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Thank you Chairman Murkowski, Ranking Member Manchin, and members of the Committee. I appreciate the opportunity to discuss carbon capture innovation and the EFFECT Act. I will be discussing today a whole new method of carbon capture called the Allam Cycle, which 8 Rivers invented 10 years ago. 8 Rivers created the company NET Power to commercialize the natural gas Allam Cycle, and it has garnered over \$150 million between its four investors: 8 Rivers, Exelon, McDermott, and Oxy Low Carbon Ventures. Toshiba has been our technology partner since 2011, supplying the two key components: the combustor and CO₂ turbine.

NET Power built a successful 50 MWth plant in La Porte Texas that achieved combustor first fire in May of 2018. This technology has the potential to sell power at a lower price than conventional power plants, while releasing zero emissions. Today, multiple 300 MW-scale NET Power plants are in early stage development around the world.

The Allam Cycle burns natural gas or coal in pure oxygen, rather than air. This creates a high purity stream of CO₂ at 300 Bar and 1150 Celsius. Instead of steam, this supercritical CO₂ is used to drive the turbine. That CO₂ can then be sent into pipeline at no additional cost. CO₂ capture is inherent to the system, and selling CO₂ is a key source of revenue. Multiple revenue streams give NET Power a cost advantage. And by using supercritical CO₂ as a working fluid, this cycle can reach the approximately the same efficiency as a conventional natural gas power plant while achieving over 97% carbon capture and creating zero air pollutants.

The Allam Cycle presents a breakthrough opportunity not just for the electricity sector, but also for the 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 and co-generating CO₂ for domestic Enhanced Oil Recovery (EOR), cement production and other forms of carbon utilization, as well as for underground sequestration. It will co-produce other valuable gases, Nitrogen and Argon, which support America's manufacturing sector.

By providing reliable, low-cost, and flexible power with virtually no carbon emissions, NET Power is an excellent complement to growing wind and solar energy portfolios around the world. Each NET Power plant can provide 150 MWH in energy storage services by taking in excess renewable electricity, using it to create pure oxygen, and storing the oxygen in tanks for later use when the sun sets or the wind slows.

This technology create a valuable export opportunity with large environmental upside. NET Power envisions a robust global market for this technology because of its low cost profile. Countries like China and India could build coal and gas Allam Cycle plants as a means of keeping their power costs low, with the added benefit of eliminating local air pollution and cutting global carbon emissions. With innovative technologies like NET Power, we believe clean energy will become affordable for the whole world.

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. Both the turbine itself and combustor are novel and specific to the Allam cycle. Toshiba manufactured these components for the La Porte facility. The turbine relies on proven technologies from both the gas and steam turbine industries. The combustor, did require R&D by 8 Rivers and Toshiba, and it has since been proven at the commercial 50 MW scale at the NET Power plant in La Porte. So while 8 Rivers was the first company to design a direct-fired, oxy-combustion, supercritical CO₂ power cycle with the performance of the Allam Cycle, it was more quickly and effectively developed due to host of industry and federal government R&D for other purposes.

NET Power applauds the committee for its introduction of the EFFECT Act. The legislation's focus on breakthrough carbon capture technologies, large-scale carbon sequestration, and carbon utilization is critical to the long-term viability and success of the carbon capture industry. As a technology that will produce 809,000 tonnes of pure CO₂ per year at each plant, we are interested in all the potential uses of CO₂ and we view NET Power as a key enabling technology that provides the low cost carbon required for a thriving carbon utilization industry. Furthermore, we appreciate the wide scope of EFFECT act across the R&D spectrum, from research and large-scale pilots to demonstration project and to front-end engineering and design, all of which are necessary to commercialize novel technologies. America is well positioned to lead the world in carbon capture and storage technology, and this legislation will bolster America's technology leadership further.

Additionally we thank Congress for its leadership in expanding the 45Q tax credit for carbon capture as part of the February 2018 Budget Bill. These credits will accelerate the deployment of 300 MW-scale NET Power plants as well as a variety of other carbon capture technologies, spurring new infrastructure and new jobs while also reducing emissions.

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. The R&D process is long, expensive, and highly uncertain; without government participation 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.

Background on the Allam Cycle

8 Rivers is the inventor of the Allam Cycle, which is a high-pressure, direct-fired, oxy-combustion, supercritical carbon dioxide power cycle. The cycle takes natural gas or gasified coal and combusts it at high pressure and with pure oxygen (as opposed to air). This virtually eliminates the presence of nitrogen and generates a working fluid that is mostly carbon dioxide. This CO₂ 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 CO₂ 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 CO₂ 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 enhanced oil recovery, carbon sequestration, 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. A specific example of this federal government R&D is in materials development. At a critical, high- 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.¹ 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 CO₂ 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.² 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, assisting with the design of a syngas-fueled combustor for supercritical CO₂ power cycles, and supporting an R&D effort in North Dakota through the Energy and Environment Research Center (EERC). Most recently, Fossil Energy announced that the coal-based Allam Cycle was one of the grant recipients under the Coal FIRST Program. In addition, the DOE has expanded its work in the field of supercritical CO₂ 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.

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 over \$150 million in investment from Exelon Corporation, a leading power company in the United States, McDermott, a global engineering and infrastructure firm; and Oxy Low Carbon Ventures, a subsidiary of Occidental Petroleum, the world's largest user of CO₂. Along with 8 Rivers, these four companies jointly own NET Power.

Separately, Toshiba has undertaken a major, multi-year effort to develop the turbine for NET Power. Together, the companies have built and are operating a 50MWth plant in La Porte, Texas.

¹NETL: <https://www.netl.doe.gov/research/coal/crosscutting/high-performance-materials/Ultrasupercritical>

² DOE Office of Energy Efficiency & Renewable Energy: <https://energy.gov/eere/sunshot/sunshot-initiative>

The design for this facility was dictated by a commercial-scale design for the Allam Cycle (300 MWe). 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. The 50 MW combustor built by Toshiba and demonstrated in La Porte is at full commercial scale- there will be 12 of this same 50 MW combustor for a larger 300 MWe facility.

The plant is the first facility of its kind in the world and has provided a major leap forward in the field of direct-fired supercritical CO₂ power cycles and carbon capture. This facility is providing sufficient confidence in the technology to execute on the 300MW commercial-scale facilities that NET Power is presently developing. NET Power announced successful first fire of the combustor, the key technical milestone for the facility, in May of 2018, and the facility is continuing operational testing.

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 CO₂, 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, NO_x production is virtually eliminated; with the coal system, SO_x, 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.³ 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. Each NET Power plant

³ 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

can provide 150 MWH (30 MW / 5 Hours) in energy storage services, by taking in excess renewable electricity, using it to create pure oxygen, and storing the oxygen in tanks for later use.

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.

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 CO₂-EOR. The ability to economically recover oil via CO₂-EOR is primarily dependent on the price of oil and the price of the CO₂ needed to produce that oil. Traditional, add-on carbon capture technologies produce CO₂ at a cost of approximately \$30-\$70/ton.⁴ With recovery rates in the range of 1.5-3 barrels per ton of CO₂ injected, these technologies require very robust oil prices in order to be economically viable.⁵ By producing EOR-ready CO₂ for virtually no cost, the Allam Cycle enables CO₂-EOR to be one of the lowest-cost methods of oil recovery available, making it resilient to drops in oil prices, and greatly expanding the economically recoverable supply here in the United States. 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 CO₂ 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.⁶ Further, the Allam Cycle's ability to provide low-to-no-cost CO₂ 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 CO₂-EOR is so significant, so is its ability to permanently and safely store vast quantities of CO₂ generated by the power sector through EOR.⁷ 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 CO₂ will be required. This equates to the 35-year CO₂ output of over 250 gigawatts natural gas power plants.⁸

NET Power is also looking to carbon utilization, from plastics to cement, and carbon sequestration as key offtakes for CO₂, which greatly expand the domestic map of potential locations for NET Power facilities. The DOE has estimated the total storage capacity in the United States ranges between 2.6 trillion and 22 trillion tons of CO₂.⁹ The ideal use of CO₂ for each plant is likely to vary highly by region and by specific plant location.

⁴ 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

⁵ IEA, *Storing CO₂ through Enhanced Oil Recovery*, pg. 12:

https://www.iea.org/publications/insights/insightpublications/Storing_CO2_through_Enhanced_Oil_Recovery.pdf

⁶ ARI, *CO₂ Utilization from "Next Generation" CO₂ Enhanced Oil Recovery*, pg. 6855: http://ac.els-cdn.com/S1876610213008618/1-s2.0-S1876610213008618-main.pdf?_tid=1d87e6fa-2e26-11e7-8a95-00000aabb0f6c&acdnat=1493612869_cba2651ceafcf29c6ee51cfae089f63c

⁷ Literature shows that only about 0.3% of the CO₂ sued for injection is lost to the atmosphere; IEA, *Storing CO₂ through Enhanced Oil Recovery*, pg. 12.

⁸ ARI, *CO₂ Utilization from "Next Generation" CO₂ Enhanced Oil Recovery*.

⁹ Carbon Capture and Sequestration (CCS) in the United States, CRS Report. <https://fas.org/sgp/crs/misc/R44902.pdf>

The Allam Cycle can also impact natural gas utilization in the United States and abroad. By providing highly cost-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, and allow for the natural gas we export to be burned without emitting CO₂. 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.

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. The EFFECT Act proposes this exact flexibility. 8 Rivers began by working on 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, because the most important development step for the coal-fueled Allam Cycle is NET Power's natural gas demonstration program. Similar crosscutting 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 from basic R&D through to deployment of the first-of-its-kind commercial-scale plant, and even into additional early commercial plants thereafter through incentives like 45Q. 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 more expensive project than the second facility of its kind will be. There are 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.

So, while a technology might easily project to outcompete incumbent technologies, a first plant will still be 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 and tax credits that assist the private sector in developing and financing these first-of-a-kind projects as critical to ensuring that promising technologies have a chance to be initially deployed 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 carbon capture, they also include the need to further expand infrastructure such as CO₂ pipelines. Tax credits like 45Q are essential to ensuring technologies like NET Power can be widely and quickly deployed. This will maximize their ability to transform the power sector with lower cost electricity while permanently storing its CO₂, whether by making cement or plastics, injecting CO₂ for enhanced oil recovery, or sequestering it in saline formations.

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