Clean Air Task Force – Oral Testimony

Sam Bailey, Regional Hubs Manager - Appalachia

Environmental Resources & Energy Committee of the Pennsylvania House of Representatives

Hydrogen Hubs Hearing
11/13/2023 10:00am

Introduction

Good morning, Chairman Vitali, Chairman Causer, and members of the Committee. My name is Sam Bailey, and I am the Regional Hubs Manager for Appalachia at the Clean Air Task Force (CATF), an environmental organization founded in 1996. CATF is a global nonprofit organization working to safeguard against the worst impacts of climate change by catalyzing the rapid development and deployment of low-carbon energy and other climate-protecting technologies. I appreciate the opportunity to testify today.

The climate challenge is vast and urgent. Achieving net-zero emissions across the energy system within several decades will require transitions in both energy production and in many varied end-use sectors. Much of that transition will occur through electrification and a vast expansion of renewable energy resources. Electrification is an essential decarbonization strategy, but it is not sufficient by itself.

Today, about 80% of end-use energy[1] is provided by fuel molecules, as opposed to electrons. Some of those end uses can be electrified or can apply carbon capture, but not all of them, so we will also need zero-carbon fuels—like hydrogen and ammonia—for full economy-wide decarbonization. Hydrogen is a versatile, carbon-free “energy carrier” that can substitute for some conventional fossil fuels. The United States already has considerable industrial experience making and using hydrogen, and we are developing and innovating improved techniques for producing very low-carbon hydrogen. In addition to its use as a fuel, hydrogen serves a key role in our economy as a feedstock for processes and products in the industrial and agricultural sectors, and low-carbon hydrogen will be necessary to decarbonize existing uses of currently unabated hydrogen.

In the United States, hydrogen provides an enormous opportunity for decarbonization in certain sectors and can contribute to reducing overall carbon dioxide equivalent (CO_2e)

[1] Of the 69.7 quads of total energy delivered in the U.S., 12.5 quads—or 18%—are from electricity. See the U.S. Energy Information Administration, U.S. energy consumption by source and sector, 2020, https://www.eia.gov/energyexplained/us-energy-facts/images/consumption-by-source-and-sector.pdf.

emissions by 10% compared to 2005 baseline levels in some of the most difficult-to-decarbonize applications.[2] Developing and commercializing the technologies needed for affordable and clean hydrogen production, transportation, and use across varied supply chains will require sustained and committed financial support from the U.S. government.

Overview of the Regional Clean Hydrogen Hubs

On October 13, the U.S. Department of Energy (DOE) took a critical step forward in accelerating clean hydrogen production by announcing its initial Regional Clean Hydrogen Hubs selections. The program, which was included in the bipartisan Infrastructure Investment and Jobs Act, represents a massive opportunity for the U.S. to establish itself as a leader in global clean hydrogen development, creating new jobs and benefits in diverse regions across the country.

Pennsylvania is the only state to host two hydrogen hubs selected for award negotiations, MACH2, the Mid-Atlantic Clean Hydrogen Hub, and ARCH2, the Appalachian Regional Clean Hydrogen Hub. Pennsylvania was also the state with the most hydrogen hub applicants; four hubs with projects sited in the commonwealth submitted final applications to the Department of Energy in April 2023. In addition to ARCH2 and MACH2, the proposed Decarbonization Network of Appalachia (DNA) and the Great Lakes Clean Hydrogen Hub (GLCH) also had projects sited in the state. It remains to be seen if either the DNA or GLCH projects will proceed independently without DOE funding.

Together, the two selected hubs create a production portfolio for the region with strong optionality in terms of production technology. This diversity of production feedstocks and technology could prove beneficial given how early-stage the clean hydrogen industry is today.

My written testimony includes further details on the selected hubs as well as a technical discussion of key considerations for clean hydrogen end-use and production. I encourage you to refer to that written testimony and reach out to Clean Air Task Force if I can be of additional assistance.

Priority end uses for clean hydrogen

I'd now like to talk about the most climate beneficial end-uses for hydrogen and necessary requirements for producing low-carbon hydrogen. The International Energy Agency (IEA) projects that the world's demand for hydrogen must increase by approximately 350% between 2021 and 2050 to hit midcentury climate goals.[3][4] Approximately 10 million metric tons (MMT) of hydrogen are currently produced in the United States each year, and 95% of that hydrogen is

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[2] See DOE Pathways to Commercial Liftoff: Clean Hydrogen https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

[3] Hydrogen demand in 2050 estimated to be 420 MT per IEA see https://iea.blob.core.windows.net/assets/66b8f989-971c-4a8d-82b04735834de594/WorldEnergyOutlook2023.pdf

[4] Hydrogen Demand in 2021 was 94 MT per IEA see https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf

'grey' or fossil-based ***without*** carbon capture. Domestic hydrogen production is responsible for approximately 100 million metric tons of carbon dioxide emissions in the U.S. each year.

Given hydrogen's physical properties, which make it energy-intensive to produce and difficult to transport and store, low-carbon hydrogen should be prioritized for use in applications where there are no other cost-effective or energy-efficient decarbonization options.

The first order priority use cases for low-carbon hydrogen are primarily sectors that are currently reliant on carbon-intensive hydrogen and are essential to our economy. These include **ammonia production, methanol production, crude oil refining and petrochemicals. Steel manufacturing** using DRI-EAF technology and greenfield steel is also a first order priority end use sector.

The second order priority use cases are primarily sectors within our transportation system that need to fully decarbonize and may be difficult to electrify. These include **aviation, heavy-duty trucking, and marine shipping.**

Niche and unlikely applications for hydrogen are sectors that have alternative, economical decarbonization pathways but may utilize hydrogen in some cases due to economic, geographic, political, or other unique circumstances. These end uses include power generation and seasonal energy storage, residential use, and light-duty vehicles.

Pennsylvania has significant opportunities to decarbonize existing sources of GHG emissions with low-carbon hydrogen, which align with CATF's priority end-use sectors including steel and iron production, petrochemicals, heavy-duty trucking, aviation, marine shipping, and other hard-to-decarbonize sectors. At the facility level, in the refining, chemicals, and metals sectors alone, Pennsylvania had 9.2 million metric tons of direct CO_2 emissions in 2022.[5]

When looking at both hydrogen hubs in Pennsylvania, we see some priority end-use applications as well as some likely niche applications as further detailed in my written testimony.

<u>Considerations for climate-friendly production of clean hydrogen in Pennsylvania</u>

Low-carbon hydrogen can be produced in multiple ways, but the two pathways most relevant to today's hearing are through water electrolysis using zero-carbon electricity or by methane reforming using natural gas with carbon capture. Producing all the low-carbon hydrogen that may be needed for a decarbonized economy (i.e., the sectors discussed above) will be a significant challenge.

The land use and infrastructure challenges of the additional renewable energy build-out associated with producing all the necessary low-carbon hydrogen via electrolysis, and the

[5] 2022 EPA Greenhouse Gas Emissions from Large Facilities, https://ghgdata.epa.gov/ghgp/main.do

potential for delay in making this hydrogen available, suggest that additional low-carbon hydrogen supplies, including hydrogen made from fossil fuels, would be beneficial for decarbonization. Greenhouse gas emission intensities for the produced hydrogen can vary drastically depending on specific decisions made by producers in each of the different production pathways.

Electrolytic Hydrogen Production

The first method of hydrogen production, via water electrolysis, is an energy intensive process and must utilize zero-carbon electricity, such as renewable energy, to achieve GHG emissions intensity close to 0 $kgCO_2e/kgH_2$. To ensure that electrolytic hydrogen is truly clean, electrolyzers should be powered by zero-carbon electricity sources such as wind, solar, or nuclear.

Fossil-based Hydrogen Production with Carbon Capture and Storage

Because it is risky to assume that electrolysis with renewable electricity can provide the volumes of hydrogen we might need by mid-century for decarbonization, we need to develop other production pathways in parallel, including reforming based pathways with carbon capture, which are often called “blue” when referring to hydrogen production.

Hydrogen produced from natural gas, either by steam methane reforming or autothermal reforming, can produce low-carbon hydrogen, with an emissions intensity as low as around 1.5 to 2.0 $kgCO_2/kgH_2$ if specific measures are taken. Upstream leak rates of methane from natural gas infrastructure must be absolutely minimized, the process must be designed for and achieve high rates of carbon capture, and zero-carbon electricity must be used to serve the process electricity demand.

Conclusion

Pennsylvania is fortunate to be a source of energy and industry for the region and the country. The same qualities that helped the commonwealth achieve this leadership role can allow it to be a leader in our clean energy future. While it will take sustained attention from policymakers to achieve this transition, the clean hydrogen hubs are a key piece of the puzzle. Properly established, these hubs can help ensure that the industries, jobs, and communities that make up this great commonwealth will benefit from our decarbonized future.

Thank you for the opportunity to contribute to this important discussion.

CLEAN AIR TASK FORCE

Clean Air Task Force – Written Testimony

Sam Bailey, Regional Hubs Manager - Appalachia

Environmental Resources & Energy Committee of the Pennsylvania House of Representatives

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Introduction

Good morning, Chairman Vitali, Chairman Causer, and members of the Committee. My name is Sam Bailey, and I am the Regional Hubs Manager - Appalachia, at the Clean Air Task Force (CATF), an environmental organization founded in 1996. CATF is a global nonprofit organization working to safeguard against the worst impacts of climate change by catalyzing the rapid development and deployment of low-carbon energy and other climate-protecting technologies. With more than 25 years of internationally recognized expertise on climate policy and a fierce commitment to exploring all potential solutions, CATF is a pragmatic, non-ideological advocacy group with the bold ideas needed to address climate change. CATF has offices in Boston, Washington D.C., and Brussels, with staff working remotely around the world. I appreciate the opportunity to testify today.

The climate challenge is vast and urgent. Achieving net-zero emissions across the energy system within several decades will require transitions in both energy production and in many varied end-use sectors. Much of that transition will occur through electrification and a vast expansion of renewable energy resources. Electrification is an essential decarbonization strategy, but it is not sufficient by itself.

Today, about 80% of end-use energy[1] is provided by fuel molecules. Some of those end uses can be electrified or can apply carbon capture, but not all of them, so we will also need zero-carbon fuels—like hydrogen and ammonia—for full economy-wide decarbonization. Hydrogen is a versatile, carbon-free "energy carrier" that can substitute for some conventional fossil fuels. We already have considerable industrial experience making and using hydrogen, and we are developing and innovating improved techniques for producing very low-carbon hydrogen. Hydrogen also serves a key role in our economy as a feedstock for processes and products in the industrial and agricultural sectors, and low-carbon hydrogen will be necessary to decarbonize existing uses of currently unabated hydrogen.

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In the United States, hydrogen provides an enormous opportunity for decarbonization in certain sectors and can contribute to reducing overall carbon dioxide equivalent (CO_2e) emissions by 10% versus 2005 baseline levels in some of the most difficult-to-decarbonize applications.[2] Developing and commercializing the technologies needed for affordable and clean hydrogen production, transportation, and use across varied supply chains will require sustained and committed financial support from the U.S. government.

On October 13, the U.S. Department of Energy (DOE) took a critical step forward in accelerating clean hydrogen production by announcing its initial Regional Clean Hydrogen Hubs selections. The program, which was included in the bipartisan Infrastructure Investment and Jobs Act, represents a massive opportunity for the U.S. to establish itself as a leader in global clean hydrogen development, creating new jobs and benefits in diverse regions across the country.

CATF works to support the development and deployment of zero-carbon fuels—as both a fuel and a feedstock—through policy design and advocacy, research, and engagement with stakeholders ranging from industry to policymakers to regional and local community and environmental organizations. CATF has engaged with more than 20 applicants to the Department of Energy's Regional Clean Hydrogen Hubs Program in regions that span the entire U.S. Beginning when the Funding Opportunity Announcement launched in September of 2022, CATF's regional Hydrogen Hubs Managers have built relationships with applicants in nearly every region of the United States. Our team brings deep expertise in the regions in which they engage, and we will continue to work with DOE, community organizations, public-sector stakeholders, and hub developers to ensure the program maximizes climate and community benefits.

Pennsylvania was the only state to host two hydrogen hubs selected for award negotiations, MACH2, the Mid-Atlantic Clean Hydrogen Hub, and ARCH2, the Appalachian Regional Clean Hydrogen Hub, in part owing to the state's robust energy economy, potential for decarbonization, and skilled workforce. Before I discuss the selected hub proposals in my testimony, I'd first like to talk about the most climate beneficial end-uses for hydrogen and necessary requirements for producing low-carbon hydrogen.

Demand for clean hydrogen & priority end uses

The International Energy Agency (IEA) projects that the world's demand for hydrogen must increase by approximately 350% between 2021 and 2050 to hit midcentury climate goals.[3][4] Approximately 10 million metric tons (MMT) hydrogen are currently produced in the United States each year, and 95% of that hydrogen is 'grey' or fossil based ***without*** carbon capture.

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[4] Hydrogen Demand in 2021 was 94 MT per IEA see https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf

Domestic hydrogen production is responsible for approximately 100 million metric tons of carbon dioxide emissions in the U.S. each year.

According to the Department of Energy's Commercial Liftoff report on Clean Hydrogen, demand for clean hydrogen in the U.S. could range from 5 to 20 MMT per year in 2030 and 27 to 80 MMT per year by 2050, with the bulk of that demand driven from ammonia and oil refining through 2030 and significant growth in fuel cell-based road transport driving post-2030 demand growth.

Given hydrogen's physical properties, which make it energy-intensive to produce and difficult to transport and store, low-carbon hydrogen should be prioritized for use in applications where there are no other cost-effective or energy-efficient decarbonization options. The graphic below outlines these sectors:

Figure 1: CATF's Priority Hydrogen End-Use Sector Applications

The first order priority use cases for low-carbon hydrogen are primarily sectors that are currently reliant on carbon-intensive hydrogen and are essential to our economy:

- **Crude oil refining and petrochemicals –** Refineries produce a wide array of products critical to the functioning of today's economy, and hydrogen is a critical feedstock in their operations. Hydrogen plays a role in production of transportation fuels, as well as non-fuel products like lubricants and components for steel and aluminum production.
- **Ammonia production –** Ammonia (NH_3) is critical for producing agricultural fertilizers. Hydrogen is an intermediate input in ammonia production, which involves reacting hydrogen with nitrogen from the atmosphere.
- **Methanol production –** Methanol (CH_3OH)[5] is a key industrial chemical used in the production of formaldehyde, acetic acid, and plastics. Hydrogen is an intermediate input in methanol production.
- **Steel manufacturing –** Hydrogen currently plays a role in steel manufacturing via the direct reduced iron-electric arc furnace (DRI-EAF) process (known by the trademark Midrex®). Using low-carbon hydrogen in existing DRI applications has been proposed to reduce climate impacts from steel manufacturing.

The second order priority use cases are primarily sectors within our transportation system that need to fully decarbonize and may be difficult to electrify:

- **Aviation –** Decarbonizing the aviation sector will require low-carbon hydrogen to upgrade biomass-based sustainable aviation fuels (bio-SAF), to produce synthetic jet fuel from hydrogen and captured carbon (synthetic SAF), and, potentially, to power aircraft that directly utilize hydrogen fuel.
- **Heavy-duty trucking –** A recent CATF analysis shows that hydrogen fuel cell vehicles (FCEVs) can play an important role alongside battery electric vehicles (BEVs) in decarbonizing the trucking sector. Heavy-duty FCEVs are a strong diesel replacement candidate on long-haul routes, thus increasing the percentage of the overall truck fleet that can be decarbonized, improving operational flexibility, and optimizing timelines as hours do not need be budgeted for charging.
- **Marine shipping –** Low-carbon ammonia may play a role as an alternative marine fuel, though health, safety, and environmental concerns associated with bunkering, storing, and combusting ammonia in marine engine rooms need to be thoroughly examined.

Niche and unlikely applications for hydrogen are sectors that have alternative, economical decarbonization pathways but may utilize hydrogen in some cases due to economic, geographic, political, or other unique circumstances:

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[5] Like urea, methanol contains a carbon atom that is normally sourced from natural gas or coal, which presents a challenge to full decarbonization in cases where the low-carbon (green) hydrogen is sourced from water electrolysis. Normally 80% of the carbon in natural gas ends up in the methanol molecule, which means that a small portion of process emissions from methanol production can be abated by 'green' hydrogen.

- **Power Generation and Seasonal Energy Storage –** Using low-carbon hydrogen for power generation can seem appealing as it can replace natural gas without emitting CO_2 when burned. However, using hydrogen as a fuel for electricity generation can be an ineffective and expensive way to decarbonize the power sector. The role that electrolytic hydrogen might more usefully play in a decarbonized power system is as long-duration energy storage for grid balancing—producing hydrogen at times when renewable generation would otherwise exceed demand and storing it until periods of higher energy demand.
- **Residential use** – Numerous independent studies have concluded that home heating alternatives such as heat pumps, solar thermal systems, and district heating are more economic, more efficient, less resource intensive, and have a smaller environmental impact compared to hydrogen.
- **Light-duty vehicles** – Hydrogen fuel cell vehicles may currently offer longer range and shorter refueling time than battery electric vehicles (BEVs), but they also require more energy input than BEVs, their costs per mile traveled are higher, and improvements to battery technology are likely to even the playing field for light-duty BEVs.

Pennsylvania has significant opportunities to decarbonize existing sources of GHG emissions with low-carbon hydrogen, which align with CATF's priority end-use sectors including steel and iron production, petrochemicals, heavy-duty trucking, aviation, marine shipping, and other hard-to-decarbonize sectors. At the facility level, in the refining, chemicals, and metals sectors alone, Pennsylvania had 9.2 million metric tons of direct CO_2 emissions in 2022.[6]

When looking at both hydrogen hubs in Pennsylvania, we see some priority end-use applications as well as some likely niche applications. For example, the KeyState Natural Gas Synthesis project, which is part of ARCH2, is planning a greenfield, natural gas-based Ammonia, Urea, and Diesel Exhaust Fluid production facility in Clinton County, PA. If the project can produce low-carbon hydrogen and low-carbon intensity chemical and fertilizer products, KeyState would be a successful example of a high priority end-use sector. Another example of a project targeting a priority end use sector is the Monroe Energy LLC refinery in Trainor, PA. As part of the MACH2 hub, this facility plans to use low-carbon hydrogen to decrease the carbon intensity of its jet fuel production, which is climate-beneficial if low-carbon hydrogen is replacing unabated grey hydrogen.

On the other hand, during the H2HUBS ANNOUNCEMENT AND SUMMARY BRIEFING held by DOE's Office of Clean Energy Demonstrations on October 16th, MACH2 listed power generation in the "End Uses" section, which CATF would consider a niche application and could delay grid decarbonization. We were also surprised to see that neither hub has announced plans to decarbonize steel in Pennsylvania, a large emitting sector which requires immediate attention. That being said, the Pennsylvania steel sector is making their own plans for decarbonization. On September 20th, US Steel and DOE's National Energy Technology Laboratory (NETL) announced

[6] 2022 EPA Greenhouse Gas Emissions from Large Facilities, https://ghgdata.epa.gov/ghgp/main.do

a trial of point source carbon capture at the Edgar Thompson Plant's blast furnaces in Allegheny County.

Considerations for climate-friendly production of clean hydrogen in PA

Low-carbon hydrogen can be produced in multiple ways, but the two pathways most relevant to today's hearing are through water electrolysis using zero-carbon electricity or by methane reforming using natural gas with carbon capture. Producing all the low-carbon hydrogen that may be needed for a decarbonized economy (i.e., the sectors discussed above) will be a significant challenge. Consider Pennsylvania, which consumes more than 419 million gallons of jet fuel each year.[7] On a direct energy basis, replacing that much jet fuel with hydrogen produced from solar electricity would require around 10 GW of photovoltaic installations.[8] This is around the total photovoltaic power currently installed in Pennsylvania, New York, and New Jersey combined.[9] Providing hydrogen just to replace the energy demand of Pennsylvania airports would require doubling the installed photovoltaic power in the region. Of course, that solar power is needed for other purposes as well, particularly for directly decarbonizing the electricity grid.

The land use and infrastructure challenges of this additional renewable energy build-out, and the potential for delay in making this hydrogen available, suggest that additional low-carbon hydrogen supplies, including hydrogen made from fossil fuels, would be beneficial for decarbonization. GHG emission intensities for the produced hydrogen can vary drastically depending on specific decisions made by producers in each of the different production pathways.

Electrolytic Hydrogen Production

The first method of hydrogen production, via water electrolysis, is an energy intensive process and must utilize zero-carbon electricity, such as renewable energy, to achieve GHG emissions intensity close to 0 $kgCO_2e/kgH_2$. To ensure that electrolytic hydrogen is truly clean, electrolyzers should be powered by zero-carbon electricity sources such as wind, solar, or nuclear. Depending on the grid, grid-connected electrolyzers can cause consequential emissions that are *twice* as high as un-abated steam methane reforming, the predominant method of producing hydrogen.[10]

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[7] *https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_jf.html*

[8] Based on typical jet fuel energy content, typical electrolyzer efficiency, and a solar photovoltaic capacity factor of 20%.

[9] *See* Solar Energy Industries Association, *Solar State by State*, https://www.seia.org/states-map, (last visited Nov. 8, 2023).

[10] Jay Bartlett & Alan Krupnick, Resources for the Future, *Decarbonized Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions* 7 (2020) ("If average grid power had been

CATF supports strong climate-beneficial requirements for long-term clean hydrogen incentives. For example, hydrogen producers seeking the federal hydrogen production tax credit under the Inflation Reduction Act (45V), the electricity, or the renewable energy credits used, should have the following three qualities (otherwise known as the "three pillars"):

1. *Additionality:* Electrolytic hydrogen producers must be able to show that the low-carbon electricity used by or claimed by the electrolyzer is *additional* to the quantity of low-carbon electricity that would have otherwise been generated to serve other electric loads;
2. *Geography-matching:* Due to the challenges of producing zero-carbon electricity around the country and the limitations of transmission capabilities to bring that electricity where it is needed, the electricity should be purchased in the same region as the electrolyzer operations so that both electricity generation and demand are occurring within the same region and are physically deliverable to one-another; and
3. *Temporal-matching:* The electrolyzer should only be operated when additional low-carbon electricity generation is available, which can be achieved by requiring that the electricity consumed to produce hydrogen and the electricity or EACs procured be matched on an hourly basis. Without this, electrolyzers would increase demand on the grid when only higher-emitting sources of generation are available and could result in higher GHG-intensity than intended.

Fossil-based Hydrogen Production with Carbon Capture and Storage

Because it is risky to assume that electrolysis with renewable electricity can provide the volumes of hydrogen we might need by mid-century for decarbonization, we need to develop other production pathways in parallel, including reforming based pathways with carbon capture, which are often called “blue” when referring to hydrogen production.

Hydrogen produced from natural gas (either by steam methane reforming or autothermal reforming) can produce low-carbon hydrogen, with an emissions intensity as low as around 1.5 to 2.0 $kgCO_2/kgH_2$ if specific measures are taken. Upstream leak rates of methane from natural gas infrastructure must be absolutely minimized, the process must be designed for and achieve high rates of carbon capture, and zero-carbon electricity must be used to serve the capture equipment electricity demand.

With Pennsylvania’s vast natural gas endowment, the commonwealth is well-positioned to produce low-carbon hydrogen at lower cost than renewable pathways today as long as low carbon intensity is ensured. Carbon capture and storage (CCS) is key to near-term low-carbon hydrogen production and decarbonization efforts in Pennsylvania. Pennsylvania was the 4th

used for electrolysis, the CO2 emissions intensity would be more than twice that of SMR because of the inefficiency in the additional step of energy conversion.”). *See also* Wilson Ricks et al., *Minimizing emissions from grid-based hydrogen production in the United States*, 2023 Environ. Res. Lett. at 2 (2023).

highest carbon-emitting state in the U.S. in 2019, with over half of its emissions attributed to its power sector and industry. While other emerging decarbonization technologies for industry and power generation are developed, CCS is a commercial technology ready for deployment[11] on methane-based hydrogen production. From a system perspective, reforming Pennsylvania's natural gas with CCS to produce hydrogen could allow this to remain a keystone of energy supply in the region, while sequestering the associated CO_2 locally instead of releasing it to the atmosphere where the fuel is consumed.

With the need for carbon capture comes the need for geologic storage. In a typical capture system, carbon is captured at the point of emission, transported to a storage site, and injected deep underground for permanent storage. Fortunately, much of Pennsylvania is situated in the Appalachian Basin, which hosts many deep sedimentary rocks that could be suitable for geologic carbon storage. Pennsylvania has multiple geologic formations in the western and northern portions of the commonwealth that could serve as potential carbon storage reservoirs. The U.S. Department of Energy estimates that the total saline storage potential in Pennsylvania is 17.34 gigatonnes[12], which is enough capacity to sequester all of PA's direct CO_2 emissions in 2021 (approximately 100 million metric tons of CO_2) every year for 170 years. However, this high-level estimate likely far exceeds realistic commercial storage potential, as it does not factor in injectivity, the ease with which fluids like carbon dioxide can flow through geologic formations, among other factors.

To better understand and verify storage potential in Pennsylvania, more detailed geologic assessment is necessary. A key challenge to identifying suitable commercial-scale storage sites in Pennsylvania is the relative lack of publicly available subsurface data for deeper saline formations. Despite the long history of oil and gas exploration in the commonwealth, publicly available data required for carbon storage capacity assessment (e.g., wireline logs, core-derived porosity and permeability data, reservoir tests, etc.) is sparce for deep saline formations. This assessment highlights the need for additional geologic characterization work in Pennsylvania. Very deep saline formations in the commonwealth are often poorly understood and could serve as potential carbon storage reservoirs once properly characterized.

That is not to say there is no history of work and funding to understand geologic characterization in Pennsylvania. The Midwest Regional Carbon Sequestration Partnership (MRCSP) was a DOE funded program conducted over 3 phases from 2003-2020, which covered 10 states and sought to assess sources and sinks in the region as well as evaluate feasibility of CCUS across the region through small scale pilots. Following the conclusion of the MRCSP, the Midwest Regional Carbon Initiative (MRCI) was founded to continue building on the foundation laid by MRCSP to move the region towards readiness for deployment of commercial CCS. Final technical reports from the MRCSP and a comprehensive database of Pennsylvania resources can be found in MRCI's Regional Database.

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[11] https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf
[12] https://www.netl.doe.gov/sites/default/files/2018-10/ATLAS-V-2015.pdf

Finally, on July 10th, 2023, DOE's Office of Fossil Energy and Carbon Management (FECM) announced a funding award of just under $1M for the PA Department of Conservation and Natural Resources' Central Appalachian Partnership for Carbon Storage which intends to "accelerate deployment of carbon management in Pennsylvania and West Virginia" by reducing barriers to entry to carbon storage project opportunities."[13] The project hopes to build on the work of MRCSP & MRCI to "construct a free, public-facing web-based tool with comprehensive datasets and information needed to inform CO2 storage permitting efforts."

Regional Clean Hydrogen Hub Program Overview

As previously noted, the Regional Clean Hydrogen Hubs Program is a critical piece of the Department of Energy's efforts to create market liftoff for clean hydrogen. DOE was directed by IIJA to evaluate and select hubs based on several criteria, including the following:

- **The extent to which production is clean:** Hubs should "demonstrably aid" the achievement of the Clean Hydrogen Production Standard of 4kg of CO2e/kgH2. Hubs will be evaluated (with the GREET model) on the extent to which they reduce emissions across the full life cycle (current hub estimates range from 1-9M MT of CO_2 reduced per year)
- **Community benefits:** Community Benefits Plans scored at 20% of total application, hubs demonstrating long-term workforce development and jobs opportunities considered favorable
- **Volumes of production:** must be capable of producing 50-100 MT of clean hydrogen per day, higher volumes are favorable
- **Diversity of hubs**: As directed by IIJA, hubs should demonstrate the following:
    - Diverse production methods (nuclear, renewable, and fossil based)
    - Diverse end uses (power, industrial, transportation, and residential/commercial heating)
    - Diverse geography, including at least two in natural gas abundant regions

Together the hubs are projecting to reduce 25 MMT of greenhouse gas emissions each year, create tens of thousands of jobs, and create a variety of community benefits including air quality improvements and reduction and workforce development and job training. If implemented thoughtfully, CATF expects to see the program develop several benefits including the following:

- Decarbonization of hard-to-electrify end-use sectors and existing hydrogen use cases: The hydrogen hubs program will play an important role in creating cost-effective decarbonization options for hard-to-abate sectors outlined above.
- Lower domestic clean hydrogen production costs: The hydrogen hubs program, coupled with the 45V clean hydrogen tax credit included in the Inflation Reduction Act, will help accelerate the clean hydrogen market by making production more cost-effective and providing significant incentives for project developers.

[13] https://www.energy.gov/fecm/project-selections-foa-2799-regional-initiative-accelerate-carbon-management-deployment

- Build-out of connective infrastructure: The hubs program has the potential to spur the creation of hydrogen and ammonia-fueled transportation corridors that connect between hubs, which can strengthen the economics for individual hubs and foster a build-out of a global clean hydrogen network.
- New jobs and community benefits: The development of hubs has the potential to create new jobs and workforce development opportunities within communities. Hubs have the opportunity to partner with local unions, vocational schools, and apprenticeship programs as they develop. Hubs can also engage in thoughtful processes with communities and community-based organizations to ensure that community concerns are addressed and that community benefits are based on direct input from communities. Additionally, tax credits for clean hydrogen production include prevailing wage requirements for producers aiming to receive federal tax credits. The hydrogen production tax credit in the Inflation Reduction Act provides that, to receive the full value of the tax credit, hydrogen producers must pay contractors and subcontractors "wages at rates not less than the prevailing rates for construction, alteration, or repair." The carbon capture tax credit, which can be used by "blue" hydrogen producers, contains similar prevailing wages requirements. Both the hydrogen production tax credit and the carbon capture tax credit also include apprenticeship requirements.

Details of the Individual Hub Proposals

Pennsylvania was the state with the most hydrogen hub applicants in the country; four hubs with projects sited in the commonwealth submitted final applications to the Department of Energy in April 2023. In addition to MACH2 (The Mid-Atlantic Clean Hydrogen Hub) and ARCH2 (the Appalachian Regional Clean Hydrogen Hub) which were selected for funding award negotiations, the Decarbonization Network of Appalachia (DNA) and the Great Lakes Clean Hydrogen Hub (GLCH) also had projects sited in the state. It remains to be seen if either the DNA or GLCH projects will proceed independently without DOE funding. More information on the non-selected applicants can be found on CATF's U.S. Hydrogen Hubs Map. The best current source of public information on the hubs can be found in slide format from the DOE Office of Clean Energy Demonstrations (OCED)'s virtual H2Hub community briefing for MACH2 and ARCH2.

The two selected hydrogen hubs in Pennsylvania have significant opportunities and challenges ahead of them. The hubs bookend the state, with MACH2 originally formed by the City of Philadelphia and ARCH2 by the government in West Virginia. These applicants plan to develop quite different production processes with some overlap in primary end-uses, according to CATF research, applicant announcements, and the OCED announcement, as shown in the table below.

	States Involved	Lead Applicant	Production Pathways	End-Users
MACH2	PA, NJ, DE	Mid-Atlantic Clean Hydrogen Hub, Inc.	Renewable Nuclear Renewable Natural Gas	Transportation Industrial Aviation Fuel Agriculture Power Generation Heating Others
ARCH2	WV, PA, OH, KY[14]	Battelle Memorial Institute	Natural Gas Reforming Renewable Natural Gas Renewable Other	Transportation Industrial Aviation Fuel Chemicals Power Generation Heating Others

The key difference between the two hubs on the production side is the stated primary production pathway. While ARCH2 is a primarily natural gas-based hub, the majority of the hydrogen MACH2 plans to produce is renewable- or nuclear-based. ARCH2 does have renewable based hydrogen projects planned out of state and there are no public announcements of in-state renewable projects for the hub. Together, the two selected hubs create a production portfolio for the region with strong optionality in terms of production technology. This diversity of production feedstocks and technology could prove beneficial given how early-stage the clean hydrogen industry is today. I will first give an overview of the ARCH2 hub with a focus on the Pennsylvania projects.

[14] There are no projects cited in Kentucky but impacts from the hub projects in neighboring states are expected.

ARCH2 Overview

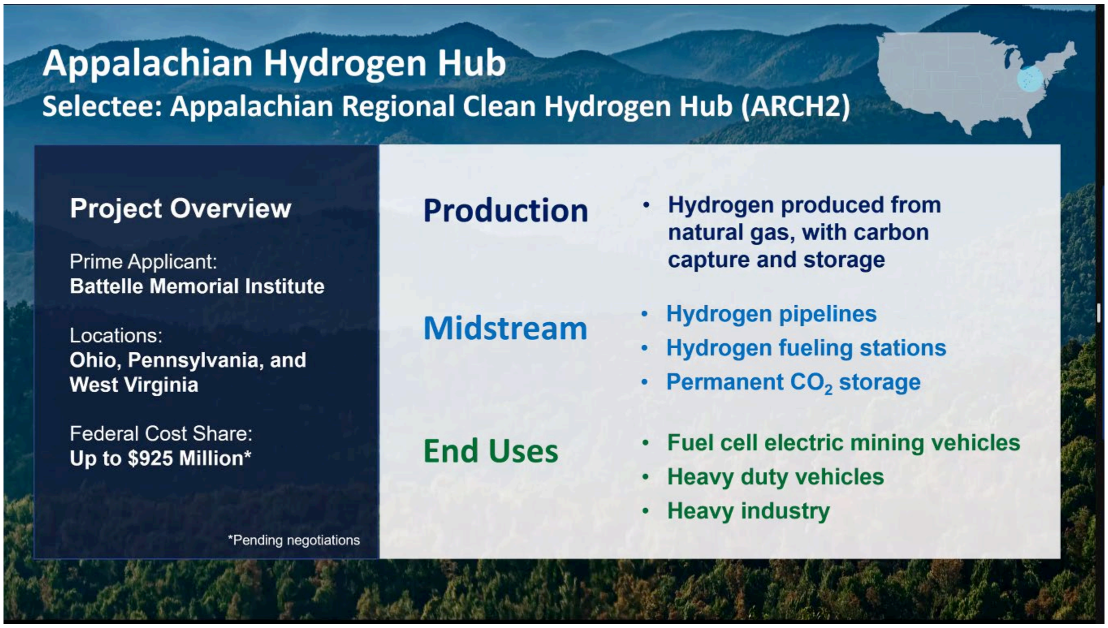

Figure 2: ARCH2 Project Overview (Source: DOE OCED Hubs Announcement and Summary Briefing)

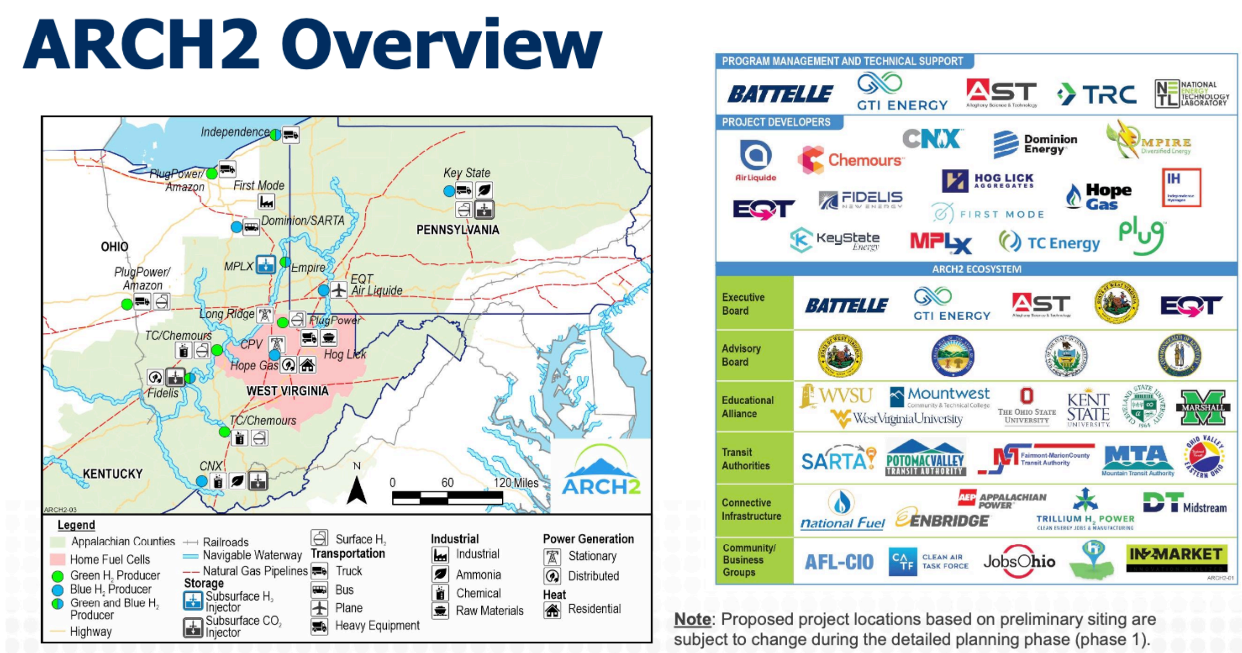

Figure 3: ARCH2 Overview (Source: DOE OCED ARCH2 Regional Briefing)

The prime applicant for ARCH2 is the Battelle Memorial Institute, which has a significant history of administering federal funding. ARCH2 was selected for up to $925 million of federal cost share, though it is currently unclear how this will be allocated to individual projects. ARCH2 has approximately 16 announced project locations including both hydrogen production and end use, with three of those currently sited in the state of Pennsylvania:

1. KeyState's ammonia facility in Clinton County, PA. The Keystate projects plans to utilize on-site methane production to produce hydrogen. The hydrogen and CO_2 captured during the reforming process will be used as feedstocks to produce ammonia, urea, and diesel exhaust fluid. Keystate also announced that Nikola would purchase hydrogen from the project for fuel cell electric truck fueling.
2. EQT-GTL plan to produce low-carbon hydrogen from natural gas which will be used for aviation fuel production. This production will be located in the southwest part of the state.
3. Air Liquide, the final announced ARCH2 project in Pennsylvania, will liquify excess gaseous hydrogen from the EQT-GTL projects for the transportation sector.

As required for all hubs, ARCH2 submitted a Community Benefits Plan as part of their final application to DOE. There is limited publicly available information, but Allegheny Science and Technology, the hub's community benefits lead, has indicated there will be local town halls in convenient locations for communities near hub projects. A slide presented during the H2Hubs announcement webinar shares highlights of ARCH2's community benefits plan:

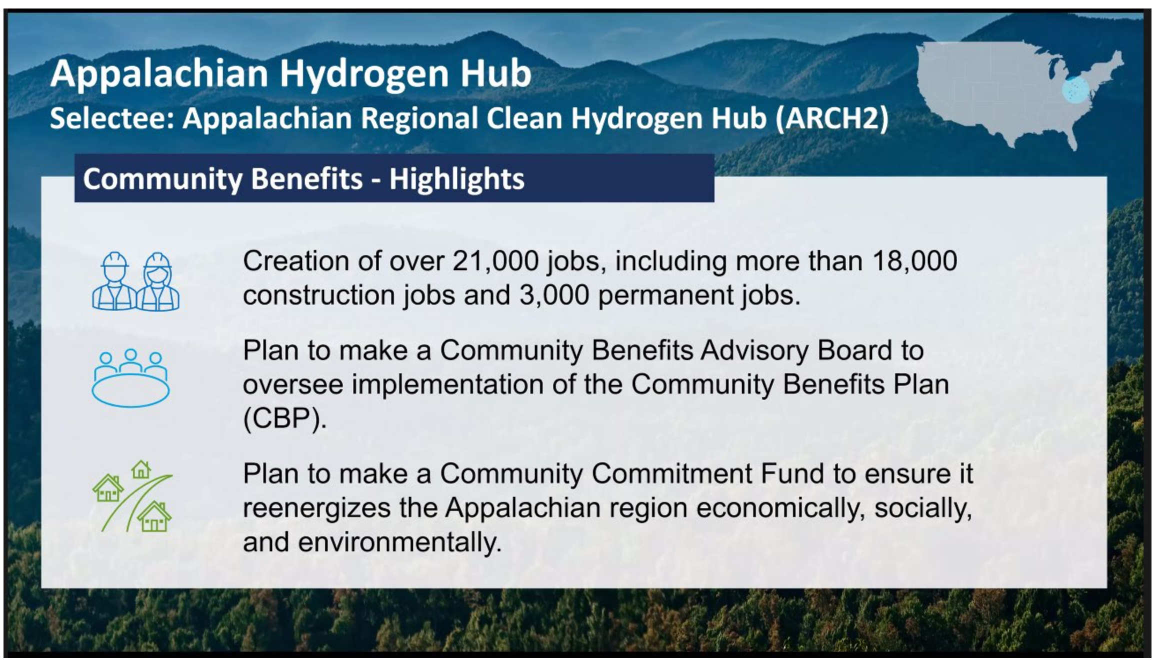

Figure 4: ARCH2 Community Benefits (Source: DOE OCED Hubs Announcement and Summary Briefing)

The hub plans to create a "Community Benefits Advisory Board" to oversee implementation of the Community Benefits Plan (CBP) as well as a "Community Commitment Fund" to ensure "economic, social and environmental" impacts are felt in the region. Notably, the hub expects creation of over 21,000 jobs, including more than 18,000 construction jobs and 3,000 permanent jobs. It is unclear how many of these jobs will be in Pennsylvania.

MACH2 Overview

The MACH2 hub is sited in the greater Philadelphia region and differs from ARCH2 in several ways. The Prime Applicant is the Mid-Atlantic Clean Hydrogen Hub, Inc., a non-profit formed to apply for hydrogen hub funding. MACH2 was selected for up to $750 million of federal cost share, but again, it is currently unclear how this will be allocated to individual projects. The MACH2 hub focuses on production of low-carbon hydrogen and transportation to end-users through new and existing pipeline infrastructure. The region has a long history of oil and gas infrastructure with existing easements and rights-of-ways connecting existing and former facilities.

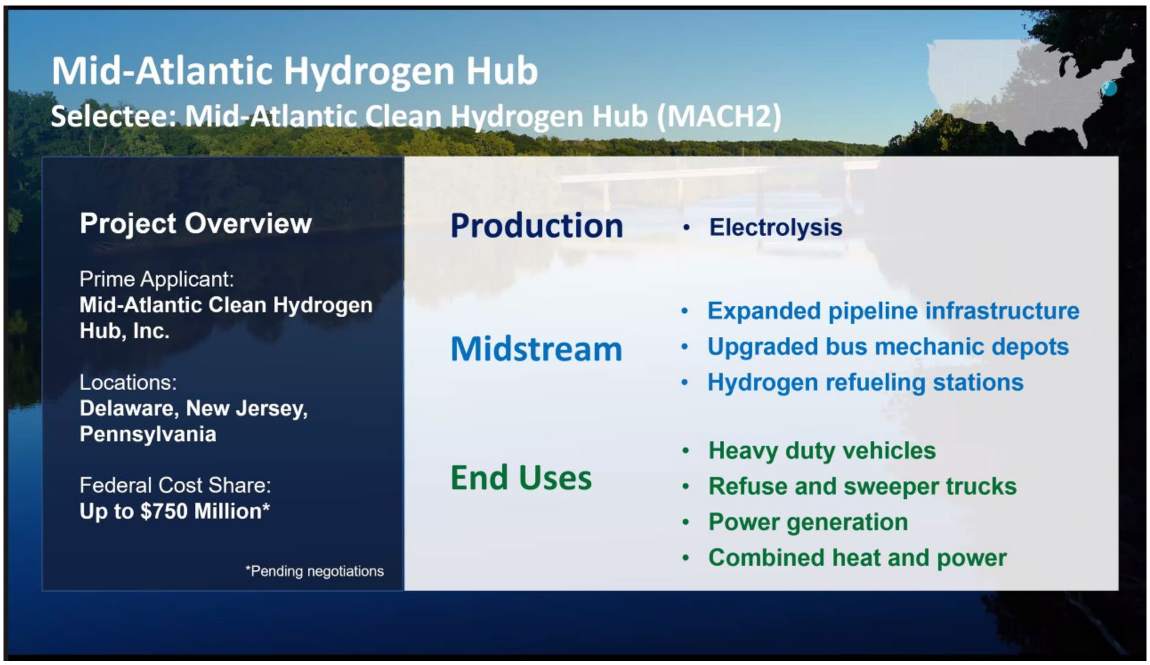

Figure 5: MACH2 Project Overview (Source: DOE OCED Hubs Announcement and Summary Briefing)

Figure 6: MACH2 Projects (Source: DOE OCED MACH2 Regional Briefing)

MACH2 has released fewer details publicly compared to ARCH2, summarizing details on two slides during their H2Hub Community briefing webinar. It is difficult to discern specific project details, but MACH2 has indicated that their total production will be approximately 271 metric tons of hydrogen per day with the mix of production at the final stage projected to be 77% renewable based, 20% nuclear based, and 3% from biogas reforming[15] with gas sourced from a "small waste methane stream in Philadelphia." At this time, it appears that all nuclear based hydrogen production for MACH2 will be located in New Jersey, with a portion from a potential new advanced nuclear installation at Holtec's Oyster Creek Facility.[16] The following is a breakdown of production, transport, and end-use project components in Pennsylvania:

- Production includes a series of electrolysis facilities and one biogas reformation facility including PGW Richmond, PGW Passyunk, Messer, & Versogen.
- Transportation of hydrogen includes PGW Passyunk Pipeline, Smartpipe retrofit of large diameter crude oil pipeline for H_2 Storage, IRPL Marcus Hook to Hilco, Delaware City Phi Pipeline, and Twin Oaks to Marcus Hook, Marcus Hook to Monroe, and Monroe to Messer Connectors.
- End Use includes SEPTA bus fleet fueling, PHI municipal fleet, DRS Terminal, Hilco Redevelopment Partners (Former PES Refinery Site), and Monroe Energy.

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[15] https://www.energy.gov/sites/default/files/2023-10/H2Hubs_Mid_Atlantic_Community_Briefing.pdf

[16] https://holtecinternational.com/2022/02/22/holtec-and-hyundai-engineering-and-construction-completed-workshop-on-smr-160-balance-of-plant-design/

Like ARCH2, MACH2 submitted a CBP as part of their final application. There is limited public information on the hub's CBP, but a few important details were shared during the H2Hubs announcement and community engagement webinars:

Figure 7: MACH2 Workforce and Jobs (Source: DOE OCED MACH2 Regional Briefing)

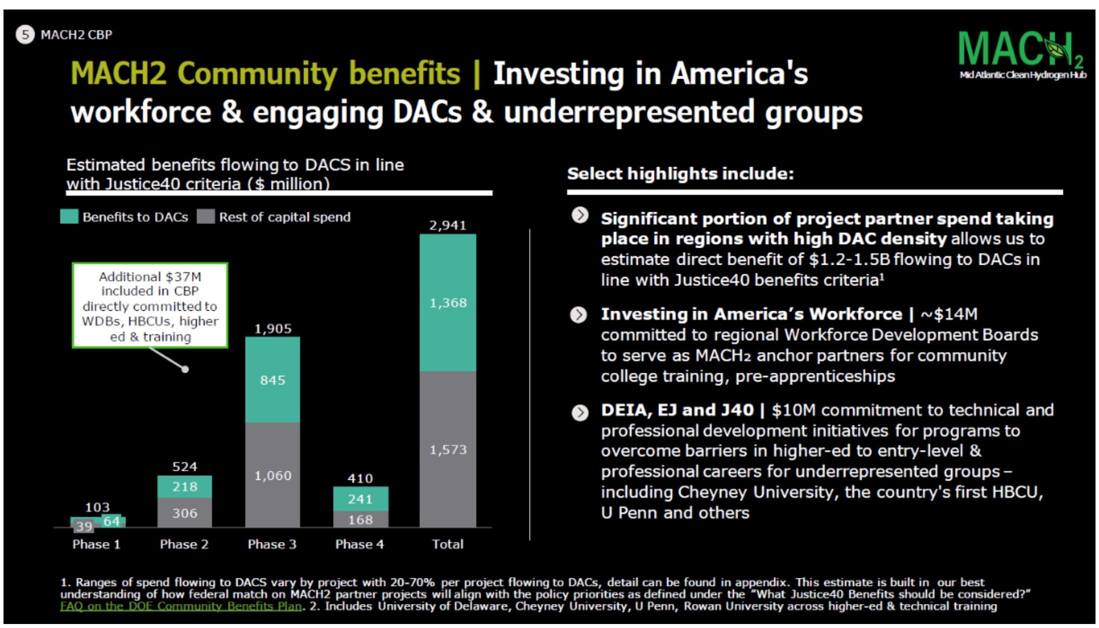

Figure 8: MACH2 Community Benefits (Source: DOE OCED MACH2 Regional Briefing)

MACH2 expects to create 20,800 jobs including 13,400 union construction jobs with the addition of plans to negotiate project labor agreements for all projects. It is unclear at this time how many jobs will be in Pennsylvania, versus Delaware and New Jersey. MACH2 has also indicated that they plan to provide almost $25 million for regional Workforce Development Boards and technical and professional development initiatives.

Recommendations for Hubs

CATF sees four key challenges that MACH2 and ARCH2 hub developers, DOE, and state policymakers should focus on to ensure the selected projects are implemented in a way that maximizes climate and community benefit:

- **Need for greater transparency:** Until the H2Hub Community Briefings in late October and early November 2023, applicants have been hesitant to release project-specific information due to the uncertain and competitive nature of the application process. Although award negotiations will likely continue through mid-2024, the announcement of selections creates an opportunity for DOE and Pennsylvania hub developers to reassess their approach to transparency and consider sharing greater details of their intended plans publicly. This could have several benefits, including trust-building with communities and creating opportunities for shared learning among hubs.
- **Increased coordination:** With selections announced, the door has been opened significantly for DOE and hubs to start thinking about coordination on several fronts:
    - DOE and hubs should consider how to harmonize Regional Clean Hydrogen Hubs funding with other related funding programs including the DOT's Clean Corridors Program, FECM's Pipeline Infrastructure Grant Program, EPA's Climate Pollution Reduction grants, FAA's Sustainable Aviation Fuels program, DOE's Direct Air Capture program, and FHWA's Charging and Fueling Infrastructure Discretionary Grant Program.
    - ARCH2 and MACH2 should consider how best to coordinate with each other and DOE on shared infrastructure, best practices, and clean transportation corridors that may connect the hubs with each other and with other regions.
    - DOE, ARCH2, MACH2, and non-selected hubs applicants should consider how best to coordinate with projects that will continue without DOE funding – particularly where projects could be folded in to selected hub proposals.
- **Deeper engagement between communities and hubs:** As ARCH2 and MACH2 move through award negotiations and begin to release details on specific project development partners and prospective project sites, hubs and DOE should meaningfully engage with impacted communities as early as possible to better understand and address community concerns. DOE and hub developers should ensure that impacted communities have adequate time, resources, and opportunity to directly give input on the types of benefits they would like to see created in their respective communities.
- **Soliciting third-party technical expertise:** Additionally, hubs should consider developing new structures and advisory bodies to source wisdom from a wide array of third-party environmental and climate technical experts including nonprofits, research organizations, and academic institutions. Seeking this expertise can help ensure the projects maximize climate, environmental, and community benefits.

Looking ahead, CATF expects to see the award negotiation phase last into early- to mid-2024, and we hope to see this process create opportunities for community input to inform the community benefits portions of the applications. Through this next phase, CATF will continue to engage deeply in Pennsylvania and Appalachia, at the regional level, and with DOE to ensure the program maximizes climate and community benefits, as well as to be a source of information on hub related developments for diverse stakeholders including hub developers, community-based organizations and local, regional, and state-level policy makers.

Conclusion

Pennsylvania is fortunate to be a source of energy and industry for the region and the country. The same qualities that helped the commonwealth achieve this leadership role can allow it to be a leader in our clean energy future. While it will take sustained attention from policymakers to achieve this transition, the clean hydrogen hubs are a key piece of the puzzle. Properly established, these hubs can help ensure that the industries, jobs, and communities that make up this great commonwealth will benefit from our decarbonized future.