Comments on “Request for Information on Industrial Decarbonization Policies”

Submitted to the Advanced Manufacturing Office at the US Department of Energy

Alan Krupnick and Lucie Bioret
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U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585
Attn: DE-FOA-0002687
Submitted via: Industrial-Decarb-RFI@ee.doe.gov

Dear Acting Director Dr. Jones-Albertus:

On behalf of the Industry and Fuels Program at Resources for the Future (RFF), I am pleased to share the accompanying comments to the U.S. Department of Energy’s Advanced Manufacturing Office in response to DE-FOA-0002687: Request for Information on Industrial Decarbonization Priorities.

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: Cement and Concrete Industry Decarbonization; Crosscutting Industrial Decarbonization Opportunities; Specific Industrial Decarbonization Challenges; and Industrial Decarbonization Workforce, Community, and Equity Considerations.

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,

Alan J. Krupnick
Director, Industry and Fuels Program
Resources for the Future
Comments on “Request for Information on Industrial Decarbonization Priorities”

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On January 27, 2022, the Advanced Manufacturing Office (AMO) at the US Department of Energy issued a Request for Information seeking to better understand industrial decarbonization priorities and opportunities. We agree with the need for a better understanding of which emerging technologies are or will be crucial to decarbonize the US industry—especially sectors considered hard to decarbonize, such as the cement, iron, and steel sectors. We also acknowledge the importance of crosscutting technologies, such as blue and green hydrogen and carbon capture, utilization, and storage (CCUS), that would allow for substantial emissions reductions in the different industrial sectors.

Category 4: Cement and Concrete Industry Decarbonization

C4.1 What emerging decarbonization technologies could have the most impact in the cement and concrete industry over the next 5-10 years, and 10-20 years?

Regarding the decarbonization of cement production, CCUS technologies are very promising to reduce most of the process-related emissions. Different CCUS technologies applicable to Portland cement kilns are being developed at the moment by major cement firms. The most advanced projects have reached the industrial-scale prototype stage but are not yet market-ready; for instance, carbon capture by chemical absorption and through calcium looping are both at Technology Readiness Level (TRL) 7. The impact of CCUS technologies on the decarbonization of cement production will grow over time with the deployment infrastructure for CO2 transport and storage.

Clinker substitution and replacement technologies also offer sizable emissions reduction potential. Firms such as Solidia and CarbonCure are developing mineral carbonation technologies respectively at the cement (TRL 8) and at the concrete (TRL 9) level. These technologies, using novel chemistries and components, directly absorb CO2 emitted during the process and can lead to net-zero emissions. Research teams in the US are also developing alternative binder solutions to the traditional Portland clinker such as alkali-activated cements.

In the short-term (the next 5 to 10 years), substituting traditional raw materials with decarbonated materials in clinker production and increasing the uptake of supplementary cementitious materials (such as slag, fly ash, or silica fume) will decrease process emissions.

Efficiency gains are also possible along the cement and concrete value chain by using digital technologies to fine-tune cement and concrete mixes to the characteristics and performances needed for each usage. More flexible production facilities will allow energy and material efficiency improvements, leading to a reduction in emissions.
C4.2 What primary factors are driving decisions on demonstrations of new technologies that reduce GHG emissions? Which promising technologies are most appropriate for demonstrating in the U.S. marketplace? Which technologies are ready for pilot plant scale-up, and which are ready for commercial demonstration?

The cost of new technologies is always a major driver of decisions in the research and development process. High capital expenditure can deter demonstration projects especially if there is uncertainty about operational expenses.

C4.4 What limiting factors or challenges does the cement and concrete industry face in broadly deploying decarbonization technologies in the United States?

The cement industry faces barriers to the development and diffusion of innovative green technologies. On the supply side, the sector is concentrated around a few international cement producers, which are also dominating the US market (LafargeHolcim, Heidelberg, Cemex). Thus, it is unlikely that competition will incentivize firms to innovate. Cement producers have strong incentives to stick to the status quo in terms of innovation as it could threaten their own position in the market. Indeed, innovative technologies currently under development are focusing on lowering or replacing the Portland clinker content of cement, which is the main production of these large companies. Thus, they may be reluctant to develop and deploy technologies which will lower the demand for Portland clinker, which might lead to losses and stranded assets for their firms.

Another important barrier on the supply side is the availability of alternative materials. Indeed, low-carbon clinker cement technologies and changes in the fuel mix require important and stable supplies of alternative raw and recycled materials. As most of them are industrial byproducts (fly ash, blast furnace slag), their availability depends on the activity of other industrial sectors. The growing demand for alternative materials might lead to rising prices with the phasing out of coal power plants and the greening of the steel sector through shifts from Blast Furnace-Basic Oxygen Furnace (BF-BOF) to Electric Arc Furnace (EAF) production and an increase of the scrap metal uptake.

In addition, cement plants are historically built near gypsum and limestone deposits to facilitate supply of raw materials. However, it can be much more difficult to access alternative materials since suppliers are not necessarily close to the cement plants and a network for the distribution of these materials might not be in place.

Finally, some standards and current regulations are deterring the use of waste and industrial by-products as alternative fuels or materials, which could lead to an increase of the carbon intensity of both the fuel mix and the production process in the short term. For instance, some alternative materials are classified as Hazardous Secondary Materials by the EPA.

On the demand side, major cement buyers are conservative in their choice of construction materials due to several factors. First, they tend to perceive low carbon cements as risky and costly products that are often difficult to use. Indeed, most of the current standards, testing procedures and requirements are designed for Portland cement, which has been used for the past hundred years. Most high-blend and novel cements have different characteristics than Portland cement, especially for setting time and early strength—and these characteristics need to be taken into account by project designers, as most of them are not one-size-fits-all construction materials like Portland cement. In addition, some alternative cements and concrete can only be used in niche applications.
Also, cement and concrete use is regulated by sets of standards or building codes that favor Portland cement. High-blend and novel cements might not meet these standards, which is slowing down their diffusion. Moreover, the process for modifying standards is usually long and burdensome for governments, leading to incentives to stick to the status quo.

**C4.5 What DOE resources would most benefit the U.S. cement and concrete industry to accelerate decarbonization?**

Since the most impactful technologies for decarbonizing the cement industry are not yet market ready, DOE has a crucial role to play in accelerating their development.

High-potential CCUS technologies can benefit from federal funding for large-scale and commercial demonstrations. The Office for Clean Energy Demonstration is especially relevant for accelerating the development and deployment of CCUS technologies in the US cement industry. Indeed, pilot and demonstration plants (PDP) are key elements to reduce the high uncertainty associated with new technologies in the clean energy-related space. These PDPs are associated with significant failure rate but are needed to get technologies underway in the market.¹ Zero-carbon alternative binders and cements can benefit from partnership with the National Renewable Energy Lab (NREL) through Lab-Embedded Entrepreneurship Program (LEEP), for instance. Indeed, zero-carbon cements are usually developed by innovative entrepreneurs and small businesses (i.e., Solidia Technologies) that will benefit from an incubation period in National Laboratories since they do not have as extensive resources as incumbent cement producers.

In addition, DOE could initiate outreach campaigns towards industry stakeholders and other branches of government to nudge the adoption of a full life-cycle approach to procurement, along with the adoption of performance-based selection criteria.

Overall, DOE could provide technical assistance to incentivize acceptance of novel cements instead of traditional Portland cement in construction projects. This technical support could take the form of assessment tools or training for construction companies and building developers to better shape their choices of materials.

**Category 6: Crosscutting Industrial Decarbonization Opportunities**

**C6.1 What emerging decarbonization technologies could have the most impact in the industrial sector over the next 5-10 years, and 10-20 years?**

Based on research undertaken at RFF², we feel that blue hydrogen could make a big impact—with the appropriate incentives—in 5-10 years, with green hydrogen having significant effects beyond that period. From our research and interviews with industry, we feel the “lowest hanging fruit” for hydrogen is (in no particular order):

- Hydrogen blended with natural gas for power and industrial uses (up to 20% by volume – 10% by energy content);

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• CCUS used to decarbonize SMR-based hydrogen at plants already producing and using their “grey” hydrogen, particularly to make ammonia for fertilizers and refineries (these two uses account for 80% of the grey hydrogen consumed); and
• Hydrogen used either directly for marine shipping or converted to ammonia for marine shipping.

If pipelines for H₂ are available to link producers to new consumers, this opens up potential for further industrial decarbonization through capture and utilization projects.

C6.2 What primary factors are driving decisions on demonstrations of new technologies that reduce GHG emissions? Which promising technologies are most appropriate for demonstrating in the U.S. marketplace? Which technologies are ready for pilot plant scale-up, and which are ready for commercial demonstration?

Based on our research on states in the intermountain west, as well as New York State, we can suggest that state governments are an unheralded but important force in building interests in commercial hydrogen production and consumption, and in hydrogen and CCUS hubs. These states are looking to the federal government to use the Infrastructure and Jobs Act money to fund investments in hubs, and both an expanded 45Q and a hydrogen tax credit to bridge the gap between the price of blue and grey hydrogen.

C6.3 What is the magnitude (e.g., output rate and cost) of potential pilot or demonstration scale projects that could be undertaken in the next five years? What are the most critical performance characteristics (e.g., efficiency, GHG emissions, capital or operating costs, product quality) these projects need to demonstrate?

Currently, steam-methane reforming (SMR) is the least expensive production method in the U.S., with the low end of costs approaching $1.00/kgH₂. Producing blue hydrogen increases costs by 20% to 50% depending on the degree of decarbonization, which can reach as much as 89%. Applying CCUS to the process stream of SMR, capturing just over half of total emissions, adds between $0.25/kgH₂ and $0.30/kgH₂ to hydrogen production costs. Applying CCUS to combustion gases captures 35 to 40 percent of emissions from SMR but at a higher marginal cost of CO₂ capture: production costs increase by $0.35/kgH₂ to $0.40/kgH₂.

Green hydrogen production costs are currently 3 to 10 times higher than those for grey hydrogen, depending on the energy source and on electricity prices. This difference is due to large capital costs—embodied in electrolyzer stacks—and usually, a lower capacity factor. Moreover, green hydrogen plants with dedicated renewable power sources depend on the capacity factor of those renewables, which is on average lower than 50%. Any pilot or demonstration scale projects should be benchmarked against these current costs and aim to eliminate the differentials between the different kinds of hydrogen.

When industrial requirements can be satisfied, for instance in cement making, replacing natural gas and coal with hydrogen combustion would reduce emissions by 7 kgCO₂/kgH₂ and 12 kgCO₂/kgH₂, respectively. Using low-carbon hydrogen for industrial heat would be cost effective for the cement, aluminum, and glass sectors with a production cost of $1.00/kgH₂ and a carbon price of $60/tCO₂ for cement and $90/tCO₂ for aluminum and glass.

Hydrogen also presents potential as a low-carbon alternative feedstock for the iron and steel sector. Indeed, hydrogen can substitute for natural gas as the reducing agent in the DRI-EAF route. Cost-effectiveness of hydrogen in steelmaking can require higher subsidies of H₂ and lower taxes on CO₂ than for industrial heat applications. With a carbon price of $50/ tCO₂, the average breakeven production cost for hydrogen is between $1.30/kgH₂ and $1.40/kgH₂.

C6.4 What limiting factors or challenges do these crosscutting technology areas face regarding broad deployment in the United States?
Investment and high production costs are major challenges for CCUS and H₂. With offtake of hydrogen or captured CO₂ needed, unless producers and consumers and fully collocated, both pipeline and storage infrastructure will be needed and will add to the cost (and price at the market).

One issue receiving little attention is the requirement for all sources undergoing major modifications or classified as “new” to undergo the New Source Review process under the Clean Air Act. This costly and time-consuming process adds to the already considerable cost burden on these new technologies.

Another key issue for CCUS is the lack of clarity at the state level on a host of legal and regulatory issues associated with CO₂ storage (such as pore space ownership and liability for leaks).

Another uncertainty that receives little attention is whether and to what extent the public will accept new CO₂ and H₂ pipelines. Presumably the states have jurisdiction and are, perhaps, more vulnerable than the federal government to pressure to restrict pipeline development for these uses. This is of particular concern given that these two technologies are opposed by the EJ community and that pipeline siting approvals are particularly vulnerable to public pressure.

The EJ community has been quite unified over their antipathy toward H₂ and CCUS as “false solutions” to the climate crisis. The primary concern we hear in our research—much of which involves direct engagement with EJ groups—is with conventional air pollution in the production/use of hydrogen and the added electricity generation (with associated conventional emissions) need to run the carbon capture equipment. As recent comments from this community in response to the CEQ guidelines show, the community does not believe that restrictions on location of new plants and mitigation measures at existing plants will happen, or if it happens, be protective of disadvantaged communities.

**C6.5 What DOE resources would be most beneficial to accelerate decarbonization?**

We think that the recent infrastructure legislation, together with provisions in Build Back Better and existing DOE programs, such as the Hydrogen Shot, give DOE adequate resources and mandates to stimulate innovation in decarbonizing the economy for the time being.

That said, if Build Back Better provisions do not become law, then perhaps the agency could partially fill these gaps by promoting development of environmental product declarations (EPDs), reviewing and endorsing various life-cycle analysis (LCA) tools, and participating in the Buy Clean Task Force to help develop product performance standards (such as for green cement) and certification processes. We understand that AMO is participating in the Task Force.

**Category 7: Specific Industrial Decarbonization Challenges**

**C7.2 What are the challenges unique to specific geographic regions of the United States?** Some regions of the United States lack critical infrastructure such as pipelines and storage facilities for CO₂ or hydrogen. Thus, implementing CCUS or hydrogen-related decarbonization solutions would require larger capital investments than in regions where this infrastructure already exists.

Regarding hydrogen-based solutions, regions without preexisting grey hydrogen production will face higher costs through higher capital expenditures if their decarbonization strategy relies on hydrogen solutions. Indeed, retrofitting traditional facilities with CCUS equipment to produce blue hydrogen is usually less costly than building entirely new plants.

In addition, hydrogen produced through electrolysis requires a large amount of water and electricity. However, some regions in the U.S. suffer from water scarcity and providing this large amount of water will be costly. The
deployment of low-carbon hydrogen can face additional barriers in certain regions. Thus, decarbonization strategy should suit regional and local characteristics to minimize costs.

C7.3 What are the challenges related to utilizing onsite carbon-free power generation (e.g., solar, wind) in industrial applications?

First, onsite carbon-free power generation increases the land use associated with a single industrial facility. Although enabling zero-carbon energy, the extensive amount of land needed for the generation facilities might create barriers in the implementation of this decarbonization strategy. Concentrated solar power, such as the technology developed by Heliogen for the cement sector, is only relevant in locations presenting optimal weather conditions. Also, carbon-free power generation is usually intermittent and thus requires energy storage facilities or access to alternate energy sources on the traditional grid. These considerations create additional constraints regarding the choice of locations for these industrial facilities.

In addition, onsite carbon-free electricity generation is not suitable for every industrial application. Electric heating is well suited for low- and medium-temperature and some specific high-temperature processes with substantial redesigns of industrial equipment and associated high capital expenditures. Thus, electricity in industrial applications might not be well suited for retrofitting but might be a potential solution for new plants.

C7.6 What are the challenges and opportunities to support and grow market demand for low carbon, U.S. made industrial products?

There are several ways that DOE could help grow the market for low carbon industrial products. Since in these areas DOE is primarily a funder of RD&D projects, DOE could use more of what are termed “demand-pull” policies to stimulate market demand for these products rather than, or in addition to, more typical “supply push” policies, such as grants and loans. These demand-pull policies include green procurement (in this case of products the government buys, such as roads and buildings, that embody low carbon cement and steel, for instance). They also include advanced market commitments, milestone payments, contracts for differences, prizes and others. RFF is drafting a detailed report on these policies but we include below the conclusions from our review of the academic literature about the efficacy and challenges of using these instruments. The key takeaways for each demand-pull policy are available in the above-mentioned report made available by the authors to AMO.

C7.7 How can DOE most effectively and transformatively support industrial decarbonization? For example, supporting facilities to reduce emissions through efficiency improvements versus demonstrations of “best-in-class” facilities that accelerate the development and commercialization of zero emission industrial processes. What are the trade-offs between the various approaches?

We appreciate that AMO is asking a question about tradeoffs, since it gets to the heart of the agency’s challenge in choosing the best proposals for its support. There are two overall issues: 1) how are otherwise eligible proposals to be distinguished and chosen as winners, and 2) what program designs are most likely to meet the goals of a particular Funding Opportunity Announcement (FOA)?

Some tradeoffs are easier to address than others. For instance, the example above is largely a temporal issue; efficiency gains are relatively easy to obtain. Our research shows that there is a high degree of heterogeneity in carbon intensity across firms in the steel, cement, and chemical industries, for instance, although this intensity varies the most for the cement sector. Some of this variation may be caused by differences in the

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3 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).
age and type of capital stock. But other variation might be caused by the quality of inputs supplied, or operating processes, or other causes that can be addressed relatively cheaply.

EPA’s Energy Star program already covers efficiency gains (BTUs per unit output) for many sectors targeted for decarbonization. However, DOE is uniquely positioned to fund RD&D to foster major advances for new sources and major modifications to existing sources. These changes are clearly mandated for several DOE offices.

Another possible tradeoff involves whether to support technologies at high vs. low readiness levels. Our view is that a diverse portfolio is justified. Early-stage technologies carry more risk but greater potential payoff than late-stage technologies, but the federal government presumably also wants to realize short-term CO₂ mitigation payoffs. Thus, a portfolio approach has merit.

As for program/solicitation design, our research clearly shows (according to academic papers) how some funding approaches work better in certain contexts than others (such as degree of readiness). In general, our research shows that demand-pull approaches are little-used as a group compared to competitive grants and loans—but in some cases, and for meeting some goals, they could be more effective.

Prizes are a good example. Some 30 prize competitions have been administered by DOE, and these have been effective at attracting bidders beyond the “usual suspects.” In addition, the particular ways these prizes have been administered via the Office of Technology Transitions addresses one of the biggest concerns with prizes: the difficulty in defining the terms for winning. Prizes are administered over multiple stages, small to start and growing larger as various milestone deadlines are reached if the participants can prove they are meeting the milestones and will do so in the future. To advance, participants are asked to define more and more specifically their final “products.” Thus, winning takes place over a series of milestones and the definition of winning is determined, in part, by the prize participants themselves. Prizes clearly are not for every situation and not when very large and ambitious grants are involved (such as for hydrogen hubs). But they could work very well for niche technologies.

One final thought is that to our knowledge there are not routine and reasonably quantitative assessments of the success of RD&D programs, although of course, there are many accounts of the benefits of various programs (that could be labeled anecdotal or generic). If this is correct, we would suggest AMO implement such a system.

An example of a laudable quantitative study of program success is Howell (2017)⁴. The abstract of the paper notes: “This paper conducts the first large-sample, quasi-experimental evaluation of R&D subsidies. I use data on ranked applicants to the US Department of Energy’s SBIR grant program. An early-stage award approximately doubles the probability that a firm receives subsequent venture capital and has large, positive impacts on patenting and revenue. These effects are stronger for more financially constrained firms. Certification, where the award contains information about firm quality, likely does not explain the grant effect. Instead, the grants are useful because they fund technology prototyping.”

We note that the “quasi-experiment” involves comparing a set of outcomes for firms that got awards to those that just missed getting awards. More specifically than in the abstract, the author finds that “the grants have statistically significant and economically large effects on measures of innovative, financial, and commercial success.”

Nevertheless, all is not positive for the DOE’s SBIR grants. The above effects apply to winners vs. losers for the Stage 1 grants (for $150,000). None of these metrics are significant for winners vs. losers in the

subsequent stage 2 grants competition (for $1 million). The author finds that some 40% of stage 1 winners do not even apply for stage 2 grants, possibly because the stage 1 grant enabled them to secure venture capital so they didn’t need to apply for stage 2. If so, those remaining in stage 2 pool might be lower performers. These considerations suggest that small grants can leverage large amounts of private equity and that, perhaps, stage 2 grants are not necessary or effective. More study is obviously needed. We note, however, that the ranking and some of the other data used in this paper are confidential and unavailable to researchers unless (at a minimum) they are an “unpaid DOE employee.” This access restriction argues for AMO to do such studies in house, to make becoming an unpaid DOE employee very easy, or to implement non-disclosure or other agreements to be able to make confidential data available to those outside the DOE. Perhaps an analytical program could be developed within DOE that would issue FAOs for such studies.

**Category 8: Industrial Decarbonization Workforce, Community, and Equity Considerations**

C8.6 *What measures should be incorporated into decarbonization efforts to ensure that harm to disadvantaged communities are mitigated?*

RFF researchers, as part of the 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 that the federal government can deploy to support these communities, as well as a county-level analysis 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.

AMO can use this and other available information to identify the overlap between the location of activities its programs may support—say, by identifying the locations of each proposal it receives—and the communities vulnerable to the energy transition. A criterion for proposal selection could be added (if not already present in the FAO) for bidders to develop a transition plan.

Accounting for environmental justice and the economic effects on disadvantaged communities (DACs) can also be made part of any FAO bidding and selection criteria. There are numerous tools for identifying DACs, 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 guidance on taking these issues into account for CCUS projects could apply to projects involving any technology and so could be applied more generally to AMO RDD funding. Building on that guidance yields the following suggestions:

- Require bidders to evaluate the impacts of proposed green technology funding 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 an FAO; and
- For winning bids, proposers should provide transparency and accountability to communities with respect to applicable mitigation measures designed to reduce adverse environmental effects.

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