Written Statement of

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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.