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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-

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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.