mr. Chairman.

I want to say this is an important subject today, and I appreciate you having a hearing on it.

Today, we will discuss recent breakthroughs in oil and gas technology. Innovators continue to build on decades of groundbreaking successes in oil and gas production, maintaining America's technology leadership. This area of research is particularly successful due to continued collaboration between industry, universities, and national labs. We also will discuss the appropriate balance between the private sector leadership and the Department of Energy in applied research and technology development.

The oil and gas industry has a long and successful history of maximizing the research conducted by DOE to further technological breakthroughs. Before hydraulic fracturing and horizontal drilling revolutionized oil and gas production, basic and early-stage research funded by the Department provided valuable tools and knowledge to industry. In the 1980s, Sandia National Lab collaborated with industry to develop the primary drill bit used in horizontal drilling. And Sandia National Lab's basic research in geology led to the development of microseismic fracture mapping techniques for hydraulic fracturing. Industry partners adapted these techniques for commercial use and deployed technology to maximize energy production across the country.

The partnership between DOE and the private sector must have the right structure for success. DOE is best suited to provide the early-stage research that allows industry the opportunity to commercialize and use new technology in the field. This approach allows for the most cost-effective and efficient technology to be deployed by oil and gas companies. We don't need mandates to motivate producers to use the most efficient production technology.

Technology that improves development often reduces the footprint and environmental impact of energy development. It also lowers costs for consumers. R&D is a great way to improve our environment and power our economy. Federally funded research in one area also can provide economic benefits and new technology where we least expect it.

One of our witnesses today—David Brower, the founder of Astro Technology—spent his career as an engineer working with NASA and the Department of Defense. After years of working on rocket propulsion and safety, he discovered that he could effectively apply many of the sensor technologies used in the aerospace industry to improve safety in oil and gas development. This is the kind of groundbreaking technology that we cannot predict when we fund basic and early-stage research.

Like many of my colleagues, I share a commitment to the long-term use of our nation's most abundant and affordable fuel source. DOE's fossil energy research programs can pave the way for industry to develop the next generation of technologies. But for this partnership to be a success, industry must continue to take a leading role.

I look forward to a discussion about what policies Congress and DOE should pursue to encourage more industry-led research and development efforts. In Congress, we have the responsibility to ensure the efficient and effective use of American tax dollars. By investing in early-stage research and encouraging strategic partnerships between DOE and industry, we will ensure that our vast natural resources will continue to provide affordable and efficient fuel for the American economy.

[The prepared statement of Chairman Smith follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
May 03, 2017

Media Contact: Kristina Baum
(202) 225-6371

Statement of Chairman Lamar Smith (R-Texas)
Oil and Gas Technology Innovation

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By investing in early stage research and encouraging strategic partnerships between DOE and industry, we will ensure that our vast natural resources will continue to provide affordable and efficient fuel for the American economy.

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Chairman SMITH. Mr. Chairman, before I close, I want to recognize James Danford, who is sitting right behind me, and he is our Science Committee Legal Assistant and Speechwriter who has helped me at numerous committee hearings and markups over the past five years. James' last day on the Committee will be next Friday.

He has been attending Georgetown Law School at night while working at the Science Committee full-time and will graduate May 21.

James and his wife Christa, my Executive Assistant, will be moving back to Texas for James to take a job at a Houston law firm. James and Christa have each been on my staff for almost six years. They are expecting their first child in July. So we wish them health, happiness, and success.

And James will you stand up and let us give you some applause here?

Chairman WEBER. So, James and did you meet your wife here on the Science Committee?

Mr. DANFORD. No, we've been dating since high school.

Chairman WEBER. Okay. So it took you a long time. I see how you are.

So thank you, Mr. Chairman. And I now recognize the Ranking Member of the Full Committee for a statement. Ms. Johnson?

Ms. JOHNSON. Thank you very much. Let me congratulate James and say good wishes for the future. And thank all of our witnesses, Mr. Chairman, for being here.

This is an interesting topic. I think it's interesting to note that both the Chairman and Ranking Member of the Full Committee and the Subcommittee Chairman and Ranking Member are all Texans, and the Secretary of Energy now is also a Texan. So you can tell that there is interest in this topic in Texas.

Certainly, the oil and gas sector is in is one area in which we see how advances in science and engineering can produce large-scale economic value, and our federal R&D agencies have played a historic role in this process. Just over a decade ago, we had little idea of the fossil resources that would be available to us today.

However, due to some critical research investments made by the Department of Energy over 40 years ago, coupled with rising oil prices and in previous decades, the American economy underwent the shale gas revolution, bringing natural gas resources online and with it a sharp increase in domestic oil production.

The DOE—that program in DOE wrapped up in the early '90s when a private company took the research performed by DOE and used it to ignite the oil and gas boom we see today. I think my colleagues would agree that that is the model of DOE's energy technology programs that we all hope to see: federal investments shepherding transformative technologies to the marketplace even when the endpoint is not clear at the beginning of the process.

That brings us to what should be fundamental questions today. Where should the Department of Energy be investing limited dollars in this area? If the standard of identifying of a government role rests in whether the private industry has the capacity to invest in R&D, then I think the answer to the question of DOE investments in oil and gas is that the federal role should be very limited. After all, it is hard to think of a sector that is much more commercial and on average more profitable than the oil and gas industry. For this reason, I believe the Department should focus its investments on environmental mitigation. At present there is little incentive for industry to spend major R&D dollars to protect the environment.

If this hearing is intended to highlight the importance of oil and gas to the economy, hopefully, I can save us some time. I am from Dallas. Oil and gas will play an important role in our nation's economy for decades to come. My hope is that our outcome of these hearings will be to push the present Administration to reconsider its position to drastically reduce R&D funding for fossil energy. I would support that endeavor as long as it comes along with strong support of DOE's other energy technology programs. When it comes to R&D funding, Republicans and Democrats should be speaking with one voice. Investments in R&D benefit our nation.

In closing, I would like to challenge the current Administration and our colleagues on this Committee to be forward-looking in our push to develop the next-generation energy economy. Drilling our way to economic growth while ignoring the long-term impacts cannot be the answer as we face a warming climate and the significant consequences that come along with that. Our environment and the health of the public is on the line.

And so I thank you, Mr. Chairman, and I yield back the balance of my time.

[The prepared statement of Ms. Johnson follows:]

<u>OPENING STATEMENT</u>

Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
Subcommittee on Energy
"Oil and Gas Technology Innovation"
May 3, 2017

Thank you, Mr. Chairman. This is an interesting topic for this subcommittee to examine today. Certainly, the oil and gas sector is one area in which we see how advances in science and engineering can produce large-scale economic value, and our Federal R&D agencies have played a historic role in this process.

Just over a decade ago, we had little idea of the fossil resources that would be available to us today. However, due to some critical research investments made by the Department of Energy over 40 years ago, coupled with rising oil prices in previous decades, the American economy underwent the shale gas revolution bringing major natural gas resources online, and with it, a sharp increase in domestic oil production.

That DOE program wrapped up in the early 1990s when a private company took the research performed by DOE and used it to ignite the oil and gas boom we see today. I think my colleagues would agree that that is the model for DOE's energy technology programs we all hope to see – federal investments shepherding transformational technologies to the marketplace, even when the endpoint is not clear at the beginning of the process.

That brings us to what should be the fundamental question of today: where should the Department of Energy be investing limited dollars in this area? If the standard of identifying of a government role rests in whether the private industry has the capacity to invest in R&D, then I think the answer to the question of DOE investments in oil and gas is that the Federal role should be very limited. After all, it is hard to think of a sector that is much more commercial and on average more profitable, than the oil and gas industry.

For this reason, I believe the Department should focus its investments on environmental mitigation. At present, there is little incentive for industry to spend major R&D dollars to protect the environment.

If this hearing is intended to highlight the importance of oil to the economy, hopefully I can save us some time. I am from Dallas. Oil and gas will play an important role in our nation's economy for decades.

My hope is that an outcome of their hearing will be to push the Trump Administration to reconsider its position to drastically reduce R&D funding for fossil energy. I would support that endeavor, as long as it comes along with strong support DOE's other energy technology programs.

When it comes to R&D funding, Republicans and Democrats should be speaking with one voice. Investments in R&D benefit our nation.

In closing, I would challenge the current Administration and my colleagues in Congress to be forward-looking in our push to develop the next generation energy economy. Drilling our way to economic growth while ignoring the long-term impacts cannot be the answer as we face a warming climate and the significant consequences that come along with it. Our environment and the health of the public is on the line.

Thank you, and I yield back.

Chairman WEBER. I thank the Ranking Member, and I will introduce the panel.

Our first witness today is Mr. Edward Johnston, Senior Vice President for Research and Development at the Gas Technology Institute. Mr. Johnston received his bachelor's degree in mechanical engineering from Mississippi State University and his MBA from University of Chicago's Booth School of Business.

And our next witness today is Mr. David Brower, founder and President of Astro Technology. Mr. Brower received both his bachelor's degree in material science and mechanical engineering and a master's of science degree from the University of Utah.

And then our next witness is Mr. Walker Dimmig, Principal at 8 Rivers Capital, LLC. Mr. Dimmig received his bachelor's degree in political science from Middlebury College.

And our last witness is Dr. Ramanan Krishnamoorti, Interim Vice President and Interim Vice Chancellor for Research and Technology Transfer at the University of Houston and University of Houston System—go Cougs—as well as Chief Energy Officer at the University of Houston. Dr. Krishnamoorti obtained his bachelor's degree in chemical engineering from the Indian Institute of Technology Madras and doctoral degree in chemical engineering from Princeton University.

I now recognize you, Mr. Johnston, for five minutes to present your testimony.

TESTIMONY OF MR. EDWARD JOHNSTON, SENIOR VICE PRESIDENT FOR RESEARCH AND DEVELOPMENT, GAS TECHNOLOGY INSTITUTE

Mr. JOHNSTON. Thank you very much, Chairman Weber, Ranking Member Veasey, Chairman Smith, and Ranking Member Johnson, and the rest of the Members of the Subcommittee.

On behalf of GTI, I'd like to thank you for the opportunity to testify before you today regarding innovation in the upstream oil and gas sector. My name is Eddie Johnston. I'm the Senior Vice President of Research and Technology Development at GTI, and we're an independent, not-for-profit R&D organization. Our vision is to turn raw technology into practical energy solutions that have meaningful impact for both the economy and the environment.

I'm here to talk about shale research, and while shale development seems like an overnight occurrence to most, decades of research and cooperative field experiments by GTI and DOE underpin the technical complexities of producing this resource.

Shale rock has very low permeability, so stimulation can be very challenging and require significant energy. In shale formations, the recovery rate is typically below 20 percent for gas and ten percent for oil and sometimes even much lower. This is the grand challenge. Field experiments we've conducted indicate that as many as 80 percent of fracture treatments did not significantly contribute to overall production. Effective, yes; efficient, no. This inefficiency has direct environmental implications, and by optimizing fracture efficiencies, fewer wells will need to be drilled, which leads to fewer trucks, less water, reduced emissions, and less community impact.

To address these issues, GTI launched the Permian project, our hydraulic fracturing test site in West Texas. Our goal is simple in concept: substantially advance the hydraulic fracturing process to optimize well spacing so fewer wells are needed. The problem, though, is multifaceted. Subsurface completion science continues to be a complex process with many variables that affect the locations where fractures propagate, their dimensions, and their ability to enhance production. Direct and reliable data is still needed about the size, shape, and distance that hydraulic fractures actually propagate.

Optimizing resource recovery techniques requires input from the best and brightest from industry, universities, national labs, research institutes, and the only way to realistically do this is via public-private partnership. So with the assistance of a $7.4 million cooperative agreement from the Fossil Energy Office, GTI was able to pull together a partner in Laredo Petroleum that provided a test site and personnel in the Permian, along with $100 million of microseismic and other background data.

A joint industry partnership of Chevron, Conoco Phillips, Core Labs, Devon, Discovery Natural Resources, Encana, Energen, Halliburton, Shell, and TOTAL that sponsored the additional $16 million of research work and also provided subject matter experts to contribute to the scope and a team of leading researchers from the University of Texas, The Bureau of Economic Geology, and NETL. And over this 11-well experiment, more than 400 fracture stages were monitored, and we continue to study the production from these fractures today.

But the key differentiator of this work is the $6 million core well as we captured 600 feet of unique core through fracture zones by drilling a one-of-a-kind slant core well. More people have actually examined rocks from the moon than they have through fractured core. Extracting core of this magnitude is an expensive and risky undertaking, but this ground truth evidence is critical to understanding fractures and improving models and to consider how predictive analytics can improve the process. Important data about propagation and proppant transport dynamics will lead to the design of optimal fracture treatments and ultimately ideal well spacing. Many of the findings will likely be transferable to other basins, but shale is a heterogeneous resource, so much work is still needed to be done.

We have planned future work in the Permian and signed a letter of intent with BHP Billiton for a test site in the Delaware basin, part of the Permian that is deeper, at higher pressures and temperatures, and different permeability than the Laredo site. Interested partners are looking for a commitment from DOE that signals continued support for this type of important research. This investment will be the catalyst for the next phase of learning.

In conclusion, shale has recalibrated world energy markets, helped resurrect our economy, provided U.S. consumers clean, affordable energy. Much has been accomplished by the mechanical innovations by industry, but the subsurface science work is clearly incomplete. Continued field experiments are critical to achieve desired recovery rates for more responsible development. The involvement of the public funding ensures the results are ultimately shared broadly rather than being held by a select few. This will allow us to maximize our national energy resource and accelerate our path to energy security and independence.

Thank you again for this opportunity to speak today, and I'd be happy to answer any questions when it's the correct time.

[The prepared statement of Mr. Johnston follows:]

Preface: Gas Technology Institute (GTI) is an independent 501(c)(3) research organization, established as an Illinois not-for-profit corporation. GTI has a 75-year history that stems from two predecessor organizations—the Institute of Gas Technology (IGT) established in 1941 as an education and research performing organization, and Gas Research Institute (GRI), created in 1976 to manage a cooperative research and development (R&D) program on natural gas. Based on a settlement between FERC and the gas industry in 1998, the traditional GRI RD&D program—and the mandatory funding to support it—ended in 2004. Today GTI is a voluntarily funded organization developing technology-based solutions for consumers, industry, and government.

Chairman Weber, Ranking Member Veasey, and Members of the Subcommittee, on behalf of GTI, I would like to thank you for this opportunity to testify before you today regarding the value of innovation, research, and Public-Private partnerships.

My name is Eddie Johnston, Senior Vice President of Research and Technology Development. I oversee GTI's entire research staff, leading efforts across unconventional supply, energy conversion, natural gas delivery, and end use market sectors. Prior to joining GTI in 2007, I worked for Atmos Energy Corporation for 15 years, and also worked hands-on in the off-shore oil and gas drilling industry with Rowan Companies.

GTI is a leading non-profit research, development, and training organization, and our vision is to turn raw technology into practical energy solutions that have meaningful impact for the economy and the environment. We have spent the last seven+ decades creating innovative solutions to critical challenges along the entire gas value chain, improving the ways of producing, transporting, converting, and using energy to benefit the general public.

We cover a robust spectrum of initiatives. In addition to reducing the environmental footprint of shale gas production, which you'll hear more about, GTI's focus includes:

- Expanding the supply of natural gas and renewable energy
- Developing clean and renewable alternatives to petroleum-based transportation fuels and chemicals
- Enhancing the integrity of our nation's vast pipeline infrastructure
- Reducing methane emissions across the value chain
- Promoting energy efficiency by developing and demonstrating high-efficiency technologies
- Advancing clean, low-cost power production from all of our energy resources

With more than 360 employees across the nation, GTI expert engineers and scientists are developing innovative new tools, technologies, and methodologies, and delivering science-based factual data that helps to guide informed decision-making and enlightened policy development.

GTI has a storied history rich in meaningful Public-Private partnerships on various energy related topics, especially in the development of our country's unconventional oil and gas resource.

Shale: Revolution or Evolution?

While shale development seems like an overnight occurrence to most, decades of research underpin the technical understanding and complexities of producing this seemingly impermeable resource. GRI, DOE, and the Research Partnership to Secure Energy for America (RPSEA) conducted focused research programs for the development of unconventional resources (coal bed methane, tight sands, and shale) spanning more than three decades and nearly $1 billion; specifically addressing fracturing in shale formations by investing more than $100 million (unadjusted figures).

Much of what now is considered seminal research was conducted in a series of field experiments that took place in eastern U.S. shales in the 1980s. Researchers from industry, national labs, and universities have studied the data sets from these empirical field tests and have successfully built important fracture models and other technology that have tremendously improved shale production over time.

It is of interest to note that this research was severely criticized by much of industry at the time, with some larger exploration and production (E&P) companies describing the research as a "waste of money". Two men, former GRI President Henry Linden and George Mitchell, CEO of Mitchell Energy who was serving on the GRI Board of Directors at that time, fortunately did not share this sentiment. Mitchell expressed his support for shale research, but also recommended a new approach. At the time, all of the research was focused on shallow, eastern U.S. Devonian shales and had been for many years. Shale production was at a miniscule 50 bcf/year and was not changing significantly.

Mitchell made a recommendation to move the research program to a new area and new geologic basins. Heeding his advice and working with Mitchell Energy, efforts were moved eventually to the Barnett shale in Texas. In 1988, GRI and Mitchell Energy initiated the first of many cooperative wells that proved through new core techniques that there was actually four times more gas in place than previously believed. This discovery at the T.P. Sims well provided the target that innovations in horizontal drilling and hydraulic fracturing effectively exploited. In 1991, GRI worked with Mitchell Energy to drill the Stella Young well in the Barnett Shale—a horizontal well stimulated with new technology that produced three times more gas than any other well up to that time. This was a pivotal point in the U.S. shale gas evolution that transformed the energy industry.[1]

Shale by the Numbers

Fast forward, oil and gas production from U.S. shale formations has become what most consider the world's "swing supply", a truly amazing success and likely the biggest energy breakthrough of the last 50 years. While the oil and gas sector is responsible for an estimated $1.2 trillion in GDP and 9.3 million U.S. jobs,[2] one of the most meaningful and visible impacts of shale gas is lower utility bills for consumers, putting $1,372 per year back into the pockets of the average American family.[3] Since shale gas is used to heat homes and produce electricity, consumers are spending less money on both natural gas and electricity bills. The increased use of natural gas in electricity generation has also produced significant reductions in CO_2 from the power sector – down 21% from 2005 levels according to EIA.[4]

The U.S. has also seen important decreases in energy imports as a result of shale development, and if development continues as projected, then we could be a net energy exporter by as early as 2030, which would be a significant improvement in balance of trade. Therefore, domestic energy security and independence is actually in sight. However, one metric must be improved to optimize the value of this resource – the recovery rate from oil and gas shale formations.

Unconventional Resources Defy Conventional Wisdom

Even during times of declining prices, domestic production has increased; primarily because of tremendous mechanical advances in drilling and completion techniques that keeps some shale production economically viable in this lower-price environment. Some may infer that all is understood and that shale development has matured; however, one look at the current resource recovery rates, and one can quickly deduce that much is left to be done.

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[1] Gas Research Institute. (1992A). *Reservoir engineering and treatment design technology. Analysis of production and well test data from Barnett Shale Wells Operated by Mitchell Energy Corporation*. GRI-92/0397. Chicago, IL. Gas Research Institute (1992B) *Reservoir engineering and treatment design technology. History match analysis of production and well test data from Mitchell Energy Corporation's Stella Young 4 Well.* GRI-92/0398. Chicago, IL

[2, 3] The Perryman Group. (August 2014). The economic benefits of oil and natural gas production: An analysis of effects on the United States and major energy-producing states. Retrieved April 27, 2017. https://www.perrymangroup.com/wp-content/uploads/Perryman-Oil-Impact-Study.pdf

[4] US Energy Information Administration. Today in Energy. (2016, May 13). Carbon dioxide emissions from electricity generation in 2015 were lowest since 1993. Retrieved April 27, 2017. https://www.eia.gov/todayinenergy/detail.php?id=26232

The primary opportunity to have meaningful impact for broader success in shale is to optimize the network of natural and induced fractures to greatly increase recovery. Shale rock can exhibit permeability properties that are a factor of nine less than conventional resources (nanodarcies versus darcies), so reservoir stimulation of shale can be quite challenging and requires significant energy. The volume of available U.S. shale gas and shale oil recovered is typically below 20% and 10%, respectively, and sometimes much lower. **This is the grand challenge.** These low recovery rates (a fraction of what conventional reservoirs offer) and rapid decline rates of wells lead to intensive drilling operations. Field experiments indicate that as many as 80% of fracture stages in a single horizontal well do not significantly contribute to the overall production of the well. So although the process may prove effective, it is certainly not efficient.

This inefficiency has direct implications on the environmental footprint of shale production. By optimizing fracture efficiencies fewer wells will need to be drilled, fewer trucks will be required, less water will be used, emissions will be reduced, and community impact will be minimized, all while producing more oil and natural gas.

Why the Permian?

The combination of the Midland and Delaware basins in the Permian of West Texas is now considered by many to be the largest hydrocarbon resource in the world, and estimates continue to rise with every evaluation. Rig activity grows daily, and now more than 40% of the domestic fleet is dispatched in West Texas. Current oil production is approximately 2.4 million barrels per day, and projections suggest that this could more than double over the next seven to ten years. Similar increases in natural gas and liquids production are likely as well. This increase in Permian production alone could set the U.S. on a very plausible path to energy security.

The Permian Project: GTI's Hydraulic Fracturing Test Site (HFTS)

Our goal is simple – substantially advance the hydraulic fracturing process to optimize well spacing so that fewer wells are needed to increase resource recovery and simultaneously reduce the environmental footprint of production.

The problem is multifaceted – subsurface completion science has the greatest uncertainty and variability of the shale development process. Yet, even as hydraulic fracturing is in wide use, it continues to be a complex and controversial process with many variables that affect the locations where the fractures propagate, their dimensions, and their ability to enhance production of hydrocarbons. The extent, complexity, and volumes of the fractures created along the horizontal holes that are drilled during each stage are not well understood. While we know that the fractures form a complex three-dimensional pattern, direct and reliable data is still needed about the size, shape, and distance of hydraulic fracturing propagation.

Understanding and optimizing this resource recovery technique requires input from scientific, engineering, and operating subject matter experts from industry (operators and service providers), universities, national laboratories, and other research institutes, and the only realistic way to do this is via a Public-Private partnership. So with the assistance of a cooperative agreement in the amount of $7.4MM from U.S. DOE Fossil Energy, GTI was able to attract:

- A host site partner in Laredo Petroleum that provided a test site in the Permian, pertinent micro-seismic and other background data with an approximate value of $100MM, and approximately 25 engineers and operations staff for the experiment.
- A Joint Industry Partnership (JIP) of service companies, independent producers, and integrated majors that sponsored the additional $16MM of research work and also provided subject matter experts to technically contribute to the program. (JIP participants are Chevron, ConocoPhillips, Core Laboratories, Devon, Discovery Natural Resources, Encana, Energen, Halliburton, Shell, and TOTAL).
- A team of leading researchers at the University of Texas (UT) Petroleum Engineering Department, at the UT Bureau of Economic Geology, and at the National Energy Technology Laboratory.

In September 2015, the HFTS research team drilled and stimulated eleven 10,000-foot-long horizontal wells. More than 400 fracture stages were completed in those wells. Using microseismic and tiltmeter technologies, the team monitored the fracturing process.

A comprehensive set of state-of-the-art technologies were used to observe and monitor activities and production throughout the project, **but the key differentiator of this field experiment is the 600 feet of unique core that was obtained by drilling a one-of-a-kind core well through created hydraulic fractures at the test site.** Extracting core of this magnitude is an expensive and risky undertaking, but all participants agreed in advance that this ground truth evidence is paramount to understanding fractures, validating and developing models, and providing for an assessment of how predictive analytics can improve the process.

The analysis of the influence of reservoir rock conditions on fracture properties will help researchers develop a cause-and-effect relationship between fracturing parameters and reservoir geology to measure the consequences of fracturing—results that can be applied to other locations and plays. Important data about subsurface fracture propagation and proppant transport dynamics will lead to the design of optimal fracture treatments and, ultimately, ideal well spacing. Many of the findings will likely be transferrable to other basins, but shale is a heterogeneous resource so much more work needs to be done.

Future Work in the Permian

GTI and BHP Billiton Petroleum (BHP) signed a letter of intent for another Hydraulic Fracture Test Site in the Reeves County area of the Delaware basin, a subset of the West Texas Permian basin that is deeper, at higher pressures, and different permeability than the Laredo site in the Midland portion of the Permian. An important feature of this experiment will be a dedicated well drilled to extract a core to better understand the stimulated reservoir volume (SRV). The diagnostic information will provide insight to the fracturing network and connectivity between fractures across horizontal wellbores. At the same time, air and water samples will be taken in the test site area to evaluate air and water quality. The information will deliver an understanding of appropriate well and fracture spacing to optimize production with reduced environmental impacts.

Some of the participants of HFTS #1 will likely participate in this second field experiment based on owning acreage in the Delaware basin, and we will pick up new participants, expanding the learnings from this critical field work. As with the first experiment in the Permian, interested industry partners are looking for a commitment from DOE that signals continued support for this important research. This investment will be the catalyst for the next phase of learning.

Conclusion

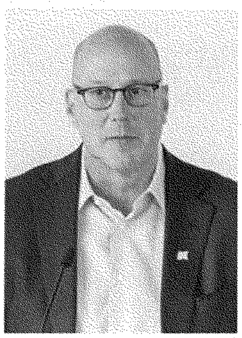
In addition to the research and technology underpinning that occurred over decades, the U.S. has a very unique alignment of factors that no other country in the world enjoys that has made shale development such an amazing success:

- Incredible and vast resource of brittle shale
- Tremendous pipeline infrastructure
- Mineral right ownership by landowners
- Robust service sector
- Entrepreneurial spirit of the independent producer
- Great access to capital
- Public policy that incentivizes development

This confluence of elements has re-calibrated world energy markets, resurrected our economy in the midst of the Great Recession, and provided consumers clean energy at the lowest prices in the world. But the work is far from finished. As you can see, the subsurface science related to resource development in U.S. shale is both complex and under-appreciated. The fact is that even with the breakthrough science performed in our Field Test Program, there is much more to learn in order to gain a sufficient understanding to maximize our national energy resources in the different shale plays we are so fortunate to have.

Continued research and field tests will be required to achieve desired recovery rates for responsible development, supported by a robust DOE research portfolio. The opportunity and funding DOE provides in this area initiates and galvanizes interest to perform research that most operators are not willing to conduct independently, and since public funding is involved, the results are ultimately disseminated across the industry and research community, rather than being held tightly by a select few.

Make no mistake, these prior public and private investments in research and field tests in unconventional development have been the catalyst that dramatically altered the energy landscape in the U.S., with these rewards being shared by consumers, taxpayers, manufacturers, and industry. With continued public support for these research efforts, the U.S. will continue to lead the world into the next evolution of shale.



Eddie Johnson

Senior Vice President, Research and Technology Development

Gas Technology Institute

BIOGRAPHY

As Senior Vice President of Research and Technology Development, Eddie Johnston leads Gas Technology Institute (GTI), driving integrated responses to energy needs. He oversees GTI's research staff—leading efforts across unconventional supply, energy conversion, natural gas delivery, and end use market sectors.

GTI's innovative technologies make energy resources economically viable, minimizing environmental footprint, and maximizing market impact, while reducing costs for consumers.

Johnston joined the company in July 2007. Prior to that, he worked for Atmos Energy Corporation for 15 years, and worked for nearly a decade, hands-on in the off-shore oil industry with Rowan Companies.

Johnston earned a B.S. degree in mechanical engineering from Mississippi State University and a M.B.A. from University of Chicago's Booth School of Business. He serves on a number of Boards of Directors and Advisory Boards for tech start-ups, advocacy groups, and research organizations across the energy value chain.

Eddie's professional affiliations include:

- President of Starline Trenchless Technologies, USA LLC
- Executive Committee for the Research Partnership to Secure Energy for America (RPSEA)
- Ex-officio member of AGA's Operations Management Committee
- Board of Advisors for Wanger Institute for Sustainable Energy Research (WISER) & Illinois Institute of Technology (IIT)

April 2017

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Chairman WEBER. Thank you, Mr. Johnston. Dr. Brower, you're recognized for five minutes.

TESTIMONY OF DR. DAVE BROWER, FOUNDER AND PRESIDENT, ASTRO TECHNOLOGY

Dr. BROWER. Mr. Chairman, Members of the Committee, thank you for having me here this morning. As mentioned, my name is David Brower. I have much experience in science and technology, and I've spent my 37-year career working on rocket technology for defense and space applications. I've also worked in the energy industry for over the past 20 years.

The combination of aerospace, energy, and government experience has allowed me to develop and implement entirely new high-technology methods into the energy industry. The primary objective of my work has been to identify and prevent potential problems before they occur. In doing so, we should be able to mitigate environmental contamination from hydrocarbon spillage and offshore and land-based operations, for example, to head off catastrophic events such as the major oil spill in the Gulf of Mexico during summer of 2010 and many less publicized smaller spills our candidates also. The innovative methods also improve safety and help increase production and operation capabilities.

Since I formed Astro Technology in 1994, I have been a committed advocate of strong working relationships between government and industry. Currently, we work under a Space Act agreement with NASA. The resulting work activity has been instrumental in transfer of high-technology methods into the energy industry. Twice—in 2004 and 2015—our efforts have been highlighted in NASA's annual spinoff report to Congress. This highly effective government-to-industry approach has led to several deep-water sensor implementations in the Gulf of Mexico with several others in progress. I should mention that our collaboration has included university support as well. Consequently, we've been able to identify and potentially prevent structural failure, ensure environmental protection, and at the same time improve operations.

Our venture began with the START treaty as part of the counter-proliferation of weapons of mass destruction in the republics of the former Soviet Union. As a result of that work, I was successful in development and application of new advanced sensors. In mid- to late 1990s, several oil and gas companies approached me about solving problems on a deep-water pipeline in the Gulf of Mexico. They needed a sensor that could measure pressure on the interior of a subsea pipeline that did not require penetrations leading to possible leak paths. After the successful task, several more oil and gas projects resulted.

Twenty years later, significant progress has been made with NASA's assistance to advanced technology in oil and gas. Much more effort is needed. Astra Technology started a research and development project called Clear Gulf approximately a decade ago. This effort includes 10 research areas such as identification and mitigation of structural integrity that could cause significant hydrocarbon spillage.

Flow assurance monitoring is another research area we're addressing to prevent blockage of flowlines from hydrocarbon and hydrate formation. Also advanced robotic development will fill a significant gap in current large-scale remotely operated vehicles. The new robots would work and live subsea. They will have dexterous capability and perform finesse work operations mimicking human capability. Another exciting research area is the repair of older or soon-to-fail structures that are in deep-water fields.

By definition, I believe the role of small business in new advanced methods is clearly that of innovation. Large companies are highly suited for implementation, and government support, encouragement, technology direction, and possible incentives.

It can be very difficult to achieve implementation of new technology methods. A stronger alliance between government and industry could solve that problem. I've been very fortunate to have a string of successful projects. My journey would've been much more difficult without government support.

My thoughts going forward involve a stronger working relationship between small business mainstream oil and gas companies, universities, and U.S. Government. My experience with oil and gas companies has been very positive. They sometimes have fear of trying anything new. However, as we move into future endeavors, it becomes increasingly important to develop and apply advanced technologies to ensure environmentally clean operations, trouble-free work effort, and better control of operational processes.

In conclusion, I recommend the formation of a short-term task team that addresses the issues discussed. The team should consist of small business entities, DOE, several subject matter experts from large oil and gas companies, and universities.

Thank you again for the invitation and your attention.

[The prepared statement of Mr. Brower follows:]

US Congress Presentation Summary

David Brower – Astro Technology Inc.

Committee on Science, Space, and Technology

May 3, 2017

Introduction Comments on Astro Technology

- Texas based – formed in 1994
- Aerospace and Energy Industry Support
- Counterproliferation of Weapons of Mass Destruction / Demilitarization of Russian Intercontinental Ballistic Missile System – START Treaty
- High Technology Sensor Development
- Space Act Agreement with NASA
    - NASA Spinoff Magazine -2004 and 2015
- Current Research and Development Program
    - Clear Gulf
    - Ten areas of research to advance oil and gas capabilities

Objectives for new innovative methods

- Prevention of potential problems before they occur
- Prevention of environmental contamination / hydrocarbon spillage
- Improve safety
- Increase production / operation capabilities

Innovation in Oil and Gas Technology

- Small Business Role - Innovation
- Large Company Involvement - Implementation
- Government Involvement – Support, encouragement, and possible incentives

Thoughts about ongoing and future working relationships between government and industry

- Form short duration task team to address above mentioned issues consisting of small business entity, DOE, several subject matter experts from large companies

David Brower - Bio

Founder & President of Astro Technology

David has built his expertise over a long career in the aerospace and energy industries. He worked in both the private sector as well as the NASA space program before becoming an entrepreneur. Constantly pursuing new ideas, he began developing Astro Technology's sensor system while working on rocket motors. He began his career after graduating in Material Science & Mechanical Engineering from the University of Utah. For the next 10 years, David worked for Hercules Aerospace Company, leading efforts in rocket motor design and fabrication. He oversaw development of rocket motors deployed in nuclear submarines for the US Navy Fleet Ballistic Missile Program.

At the end of the Cold War, he moved his family from Salt Lake City to Houston to work in the space program with NASA. He helped design a lunar-based rocket motor that used materials mined from moon rock. The rocket motor was designed to propel a lunar-based vehicle that could rendezvous with an orbiting space vessel and subsequently supply a manned colony on the moon.

Innovating to create subsea systems

After five years in the space program, David founded Astro Technology. Due to his expertise in rocket motors and through the US Department of Defense, he participated in the counter-proliferation of weapons of mass destruction that resulted from treaties between the United States and Republics of the former Soviet Union. His role was to demilitarize Russian Intercontinental Ballistic Missiles.

During his work with rocket motors, David designed a new sensor system that could be safely used in contact with propellants. The oil and gas industry began using this system to measure pressure, strain and vibration on subsea pipe lines. David later advanced the sensor system and has installed it in deepwater fields throughout the oil and gas industry. He has installed operational sensors on subsea equipment in water depths of 7,500 feet and on deepwater flowlines up to 60 miles in length.

He currently is leading a joint technology development project with NASA and subject matter experts in the oil and gas industry. This effort is designed to implement new technologies into subsea oil and gas projects that will greatly reduce the risk of oil spillage and environmental contamination such as the event in the Gulf of Mexico in the summer of 2010. This study is unique in that it combines the technologies of two major industries, NASA and energy. The net result will be better systems and job creation that will benefit the local area and economy.

Mr. Brower has approximately 12 patents pending and several others in progress.

A commitment to new ideas, family and travel

David is deeply committed to his family – and to travel, sport and outdoor adventure. Having fished, camped and hunted in the Rocky Mountains during his youth, he became an avid high altitude mountain climber after trekking in the Himalayas. His climbs have included Kilimanjaro, Elbrus, Whitney, Rainier, and Aconcagua – the highest mountain in the Western Hemisphere, with an elevation exceeding 22,800 feet. He has researched and spent time exploring the jungles of Central America in search of pre-Columbian ruins and artifacts.

David's history with sport includes a stint playing football in a semi-professional league. As a biker, he completed the charity ride for the Multiple Sclerosis Society, traveling 150 miles from Houston to Austin. David seeks to share the values and experiences he has gained from sport and other activities – he is active in the Boy Scouts of America as well as his church, where he has held many voluntary roles designed to enhance the lives of others.

Bringing boundless curiosity to his work, David also collects rocks, fossils and petrified wood, and is an avid student of astrophysics and astronomy.

He considers his family his greatest accomplishment. He has been married to his wife, Robyn, for 34 years and has 4 children.

Chairman WEBER. Thank you, Mr. Brower.
Mr. Dimmig, you're up.

TESTIMONY OF MR. WALKER DIMMIG, PRINCIPAL, 8 RIVERS CAPITAL, LLC

Mr. DIMMIG. Thank you, Chairman Weber, Ranking Member Veasey, and Members of the Committee. I appreciate the opportunity to discuss energy technology innovation with you today.

Eight Rivers is a technology commercialization firm focused on developing breakthrough industrial innovations. Today, I will be sharing perspective gained from developing one such innovation on the natural gas utilization side known as the Allam cycle, which is a new direct-fired supercritical CO_2 power cycle for use with natural gas or coal. It projects to compete on the cost of electricity basis with existing best-in-class power plants today. Importantly, the technology does this while producing virtually no air emissions. Water and high-pressure, high-purity CO_2 are the only byproducts of the cycle.

Because the cycle can inherently produce pipeline-ready CO_2, it presents an opportunity to transform the enhanced oil recovery industry by providing a supply of affordable CO_2, which would enable over 100 billion barrels of domestic oil to be accessed even in low-oil-price environments. In order to produce this oil, billions of tons of power sector CO_2 would be sequestered. In short, the Allam cycle has the potential to be a major win for the electricity sector, the oil and gas industry, the environment, and consumers.

Today, NET Power, a company owned by 8 Rivers, the power company Exelon, and the engineering firm CB&I is building a 50-megawatt thermal pilot-scale natural gas demonstration plant down in La Porte, Texas, with over $140 million in private investment into it. The plant is within months of entering into operation, and it is designed to provide the information required to then build the first 300-megawatt commercial-scale natural gas plant.

Eight Rivers' experience in commercializing this technology and others supports the view that federal government support has an important role in energy technology development from R&D through to deployment. The R&D process is long, expensive, and highly uncertain. Without government participation at this stage, it would be difficult for 8 Rivers to execute on its model for commercializing important energy innovations.

Examples of federally funded R&D are present all throughout the Allam cycle. Most commonly, 8 Rivers has been able to take proven R&D that was originally pursued for other purposes such as materials for supercritical coal boilers or heat exchanger learnings from a solar program and apply that technology in the Allam cycle.

In addition, the DOE has a new supercritical CO_2 crosscutting initiative, and we're hopeful this program will lead to opportunities to further advance the Allam cycle in important ways. But our experience is also that public-partner private partnerships remain critical all the way through to deployment of first-of-a-kind commercial plants. The Allam cycle is currently entering this challenging period.

A first-of-a-kind commercial facility needs to operate successfully in the market against fully mature technologies, and yet it has to do so with costs that are significantly higher than even the second facility of its kind. Reasons for this can include inefficient supply chains, designs that have not yet been fully optimized, large first-time engineering costs, increased contingency fees, and even less competitive warranties.

Programs that partner with the private sector through grants to assist in building first-of-a-kind projects can be essential. One such program is the Clean Coal Power Initiative. Importantly, a similar program for natural gas projects such as the one IN that Power is now pursuing, does not exist. Cost challenges do not completely dissipate by the second plant. They reduce over time. Ongoing assistance for these projects through mechanisms such as a reformed 45Q tax credit for CCS can be critical to ensuring these technologies are able to reach their full potential and are not just developed into niche applications.

Finally, we believe federal R&D programs should be very goal-oriented across the technology portfolio, and, rather than being too technology-prescriptive, programs should have the flexibility to pivot with industry to achieve those goals. For example, 8 Rivers began by developing the Allam cycle for coal, but it became quickly apparent that the coal development pathway must first proceed through natural gas. This was the lowest-cost, least-risky, and most impactful approach.

Similarly, federal programs could benefit from being structured to work with both coal and natural gas utilization technologies as this flexibility could help technologies move forward for one fuel in a way that also represents a major advance for the other fuel and achieves broader program goals.

Thank you for the opportunity to testify today, and I welcome any questions you have.

[The prepared statement of Mr. Dimmig follows:]

Statement of Walker Dimmig
Principal
8 Rivers Capital, LLC

House Committee on Science, Space, & Technology
Subcommittee on Energy
Hearing on Oil and Gas Technology Innovation

May 3, 2017

Thank you Chairman Weber, Ranking Member Veasey, and members of the Committee. I appreciate the opportunity to discuss oil and gas technology innovation with you today. For the past seven years at 8 Rivers Capital, a technology development and commercialization firm, I have worked with energy technologies across the development timeline, from ideation and innovation, to pilot demonstration, and now to deployment. Today I will be sharing 8 Rivers' perspective gained from developing a technology known as the Allam Cycle.

The Allam Cycle is a new natural gas and coal power system that presents a breakthrough opportunity for the electricity, oil and gas, environmental, and petrochemicals sectors in the United States. The technology has the potential to lower the cost of electricity from fossil fuels, while virtually eliminating all air emissions, co-generating CO_2 as a low-cost feedstock for the domestic Enhanced Oil Recovery (EOR) industry, and co-producing a number of other valuable industrial feedstocks. Over $140 million in private capital has been invested into this technology, and it is within months of being demonstrated in a large-scale pilot demonstration plant that is under construction in La Porte, Texas.

8 Rivers' experience in commercializing this technology and others supports the view that the Federal Government has an important role in energy sector technology development, from R&D through to deployment. 8 Rivers has built its technologies on a foundation of critical, government-supported R&D. The R&D process is long, expensive, and highly uncertain; without government participation at that stage in the technology development process, it would be difficult for 8 Rivers to execute on its model of commercializing important energy innovations. Further, while private capital can and should play a major role in the demonstration and deployment of energy technologies, as it has with the Allam Cycle, development of first-of-their-kind commercial-scale facilities, and achieving initial market penetration thereafter, presents major challenges even for the most promising technologies, and the federal government is uniquely positioned to play an important role in overcoming those challenges.

1. **Introduction to 8 Rivers**

8 Rivers Capital focuses on developing infrastructure-scale technologies in the energy, communications, and aerospace fields. In addition to the energy technology that will be discussed in this testimony, 8 Rivers is developing a number of other energy systems, a wireless communications technology that enables fiber speeds through the air, and a ballistic space launch technology with the potential to reach space at 1/20th the cost of traditional launch methods.

It is instructive to introduce 8 Rivers' commercialization model in order to provide context for how the company views energy technology development and the role of the federal government. The 8 Rivers approach aims to address many of the difficulties faced by the private sector when developing industrial-scale technologies. Long development timelines, large capital requirements and deep technology domain expertise have made this space challenging for traditional venture capital, which has driven step-change innovation in other fields. (1) Large corporations can tolerate longer development timelines and have the capital and deep domain expertise required to execute in these fields, but they tend to focus on more incremental innovation within their existing product lines. (2) 8 Rivers' model seeks to marry the fast-moving, entrepreneurial, breakthrough-innovation approach of traditional venture capital with the execution ability of large corporations.

While 8 Rivers will engage in its own basic R&D, the company prefers to take existing R&D, often developed through federal R&D programs, and apply it in new technical settings, with other innovations in novel, larger systems, and/or in innovative business environments. The company will invest its own capital to build out the technology foundation and intellectual property portfolio, the business plan, and the development strategy, and then it seeks to bring in large strategic partners that have the financial, intellectual and human capital required to help execute on demonstration and deployment.

2. Background on the Allam Cycle

8 Rivers is the inventor and developer of the Allam Cycle, which is a novel, high-pressure, direct-fired, oxy-combustion, supercritical carbon dioxide power cycle. The cycle takes natural gas or gasified coal syngas and combusts it at high pressure and with pure oxygen (as opposed to air), which virtually eliminates the presence of nitrogen and generates a working fluid that is mostly carbon dioxide. This CO_2 working fluid is then used to drive a high-pressure gas turbine to produce power. The working fluid is then cooled in a heat exchanger so that water can be removed, and the remaining nearly-pure CO_2 working fluid is compressed, pumped, re-heated in the heat exchanger, and sent back into the combustor at high pressure and temperature. A portion of this high pressure CO_2 must be exported from the cycle; along with liquid water, it represents the only other emission from the process, and it can be removed already at pipeline conditions for use in EOR or as an industrial feedstock.

While the Allam Cycle is a major technology breakthrough, it benefits from being a novel industrial process that mostly utilizes already-proven components, many of which were developed with federally supported R&D and operated at the required conditions of the Allam Cycle in other industries, such as the oil and gas industry. Only the turbine and combustor are novel, but the turbine relies on proven technologies from both the gas and steam turbine industries. The combustor, though, did require R&D by 8 Rivers and Toshiba, and it has since been proven at the 5MW scale. So while 8 Rivers was the first company to design a direct-fired, oxy-combustion, supercritical CO_2 power cycle with the performance of the Allam Cycle, it could be much more quickly and effectively developed due to host of industry and federal government R&D for other purposes.

A specific example of this federal government R&D is in materials development. At a critical, high-

1 MIT Energy Initiative 2016: https://energy.mit.edu/wp-content/uploads/2016/07/MITEI-WP-2016-06.pdf

2 See Clayton Christensen, *The Innovator's Dilemma*

temperature portion of the Allam Cycle, it relies on an advanced nickel alloy that was developed, tested, and proven as a result of the U.S. Department of Energy (DOE) Fossil Energy Office's support of the Advanced Ultrasupercritical Steam Boiler and Turbine Consortium. (3) This program and material was originally developed to advance the steam boiler and turbine industry, but its results have also been key to the development of the Allam Cycle, where the materials enable us to push our temperatures higher and thereby reach higher efficiencies.

Similarly, the Offices of Nuclear Energy and EERE have previously funded work on "closed-loop" supercritical CO_2 power cycles. One such program, the SunShot Initiative, resulted in the development of corrosion and heat exchanger learnings that advanced the field for all technologies in the space, including the Allam Cycle. (4) Similar instances to these exist across a variety of technology fields supported by the U.S. Department of Energy, including gasification technologies, control systems, pump and compressor optimization, and others.

The Fossil Energy office has also directly participated in the Allam Cycle through corrosion testing, assisting with the design of a syngas-fueled combustor for supercritical CO_2 power cycles, and supporting an R&D effort in North Dakota through the Energy and Environment Research Center (EERC). In addition, the DOE has recently expanded its work in the field of supercritical CO_2 power cycles with a crosscutting initiative aimed at developing R&D for nuclear, renewable, geothermal and fossil systems. 8 Rivers is hopeful that this effort advances the capabilities and expands the currently limited supplier-base for certain equipment in this important field.

3. Status of the Allam Cycle and NET Power

8 Rivers began developing the Allam Cycle in 2009, and it formed NET Power as a commercialization company for the natural gas-fueled version of the technology. NET Power has received $140 million in investment from Exelon Corporation, the leading competitive energy provider in the United States, and CB&I, a global engineering and infrastructure firm; with 8 Rivers, the three companies jointly own NET Power.

Separately, Toshiba has undertaken a major, multi-year effort to develop the turbine for NET Power. Together, the companies are building a 50MWth pilot-scale demonstration plant in La Porte, Texas, which is under construction. Commissioning is already underway on a number of aspects of the plant, and construction will be complete later this year.

The design for this facility was dictated by a commercial-scale design for the Allam Cycle (300MWe, or 500MWth). The commercial plant was then scaled down as much as possible without fundamentally altering the design in order to minimize capital requirements while maximizing both risk reduction and scalability back to the commercial size. The result is a plant that is 10X smaller than a commercial-scale plant, but is a full Allam Cycle supercritical carbon dioxide power system (with the exception that oxygen will be purchased from a pipeline as opposed to constructing a dedicated air separation unit) that will sell power into the Texas market.

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3 NETL: https://www.netl.doe.gov/research/coal/crosscutting/high-performance-materials/Ultrasupercritical
4 DOE Office of Energy Efficiency & Renewable Energy: https://energy.gov/eere/sunshot/sunshot-initiative

The plant is the first facility of its kind in the world and will provide an opportunity for a major leap forward in the field of direct-fired supercritical CO_2 power cycles and carbon capture. The goal of the facility is to provide sufficient confidence in the technology to execute on a first-of-its-kind 300MW commercial-scale facility, which NET Power is presently developing.

4. Impact and Benefits of the Allam Cycle

The Allam Cycle offers a number of major benefits to the power sector, the environment, and the oil and gas industry.

For the power sector, the technology is targeting a cost of electricity that competes with current best-in-class fossil technologies that do not eliminate carbon emissions, without ascribing any economic value to the Allam Cycle's usable byproducts, such as pipeline quality CO_2, nitrogen, argon and oxygen. When reasonable values are assumed from selling these byproducts, the Allam Cycle is actually capable of dramatically undercutting the cost of electricity from these incumbent technologies. This is because the cycle is highly efficient – on par with today's NGCC plants without CCS and much higher than the best-available coal plants without CCS – and has low capital costs – targeting comparable costs to NGCC for natural gas and much lower costs than IGCC for coal.

For the environment, the Allam Cycle provides vastly superior environmental performance when compared to today's best fossil fuel technologies. Because the cycle utilizes oxy-combustion, NOx production is virtually eliminated; with the coal system, SOx, mercury, and particulate emissions are also virtually eliminated. Additionally, the cycle offers the ability to have greater than 97% carbon capture with virtually no economic penalty to the plant because the cycle is designed to derive its efficiency from using a nearly pure, high-pressure carbon dioxide working fluid to produce power; it does not require a separate, bolt-on carbon capture system.

By providing reliable, low-cost, and flexible power that has virtually no carbon emissions, the Allam Cycle is an excellent complement to growing wind and solar energy portfolios around the world. The IPCC Fifth Assessment modeling concluded that trying to reach carbon emissions reduction targets without CCS would result in the highest costs and least number of successful reduction scenarios. (5) The Allam Cycle is ideally suited to fit into the overall generation portfolio in a way that supports renewable technologies on the grid and enables the deepest possible emissions reductions to be achieved without resulting in increased costs to, and decreased reliability of, the electricity system.

For the oil and gas and petrochemicals industry, the Allam Cycle can drive down costs, expand development, and improve environmental performance. The Allam Cycle uses a conventional cryogenic air separation unit (ASU) to produce oxygen for combustion. The ASU will also produce nitrogen, argon, and excess oxygen (at times when the power plant isn't utilizing the oxygen), all of which are important industrial feedstocks and salable byproducts that can be affordably produced by the plant.

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5 IPCC 5th Assessment Synthesis Report, *Summary for Policy Makers*, pg. 25: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

The most immediate impact the Allam Cycle will have on the oil and gas industry is its ability to produce low-cost, pipeline-ready carbon dioxide for CO_2-EOR. The ability to economically recover oil via CO_2-EOR is primarily dependent on the price of oil and the price of the CO_2 needed to produce that oil. Traditional, add-on carbon capture technologies produce CO_2 at a cost of between \$60-\$90/ton. (6) With recovery rates in the range of 1.5-3 barrels per ton of CO_2 injected, these technologies require very robust oil prices in order to be economically viable.(7) By producing EOR-ready CO_2 for virtually no cost, the Allam Cycle enables CO_2-EOR to be one of the lowest-cost methods of oil recovery available, making it resilient to drops in oil prices below \$30/barrel (well below the breakeven for traditional carbon capture systems) and greatly expanding the economically recoverable supply here in the United States.

How big is that opportunity? The National Energy Technology Laboratory's (NETL) 2010 CO_2-EOR Primer estimated that about 85 billion barrels of oil are recoverable using traditional EOR practices. (8) A 2013 Advanced Resources International (ARI) report estimates that 100 billion barrels are economically recoverable using "next generation" technologies (assuming oil at \$85/barrel and CO_2 at \$40/ton). In that same report, ARI also estimates that new, un-tapped "Residual Oil Zones" hold an additional 140 billion barrels of oil, of which 27 billion barrels are economically recoverable. (9) And new research is ongoing into the ability to utilize CO_2 to increase oil production from the same shale formations that have driven the current resurgence of domestic oil production. (10) Further, the Allam Cycle's ability to provide low-to-no-cost CO_2 would increase the amount of oil believed to be economically recoverable in each of these projections.

Importantly, because the Allam Cycle's potential to expand domestic oil production from CO_2-EOR is so significant, so is its ability to permanently and safely store vast quantities of CO_2 generated by the power sector through EOR.(11) In order to produce the 100 billion barrels of oil that ARI estimates are economically recoverable with next generation technologies, approximately 33 billion tons of CO_2 will be required. This equates to the 35-year CO_2 output of nearly 140 gigawatts of coal-fired power plants; for natural gas, the number is nearly double that. (12) 8 Rivers has estimated that the lifetime CO_2 output from all US fossil fuel capacity additions projected by the IEA to be built between now and 2040 could be absorbed by CO_2-EOR.

In addition to increasing production for the oil and gas industry while sequestering CO_2, the Allam Cycle can also impact natural gas utilization in the United States and abroad. By providing highly cost-

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[6] US DOE, *Carbon Capture, Utilization, and Storage: Climate Change, Economic Competitiveness, and Energy Security*, pg. 5: https://energy.gov/sites/prod/files/2016/09/f33/DOE%20-%20Carbon%20Capture%20Utilization%20and%20Storage_2016-09-07.pdf

[7] IEA, *Storing CO_2 through Enhanced Oil Recovery*, pg. 12: https://www.iea.org/publications/insights/insightpublications/Storing_CO2_through_Enhanced_Oil_Recovery.pdf

[8] NETL, *Carbon Dioxide Enhanced Oil Recovery*, pg. 16: *https://www.netl.doe.gov/file%20library/research/oil-gas/small_CO2_EOR_Primer.pdf*

[9] ARI, *CO_2 Utilization from "Next Generation" CO_2 Enhanced Oil Recovery*, pg. 6855: http://ac.els-cdn.com/S1876610213008618/1-s2.0-S1876610213008618-main.pdf?_tid=1d87e6fa-2e26-11e7-8a95-00000aab0f6c&acdnat=1493612869_cba2651ceafcf29c6ee51cfae089f63c

[10] EERC, *Concepts for CO_2-EOR in the Bakken Formation: http://www.co2conference.net/wp-content/uploads/2013/12/14-Sorensen-EERC-Bakken-CO2-EOR-WOrk.pdf*

[11] Literature shows that only about 0.3% of the CO2 sued for injection is lost to the atmosphere; IEA, *Storing CO_2 through Enhanced Oil Recovery*, pg. 12.

[12] ARI, *CO_2 Utilization from "Next Generation" CO_2 Enhanced Oil Recovery.*

competitive and clean power generation from natural gas, the Allam Cycle can increase natural gas export opportunities for the United States, particularly to areas that are beginning to restrict and tax carbon emissions. The Allam Cycle also has the ability to efficiently and cleanly burn unprocessed natural gas. This ability to burn these gases lowers the cost of natural gas, as certain clean-up steps are eliminated from gas processing, and enables natural gas that would otherwise be unused or flared to be utilized, decreasing emissions from the oil and gas sector.

5. Concluding Perspectives on the Role of the Federal Government in Energy Technology R&D

The development of the Allam Cycle and NET Power demonstrates that R&D partnerships with the federal government are critical to the advancement of energy innovations, even if it is ultimately applied in unexpected settings. In particular, entrepreneurial firms such as 8 Rivers would be unable or unlikely to independently take on the timeframe, cost, and uncertainty of developing something as essential as a new alloy in order to deploy a brand new energy system; DOE collaboration is critical in these areas and has had a significant impact, even if it is not always immediately apparent.

A critical theme to 8 Rivers' process is that innovation is highly unpredictable, and neither the private sector nor the Federal Government can always be certain where it will lead. 8 Rivers looks to be problem-focused, rather than wed to a technology, and the company must remain flexible and willing to pivot a technology when necessary. Similarly, Federal R&D programs should also be highly goal-oriented across the technology portfolio, not just within each technology silo, and programs should not be so prescriptive as to prevent them from pivoting in new directions when necessary and within reason. Encouraging this flexibility would not only help DOE efforts to move more quickly, but it would also help the private sector engage in those efforts more easily, as they can remain highly relevant to the direction in which the private sector is moving.

An example related to the Allam Cycle where added flexibility for the DOE would be beneficial is to have a greater ability to participate in both coal and natural gas power technologies within the Office of Fossil Energy. 8 Rivers began by working on the Allam Cycle for coal, but it become quickly apparent that the coal development pathway must first proceed through natural gas; this was the lowest-cost, least-risky, and most-impactful approach, because the most important development step for the coal-fueled Allam Cycle is NET Power's natural gas demonstration program. Similar cross-cutting opportunities exist across the Department of Energy Fossil Energy technology portfolio, and the flexibility to also collaborate on natural gas technologies can also enable technology to advance more quickly and with less risk for both fuel sources.

Finally, 8 Rivers' experience is that Federal Government partnerships remain critical to the technology development process through to deployment of the first-of-its-kind commercial-scale plant, and even into additional early commercial plants thereafter. While 8 Rivers was able to privately fund the development of its pilot-scale demonstration plant with several hundred million dollars of private investment, the next step – the first-of-its-kind 300MWe commercial-scale plant – will be even more challenging.

A first-of-its-kind commercial-scale facility will need to operate commercially in the market in order to be developed, and yet it will be a significantly more expensive project than the second facility of its kind will be. First commercial-scale projects suffer from a number of challenges that are unique to being a first-of-a-kind. Because they are not yet mature technologies with full customer order-books, they will not receive the benefit of a supply chain that has maximized its efficiencies and become fully competitive. Every piece of equipment in the plant is likely to be more expensive than in an "Nth-of-a-kind" facility; the design of the plant will not yet have been fully optimized; there will be large engineering costs unique to a first-of-a-kind design; and contingencies are typically added across the development process for the increased risk of the project.

So, while a technology might easily project to outcompete incumbent technologies, a first plant is significantly more expensive, making it an enormous challenge for it to be successful in the market. 8 Rivers views programs that partner with the private sector through grants that assist the private sector in developing and financing these first-of-a-kind projects, such as the Clean Coal Power Initiative (CCPI), as critical to ensuring that promising technologies have a chance to be initially deployed into the market, where they can then demonstrate the ability of the underlying technology to compete. At present, the CCPI is expected to be unfunded moving forward in 2017, and no program exists for collaborating with first-of-its-kind commercial-scale natural gas projects such as the one NET Power is currently developing. Providing the Department of Energy with the ability to partner on projects like the first commercial-scale Allam Cycle plant are critical to enabling their deployment into the market.

The cost challenges seen with first-of-a-kind facilities do not completely dissipate by the second plant, though. They reduce over time, and as the technology becomes more widespread, in the case of the Allam Cycle, they also include the need to further expand infrastructure such as CO_2 pipelines. Ongoing assistance for CCS projects, particularly through a mechanism such as reforming the 45Q Tax Credit, is essential to ensuring technologies such as the Allam Cycle are able to be widely deployed, not just developed in niche applications. This will maximize their ability to transform the power sector with lower cost electricity and dramatically increase production and utilization of critical domestic oil resources, all while permanently storing power-sector carbon dioxide underground.

Thank you for the opportunity to testify today, and I welcome any questions you have.

Walker Dimmig

Biography

Walker Dimmig is a Principal at 8 Rivers Capital, a company that invents and commercializes breakthrough industrial technologies. Walker oversees the public-facing facets of the company, including commercial development, fundraising, communications, and government relations activities.

Walker was on the founding team of 8 Rivers' portfolio company NET Power, where for the past seven years he has helped lead its commercialization through raising $140 million in private capital and building major industrial partnerships with Exelon Corporation, CB&I, and Toshiba Corporation, among others. Walker currently helps manage commercial sales and development, marketing, and government affairs for NET Power.

Walker's background is in political communications, policy and government relations. Prior to joining 8 Rivers Capital in 2010, Walker worked at the Washington, DC-based public affairs firm of Quinn Gillespie and Associates. He has also spent time in the White House, on the Hill, and in a number of political campaigns.

Walker is a graduate of Middlebury College, where he received his bachelor's degree in Political Science.

Chairman WEBER. Thank you, Mr. Dimmig.
Dr. Krishnamoorti, you're up.

TESTIMONY OF DR. RAMANAN KRISHNAMOORTI, INTERIM VP/VC FOR RESEARCH AND TECHNOLOGY TRANSFER, UNIV.OF HOUSTON & UNIV. OF HOUSTON SYSTEM; AND CHIEF ENERGY OFFICER UNIVERSITY OF HOUSTON

Dr. KRISHNAMOORTI. Thank you so much, Chairman. Thank you for asking me today to talk about the critical partnership between academia, industry, and national labs that are helping move the oil and gas industry forward.

My name is Ramanan Krishnamoorti. I'm the Interim Vice President, Vice Chancellor for research and technology transfer at the University of Houston, but I'm also the Chief Energy Officer.

Guided by a distinguished panel of the—of our Energy Advisory Board comprising top executives from the energy industry, we at the—at UH are committed to becoming the energy university.

At the University of Houston, located in the energy capital of the world, we strongly believe that fundamental advances in science and engineering, when appropriately coupled with industry-based pull, can help transform the capital-intensive oil and gas industry. Just as hydraulic fracturing and horizontal drilling have transformed the availability of shale oil and gas, UH is working with industry and national laboratories and other academic institutions to create the next transformative technologies to advance conventional and unconventional, as well as terrestrial and offshore oil and gas.

We are focused on dramatically increasing the amount of hydrocarbon resources that can be recovered, while minimizing the impact on the environment and therefore ensuring the continued supply of affordable energy solutions. Such a focus requires commitment to all aspects of the oil and gas industry, including regulation, business policy and management, public policy, human factors, and naturally, fundamental and applied science, engineering, and technology.

In my written testimony I've provided a detailed report on the impact of the University of Houston in providing innovative strategies to lower costs and develop safer methods to find and produce oil and gas. These innovative solutions include responses to immediate challenges and strategic long-term disruptive technologies. The key issues are summarized as—I'm going to have four points here.

First, technology innovations require a strong connection between industry pull for targeted applications and the academic push for fundamental and applied advances in science, engineering, and technology. Some notable examples of industry collaboration-driven advances are the significant speeding up of seismic interpretation through advanced computing, the development of smart cements, developing enhanced oil recovery formulations for high-temperature and high-salinity reservoirs, and sensing and preventing microbial corrosion of pipelines. For these innovations to continue, the business of oil and gas will require the embrace of human factor-centric design, standardization, and system integration.

The second point is disruptive technologies advances in oil and gas are likely to come from fundamental advances in various fields, including nanotechnology, life sciences, data analytics, and cognitive computing. But given the capital expenses and long runways between fundamental research, applied development, deployment, and commercialization, those advances would require continued engagement by federal and state agencies for fundamental breakthroughs and possibly by incubation through engaged national laboratories as technologies are developed. Specifically, engaging NASA Johnson Space Center with the University of Houston and the Subsea Systems Institute for the adoption and deployment of automated underwater vehicles and risk modeling for deep-water missions are examples of best-in-class engagement.

My third point, the oil and gas industry is challenged with so-called crew change as experienced geophysicists, geoscientists, engineers, and others retire, taking with them an enormous amount of expertise over the next ten years. Academia plays a critical role in partnering with industry in the continued enhancement of the workforce for this industry and the continued engagement of subject matter experts to advance technological solution.

Finally, it is important to emphasize the cyclical nature of the industry with boom and bust cycles all too common. Combined with the long runways for the development of resources such as those in the ultradeep water and those found in high-temperature, high-pressure reservoirs, the continued development of technology innovations remains critical and requires sustained public investment.

Mr. Chairman, at the University of Houston we are proud of the interactions we've forged with the industry and the demonstrated value of these partnerships. I thank you for the opportunity to provide testimony today and look forward to answering your questions. Thank you.

[The prepared statement of Mr. Krishnamoorti follows:]

Written Statement of

Ramanan Krishnamoorti

Interim Vice President and Vice Chancellor for Research and Technology Transfer

Chief Energy Officer

University of Houston

Before the

House Committee on Science, Space and Technology

Subcommittee on Energy

United States Congress

"Technology Innovation in Oil and Gas: Successful Collaboration between Industry, Universities, and National Labs"

May 3, 2017

University of Houston

4800 Calhoun Rd

Houston, TX 77004

713-743-4307

Thank you for asking me here today to talk about the critical partnerships between academia and industry that are helping to move the oil and gas industry forward. My name is Ramanan Krishnamoorti, interim vice president/vice chancellor for research and technology transfer at the University of Houston, where I am also chief energy officer.

We at the University of Houston, located in the energy capital of the world, strongly believe fundamental advances in science and engineering, when appropriately coupled with "industry based pull," can transform this capital intensive industry. Just as hydraulic fracturing and horizontal drilling have unleashed shale oil and gas, UH is working with industry, the national laboratories and other academic institutions to create the next transformative technologies to advance conventional and unconventional, terrestrial and offshore oil and gas.

The work is two-fold: We are focused on dramatically increasing the amount of hydrocarbon resources that can be recovered, while minimizing the impact on the environment to ensure the continued supply of affordable energy. Such a focus requires commitment to all aspects of the industry, including regulation, business policy and management, public policy, human factors, and naturally fundamental and applied science, engineering and technology.

In this testimony, I will detail the impact of the University of Houston in providing innovative strategies to lower costs and develop safer methods to find and produce oil and gas. The key issues are:

- Technology innovations require a strong connection between the "industry pull" for very targeted applications and the "academic push" for fundamental and applied advances in science, engineering and technology. Continued innovation will require the embrace of human factors centric design, standardization, and system integration.
- Disruptive technological advances in oil and gas are likely to come from fundamental advances in fields including nanotechnology, life sciences, data analytics and cognitive computing, but given the capital expenses and long runway between fundamental research, applied development and commercialization, those advances will require continued engagement by federal and state agencies and possibly incubation through engaged national laboratories. Early stage discoveries and

platform inventions such as advanced materials, data analytics, and genomics require continued Government investment.

- The oil and gas industry is threatened with the so-called "crew change," as experienced geophysicists, geoscientists, engineers and other industry experts retire, taking with them an enormous amount of expertise over the next 10 years. Academia plays a critical role in partnering with industry to strengthen the workforce and in the continued engagement of subject matter experts and evolving technology to advance innovative solutions.

THE PRODUCTION CUTTING EDGE:

The United States is fortunate to have large underutilized energy resources that rival the tight oil and gas plays: Kerogen and heavy oil could transform the energy equation yet again should they become economically accessible and environmentally sustainable. One of the most promising projects along these lines involves direct power heating of heavy-oil reservoirs to improve the efficiency of oil recovery and of kerogen formations for in-situ conversion. Improving recovery rates is a critical issue, especially as companies pursue every possible cost advantage in today's low-price environment. While horizontal fracturing and other techniques have allowed industry to tap new fields for both oil and gas, recovery from these reservoirs remains low – in the single digits in shale, tight rock and other unconventional fields and only modestly higher for conventional drilling. Improving recovery rates is crucial to make investment in new drilling more profitable.

To achieve that goal, PowerIn, a spinoff-off company at UH, has proposed combining superconducting power cables with subsurface electric heaters for improved in-reservoir extraction of heavy oil and bitumen reserves.

Superconductivity has been a pillar of the UH research enterprise for 30 years, and with the recent focus on advancing this technology to commercial scale manufacturing through the Advanced Superconductor Manufacturing Institute, we believe it is well placed to rapidly scale-out into oil and gas production. Application of superconductors is intended to overcome the latent heat losses currently experienced within traditional steam assisted gravity drainage (SAGD) operations, as the steam required to improve oil recovery traverses the length of both the vertical and horizontal portions of the steam injector. This is accomplished by electrically reheating steam subsurface, within the horizontal portion of the steam injector and just prior to introducing it into the bitumen reservoir.

By replenishing heat in this manner, an equivalent amount of the energy used to produce high quality steam beneath the surface can now be saved. PowerIn's proposed concept, Superconducting Power Enhanced SAGD™, has the potential to significantly reduce energy consumed, production complexity, water usage and the cost of production.

RESERVOIR MANAGEMENT, EOR AND OFFSHORE

The PowerIn collaboration is just one of the projects dealing with reservoir management and enhanced oil recovery at UH. Ganesh Thakur, a member of the National Academy of Engineering and former president of SPE International, joined the university less than a year ago as director of Energy Industrial Partnerships, which involves multidisciplinary teams working in 3-D and 4-D seismic technology, petrophysics, geology and geochemistry, enhanced oil recovery for conventional and unconventional reservoirs and high performance computing. Thakur, a former Chevron Fellow, focuses his research on waterflood management as applied to secondary recovery of oil and has developed collaborative projects with several companies towards integrated research management. His research group also collaborates with the Norwegian Research Council and a consortium of global industry partners to use carbon dioxide as an enhanced oil recovery agent, either as a miscible gas or as a foam.

Like Thakur, a number of our faculty came to the university with industry experience, which both informs their understanding of industry challenges and cements those relationships. That includes petroleum engineering faculty Lori Hathon and Michael T. Myers, both of whom worked at Shell International Exploration and Production before joining the university and are now working with Shell to characterize permeability in unconventional fields under realistic conditions.

Another member of the National Academy of Engineering, Christine Ehlig-Economides, is now a professor of petroleum engineering at UH after a successful career at Schlumberger. She works in collaboration with other faculty at UH including Mohamed Soliman and independent and multinational oil companies on well design and performance evaluation for shale gas and tight oil production. She also chairs a task force preparing the first peer-reviewed report for The Academy of Medicine, Engineering, and Science of Texas (TAMEST) on "Environmental and Community Impacts of Shale Development in Texas." This report is scheduled for distribution in June.

A significant portion of our research work at UH, as in the examples just cited, aim to provide direct technological solutions to industry problems and address challenges currently faced by the industry. Other projects would take the industry in entirely new directions.

Biochemist Preethi Gunaratne, for example, is developing genomics applications to reduce microbial-induced corrosion and minimize bio-fouling issues. She is collaborating with numerous operators and service providers to map the bacterial species found in produced fluids and to develop remediation measures and site-specific early detection and prevention for corrosion.

Interestingly, combined with the geochemistry work of Adry Bissada, these genomics techniques are also being used to develop new "fingerprinting" techniques for oil and gas reservoirs, an approach that is of significant interest to the industry.

Bissada and other geochemists, through the UH Center for Petroleum Geochemistry, are also actively engaged in other ventures with industry. I've listed a few here:

- Work with Shell Oil on processes for creating producible hydrocarbons from organic-rich rocks in Colorado and upgrading un-producible extra-heavy tars to producible hydrocarbons in Canada.
- Work with Sandia National Laboratories, Schlumberger and Baker Hughes to promote the successful recovery of tight, liquids-rich mud-rock reservoirs and to investigate the role of kerogen structure in providing "storage capacity" for generated hydrocarbons. They have developed a unique process for the isolation and recovery of ultra-pure kerogen, naturally occurring organic matter that cannot be extracted using organic solvents.

- Work with Shell Oil and Chevron is focused on pre-injection impact studies to avoid potentially souring the reservoir as a result of thermal enhanced oil recovery and water flood operations in heavy oil reservoirs.
- A collaboration with ConocoPhillips to develop a method to measure sulfur content and sulfur isotopic composition in extremely volatile, low-sulfur content oils and condensates.
- Work with Baker Hughes to assemble a consortium of industry sponsors to advance the understanding of and means for objective assessment of controlling facets of liquids-rich shale resources – optimum oil richness, optimum hydrocarbon-storage capacity of the reservoir and optimum fracability potential.

We also are addressing hydrocarbon recovery rates through nanotechnology. Physicist Zhifeng Ren is working with operators and service providers to test his discovery of a graphene nanotechnology-based solution, which early results show can boost tertiary oil recovery by 15 percent, at a lower cost and without the potentially toxic chemicals now in use.

My lab recently concluded a project with Shell's GameChanger program and was previously funded by Chevron's Upstream Technology Company to develop polymer-nanoparticle hybrid composites to serve as nanofluids to enhance oil recovery from high temperature and high salinity reservoirs. These materials outperform current technologies and extend polymer-based EOR methods to high salinity reservoirs with temperatures up to 300 F, at a fraction of the current technology's cost.

And the Subsea Systems Institute, funded through the RESTORE act as a collaboration led by UH and involving Rice University and NASA Johnson Space Center, is involved in a broad range of issues affecting offshore drilling. Serving as a neutral third party to provide industry and government regulators with new technologies, science-based policies, education and workforce training, it is led by Bill Maddock, who previously worked on Arctic issues for BP America, and is advised by the National Energy Technology Laboratory (NETL), leading offshore operators, service providers and drillers.

Included in the institute's research portfolio are:

- The application of 4-D seismic and distributed acoustic sensing (DAS) for reservoir monitoring
- Real-time blow out preventer (BOP) monitoring
- Advancing subsea power through nanotechnology-derived battery power
- Improving subsea production through the application of automation, robotics and autonomous underwater vehicles or AUVs
- Adoption of risk modeling strategies pioneered in the aerospace industry
- Application of advanced wireless technologies for subsea communications.

The AUV project takes advantage of the Neutral Buoyancy Laboratory at NASA's Johnson Space Center and demonstrates the dual-use capability of some of our national investments. NASA-JSC's engagement in the risk-based analysis and modeling of deepwater exploration and production also demonstrates the value our national laboratories bring to finding solutions to the threats facing the oil and gas industry. All of the institute's projects are done in collaboration with multiple industry partners, illustrating the commitment of academia and industry to work together to ensure the safety of future oil and gas exploration, production and decommissioning, while minimizing environmental impact and cost.

SEISMIC ACQUISITION AND INTERPRETATION

UH has been a leader in seismic interpretation, which relies upon a sophisticated understanding of how energy waves move through the earth's subsurface and is a critical tool in deciding where to drill. That has become more important as companies move further offshore, where drilling is progressively more expensive as well as technically more complex. Companies save both time and money when they can reduce the chance of drilling an unproductive well.

The Mission-Oriented Seismic Research Program (M-OSRP) at UH has made immense strides in that regard since its founding 16 years ago by Arthur Weglein, a physicist who joined the university in 2001 after more than two decades in the petroleum industry.

M-OSRP currently has 15 active industry partners and has had as many as 23, including multinational corporations and national oil companies. One of its most significant achievements, working with IBM, ConocoPhillips and other consortium partners, has been to speed up the seismic inversion code by a factor of 1,000. To put that in perspective, computations that might have taken several years can now be completed in less than a day. This has led to far higher efficacy in reaching "pay zones" during drilling and has been especially important in cases where there is complex geology, thin pay zones and significant pre-salt reservoirs, such as those seen offshore.

DRILLING, COMPLETION AND PIPELINES

Once seismic work is completed, producers move on to drilling and completing a well, a task that involves significant risks. A key issue has been determining how to evaluate the state of the cement that holds the well casing in place. A UH engineer developed a "smart" cement, using nanomaterial additives to produce a cement capable of reporting on its status using simple electrical resistivity measurements.

Working with Baker Hughes on a project initially funded by RPSEA (Research Partnerships to Secure Energy for America), engineer Cumaraswamy Vipulanandan validated this technology in a test well at the UH Energy Research Park, demonstrating the direct extension of laboratory scale testing to pilot scale testing, with commercial scale testing as the next step.

The same technology is now being used for "smart" drilling fluids that have the ability to monitor for fluid loss. As we are all aware of previous catastrophic failures, this partnership offers powerful evidence that fundamental advances in nanotechnology can be adapted to address important technological challenges. This innovation and scale-up was feasible only because of the collaboration between UH, cement manufacturers and oil service providers and was prompted by the RPSEA-funded project.

As we access more high temperature high pressure (HPHT) reservoirs with ultra-deep water exploration and production, the materials challenges have become more significant. My laboratory, in collaboration with Hung-Jue Sue at Texas A&M University, is developing polymeric materials for such applications. Working with several original equipment manufacturers and service providers, we are creating accelerated testing protocols to help rapid validation of materials for such extreme environments as well as developing advanced materials for such applications.

Among other noteworthy projects at UH:

- Matthew Franchek, founding director of the subsea engineering graduate program at UH, the first in the nation to address specialized engineering for deepwater operations, worked with service companies Cameron International and National Oilwell Varco to develop and test a system that makes better use of the terabytes of data produced by monitoring sensors built into modern drilling equipment. Most recently, Transocean is working with Franchek and his students by providing drill ship data to validate their real-time conditioning and performance monitoring models.

  The system allows oil and gas producers to more efficiently use and maintain equipment, shifting from scheduled maintenance shutdowns to performing maintenance only when needed. It also can reduce the amount of data companies are required to store, cutting costs both by avoiding unneeded shutdowns and by reducing data storage costs. Franchek has created a curriculum to teach engineers to deploy the system, which will allow for wider adoption across the industry.
- Engineering professor Gangbing Song and his students, working with OneSubsea and Cameron, have developed methods to monitor the structural health of subsea equipment using piezoelectric (PZT) sensors. Additionally, they have advanced the use of Fiber Bragg Grating (FBG) sensors previously developed for biomedical applications to monitor pipeline leakage and to identify leakage locations. During manufacturing, installation and service, pipelines are susceptible to damage and corrosion. In addition, pipelines must operate in an unpredictable environment and the threat of natural hazards such as seabed earthquakes, sea storms, ice loads and landslides can lead to fatigue, crack formation, metal cuts, buckling, free spanning and leakage, potentially with disastrous consequences, both economic and environmental. The FBG and PZT sensors being developed at UH provide real-time monitoring of subsea structures, including steel, concrete and PVC pipelines.

- Similarly researcher Ray Taylor, formerly of Pioneer Natural Resources, is continuing his work on corrosion protection through nondestructive characterization of corrosion kinetics on complex interfaces.

As you have heard, much of our work at the University of Houston is focused on science and technology applications for the oil and gas industry. But in addition to these substantial efforts, researchers also are addressing human factors issues that companies face today, including culturally competent training for companies that operate internationally. Christiane Spitzmuller, an industrial organizational psychologist with the Center for Applied Psychological Research at UH, works with energy companies to provide research-based solutions to training as their technical workforces increasingly include large numbers of non-Western nationals, including in the Middle East and West Africa. This work has reiterated the importance of including and organizing human factors into technological innovations and will ensure the rapid and successful adoption of important new technologies.

SUMMARY

All of these projects have two things in common – academic faculty and researchers who understand industry needs and a focus on transforming the industry through improving both environmental and financial performance. These technological innovations have leveraged breakthroughs in fundamental science and engineering that have been advanced over many decades.

These new technologies, procedures and computational improvements will be of little use to industry, however, if they are unable to hire a skilled workforce trained to use them. As I mentioned at the beginning of these remarks, the looming retirement of the baby boomers who have made up the most-experienced tier of energy employees for decades will pose a serious challenge, although the most recent downturn and the rise of automation have delayed the most severe impacts.

Academic partners, including UH, are working to address that challenge, collaborating with industry to determine its future needs and developing curricula to meet them. We are committed to working together to meet the demand through a mix of solutions, from traditional four-year and graduate degrees to certificate programs, stackable credentials, online course delivery designed for busy workers and even developing training that can be delivered on-site.

Bio - Ramanan Krishnamoorti, Ph.D.

Ramanan Krishnamoorti is Interim Vice Chancellor for Research and Technology Transfer for the UH System and Interim Vice President for Research and Technology Transfer for UH, a role he assumed in July 2015. Krishnamoorti has oversight responsibilities for the Division of Research, and various centers and institutes that report to the Division of Research.

Ramanan Krishnamoorti also holds the position of chief energy officer at the University of Houston since February 2013, leading the university's efforts to establish energy-centered partnerships on an industry and university level to address the world's most pressing energy challenges. During his tenure at the university, he has served as a department chair of the UH Cullen College of Engineering's chemical and biomolecular engineering, associate dean of research for engineering, professor of chemical and biomolecular engineering with affiliated appointments as professor of petroleum engineering and professor of chemistry.

Krishnamoorti obtained his bachelor's degree in chemical engineering from the Indian Institute of Technology Madras and doctoral degree in chemical engineering from Princeton University in 1994.

Chairman WEBER. Thank you, Doctor.

I now recognize myself for five minutes. This will be a question for all of you, which I would like to keep short if we can, your answer. We're going to try to get back to some more questions. In your opinion, what is the appropriate role of government in oil and gas research and development? Let me explain. Are we better off focusing limited federal funds on applied energy research or the demonstration and commercialization of energy technologies? Mr. Johnston?

Mr. JOHNSTON. So I would start by saying the leverage of the funds of the project that we have I think are a very appropriate way to utilize that fund. So we're actually taking first principles and marrying them with industry, so trying to get to the fundamental issue that's causing the inefficiencies in hydraulic fracturing but also bringing partners along with that. I think that is a very appropriate role for these types of funds in these private-public partnerships.

Chairman WEBER. Okay. Thank you. Mr. Brower?

Dr. BROWER. I think one of the fundamental issues about research in general in the oil and gas industry starts really with the definition of what research and development really is because when I made the transition from aerospace into the oil world, research is defined much differently in both those environments. Research in aerospace oftentimes can start with a blank piece of paper and just thoughts as they start to generate. In oil and gas, research typically begins with something that's already somewhat downstream.

I think if I were looking at where some of the funding could be utilized very effectively, it would be to have a hybrid of both those two methods, whereas you're thinking of new innovative methods that could solve some of the problems in oil and gas and combine that with things that are a little bit more mature.

Chairman WEBER. All right. Thank you. I appreciate it. Mr. Dimmig?

Mr. DIMMIG. I think it's in our experience not an either/or scenario. I think—we wouldn't have technologies to deploy if we don't have a robust R&D base. And we've benefited from R&D all throughout the Department of Energy, even R&D that wasn't intended for fossil fuels. So we have to start there.

At the same time I think we have to recognize that certain technologies that we think are very promising and the market thinks are very promising are very capital-intensive, very difficult to get into the market in—with that first deployment. And so if we don't follow through with the most promising of those technologies, we might leave them behind.

Chairman WEBER. Okay. Got you.

Doctor?

Dr. KRISHNAMOORTI. I agree with my panelists. It's not an either/or. I think we learn some of our best lessons when we go to deploy them. When we go to deploy technologies we come back and say do we have to do research or fundamental basic research that gets applied? And I think we've got to have a complete stream of this, but to the boom and bust cycles that are so common in the industry are today. Industry funding alone cannot move this industry forward.

Chairman WEBER. Got you. And you're—actually my next question, in your testimony you discussed how oil and gas production is testing the limits of current understanding of engineering principles and presenting new problems along the way. For example, you wrote to that, "As we access more high-temperature, high-pressure reservoirs with ultradeep water exploration production, the material challenges have become more significant". You go on to write that your colleague is conducting materials research to develop new polymers to solve this challenge. Engineering is a practical field. Do you think these practical problems are actually leading to basic science research? And before you answer that, you said in your prepared—in your remarks earlier you wanted U of H to be the energy universe, so we want to make sure that happens. Do you think that these practical problems are leading to basic research?

Dr. KRISHNAMOORTI. Absolutely in that basic research in materials design and materials development, processing, and deployment is where these practical problems are leading to a significant change. And these are not going to just impact the oil and gas industry. It's going to have a much broader application, for instance, in the aerospace industry. You know, the—we've had challenges in the deep water with the hydrogen embrittlement of bolts. This has got parallels to the aerospace industry, and what we've learned from either of those fields has led to really understanding and improving the technology in the field.

Chairman WEBER. Thank you.

Mr. Johnston, I'm going to jump back to you. Can you give us an update on the research at GTI's hydraulic fracturing test site? What are some open problems that the scientists and engineers are trying to understand?

Mr. JOHNSTON. What they're really trying to figure out now is actually where the proppant goes through the—so we—in this project we actually physically, chemically, and radioactively trace the proppant so that we have a better understanding of what happens within the transport mechanism. So today, it's really more of analyzing the production, inferring information about the physical evidence that we have, and validating and building new models that really help understand, you know, the process.

Sometimes you induce as many questions as you answer with projects like this, and I think that's why, you know, continued research in this field is very important.

Chairman WEBER. Well, that's true about a lot of research in——

Mr. JOHNSTON. It is.

Chairman WEBER. Yes.

Mr. JOHNSTON. It is.

Chairman WEBER. All right. My time has expired. I'll now recognize Mr. Veasey.

Mr. VEASEY. Thank you, Mr. Chairman. And this question is for Mr. Dimmig.

Mr. Dimmig, the IEA, among many other widely respected analysts and institutions, has concluded that developing and deploying carbon capture technologies in the power generation sector, notably including such technologies for natural gas-fired power plants, will be critical to achieving the goals of the Paris agreement. I wanted to ask you, because NET Power is developing a unique design for a natural gas power plan, which would completely eliminate the smokestack, how do you see designs like yours fitting into the long-term emissions reduction strategy of the United States and other countries that are participating in the Paris agreement?

Mr. DIMMIG. We think it's critical. We've looked at all of the sort of major studies out there, and I would agree they all tend to conclude that without CCS, we're not going to get to the various climate goals we've set. So at 8 Rivers we view finding a fossil fuel solution to carbon emissions as a critical requirement mostly because we also see that fossil fuels aren't going anywhere. We have abundant oil and gas here in the United States. We'll be using that for some time to come.

There's abundant oil and gas around the world. Coal is being utilized in the developing world quite abundantly, so we know these fuels are going to be used and we know in order to meet these goals, we're—then we're going to have to deal with carbon emissions from that. Our main goal is to try to make that sort of an economically relevant choice to make—give people the option to build a plant using low-cost abundant fossil fuels and do so in a way that limits or eliminates carbon emissions and not make it an environmental or an economic choice and make both options palatable in the same facility.

Mr. VEASEY. As developing countries try to improve their way of life, how do you see these technologies playing into all of this for those places around the world?

Mr. DIMMIG. You know, I think the developed world sort of built its economies on the back of abundant low-cost fossil fuel. Those fields are also abundant in the developing world, and if we want—you know, those folks are going to want to bring the same quality of life and type of lifestyle we have in the developed world to their world. And so fossil fuels are going to be utilized to do that. We have an opportunity to do that differently. We have an opportunity to do that by building from the start even cleaner infrastructure to utilize those fossil—those low-cost abundant fossil fuels.

Mr. VEASEY. One of the key challenges that have plagued carbon capture projects is scalability. I know your pilot scale project is 1/10 the size of the eventual powerplant that NET Power would like to commercialize. What are some of the challenges that NET Power faces in scaling the technology?

Mr. DIMMIG. Sure. So we started by designing a commercial-scale plant rather than focusing on sort of taking R&D and scaling it just to whatever we felt like the next most cost-effective size was. We said what does the best commercial product look like and then we scaled that as small as we could to build a demonstration plant without trying to fundamentally alter that design, fundamentally alter the equipment in the plant. So every piece of equipment in that plant is being supplied by a supplier that can also supply the same piece at a larger size. So we're very confident about the all the equipment in that facility.

The key piece then to scale would be the turbine. That turbine does not exist yet at a larger scale, but we're benefiting from the fact that that turbine could only be made so small due to the pressures of the system so it's actually operating at less than its full capacity and that will—that turbine will actually—in the demonstration plant, it'll actually then scale up to a commercial plant more of a 4X scale-up than a 10X. So we really reduce the scaling as much as possible and eliminated sort of technology changes from small scale to commercial scale.

Mr. VEASEY. Interesting. And in your opinion—because we always have this debate on this Committee is what role do you see government playing in helping with the scaling up of the technologies like the one you're testing?

Mr. DIMMIG. Yes, as I mentioned in my written testimony at length and then a little bit of my oral testimony that there—as you scale up, there are new risks even if you have the same piece of equipment and you're just making it larger. There's a new turbine in the middle of a plant like this. It's got to operate against very, very mature technologies such as, say, natural gas combined cycle plant that's been in the market operating and becoming efficient for 40 years. So it's a very challenging hurdle to overcome. And so when we take that step, you have to figure out how to make that plant—that first plant more cost-effective against what's in the market today.

Mr. VEASEY. Mr. Chairman, I yield back. Thank you. Thank you, Mr. Dimmig.

Chairman WEBER. I now recognize Mr. Dunn for five minutes.

Mr. DUNN. Thank you, Mr. Chairman.

This is a fascinating subject. I could quiz you guys all afternoon, but let me jump right in here and start with Mr. Johnston. So the shale revolution, talk about the first, I would like to get a sense of how that actually impacts the average American family and if you could also tell us—sort of give us a time horizon how long can we count on our shale revolution to take care of us?

Mr. JOHNSTON. Well, we refer to it as the shale evolution because there was decades of investment and field experiments that went into this where, you know, most people do see it as an overnight occurrence. The average American family today is getting approximately $1,400 back into their pockets through lower utility bills on the electric and gas side together because there's been such a shift in power generation from coal to natural gas and lower gas bills as well.

If you look at—just take the Permian basin, for example, you know, it's just one basin but it is now the world's—considered by many the world's largest super basin of hydrocarbons. And with estimates of 160 billion barrels of oil and looking to double and beyond and you'll see kind of similar growth——

Mr. DUNN. Well, what technology barriers do you see to continuing to efficiently extract all that potential?

Mr. JOHNSTON. Yes, it's really more fundamental learning than I think it is the technology itself. It's really about being able to understand and predict where you actually make the fractures because, as I pointed out, so many of these are not actually producing toward the overall production of the well. So it's about having a better understanding of how the fractures propagate. There could be some fundamental things and materials in the proppant itself and having more intelligence with the proppants. But it's really about predictive analytics at this point.

Mr. DUNN. Thank you. So I want to turn my attention to Mr. Brower. I loved your bio. Sometime I want to get you to come back and tell us how you make a spaceship on the moon—out of the moon. That's a great, great background there. But I'm going to ask you a different question, though, today. What—you have a relatively small company and a very exciting company. What impact are you going to be making on the shale revolution?

Dr. BROWER. Well, hopefully bigger than most of us think. You know, the—it's the ideas I think that are generated that have the impact and not the size of the company. You know, I think back to some of the early pioneers in technology such as Thomas Edison, you know, just a very small group of people that were able to come up with some great innovations. And, you know, he met with a lot of opposition, too, when he was developing the lightbulb. Most people were really opposed to it because they thought, you know, we already have kerosene lamps; why do we need an electric light bulb?

You know, and so I think that we come up with those kind of barriers whenever you—whenever we innovate something new. There's resistance to anything new in a certain level, some of it a lot of resistance and some of it much more gentle. But I think that the concepts are what really make the difference rather than the size of the company.

Mr. DUNN. And I was actually very fascinated by all the areas you're—you've fringed into professionally in your life.

Mr. Dimmig, I'm going to ask you because you have such a great testimony, more written than oral here. If you can direct us may be offline to more information on the Allman cycle that's more than we can dive into in the remaining minute we have here, but I'm just going to ask you if you could have somebody send us on the Committee more information on how that energy cycle actually works, just a simple request.

Mr. DIMMIG. I'd be happy to do that. Thank you.

Mr. DUNN. Thank you very much. And then, Dr. Krishnamoorti, so we're talking about an insufficient supply of engineers and scientists. What's the University of Houston doing about that?

Dr. KRISHNAMOORTI. Well, we started a petroleum engineering program seven years ago. We now have 1,000 students in that program. We've created the nation's only subsea engineering program, and today, we are graduating about 50 graduate students annually in that program. We've created a program that is focused on upstream data analytics that is looking at how do you bring all the advances we've done in high-performance computing and data analytics to the upstream world.

Mr. DUNN. So I'm not going to trip you up with that question. That's—good job. Thank you very much, Mr. Chairman. I yield back.

Chairman WEBER. Thank you, sir.

The Chair now recognizes the gentleman from California, Mr. Takano, for five minutes.

Mr. TAKANO. I thank the Chairman.

My question—my first question is for Mr. Johnston. Mr. Johnston, data released by the Occupational Safety and Health Administration, OSHA, shows that the rate of severe injuries across various—well, it shows the rate of severe injuries across various U.S. industries. The upstream oil and gas industry was once again one of the more dangerous places to work according to these—this report. It tends to have a low injury rate but a very high fatality rate. What is the industry doing to improve safety for oil and gas industry workers? Is there anything on the technology and research front that industry is funding or could fund to bring the fatality rate down?

Mr. JOHNSTON. Thanks for your question. I grew up as a roughneck on an offshore drilling rig, so this is something kind of personal to me.

Mr. TAKANO. Yes.

Mr. JOHNSTON. So, you know, it is a hazardous occupation. I would have to say that safety, it starts with culture and engineering controls, administrative controls, and things of that nature. From the time that I worked offshore in the '80s to what I saw on the—our hydraulic fracturing test site is a huge transformation and attention to safety and culture and so on. I was very impressed with what our host site Laredo was doing. I'm also our executive sponsor of our corporate EH&S team. So I think it really starts with having that commitment to a safety management system.

As far as specific technology, GTI is not developing any technology in the upstream oil and gas sector that's safety-related. We do more in the downstream segment of that business with the distribution companies and public safety in that regard. I'm sure, though, that the industry is—has a keen awareness on that.

Mr. TAKANO. I'm not—you know, I'm not from Texas. I don't—I'm not around it.

Mr. JOHNSTON. Yes.

Mr. TAKANO. I'm just wondering is—are refineries considered upstream or downstream?

Mr. JOHNSTON. Downstream, yes.

Mr. TAKANO. Yes. I mean, I—we do have refineries in California——

Mr. JOHNSTON. Yes.

Mr. TAKANO. —and I know that we've had some serious incidents and accidents in those types of environments. And I'm just wondering if there's any way in which there can be an improvement in technology there or more intensive research.

Mr. JOHNSTON. Certainly. There's a great book called Failure to Learn that is a historical recount of the Texas City Refinery explosion and the deaths that occurred. Every one of my directors has read it. I bought them all copies of it because I think that's one of the key pieces of that. But there's certainly monitoring technology and advanced controls and things that are continuing to accelerate down the technology path.

Mr. TAKANO. Well, thank you.

Mr. Dimmig, I'm going to try and get this question in. Some of my colleagues across the aisle often complain that the Department of Energy is, quote, "picking winners and losers," end quote, and interfering with the free market by, quote, "crowding out private investment," end quote. I would be interested in your perspective given NET Power's experience in utilizing technologies developed by government, as well as in securing private sector investment. Should the Department support all research proposals in areas equally or should it prioritize investments based on where we can get the most value for taxpayer dollars?

Mr. DIMMIG. I think it should—there should be a priority on value. And I think at the end of the day if we believe that these technologies—there's a great public interest in having them available to us and that the R&D was worth it and we want to sort of get them into the market. Ultimately, there will be winners and losers selected and I think it—the key is to have market pull because the market is very good at picking winners and losers. And so getting market—the market to really drive those decisions but have the DOE and the federal government as a partner I think is a smart way to sort of blend the benefits of both.

Mr. TAKANO. Dr. Krishnamoorti, I see you nodding your head. Do you agree with that?

Dr. KRISHNAMOORTI. Absolutely. The idea of having an industry pull is critical in determining what types of solutions we put together. It cannot be done in isolation of industry pull.

Mr. TAKANO. Well, has the Department picked a lot of important winners in the past few decades such as—well, hasn't it really picked some important winners and losers in the past few decades such as breakthrough hydraulic fracturing techniques? Is this a bad thing?

Mr. DIMMIG. No, I don't think that is a bad thing. And again, it's—there's industry involvement, industry pull that really helped drive that technology into the market, but clearly, the Department of Energy and the federal government had an important role in getting that technology to market and then out the door.

Mr. TAKANO. Before I yield back, I'll just note for the record that Dr. Krishnamoorti was also nodding his head.

Chairman WEBER. Did the gentleman yield back?

Mr. TAKANO. I did.

Chairman WEBER. Okay. And did you say that the other side was complaining? You know, we're husbands. It's in our job description. I'm just saying.

The gentleman from New York is recognized for five minutes.

Mr. TONKO. Thank you, Mr. Chair. The energy challenges facing the United States today are real and growing. The only way to meet these challenges is by investing in research and development. Having an R&D portfolio that covers the spectrum from advances in basic sciences to cutting-edge technology development, testing and deployment greatly augments the critical work being done by our private sector in our nation's colleges and universities. Sustained support of these advances produces significant economic dividends for the United States, lowering costs and improving performance of widely used energy technologies.

President Trump's fiscal year 2018 budget proposal would deal a critical blow to the United States cutting-edge innovation and research in the energy field. It would carve away at critical programs, including the Department of Energy's Office of Energy Efficiency and Renewable Energy, DOE's Office of Science, and even the visionary energy advancements being achieved through ARPA–E, the Advanced Research Projects Agency for Energy, with a proven record of moving the horizon of energy research forward.

At a time when we should be adding to our investments in our nation's future, these cuts would put American research and innovation far behind that of other nations. Many members claim to support an all-of-the-above strategy for energy production. I believe we also need an all-of-the-above energy research strategy to complement it.

I recognize the value of federal fossil fuel research when it helps us to achieve greenhouse gas emission reductions, improve efficiency, and protect Americans' public health and safety. That is why I have authorized bipartisan legislation—I've introduced bipartisan legislation to authorize a gas turbine efficiency R&D program. Without DOE's support, we will lose our nation's advanced manufacturing edge to countries that are investing in advanced turbine research.

Instead, with appropriate investments in turbine efficiency research, we can be saving and creating American jobs while we're working to reduce emissions. Simply put, an all-of-the-above approach cannot be limited to oil and gas technology. We must support research targeting renewables, storage, grid modernization, and all other viable options to secure our nation's energy independence and our global leadership in energy innovation.

Advanced Research Projects Agency for Energy, or ARPA–E, modeled on the Defense Department's DARPA program, invests in high-potential, high-impact technologies that are too risky for the private sector at this time. ARPA–E is advancing America's competitiveness around the world. It has fostered cooperative projects with academic, federal, and private sector researchers, pushing forward cutting-edge ideas with an eye toward the marketplace.

So, Mr. Johnston, as far—as it has been widely reported, we understand that ARPA–E is now subject to a no-contract action order which prevents the program from taking any action to distribute and manage fiscal year 2016 or prior year funds, as directed by law. It has also been reported to Committee staff that, as part of this order, requests for routine no-cost extensions of contracts, which are critical tools for effective program management, are not even being considered by the agency.

GTI is currently leading or participating in several active and announced ARPA–E projects. So to the best of your knowledge, how has this no-contract action impacted the work you do or what you need to move forward in terms of research?

Mr. JOHNSTON. Thank you for the question. We had received notification of an award through the refuel program back in the fall, and that particular project has not been contracted yet, so it's been delayed. We go through a period of negotiation with Contracting Officer and the Program Director, and it's—you know, it's clearly in DOE's court now before that contract is initiated.

Mr. TONKO. Is such an order unusual in your experience?

Mr. JOHNSTON. It's not unusual to have delays when there is an administration change. This one seems to have gone on, you know, a little bit longer than typical.

Mr. TONKO. And in regard to the new contract action——

Mr. JOHNSTON. I'm not sure of the no-contract action. I just kind of look at our internal process and see that, you know, an award was made and it's—you know, it's 8 months into, you know, the notification and we still don't have a contract.

Mr. TONKO. Beyond ARPA–E, have you encountered similar issues in working with or receiving funding from other DOE programs within the last few months?

Mr. JOHNSTON. Have we received others?

Mr. TONKO. Yes.

Mr. JOHNSTON. Yes.

Mr. TONKO. And such as?

Mr. JOHNSTON. In the Fossil Energy Office we have a supercritical CO_2 Brayton cycle project that's a large project with other partners through the Fossil Energy and NETL.

Mr. TONKO. So what impact will that have?

Mr. JOHNSTON. Of getting that project? Well, we just kicked the project off and so, you know, our teams are now fully engaged in delivering that project, and it's a team of different research institutes and other researchers.

Mr. TONKO. Thank you. I'll yield back, Mr. Chair.

Chairman WEBER. Thank you, sir.

The gentleman from California is recognized.

Mr. MCNERNEY. Well, I thank the Chair. I thank the witnesses. I'm going to be confining my questions to shale oil. In California we're very concerned about groundwater. We have a limited amount of it. We have a limited amount of rain. What are the best ways to minimize contamination of groundwater in the shale process, Mr. Johnston?

Mr. JOHNSTON. So as far as groundwater, I think it's all about surface retention. There's, you know—the actual hydraulic fracturing happens so far between—you know, below the groundwater table——

Mr. MCNERNEY. Right. Yes.

Mr. JOHNSTON. —that there's really, you know, infinitesimally small risk that could ever happen unless you had a surface casing issue. But really, you're probably much more limited to surface type of contamination to groundwater.

Mr. MCNERNEY. Surface——

Mr. JOHNSTON. Spills or something of that——

Mr. MCNERNEY. Okay. I'm not quite sure I'm convinced, but I've heard that before so I will go with that for now. What about—what's the best way to minimize leakage of methane into the atmosphere from the fracking process? Or are you the right person to ask that question?

Mr. JOHNSTON. I'm certainly—I've been around—I was on my first frack job in 1985, so I've been around it for a little bit. So fracturing from the—or methane emissions from the hydraulic fracturing process are typically lower than they are from actually conventional gas production. As with anything, you know, I think operators want to keep as much of the product as they can.

Mr. MCNERNEY. Right.

Mr. JOHNSTON. The real significant points of the process that have more—are more apt to leak methane would be through the flow back process. And you can have green completions where you actually capture the methane through that process, in the gas processing process as well. So—and sometimes in storage——

Mr. MCNERNEY. So would regulations be the way to encourage companies to use that technology?

Mr. JOHNSTON. What I see that's been very effective today is when policymakers, environmental NGOs, and industry can come together and have a discussion and develop, you know, policy around that. I look at Colorado, for example. They have what I would consider to be a great case study of how you address methane reductions and a methane target within a state. And then, you know, there's technology—Senator Tanaka—or Congressman Tanaka mentioned ARPA–E.

Mr. MCNERNEY. Right.

Mr. JOHNSTON. There's a lot of new technology actually coming out of the ARPA–E monitoring—monitor program that will be there for the commercial sector to bring into account so a lot more monitoring of more remote sites on the horizon.

Mr. MCNERNEY. Mr. Dimmig, do you agree that environmentalists, industry, and policymakers come together to find solutions?

Mr. DIMMIG. I do. I do. We work quite extensively with NGOs to try to educate them about what we're doing and learn from them about where their concerns are and figure out how we can address those. Methane emissions is one of those areas. And from our conversations and where we see things with monitoring, many of these emissions issues are very easily addressed. But we have that conversation on the—very regularly with NGOs and policymakers.

Mr. MCNERNEY. Okay. Good to hear. Mr. Johnston, again, concerning wastewater, there's a significant and growing concern about the wastewater injection back underground causing earthquakes and other sorts of problems. Would it be feasible to require fracking operations to clean up the wastewater so that it can be usable if not potable?

Mr. JOHNSTON. I think it's—in some instances it's more of a market question because they can dispose of this water so inexpensively, and specifically in the—and what you've seen in Oklahoma and some of the other areas. It's actually not from shale where a lot of this water is being produced. It's from the Mississippi lime formation and that's what—and that—a lot of that deep-water injection has caused some of the induced seismicity in the Arbuckle formation there. They seem to be able to manage that pretty well as a reduce the amount.

You know, we're constantly looking for technology and innovations that make that decision very easy for operators to recycle as much of the water and to clean it up as—and reuse. So that's a big priority for GTI.

Mr. MCNERNEY. Okay. All right. Mr. Chairman, I'll go ahead and yield back and let you terminate the hearing if you wish.

Chairman WEBER. Actually, we're—I think we're going to do a second round of questions if you have more, Jerry, so hang in there.

Gosh, where do I start? Well, let me do it this way. Mr. Johnston, I'll start with you. What policies could Congress and DOE implement to encourage more industry-led development—research and development efforts? Are there existing—in other words, what policies could we implement, more industry-led research. You talked about being a roughneck basically back in '85. Is that what you said? Okay. So you've watched this industry develop. So how do we get industry more involved?

Mr. JOHNSTON. Well, one of the reasons I wanted to highlight the project that we have today is just that. I mean, how—I mean, that's tremendous leverage. It's working on a big problem, and it takes lots of different stakeholders to come together and solve the problem. So I think if you set out more grand challenges that can really have an impact for consumers, for industry, for the government to be able to point to that impact that they're making, I think that's the way to do it.

That's one thing I really like about, you know, even the ARPA–E model is they put big stakes in the ground and you have to innovate to those, so not be prescriptive but put big opportunities out there and let innovators and in the industry come together to try to solve those.

Chairman WEBER. Okay. Mr. Dimmig, I want to come to you offline afterwards. I'm very interested—you know, I own an air conditioning company, furnaces. We're about 80 percent efficient, so natural gas, about 20 percent of the heat and energy goes out the roof through the vent, and I'm curious about how exactly you all intend to get them to zero emissions.

But I want to come to the doctor here. When you talk about those kinds of measuring—or maybe it's Mr. Brower, I'm not sure or both of you—measuring—being able to measure abilities of pipelines subsea. You talked about ROVs, unmanned ROVs, subsea, acting like human capabilities—I think it was you—where you can measure that pressure differential or pressure change. My question is would—could that be applied downhole when that drilling is happening onsite? When you've got a wildcat or a rig going, are you able to measure pressure on those kinds of downhole or is that just out of the question?

Dr. KRISHNAMOORTI. Measuring anything downhole while drilling is extremely difficult. The head of the bit is a real challenge. But there are technology solutions that are coming through right now that are likely to transform that. One is through smart fluids, putting fluids that can actually measure ahead of the bit has become a way to control fluid loss. The other is looking at acoustic signals that are able to look beyond the drill noise and be able to actually tell what's going on in the head of the bit. And those are coming along. In perhaps 3 to five years those technologies will be mature.

Chairman WEBER. Okay. Well, if you can shorten that, we can get you more money. I'm just saying.

Mr. Brower, would you agree with that?

Dr. BROWER. Yes, I agree with shortening it, too.

Chairman WEBER. I figured you'd like that.

Dr. BROWER. Yes, the faster the better. Downhole measurements like differential pressure in downhole is like the Holy Grail of measurements in that arena. It's very difficult to get. Right after the Macondo incident, I was asked by BP to participate on one of their steering group, and that was one of the items that we addressed.

There—that there is ways and there are ways to do downhole monitoring. As the doctor said, it's extremely difficult. We have certain monitoring methods that we use and are continuing to further develop that are used in the deep-water area that we are now starting to put into downhole operations. And so I think in the next little—you know, in the next few years that it will be very doable to get those differential pressure measurements——

Chairman WEBER. Recently, I heard GE's plant—they would build blowout preventers that are megatons and they use redundancy in putting those on the floor of the ocean, for example. So it's a very interesting thing that we can monitor that.

But, Doctor, I want to come back to you. Mr. McNerney from California had some questions about the water issue. Would you like to further expand on that? Do you want some more time?

Dr. KRISHNAMOORTI. Sure. So there are some very interesting technologies that are in place that are allowing for the use of geothermal energy to clean up the water. These are being done through nanotechnology. There is a startup company from the University of Houston——

Chairman WEBER. Geothermal onsite?

Dr. KRISHNAMOORTI. Onsite. So they're able to bring—not use fossil energy but use geothermal energy to clean up water. This is a nanotechnology company called Wave. They have got—they've developed these materials that can pull out most of the contaminants that are there and make the water as good as potable water. And that's the kind of thing—even though you can clean it up, the idea is to reuse and recycle that water so that it can be used for refracking or for other fracturing operations.

Those—I think that's an opportunity where the challenge has been there. These are technologies that have been developed for other applications such as in the developing world where clean potable water has been a challenge, and those are being brought to bear on the oil and gas industry.

Chairman WEBER. Thank you, Doctor. I'm going to yield my time and go to Mr. Veasey.

Mr. VEASEY. Yes, thank you, Mr. Chairman. My question is, again, for Mr. Dimmig. I know that NET Power intends to use the captured carbon dioxide for EOR. If carbon capture technologies are expanded widely across the market, will the capacity for additional CO_2 EOR meet the influx of carbon dioxide that will be available or would the there be a market saturation?

Mr. DIMMIG. In most of the analyses we've seen are that there's a huge opportunity for CO_2-based enhanced oil recovery, and that opportunity can absorb the carbon emissions from really gigawatts of power plants. So there's a study by Advanced Resources International that argues there are 100—about 100 billion barrels of next-generation CO_2 EOR barrels recoverable, economically recoverable, and I think those—to recover that oil would require 33 billion tons of carbon dioxide, which is approximately I think—it was 260 or 280 gigawatts of natural gas plants over a 35-year life.

Mr. VEASEY. Well, thank you very much.

Mr. Johnston, to many, the idea of using carbon captured dioxide to extract additional greenhouse gas emitting resources—in this case oil—seems to run counter to the purpose of capturing carbon dioxide in the first place. Can you explain why CO_2 EOR—how that benefits the climate?

Mr. JOHNSTON. Well, currently, you know, most—a lot of the EOR operations come from natural—naturally occurring so it's mined basically. It's drilled for to produce the CO_2. And if you take anthropogenic CO_2 from power plants or other industry and you reuse that in an EOR application, you're actually sinking that and it becomes a miscible fluid. It helps, you know, bring up that tertiary produced oil that you can't extract today.

So I think IEA did a study where they're looking at if all the potential EOR applications that are technically recovery were done, there would be like a 63 percent carbon reduction from using manmade CO_2 for enhanced oil recovery.

Mr. VEASEY. Amazing. So in that same context can you explain what a carbon advantage barrel of oil actually means?

Mr. JOHNSTON. I would have to infer that it's something on that, you know, guideline. I'm not really dialed into that. But it—I think it has to do with using the manmade CO_2 to bring that oil to bear to the market.

Mr. VEASEY. Okay. Do you have an estimate of how much private industry invests in R&D into new technologies annually compared with the Department of Energy's Office of Fossil Energy?

Mr. JOHNSTON. Are you talking about across the value chain——

Mr. VEASEY. Yes.

Mr. JOHNSTON. —of oil and gas? I mean it's orders of magnitude more than what DOE would put in. I mean, because the Fossil Energy Office has put 600—roughly $600 million a year. I think, you know, there—it'd be orders of magnitude more by industry, you know, across—are you just talking about the United States? Even it's at least an order of magnitude, probably higher.

Mr. VEASEY. Okay. That would be interesting to have—to see those numbers. Would the government best fulfill its obligation to the public by pursuing more efficient extraction methods and technologies or by pursuing more effective environmental protections?

Mr. JOHNSTON. Could you repeat that? I'm sorry.

Mr. VEASEY. Yes, absolutely. Would the government best fulfill its obligations to the public by pursuing more efficient extraction methods and technologies or by pursuing a more effective environmental protection policy?

Mr. JOHNSTON. Yes, you know, those things are so closely coupled, and I don't think people realize that or a lot of people, so—and as I pointed out in my testimony, the more you're driving that efficiency, the more you're reducing the environmental impacts and the community impacts on top of that, which is very important to people. So I think they are much more tightly linked and it's not an either/or, and I think that's the conversation we should be having more.

Mr. VEASEY. Mr. Dimmig, do you—it looked like you wanted—did you want to comment on that? Okay. All right. No, thank you, Mr. Chairman. I yield back my time. Thank you.

Chairman WEBER. He wasn't going to touch that with a 10-foot drill stem.

Mr. McNerney?

Mr. MCNERNEY. Well, I thank the Chairman again.

You know, shale revolution really has changed our country's energy outlook. In 2007 we were talking about running out of oil and prices and all, and now we have oil. We're talking about exporting natural gas. But shale has a bad rap. I mean, it does. If you look at the State of Maryland, didn't they just pass a law that would forbid fracking? I mean, states, even Oklahoma, there's a lot of concern out there about shale.

So what can we do? Is it more government regulation? Is it just improving technology? I mean, I'm at a little bit of a loss here. How do we change that image of fracking as a nasty, polluting, earthquake-causing business?

Mr. DIMMIG. Sure, Professor.

Dr. KRISHNAMOORTI. So I direct you to my testimony. There is a report that the Academy of Medicine, Engineering, Science, and Technology at the State of Texas is creating is led by one of our UH faculty members Christine Economides. She's a National Academy of Engineers member. They have looked at all of the different aspects of shale gas, and this is the technology, the water, the infrastructure, and there are best practices in place that can be put in play that will ensure that this can be done safely, can be done economically, and can be done in a way that actually minimizes environmental and infrastructure damage. And I think those are the best practices that have been established. It's been about 10, 12 years of the industry working really hard to do it rights.

And I think even though there has been a lot of publicity about the ills of shale gas and the unconventional resources, I think that this is a resource that, if managed right and if done right, can be an incredible resource for all of us.

Mr. MCNERNEY. Well, I mean, you talk about best practices, okay, but it just takes one or two bad players to give the whole industry a bad rap. And, I mean, is it going to take additional government regulation or enforcement? I mean, how are we going to make sure that the industry follows those best practices?

Dr. KRISHNAMOORTI. So the challenge is how distributed the resources and how many operations that are continuously being developed or drilled and production. And so to try and do this by just simply regulatory oversight is a mistake. This has to be a partnership with the industry and with best practices being put in place and where the effectiveness is monitored by the industry. It cannot be monitored by regulatory agencies.

Mr. MCNERNEY. I don't quite buy that. I mean, that's like saying you're going to have the financial industry regulate itself. No, that doesn't work.

Mr. Johnston, did you want to chime in here?

Mr. JOHNSTON. I do think that having un-polarized conversations would be a good start. And I don't know who is the facilitator——

Chairman WEBER. Yes, we'll get right on that here in Congress.

Mr. JOHNSTON. Yes, exactly. I wasn't going to bring that up. But anyway—but, I mean, that would be a huge start, just to bring the NGOs, industry, and policymakers together to really—because we have an unprecedented opportunity. You know, you talk about in our country going to—being an exporter of hydrocarbons and, you know, ten years ago we were talking about building LNG import terminals and, you know——

Mr. MCNERNEY. Now we want to know how to make them export terminals.

Mr. JOHNSTON. Yes.

Mr. MCNERNEY. But, I mean, the thing is even if the United States—all the players in the United States are good, you know, angels and they don't ever—they follow best practices, then we're—there's other countries in other parts of the world that are going to take up this technology and they're going to be bad players. So, I mean, we still have a huge challenge in terms of our leadership and in terms of our example on how we do this.

Mr. JOHNSTON. Yes. Fracking is not a good, you know, name, right, anywhere you look, and it's painted with a broad brush——

Mr. MCNERNEY. Yes.

Mr. JOHNSTON. —whether it's actually the culprit or not. And I don't know how you redirect that conversation, but, you know, it's been around since 1947. It's not—it's—and, you know, I don't know how you change the conversation, but that's really what needs to happen.

Mr. MCNERNEY. I mean, as a tree hugger, I want to see more renewables and maybe more nuclear, but we can't just turn off. And so we're going to have to rely on fracking, and we want it to be as clean and as safe as possible.

Mr. JOHNSTON. Well, there's ways to—you know, there are best practices and I think there are commonsensical ways to address the issues that are out there. Like I said, I pointed to Colorado in the case of methane emissions. That's a great case study and then how you take that from there.

Mr. MCNERNEY. All right. Thank you, Mr. Chair. I'm going to yield back to you.

Chairman WEBER. Okay. Well, now that we have fixed all those problems, I want to thank the witnesses for their valuable testimony and the Members for their questions. Jerry, thank you for your difficult questions, too. I mean, that's a lot of frank discussion. I appreciate that.

The record will remain open for two weeks for additional comments and written questions from the members. This hearing is adjourned.

[Whereupon, at 11:37 a.m., the Subcommittee was adjourned.]

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