RYAN A. BIZZARRO, CHAIRMAN
414 MAIN CAPITOL BUILDING
P.O. BOX 202003
HARRISBURG, PENNSYLVANIA 17120-2003
(717) 772-2297
FAX: (717) 780-4767

HOUSE DEMOCRATIC POLICY COMMITTEE
WEBSITE: WWW.PAHOUSE.COM/POLICYCOMMITTEE
EMAIL: POLICY@PAHOUSE.NET
@PADEMPOLICY

HOUSE OF REPRESENTATIVES
COMMONWEALTH of PENNSYLVANIA

House Democratic Policy Committee Hearing

Carbon Capture and Pennsylvania's Energy Future
Wednesday, July 21, 2021 | 11 a.m. to 1 p.m.

Representative Joe Hohenstein

11 a.m. — Mark Szybist, Senior Attorney, Climate & Clean Energy
Natural Resources Defense Council

Q & A with Legislators

11:20 a.m. — Rachel Fakhry, Senior Policy Analyst
Natural Resources Defense Council

Q & A with Legislators

11:40 a.m. — Perry Babb, President & Acting CEO
KeyState Zero

Q & A with Legislators

12 p.m. — Dr. Jennifer Wilcox, Acting Assistant Secretary & Principal Deputy Assistant Secretary
Office of Fossil Energy and Carbon Management, U.S. Department of Energy

Q & A with Legislators

12:20 p.m. — Andrew Place, Director, U.S. State Energy & Climate Policy
Clean Air Task Force

Q & A with Legislators

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TESTIMONY OF THE NATURAL RESOURCES DEFENSE COUNCIL

Mark C. Szybist, Senior Attorney

Before the House Democratic Policy Committee

Concerning Carbon Capture

Philadelphia, Pennsylvania
July 22, 2021

Chairman Bizzarro, Representative Hohenstein, honorable members of the Committee: good morning and thank you for the invitation to speak to you on the topic of carbon capture.

My name is Mark Szybist and I am a senior attorney with the Natural Resources Defense Council, a nationwide non-profit environmental organization with approximately 17,000 members in Pennsylvania. My job is to advocate for equitable clean energy policies in the Commonwealth.

My testimony[1] has three parts:

- First, I will summarize the actions that Pennsylvania and the world need to take – including the deployment of carbon capture technology – to eliminate greenhouse gas (GHG) emissions on a net basis by 2050, which is necessary to avoid the worst effects of climate change;[2]
- Second, I will discuss in general terms the role that NRDC envisions for carbon capture in decarbonizing the United States' economy; and
- Third, I will discuss the need to eliminate carbon dioxide (CO_2) emissions from the manufacture of concrete and recommend policy steps that Pennsylvania legislators can take to drive the production of "low embodied carbon concrete" and, in turn, the use of carbon capture.

In addition to the present testimony, NRDC is also submitting testimony by my colleague Rachel Fakhry that discusses the potential role of hydrogen in decarbonizing Pennsylvania's economy and describes the three most commonly discussed pathways for the production of low or zero-carbon hydrogen: "green hydrogen" (the production of hydrogen from water using electrolysis powered by renewable energy), "pink hydrogen" (the production of hydrogen from water using nuclear-powered electrolysis) and "blue hydrogen" (the production of hydrogen using conventional steam methane reforming technology with carbon capture).

Decarbonizing the Economy

In 2018, the United Nations Intergovernmental Panel on Climate Change (IPCC) issued a special report titled *Global Warming of 1.5º C.*[3] It concluded that to avoid the worst impacts of climate change, we must keep the increase in average global temperatures below 1.5 degrees Celsius, and that to do that the world must reduce net GHG emissions 45 percent by 2030, and attain net zero emissions by 2050.

Since the IPCC report, a number of studies have analyzed different technological pathways for attaining these goals, which are often described as pathways to "deep decarbonization." The consensus emerging from those studies[4] is that to achieve deep decarbonization, we must:

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[1] This testimony was written by Chris Neidl (cneidl@gmail.com) and Sasha Stashwick (sstashwick@nrdc.org) from NRDC's Industrial Decarbonization team.
[2] For a comprehensive overview of the current and projected impacts of climate change in Pennsylvania, see the Department of Environmental Protection's most recent Climate Impacts Assessment, released in May, 2021, at https://www.dep.pa.gov/Citizens/climate/Pages/impacts.aspx
[3] Available at https://www.ipcc.ch/sr15/.
[4] *See* NRDC, "The Biden Administration Must Swiftly Commit to Cutting Carbon Pollution at Least 50 Percent by 2030," FN 6. Available at https://www.nrdc.org/sites/default/files/2030-biden-climate-pollution-ib.pdf.

- Generate our electricity from zero-carbon sources, especially renewables;
- Electrify our buildings and our vehicles;
- Improve the energy efficiency of our buildings and industrial processes;
- Reduce emissions of GHGs other than CO_2, including methane, nitrous oxides, and fluorinated gases; and
- Increase our capacity to remove CO_2 from the atmosphere through forest protection and reforestation, improved agricultural practices, carbon capture, and other practices.

Reducing our net emissions by 45 percent in the next eight years and achieving net zero emissions by 2050 is a massive undertaking. But the analyses also show that it is both possible and affordable, to a large extent with existing technologies[5] and established legal and policy pathways.[6]

Crucially, decarbonizing our economy is also a massive opportunity to invest in American workers and families and create a fairer, more sustainable, and less precarious economy than the one we have now. That is why many U.S states are developing ambitious plans to drive renewable energy, limit carbon pollution, and pursue other decarbonization pathways. Since 2008, for example, state and local commitments have led to a near-doubling of renewable energy generation in the U.S. and six states have made legal commitments to 100 percent carbon-free electricity by 2050 or earlier. Another 10 states have longer-term 100 percent goals.[7] Pennsylvania, though, has fallen behind.

The Role of Carbon Capture in Deep Decarbonization

The selective use of carbon capture, utilization, and storage (CCUS) should not be viewed as a leading decarbonization strategy on par with avoiding emissions in the first place via energy efficiency and renewable energy, but as a complement to those strategies. NRDC opposes reliance on CCUS in the power sector because there, more than anywhere, efficiency and renewables are readily available superior alternatives and the use of CCUS could lead to continued dependence on fossil fuels. Not only are the alternatives available, they are also far cheaper. In addition, NRDC opposes subsidies for CCUS applications that compete with clean, renewable energy or energy efficiency.

By contrast, NRDC sees an important role for CCUS as one of a suite of advanced technologies to decarbonize emissions-intensive industrial subsectors in which a significant share of emissions cannot be abated using energy efficiency, fuel switching and/or electrification and where

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[5] *See id.* at 3.
[6] *See* Michael B. Gerrard and John C. Dernbach, editors, *Legal Pathways to Deep Decarbonization* (March, 2019). Available at https://www.eli.org/eli-press-books/legal-pathways-deep-decarbonization-united-states.
[7] *See* NRDC (Sophia Ptacek with support from Amanda Levin), "Race to 100% Clean," at https://www.arcgis.com/apps/Cascade/index.html?appid=714cd31f37a64314b8d1e7e502c13c58

industrial materials have no readily available replacements. NRDC supports funding for carbon capture projects at industrial facilities like cement and steel plants that send captured CO_2 to secure saline geologic storage rather than for enhanced oil recovery. However, policy safeguards are needed to ensure that CCUS is effective in isolating captured CO_2 and leads to measurable, securely stored, and long-term emissions reductions.

Major investment in cleaning up heavy industry here in the United States is much-needed. The industrial sector is responsible for roughly one-third of U.S. emissions when accounting for direct and indirect (i.e., electricity-use) emissions. Under business as usual, the industrial sector is on track to become the largest source of U.S. GHG emissions within the decade. According to the Pennsylvania Department of Environmental Protection's most recent emissions inventory, the industrial sector is already the largest source of emissions in Pennsylvania. Thus, as in the power, transportation, and buildings sectors, decarbonizing U.S. industry is critical to achieving near-term climate targets. Modeling analysis by NRDC shows that to reduce economy-wide GHG emissions 50 percent by 2030, industrial emissions must fall by one-third below 2005 levels.[8]

Because heavy industry is heterogeneous, heavily dependent on fossil fuels, and has complex supply chains, decarbonizing it will not be simple. Yet, we cannot avoid decarbonizing the sector; industrial building materials like cement and steel are foundational to our way of life. Our communities will continue to depend on industrial products for our infrastructure for years to come, so we need to take steps to make our domestic industrial manufacturing base compatible with our climate targets.

To an extent, we can reduce emissions from manufacturing cement (and other emissions-intensive industrial products) by relying on energy efficiency, electrification and/or fuel switching. But, as is discussed in detail below with respect to cement, making industrial products like cement and steel often involves unavoidable processes that release CO_2. Thus, beyond 2030, as we begin to need much deeper decarbonization in these sectors to stay on track to meet net-zero midcentury emissions targets, carbon capture and storage offers an available and viable lever to abate the substantial remaining emissions that cannot be tackled via these other strategies. However, for these advanced technologies to be available at scale when we need them, investments must start now to bring down their costs and risks.

[8] Rachel Fakhry and Starla Yeh, NRDC Issue Brief, "The Biden Administration Must Swiftly Commit to Cutting Climate Pollution at Least 50 Percent by 2030, March 30 2021, https://www.nrdc.org/resources/biden-administration-must-swiftly-commit-cutting-climate-pollution-least-50-percent-2030

Decarbonizing Concrete

Concrete is the second most commonly used material on earth, after water; and by a large margin the world's most common building material.[9] Approximately 18 billion tons of it are produced annually around the globe.[10] According to the Pennsylvania Aggregates and Concrete Association, our yearly output here in the state is roughly 13.4 million tons[11], or 9.6 million cubic yards -- a volume that could fill 450 Heinz Fields to a depth of 10 feet (or up to the field goal crossbar).

These figures provide a measure not only of the staggering scale of concrete's use, locally and globally, but of its indispensability to contemporary construction, and architectural and engineering knowledge and practice. Its unique physical, performance, supply and cost characteristics make it, quite literally, a foundation of the modern built environment; and, critically, one with no viable substitute that can realistically replace it at scale in the foreseeable future.

Further, it is safe to assume that not only is concrete here to stay, but that its footprint will expand in the 21st Century. This growth will be driven by increased urbanization in emerging economies, as well as building stock and infrastructure renewal in wealthier nations like the United States.[12]

Concrete is not only a key ingredient in the buildings, roads, bridges and countless other forms of infrastructure that our way of life depends on; it is also the direct and indirect source of tens of thousands of jobs here in Pennsylvania, and millions around the globe. The material's physical properties require it to be produced close to where it is used. As a result, its supply overwhelmingly comes from local businesses, many of them small, privately-owned, and deeply anchored in the communities in which they are located. And the same holds for the many construction and contracting firms that pour, pave and install concrete throughout the state. According to the National Ready Mix Concrete Association, concrete-related economic activity contributes as much as $1.5 billion annually to Pennsylvania tax revenue.[13]

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[9] Shuchi Talati, Na'im Merchant, Neidl, Chris. 2020. "Paving the Way for Low Carbon Concrete: Recommendations for a Federal Procurement Strategy". Carbon180. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5fd95907de113c3cc0f144af/1608079634052/Paving+the+Way+for+Low-Carbon+Concrete

[10] Cao, Z., Masanet, E., Tiwari, A., and Akolawala, S. 2021. "Decarbonizing Concrete: Deep decarbonization pathways for the cement and concrete cycle in the United States, India, and China". Industrial Sustainability Analysis Laboratory, Northwestern University, Evanston, IL.

[11]The Pennsylvania Aggregates and Concrete Association. 2021. "Our Industry: About the Aggregates, Ready Mixed Concrete and Cement Industries in Pennsylvania". https://www.pacaweb.org/community/our-industry

[12] Cao, Z. et al. 2021

[13] The Portland Cement Association. 2016. "Pennsylvania Cement Industry: Building the Foundation of Pennsylvania's Economy," https://www.cement.org/docs/default-source/ga-pdfs/cement-industry-by-state-2015/pennsylvania.pdf?sfvrsn=2&sfvrsn=2

Concrete's importance, value and staying power are clear and uncontroversial. However, the material's present and future relationship to our changing climate presents a far more complex picture, and one that must be assessed by policymakers in terms of its own distinct features, constraints and opportunities. First and foremost, what must guide policymaker thinking about concrete and climate is that the material is here to stay – or, at minimum, it is sure to remain with us during the critical timeframe for action to address the climate emergency. This is also likely to hold, though perhaps to a lesser extent, for concrete's core binding ingredient, Portland cement. The latter, as I will discuss at greater length below, is overwhelmingly responsible for the emissions associated with concrete's production and use.

Concrete, Cement and the Climate

State and federal policy making related to concrete decarbonization is a relatively new domain, but one that is today making up for lost time. As more climate responsive legislatures and executives seek effective avenues to help realize economy-wide emissions reductions, attention to concrete and cement has inevitably been elevated in recent years.

These efforts have brought to the fore many of the unique complexities that are inherent to these industries and must be grappled with in efforts to reduce their emissions. Some important questions concerning concrete's net impact on the climate necessitates a nuanced perspective. Exploring this basic matter with the objective of reaching informed policy decisions requires us to make three important distinctions.

Concrete has both positive and negative climate attributes

First, we must distinguish between concrete's *operational carbon* and *embodied carbon*; or between the emissions that can be linked to concrete post-construction, over its full lifecycle, and those that are produced, up front, as a result of its production. On balance, once installed, concrete offers many advantages in terms of climate and environmental performance that should not be discounted. It's high thermal mass boosts building energy efficiency by limiting heating and cooling loads. It is durable and long-lasting; and at the end of its life, it can be recycled and locally reused as an input in new concrete, substituting sand and gravel as *aggregate*. Concrete's relatively high *albedo* means that it reflects more light than alternative materials used for road and sidewalk construction, such as asphalt, and therefore contributes less to the urban heat island effect.

Less widely appreciated but more pertinent to our discussion today, concrete also has the remarkable property of absorbing and storing CO_2 directly from the air over time through a gradual process known as *carbonation*. A recent peer-reviewed study published in the journal

Nature found that nearly half of CO_2 generated in the production of concrete may be reabsorbed back into the material over its lifetime.[14] Concrete's unique natural function as a *carbon sink* can now be enhanced and augmented with new technologies and methods, a development which will be explored later in this testimony.

<u>Concrete and cement are related but separate materials. Effective policy responses must internalize this fact.</u>

The greatest challenges linking concrete to the climate relate to the material's *embodied carbon*, or the emissions generated during the manufacturing process, prior to construction. This points to an important second distinction that must be made in our analysis, one that differentiates between *concrete* and *cement*, and more specifically, *Portland cement*, the most widely used form of the latter. Portland cement is the ingredient within concrete which, when activated by water, binds and gives it its unique properties of strength and versatility. In common usage, even in policy circles, much confusion is caused when the word "cement" is all too often mistakenly used interchangeably with "concrete."

Cement is an ingredient in concrete, not a synonym for it. But when we assess the challenges and opportunities of concrete within the context of climate action, we are almost entirely concerned with the status of cement. This is because Portland cement, while typically making up no more than 10 percent of concrete by mass in most applications, accounts for approximately 80 percent of emissions linked to concrete production.[15]

Under conventional conditions, the production of 1 ton of cement generates over 800 kG of CO_2, making it one of the most carbon-intensive materials on the planet.[16] At a global annual output of nearly 5 billion tons, CO_2 emissions generated by cement production account for up to 8 percent of total emissions, a volume rivaled only by iron and steel among industrial sector sources.[17] If cement were a country, it would be the world's fourth largest emitter of CO_2.

Cement is produced through the *pyroprocessing* of limestone in kilns at temperatures of 2700 degrees Fahrenheit. Attaining this heat level is achieved using carbon-rich, energy dense fossil

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[14] Xi, F., Davis, S., Ciais, P. *et al.* 2016. Substantial global carbon uptake by cement carbonation. *Nature Geosci* **9,** 880–883. https://doi.org/10.1038/ngeo2840
[15] Cao, Z. et al. 2021
[16] Cao, Z. et al. 2021
[17] Thomas Czigler, Reiter, S., Schulze, P. and Somers, K. (2020). "Laying the Foundation for Zero-Carbon Cement." McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

fuels, and most commonly coal.[18] However, over half of the CO_2 released in cement production is from so-called *process emissions* that result not from fuel incineration but from the chemical breakdown of limestone (CaCO3) at these ultra-high temperatures. Consequently, even if cement kilns are retrofitted in the future to accommodate low-carbon fuels, such as green hydrogen or electrification, the majority of CO_2 emissions produced in the process will remain unaffected.

Unlike in the power and transportation sectors, this reality all but ensures an essential role for point source carbon capture at cement plants if the sector is to be significantly decarbonized in the coming decades. Indeed, the International Energy Agency (IEA) and Sustainable Cement Initiative's 2019 Technology Road Map projects that nearly 50 percent of CO_2 emissions reductions in the cement sector by 2050 will need to be realized through carbon capture technologies.[19] And capturing carbon at scale also entails the development of infrastructure to transport it to sites where it can be permanently and safely sequestered.

The IEA report estimates that the investment required globally to scale up capture and storage capacity across the global cement industry would be on the order of $370 billion dollars.[20] For a trade exposed commodity industry in which competition is fierce and price sensitivity extreme, this requires carefully designed policies that combine incentives with common-sense emission reduction requirements.

Today there are only a handful of carbon capture and sequestration demonstration projects operating at cement facilities around the world. However, growing commitments by the sector's leading producers -- pressed by investors and public regulation and laws -- to attain net-zero emissions by mid-century are beginning to materialize in specific plans for commercial projects, and comprehensive strategies for investment. HeidelbergCement, the world's fourth largest cement manufacturer, announced last month its plan to commission the first carbon neutral cement plant in Sweden by 2030. The plant will capture 1.8 million tons of CO_2 per year which will be transported and sequestered offshore.[21] This project will follow from the company's present CCS project under development in Brevik, Norway, which will capture 50 percent of plant emissions starting in 2024. Within this same timeframe here in the United States, Lafarge Holcim, the largest cement manufacturer in the world, plans to commission CCS technology at its plant in Florence, Colorado. Carried out in partnership with the Canadian CCS technology

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[18]Andrew Logan. 2020. Explained: Cement vs. concrete — their differences, and opportunities for sustainability". MIT News. https://news.mit.edu/2020/explained-cement-vs-concrete-understanding-differences-and-sustainability-opportunities-0403

[19] The International Energy Agency and the Sustainable Cement Initiative. 2018. "Technology Roadmap: Low Carbon Transition in the Cement Industry." https://iea.blob.core.windows.net/assets/cbaa3da1-fd61-4c2a-8719-31538f59b54f/TechnologyRoadmapLowCarbonTransitionintheCementIndustry.pdf

[20] International Energy Agency, et al. 2018

[21] Christoph Beumelburg. 2021. "HeidelbergCement to build the world's first carbon-neutral cement plant". HeidelbergCement Group. https://www.heidelbergcement.com/en/pr-02-06-2021

provider Svante and with grant support from the U.S. Department of Energy, the project will capture upwards of 700 thousand tons of CO_2 annually.[22]

While the emergence of these and other projects provide some indication of movement, change is not happening fast or widely enough. Here in the United States at the federal and state level a more concerted effort to drive investment and transition to carbon capture at cement plants with secure saline storage for the captured CO_2 must materialize. Pennsylvania can play a leadership role in this effort, and we have an obligation to do so. According to the U.S. Geological Survey our state is the 7th largest cement manufacturing state in the country,[23] producing upwards of 4 million metric tons of cement per year at 9 different plants.[24] Our position creates an opportunity for us to act, in partnership with local industry, large cement consumers and counterparts in other states and at the federal level.

The emissions profile of concrete today could change dramatically in the future given different technological, policy and market conditions.

The imperative to advance CCS in the cement industry, globally and locally, points to a third and final important distinction that we must make in our planning and analysis. And that is between what concrete is and means for the climate today, versus what it could be and mean in the future, under different innovation, policy and market scenarios.

Concrete is an ancient material that has resisted transformation due to both internal and external influence and inertia. But today this is changing. A growing spectrum of alternative methods, materials and technologies can be employed at various stages of the supply chain to improve the climate performance of concrete. Some of these are highly innovative, cutting edge and just now emerging; while others are decidedly simple and low-tech, and already well established or underway.

Efficiency, waste reduction and reuse measures can be realized economically throughout the process, from cement manufacturing to final concrete installation. Improvements in cement plant efficiency have largely already been implemented across much of the United States in recent years, but additional incremental gains can still be realized. At the other end of the process,

[22] Cementnet.com. 2020. "LafargeHolcim awarded US$1.5m grant for Florence carbon capture project“. https://www.cemnet.com/News/story/169743/lafargeholcim-awarded-us-1-5m-grant-for-florence-carbon-capture-project.html
[23] The United States Geological Survey. 2021. ”Cement Data Sheet - Mineral Commodity Summaries 2020“. https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-cement.pdf
[24] The Portland Cement Association. 2015. “Pennsylvania Cement Industry: Building the Foundation of Pennsylvania's Economy“. https://www.cement.org/docs/default-source/ga-pdfs/cement-industry-by-state-2015/pennsylvania.pdf?sfvrsn=2&sfvrsn=2
24

methods of avoiding or repurposing unused, wasted and demolished concrete at the construction stage are becoming more common and sophisticated. The use of recycled concrete aggregate (RCA) in place of conventional aggregate is another emerging application that substitutes locally available demolished concrete that would otherwise be landfilled, for sand and gravel. This reduces emissions tied to material processing and transportation. More sophisticated waste reduction methods at an earlier stage of market deployment show promise. These include both forms of modular construction methods, and 3D-printing production methods that cut down on material waste through improved precision, accounting and process optimization.

Another decarbonization lever is fuel substitution in the process of making Portland cement. Hydrogen and even electrification may represent longer-term options.[25]

Many other decarbonization levers involve altering the proportion of conventional, high emissions ordinary Portland cement used in concrete mixes. Many established and emerging inputs, called *supplementary cementitious* materials, or SCMs, include silica fume, calcined clay, natural pozzolans, and ground glass pozzolan, which is made from post-consumer glass.

More recent developments with longer-term promise involve substituting ordinary Portland cement with alternative novel cements produced with materials that have lower carbon chemistries. Examples such as reactive belite cement clinker, calcium sulfoaluminate, celitement, and Magnesium oxides derived from magnesium silicates (MOMS) are in various stages of commercial development and have the potential to dramatically reduce both process and thermal emissions.[26]

Perhaps one of the most high-impact and viable measures that can be taken to reduce cement content and decarbonize concrete in the near-term involves standards embedded in construction practice and building codes, rather than specific technologies and methods, per se. Here I refer to the need for a general transition away from *prescriptive specification standards* and towards more *performance-based specification standards.*

Prescriptive specifications dictate the specific material inputs and proportions that are acceptable for different construction applications. By contrast, performance-based specifications are agnostic to materials and proportions, and instead dictate desired performance conditions, including strength and durability. The advantage of the latter approach is that it creates more openings for innovation and improvement, but without compromising quality and safety. The persistence of prescriptive standards in building codes represents a substantial and fundamental

[25] Julio Friedmann. 2020. "Concrete Change: Pathways to Decarbonize Cement and Concrete Production and Use". Presentation to the Natural Resources Defense Council. New York City. https://www.youtube.com/watch?v=jgHI6xUKjsc
[26] Cao, Z. et al. 2021.

barrier to many of the transitional and breakthrough approaches that I am describing in this testimony.

Over time, moving to a performance-based standard will catalyze market-based innovation and improvements throughout the concrete supply chain and material palette.[27] One recently published case study from California shows the promise that this shift holds within the context of a single project. By moving to a performance-based standard for concrete, the project empowered project managers and their vendors to identify workable, cost-effective local solutions that resulted in a 24 percent embodied carbon reduction at no additional cost.[28] It's not difficult to imagine how a general transition to performance-based specification standards on the municipal, state and federal level would catalyze change.

I have already introduced the special circumstances that make CCS an important tool within the context of cement decarbonization. This relates to the high degree of process emissions that cannot be mitigated through alternative energy pathways. The most efficient technology categories of carbon capture today are oxy-fuel firing and post-combustion capture.[29] The former promises high efficiency capture rates of up to 80-99 percent, but can entail substantial redesign of existing plant systems; whereas the most common form of post-combustion capture, chemical absorption using amines, require comparatively less investment in capital upgrades, and has been in use in some industries for many years. Calcium looping is a newer alternative post-combustion capture method that could deliver high thermal efficiency gains relative to more established practices. Recently, amine-based absorption and calcium-looping technologies have been piloted in the cement sector in both China[30] and Norway.[31]

Carbon capture represents a key long-term component of emissions management in the cement process, but to produce a climate benefit the captured CO_2 must be safely and permanently sequestered. Geological sequestration on a large scale -- along the lines of what is being pioneered in Northern Europe -- will be necessary. And opportunities exist for substantial carbon storage here in our state. Indeed, the Pennsylvania Department of Conservation and Natural

[27] Michael Thomas. 2020. "The Case for Performance Based Concrete Specifications," https://www.carboncure.com/concrete-corner/concrete-expert-dr-michael-thomas-makes-the-case-for-performance-based-specs/

[28] Donald Davies, Price, K., Berahman, F., 2021, "A New Benchmark for Reducing High-Rise Construction Costs and Carbon Footprints," Structure. https://www.structuremag.org/?p=17858

[29] Cao, Z. et al. 2021.

[30] Global CCS Institute. 2018. "World's largest capture pilot plant for cement commissioned in China". https://www.globalccsinstitute.com/news-media/insights/worlds-largest-capture-pilot- plant-for-cement-commissioned-in-china/

[31] Bjerge, L.-M.; Brevik, P. 2014. "CO2 Capture in the Cement Industry, Norcem CO2 Capture Project (Norway)," *Energy Procedia, 63,* 6455–6463. https://doi.org/10.1016/j.egypro.2014.11.680.

Resources has been studying carbon storage potential in our state for nearly 20 years[32] and is an active participant in multi-state collaborative efforts to study storage opportunities in the broader region.[33] Determining viable, economic and safe pathways for storage here will depend on further coordination between state regulators and their federal counterparts, and partnership with private sector actors and asset owners in cement and other hard-to-abate industrial sectors of prominence in Pennsylvania (most significantly steel manufacturing).

However, geological sequestration does not represent the only pathway for permanently storing CO_2. Concrete is by far projected to be the largest potential market within the emerging carbontech or carbon utilization building sector. An analysis by the leading think tank and advocacy organization Carbon180 estimates an $800 billion dollar market opportunity.[34] Today it is also the most mature, with multiple carbon utilization and mineralization technologies and methods already commercialized or approaching market entry. The most common category of carbon utilization involves different curing methods that deploy CO_2 from industrial sources as an input in concrete production. The CO_2 used in the process can displace Portland cement, as well as water and other resource, and represents a permanent form of chemical storage as, or more, reliable than geological sequestration. According to a 2020 McKinsey and Company market report, current low-carbon cement technologies can store up to 5 percent of CO_2, with an upward potential of 30 percent.[35]

Another promising form of carbon utilization in concrete involves making or enhancing other common high-volume inputs, such as aggregate and SCMs, with CO_2. Aggregate, which makes up roughly 80 percent of most concrete mixes by mass, could one day amount to a substantial carbon sink if cost effective methods can be scaled. Two companies, U.S-based Blue Planet and England-based Carbon8, have already developed commercial products that produce carbon mineralized aggregate.

Companies such as CarbonCure, Solidia, CarbonBuilt and Blue Planet represent early market leaders in the concrete carbon utilization space. But they are joined by a growing number of other investor-backed firms, helping establish a new and still emerging, but diverse industrial category.

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[32] The Pennsylvania Department of Conservation and Natural Resources. (accessed) 2021. "Carbon Capture Utilization and Storage."
https://www.dcnr.pa.gov/Conservation/ClimateChange/CarbonCaptureStorage/Pages/default.aspx
[33] The Midwest Regional Carbon Initiative. https://www.midwestccus.org/
[34] Rory Jacobson and Lucas, M. 2018. "A Review of Global and U.S. Total Available Markets for Carbontech." Carbon180.
https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5c0028d270a6ad15d0efb520/1543514323313/ccr04.executivesummary.FNL.pdf
[35] Thomas Czigler, Reiter, S., Schulze, P. and Somers, K. (2020). "Laying the Foundation for Zero-Carbon Cement." McKinsey & Company. https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

How far, practically, can the combined impacts of decarbonization approaches, carbon capture and carbon utilization take us towards a fully climate benign concrete in the future? Leading subject expert and founding director of MIT's Concrete Sustainability Hub, Professor Jeremy Gregory is not alone in asserting that a carbon negative -- not just neutral -- concrete that stores more CO_2 than is released in its production is not just pie in the sky, but an actual future scenario worth aspiring towards.[36] "We are not there yet," according to Gregory, "but in the right circumstances the production of concrete could actually store more CO_2 than it releases into the atmosphere."

Potential Policy Interventions to accelerate decarbonization of concrete in Pennsylvania.

Given the scale and ubiquity of concrete use, the prospect of evolving the material into a net carbon sink for the planet would have enormous climate benefits. Targeted public policies implemented at the federal and state level can play a significant role in removing barriers and accelerating concrete's transformation into a low or even carbon negative material. The following measures represent areas of strategic focus that can be explored and acted upon in the near-term in Pennsylvania.

Leverage public procurement dollars to create demand for lower carbon concrete.

As much as 39 percent of all concrete in North America is purchased by public agencies.[37] This means that the purchasing power and decisions of federal and state governments have the unique potential to catalyze demand for various forms of low carbon concrete. Neighboring New Jersey and New York have either introduced or passed legislation in the last year that, as law, would require state agencies to factor embodied carbon into selection criteria.[38]

The California Legislature is considering legislation to amend its existing environmental procurement program, Buy Clean, to include concrete and cement as regulated materials. The City of Portland Oregon was the first in the nation to implement a low carbon concrete procurement program which will require vendors bidding on city contracts to ultimately meet certain carbon-intensity thresholds to participate in RFP solicitations. Pennsylvania can learn from and adapt these and other approaches to develop a low carbon concrete program that aligns with its state goals and targets.

[36] Jeremy Gregory. 2020. "Concrete". MIT Climate Portal. https://climate.mit.edu/explainers/concrete
[37] Hasanbeigi, A., and Khutal, H. 2021. "Scale of government procurement of carbon intensive materials in the U.S. Tampa Bay, FL." Global Efficiency Intelligence, LLC. Accessed March 25 2021. https://www.globalefficiencyintel.com/scale-of-government-procurement-of-carbonintensive-materials-in-us

[38] Sasha Stashwick. 2021. "In NY, a Chance to Create a Model Policy to Green Concrete," The Natural Resources Defense Council, https://www.nrdc.org/experts/sasha-stashwick/ny-chance-create-model-policy-green-concrete

Shift to a Performance-Based Specification Standard for Concrete.

As detailed earlier, innovation and market acceptance of new low carbon materials and approaches is halted by overly prescriptive specifications in local and state building codes. To fully unleash the creative power of markets and private sector initiative, Pennsylvania should convene a stakeholder process to develop and implement performance-based specification standards for concrete. The state can learn from best practices employed in a host of private sector projects from around the country, as well as initiatives taken by the public sector. For example, Marin County, California Low Carbon Concrete Building Code, implemented in 2020, incorporates a performance-based specification standard pathway that can offer valuable design guidance for efforts in other jurisdictions, including PA.[39]

Thank you again for the opportunity to testify today. I look forward to answering any questions you may have and discussing these important issues.

[39] County of Marin Low Carbon Concrete Project. https://www.marincounty.org/depts/cd/divisions/sustainability/low-carbon-concrete-project

TESTIMONY OF THE NATURAL RESOURCES DEFENSE COUNCIL

Rachel Fakhry, Senior Policy Analyst

Concerning the Merits and Limitations of Hydrogen Technology as a Decarbonization Tool

Before the Pennsylvania House Democratic Policy Committee

July 2021

Chairman Bizzarro, Representative Hohenstein, honorable members of the Committee: thank you for inviting me to comment on the merits and risks of hydrogen as Pennsylvania begins exploring it as part of the state's future energy mix. My name is Rachel Fakhry and I am a Senior Analyst for the Natural Resources Defense Council (NRDC), a member-based non-profit environmental organization with more than 90,000 members and activists in Pennsylvania. NRDC works in the U.S. and internationally to protect the air, water, and land that support human health and long-term economic growth. My work is focused on designing policy mechanisms that reduce emissions of greenhouse gases and other air pollutants across the U.S. I also lead NRDC's hydrogen work and engage with international and domestic stakeholders on designing the policy and regulatory frameworks that would both leverage the technology's potential to support the deep decarbonization of the economy and avoid the pitfalls that may ensue from its indiscriminate deployment. I have had the opportunity to be featured in a number of high-profile media outlets in relation to hydrogen (a list of media appearances is included in Exhibit A below).

The following testimony:

- Highlights the potential for hydrogen to support deep decarbonization goals by substituting for fossil fuels in the most challenging sectors of the economy, including aviation, maritime shipping, steelmaking and long-distance freight trucking.
- Provides some brief background on the current state of the hydrogen industry in Pennsylvania and the U.S.
- Discusses the two hydrogen production pathways currently receiving much of the policy and investor interest – zero-carbon hydrogen and blue hydrogen – and argues that zero-carbon hydrogen offers a more compelling case and a safer bet for Pennsylvania based on current evidence.
- Discusses the various end-use applications for hydrogen and argues that while it has great potential to decarbonize challenging sectors where electrification faces technical hurdles, it is inefficient relative to electrification in a wide range of applications –notably as a source of building heat.
- Calls into question claims that hydrogen would be a "no-disruption" solution relative to electrification owing to the potential to repurpose the existing gas network.
- Highlights the necessity of exercising caution in relation to hydrogen blending initiatives, the near-term repurposing of methane gas pipelines and the buildout of new dedicated hydrogen networks to avoid the stranding of methane gas and hydrogen assets and locking Pennsylvanians into expensive decarbonization routes.

- Puts forth what I consider to be a sensible policy framework for Pennsylvania policymakers to consider in relation to hydrogen that would both leverage the technology's unique potential and internalize the necessary guardrails to avoid saddling Pennsylvanians with unnecessary costs and undermine climate progress.

I. HIGH-LEVEL SUMMARY

Hydrogen has unique potential to support decarbonization goals, but it also has important drawbacks to which policymakers must be acutely sensitive.

Hydrogen can support the deep decarbonization of the economy by acting as a valuable complement to proven and established climate solutions like energy efficiency, clean electricity and electrification. It offers unique potential to substitute for fossil fuels in challenging sectors where electrification faces technical hurdles, including aviation, maritime shipping, steelmaking and long-distance freight trucking. It could also support a very high renewable grid by serving as a seasonal form of electric storage. In Pennsylvania, hydrogen can bolster the reliability of a highly clean electric grid and support the state's efforts to enact a strong clean energy standard and can unlock a competitive future for the state's steelmaking industry in a clean economy.

However, because the market for hydrogen is nascent, hydrogen's deployment as a decarbonization tool is fraught with uncertainties and requires that decisionmakers first understand hydrogen's strengths and limitations. Hydrogen's potential is accompanied by potential pitfalls associated with its production, transport and use, which I discuss below and to which policymakers and stakeholders must be acutely sensitive. One of the main risks associated with an overeager switch to hydrogen includes steering limited public and private investments away from deploying reliable, cost-effective and readily available decarbonization solutions like direct electrification. This could lock Pennsylvanians into unnecessarily expensive decarbonization pathways or lead to the stranding of hydrogen assets should challenges to hydrogen-heavy pathways prove too great, undermining necessary climate progress in this decade and beyond.

I recommend that Pennsylvania policymakers endeavor to design a strategic, targeted and evidence-based policy framework that leverages hydrogen's unique potential while avoiding unintended economic, public health and climate consequences. Specifically, I urge decisionmakers to adopt a policy framework for hydrogen within a broader ambitious clean energy agenda by:

1. Identifying hydrogen's strengths and limitations by way of an independent, system-wide assessment.
2. Endeavoring to ensure that a hydrogen agenda does not derail necessary action on proven, readily available solutions that must be taken today.
3. Orienting subsidies and support for hydrogen deployment towards applications where it adds the most value, commensurate with the system-wide assessment.
4. Orienting investments, policy incentives and subsidies towards zero-carbon hydrogen.
5. Exercising caution in relation to proposals for hydrogen blending, the repurposing of existing gas pipelines and the buildout of new hydrogen pipelines

II. HYDROGEN: BACKGROUND

The current hydrogen hype is largely driven by proliferating national deep decarbonization goals.

One of the main reasons that hydrogen is receiving an elevated level of hype, both globally and in the U.S., is the proliferating national commitments to deep decarbonization, commensurate with the demands of the climate crisis. To date, 59 countries have established economy-wide net-zero greenhouse gas (GHG) emissions targets by sometime around 2050. Those commitments have driven countries to grapple with the necessity of finding clean energy solutions to substitute for fossil fuels in the most challenging sectors of the economy, including aviation, maritime shipping, steelmaking and long-distance freight trucking[1]. Those applications require either a chemical feedstock to drive a chemical reaction – as in steelmaking – or dense forms of energy to propel heavy equipment like vessels, aircrafts, and large trucks across long distances. Electrification – the solution to decarbonize much of the economy – faces technical hurdles in those applications because it may either require an entirely new process to forgo chemical reactions which it cannot serve – as in steelmaking- or may require very large batteries to propel heavy equipment across long distances, creating weight and payload issues for freight trucks, aircrafts and

[1] Michael Liebreich, *Separating Hype from Hydrogen – Part Two: The Demand Side*, Bloomberg New Energy Finance, October 2020, https://about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-two-the-demand-side/ ; Simon Evans, John Gabbatiss, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change,* CarbonBrief, November 2020, https://www.carbonbrief.org/in-depth-qa-does-the-world-need-hydrogen-to-solve-climate-change

shipping vessels. In contrast, hydrogen offers many of the attributes that those challenging applications demand: it has high energy density – nearly three times that of diesel or gasoline – and can act as a chemical feedstock in heavy industry applications. Hydrogen has thus emerged as a compelling potential tool for decarbonization, as a complement to established climate solutions like electrification, efficiency and renewable energy.

Hydrogen is a well-established energy resource mainly used in the U.S. and global industrial sector.

Although interest in employing hydrogen as a decarbonization tool is nascent, the hydrogen industry is not. Hydrogen is a molecule that has been used in the U.S. industrial sector for several decades. Today, its two main applications are in the oil refining process, where it is used to strip sulfur impurities from crude oil, and as the primary feedstock in the production of ammonia, the main ingredient of agricultural fertilizer. The U.S. hydrogen industry is an $18 billion dollar industry. [2] Pennsylvania houses a few small-scale hydrogen facilities concentrated in the western part of the state, but it is unclear in which manner the hydrogen is consumed, although it can be reasonably assumed that a measurable portion of it serves the state's handful of refineries and fertilizer plants.[3]

III. HYDROGEN PRODUCTION

The current hydrogen production process is highly polluting.

Hydrogen gas is not found in stand-alone form on earth and must be produced from another element that contains it. More than 95% of all hydrogen used in the U.S. is produced from methane gas in a process called steam methane reformation (SMR)[4]. In this process, methane gas is both used as the source of hydrogen, i.e., "feedstock," and combusted at high temperatures to provide the energy that drives the process. SMR is a major source of climate pollution in the U.S., emitting more than 90 million metric tons of carbon dioxide per year – more than the total carbon footprint of Pennsylvania's power sector – as well as large amounts of health-damaging air pollutants such as nitrogen oxides, volatile organic

[2] Hydrogen Council, *Roadmap to a US Hydrogen Economy*, 2020, https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf%22%20/
[3] U.S. Department of Energy, *Fact of the Month May 2018: 10 Million Metric Tons of Hydrogen Produced Annually in the United States*, May 2018, https://www.energy.gov/eere/fuelcells/fact-month-may-2018-10-million-metric-tons-hydrogen-produced-annually-united-states
[4] U.S. Department of Energy, *Hydrogen Production: Natural Gas Reforming*, https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

compounds and particulate matter.[5] Hydrogen produced through SMR is generally referred to as "grey" hydrogen.

Hydrogen production can be cleaned up to produce low and zero-carbon hydrogen.

The use of hydrogen as a tool for deep decarbonization is premised on the decarbonization of its production process. To date, various alternatives to conventional SMR have been proposed, but the two currently receiving the most interest and attention are electrolysis, particularly if powered by renewable electricity, and SMR coupled with carbon capture. In the electrolysis process, water is used as the hydrogen feedstock, rather than methane gas. Electricity is used to split water into its constituents, hydrogen and oxygen, and to the extent that the electricity is generated by a renewable resource such as wind, solar or hydro, the hydrogen is zero-carbon and air pollution-free. Hydrogen produced in this manner is often referred to as "green hydrogen." If the electricity is instead sourced from a nuclear plant, the hydrogen produced through electrolysis is sometimes referred to as "pink" hydrogen. For ease of reference, I will henceforth use the umbrella term "zero-carbon hydrogen" to refer collectively to both green and pink hydrogen.

Alternatively, the SMR process can be equipped with carbon capture to produce "blue hydrogen." In this case, the hydrogen produced is low-carbon, but for two reasons it is not zero-carbon. First, the efficiency of carbon capture has not been demonstrated beyond 90 to 95%, so the SMR process will likely result in a certain amount of residual emissions. Second, there will be methane emissions from leakage during the production of methane gas and its transport to the SMR facility.[6] This is particularly pertinent to Pennsylvania considering the state's grappling with elevated methane leakage rates at gas wells[7].

Today, zero-carbon and blue hydrogen are more costly than grey hydrogen. Green hydrogen currently costs up to 5 times more and blue hydrogen costs about 2 times more than grey hydrogen. However, significant cost reductions are projected by 2030 and beyond, notably in green hydrogen production (Figure 1). This is owing to anticipated large equipment cost reductions linked to projected increased deployment and ensuing economies of scale together with continued reductions in the costs of renewable

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[5] Pingping Sun, Ben Young, Amgad Elgowainy, Zifeng Lu, Michael Wang, Ben Morelli, and Troy Hawkins, *Criteria Air Pollutants and Greenhouse Gas Emissions from Hydrogen Production in U.S. Steam Methane Reforming Facilities*, ACS Publications, April 2018, https://pubs.acs.org/doi/10.1021/acs.est.8b06197

[6] Dennis Y.C. Leunga, Giorgio Caramannab M. Mercedes, Maroto-Valerb, An overview of current status of carbon dioxide capture and storage technologies, November 2014, Science Direct, https://www.sciencedirect.com/science/article/pii/S1364032114005450

[7] Environmental Defense Fund, *EDF Analysis Finds Pennsylvania Oil and Gas Methane Emissions are Double Previous Estimate*, May 2020, https://www.edf.org/media/edf-analysis-finds-pennsylvania-oil-and-gas-methane-emissions-are-double-previous-estimate

electricity[8]. Bloomberg New Energy Finance (BNEF) estimates that, preconditioned on strong policy support, green hydrogen could nearly compete with grey hydrogen and outcompete blue hydrogen in the U.S. by 2030. Recently announced federal and regional initiatives targeting ambitious green hydrogen cost reductions by 2030 - including the Department of Energy's Hydrogen Shot initiative and the HyDeal L.A. initiative in the West – increase the plausibility of the BNEF projections materializing[9]. By 2050, BNEF projects, green hydrogen will have a decisive cost advantage over both grey and blue hydrogen.

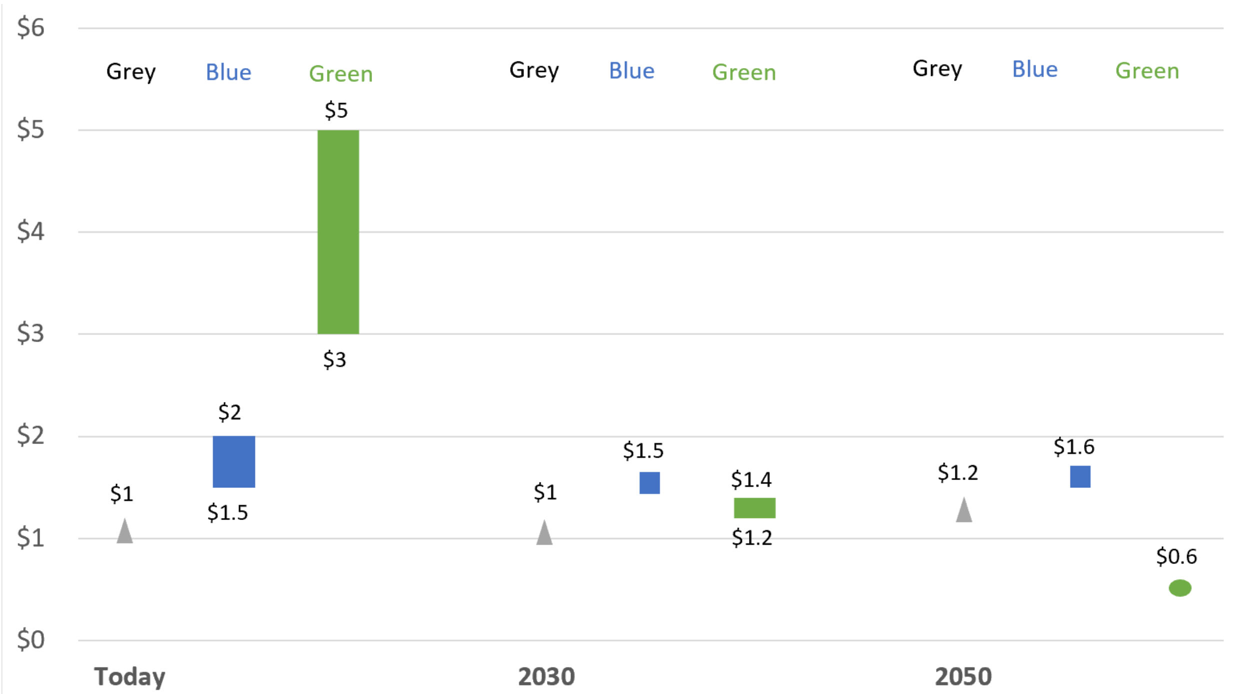

Figure 1: U.S. Hydrogen Production Costs ($/kg). Data sourced from BNEF, U.S. DOE and Resources for the Future[10].

[8] HIS Markit, *IHS Markit: Production of Carbon-Free "Green" Hydrogen Could Be Cost Competitive by 2030*, July 2020, https://news.ihsmarkit.com/prviewer/release_only/slug/bizwire-2020-7-15-ihs-markit-production-of-carbon-free-green-hydrogen-could-be-cost-competitive-by-2030

[9] US Department of Energy, *Secretary Granholm Launches Hydrogen Energy Earthshot to Accelerate Breakthroughs Toward a Net-Zero Economy*, June 2021, https://www.energy.gov/articles/secretary-granholm-launches-hydrogen-energy-earthshot-accelerate-breakthroughs-toward-net ; BusinessWire, *LADWP Joins HyDeal LA, Targets Green Hydrogen at $1.50/kilogram by 2030*, May 2021, https://www.businesswire.com/news/home/20210517005210/en/LADWP-Joins-HyDeal-LA-Targets-Green-Hydrogen-at-1.50kilogram-by-2030

[10] BloombergNEF, *'Green' Hydrogen to Outcompete 'Blue' Everywhere by 203*0, May 2021, https://about.bnef.com/blog/green-hydrogen-to-outcompete-blue-everywhere-by-2030/ ; US Department of Energy, *Secretary Granholm Launches Hydrogen Energy Earthshot to Accelerate Breakthroughs Toward a Net-Zero Economy*; Jay Bartlett and Alan Krupnick, *Decarbonized Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions* , December 2020, Resources for the Future , https://www.rff.org/publications/reports/decarbonizing-hydrogen-us-power-and-industrial-sectors/

Zero-carbon hydrogen offers a more compelling case and a safer bet relative to "blue" hydrogen in the U.S. and Pennsylvania.

Zero-carbon hydrogen offers a more compelling case and a safer bet relative to blue hydrogen for the U.S. and Pennsylvania alike. Blue hydrogen faces a number of challenges to which Pennsylvania policymakers should be sensitive.

First, and as I discuss above, blue hydrogen is projected to face challenging medium and long-term economics relative to green hydrogen. A number of best available projections converge with BNEF and estimate that owing to its anticipated rapid scale up in this decade, green hydrogen could compete with, and even outcompete, blue hydrogen in the U.S. on a cost basis by 2030, with a widening cost differential in favor of green hydrogen thereafter[11]. This is owing to both projected dramatic cost reductions in the capital costs of electrolyzers – the equipment where the water splitting process occurs – and expected continued reductions in the cost of wind and solar energy. In contrast, the SMR process is fairly mature with markedly slimmer opportunities for cost reductions. The following quote by BNEF's lead hydrogen analyst, Martin Tengler, summarizes the cost dynamics well: "*By 2030, it will make little economic sense to build blue hydrogen production facilities in most countries, unless space constraints are an issue for renewables. Companies currently banking on producing hydrogen from fossil fuels with CCS will have at most ten years before they feel the pinch. Eventually those assets will be undercut, like what is happening with coal in the power sector today.*"[12] Therefore, it is a better bet for Pennsylvania to focus on a zero-carbon hydrogen trajectory that is poised to offer continuous cost reductions.

Second, the emissions from methane leakage and residual carbon emissions at the SMR site reduce the compatibility of blue hydrogen with a pathway to net-zero GHG emissions and thereby raise its risk profile due to the potential for asset stranding. This shortcoming is manifested in reputable and independent studies showing little blue hydrogen deployment in net-zero pathways relative to other clean hydrogen sources.[13] Furthermore, the air pollution impacts of blue hydrogen remain not fully understood, a potential drawback that may raise equity challenges for communities living in the vicinity of projects.

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[11] IRENA, *Green Hydrogen Cost Reduction*, December 2020, https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[12] Institute for Energy Economics and Financial Analysis, Green hydrogen to be cost-competitive by 2030—BloombergNEF, April 2021, https://ieefa.org/green-hydrogen-to-be-cost-competitive-by-2030-bloombergnef/

[13] James H. Williams, Ryan A. Jones, Ben Haley, Gabe Kwok, Jeremy Hargreaves, Jamil Farbes, Margaret S. Torn , Carbon-Neutral Pathways for the United States, January 2021, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020AV000284 ; Princeton University, *Net-Zero America Project*, December 2020, https://acee.princeton.edu/rapidswitch/projects/net-zero-america-project/; Sustainable Development Solutions Network, *America's Zero Carbon Action Plan*, November 2020, https://www.unsdsn.org/Zero-Carbon-Action-Plan

Third, pursuing a blue hydrogen-heavy pathway forgoes a set of compelling benefits associated with zero-carbon hydrogen. As I discuss in section IV below, green hydrogen production can bolster the economics and reliability of a highly renewable grid. Similarly, the production of pink hydrogen could bolster the profitability of Pennsylvania's nuclear fleet, maximizing its value in the state's energy future and protecting the economic activity linked to it.[14] Accordingly, pursuing zero-carbon hydrogen is consistent with the state's exploration of an ambitious clean electricity standard.

It would therefore be prudent for Pennsylvania policymakers to hedge against the series of risks and uncertainties associated with blue hydrogen by orienting investment agendas to zero-carbon hydrogen, harnessing the full potential of the state's abundant renewables potential and nuclear resource. In parallel, policymakers could commission independent assessments evaluating specific contexts where blue hydrogen may offer additional value relative to zero-carbon hydrogen; those may include opportunities to retrofit existing hydrogen production facilities with carbon capture. Should a predominant focus on zero-carbon hydrogen prove challenging, the deployment of blue hydrogen is always an option. However, based on current evidence, a focus on a zero-carbon hydrogen pathway would be a safer and better bet for Pennsylvanians.

The challenges facing blue hydrogen also have bearing on the prudence of pursuing a twin track approach whereby Pennsylvania seeks to deploy blue hydrogen in the near-term as a transition to a zero-carbon hydrogen future. There is growing skepticism among experts around this qualification of blue hydrogen as a "bridge" technology largely due to multiplying projections that green hydrogen could compete with it by 2030 on a cost basis.[15] Blue hydrogen also requires investments in long-lived infrastructure and assets such as carbon pipelines and carbon storage basins which may impede a cost-effective switch to a zero-carbon hydrogen track. Therefore, pursuing a twin track approach carries a risk of lock-in to a blue hydrogen pathway that may be costlier than a zero-carbon one. Expert groups in the U.K. are now urging their government to abandon intentions to pursue such a twin track approach on account of those risks[16].

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[14] US Department of Energy, *Could Hydrogen Help Save Nuclear?*, June 2020, https://www.energy.gov/ne/articles/could-hydrogen-help-save-nuclear; Sonal Patel, Hydrogen May Be a Lifeline for Nuclear—But It Won't Be Easy, PowerMag, June 2020, https://www.powermag.com/hydrogen-may-be-a-lifeline-for-nuclear-but-it-wont-be-easy/;

[15] David Iaconangelo, *Hydrogen with CCS faces same fate as coal — report*, E&E News, April 2021, https://www.eenews.net/energywire/2021/04/08/stories/1063729469

[16] Juliet Philipps, Lisa Fisher, *Between hope and hype: a hydrogen vision for the UK*, E3G, March 2021, https://www.e3g.org/publications/between-hope-and-hype-a-hydrogen-vision-for-the-uk/

IV. HYDROGEN END-USE APPLICATIONS

Hydrogen is uniquely suited to decarbonize the challenging sectors of the economy where electrification faces hurdles.

The production and use of hydrogen typically involve a series of energy conversions that incur high efficiency losses. For instance, more than 20% of electricity is lost in the production of green hydrogen, and hydrogen equipment and appliances such as fuel cell cars and boilers are generally much less efficient than electric alternatives. These losses make hydrogen a relatively costly option for many applications that can be feasibly served by more efficient solutions like direct electrification. It stands to reason that using renewable electricity directly to power building appliances and cars would be a more efficient solution relative to using it to first produce hydrogen which would then serve the various applications. The most compelling technical and economic case for hydrogen is therefore in applications where it is uniquely suited to the task – i.e. where direct electrification is either not technologically feasible or is very costly.[17] Those include aviation, maritime shipping, steelmaking, chemicals productions and long-distance freight trucking.

Zero-carbon hydrogen could also bolster the reliability and cost-effectiveness of a highly clean grid. On the one hand, green hydrogen is a promising form of seasonal electricity storage.[18] It can be produced when there is excess renewable energy, especially in the fall and spring, stored for several months and then burned in turbines or run through fuel cells to generate electricity when wind and solar output is low. By helping the electricity grid ride through the seasonal differences in renewables performance, green hydrogen could meaningfully bolster the reliability and resiliency of a very high renewable grid. On the other hand, by making use of excess renewable or nuclear electricity that would otherwise be curtailed, zero-carbon hydrogen could bolster the cost-effectiveness of a highly clean grid and lower costs for Pennsylvania customers given that power projects would need to recoup less of their investment from electricity customers.

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[17] Michael Liebreich, *Separating Hype from Hydrogen – Part Two*; Evans et. al, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change*, CarbonBrief

[18] National Renewable Energy Laboratory, *Answer to Energy Storage Problem Could Be Hydrogen*, June 2020, https://www.nrel.gov/news/program/2020/answer-to-energy-storage-problem-could-be-hydrogen.html#:~:text=An%20analysis%20from%20NREL%20researchers,energy%20storage%20in%20the%20future.&text=They%20developed%20a%20multi%2Dmodel,technologies%20in%20determining%20cost%2Dcompetitiveness.

The visual below provides a helpful summary of hydrogen's potential across the energy sector and ranks applications based on feasibility and economics relative to other available solutions like direct electrification (Figure 2).

Michael Liebreich's "hydrogen ladder" chart identifying the merits of use cases for clean hydrogen. Photo: Liebreich Associates

Figure 2: Hydrogen- The Ladder[19]

In Pennsylvania, a hydrogen roadmap, which I discuss in Section VI below, would be critical in identifying applications where hydrogen would add value relative to other climate solutions. Based on the set of consensus high-value applications for hydrogen (Figure 2 above), there exists a subset of potentially compelling use cases in Pennsylvania that merit investigation. Notably, hydrogen could support a competitive future for certain industries, such as steel and freight, and bolster the decarbonization of the power sector:

- **Steelmaking:** Hydrogen could constitute an effective decarbonization solution for Pennsylvania's cohort of steel plants by substituting for fossil fuels as the feedstock driving the chemical reaction. Considering Pennsylvania's robust steelmaking legacy, hydrogen could help make this sector and

[19] Leigh Collins, *Liebreich: 'Oil sector is lobbying for inefficient hydrogen cars because it wants to delay electrification',* Recharge News, June 2021, https://www.rechargenews.com/energy-transition/liebreich-oil-sector-is-lobbying-for-inefficient-hydrogen-cars-because-it-wants-to-delay-electrification-/2-1-1033226

the jobs and economic activity associated with it a long-term, sustainable and climate-compatible economic engine for the state.

- **Heavy-duty freight trucks:** Pennsylvania's central standing along the I-80 corridor creates an opportunity for the state to be a pioneer in driving the decarbonization of the U.S. fleet of heavy-duty freight trucks. It could do so by launching near-term demonstration programs for heavy-duty fuel cell trucks and investigating the potential to deploy job-creating hydrogen refueling stations along the portion of corridor located in the state.
- **Support for a clean electricity grid:** Hydrogen could bolster the reliability and cost-effectiveness of a highly clean grid by making use of excess renewable and nuclear generation that would otherwise be wasted and acting as a seasonal storage option to help the grid ride through long periods of low wind and solar output. Hydrogen thereby merits consideration in discussions concerning the development of an ambitious Clean Energy Standard in Pennsylvania.

The inefficiencies of hydrogen use to heat buildings, and why prioritizing direct electrification instead is a sensible strategy.

Hydrogen gas can technically substitute for methane gas in supplying heat to buildings. However, a growing base of evidence demonstrates that hydrogen as a large-scale solution for building heating is likely an inefficient and costly solution relative to readily available and proven solutions like direct electrification. A range of studies estimate that heating a home with green hydrogen would require 5 to 6 times more renewable electricity than heating that same home with a highly efficient heat pump.[20] This wide differential is driven by inefficiencies on both the hydrogen production side and the end-use side (Figure 3). Sourcing renewable electricity to produce hydrogen is inefficient compared to directly using this renewable electricity, with more than 20% of the electricity lost in the production process. On the end-use side, readily available high-efficiency heat pumps can be up to 4 to 5 times more efficient relative to the still pre-commercial hydrogen boilers. The large efficiency differential has important implications on the costs of a hydrogen-heavy pathway and the required infrastructure buildout. Prioritizing direct electrification as a readily available and proven to be cost-effective solution to decarbonize buildings heat

[20] Jan Rosenow, Heating homes with hydrogen: Are we being sold a pup?, RAP, September 2020, https://www.raponline.org/blog/heating-homes-with-hydrogen-are-we-being-sold-a-pup/ ; Fraunhofer IEE, *Green hydrogen or green electricity for building heating?*, July 2020, https://www.iee.fraunhofer.de/en/presse-infothek/press-media/overview/2020/Hydrogen-and-Heat-in-Buildings.html#:~:text=The%20study's%20findings%20are%20clear,equivalent%20number%20of%20heat%20pumps.

would be a sensible strategy to avoid imposing unnecessary high costs on Pennsylvanians, with hydrogen explored in niche contexts.

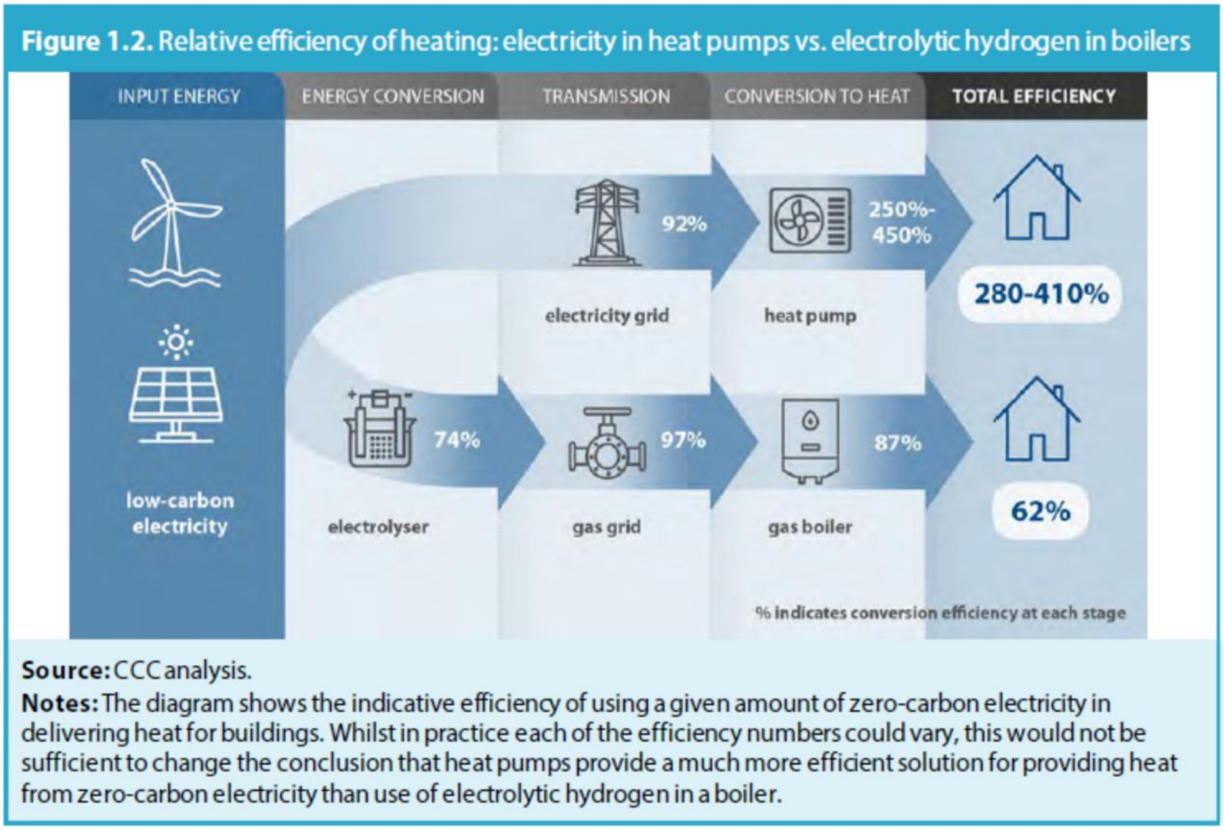

Figure 3: Relative Efficiency of Heating Electricity in Heat Pumps vs. Electrolytic Hydrogen in Boilers- Pulled from the study conducted by the U.K. Climate Change Committee[21]

The issue with the "no-disruption" slogan propagated by some in the gas industry.

Some interests have argued that using hydrogen to heat buildings is a "no-disruption" solution relative to electrification via heat pumps, owing to the potential to utilize the existing gas network to transport the hydrogen. However, this is a misleading claim. Hydrogen is a fundamentally different gas relative to methane gas, and when it is blended with methane gas at high levels, its chemical properties cause embrittlement to steel gas pipelines. Consequently, while blending hydrogen with methane in low proportions (e.g. 5 to 15% by volume) could be achieved with minimal investments into the existing gas system, any quantity of hydrogen exceeding this threshold is likely to require either major network

[21] UK Climate Change Committee, *Hydrogen in a low-carbon economy*, November 2018, https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/ . The CCC is an independent, non-departmental public body, formed to advise the UK and devolved Governments and Parliaments on tackling and preparing for climate change.

upgrades and repurposing measures or the buildout of an entirely new dedicated hydrogen pipeline network.[22] Existing gas boilers and cookstoves would also have to be replaced with hydrogen-compatible alternatives, which remain pre-commercial and require additional demonstration. As of today, there is no blueprint for such investments, and the costs and technical implications remain decidedly uncertain. For all these reasons, and because of the inefficiencies of hydrogen use in buildings relative to electrification, the premise that hydrogen would be a cost-effective solution for buildings due to the capacity to repurpose an existing gas network in some fashion is tenuous, at best. In fact, the U.K.- based Climate Change Committee recently found that the sunk costs of having an extensive gas grid do *not* give the hydrogen pathway a decisive advantage over electrification[23]. Of course, utilizing existing assets in lieu of wholesale decommissioning is an attractive proposition, and there may be specific cases where repurposing portions of the existing gas network would be expedient to climate and economic goals. However, it would be prudent to exercise caution in relation to both near-term proposals for hydrogen repurposing efforts and proposals for continued investments in the gas grid that contemplate future repurposing.

Why claims around the benefits of widespread hydrogen use in buildings in lieu of electrification may be harmful to Pennsylvanians and undermine climate progress.

There is a risk that the promise of hydrogen either dulls necessary near-term investments in proven and readily available solutions or encourages a set of misguided near-term actions. "Tech-crastination" is a coinage to refer to this risk whereby the promise of a future technology derails investments in proven and reliable technologies that should be made today[24]. Pursuing large-scale investments in the existing gas system with future repurposing to hydrogen in mind risks derailing necessary investments in building electrification and locking in Pennsylvanians into a relatively expensive and inefficient pathway to deep decarbonization. It could also result in the stranding of gas or hydrogen networks, following an ultimate switch to electrification. As I note above, it would be prudent for policymakers to decisively proceed with proven, readily available and cost-effective solutions for buildings like electrification and energy efficiency and consider potential niche roles for hydrogen – and associated infrastructure implications – if and when new evidence emerges to warrant such consideration.

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[22] M. W. Melaina, O. Antonia, and M. Penev, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues,* NREL, March 2013, ,https://www.nrel.gov/docs/fy13osti/51995.pdf
[23] UK Climate Change Committee, *Hydrogen in a low-carbon economy*
[24] Stian Westlake, *Bionic Duckweed: making the future the enemy of the present*, September 2020,https://stianstian.medium.com/bionic-duckweed-using-the-future-to-fight-the-present-3e471b642c28; Evans et. al, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change,* CarbonBrief

V. HYDROGEN BLENDING AND TRANSPORT

Safeguards are needed to avoid that hydrogen blending initiatives produce lock-in effects into expensive decarbonization pathways.

Hydrogen blending initiatives in the existing gas network are proliferating across the U.S.[25] Blending low shares of hydrogen in the existing gas network could be an effective measure to boost demand for zero-carbon hydrogen production, modestly reduce the carbon emissions of delivered gas and build the knowledge base in relation to the behavior of hydrogen in existing gas pipes. However, as I note above, blending hydrogen beyond the low threshold of 5% to 15% by volume would potentially require major network and appliance refurbishing costs.[26] Therefore, and in considering potential future hydrogen blending proposals in Pennsylvania, it would be prudent for policymakers to institute robust guardrails limiting blending to low thresholds warranting little to no investments in network upgrades; similar safeguards are necessary to avoid that blending programs lock-in Pennsylvanians in a potentially expensive pathway on account of major expenses poured into the gas network. The Renewable Hydrogen Coalition- a hydrogen lobby group in Europe- has recently argued for the avoidance of hydrogen blending altogether, citing the risks that investments in the gas grid to accommodate high blends of hydrogen become stranded.[27]

The need to exercise caution in relation to proposals for the refurbishing of existing gas pipelines or the buildout of dedicated hydrogen networks to avoid lock-in effects into expensive pathways and the stranding of assets.

There are emerging proposals across Europe and recently, in the U.S. west, to build dedicated hydrogen pipelines and/or repurpose the existing gas network to accommodate hydrogen in anticipation of a

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[25] Tom DiChristopher, *How National Grid plans to advance US renewable gas, hydrogen deployment*, S&P Global, January 2021, https://platform.mi.spglobal.com/web/client?auth=inherit#news/article?id=62227805&cdid=A-62227805-12335&KeyProductLinkType=58&utm_source=MIAlerts&utm_medium=scheduledalert&utm_campaign=Alert_Email

[26] M. W. Melaina, et.al, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*, NREL

[27] Camilla Naschert, EU hydrogen lobby group calls for guarantees of origin, downplays gas blending, S&P Global, June 2021, https://platform.marketintelligence.spglobal.com/web/client?#news/article?id=65119834&KeyProductLinkType=58&utm_source=MIAlerts&utm_medium=realtime-minewsresearch-newsfeature-energy%20and%20utilities-the%20daily%20dose&utm_campaign=Alert_Email

growing market.[28] Those would entail large investments in long-lived assets that require a clear near, mid and long-term business case. This is largely lacking as of today, due to the nascency of the hydrogen market, and such investments thereby remain fairly premature- a case of putting the cart before the horse. In particular, there remain many uncertainties in relation to hydrogen's ultimate scope in the economy and the mid and long-term landscape of its supply and demand centers.[29] A near-term leap into hydrogen transport infrastructure risks imposing unnecessary costs on Pennsylvanians and creating stranded assets. Recognizing the risks, an increasing group of stakeholders across Europe are now arguing for holding off on large-scale investments in hydrogen pipelines until a clear demand pattern has emerged.[30] Other groups have proposed to future-proof near-term investments in hydrogen pipelines or repurposing efforts by focusing on a small-scale buildout of pipelines around what are expected to be secure long-term hydrogen demand centers, and gradually expanding networks if and when an economic and climate case for such an expansion emerges[31]. Considering the scale of the investments and the risks that they become stranded, a judicious approach for Pennsylvania policymakers and regulators to consider would be to start by advancing zero-carbon hydrogen use in hubs- or a cohort of hydrogen suppliers and users situated in close proximity such that large-scale hydrogen transport infrastructure is unnecessary- and commission independent assessments investigating where new hydrogen networks or repurposing measures would be cost-effective, secure investments that carry low risks of becoming stranded.

VI. RECOMMENDATIONS

The building blocks of a targeted policy framework that would both develop hydrogen to leverage its potential and internalize the guardrails critical to addressing the potential drawbacks.

A strategic vision for hydrogen deployment must start with a recognition that the hydrogen space is new and that a series of uncertainties still exist across its value chain in relation to the most expedient

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[28] Enagás, Energinet, Fluxug Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas, Teréga, *European Hydrogen Backbone*, July 2020, https://gasforclimate2050.eu/wp-content/uploads/2020/07/2020_European-Hydrogen-Backbone_Report.pdf

[29] Camilla Naschert, Hydrogen lobbying sets wrong priorities, says BloombergNEF founder, S&P Global, May 2021, https://platform.marketintelligence.spglobal.com/web/client?auth=inherit#news/article?KeyProductLinkType=2&id=64534120 ; Evans et. al, *In-Depth Q&A: Does the World Need Hydrogen to Solve Climate Change*, CarbonBrief

[30] Camilla Naschert, Hydrogen lobbying sets wrong priorities, says BloombergNEF founder, S&P Global

[31] Agora Energiewende, *No-Regret Hydrogen*, February 2021, https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_02_EU_H2Grid/A-EW_203_No-regret-hydrogen_WEB.pdf; Climate Action Network Europe, *CAN Europe's Position on Hydrogen*, February 2021, https://caneurope.org/content/uploads/2021/02/CAN-Europe_position-on-hydrogen_February-2021.pdf

production, transport and use patterns. In addition, the hydrogen agenda is currently in part driven by vested interests of those with stakes in the technology's indiscriminate deployment, which may not align with the interests of Pennsylvanians.[32] Pennsylvania policymakers should endeavor to future- proof hydrogen policies and investments by pursuing evidence-based decision-making that roots choices in independent studies and avoids an overeager leap to hydrogen that may engender unintended economic, public health and climate consequences to Pennsylvanians. The following recommendations constitute the building blocks of a prudent hydrogen strategy:

1. Identify hydrogen's strengths and limitations by way of an independent, system-wide assessment.

While hydrogen could act as a valuable complement to proven and established climate solutions like energy efficiency, renewable energy and electrification, evidence suggests that it will not be the most cost-effective nor efficient decarbonization pathway for many sectors. Therefore, a sensible and strategic hydrogen strategy should begin with a clear-eyed understanding of its strengths and limitations. Pennsylvania policymakers are advised to begin by commissioning independent and rigorous system-wide studies evaluating applications where hydrogen offers value relative to other solutions in deep decarbonization pathways and where hydrogen deployment would deliver benefits to Pennsylvanians. Such assessments could then constitute the bedrock of a state hydrogen strategy or roadmap guiding investments in a manner that is aligned with broader economic, public health and climate goals. For example, a California bill under deliberation [SB 18] directs state agencies to investigate the potential role for green hydrogen in supporting the state's climate goals and to produce a hydrogen roadmap pursuant to such an assessment. Similarly, Government Cuomo recently announced a planned collaboration between New York state agencies and the National Renewable Energy Laboratory on a hydrogen strategy study aiming to identify hydrogen opportunities and evaluating how those may be commensurate with broader renewable energy and climate goals.[33]

[32] Leigh Collins, *Liebreich: 'Oil sector is lobbying for inefficient hydrogen cars because it wants to delay electrification',* Recharge News
[33] Office of the Governor, New York State, *Governor Cuomo Announces New York Will Explore Potential Role of Green Hydrogen as Part of Comprehensive Decarbonization Strategy*, July 2021, https://www.governor.ny.gov/news/governor-cuomo-announces-new-york-will-explore-potential-role-green-hydrogen-part

2. Endeavor to ensure that a hydrogen agenda does not derail necessary action on proven, readily available solutions that must be taken today.

The promise of hydrogen should not delay, let alone be substituted for, necessary near-term steps to decarbonize Pennsylvania's economy. Policymakers are advised to pass and implement programs and policies targeting the large-scale deployment of clean electricity resources and widespread electrification of end-uses, notably buildings and passenger cars. Those are proven, cost-effective and readily available solutions and will be central pillars of any decarbonization strategy, regardless of the ultimate role of hydrogen.

3. Orient subsidies and support for hydrogen deployment towards applications where it adds the most value, commensurate with the system-wide assessment.

State subsidies and support programs for hydrogen should be oriented to channel the deployment of hydrogen toward applications where it adds value relative to alternative solutions, in accordance with the system-wide analysis of deep decarbonization pathways. Policy mechanisms could include financial support for projects aiming to demonstrate and advance the use of hydrogen as a feedstock in steelmaking and chemicals manufacturing, supporting fleet demonstrations for hydrogen heavy duty trucks, and funding demonstrations of seasonal hydrogen storage.

4. Orient investments, policy incentives and subsidies towards zero-carbon hydrogen.

That Pennsylvania has an abundant gas resource should not muddle the objective advantages that zero-carbon hydrogen is likely to have over blue hydrogen and the likelihood of it being a safer bet for Pennsylvanians. As I mention above, green hydrogen is projected to either compete with or outcompete blue hydrogen in this decade owing to larger opportunities for technology cost reductions and virtuous learning effects, with a decisive cost advantage for green hydrogen after 2030. In addition, the residual greenhouse gas emissions associated with blue hydrogen reduce its compatibility with a net-zero pathway, raising its risk profile due to the potential stranding of assets. Blue hydrogen also raises equity concerns for communities situated in the vicinity of production facilities due to potential public health concerns. Therefore, Pennsylvania policymakers would be advised to orient policy incentives and subsidies towards the deployment of zero-carbon hydrogen, harnessing the state's large renewable energy and nuclear potential, and investigate targeted opportunities where blue hydrogen may offer a compelling economic, climate and public health case for Pennsylvanians. Should a strong focus on zero-carbon hydrogen prove too challenging, deployment of blue hydrogen is always an option.

5. **Pursue an ambitious clean energy agenda.**

The success and scalability of zero-carbon hydrogen is closely tied to the rapid deployment of renewable and zero-carbon electricity. The enactment of a clean energy standard (CES) that includes hydrogen could help set up the foundation for a strong zero-carbon hydrogen industry in Pennsylvania, and the prospects for the development of such an industry furnishes an additional reason to double down on CES ambition or add hydrogen to a strengthened Alternative Energy Portfolio Standard.

6. **Exercise caution in relation to proposals for hydrogen blending, the repurposing of existing gas pipelines and the buildout of new hydrogen pipelines**

Pennsylvania policymakers are advised to exercise caution in relation to near-term proposals for blending hydrogen in the existing gas network, the repurposing of the existing network and the buildout of new hydrogen-dedicated pipelines. In particular, in considering blending proposals, I would recommend that policymakers implement safeguards to limit hydrogen blending to low thresholds- not exceeding 15% of hydrogen blended by volume- warranting little to no investments in network upgrades. An equal level of prudence is warranted in considering proposals for the wholesale repurposing of existing pipelines or the buildout of a new hydrogen-dedicated network; as I discuss above, such investments are largely premature as of today on account of the chain of uncertainties that permeate the long-term hydrogen vision and risk locking Pennsylvanians into expensive pathways or becoming stranded. Considering the risks, I would advise Pennsylvania policymakers to start by advancing zero-carbon hydrogen use in hubs, requiring no major hydrogen transport infrastructure. In parallel, policymakers should commission independent and transparent studies identifying future-proof and no-regret pipeline corridors- commensurate with secure future hydrogen demand centers teased out by the system-wide assessment- with the buy-in and meaningful participation of local communities impacted by said pipeline corridors.[34] Hydrogen pipeline networks could then be gradually expanded if and when a techno-economic and equity case for such an expansion emerges. Some European expert groups are now advocating for such sensible, no-regret early investments in hydrogen transport infrastructure.[35]

[34] Camilla Naschert, *Prioritizing heavy industry cuts stranded asset risk for hydrogen infrastructure* , S&P Global, February 2021, https://platform.marketintelligence.spglobal.com/web/client#news/article?KeyProductLinkType=2&id=62620184

[35] Agora Energiewende, *No-Regret Hydrogen*, February 2021, https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_02_EU_H2Grid/A-EW_203_No-regret-hydrogen_WEB.pdf

Chairman Bizzarro, Representative Hohenstein, thank you again for the opportunity to testify on the merits and drawbacks of hydrogen and put forth my recommendations for a sensible policy framework to maximize the benefits for Pennsylvanians and avoid unintended consequences. I would be happy to answer any questions you may have.

EXHIBIT A

- Panelist on the *BBC News* podcast "The Real Story". Discussed the pros and cons of using green hydrogen to replace fossil fuels. The story was picked up by over 180 *National Public Radio (NPR)* affiliate radio stations as well as *Sirius XM* Radio.

- Sole guest on Marketplace's Tech podcast explaining green hydrogen, how it can reduce climate emissions in difficult to electrify sectors, and its pitfalls and potential. The Marketplace broadcast portfolio is heard by more than 14 million unique listeners each week on more than 800 public radio stations nationwide.

- Guest speaker on S&P Global's ESG Insider podcast discussing the hydrogen opportunity in the U.S. and globally.

- Quoted in a number of major news outlet in relation to hydrogen:

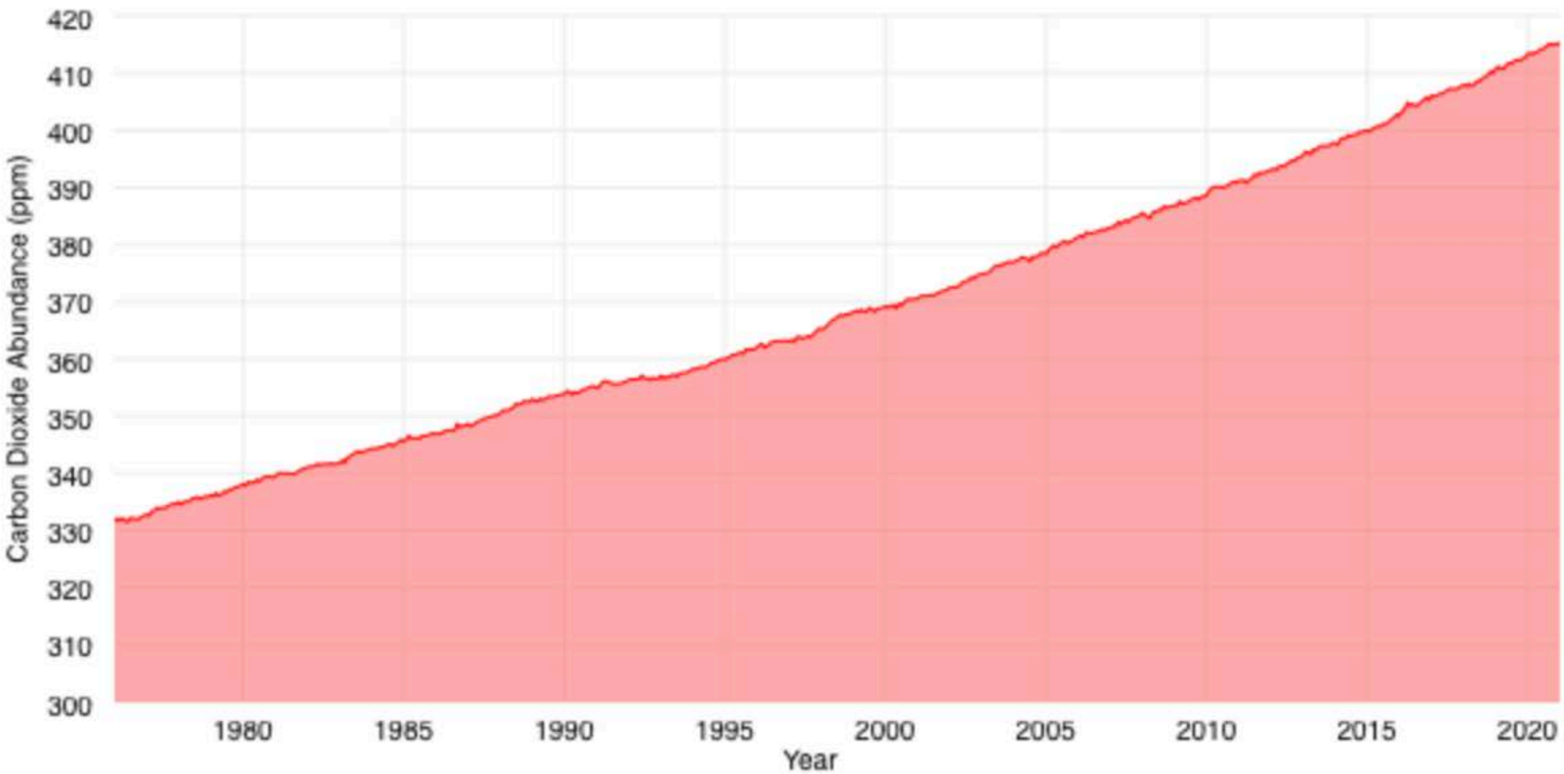
    - "The new fuel to come from Saudi Arabia", BBC News, https://www.bbc.com/future/article/20201112-the-green-hydrogen-revolution-in-renewable-energy
    - "Green Hydrogen Backers See Opening in Biden Climate Ambition, Bloomberg, "https://news.bloomberglaw.com/daily-tax-report/green-hydrogen-backers-see-big-chance-for-sector-development?context=search&index=0
    - "California coalition aims to make hydrogen power cost-competitive by 2030", UtilityDive, https://www.utilitydive.com/news/california-coalition-aims-to-make-hydrogen-power-cost-competitive-by-2030/600239/

- “Green Hydrogen: Could It Be Key to a Carbon-Free Economy?”, Yale Environment 360, https://e360.yale.edu/features/green-hydrogen-could-it-be-key-to-a-carbon-free-economy
- “Hydrogen: 3 things to watch in 2021”, E&E News, https://www.eenews.net/stories/1063721655
- “Meet the 'hydrogen home': Is it key to a 100% clean grid?”, E&E News https://www.eenews.net/energywire/2020/12/21/stories/1063721161?utm_campaign=edition&utm_medium=email&utm_source=eenews%3Aenergywire
- “Utilities launch groundbreaking 'green' hydrogen-gas project”, E&E News https://www.eenews.net/stories/1063719323
- “Developer plans to build hydrogen plant that runs on waste in Southern California”, Utility Dive, https://www.utilitydive.com/news/developer-plans-to-build-hydrogen-plant-that-runs-on-waste-in-southern-cali/578381/


Pennsylvania House Minority Policy Committee
Public Hearing 7/21/21
Testimony & Supporting Material
PENNSYLVANIA'S NEXT ENERGY REVOLUTION
KeyState
to Zero
JOBS CREATION
CLIMATE CONCERNS
ECONOMIC DEVELOPMENT
EMISSIONS REDUCTIONS
FOSSIL ENERGY ECONOMY
HYDROGEN ECONOMY


KeyState
to Zero
'Net Zero by 2050'
How to Get There?
'100% Reduction by 2050'
What Happens the Next 30 yrs?
Net Zero NEW GHG Emissions
CO2 Emissions are Cumulative
-100% 2050
-50%….-75%….-90% Now

CO2 Emissions in the Atmosphere are Cumulative Over Time



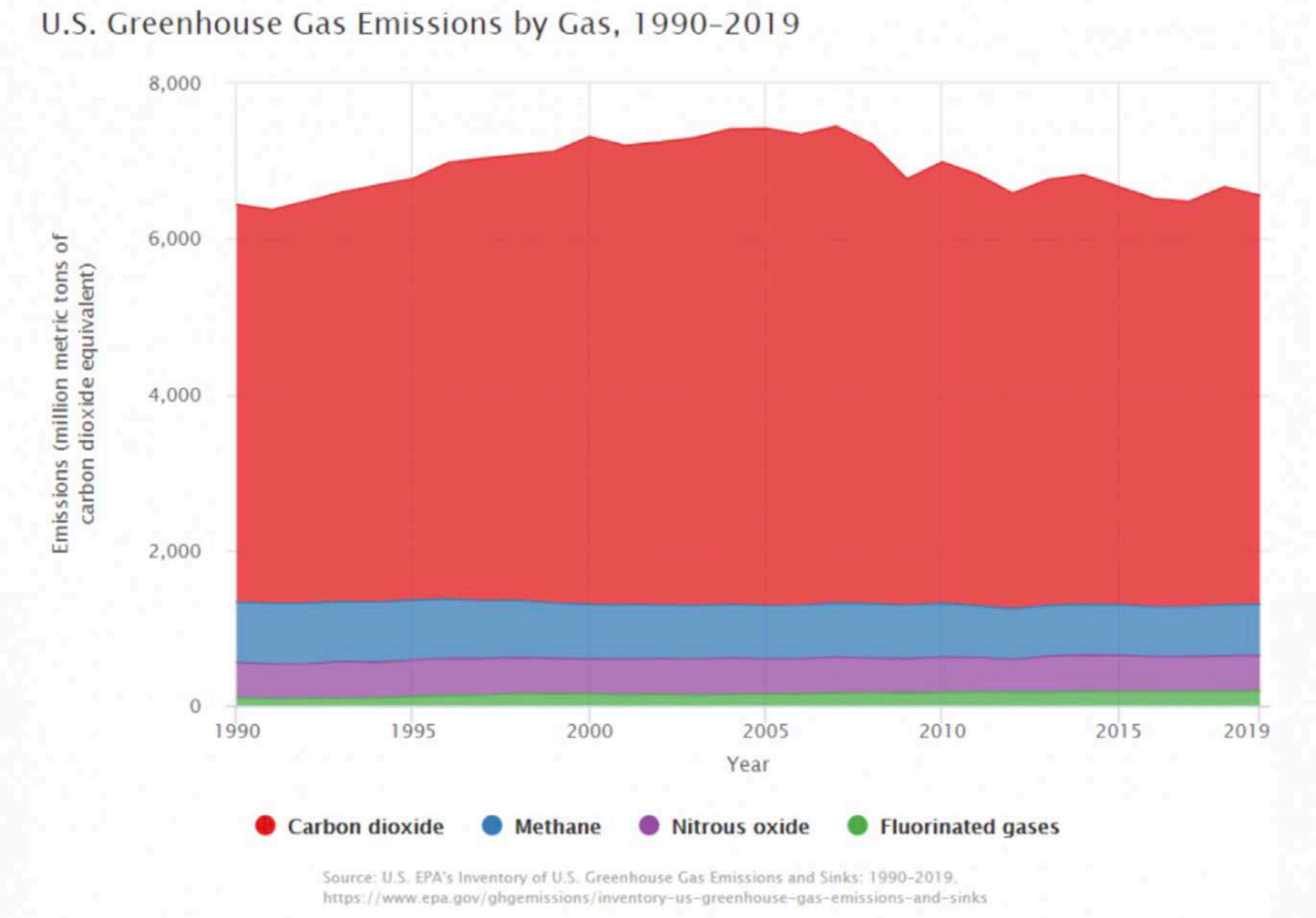
https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

-100% by 2050

and -50%….-75%….-90% Now

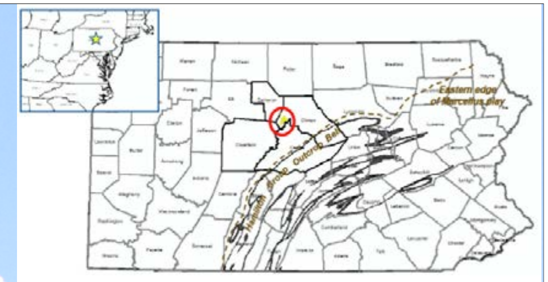
KeyState
Pennsylvania's Next Energy Revolution

US GHG Emissions Peaked in 2005



KeyState

Natural Gas Synthesis & Carbon Storage



Integrating Natural Gas Production and Natural Gas Synthesis with Carbon Capture Use and Storage

Displacing
Higher-Carbon-Higher-Cost Products with Lower-Carbon-Lower-Cost Products

Result =
High Paying Job Creation with Dramatic Emissions Reduction

Pennsylvania's Next Energy Revolution

KeyState Natural Gas Synthesis & CCUS

Clinton County, Pa. > $410,000,000

Low-Carbon Products:

CO2 Emissions Reduced by 50 to 80% per ton
- Blue Hydrogen
- Blue Ammonia

Emissions Reduction Products:
- Diesel Exhaust Treatment (DEF)
- Power Plant Exhaust Treatment (NH3)

CO2 Use & Stored
- Used In DEF Production = 170,000 tpy
- Stored Process CO2 = 104,000 tpy
- Post Combustion CO2 Capture + 85,000 tpy

Natural Gas Used

6,800,000 mmbtu per year

136,000,000 mmbtu over 20 years

CO2/H2 Storage Asset

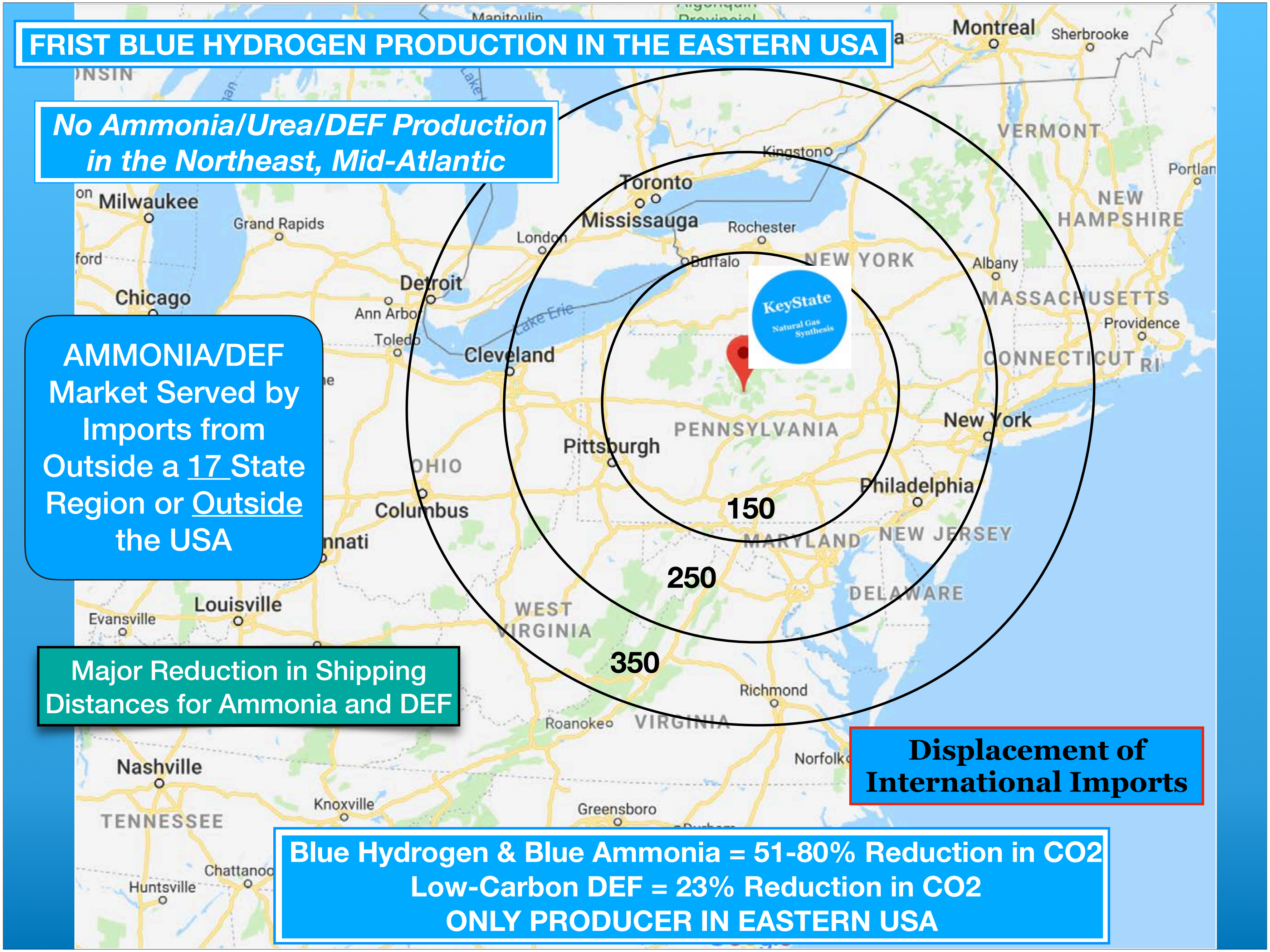
7,000 acres, contiguous, 1 owner

KeyState
Natural Gas
Synthesis &
Carbon Storage

INTEGRATING CARBON CAPTURE & GEOLOGICAL STORAGE WITH NATURAL GAS PRODUCTION AND MANUFACTURING OF LOW-CARBON PRODUCTS & FUELS

ENERGY TRANSITION CHECKLIST

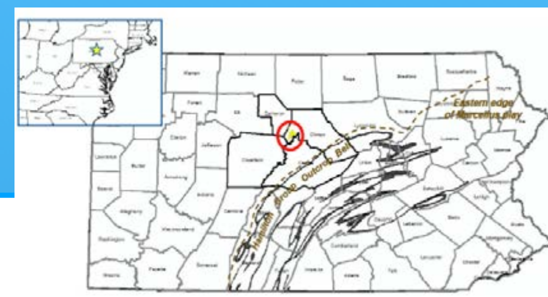
- ✓ Carbon Capture
- ✓ Carbon Usage
- ✓ Onsite Carbon Storage
- ✓ Major GHG Reduction
- ✓ Industrial CO2 Source
- ✓ Commercial Scale
- ✓ Solution for Stranded & Market- Constricted Gas
- ✓ ‘Anchor Project’ for Low-Carbon Industrial Hub
- ✓ CO2 Storage Cluster
- ✓ Proven Technology
- ✓ Experienced Team
- ✓ Industry Leading EPCs
- ✓ Co-Investment
- ✓ Credit-Worthy Off-Takers
- ✓ Public Sector Support
- ✓ Displacing Higher-Carbon, & Higher Priced Products
- ✓ Pioneering Fugitive Methane Remediation System
- ✓ ESG Certifiable


FRIST BLUE HYDROGEN PRODUCTION IN THE EASTERN USA
No Ammonia/Urea/DEF Production in the Northeast, Mid-Atlantic
AMMONIA/DEF Market Served by Imports from Outside a 17 State Region or Outside the USA
Major Reduction in Shipping Distances for Ammonia and DEF
Displacement of International Imports
Blue Hydrogen & Blue Ammonia = 51-80% Reduction in CO2
Low-Carbon DEF = 23% Reduction in CO2
ONLY PRODUCER IN EASTERN USA
KeyState
Natural Gas Synthesis
150
250
350
Montreal
Sherbrooke
VERMONT
Portlan
NEW HAMPSHIRE
Kingston
Toronto
Mississauga
Rochester
Buffalo
NEW YORK
Albany
MASSACHUSETTS
Providence
CONNECTICUT
RI
Milwaukee
Grand Rapids
London
Chicago
Detroit
Ann Arbor
Toledo
Lake Erie
Cleveland
PENNSYLVANIA
Pittsburgh
New York
OHIO
Philadelphia
Columbus
MARYLAND
NEW JERSEY
DELAWARE
Louisville
Evansville
WEST VIRGINIA
Richmond
Roanoke
VIRGINIA
Norfolk
Nashville
Knoxville
Greensboro
TENNESSEE
Chattanoo
Huntsville

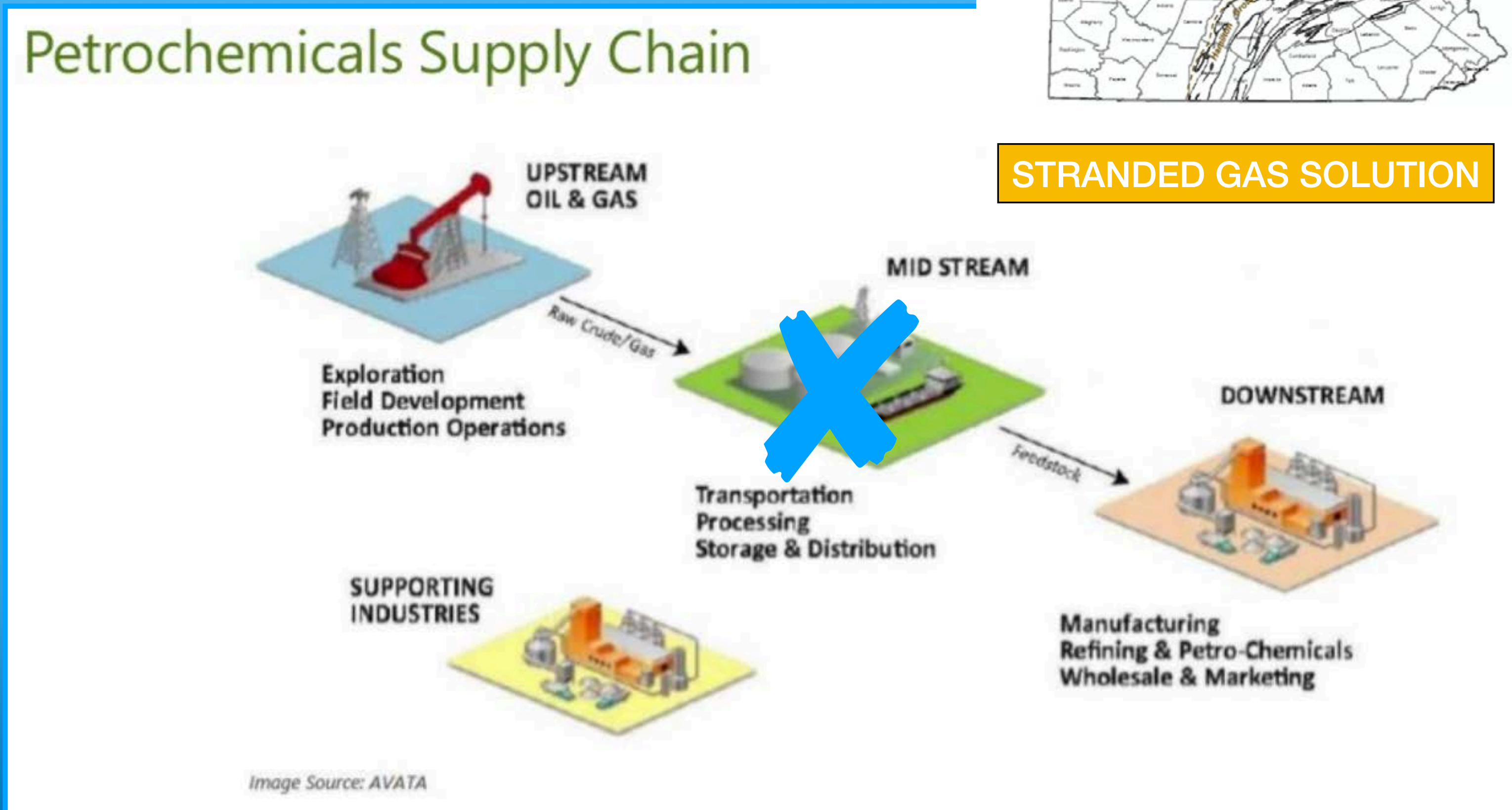
‘CLOSED METHANE SYSTEM’
& the Elimination
of Fugitive Methane Emissions

- Integrated gas production, pipeline gathering & manufacturing.
- All new wells, new pipeline
- No compressor stations.
- No gas of unknown origin.

KeyState’s Integrated, On-Site Gas Supply Eliminates Mid-Stream Costs and Emissions



STRANDED GAS SOLUTION




JOBS CREATION
CLIMATE CONCERNS
Pennsylvania's NEXT Energy Jobs
Direct use of natural gas as feedstock and power source in onsite manufacturing
...with carbon capture use and storage
800 Construction & Permanent Jobs
+ Indirect + Induced Jobs
www.pamanufacturers.org/nepanatgas
KeyState
Pennsylvania's
Next Energy
Revolution

Justice40 Impacts

Independent Study Economic Impact Gas Synthesis Plant in Clinton Co.

DURING CONSTRUCTION

Total economic output: construction of natural gas synthesis plants combined

Location	Labor Income	Value Added	Total Economic Output
Clinton County	$137,977,974.67	$180,842,342.55	$364,962,192.10

Total jobs related to construction of natural gas synthesis plant combined

Location	Direct	Indirect	Induced	Total
Clinton County	800	78	143	1,021

DURING OPERATIONS

Total economic output: combined-permanent jobs from natural gas synthesis plant

Location	Labor Income	Value Added	Total Economic Output
Clinton County	$83,009,918.22	$118,909,211.18	$260,995,083.52

Total jobs related to completion of natural gas synthesis plant (combined-permanent)

Location	Direct	Indirect	Induced	Total
Clinton County	150	144	232	526

"Based on the results, it's clear that these projects would be transformative to northeast Pennsylvania, and the commonwealth as a whole. Entire economies are centered around this type of economic activity and will sustain regions for generations to come. Attracting and retaining natural gas synthesis manufacturing ought to be a priority of policymakers at the state and federal level to ensure this prosperity occurs in our commonwealth as opposed to a competitor state."

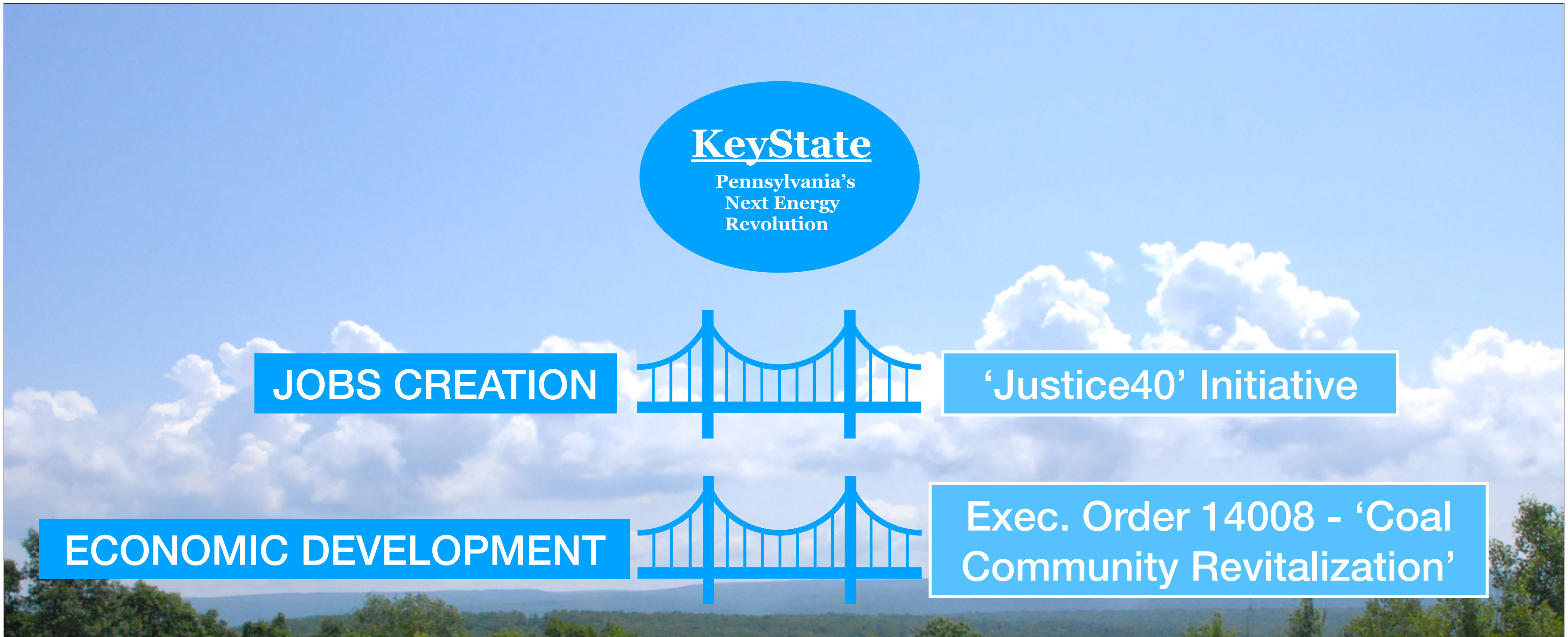
DAVID N. TAYLOR, PRESIDET & CEO - PMA

PMA full report: www.pamanufacturers.org/nepanatgas

http://www.pamanufacturers.org/NEPAnatgas

- **Major Rural Economic Impact**
- **Multi-County Impact**
- **The New Energy Jobs**
- **Industry Breakthrough**
- **Manufacturing Breakthrough**

KeyState
Pennsylvania's Next Energy Revolution



Justice40 Initiative

Presidential Executive Order 14008 Sec. 223

(a) Within 120 days of the date of this order, the Chair of the Council on Environmental Quality, the Director of the Office of Management and Budget, and the National Climate Advisor, in consultation with the Advisory Council, shall jointly publish recommendations on how certain Federal investments might be made toward **a goal that 40 percent of the overall benefits flow to disadvantaged communities. The recommendations shall focus on investments in the areas of clean energy and energy efficiency; clean transit; affordable and sustainable housing; training and workforce development; the remediation and reduction of legacy pollution; and the development of critical clean water infrastructure. The recommendations shall reflect existing authorities the agencies may possess for achieving the 40-percent goal as well as recommendations on any legislation needed to achieve the 40–percent goal.**

Presidential Executive Order 14008 Sec. 218

'...Coal and Power Plant Communities and Economic Revitalization'.

KeyState lies within one of the top 25 communities as identified in this Executive Order

https://netl.doe.gov/sites/default/files/2021-04/Initial%20Report%20on%20Energy%20Communities_Apr2021.pdf

Presidential Executive Order 14008 Sec. 218

'...Coal and Power Plant Communities and Economic Revitalization'.

INITIAL REPORT TO THE PRESIDENT ON EMPOWERING WORKERS THROUGH REVITALIZING ENERGY COMMUNITIES

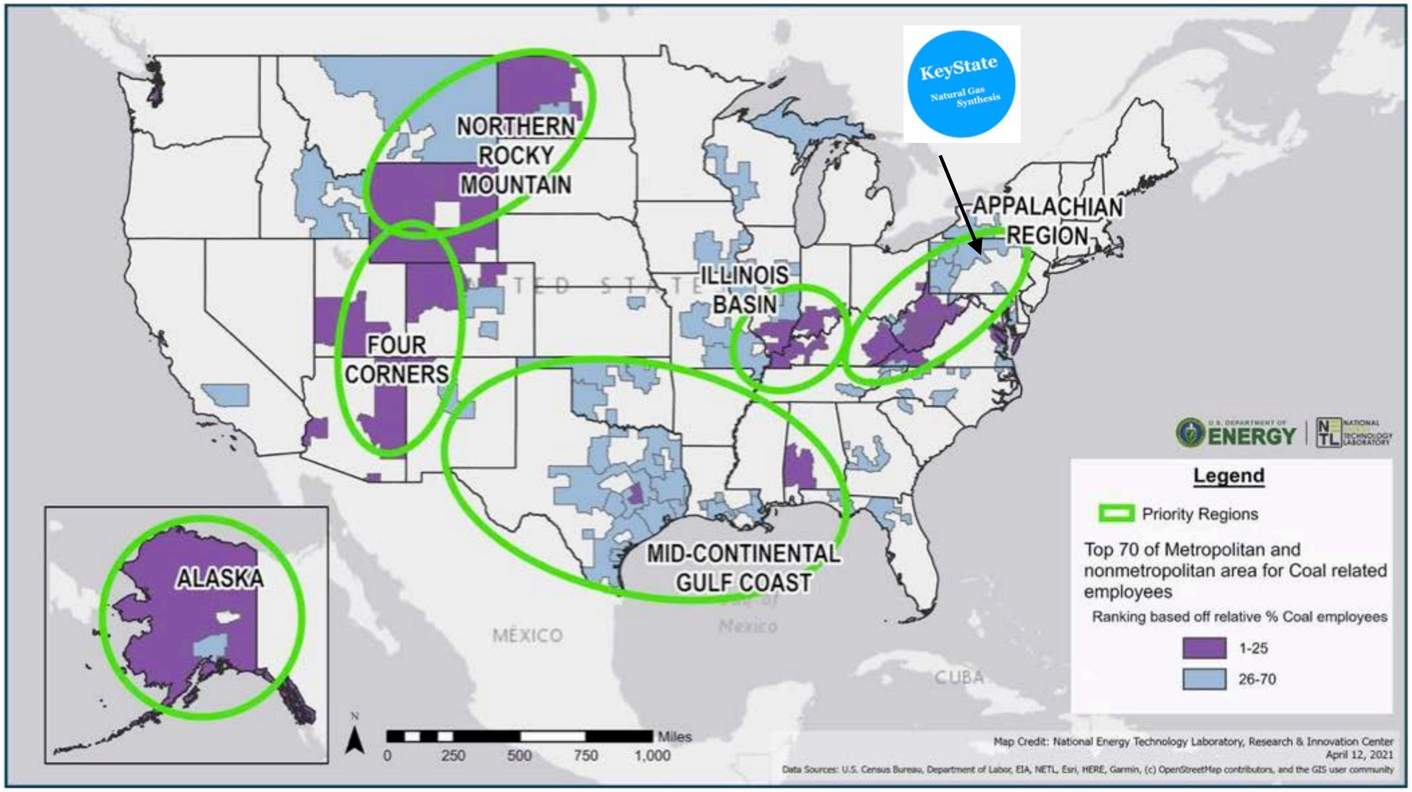
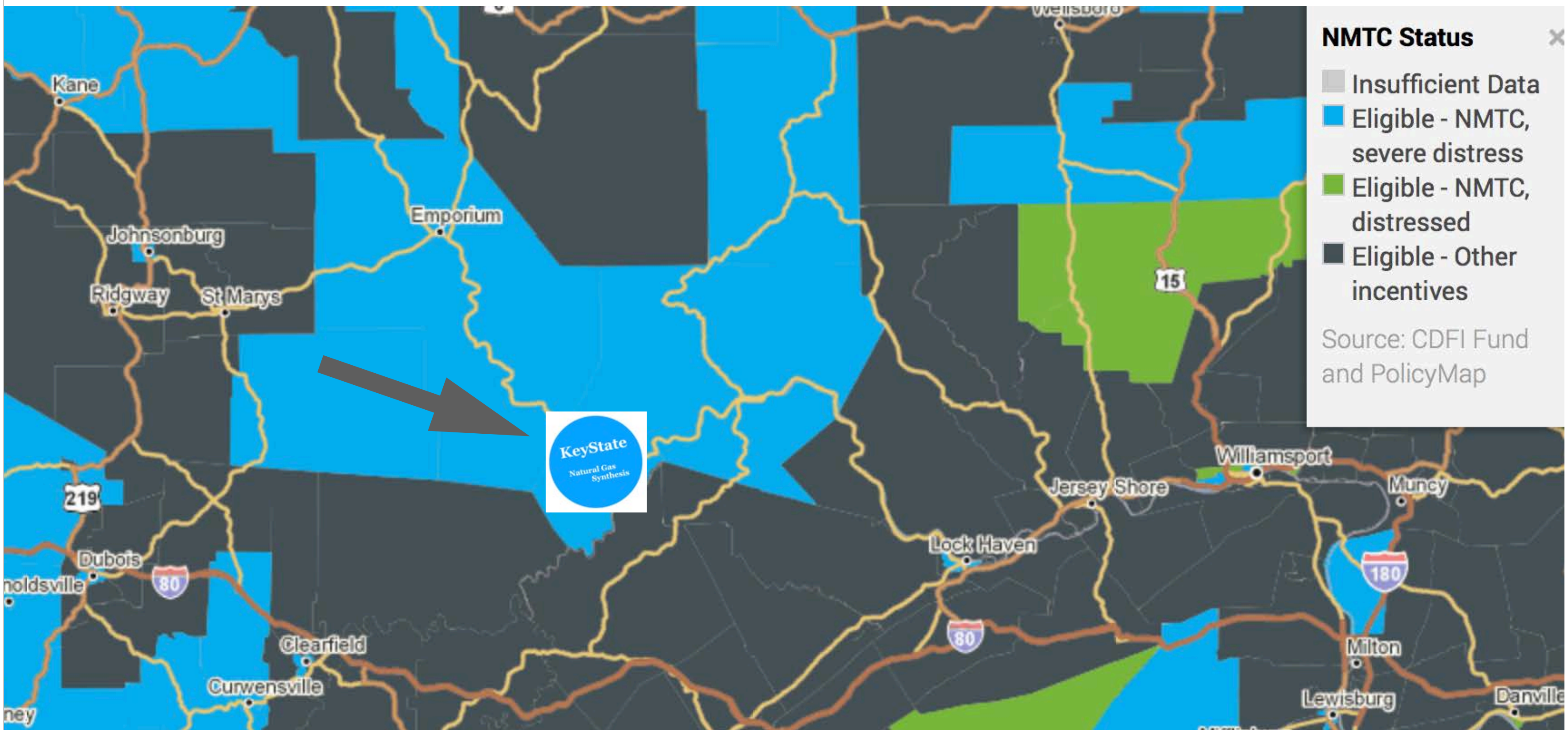


Figure 2. Shading highlights BLS metro and non-metro areas that are communities vulnerable to impacts from coal-specific job losses.

https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

Justice40 Impacts

Entire 7,000 Acre Frontier/Winner Tract lies within a New Market Tax Credit 'Severe Distressed Zone'



K&L GATES

https://bakertilly.com/new-markets-tax-credits-map/?gclid=Cj0KCQjw
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Justice40 Impacts

Entire 7,000 Acre Winner Tract lies within a **Federal Qualified Opportunity Zone**

An **Opportunity Zone** is an **economically-distressed community** ………..
Opportunity Zones were created under the 2017 Tax Cuts and Jobs Act, signed into law by President Donald J. Trump on December 22, 2017, **to stimulate economic development and job creation, by incentivizing long- term investments in low-income neighborhoods.**
There are more than 8,760 designated Qualified Opportunity Zones (PDF) located in all 50 States, the District of Columbia, and five United States territories.

www.eda.gov/opportunity-zones/

AREA DESIGNATED BY LOCAL, COUNTY, STATE AND FEDERAL ACTION FOR MAJOR ECONOMIC DEVELOPMENT

http://dced.maps.arcgis.com/home/webmap/viewer.html?webmap=b0bd4d703ddc498fb0a993a00d77ed4c

KeyState
Pennsylvania's Next Energy Revolution

PENNSYLVANIA

HYDROGEN SUPERPOWER

2024 TO 2060

WHY ??

HOW ??

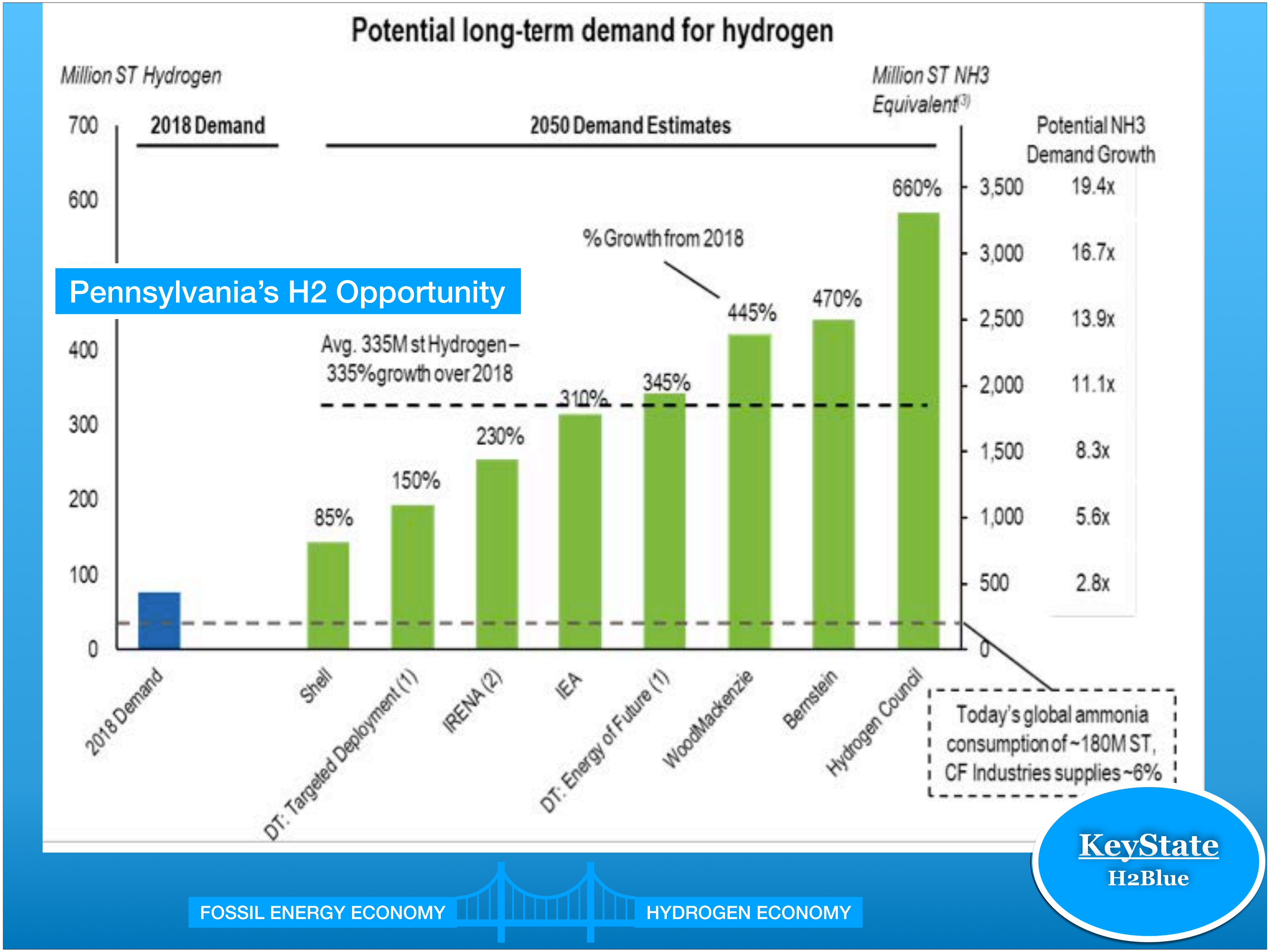
COSTS

ABILITY TO SCALE

Illustrated by

KeyState

H2Blue


Potential long-term demand for hydrogen
Pennsylvania's H2 Opportunity
Million ST Hydrogen
700
600
400
300
200
100
0
2018 Demand
2050 Demand Estimates
Million ST NH3 Equivalent(3)
Potential NH3 Demand Growth
3,500 19.4x
3,000 16.7x
2,500 13.9x
2,000 11.1x
1,500 8.3x
1,000 5.6x
500 2.8x
0
% Growth from 2018
Avg. 335M st Hydrogen – 335% growth over 2018
85%
150%
230%
310%
345%
445%
470%
660%
2018 Demand
Shell
DT: Targeted Deployment (1)
IRENA (2)
IEA
DT: Energy of Future (1)
WoodMackenzie
Bernstein
Hydrogen Council
Today's global ammonia consumption of ~180M ST, CF Industries supplies ~6%
FOSSIL ENERGY ECONOMY
HYDROGEN ECONOMY
KeyState
H2Blue

Implications

FOSSIL ENERGY ECONOMY — HYDROGEN ECONOMY

Hydrogen Economy Breakthrough

Low-Carbon Hydrogen Produced from Natural Gas + CO2 Capture & Storage

Grey hydrogen	*Blue hydrogen*	*Green hydrogen*
Split natural gas into CO_2 and hydrogen	Split natural gas into CO_2 and hydrogen Residual gasses also in H-vision scope	Split water into hydrogen by electrolysis powered by wind and sun
CO_2 emitted in the atmosphere	*CO_2 stored or re-used*	*No CO_2 emitted*

'Using blue hydrogen for the power sector and industry, to replace natural gas, coal, and possibly also residual gases from the petrochemical industry, can rapidly achieve megaton-scale CO2 emissions reduction.' https://blog.sintef.com/sintefenergy/elegancy-tno-h-vision-project/

SINTEF

https://www.youtube.com/watch?time_continue=6&v=h3h_YihGKdc&feature=emb_logo

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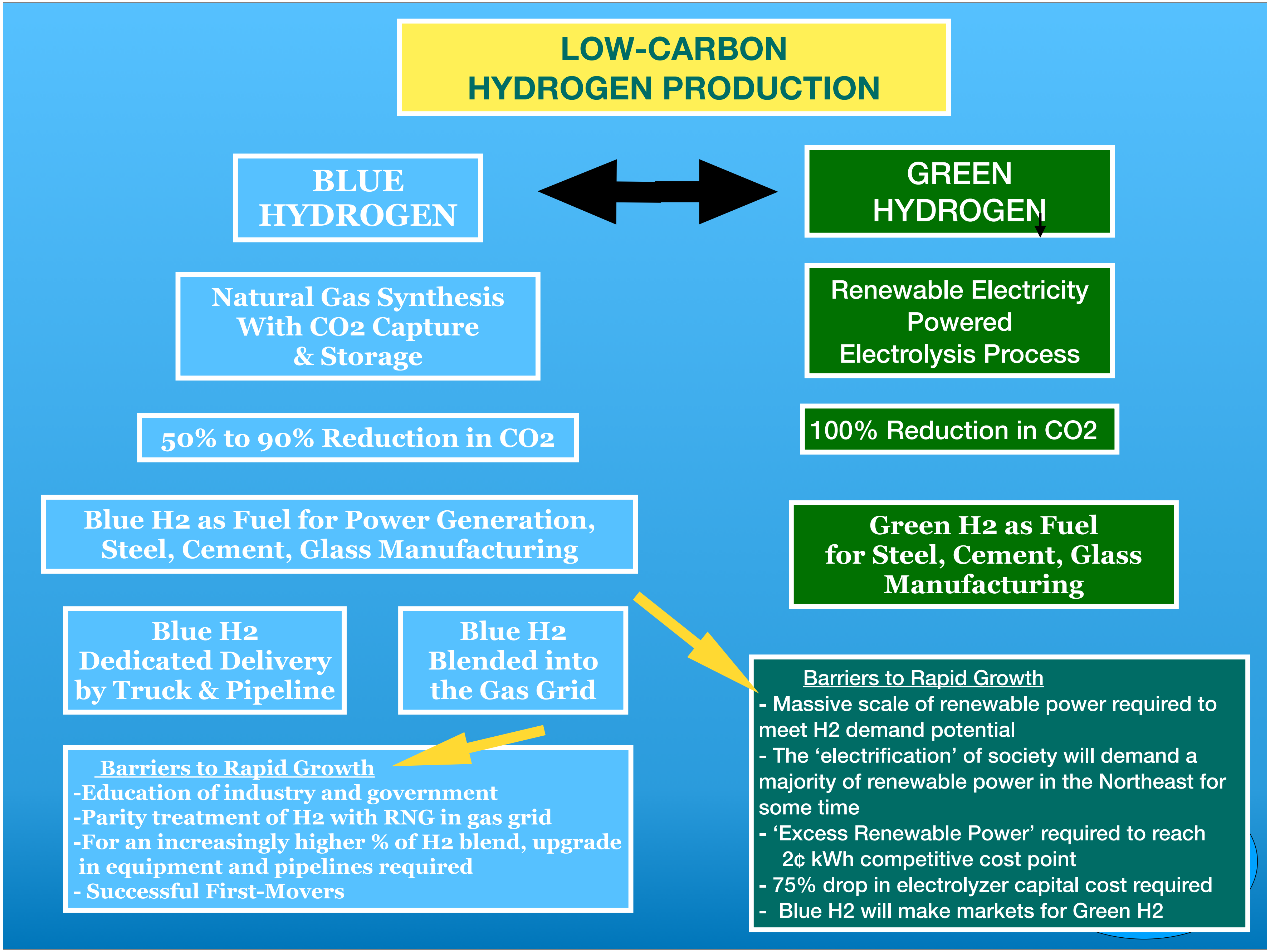
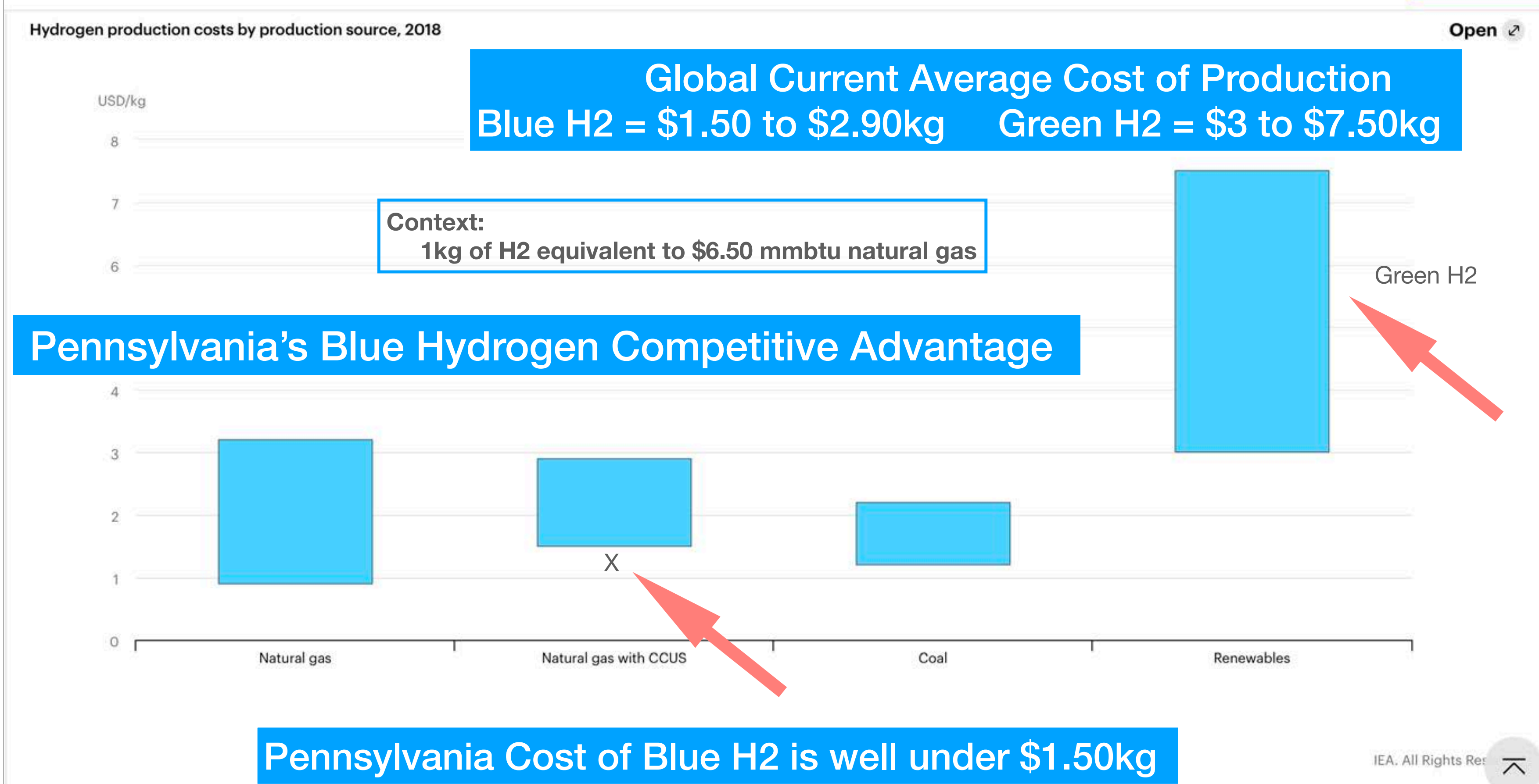

LOW-CARBON
HYDROGEN PRODUCTION
BLUE
HYDROGEN
GREEN
HYDROGEN
Natural Gas Synthesis
With CO2 Capture
& Storage
Renewable Electricity
Powered
Electrolysis Process
50% to 90% Reduction in CO2
100% Reduction in CO2
Blue H2 as Fuel for Power Generation,
Steel, Cement, Glass Manufacturing
Green H2 as Fuel
for Steel, Cement, Glass
Manufacturing
Blue H2
Dedicated Delivery
by Truck & Pipeline
Blue H2
Blended into
the Gas Grid
Barriers to Rapid Growth
-Education of industry and government
-Parity treatment of H2 with RNG in gas grid
-For an increasingly higher % of H2 blend, upgrade in equipment and pipelines required
- Successful First-Movers
Barriers to Rapid Growth
- Massive scale of renewable power required to meet H2 demand potential
- The 'electrification' of society will demand a majority of renewable power in the Northeast for some time
- 'Excess Renewable Power' required to reach 2¢ kWh competitive cost point
- 75% drop in electrolyzer capital cost required
- Blue H2 will make markets for Green H2

COSTS — ABILITY TO SCALE



Global Current Average Cost of Production
Blue H2 = $1.50 to $2.90kg   Green H2 = $3 to $7.50kg

Context:
1kg of H2 equivalent to $6.50 mmbtu natural gas

Pennsylvania's Blue Hydrogen Competitive Advantage

Pennsylvania Cost of Blue H2 is well under $1.50kg

Needed to achieve $1 kg Hydrogen from Renewable Electricity:

- saturation volumes of renewable power
- massive amounts of 2¢ kWh renewable electricity
- 75% drop in capital cost of electrolyzer

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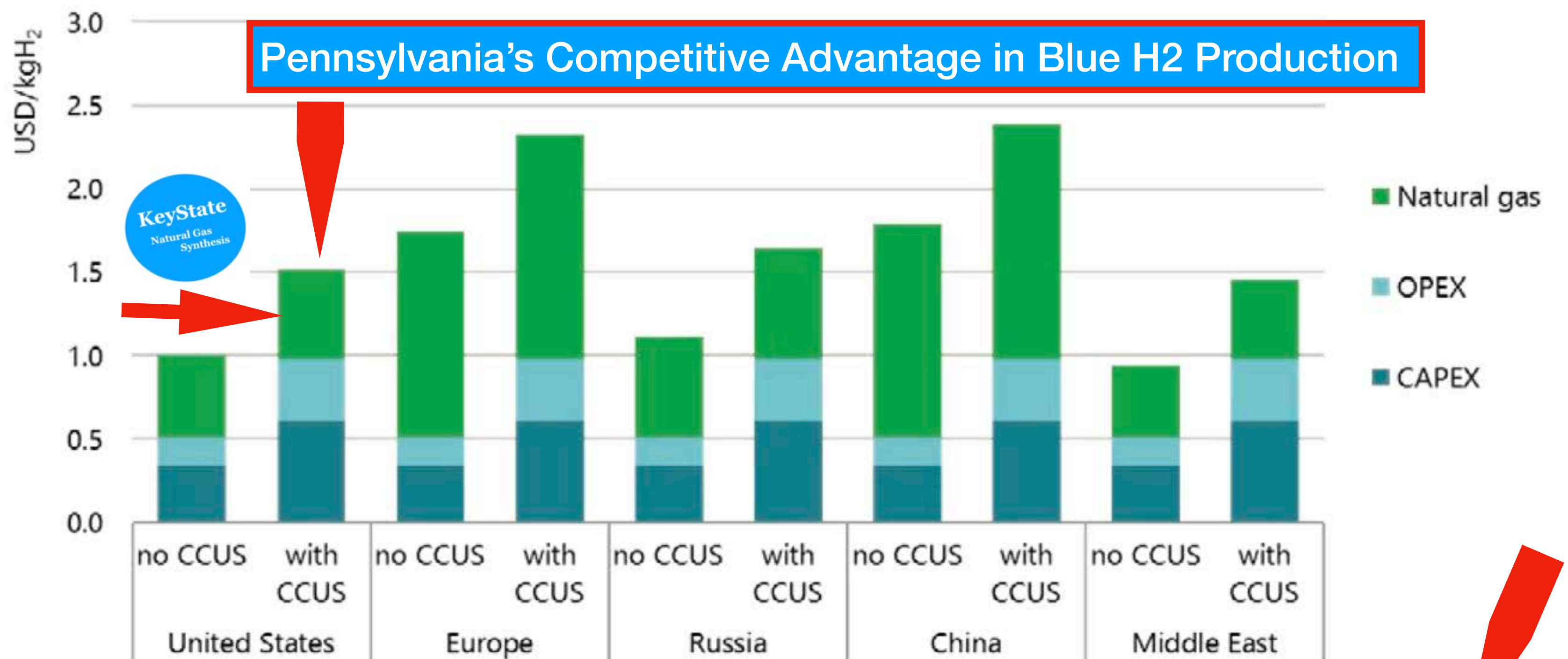
Grey & Blue Hydrogen Production Costs by Region

Figure 9. Hydrogen production costs using natural gas in different regions, 2018



Notes: kgH_2 = kilogram of hydrogen; OPEX = operational expenditure. CAPEX in 2018: SMR without CCUS = USD 500–900 per kilowatt hydrogen (kW_{H2}), SMR with CCUS = USD 900–1 600/kW_{H2}, with ranges due to regional differences. Gas price = USD 3–11 per million British thermal units (MBtu) depending on the region. More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

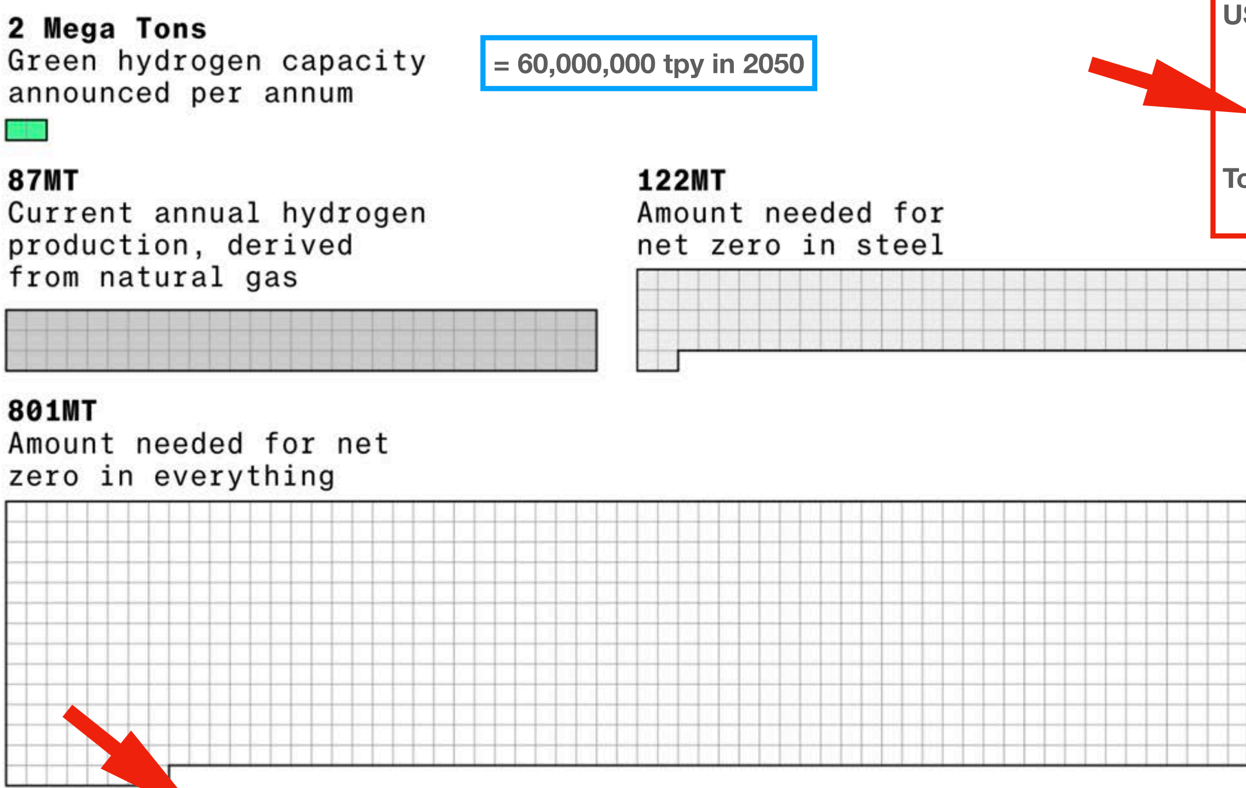
Source: IEA 2019.

Availability of low-cost gas is a crucial cost determinant for SMR-based hydrogen.

COSTS | ABILITY TO SCALE

Nowhere Near

Planned green hydrogen capacity in 2050 is far less than the needs of industry



US Annual Diesel for Transportation
= 37.2 billion gallons
= 40 billion kg of H2 per year
= 55,000,000 tpy

Total US H2 Production
= 10,000,000 tpy

Note: Assumes 50% utilization rate and 50kWh/kg for green hydrogen, capacity installations as of start of 2021

Sources: BNEF, IEA, Bloomberg calculations

https://www.bloomberg.com/graphics/2021-green-steel/

https://www.eia.gov/energyexplained/diesel-fuel/use-of-diesel.php

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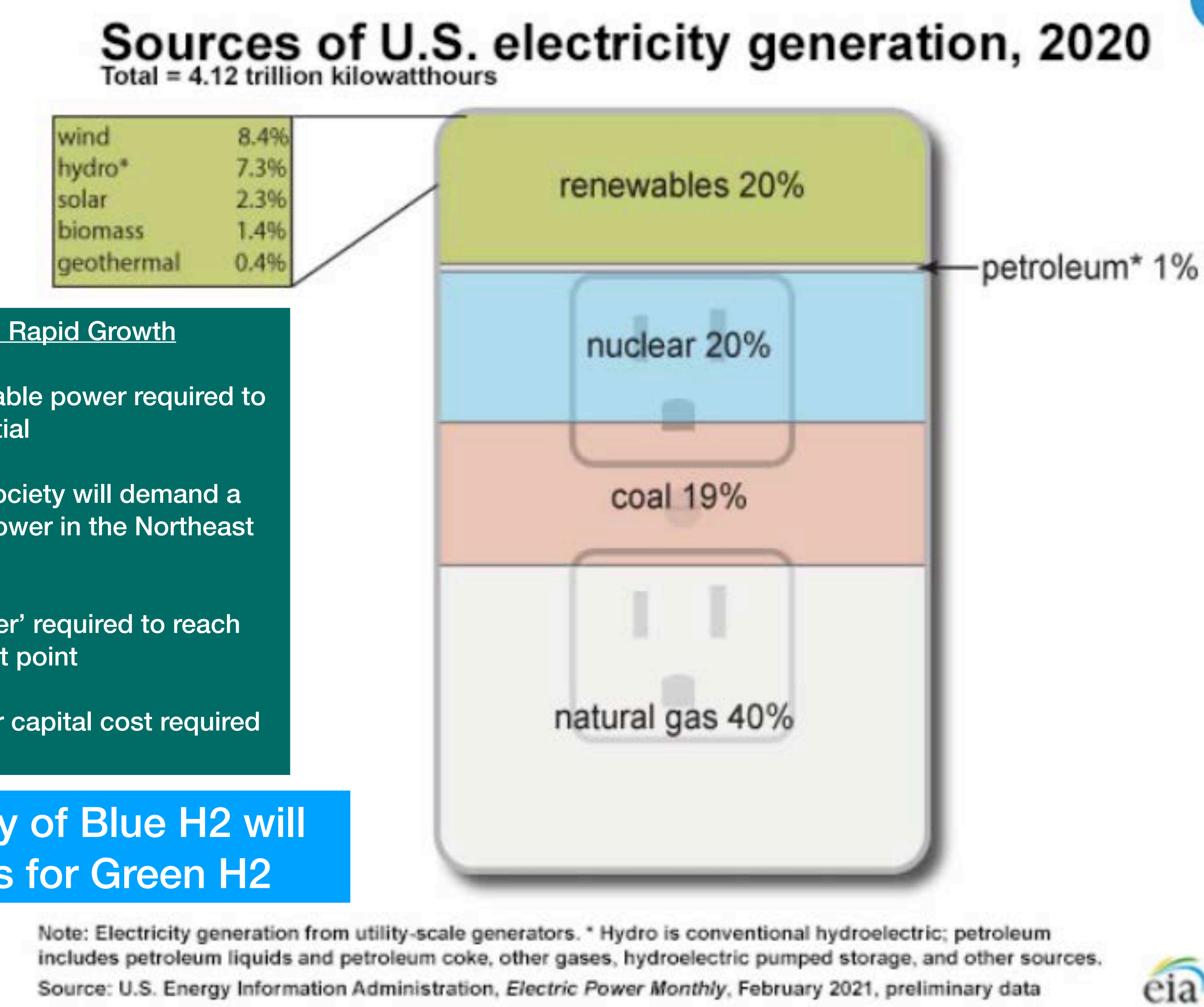
COSTS

ABILITY TO SCALE



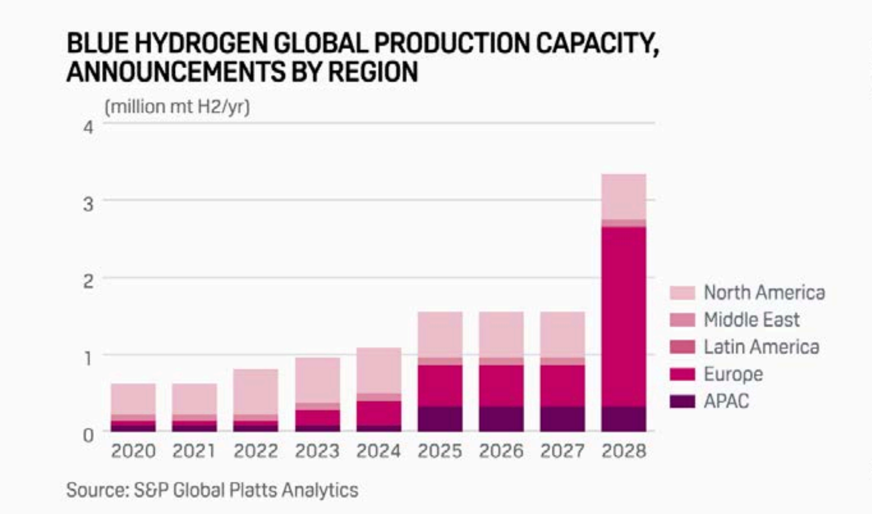
Green H2 - Barriers to Rapid Growth

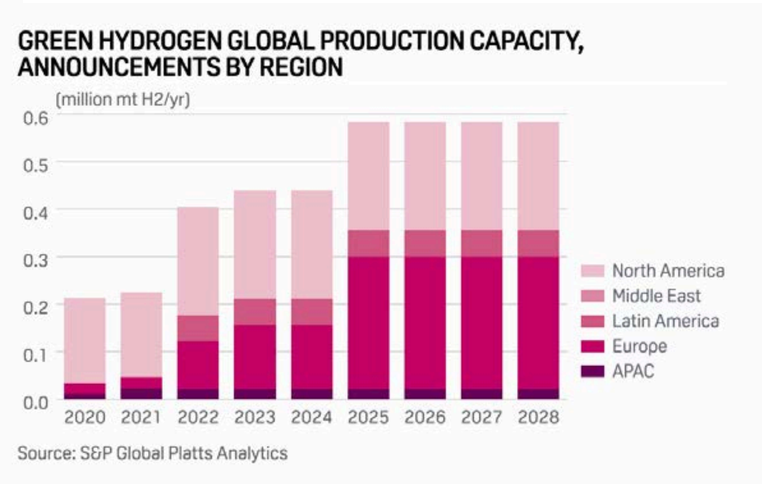
- Massive scale of renewable power required to meet H2 demand potential
- The ‘electrification’ of society will demand a majority of renewable power in the Northeast for some time
- ‘Excess Renewable Power’ required to reach 2¢ kWh competitive cost point
- 75% drop in electrolyzer capital cost required

Wide availability of Blue H2 will Make Markets for Green H2

'BLUE H2' MARKET ANALYSIS

Cost, logistics offer 'blue hydrogen' market advantages over 'green' alternative





Preexisting hydrogen production assets in the US and Europe, comparatively low feedstock costs and favorable geological options for carbon storage make the production method particularly well suited to the two continents, market experts with S&P Global Platts Analytics said in a webinar hosted this week.

"Blue versus green is and will continue to be a regional question" said Zane McDonald, lead hydrogen and alternative transport analyst with Platts Analytics.

According to McDonald, regions with ample low-cost natural gas and the potential for CO2 storage capacity in retired oil and gas wells and/or salt caverns – more readily available in both North America and Europe – could make both locations viable markets for launching a blue hydrogen market.

OUTLOOK

Globally, production capacity of blue hydrogen is expected to grow significantly over the next decade, dramatically outpacing planned capacity for its more costly alternative, green hydrogen.

By 2028, blue hydrogen production should reach about 3.3 million metric tons per year, up from its current capacity 0.6 million mt/yr, according to data from Platts Analytics' Hydrogen Market Monitor. A majority of that production is expected to come from Europe, followed by the US in a distant second place.

Over the same period, green hydrogen is only expected to grow to about 0.6 million mt/yr globally, up from roughly 0.2 million mt/yr currently. Capacity additions are expected to come mostly in Europe, more closely followed by the US market's buildout.

Source: S&P Global Platts Analytics

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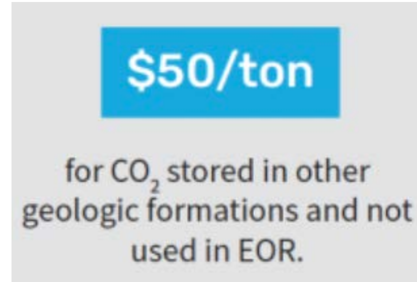
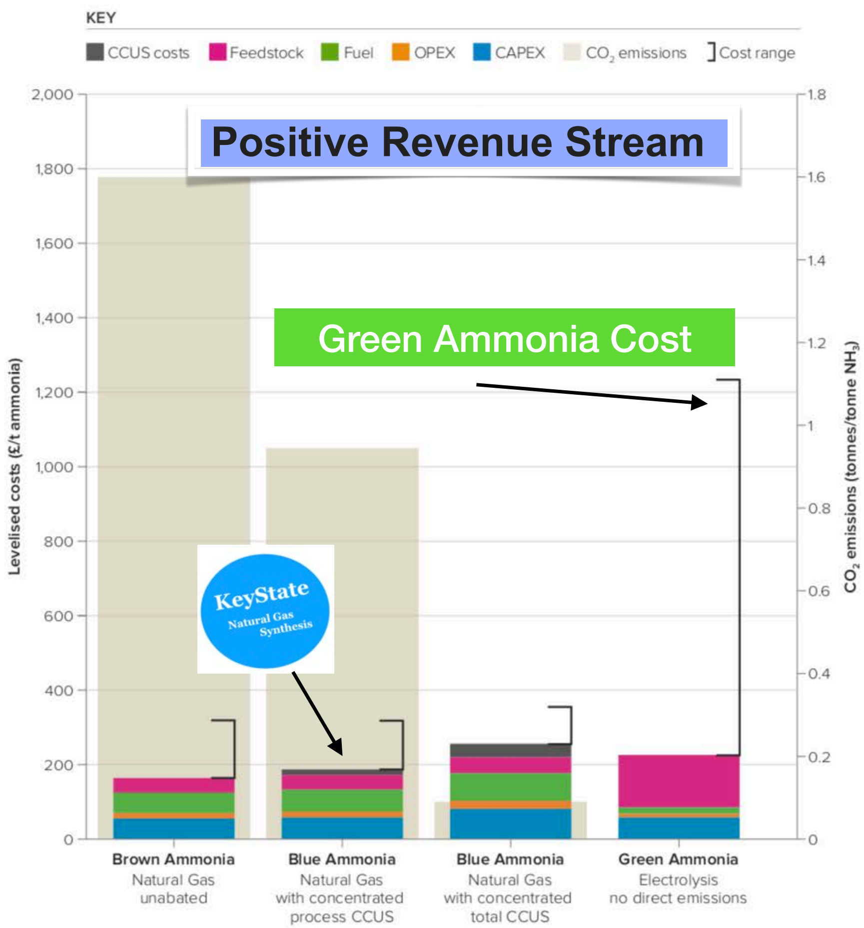
CCUS Economics

45Q - CARBON USE & STORAGE TAX CREDIT



Cost comparison of ammonia production via different methods[26].



Note: Range refers to the range of total levelised costs across regions, the lower end of the range is disaggregated into cost categories. Electrolysis is assumed to be powered by 100% renewable electricity; the 'feedstock cost' is the electricity for the electrolyser, and 'fuel cost' is additional electricity for the air separation unit, synthesis loop etc. CCUS costs include capture, transport and storage of carbon dioxide; process CCUS is only process emissions; total is process and energy related emissions. % carbon dioxide reduction is relative to unabated production with natural gas (1.6 tonnes/tonne NH_3).

Why is the 45Q tax credit important?

The revamped federal 45Q tax credit provides a foundational policy for incentivizing carbon capture deployment in multiple industries, much like the role the federal production tax credit and investment tax credit has played in wind and solar development, respectively. To fulfill carbon capture's full potential for reducing emissions, enhancing domestic energy and industrial production, and protecting and creating high-wage jobs, a suite of federal and state policies is ultimately required to complement 45Q and drive investment, innovation, and cost reductions sufficient to achieve economy wide deployment (just as a full portfolio of federal and state policies has accomplished for wind and solar).

How does 45Q support carbon capture projects?

The expansion and reform of 45Q reduces the cost and risk to private capital of investing in the deployment of carbon capture technology across a range of industries, including electric power generation, ethanol and fertilizer production, natural gas processing, refining, chemicals production, and the manufacture of steel and cement.

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PENNSYLVANIA

HYDROGEN SUPERPOWER

2024 TO 2060

WHY ??

COSTS

HOW ??

ABILITY TO SCALE

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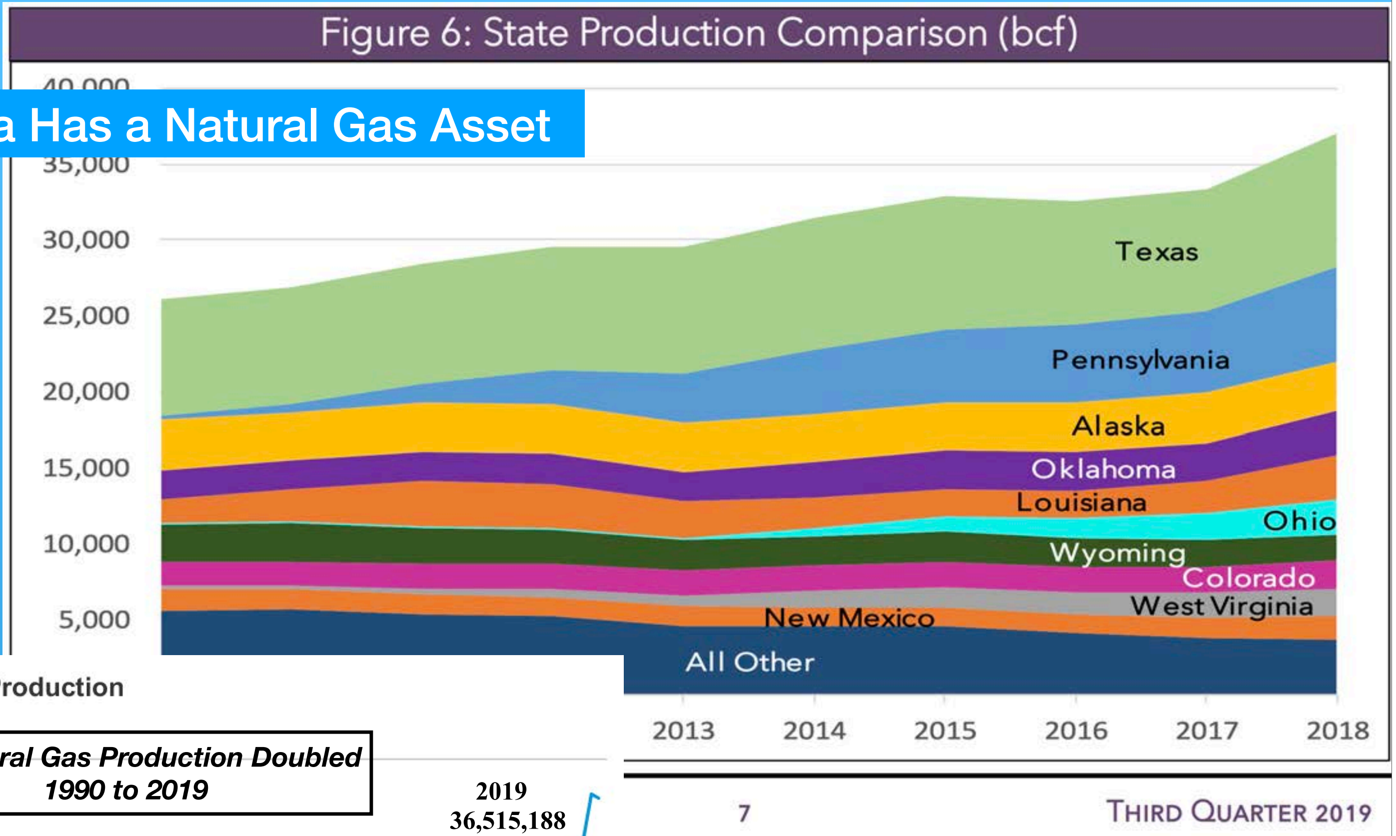
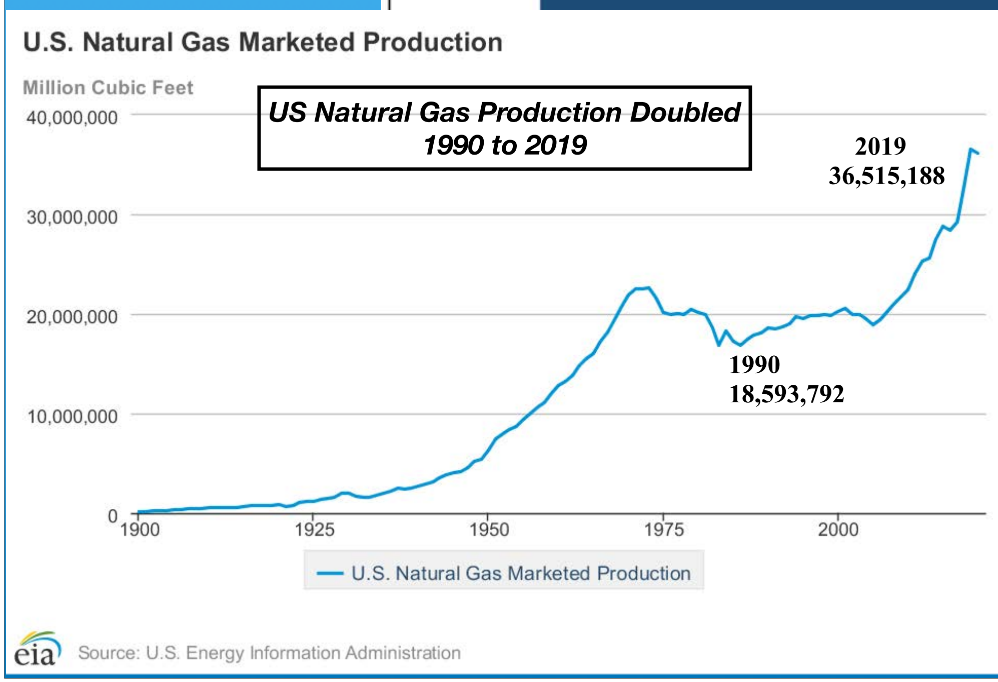
H2Blue

#1. Pennsylvania Has a Natural Gas Asset

Pennsylvania's Natural Gas Asset





http://www.ifo.state.pa.us/download.cfm?file

https://www.eia.gov/dnav/ng/hist/n9050us2a.htm

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#2. Pennsylvania Has a Geological Storage Asset

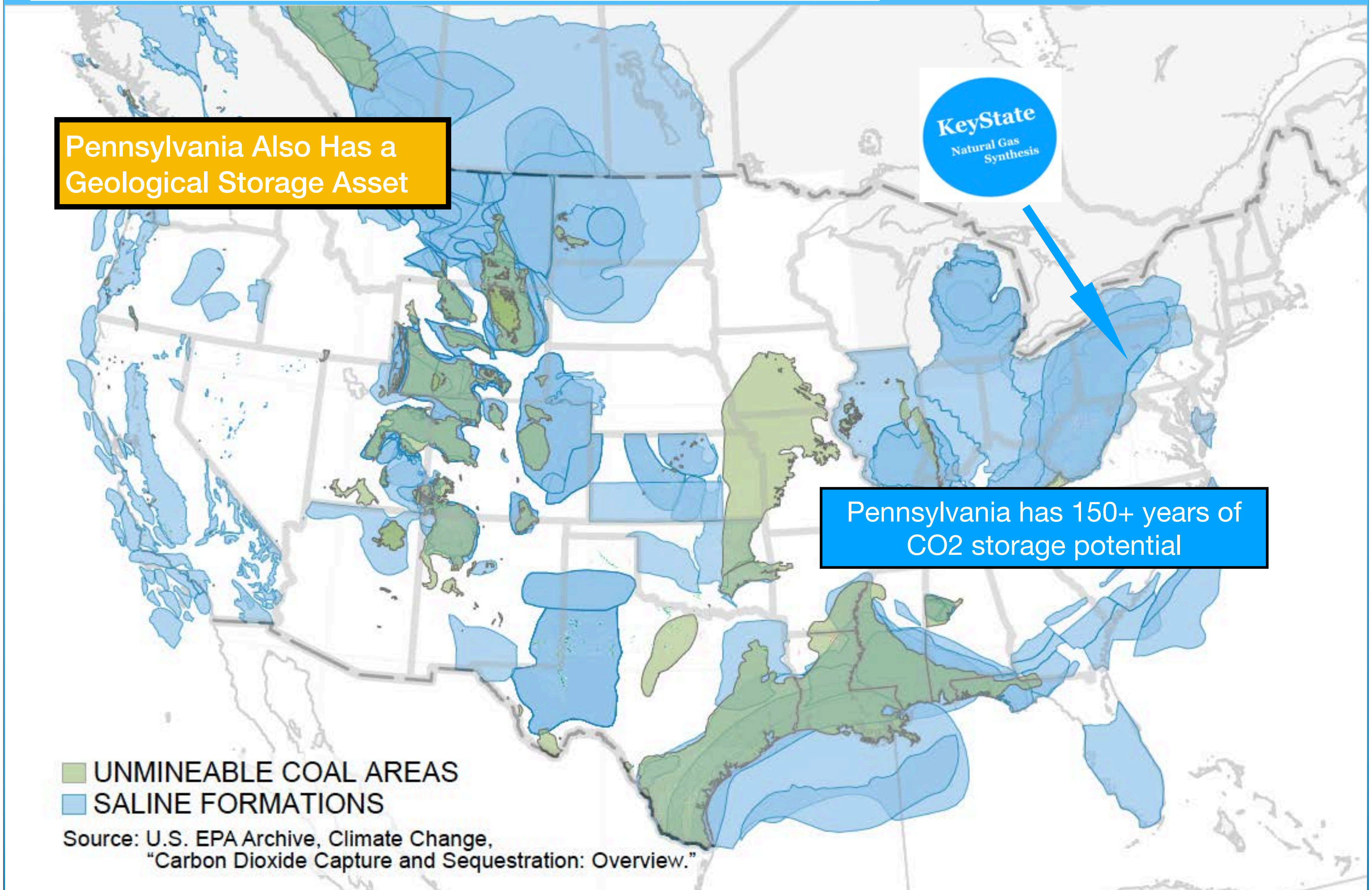

***Figure ES-10.** U.S. Assessment of Geologic CO_2 Storage Potential*

#2. A Geological Storage Asset

Pennsylvania
CO_2 Emissions and Carbon Storage Potential
CCUS Atlas - NETL 5th Addition 2015 pg. 111

150 YEARS OF CO_2 STORAGE

State/ Province	CO_2 Emissions		Oil and Natural Gas Reservoirs Storage Resource			Unmineable Coal Storage Resource			Saline Formation Storage Resource			Total Storage Resource		
			Billion Metric Tons			Billion Metric Tons			Billion Metric Tons			Billion Metric Tons		
	Million Metric Tons Per Year	Number of Sources	Low Estimate	Medium Estimate	High Estimate	Low Estimate	Medium Estimate	High Estimate	Low Estimate	Medium Estimate	High Estimate	Low Estimate	Medium Estimate	High Estimate
Pennsylvania	132	281	0.80	1.34	2.45	0.27	0.27	0.27	17.34	17.34	17.34	18.41	18.95	20.06

According to the Midwest Regional Carbon Sequestration Partnership (MRCSP),[1] Pennsylvania has an estimated geologic capacity to store hundreds of years' worth of carbon emissions at present rates. If that resource can be proven, and appropriately and safely developed along with all of the other technological requirements of CCS, the Commonwealth may be able to substantially reduce its global warming emissions and protect our environment, our economy, and public health - while preserving its position as a net energy exporter and creating jobs in the process.

http://elibrary.dcnr.pa.gov/GetDocument?docId=1743513&DocName=Viability-of-a-Large-Scale-CCS-Network-in-PA-2009.pdf

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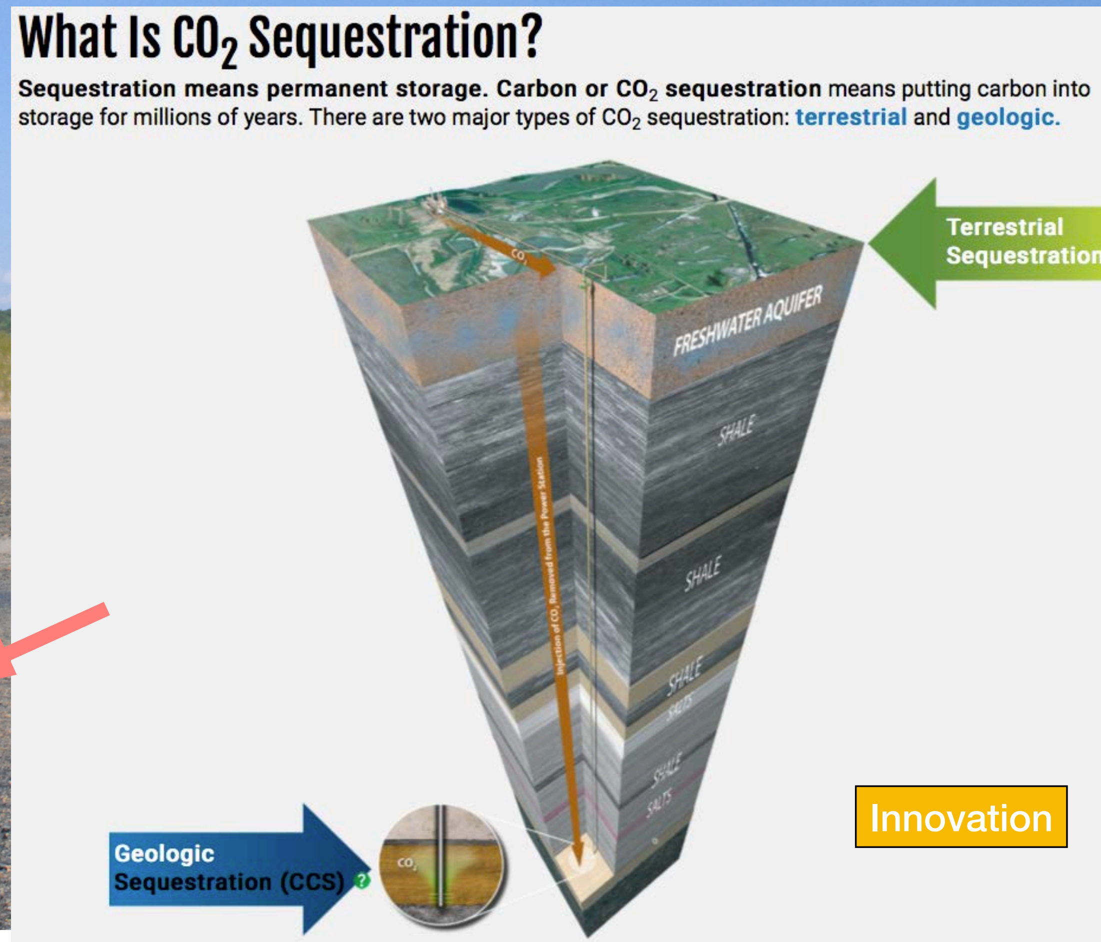
Implication of Associating Natural Gas Production and Uses with CCUS:

The same know-how, skills, equipment and workforce which safely and efficiently did the impossible and brought shale gas up from a mile or more below the surface to make America energy Independent will also lead in the carbon storage & Blue Hydrogen revolution.

<u>CCUS</u>
A new industry
A business opportunity
A vehicle for unprecedented CO2 emissions reductions.



Innovation

A Low-Carbon Future for Natural Gas

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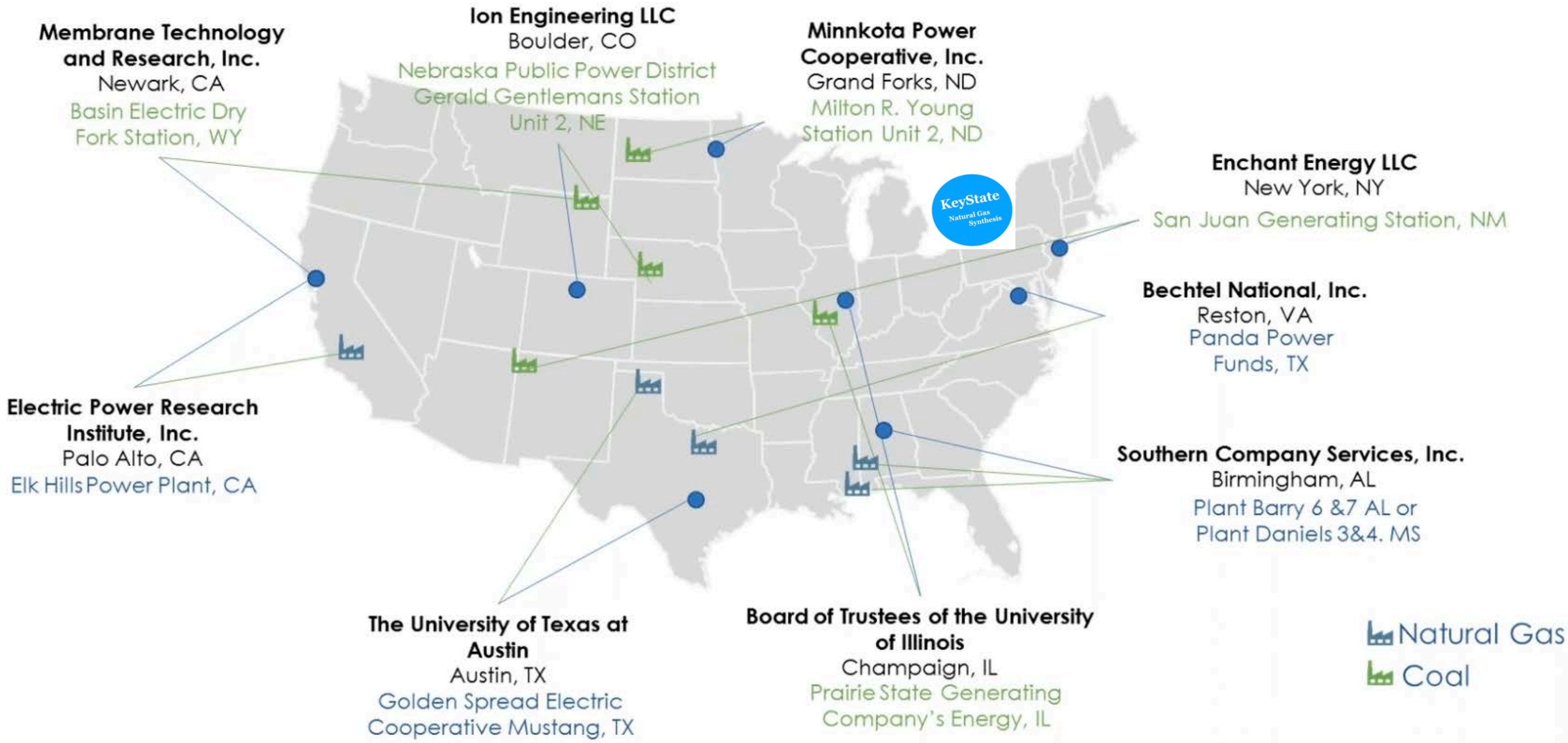
FOR BACKGROUND INFORMATION ON CCUS: Pennsylvania's Carbon Capture Utilization and Storage Research
Kristin Carter, Assistant State Geologist PA DCNR, Bureau of Topographic & Geologic Survey

COMMERCIAL CARBON CAPTURE FEED STUDY PROJECTS

$55M DOE - 2019



KEYSTATE 'FIRSTS':

Climate Impacts & Justice40 Impacts

FIRST to Demonstrate a Low-Carbon Future for Pennsylvania's Natural Gas

- **FIRST commercial CCUS Project in Pennsylvania and the East.**
- **FIRST to integrate carbon storage and shale gas production.**
- **FIRST to demonstrate the carbon storage potential of Pennsylvania's Marcellus Region**
- **FIRST Blue Hydrogen/Blue Ammonia/Blue Nitrogen production in the Eastern USA.**
- **FIRST in the East to demonstrate the link between CCUS and the new Hydrogen economy**
- **FIRST to demonstrate a low-carbon-low-price product directly DISPLACING a higher-carbon-higher-priced product.**
- **FIRST to demonstrate onsite gas production, onsite manufacturing, and onsite carbon storage**
- **FIRST validation of 'several hundred years' of carbon storage' geology in Pennsylvania.**
- **FIRST to show Pennsylvania's potential as Hydrogen *SuperPower* for the next 30 years.**
- **FIRST to demonstrate that both major GHG emissions reduction objectives and natural gas production with CCS can work together resulting in massive longterm job creation and economic development for chronically poor, former coal mining and rust-belt areas.**
- **First to demonstrate 'clean' natural gas production via a 'Closed Methane System' of gas production, transport and manufacturing to reduce and eliminate methane emissions.**

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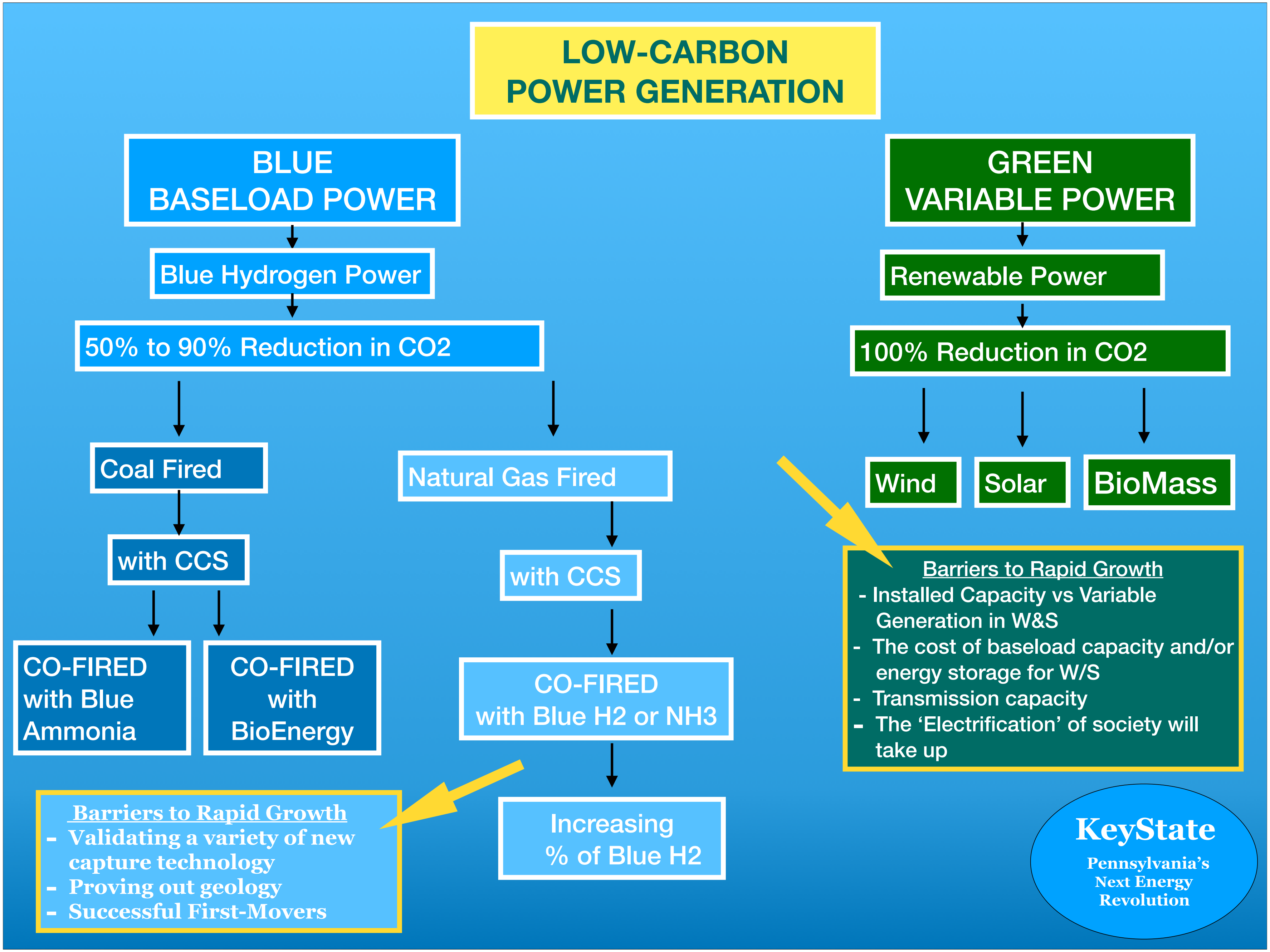
LOW-CARBON
POWER GENERATION
BLUE
BASELOAD POWER
Blue Hydrogen Power
50% to 90% Reduction in CO2
Coal Fired
with CCS
CO-FIRED
with Blue
Ammonia
CO-FIRED
with
BioEnergy
Natural Gas Fired
with CCS
CO-FIRED
with Blue H2 or NH3
Increasing
% of Blue H2
Barriers to Rapid Growth
- Validating a variety of new capture technology
- Proving out geology
- Successful First-Movers
GREEN
VARIABLE POWER
Renewable Power
100% Reduction in CO2
Wind
Solar
BioMass
Barriers to Rapid Growth
- Installed Capacity vs Variable Generation in W&S
- The cost of baseload capacity and/or energy storage for W/S
- Transmission capacity
- The 'Electrification' of society will take up
KeyState
Pennsylvania's
Next Energy
Revolution

KEYSTATE DEVELOPMENT TIMELINE	2021	2021	2022	2022	2023	2024/2025
	1st qt	3rd qt	1st qt	4th qt	1st qt	
DEVELOPMENT PHASE I	COMPLETE					
DEVELOPMENT PHASE II Pre-FEED Phase		COMMENCE	COMPLETE			
DEVELOPMENT PHASE III FEED Phase			COMMENCE	COMPLETE		
CONSTRUCTION PHASE					COMMENCE	COMPLETE
COMMERCIAL OPERATIONS						COMMENCE

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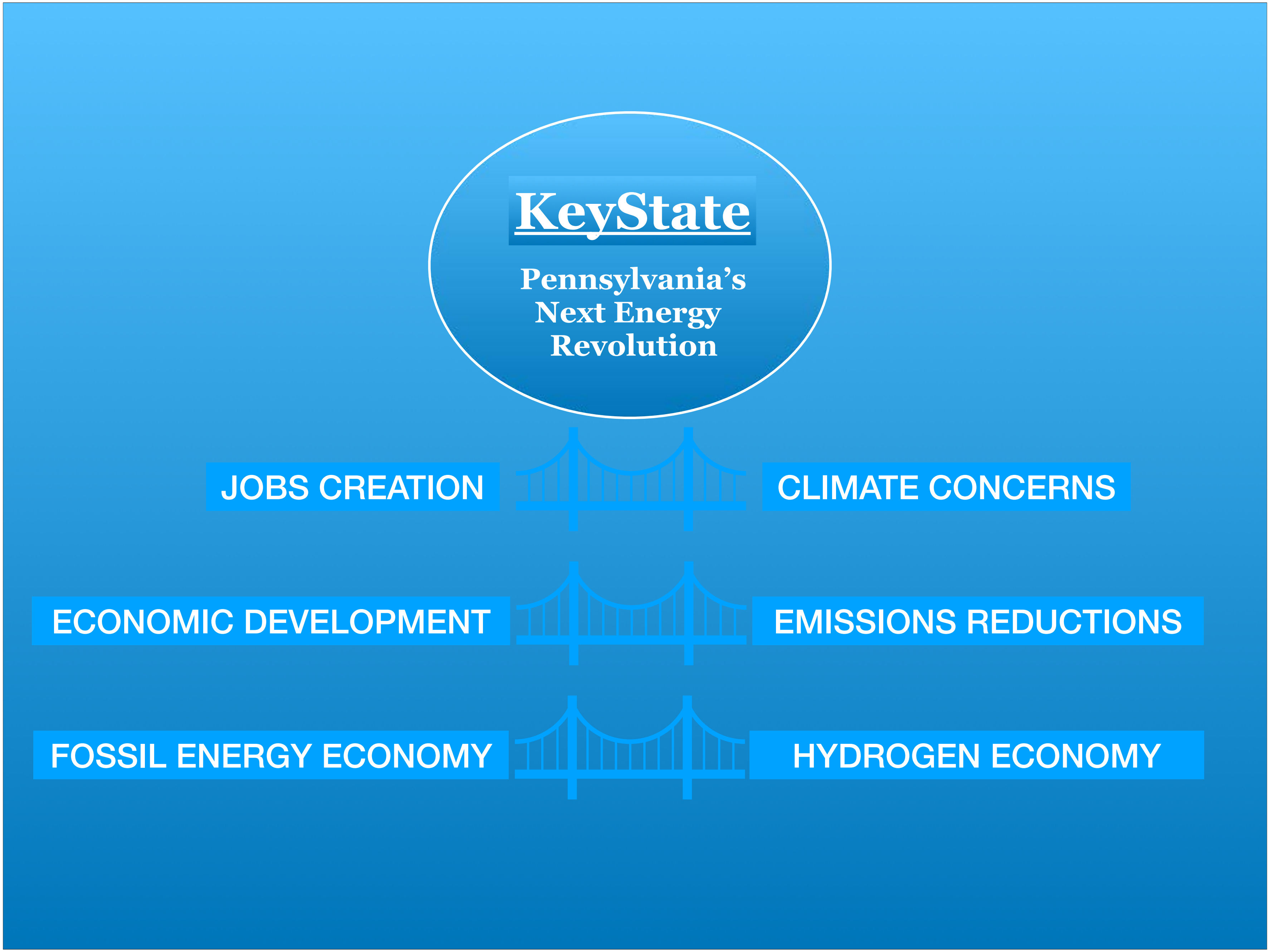
Next Energy
Revolution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JOBS CREATION
CLIMATE CONCERNS
ECONOMIC DEVELOPMENT
EMISSIONS REDUCTIONS
FOSSIL ENERGY ECONOMY
HYDROGEN ECONOMY

Statement by Dr. Jennifer Wilcox
Acting Assistant Secretary and Principal Deputy Assistant Secretary
For the Office of Fossil Energy and Carbon Management
U.S. Department of Energy

Before the
Pennsylvania House Policy Committee

<u>Philadelphia, PA</u>
July 21, 2021

Chairman Bizzarro and members of the Policy Committee, it is my pleasure to appear before you today to discuss what we are doing in the Department of Energy (DOE) – and, more specifically, in the Office of Fossil Energy and Carbon Management (FECM) – to advance the Biden-Harris Administration's mission to decarbonize the electricity sector by 2035 and all sectors of the U.S. economy by 2050.

That mission – and the work required to achieve it – is more urgent than ever before. We have little time left to avoid some of the worst impacts of climate change. The climate crisis threatens our people and communities, public health and economy, and, to be even more direct – our ability to live on planet Earth.

Rising to and meeting that challenge is one of President Biden's primary goals – and the reduction, removal and avoidance of greenhouse gas emissions are indispensable to getting us to net-zero carbon emissions by 2050. That applies not just to the ways we develop, deliver, and use energy, but also applies to our industrial sectors.

Research, development, demonstration, and deployment (RDD&D) of decarbonization technologies will drive the critical energy transition needed to get us to net-zero by 2050. Advancing technologies and infrastructure of carbon capture and storage (CCS), carbon dioxide removal (CDR) technologies, and hydrogen production, transport, and use in the economy are indispensable to this effort. I would like to first examine what FECM is doing to advance CCS.

Although not nearly enough, we have seen some progress on CCS over the past decade. For example, in their recent CCS status report, the Global Carbon Capture and Storage Institute noted that in 2020 there were 65 commercial CCS projects in various stages of development worldwide – a 33 percent increase over 2019.

Many of these projects are here in the United States, and the team I lead at the Department of Energy has been at the forefront of these accomplishments. Of course, there are still challenges to these technologies – including, most notably, a shortage of policies that help to make carbon capture and dedicated storage economically viable. But through increased demonstration and deployment supported by our office, we're making progress on driving those costs down through learning by doing.

As you know, DOE has invested a great deal of time and resources on CCS on Coal. In the U.S., the fleet is aging and many of the units are based on older and inefficient technology such as subcritical boilers. In addition, in the U.S. we are fortunate to have a wide variety of low-carbon energy options that do not come with the added challenge of managing CO_2 or other hazardous air pollutants.

CCS should not be seen as a blanket solution - and where and how it is deployed takes thought and a strategic approach for it to be successful and sustainable in the long-term. The portfolio of solutions to getting to net-zero carbon emissions in the U.S. may be quite different than that of other parts of the globe. It is important to recognize that the investments we have made in CCS on coal will be leveraged. For instance, some of the same technologies for capturing emissions from coal-fired power plants can also be used for carbon capture from the natural gas power sector and even the process emissions from some industrial sectors like cement and also steel production.

Carbon capture on committed emissions infrastructure such as natural gas fired power plants that likely will not reach retirement age for another decade or two may be good candidates for CCS. In addition, increased focus will be on parts of the industrial sector that we rely heavily on – such as cement and steel production. Earlier this year, FECM released a funding opportunity announcement for $75 million for R&D and FEED studies for carbon capture and dedicated storage on natural gas power plants and industrial plants.

Therefore, going forward, we want to take carbon capture out of its silo and leverage some of the work already being done by FECM to expand the potential of CCS to focus more on deployment and toward the development of low-carbon products like cement and concrete, steel, paper, fuel, nylon polyester, and other important products.

In particular, for the production of synthetic fuels and chemicals with CO_2 as a feedstock, the sourcing of low-carbon hydrogen will be critical and there is significant potential in applying carbon capture to help advance a low-cost and low-carbon hydrogen economy.

But as critical as CCS is, it is just one pathway that we need to pursue to achieve net zero. The reality is that we need an economy-wide effort to get to where we need to be.

Climate models make it clear that <u>both</u> CCS and carbon dioxide removal (CDR) technologies will be needed to meet climate goals. To achieve net zero we will need CDR approaches that can permanently remove CO_2 from the accumulated pool in the atmosphere. That is where our direct air capture research and development (R&D) efforts can play an important role. Separating CO_2 from the atmosphere has some aspects that overlap with point source capture, which has been a significant part of FECM's CCS R&D program – both in terms of the separation processes and its reliable storage.

So, as part of a broader DOE effort to advance CDR technologies, we are leveraging much of our work on CCS to help advance direct air capture. In fact, FECM recently awarded $12 million to six projects we believe will help advance direct air capture – including a project that will increase the amount of CO_2 captured through direct air capture and another project that will use low-carbon energy sources to power commercial scale direct air capture operations.

Finally, I want to note that our future work on CCS will focus less on early stage R&D and more on the development and deployment of CCS technologies. We look forward to working with our stakeholders on front end engineering and design studies, developing regional storage facilities, and maturing some of our advanced CCS and CDR technologies for commercial deployment.

Turning to hydrogen, FECM has invested considerable resources to support the development of gasification systems with pre-combustion carbon capture for producing hydrogen as a feedstock for fuel as well as hydrogen turbines and fuel cells for electricity generation. We have also conducted technical and economic system studies evaluating hydrogen production through processes like steam methane reforming. In the meantime, one of our major CCS demonstration projects in Port Arthur, Texas– is successfully combining carbon capture with steam methane reforming to produce hydrogen. The facility is capturing over 90 percent of the CO_2 that is generated from the production of clean hydrogen. The project has captured over 7 million tons of CO_2 since 2013.

Additionally, our National Energy Technology Laboratory (NETL) is part of a two-year, $15 million research consortium tasked with examining the impact of blending hydrogen in natural gas on existing gas infrastructure to support the eventual transition to pipelines that can carry 100% hydrogen.

Earlier this year we awarded four projects to evaluate the conversion of plastics, biomass residuals, waste coal and existing coal using gasification with carbon capture to produce clean hydrogen. In our Fiscal Year 2022 budget request we have a strong emphasis on hydrogen production and use as we plan to accelerate the development and deployment of modular gasifiers integrated with CCS, 100 percent fired hydrogen turbines, to support the clean hydrogen deployment.

The decarbonization of the electricity, industrial, and transportation sectors will require a significant increase of critical minerals and materials in the market to support the manufacturing of clean energy products such as rotors and magnets for renewable energy and electric vehicles, sorbents and membranes for carbon capture systems, and novel catalysts in processes for clean hydrogen production and CO_2 conversion. The Minerals Sustainability Division in my Office and NETL are supporting R&D focused on the characterization, recovery, and production of critical minerals from coal refuse and acid mine drainage which can support the reclamation of existing mine lands. In April we announced that Penn State was selected to receive an award to identify critical minerals resources in north Appalachia.

While we focus on the work needed to scale these critical technologies, we must also incorporate a new way of thinking, where environmental justice, equity, and workforce development are at the center of our work. To put it in President Biden's words, we have an opportunity to build back better – to build and deploy these important technologies in a better way than we have done previously. To incorporate and engage local communities – especially those that have been disempowered –and engage them in the decision-making process.

For example, apart from determining the technologies we need, we also need to choose carefully where to site projects. We need to recognize that they must be sited in locations where there is support for those projects, community involvement, and real benefits for the surrounding populations.

President Biden is prioritizing a whole-of-government approach to address injustices, both past and present – and he is committed to making that approach central to all federal climate action. To that end, this administration is working on the Justice40 Initiative to deliver 40 percent of the overall benefits of climate investments to disadvantaged communities. These investments will make sure the communities who have been impacted the most from pollution are first to benefit.

For us at DOE, that means that we will work at every level to address the disproportionate health, environmental, economic, and climate impacts on disadvantaged communities.

Mr. Chairman, and members of the committee, this completes my prepared statement. I would be happy to answer any questions you may have at this time.

Prepared Testimony of

Andrew G. Place
Director, U.S. State Energy and Climate Policy
Clean Air Task Force

before the
Pennsylvania House Democratic Policy Committee
Hearing on Carbon Capture

July 21, 2021

Clean Air Task Force
114 State Street, 6th Floor
Boston, MA 02109
(617) 624-0234
http://www.catf.us

Good morning, Chairman Bizzarro and members of the Committee. I am Andrew Place, Director, U.S. State Energy and Climate Policy at the Clean Air Task Force (CATF). It is a pleasure to be in front of you this morning. I am a resident of Greene County. Prior to joining CATF in 2020 I served as a commissioner on the Public Utility Commission, having been nominated by Governor Wolf. Prior to my tenure on the Commission, I was Corporate Director of Energy and Environmental Policy at natural gas producer EQT, as well as formerly holding a research fellowship in Carnegie Mellon University's Department of Engineering and Public Policy, with a particular focus on energy system innovation, particularly carbon capture and sequestration.

Why CCS

Carbon capture and storage (CCS) represents a powerful tool to reduce CO2 emissions in Pennsylvania. The technology can remove CO2 from the emissions of power plants, industrial facilities and create near zero-emission fuels for the heavy transportation and other sectors. CCS can be built as part of new plants or added to existing ones. The technology is flexible and can remove emissions from combustion or process steps. It can even remove CO2 from the atmosphere (Direct Air Capture or DAC). IEA calls carbon capture and storage (CCS) "vital" and "essential," accounting for about 14% of the CO_2 cuts (6,000 million tonnes) in 2050 needed to avoid temperature increases of 2 degrees Celsius.[1]

My testimony will focus on CCS in the industrial and power sectors. I'll also describe how CCS can help establish a new industry, making clean hydrogen available alongside renewable resources. CCS removes 90% of the CO2 in these applications, but as climate goals increasingly target net-zero emissions, CCS can adapt to eliminate over 99% of the CO2 from these emission sources.

CCS combines three distinct technologies: 1) Carbon capture, which separates CO2 from flue and process gases and compresses it to a liquid-like state; 2) Transportation, which moves the compressed CO2 often through dedicated pipelines; and 3) Storage that injects the compressed CO2 deep below the ground surface to permanently isolate it in saline formations or aging oil fields through a process called enhanced oil recovery (EOR).

I will begin my testimony by describing where CO2 is most likely to be stored in the state. That's likely to be in the western half of the Commonwealth because the storage geology is more favorable. The first CCS projects will likely be close to storage to limit transportation costs, implying that steel mills, power plants, cement plants, and other facilities located in Western Pennsylvania will go first. I'll describe the opportunities and challenges these

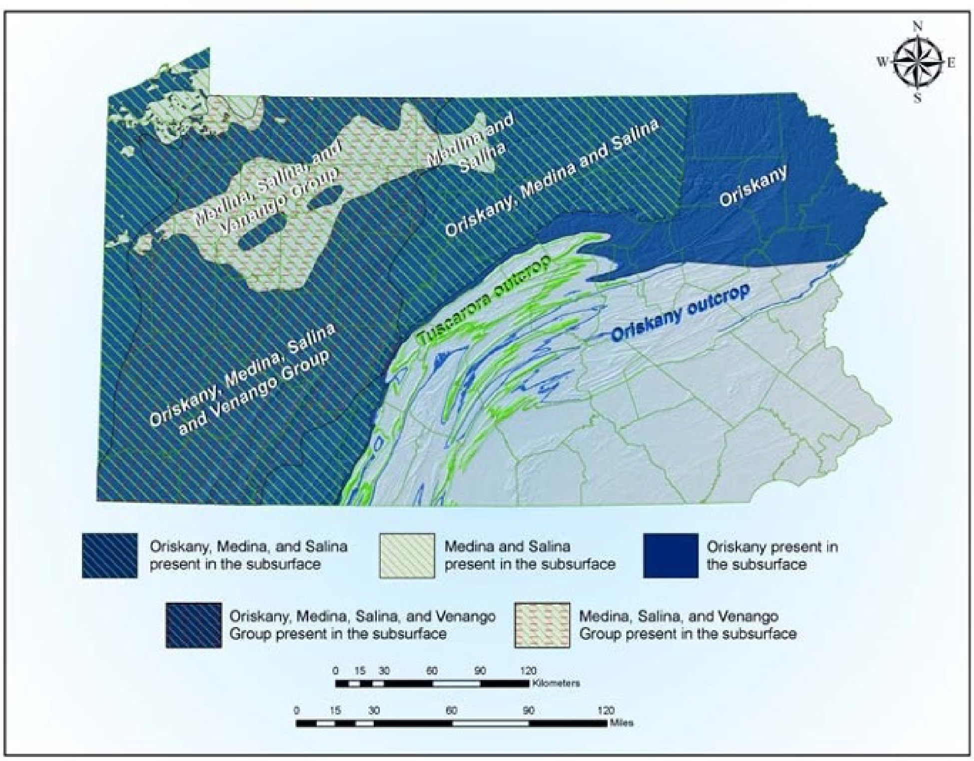
[1] International Energy Agency, Energy Technology Perspectives 2015, pages 207, (2015), *available at*: https://www.iea.org/etp/etp2015/

sources face and how creating a network of pipelines and storage sites called a "hub" can lower costs. Over time, this hub can expand so that sources across the state can use CCS.

I'll also talk about emerging opportunities to use carbon capture to facilitate the emergence of a new industry in the state: turning our natural gas resources into clean hydrogen to fuel buses, heavy-duty trucks, and feedstock and heat used in industrial applications. None of this progress can occur without federal and state policy support, so I will outline the needed actions both in DC and in Harrisburg.

<u>Where</u>

Significant carbon storage resources exist in Pennsylvania's subsurface. The Appalachian Basin hosts sedimentary rock formations that have the capacity for CO_2 sequestration, including deep saline formations and depleted oil and gas reservoirs. The Midwest Regional Carbon Sequestration Partnership (MRCSP) Phase I study indicates that Pennsylvania has a storage capacity of approximately 75.6 gigatonnes (Gt) within its deep saline formations, with additional storage potential in oil and gas reservoirs via storage associated with enhanced oil recovery (EOR). The primary potential deep saline reservoirs in PA are the Medina Group, Salina Group, and Oriskany Sandstone. Storage potential in Pennsylvania is mostly limited to western counties of the commonwealth due to geologic complexity and deformation associated with the Appalachian Structural Front in central and eastern PA, as seen in the map below.

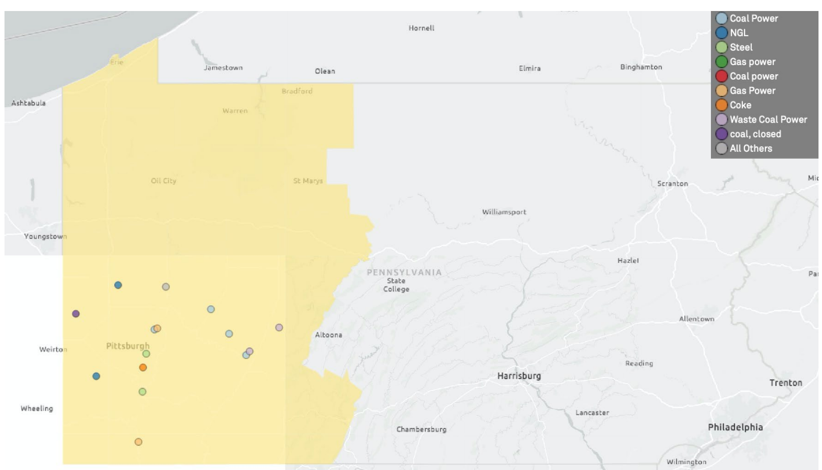


Geographic distribution of potential geologic storage reservoirs in Pennsylvania (source: PA DCNR)

While the results of the MRCSP Phase I study are promising in terms of storage potential in PA, significant geologic uncertainty exists in the region and detailed characterization programs must be executed in order to refine storage estimates and demonstrate feasibility of safe storage. The MRCSP estimate of 75.6 Gt storage capacity is likely overly optimistic and represents a first pass regional assessment of storage capacity based on existing and readily available data. More accurate and realistic storage estimates must be determined via site-specific advanced characterization efforts in order to reduce geologic uncertainty and evaluate risk. Pennsylvania's geologic storage resources have the capacity to mitigate significant amounts of CO_2 emissions, however a greatly expanded decarbonization market may require additional storage options outside of PA. In this scenario, CO_2 could be transported out of state to geologic storage sites that have additional capacity such as offshore mid-Atlantic.

<u>First CCS Projects</u>

The map below illustrates 15 different steel, cement, coal-fired, and gas-fired power plants that might be good candidates for CCS projects in Western Pennsylvania. To be sure, some of these sources might adopt different CO2 reduction strategies, but together these sources released 41 million tons of CO2 releases in 2019, so their size makes them worthy of consideration. Also, there are other sources not on the map that could be good CCS candidates. These sources are likely to come first from the lightly colored counties indicated on the map.



Source: CATF based on EPA GHG FLIGHT data

One of the main barriers these projects face in implementing CCS is cost. Each capture project is different, and costs depend on several factors, including the concentration of CO2 in the emissions, how many other pollutants must be removed to protect the capture system's solvent, and the ease with which equipment can be added to an existing site. For first projects with favorable characteristics, the capture costs can vary for the industries shown in the map between $40 and $65 per metric ton of CO2.[2]

In addition to capture, the costs of CCS also include transportation and storage at secure geologic sites. These costs depend upon several factors. Transportation costs generally decrease with quantity (the more CO2, the lower the unit costs), distance (shorter is cheaper), and terrain. Storage also depends on quantity (generally, unit costs decrease with more CO2), but costs also depend on the quality of the geology. As a first estimate, it's not unrealistic to think transport and storage costs for CO2 in the state could be around $25 per metric ton of CO2. Of course, the costs could be higher or lower. But it implies as a first approximation that the incentives needed for the combined cost of capture and transport/storage in the state might need to be in the vicinity of $85 per metric ton of CO2.

For these reasons, creating a network of pipelines and storage sites, called a hub, can reach economies of scale that lower costs. One example of a hub is the Permian Basin in Texas. Since the 1970s, aging oil fields in Texas have injected CO2 underground as part of EOR operations. The pipelines and EOR fields form a hub that minimizes transportation costs. Creating a similar hub for saline storage would help Western Pennsylvania lower costs for CO2 mitigation purposes. Once established, it is easier to connect CO2 sources outside of Western Pennsylvania to the hub, making it possible to reduce CO2 emissions from sources in the eastern part of the state.

Hydrogen

Many current uses of fossil fuels could be transitioned over time to hydrogen which -- because it does not contain carbon -- emits no carbon dioxide when used. These current uses include diesel fuel in heavy trucking, fuel oil in marine shipping, natural gas in industry, and coal in ironmaking. While hydrogen is not a direct substitute for fossil fuels in all cases, the technology to use hydrogen is entering the commercial market. Heavy trucks with hydrogen fuel tanks, fuel cells, and electric drivetrains are being tested at the Port of Los Angeles and other places. The Los Angeles testing is sponsored in part by the California Air Resources Board because the trucks are zero-emitting at the tailpipe, which is of immediate benefit to the local community.

In the marine shipping industry, internal combustion engines burning ammonia have been developed and are being evaluated for pilot routes over the next several years. Ammonia is derived from hydrogen and nitrogen in the air, and like hydrogen it creates no CO2 when burned. Direct reduction of iron ore with hydrogen is being tested at significant scale in Europe, and replacement of some coke (a product of coal) with hydrogen in existing blast

[2] *Transport Infrastructure for Carbon Capture and Storage*, Great Plains Institute and the University of Wyoming, https://www.betterenergy.org/wpcontent/uploads/2020/06/GPI_RegionalCO2Whitepaper.pdf page A5.

furnaces appears possible. Industrial burners in chemical manufacturing plants already use high levels of hydrogen in some cases and this practice could be expanded to reduce CO2 emissions.

These applications and others are expected to grow rapidly over the coming decades and analysts such as Bloomberg New Energy Finance and the International Energy Agency have concluded that hydrogen might provide 10 – 20% or more of global energy by mid-century across disparate sectors. The Fuel Cell and Hydrogen Energy Association estimates that hydrogen could be a $140 billion per year industry in the US alone by 2030, and $750 billion per year by 2050.

Pennsylvania is well-positioned to capitalize on this opportunity. Our hydro resources are already being explored for their hydrogen production potential using electrolysis technology, and Pennsylvania's wind resources are stronger than in some neighboring states. Our substantial natural gas endowment is probably our greatest asset for hydrogen production, however. These resources are vast, are additional to renewable electricity supplies needed for grid decarbonization, and through reforming technologies with deep carbon capture can likely produce hydrogen at substantially lower cost than renewable pathways today, at least where natural gas is inexpensive. From a system perspective, reforming Pennsylvania's natural gas with CCS to produce hydrogen could allow us to remain a keystone of energy supply in the region, while sequestering the associated carbon dioxide locally instead of releasing it to the atmosphere where fuels are consumed.

Development of hydrogen production, transportation, storage, and distribution, and end-use applications and markets, will take resources. Fortunately, some of these appear to be increasingly available from the federal government. There are many proposals in Washington, D.C. currently to establish tax credits for production of hydrogen that meets overall clean criteria (which would include CCS). Just as importantly in the near term, the Energy Infrastructure Act moving in the US Senate Energy and Natural Resources Committee would provide up to $8 billion in federal funding for development of "clean hydrogen hubs", each including both production and end-uses. Hubs such as these are under consideration in Los Angeles and Houston in the US, and Edmonton, Rotterdam, and Singapore overseas, often associated with port activities.

If enacted, a federal law supporting clean hydrogen hubs could provide the funding needed to kick-start hydrogen in Pennsylvania and enable us to maintain our energy leadership while supporting significant carbon dioxide reductions at the same time. The Pittsburgh area and the Delaware River port complex area would be obvious candidates for hydrogen hub development. Some exploratory work is already underway, including a recent high-profile MOU between US Steel and the Norwegian firm Equinor that would include both clean hydrogen and CCS.

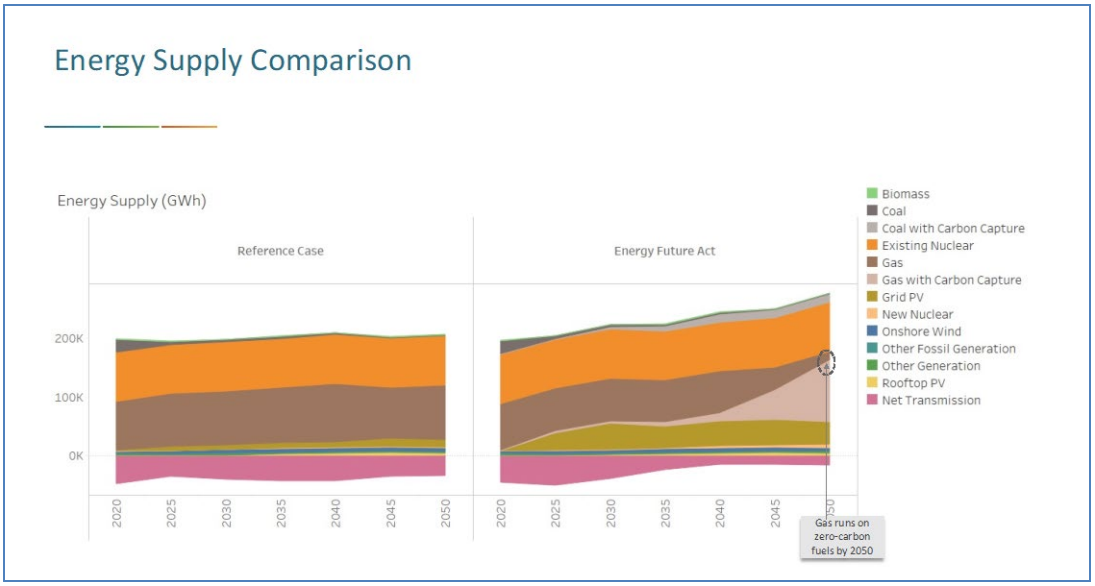
What Policies are Needed for CCS?

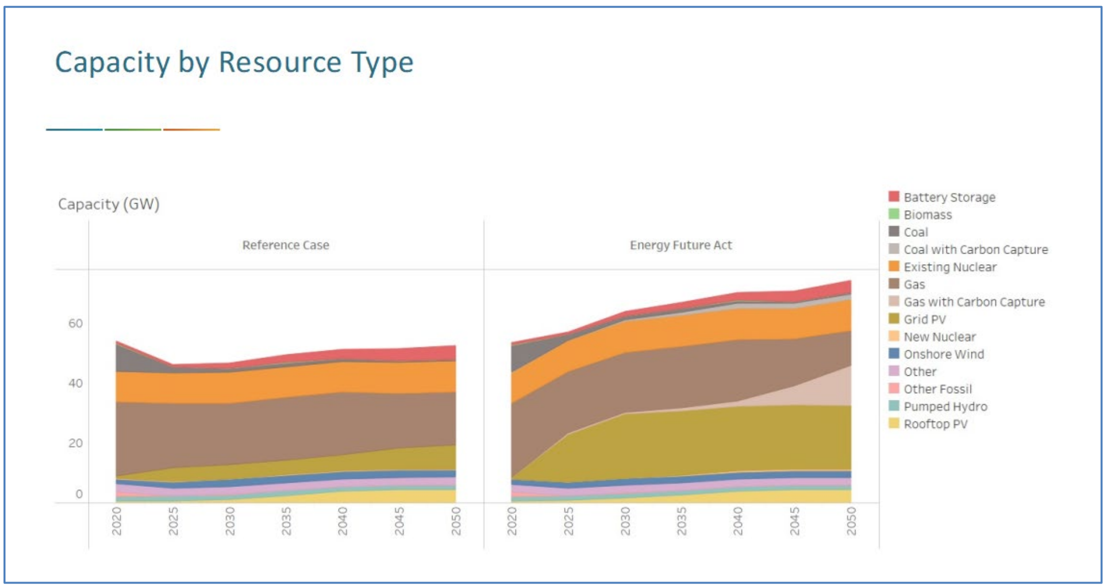
With respect to CCS, Congress is considering two sets of policies that would address the economic barriers to CCS. First, several bills would raise the value of 45Q tax credits from $50 per metric ton of CO2 stored in saline formation to $85 per metric ton. This is important, because as I testified earlier, the total cost of CCS might be in this range. If Congress increases the value of this incentives and makes other changes that include "direct pay," extending the commence construction window, and eliminating size-based eligibility thresholds, it would send a strong signal to the state's power and industrial sectors.

Still, the largest uncertainty facing CCS in the state is transport and storage costs. Another bill before Congress is the SCALE Act. It would provide nearly $5 billion in grants to drive regional transport and storage networks. This legislation, in combination with 45Q enhancements, could establish wide-scale CCS in the state.

Of course, the state can also take measures to drive CCS. I particularly draw your attention to the value of Pennsylvania adopting a Clean Energy Standard. Ten States have standards for eliminating CO2 emissions from the power sector by midcentury – with Arizona and Oregon joining the list in June and Illinois appearing to be in final deliberations to do the same. Illinois's draft language is particularly of salutary value in its consideration of economic justice, environmental justice, employment, rate modernization and ratepayer impacts.

Eliminating CO2 emissions from the commonwealth's power sector by 2050 – net-zero by 2050 – while ensuring economically just and readily dispatchable power, will most certainly include power derived with carbon capture. Existing nuclear will need to be retained as will profound investments in grid-scale renewables, and transmission, both intra and inter-state. CATF undertook to model this decarbonized energy system – through an expansion, both in scale and scope, of Pennsylvania's Alternative Energy Portfolio Standard. The results, illustrated in the graphs below, make clear the scale and sources of generation within the commonwealth in a fully decarbonized energy system – including that Pennsylvania would remain a robust exporter of power to its neighbor states.





In closing, I hope that I have provided insight into the necessity to deploy and commercialize carbon capture and storage if the commonwealth is to fully decarbonize its power system in a manner that is economically just; as well as the related value and necessity of zero-carbon fuels for decarbonizing the economy as a whole.

Clean Air Task Force, if called upon, certainly remains committed to proffering analysis to inform the economic and technology debates required to meet the dual obligations for system decarbonization and affordable and reliable power for the commonwealth's citizens and commerce.

Thank you. I would be happy to address any of your questions.