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CONGRESSIONAL TESTIMONY OF **DR. S. JULIO FRIEDMANN**

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BEFORE A JOINT HEARING OF THE **COMMITTEE ON ENERGY AND NATURAL RESOURCES**, UNITED STATES SENATE, 2ND SESSION, 115TH CONGRESS

Chairman Murkowski, Ranking Member Manchin and Members of the Committee, thank you for inviting me here today to discuss issues of Carbon Management. My name is Julio Friedmann. I am a Senior Research Scholar at Columbia University's Center on Global Energy. From 2013-2016, I served as Principal Deputy Assistant Secretary for the Office of Fossil Energy at DOE, and before that served at Lawrence Livermore National Lab for 15 years.

It is an honor to appear again before this Committee to discuss carbon management broadly. Since my last congressional testimony 14-months ago, the nation and the world have changed dramatically, and I am compelled to acknowledge this extraordinary moment and its circumstances. The unprecedented COVID-19 pandemic has taken the lives of more than 143,000 Americans. It has damaged the US and global economy. and underscored inequity, racial strife and problematic aspects of our health care and judicial systems. It has also accentuated the central need for science and fact-based policy making, which adds import and salience to this hearing. Climate change is a looming threat – and a challenge that will strain greatly every aspect of our society and economy. The challenges demand courage, ingenuity, humility, and generosity to meet and overcome them.

These demands advise my own research at the Center on Global Energy Policy where I lead the Carbon Management Research Initiative. Our team draws on the broad and interdisciplinary expertise of scholars across Columbia University, including scientists, lawyers and former policymakers at the Earth Institute, the Sabin Law Center, and the Schools of Earth Science, Engineering, Law, Medicine, International and Public Affairs, as well as Columbia's burgeoning School of Climate,

It is abundantly clear that if we are to counter the risks of climate change, protect our economy and maintain our global competitiveness, we must pursue technologies that manages emissions by reducing and removing CO_2. These include conventional carbon capture and storage (CCS), CO_2 use and recycling, and CO_2 removal (both through managed ecosystems and engineered approaches). All are essential components of combining rapid, deep decarbonization with a muscular economy.

These technologies are essential for the energy sector, especially for power generation and heavyl industries. They are beginning to contribute to every other sector of our economy –

manufacturing, forestry, farming and high tech. Our research shows these technologies often present the lowest-cost, most actionable pathway for profound emissions reduction and that in some sectors they are the only pathway.

New studies by groups like the International Energy Agency,[1] Global CCS Institute,[2] Goldman Sachs,[3] McKinsey[4] and the Energy Transition Commission[5] have underscored carbon management's essential component to supporting both economic growth and rapid, deep decarbonization. It should be clear from all of this that carbon management deployment is not some greenwashing or a license to pollute. Quite the opposite – it is an overt, committed pathway to deeply and quickly reduce greenhouse gas (GHG) emissions in a cost-effective way while sustaining economic growth and communities at risk – from Alaska Natives living a subsistence lifestyle along the North Slope and the fishermen and oil workers in Prudhoe Bay to the miners, roughnecks, and biotech workers in West Virginia and Kentucky. Leading US companies and institutions have adopted carbon management strategies as part of their business plans, creating new companies and services to provide carbon management to rapidly growing global markets.

My testimony will focus on large-scale carbon management, including carbon capture and storage (CCS); CO_2 use and recycling; CO_2 removal, including engineered and managed ecosystem approaches; the need to invest in innovation; and the implications for competitiveness & industrial productivity. I'll also comment on how government agencies can help the US maintain leadership, sustain jobs and communities, innovate quickly, and rapidly reduce carbon pollution.

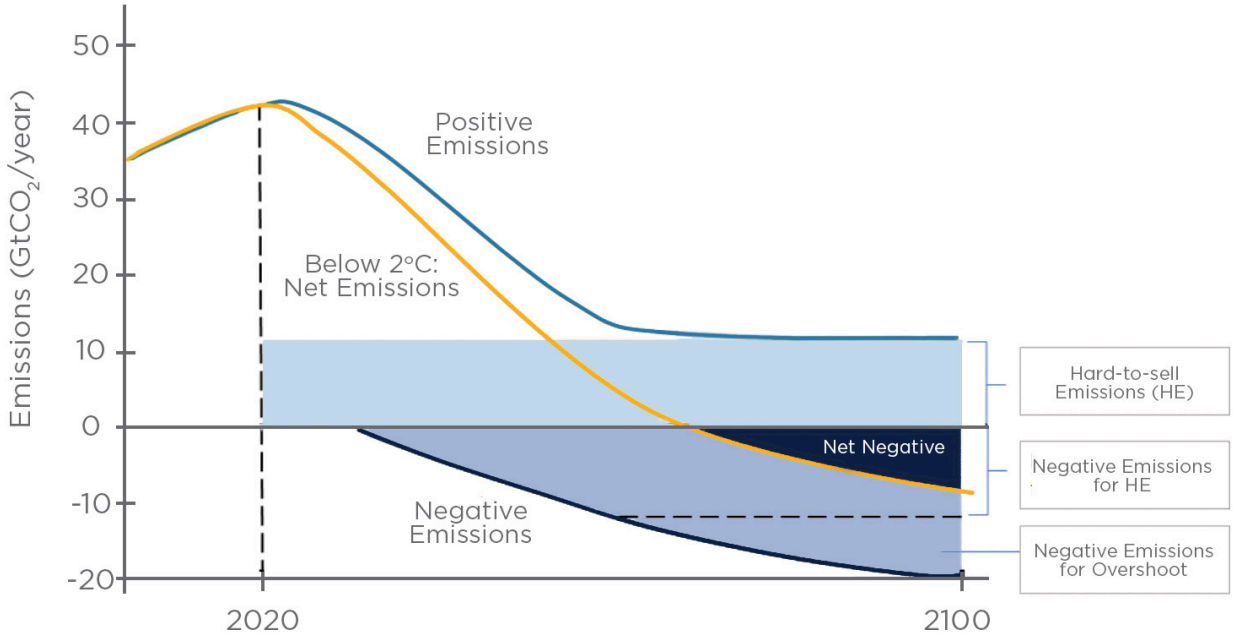
Net-zero Framework: Climate and US Competitiveness

Core to the continued and growing interest in carbon management is the recognition that national and global economies must achieve net-zero greenhouse gas emissions. Importantly, this is required to achieve ANY climate stabilization target. If net-zero emissions are not achieved, atmospheric concentrations of greenhouse gases will increase, as will the risks and damages from climate change, with which you are familiar. That is true for stabilization at 1.5°C, 2°C, 3°C or higher. Net-zero is the core arithmetic to stabilize climate: ***any residual CO_2 emissions must be balanced by an equal amount of CO_2 removal***.

$$\mathbf{CO_2 emissions - CO_2 removals = 0}$$

By definition, achieving net-zero emissions requires that any emissions that are not *reduced* must be *removed*. To achieve net-zero emissions, all emissions trajectories must decrease (figure 1). However, if there are any residual emissions that are not reduced or mitigated, net-zero requires an equal mass of CO_2 removal. In many scenarios and descriptions, residual emissions are considered "hard-to-abate," meaning either the cost is extremely high (e.g., for aviation) or the technology does not exist (e.g., application of fertilizer).

Figure 1: Representative pathway to net-zero and net-negative emissions. The orange line represents emissions trajectory as the sum of the green and blue trajectories



Source: J. Wilcox et al. 2020..

This sensibility has led to specific policy decisions by nations, states and municipalities. Multiple nations now have legislated net-zero economies by 2050, and others have legislated net-zero for key sectors (e.g., electric power generation). That is also true of many states – nine have legislated 100% net-zero power standards, and several have committed to net-zero economies (e.g., CA & NY). These represent substantial markets, and the growth in commitments produces a growing fraction of the national and global market that demands net-zero goods & services.

National and regional policies of these kinds have helped prompt leading companies to make commitments to net-zero emissions as well. These include:

- Tech giants such as Microsoft & Amazon
- Industrial giants like Dow and Unilever
- Oil & Gas companies including Occidental and Shell
- Power companies like Southern and Xcel
- Airlines like Delta
- Retailers like Nike

These commitments include operations, supply chains and products – all net-zero. Some companies, such as Microsoft, have committed to removing their legacy of emissions representing their whole corporate history – more than 200 million tons in total! All have realized that they need all tools available to achieve these goals, including carbon management in all its forms.

Technical and Commercial Status of Carbon Management

Since my testimony before this Committee 14 months ago, a great deal has changed for all carbon management approaches. In fact, a signature aspect of the carbon management landscape is rapid and sometimes revolutionary change. In this, there are similarities to carbon management now and solar & EV enterprises in 2005. Fifteen years ago, both enterprises were considered prohibitively expensive, immature, hard to scale and reliant on market aligning policies. Instead, steady investments in innovation, changing consumer culture and international markets, and multiple market-aligning policies created opportunities, jobs, wealth, and a cleaner energy system and environment. Carbon management can deliver these benefits even more quickly but will require a similar mix of innovation, policy incentives, and a national posture of development and commercialization.

I have streamlined this section for clarity and have added substantial additional materials on all these topics in a technical appendix at the end of this testimony for completeness.

Carbon Capture and Storage (CCS)

CCS represents a set of technologies that capture & separate CO_2 from large point sources, transport them to sites of geological storage, compress & inject them deep in the earth's crust, and monitor them to validate safe and secure storage operations. Today, 21 large-scale CCS facilities operate worldwide, safely and securely keeping more than 40 million tons of CO_2 from the air and oceans every year. In total, the world has managed more than 260 million tons of man-made CO_2 this way.[6] More information can be found in the technical appendix.

CCS can and will play a critical role in managing the emissions from these key sectors:

- Heavy industry, including cement, steel, chemicals, refining, ethanol, pulp & paper, and glass[7]
- Existing power stations, most notably coal- and gas-fired electricity production[8]
- In the near-term production of low-carbon and zero-carbon hydrogen, as is currently done in five facilities worldwide,[9] including the Air Product project in Port Arthur, Texas

Although these applications are very important for the US, they have enormous potential applications in China, India, Southeast Asia, Europe and the Middle East. These provide commercial opportunities to US manufacturers and companies to provide carbon management goods & services, as detailed in a recent NPC report.[10]

CO_2 Use and Recycling

For good reasons, many seek to find ways to use CO_2 to create economic value in a climate-

positive way. Today, the primary use of CO_2 is for enhanced oil recovery. This is an important near-term pathway and provides opportunities to finance projects, scale-up technologies and reduce costs. Many see the value in turning CO_2 into goods for scale - that will be essential at some point for a circular carbon economy.[11] The main types of valuable products made from CO_2 include synthetic fuels; chemical feedstocks like carbon monoxide, syngas & methanol;[12] CO_2-based cement, concrete & aggregates; and durable CO_2-based-products, including carbon fiber/tubes, plastics and composites, etc. While it is unlikely that these approaches and products will lead to profound GHG emissions reductions, they are engines for growth and are already supporting hundreds of US companies making and selling these products.

CO_2 Removal

Driven in part by the science, market forces and arithmetic discussed above, CO_2 removal has gained dramatic and profound increased prominence as an enterprise and as a necessary component of climate action. The National Academies has described the different pathways and what is needed for them to scale and succeed.[13] They include both engineered and managed ecosystem approaches.

- *Engineered pathways:* These approaches use machinery and conversion equipment to separate CO_2 from ambient air. This can involve direct-air capture with storage (DACS), bioenergy with carbon capture and storage (BECCS), and carbon mineralization. The US currently has one operating BECCS facility (the ADM ethanol plant at Decatur, IL) with many more announced projects. There are seven DAC companies, with plans under development for projects in West Texas (Carbon Engineering + Occidental Petroleum), Huntsville, Alabama (Global Thermostat & Coca-Cola), and others.

- *Managed Ecosystems:* Sometimes called "nature-based solutions," managed ecosystems include modifying working forest operation, reforestation, adding forests (afforestation), soil carbon storage and wetland restoration including mangrove plantation ("blue carbon"). In addition to removing CO_2, these approaches often have ancillary benefits (e.g., water quality, biodiversity, soil health). Many companies, including technology companies (e.g., Pachama, Indigo, LandLife), are executing projects in the US and seeking to expand their markets.

A number of large US companies have made commitments to CO_2 removal, both as an environmental goal and as an investment opportunity. These include technology giants Microsoft, which just last week announced a request for proposals as part of its action plan and $1 billion investment strategy;[14] Amazon, which has announced a $2 billion investment strategy;[15] Nike & Unilever, which have joined Microsoft in creating a buyers club for CO_2 removal services;[16] and Dow, which has committed to a net-zero footprint.[17] Several US companies, including Winrock and American Carbon Registry, serve to certify and authenticate these services and will help mature CO_2 removal as an industry.

Key Policy Concerns

To maintain leadership and global competitiveness in these markets and to achieve important climate goals, strong policies are needed to bring carbon management tools, technologies

and practices to market. In my last testimony, I discussed a wide range of potential policies. I will focus today on a subset of those approaches and additional new policies that this Committee and this Congress can consider.

Incentives for Deployment

In the past, the US has stimulated market adoption of clean energy technologies through incentives, such as investment tax credits and production tax credits, augmented by state-level mandates (e.g., renewable portfolio standards). The value of these has ranged from $60-$150/ton for the wind production tax credit to ~$40-$120/ton for the solar investment tax credit.

For carbon management, the only national incentive is the 45Q tax credit, worth $50/ton for saline formation storage and $35/ton for CO_2 reuse (e.g., EOR) and recycling and for direct-air capture. Recent analyses including our own at Columbia[18] and the National Petroleum Council[19] make clear that this is insufficient for widespread market adoption. Our work estimates that for utility-owned gas-fired power plants to deploy CCS, they would require $80/ton incentives and for merchant power plants closer to $110/ton, in line with existing renewable tax credit provisions. Important enhancements to 45Q are under consideration in Congress today, including these provisions to:

- Extend the construction eligibility criteria 2-5 years (or to make the credit permanent)
- Increase the value of direct-air capture to $65/ton or higher
- Increase the value of saline formation storage
- Make the credits fully refundable (e.g., under Section 1603), as was done during the 2009 stimulus response.

Incentives of these kinds are vitally important for CCS projects to receive project financing. The greater the incentives, the more CO_2 capture systems will be deployed and the more tons of CO_2 reduced or removed.

Augmenting Policies

Many other important policy options fall within the jurisdiction of this Committee, affecting opportunities around many forms of carbon management. Three important options merit consideration and legislative treatment:

Land Use (Forests)

The US Forest Service has programs and authorization to prioritize forest health and disburse funds. One action to consider would be to prioritize and augment funding for states to expedite implementation of elements of State Forest Action Plans required under the 2008 Farm Bill and present in every state. In addition to creating jobs for forest workers (many in rural communities), it would improve forest resilience and increase rates of carbon drawdown. These funds would provide critical financial support to states addressing high wildfire risk (including fuel clearing and other labor-intensive forest health treatments).

A related action would be to lift the cap on the Reforestation Trust Fund (RTF). The fund was established in 1980 to regrow and replace US forests impacted by wildfire, pests, disease or timber harvests. Today, RTF is funded by existing tariffs imposed on imported timber and wood products but is capped at $30 million. Lifting the cap to $60 million would not lift tariffs and would allow important existing funds to flow to forest restoration projects.

Pore Space Access

CCS, DACS and BECCS all require access to subsurface pore volumes. For saline formation, access and injection rights commonly belong to the surface owners. This means the rights to enormous CO_2 storage capacity, potentially over a trillion tons, belong to the US Government on Federal lands. The BLM should establish a program to provide access to pore volumes on Federal Lands, ideally at low-cost or zero-cost, and begin to create processes to resolve issues of pore-volume access for projects with multiple landowners and post-injection site care.

Resource Assessment

The US Geological Survey has done an excellent job assessing the potential CO_2 storage resources in conventional geology,[20] notably saline formations and depleted oil & gas fields. The US Department of Energy has similarly done an excellent job in assessment through the Regional Partnerships Programs,[21] and is greatly improving the confidence and resolution of these assessments through the CarbonSAFE program.[22] This work is the global standard of excellence for geological storage resource assessment. This Committee should consider expanding the CarbonSAFE program's funding and continuing the USGS assessment work.

That work should expand into carbon mineralization assessment. Although the USGS has made an initial effort to map and assess US CO_2 mineralization resources that is very helpful,[23] it is too coarse for states or companies to consider policies and investments. A more detailed representation of key ultramafic and mafic rock bodies, including detailed mineralogy and petrology assays, would provide data both scientists and entrepreneurs could use.

Finally, BOEM within the Department of the Interior could undertake similar assessments for the continental shelf region, starting with the near-shore Gulf of Mexico. As discussed above, they could also provide zero-cost or near-zero cost access to saline formation pore volumes in federal waters.

Infrastructure

As I have indicated in prior testimony,[24] CO_2 infrastructure is essential to deployment. A new study by the Great Plains Institute,[25] supported by 17 governors through a multi-state working group, shows just how valuable that infrastructure could be, reducing 280-670 million tons each year (Table 1), supporting hundreds of large-scale projects and creating tens of thousands of jobs. The projected network size would be 30,000 miles (only six times what exists today) and would cost roughly $15 billion. This would launch some of the fastest and cheapest abatement the US could undertake, including from ethanol, hydrogen and fertilizer production.

Table 1: CO_2 storage, land-use and investment across primary scenarios. Source: Great Plains Inst., 2020

Scenario	CO_2 Stored	Miles of Transport Network	Capital Investment	Project Labor Investment	Annual O&M Spending
Near- and Medium-Term	281 million metric tons	29,710 miles	$16.6 billion	$14.3 billion	$252 million
Midcentury	669 million metric tons	29,922 miles	$19.3 billion	$15.3 billion	$254 million
Impact of midcentury planning horizon	x 2.38 mroe CO_2 stored	+0.7%	+16.3%	+7.0%	+0.8%

The EFFECT Act has provisions to authorize the Department of Energy to provide grants for CO_2 pipelines. The Invest CO_2 Act would do the same with the Department of Transportation. This Committee could support these bills and could also expand the authorization of the DOE Loan Program Office to include investments in CO_2 pipeline infrastructure.

Innovation

Innovation is our nation's strong suit, and sustained, substantial support by the Federal Government has always played an important role, ranging from basic science to applied science to funding of pilots and demonstrations. A pending report from the Center on Global Energy Policy explains both the history and the opportunity innovation investment could play in maintaining US competitiveness as well as enabling and achieving deep carbon reductions.

In no area is this clearer than in carbon management. The report calls for dramatic increases in funding for both CCS and CO_2 removal, and adding that funding to multiple agencies. These recommendations follow the lead of the Energy Futures Initiative report from last year,[26] which lays out specific line items and budgets for US agencies. This recommendation is matched by the Rhodium Group recommendations around capturing leadership for direct-air capture.[27] Dramatic increases in carbon management innovation support represent a no-regrets pathway.

The same is true for data gathering & analysis around carbon management. Gathering data & information and undertaking analysis remain core government functions, and themselves enable opportunities that would not otherwise come to light. As one example, a recent report on achieving net-zero emissions for California by Lawrence Livermore National Lab[28] reveals key opportunities for CO_2 removal, both engineered and through managed ecosystems, and was only possible due to the decade of data made available on crops, forests, geological resources of all kinds, municipal solid waste and water. This Committee should empower agencies to gather key data (e.g., on industrial heat use, power market data, land use and facility engineering) to enable new carbon management technologies and projects.

Industrial Opportunities

In two reports on industrial decarbonization and in my recent House Testimony, my co-authors and I make a set of recommendations regarding how to rapidly and cost-effectively reduce emissions from heavy industry. New scholarship which we will publish soon shows unambiguously that CCS is one of the lowest-cost, most actionable pathways for profound emissions reduction, especially in the cement, steel, chemical and refining sectors. One important and under-utilized approach involves government procurement authorities, since governments buy 50% of the concrete, 20% of the steel and 5% of fuel in the US. Legislative opportunities include the Army Corp reauthorization, Highway bill reauthorization and Defense authorization. The Government can purchase low-carbon production from these industries, stimulating market competition and new products. This has often been the path for advanced technologies entering the marketplace. Importantly, these kinds of industrial investments and incentives will protect the US against border carbon adjustments and position US manufacturers for emerging global market opportunities.

Similarly, low-carbon hydrogen will be a major workhorse for a net-zero global economy. Policy measures that support low-carbon hydrogen production and use, including low- and zero-carbon production using hydrocarbons & CCS, will further US interests in many ways. In addition to procurement, infrastructure investments, tax credits for low-carbon hydrogen production and investments in innovation will all support this key industrial pathway.

Closing Thoughts

Carbon management is both the industry of the future and a keystone to a just, verdant world. The technology, physics and chemistry are well understood, and other aspects of the science are gaining clarity every day. A dedicated, committed effort by the US Government would lay the cornerstone for commercial activity, high-paying jobs, helping communities at risk, and tackling the hardest, most stubborn aspects of climate change. US leadership in this space is not inevitable but is very much possible by taking the right measures.

With that, I look forward to your comments and questions.

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