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Comments in Response to the RFI on ‘Regional Clean Hydrogen Hubs Implementation Strategy’

Alan Krupnick and Lucie Bioret

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US Department of Energy
1000 Independence Avenue SW
Washington, DC 20585
Attn: DE-FOA-0002664
Submitted via: **H2Hubs@hq.doe.gov**

Dear Director Dr. Satyapal:

I am pleased to share the accompanying comments to the US Department of Energy's (DOE) Hydrogen Program in response to Request for Information (RFI) DE-FOA-0002664: Regional Clean Hydrogen Hubs Implementation Strategy.

RFF is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. RFF is committed to being the most widely trusted source of research insights and policy solutions leading to a healthy environment and a thriving economy.

While RFF researchers are encouraged to offer their expertise to inform policy decisions, the views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors. RFF does not take positions on specific legislative proposals.

Based on research undertaken here at RFF, underpinned by conversations with relevant players in industry, we offer comments on questions in the following sections of the RFI: Regional Clean Hydrogen Hub Provisions and Requirements; Solicitation Process, FOA Structure, and Implementation Strategy; and Market Adoption and Sustainability of the Hubs.
All authors' comments are our own and submitted as independent authors.

For future reference, all of RFF's work related to industrial decarbonization can be found at **https://www.rff.org/topics/industry-and-fuels/.** If you have any questions or would like additional information, please contact me at **krupnick@rff.org.**

Sincerely,

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Comments in Response to the RFI on ‘Regional Clean Hydrogen Hubs Implementation Strategy’

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With special thanks to Jay Bartlett, Resources for the Future

On February 15, 2022, the US Department of Energy’s (DOE) Hydrogen Program issued a Request for Information seeking to obtain public input regarding solicitation process and structure of a DOE Funding Opportunity Announcement (FOA) to fund regional clean hydrogen hubs, in accordance with the Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL). Considering the scale of the program, we support public consultation to refine the selection process. We acknowledge the importance of Regional Clean Hydrogen Hubs (H2Hubs) to demonstrate technology readiness and to decrease risk associated with different hydrogen production processes and potential end-uses for clean hydrogen.

Category 1: Regional Clean Hydrogen Hub Provisions and Requirements

1. The BIL defines a “regional clean hydrogen hub” as “a network of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in close proximity.”

a. What should qualify as ‘close proximity’ in context of the hub requirements?

The essential idea implied by many of the RFI questions is that there are tradeoffs among multiple, sometimes conflicting objectives, hub definitions, and other elements noted in the BIL and RFI. In that light, and as an example pertinent to question 1.1.a, close proximity should be left undefined. One group may have elements that are not in as close proximity as another group’s elements, but have other advantages that make the former group more competitive (with respect to cost, cost-effectiveness, etc.) even with higher costs allocated to pipeline transport.

b. What existing facilities and infrastructure, including pipelines and storage facilities, could be most easily leveraged by the H2Hubs?

We do not have any direct knowledge about plans for applications for hubs, other than the four-state intermountain west group, through our partnership with the I-WEST Consortium led by Los Alamos

National Lab and funded by the offices of Fossil Energy and Carbon Management (FECM) and of Energy Efficiency and Renewable Energy (EERE) at DOE. Wyoming, Colorado, Utah and New Mexico have already published a Memorandum of Agreement and are planning on submitting a joint application to the future H2Hubs Funding Opportunities. Following the principle that the least risky place to build new infrastructure is next to existing infrastructure, they explore plans to build pipelines along the I-80 corridor. Besides, new pipelines dedicated to CO_2 could be built using the right of way established along existing oil and gas pipelines. The organizers note the need for better definition and guidelines regarding existing and future permitting and regulation from the Federal Energy Regulatory Commission (FERC), the Pipeline and Hazardous Materials Safety Administration (PHMSA), and the US Environmental Protection Agency (EPA).

Concerning other locations, a hub on the Gulf Coast of Texas and Louisiana would be able to leverage the only lengthy hydrogen pipeline networks that currently exist in the United States[1] (CRS 2021). Additionally, all three US hydrogen storage facilities are in Texas[2]. Along with hydrogen pipelines, salt cavern storage, and industrial consumers, a Gulf Coast hub could leverage existing hydrogen production facilities, thereby demonstrating how current hydrogen production could be decarbonized through retrofitting with carbon capture technology.

Although hydrogen pipelines are very limited outside of the Gulf Coast[3], natural gas pipelines could be converted—with some necessary technical upgrades—to serve as dedicated hydrogen pipelines. Although experience in repurposing natural gas pipelines for hydrogen is limited, preliminary European studies suggest that conversions could cost significantly less than new hydrogen pipelines[4]. Thus, a hydrogen hub could potentially leverage existing natural gas pipelines that are no longer needed for natural gas. Of course, blending hydrogen and natural gas in natural gas pipelines is also an option, but only for comparatively low blends of hydrogen—possibly up 10 to 20 percent by volume[5].

For hydrogen storage, while the only existing facilities are in Texas, a hub elsewhere could leverage favorable geology in the region. Of the storage options for hydrogen (salt caverns, rock caverns, depleted oil or gas fields, and aquifers), salt caverns are estimated to have the lowest storage costs for hydrogen by a large margin[6]. Outside of the Gulf Coast, there are salt basins in the Great Lakes, Western Plains, and Rocky Mountain regions[7], suggesting the possibility of salt cavern storage in these areas.

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[1] Congressional Research Service (2021), **Pipeline Transportation of Hydrogen: Regulation, Research, and Policy,**

[2] IEA (2021), *Global Hydrogen Review 2021*, IEA, Paris, **https://www.iea.org/reports/global-hydrogen-review-2021.**

[3] Congressional Research Service (2021), Pipeline Transportation of Hydrogen: Regulation, Research, and Policy.

[4] IEA (2021), *Global Hydrogen Review 2021*.

[5] Gielen, Dolf, Emanuele Taibi, and Raul Miranda. "**Hydrogen: A renewable energy perspective (irena.org).**" *Abu Dhabi: International Renewable Energy Agency* (2019).

[6] BloombergNEF (2020)**, Hydrogen Economy Outlook (2020).**

[7] Steward, D., et al**. Lifecycle cost analysis of hydrogen versus other technologies for electrical energy storage**. No. NREL/TP-560-46719. National Renewable Energy Lab. (NREL), Golden, CO (United States), 2009.

c. What types of new 'connective infrastructure' will be needed by the H2Hubs (e.g., pipelines, storage, etc.)?

New dedicated hydrogen pipelines—whether newly constructed or repurposed from pre-existing natural gas pipelines—will be critical in connecting hydrogen production with end-use facilities. While blending a low proportion of hydrogen into natural gas pipeline networks could be a transitory step, many end-use facilities (e.g., ammonia production) would require pure hydrogen rather than a hydrogen/natural gas blend. Furthermore, a low blend of hydrogen within natural gas would not fit into the model of a clean hydrogen hub.

Storage is also a vital component of a hydrogen hub, and the amount of storage needed will depend on the variability of hydrogen production and use. If hydrogen production within the hub is from natural gas with CCUS ("blue hydrogen") and hydrogen use is for oil refining and ammonia synthesis, both hydrogen production and use facilities may operate nearly constantly, and the necessary amount of storage will be small. However, if hydrogen generation is from solar powered-electrolysis, production will be variable, requiring significant storage capacity to ensure a reliable supply of hydrogen.

2. The BIL states that H2Hubs must (1) demonstrably aid the achievement of the clean hydrogen production standard developed under Section 822(a) [defined as 2 kg CO_2 e/kg H_2 *at the point of production]; (2) demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen; and (3) can be developed into a national clean hydrogen network to facilitate a clean hydrogen economy.*

The clearest way to incentivize any behavior is to make the desired outcome a criterion for funding. This will be hard to do in Phase 1 because proposers are likely to claim they can meet whatever standard is set or that they will do well against any outcome metric. But Phase 2 funding should depend heavily on doing well against outcome metrics in the detailed plans developed under Phase 1. If possible, it would be better to award credit for beating whatever performance standard is defined, rather than using a binary metric. Ideally the CO_2 / H_2 standard would be treated as a benchmark, or maybe a minimum qualifying level, but proposals that perform better (according to their Phase 1 plan) are given a higher likelihood of moving on to the next funding phase.

a. What CO_2 equivalent emissions should be met within the project and its supply chain? What strategies are available for, and how can DOE incentivize, the H2Hubs to reduce emissions not only at the point of production but also including upstream emissions? What challenges are there in measuring CO_2 equivalent emissions?

With respect to how the CO_2 / H_2 metric is calculated, the proposers should be required to take a lifecycle approach to capture the full impact of their proposed hub. This will automatically favor locations with low carbon electricity, for instance. DOE could specify a particular lifecycle model to be used by all proposers, which would ease the comparison of proposals according to this metric. Given the law, perhaps at least two metrics could be required: 1) a production/transmission/consumption of CO_2 / H_2 metric and 2) a metric that includes the complete lifecycle, including upstream emissions. Proposals should ideally be judged on the latter, but if that is not appropriate given the law, perhaps both could be used.

As an example, as discussed in **Bartlett and Krupnick 2021a**[8], there are five important sources of GHG emissions for blue hydrogen: "(i) CO_2 from natural gas reforming and combustion (to produce heat for the process), (ii) methane leakage attributable to the natural gas supplied for reforming and process heat, (iii) CO_2 from the generation of electricity used to power carbon capture, (iv) methane leakage attributable to the natural gas used for electricity generation, and (v) upstream CO_2 emissions for the production, processing, and transportation of natural gas."

A blue hydrogen producer could take several actions to minimize lifecycle emissions. First, on-site CO_2 emissions—source (i)—could be reduced by increasing the percentage of carbon capture. For example, autothermal reforming reactors with CCUS have been projected to capture 94% of on-site CO_2 emissions[9] . Second, the electric power used for carbon capture could come from renewable or nuclear energy, which would eliminate emissions sources (iii) and (iv). Third, the blue hydrogen producer could procure natural gas with low-methane emissions, reducing source (ii). Certifications, such as those developed by **MiQ**[10], would help verify reduced methane leakage for the natural gas used in hydrogen production.

c. Given the level of funding, and with the ultimate goal of developing a national clean hydrogen network, would four (4) large H2Hubs that each produce more than a certain amount of hydrogen (e.g., more than 1,000 tons/day, see question 3 to specify amount) or 6-10 H2Hubs of varying size be more effective?

We agree that Phase 1 should involve many winners, each getting a small amount of funding. Given the detailed plans and funding requirements available at the end of Phase 1, and given the cap on total funds available, DOE can then make better-informed decisions on how far the funding can go and how many Phase 2 proposals can be funded.

In deciding on the number of hydrogen hubs, the DOE will need to weigh the benefits of demonstrating a greater number of hydrogen production technologies against the benefits of plant economies of scale. With respect to the former, a green hydrogen hub could utilize alkaline, proton exchange membrane, or solid oxide electrolyzers, and a blue hydrogen hub could employ steam methane reforming or autothermal reforming technology. Additionally, blue hydrogen production could come from a new plant or from retrofitting an existing steam methane reforming facility with CCUS. There would be benefits in demonstrating each different technology and construction pathway.

While plant economies of scale exist for all hydrogen production, they are far more significant for blue hydrogen than for green hydrogen. The two operational blue hydrogen projects in the United

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[8] Jay Bartlett and Alan Krupnick (2021), The Right Policies Can Incentivize Cleaner "Blue" Hydrogen. *Resources Magazine*.

[9] H21 (2018), North of England Report.

[10] Justin Gerdes (2021), How pricing methane from the oil and gas industry can slash emissions. *Energy Monitor*.

States, **Coffeyville and Air Products**[11], produce 200 and 500 tonnes of hydrogen per day, respectively. Reduced plant sizes could entail significantly higher production costs. In contrast, the modular nature of electrolyzers limits plant economies of scale, allowing green hydrogen projects to be substantially smaller and incur only a modest cost penalty. IRENA 2020[12] estimates that production costs from alkaline electrolysis and proton exchange membrane electrolysis are rather flat beyond 30 MW.

We cannot judge the optimal number of hubs to fund, as this would come out of an iterative phased process. We can hypothesize that considering the benefits of both technological diversity and production economies of scale, funding 2 or 3 large blue hydrogen hubs (e.g., producing at least several hundreds of tonnes per day) and at least 3 smaller green hydrogen hubs would strike a reasonable balance. The optimal number of green hydrogen hubs is likely limited—not by production economies of scale—but rather by economies of scale of the other hydrogen hub components: pipelines, storage, and end-use facilities.

e. How should the H2Hubs be asked to measure progress toward the administration's goal of transforming the economy by 2050 to achieve net-zero emissions goals? Please be as specific as possible.

We do not think it is reasonable or necessary to ask proposers to estimate how their hub will help achieve the 2050 goals, as this could easily become a game of spin rather than a substantive element to judge proposals. If the proposer does well on the metrics and other criteria, that should be enough. Nevertheless, H2Hubs should keep track of their progress in decreasing life-cycle emissions for the different activities using clean hydrogen instead of fossil fuels.

3. FEEDSTOCK DIVERSITY: "To the maximum extent practicable– (i) at least 1 regional clean hydrogen hub shall demonstrate the production of clean hydrogen from fossil fuels; (ii) at least 1 regional clean hydrogen hub shall demonstrate the production of clean hydrogen from renewable energy; and (iii) at least 1 regional clean hydrogen hub shall demonstrate the production of clean hydrogen from nuclear energy."

a. Should DOE require a minimum level of hydrogen production per regional clean hydrogen hub, and if so, what should that minimum amount be (i.e., X tonnes/day)? Should this requirement vary for clean hydrogen produced from fossil fuels with carbon capture and storage (CCS), renewable energy, and nuclear energy? If a minimum is not specified, how may DOE incentivize larger capacity hubs?

Our presumption is that larger hubs are better than smaller hubs because they can demonstrate performance at scale. If this is generally true, then the Hydrogen Program (HP) should make scale a criterion, giving more credit to larger proposed hubs in the Phase 2 competition (or perhaps even Phase 1?). It might be harder to develop large hub projects with hydrogen produced from renewables since it is a less concentrated and more variable energy source than natural gas or nuclear power.

[11] Alex Zapantis, (2021), Blue Hydrogen. *Global CCS Institute*.

[12] Taibi, Emanuele, et al. (2020), "Green hydrogen cost reduction."

In general, with multiple criteria/metrics, a smaller hub may outperform a larger one according to some metrics, implying no minimum scale should be set. Another reason not to set a minimum is that it would discourage truly innovative plans that are not ready for major scaling. Another approach to give some due to this point would be to set no minimum for Phase 1 and then set a minimum for Phase 2.

b. Related to 3a, how should DOE take into account specifying minimum required hydrogen production when considering capacity factors and the potential intermittency of generation, which would increase the cost and requirement for hydrogen storage?

To repeat our central theme, HP does not need to make these calls. Let cost or cost-effectiveness and production metrics embody the intermittency and other issues.

c. What terms should be required for an H2Hub powered by renewable energy to demonstrate clean production (e.g., a power purchase agreement with a renewable generator, or direct connection to a co-located renewable generator)?

The objective of the IIJA funding is to create novel clean hydrogen hubs, with clean hydrogen production, connective infrastructure, and end use. It is not to support the addition of renewable power capacity, which is already incentivized by federal investment and production tax credits and state renewable and clean energy standards. Therefore, the renewable energy hub(s) should require that electricity for electrolysis come from renewable sources, whether that renewable power is from existing or new capacity. Correspondingly, we would not expect that the nuclear energy hub would require a new nuclear power plant. There are numerous ways to demonstrate purchase of renewable power, including renewable energy certificates, green tariffs, and power purchase agreements.[13]

d. Should DOE prioritize the repurposing of historic fossil infrastructure in the regional hub(s) focused on production from fossil fuels and if so, over what time frame? If yes, should DOE incentivize an eventual transition from fossil fuels to another fuel source? What conditions should DOE place on the carbon intensity of the fossil fuels (with CCS) used in this hub other than what is already specified in the BIL?

We think it is asking too much of the proposers to specifically try to repurpose fossil fuel infrastructure—but we assume that HP will include a criterion for creating jobs for workers in the oil and gas sector, which would provide some incentive to do so. Other policy levers specific to the oil and gas industry (such as eliminating subsidies or raising royalty rates) can help motivate the transition more holistically.

The final question here—the carbon intensity of the fossil fuels used—raises the issue of whether coal-based blue hydrogen should be considered. Blue hydrogen produced with coal could potentially attain the required standard of 2 kg CO_2e/kg H_2 at the point of production if 90 percent of emissions were captured[14] higher cost of capturing the required emissions from coal-based blue hydrogen in

[13] EPA Guide to Purchasing Green Power (2018).
[14] IEA (2019), The Future of Hydrogen, IEA, Paris, **https://www.iea.org/reports/the-future-of-hydrogen.**

the United States—including the ancillary costs of air pollution from coal combustion (e.g., SOx, NOx, and particulates)—would challenge the motivation for a coal-based, rather than a natural gas-based, blue hydrogen demonstration project.

e. How might hydrogen production be constrained by the availability of clean electricity or natural gas supply and distribution? Will hydrogen producers provide a sustainable market/revenue stream for clean electricity and natural gas that encourages new investments to expand electricity generation and natural gas production capacity? Are separate federal, state, or local incentives to expand clean electricity generation or natural gas production capacity available, necessary, or adequate?

The main challenge for clean hydrogen is that its production cost is at a premium to gray hydrogen or other fuel for which it would substitute (addressed in Questions 4, 32, and 39 below). Adequate supplies of natural gas and zero-carbon power for clean hydrogen hubs are prevalent across the country, and renewable power is already subsidized (discussed in C1.3c). However, there are regional infrastructure constraints to the reliable delivery of natural gas and zero-carbon power. Thus, the selection of clean hydrogen hubs should ensure that there are sufficient regional capacities in existing natural gas pipelines (for blue hydrogen hubs) and electricity transmission (for renewable- and nuclear-powered hydrogen hubs).

f. Should H2Hub funding be made available to upgrade or develop new dedicated clean electric or heat generating energy resources (e.g., renewables or other clean generation sources) needed to produce clean hydrogen?

Proposers who want to build dedicated clean electricity into their proposal will factor this into costs. Renewable power is already both cost-competitive and subsidized: on the supply side through federal investment and production tax credits, and the demand side through state renewable and clean energy standards. As long as cost is a criterion, HP doesn't need to get into this issue.

4. END-USE DIVERSITY: "To the maximum extent practicable– (i) at least 1 regional clean hydrogen hub shall demonstrate the end-use of clean hydrogen in the electric power generation sector; (ii) at least 1 regional clean hydrogen hub shall demonstrate the end-use of clean hydrogen in the industrial sector; (iii) at least 1 regional clean hydrogen hub shall demonstrate the end-use of clean hydrogen in the residential and commercial heating sector; and (iv) at least 1 regional clean hydrogen hub shall demonstrate the end-use of clean hydrogen in the transportation sector."

a. What are the ideal timing and desirable features, terms, and conditions of off-taker agreements that would encourage construction and development of hydrogen hub infrastructure and long-term sustainability leading to local economic prosperity including union jobs and benefits to disadvantaged communities? Would hubs that supply multiple end users provide advantages, and in what ways?

Desirable features for off-take agreements generally include: (i) a long duration and (ii) pricing that is sufficient to realize a market return. For most wind and solar projects, off-take contracts have taken the form of power purchase agreements of 15 to 25 years, close to the economic life of the asset, with fixed pricing for each kWh generated[15] . Wind and solar projects have no input fuel costs and only modest fixed operating and maintenance costs[16], so their costs of power production can be predicted with a high degree of certainty.

In contrast, clean hydrogen production costs will be subject to considerable uncertainty. First, because few clean hydrogen projects have been deployed on a commercial scale, their capital costs can only be estimated imprecisely. Second, over half of clean hydrogen production costs are from fuel—either natural gas or electricity[17]. While green hydrogen producers could enter into a fixed-price power purchase agreement with a wind or solar project, the hydrogen producer would still face price risk on any residual power it needs to procure (given the intermittent nature of wind and solar power). The uncertainty in clean hydrogen production costs will likely require off-take contracts to account for fluctuations in input fuel costs (natural gas and zero-carbon power).

b. What approaches can applicants use to guarantee off-taker commitments and matching of supply and demand?

As noted in C1.3e, clean hydrogen—even if its capital costs are subsidized—will be more expensive than the high carbon fuel it displaces: gray hydrogen, natural gas, petroleum, or coal. In addition, other than the federal 45Q tax credits for CCUS and California's Low Carbon Fuel Standard, clean hydrogen does not yet have supply- or demand-side deployment incentives. Consequently, unless sufficient federal or state clean hydrogen deployment incentives are enacted, the off-take agreement(s) with end user(s) will need to be subsidized as part of the hub funding.

With respect to the matching of hydrogen supply and demand, the hub will need to have adequate storage. As discussed in C1.1c, the amount of storage required will vary inversely with the correlation between hydrogen production and use. A solar-powered hydrogen hub, for example, would likely need substantial storage—given the low capacity factor of solar—to ensure a reliable supply of hydrogen.

c. The climate value of displacement may vary across end uses. How should the climate benefit of different hydrogen end uses be considered?

The climate benefit to different users of H_2 is simply the GHGs that are displaced by substituting "clean" hydrogen for the fuels/processes being used. Since the definition of a hub includes producers *and* consumers of H_2, consumers should specify in the proposal the CO_2 emissions of current fuels and processes that would be displaced.

5. GEOGRAPHIC DIVERSITY: "To the maximum extent practicable, each regional clean hydrogen hub– (i) shall be located in a different region of the United States; and (ii) shall use energy resources that are abundant in that region."

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[15] Jay Bartlett (2019), "Reducing risk in merchant wind and solar projects through financial hedges." *Resources for the future. Last Accessed* 23.
[16] Lazard's levelized cost of energy analysis. (2021).
[17] IEA (2019), The Future of Hydrogen, IEA, Paris, **https://www.iea.org/reports/the-future-of-hydrogen.**

b. In addition to sufficient energy and feedstock/water resources, what other regional factors should be considered when identifying and selecting regional hubs (e.g., economic considerations, policy considerations, environmental and energy justice considerations, geology, workforce availability and skills, current industrial and other relevant infrastructure and storage available/repurposed/reused, industry partners, minority-serving institutions [MSIs], minority-owned businesses, regional specific resources, security of supply, climate risk, etc.)?

This question introduces the critical question of what the metrics/criteria will be to judge proposals. Some of these metrics can be quantified through a cost metric. Others are hard to define, let alone quantify, such as sufficiency. Unless markets are heavily regulated, the costs of energy and feedstocks should be factored into the overall cost estimates, so these elements of the plan don't need any special treatment. The same goes for many of the other items listed in this question. Exceptions are environmental justice (EJ), environmental considerations more generally, minority business preferences and climate risk. These are either externalities or lie outside standard market considerations. See our responses to questions in Category 2 for details.

6. HUBS IN NATURAL GAS-PRODUCING REGIONS: "To the maximum extent practicable, at least 2 regional clean hydrogen hubs shall be located in the regions of the United States with the greatest natural gas resources."

While Congress may have required hubs to be located in areas with the most natural gas resources, these concepts are, in fact, difficult to quantify. Rather, economic welfare in site selection would be better served by recognizing that the delivered price of natural gas is the key indicator of abundant supplies and accessible pipelines.

7. EMPLOYMENT: DOE "shall give priority to regional clean hydrogen hubs that are likely to create opportunities for skilled training and long-term employment to the greatest number of residents of the region."

RFF researchers, as part of our organization's Equity in the Energy Transition initiative, have examined a broad range of state, federal, and international policies designed to support workers and communities experiencing the effects of the energy transition. This includes a detailed assessment of existing policy tools[18] that the federal government can deploy to support these communities, as well as a county-level analysis[19] of which energy-producing communities in the US may be most vulnerable to the effects of the energy transition. This work, along with other recent publications carried out as part of the Equity in the Energy Transition initiative, reflects RFF's effort to understand, quantify, and identify policy tools to support communities affected—both positively and negatively—by the energy transition.

[18] Daniel Raimi (2021), "**Mapping County-Level Exposure and Vulnerability to the US Energy Transition" (rff.org).**

[19] Wesley Look et al (2021), "**Enabling Fairness for Energy Workers and Communities in Transition" (rff.org).**

Category 2: Solicitation Process, FOA Structure, and H2Hubs Implementation Strategy

8. DOE is evaluating funding mechanisms for the H2Hubs projects in accordance with the BIL. What applicable funding mechanisms are best suited to achieve the purposes of the H2Hubs (e.g., Cooperative Agreements, Grants, Other Transactions Authority)?

We think it would be useful to use the Other Transactions Authority (OTA) to enable non-traditional contractors to benefit from DOE funding. DOE may want to commission or do in-house relatively small projects in support of the hubs, such as to establish an appropriate life-cycle analysis model for all bidders and winners to use.

The set-up of the planned grantmaking process reminds us of a milestone payment model. Milestone payments seem to be a relevant funding mechanism for H2Hubs projects where DOE funding will be spent conditionally on successfully reaching certain steps of the hub deployment. This funding mechanism will also dissuade planning teams to make unreachable claims in Phase 1 by setting the milestones based on the planning work from Phase 1. Milestones can be embedded in the Go/No-Go decision at the end of each Budget Period in Phase 2.

Overall, independently of the funding mechanism chosen, Phase 1 should incentivize planning teams to exceed DOE funding (and matching requirements) to present a better plan and raise their probability of moving on in the process. This gives a similar incentive to entering a competition for a prize while not creating too many losers, since any bidders not chosen in Launch 1 would be allowed to enter Launch 2.

9. What are the key review criteria (e.g., technical merit, workplan, market transformation plan, team and resources, financial, regional economic benefits, environmental justice, DEI) that DOE should use to evaluate and select the H2Hubs as well as evaluate readiness to move from Phase 1 to Phase 2?

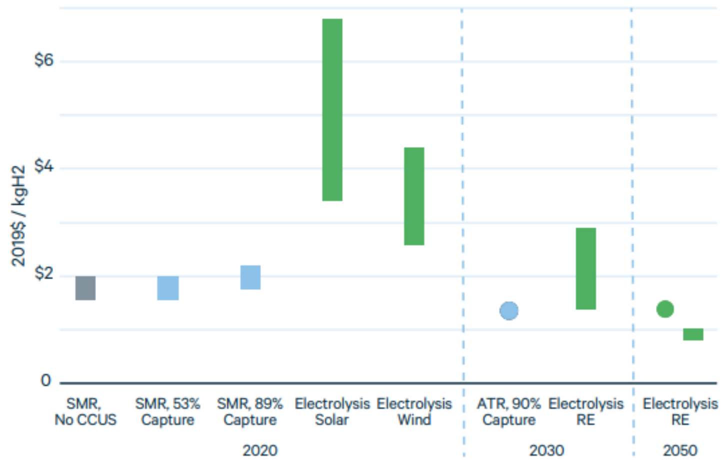
We suggest that HP establish a set of metrics to be used to judge both planning projects and actual built projects in later phases. These would need to be supplemented by more qualitative metrics and given appropriate weights. Whatever the system, as with current FAOs, these criteria and weights should be provided up front in each phased competition.

Some of the most important metrics are 1) the costs of the hub over current costs (e.g., buying blue rather than grey hydrogen and 2) the CO_2 emitted as a result of the hub, less any CO_2 backed out by, for instance, substitution of blue or green hydrogen for grey hydrogen. These two key metrics can be summarized in a cost-effectiveness metric (\$/ton CO_2). Note that the cost metric also picks up the benefits of economies of scale in dealing with larger production and transportation volumes of both H_2 and CO_2.

See estimation of current and projected costs in RFF report on Decarbonized Hydrogen[20] (Excerpted figures are below).

[20] Bartlett, Jay, and Alan Krupnick. "Decarbonized Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions." December 2020. **https://www.rff.org/publications/reports/decarbonizing-hydrogen-us-power-and-industrial-sectors.**

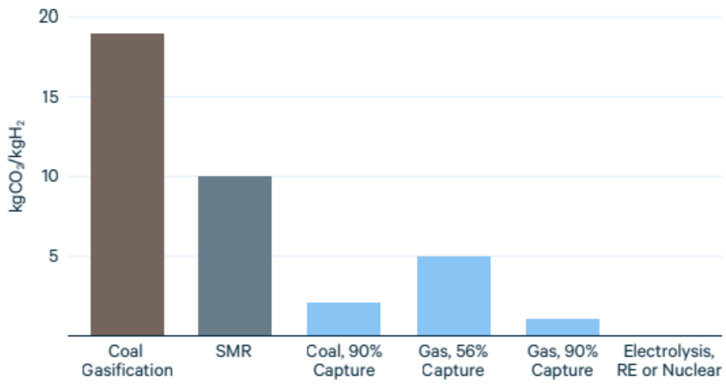
Figure 9. Current and Projected Hydrogen Costs



When accounting for the social cost of carbon, which is here proxied by a tax credit equal to \$50/tCO_2, the cost of blue hydrogen is already competitive with grey hydrogen. Projected costs for 2030 anticipate an increase in scale of production and a switch in technology from SMR (Steam Methane Reforming) to ATR (Autothermal reforming), which leads to lower costs for blue hydrogen. The projected decrease in green hydrogen production cost between 2030 and 2050 is based on reductions in electrolyzer and power costs. According to different estimates, green hydrogen costs will be contained between \$0.80/kgH_2 to \$1.38/kgH_2. However, DOE investment in electrolysis technologies could generate further improvements and cost reductions in the future.

Given the law, as noted above, a metric for CO_2e/H_2 would also be used. Benchmark values for *CO_2* emissions by hydrogen production method can also be found in the above-mentioned report. As Figure 2 and 3 show, the current clean hydrogen standard of 2kg CO_2/kg H_2 already restricts the choice of production methods. Note that this estimates to not count methane emissions from the natural gas value chain.

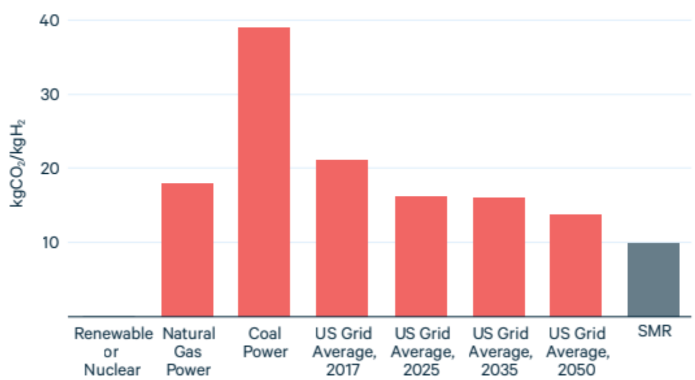
Figure 2. CO_2 Emissions, by Hydrogen Production Method



Source: IEA 2019.

Note: Includes only CO_2 emissions from combustion and chemical conversion. RE = renewable energy. SMR = steam methane reforming.

Figure 3. CO_2 Emissions from Electrolysis, by Power Source



Other quantitative metrics, such as jobs expected to be (or actually) created, could be used, as this is an important part of Congressional intent. But it should be recognized that in a fluid labor market, what is actually a new job is difficult to estimate accurately and easily overestimated. A related metric is the addition to regional wages. This metric gives credit to hub jobs being better paid than the job(s) a new employee previously had.

Other criteria that are not obviously quantitative include, for example, environmental justice considerations—although even these could be quantitative. EJ Screen and other tools permit identification of disadvantaged communities, and a hub's impact on these communities (in terms of air pollution) is amenable to modeling, as we are doing in a project examining the consequences for such communities as a result of policies to meet New York State's 2050 net zero goals. Comparing these likely or actual consequences to other communities in the hub's airshed gives a sense of the relative impacts. Of course, to the extent CO_2 reductions are correlated with conventional air pollutant reductions, nearby communities would benefit.

Regional economic benefits are relatively easy to model using platforms such as REMI.

Metrics for sustainability and eventual market size are, of course, very difficult to predict and depend more on the size and geographic scope of the entire hub program, plus many other government policies supporting innovative breakthroughs. Absent a way of modeling these impacts, we would recommend not making them a criterion.

HP should plan to collect, keep track of and assess data regarding emissions of GHG, water and energy use during the project and should make public (under appropriate confidentiality restrictions) these and other data useful for assessing the net benefits of the hub program. Building this plan into the program from the start will be most useful.

10. Does offering multiple launches roughly a year apart, as shown above in Figure 2, help facilitate expanding the hydrogen hub concept to more regions?

Yes. Some situations are clearly more ripe for a hub than others. For instance, those anchored by existing grey H_2 production that could be turned blue might be easier to develop into a plan than more greenfield operations lacking networks for offtake, pipelines and other infrastructure.

11. What specific activities should be conducted in Phase 1 vs. Phase 2? Should Phase 2 be further broken into multiple sub-phases, and if so, what should be included in each sub-phase?

The first phase should develop baseline conditions to measure hub benefits against, including data on CO_2 emissions, water and energy use, jobs, etc. Contractors in subsequent phases should be required to create a rich data trail to help track progress and apply lessons learned elsewhere.

We support the breaking down of Phase 2 into multiple sub-phases as it will allow closer monitoring of the progress of each project and reduce the probability of funded failures. The tradeoff with multiple phases is a greater reporting burden, but with funds being so large, these burdens would be relatively small as a proportion of overall support. Alternatively, HP could hold back a small amount of the hub funds to provide funding specifically for record keeping, model runs, etc. In any event, the Go/No-Go Decision at the end of each sub-phase should be based on criteria and metrics specifically defined beforehand for each activity to move on to the next Budget Period.

17. What environmental reviews and permitting challenges might H2Hubs encounter? Where can approaches such as "dig once" relating to buried conduits, pipelines, and other infrastructure (e.g., CO_2 pipelines) be developed and incentivized to reduce impact? Please provide examples of how community consultation and consent-based siting can successfully be included in the environmental and permitting review process.

H2Hubs can encounter permitting challenges when dealing with patchwork regulations as can be the case when a hub encompasses multiple states or even counties. Indeed, each state is a different permitting entity and for states such as Minnesota or Nebraska, the regulations differ by county, which will impact the complexity of the Phase 1 plan. The permitting process will be made easier with the publication of a proper set of guidelines by the DOE.

Approaches designed to reduce the impact will likely also have a reduced cost, which can help incentivize their development.

19. What external non-project partners/stakeholders (e.g., CBOs, DACs, tribal groups, state and local governments, economic development organizations, labor representatives) will be critical to the success of the H2Hubs? What types of outreach and engagement strategies are needed to make sure these stakeholders are involved during each phase of the H2Hubs? Are there best practices for equitably and meaningfully engaging stakeholders?

In our work with EJ groups, we provide funding for participation of these groups and involve them in the full lifecycle of project completion. Bidders should be required to make their best efforts to include EJ groups on their team. At least in our experience, EJ groups can be very opposed to hydrogen and CCUS (for blue hydrogen production) as a decarbonization strategy. DOE/HP could use hub funds to support a study to help all the hub bidders by determining what conditions, if any, would garner EJ support. DOE, along with more trusted agencies to EJ groups) could hold a series of meeting with these groups to understand EJ concerns and work to find solutions, As for identifying DACs, there are numerous tools, such as EJ Screen from the EPA or the new White House Climate and Economic Justice Screening Tool. Bidders could be asked to use these tools to identify DACs affected (both positively and negatively) by their proposals and address these issues in the proposal.

The recently issued CEQ guidance[21] on taking these issues into account for CCUS projects could apply to projects involving any technology and so could be applied more generally to hub proposals. Building on that guidance yields the following suggestions:

- Require bidders to evaluate impacts of proposed hubs on potential host communities in their proposals and suggest mitigating strategies, if necessary;
- Require that bidders engage with Tribes and EJ groups prior to responding to the FOA; and
- For winning bids, proposers should provide transparency and accountability to communities with respect to applicable mitigation measures designed to reduce adverse environmental effects.
- Require that EJ and Tribal groups, where applicable, be part of the proposal team.

20. The H2MatchMaker tool will be available to help identify potential regional project partners. What specific fields/information would be valuable to include in the tool? What other mechanisms can DOE use to help facilitate teaming?

To show greater end-use diversity, it might be relevant to show regions with a high density of industrial facilities. Indeed, fossil-fuel dependent industries represent potential future hydrogen consumers, especially for process heat generation.

Industrial facilities also represent a potential demand for carbon transportation, storage and utilization infrastructure, and thus rely on the same infrastructure as blue hydrogen. With the same purpose in mind, H2MatchMaker could also show existing CO_2 pipelines and storage facilities. Although perhaps too ambitious, HP could use the EJ screening tools to identify DACs and put them in the Matchmaker. This would obviously extend beyond matchmaking!

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[21] Carbon Capture, Utilization, and Sequestration Guidance, CEQ (2022), **https://www.whitehouse.gov/ceq/news-updates/2022/02/15/ceq-issues-new-guidance-to-responsibly-develop-carbon-capture-utilization-and-sequestration/.**

More to the point on matchmaking, DOE could provide names, location and contact info for EJ groups around the country if some of the above suggestions are followed.

22. Is there sufficient manufacturing capacity to produce the necessary hydrogen related components/equipment within the US to supply all the eventual H2Hubs? What incentives/programs exist or can be put in place to encourage and foster US manufacturing? What potential challenges or opportunities might exist to meet the new Buy American requirements in the BIL?

We believe that a robust hub program and declining hydrogen production costs will stimulate U.S manufacturing, irrespective of special programs. Obviously, policies such as hydrogen tax credits, carbon taxes, CO_2 performance standards for industry and power, and the like would also change the investment climate as well as industrial strategies for supplying the hydrogen revolution.

Other provisions of the BIL like the Clean Hydrogen Electrolysis Program seek a decrease in costs associated with clean hydrogen production to less than 2$ per kg by 2026. Such programs targeting lower costs should incentivize production of the needed equipment within the US.

24. What types of cross-cutting support (e.g., technical assistance) would be valuable from the DOE/national laboratories, and/or from other federal agencies, to provide in proposal development or project execution? Are there other entities that DOE could fund to provide technical assistance across multiple H2Hubs?

DOE can provide technical assistance with a goal of harmonizing practices across the H2Hubs planning teams. This shared toolbox should contain a Life Cycle Assessment tool and guidelines regarding carbon emissions accounting and inclusion in total project costs.

We also feel it important to note here that making the responses to this RFI publicly available would be extremely valuable to the broader research community (like RFF) that is seeking to support DOE and other stakeholders in making the hubs a success. We understand concerns over confidentiality, but would encourage DOE to consider whether any confidential business information could be redacted and a subset of comment responses could be shared.

Category 3: Equity, Environmental and Energy Justice (EEEJ) Priorities

27. What strategies, policies, and practices can H2Hubs deploy to support EEEJ goals (e.g., Justice40)? How should these be measured and evaluated for the H2Hubs?

Equity, Environmental and Energy Justice concerns should be embedded in H2Hubs projects from the outset. First steps towards that goal should be to encourage communication between stakeholders through meetings and summits. Emphasis should be put on representation of and ongoing engagement with the most at-risk communities regarding the clean energy transition.

Large transformative investments, such as the H2Hubs, should consider each community characteristic and require communication and coordination between local leaders and federal government planning agencies. This can be achieved by creating a network of community hubs[22] relying on community-based organizations, whose role would be to facilitate access to federal programs and funding opportunities and to provide feedback and insights to federal agencies. At the federal level, an organization is needed to keep track of the long-term view and to coordinate among federal programs.

Category 4: Market Adoption and Sustainability of Hubs

32. What mechanisms (e.g., tax/other incentives, offtake structures, prizes, competitions, alternative ownership structures for hydrogen production bundling demand, contracts for difference, etc.) would be valuable to incentivize market-based supply and demand?

Market based supply and demand for clean hydrogen can be incentivized through a tax credit targeting decarbonization, as argued in an RFF report[23] on decarbonized hydrogen. We support the introduction of a 45Q-like credit program for decarbonized hydrogen covering both production and use and favor a PTC over an ITC.

In addition, a use credit could be developed to encourage hydrogen use and help cover price premiums of blue or green hydrogen over grey hydrogen. It is still unclear how green hydrogen producers will show compliance considering that H_2 produced from the US electric grid will certainly not always present lower CO_2 emissions than the SMR method.

The implementation of these instruments would require the subsequent development of a related monitoring, reporting and verification system, which will require new regulation and standardization procedures to track eligible producers, transporters, consumers and their displaced emissions.

Contract for Differences (CfDs) is another approach to sustain production by guaranteeing a fixed price for clean hydrogen compared to the market price. This mechanism could support clean hydrogen penetration in existing end-uses, such as in the ammonia industry where the green premium can be compensated by CfDs. Although the fixed strike price might be competitive at the beginning of the contract, however, that might not be the case after several years (more than 10 years for solar contracts) if production costs of green hydrogen decline over time, which may well occur from private sector innovations, ramping up production scale, and from RDD programs such as Hydrogen Shot.

A green procurement policy can also be a relevant instrument to incentivize production and use of clean hydrogen. As detailed in a forthcoming RFF report[24] on demand-pull policies to decarbonize US industries, green procurement policies leverage governments purchasing power to help create market demand. Such a policy can be implemented in the transportation sector, for instance, with the

[22] Wes Look, Mark Haggerty and Daniel Mazzone (2022). Community Hubs to Support Energy Transition. Resources for the Future and Environmental Defense Fund.

[23] Bartlett, Jay, and Alan Krupnick. "Decarbonized Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions." December 2020. **https://www.rff.org/publications/reports/decarbonizing-hydrogen-us-power-and-industrial-sectors.**

[24] Krupnick, Alan, Haerle, Daniel and Bioret, Lucie. "Targeted demand-pull innovation policies to reduce greenhouse gas emissions from industry." (Forthcoming, available from the authors: krupnick@rff.org).

government procuring a low-carbon vehicle fleet, which will increase the demand for clean hydrogen as a fuel. Procuring low-carbon materials such as steel or cement for large infrastructure projects, such as road and bridge building, is another indirect way of incentivizing the production and utilization of clean hydrogen in industrial applications. It should be noted that performance-based standards should be preferably used in procurements rather than technology-based standards.

New demand for clean hydrogen can be sustained by the use of prizes awarding innovative zero-carbon solutions in the different end-use sector defined in the BIL (electricity production, residential and commercial heating, industrial decarbonization and transportation sector). Indeed, prizes are an effective tool for inducing non-incremental innovation as demonstrated by American Made Challenges.

Potential mechanisms to incentivize clean hydrogen demand will vary by production pathway and location. In a blue hydrogen hub, if the production facility begins construction by the end of 2025, the producer would benefit from the 45Q tax credits for CCUS. In a California hub, demand for clean hydrogen would benefit from the state's low carbon fuel standard (LCFS). A hub on the Gulf Coast, with its network of merchant hydrogen suppliers and industrial consumers, could potentially use contracts for differences if there is a transparent market price for hydrogen.

New federal or state deployment incentives for clean hydrogen, whether on the supply side (as with 45Q) or demand side (as with California's LCFS), could expand the market potential for clean hydrogen.

33. What role/actions can DOE take to support reliable supply and demand for potential hydrogen producers and customers?

DOE should continue supporting research and development in industrial decarbonization as clean hydrogen represents one of the main pathways for hard-to-electrify industries. BIL is already providing funding for clean hydrogen manufacturing and recycling and for electrolysis innovation, which will support the supply of clean hydrogen by incentivizing the production of essential equipment within the US.

34. If DOE asks for a market analysis as part of the application process, what should the analysis include so that DOE can be confident that a proposed project will be successful?

Regarding sustainability, a market analysis should look at potential future demand, especially in less developed end-uses such as in the industrial sector. Thus, the proximity of industries that will use hydrogen for heat generation of other processes when technologies are ready can be a valuable indicator.

36. How can DOE support the H2Hubs in working together to increase competitiveness and scale?

The creation of a clearinghouse for data collection is an important tool for sharing knowledge and best practices among the H2Hubs.

The goal is for the H2Hubs to be sustainable beyond the BIL funding (i.e., without additional government funding). To what extent will the H2Hubs be capable of demonstrating a path to *economic viability after the BIL funded phases and how should the FOA and project (once awarded) be structured to ensure this outcome?*

The need for ongoing funding to ensure the economic viability of the H2Hubs will depend on the choice of clean hydrogen production pathways and end uses for hydrogen.

At one end of the spectrum, a hub that uses blue hydrogen to displace gray hydrogen in existing applications—oil refining and ammonia production—may require little funding beyond the initial capital investments. The main reasons for the economic sustainability of this hub are three-fold. First, the estimated cost of blue hydrogen is between one-quarter and one-half of the cost of green hydrogen.[25] Second, gray hydrogen itself has a higher cost than most fossil fuels, so blue hydrogen would be displacing a comparatively high-cost fuel. Third, a blue hydrogen producer would benefit from the 45Q credits for CCUS of \$50/ton CO_2. With a cost differential between blue hydrogen and gray hydrogen of about \$0.70/kgH_2 and an effective 45Q credit of \$0.45/kgH_2 for blue hydrogen producers,[26] the BIL's investment funding may be sufficient. Even if not, there will be only a small gap between the market value of the blue hydrogen and its cost, after accounting for the BIL funding and 45Q tax credit value.

On the other end, a hub that uses green hydrogen to displace natural gas—for example, to produce heat or power—would likely require substantial ongoing funding to maintain its viability. This hub would combine a high-cost source of clean hydrogen with a low-value use. At a cost of \$5.00/kgH_2, green hydrogen would be ten times as expensive as natural gas on an equivalent energy basis.[27] While the cost of green hydrogen is expected to decline considerably over the next decade[28] , a green hydrogen project installed within the next couple of years may benefit from only a fraction of projected cost declines. Capital costs will be fixed upon investment, and if the green hydrogen project enters into a power purchase agreement, energy costs will also be fixed. With the large disparity between clean hydrogen cost and value in this hub, and because there is no analog to 45Q for green hydrogen unless a hydrogen production tax credit is enacted[29], significant funding may be needed on an ongoing basis to sustain the hub.

[25] Galen Hiltbrand, Whitney Herndon, Eric G. O'Rear, and John Larsen, Clean Hydrogen: A Versatile Tool for Decarbonization. Rhodium Group (2021).
[26] Jay Bartlett and Alan Krupnick (2021), Effective Incentives for Hydrogen Production, with Long- and Near-Term Climate Benefits. Resources Magazine.
[27] US Energy Information Administration, Annual Energy Outlook 2022 (AEO2022).
[28] BloombergNEF (2019), Hydrogen's Plunging Price Boosts Role as a Climate Solution.
[29] Jay Bartlett and Alan Krupnick (2021), Effective Incentives for Hydrogen Production, with Long- and Near-Term Climate Benefits. Resources Magazine.