Pathways to Decarbonize the PVC Value Chain in 2050
Appendix 6

Insights for Petrochemical Industry Decarbonization Policy

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Introduction

"Pathways to Decarbonize the PVC Value Chain" is a first-of-a-kind bottom-up model of the cost and emissions impact of decarbonizing a major chemical industry value chain.[1] The chemicals sector is one of the three highest-emission industrial sectors globally and within the United States. It is far more diversified in terms of products and processes than the other two leaders, steel and cement, and therefore its solution set for emissions reduction is likely to be more diverse as well. The study's value chain approach provides a granular analysis of some of the most important opportunities available in the near future to decarbonize this industry as well as some of the major challenges.

Polyvinyl chloride (PVC) is the third largest plastic material, by volume, produced in the United States. It is used primarily in durable applications, notably in construction, but also in automobiles, medical products, and other sectors. The US PVC value chain is directly responsible for approximately 15,000 jobs, paying above average wages, and it leads the world in exports. Our study estimates that production facilities involved in making PVC were responsible for about 18 million tons (MT) carbon dioxide (CO_2) emissions in 2020.[2]

The PVC value chain is thus important for its own sake. Our study of it may also be important for insights into decarbonization pathways for the broader chemical industry. Some key sources of emissions within the PVC value chain, such as ethylene crackers (factories that make the chemical ethylene, a key input to PVC) and power plants that also produce high-temperature steam for industrial use (known as combined heat and power plants or CHP) are also present in other value chains. On the other hand, the PVC value chain is unique in some respects. In particular, because of PVC's durability, the carbon embodied in this material is more likely to stay embodied in a product than other plastic materials, even after the product has been discarded. By contrast, single-use plastics, such as those used in packaging, are more likely to be combusted or degrade and thus release carbon into the environment at the end of their lifecycle.

Therefore, although the study affords insights into opportunities for public policy to catalyze the decarbonization of the chemical industry, it does not yield specific recommendations. PVC is an important product, but it is not important enough to warrant its own policies. Indeed, because the PVC value chain interconnects with others, it would be impossible to decarbonize PVC production alone, even if one wanted to, without reconfiguring the industry. This initial study must be validated as well as extended to other value chains before any recommendations would be sufficiently well-grounded to warrant action. In addition, the study takes an in-depth approach on a small number of technology options. A broader approach would include options for decarbonizing the chemical industry that encompass technologies that have not yet reached maturity as well as energy and material efficiency, product substitution, and recycling.[3]

This appendix sets forth policy insights across three loosely-defined time scales. In the near-term, it focuses on:

- Research, development, and demonstration
- Infrastructure, and
- Grid decarbonization.

In the medium-term, the topics include:

- Incentives for early technology adoption, and
- "Clean" procurement.

Over the long-term, key policies for consideration include:

- Carbon pricing,
- Air pollution regulations, and
- International trade policies.

Research, Development, and Demonstration

The study primarily investigates two major technological pathways to decarbonize the PVC value chain, carbon capture and sequestration (CCS) and hydrogen fuel. The study also briefly examines several less-mature and less-widely-applicable options for specific stages of the value chain, notably electrified crackers. (A second forthcoming study will explore a range of other technological possibilities, such as chemical recycling and electrochemistry.)

The fundamental characteristics of the CCS and hydrogen pathways are well-known. Both have been studied for decades. Both have diverse applications outside the chemical industry and so have been of interest not only to the highly capable, R&D-intensive firms, academic institutions, and government laboratories associated with that industry globally, but many others beyond it. While unexpected breakthroughs can never be ruled out, the key technoeconomic challenges likely to be encountered while pursuing these pathways lie in adapting the basic technologies to specific chemical industry applications.

Such challenges are best addressed by demonstration projects. The International Energy Agency (IEA) defines technology demonstration as the "operation of a prototype. . .at or near commercial scale with the purpose of providing technical, economic, and environmental information."[4] Successful demonstrations instill confidence in developers, users, and investors that a technology will perform predictably from both a technical and economic perspective. Demonstration projects are required because it is difficult to extrapolate the cost and performance of commercial-scale systems from experience with smaller prototypes, especially for complex technologies and systems like chemical plants.[5]

Key technologies adopted by plants in the study, like CHP with CCS, and cracker furnaces and CHP fueled by hydrogen, have not been demonstrated at commercial scale, and they are costly. The risks posed by such projects, especially in commodity industries with modest profit margins, can be daunting. A comprehensive review of demonstration projects across eight sectors over the last half century by Gregory Nemet and his colleagues found that a majority of them received public funding. Such cost- and risk-sharing is essential to surmounting the so-called demonstration "valley of death."[6]

The Infrastructure Investment and Jobs Act (IIJA), which passed Congress with bipartisan support in 2021, includes funding that might support demonstration projects that would advance decarbonization in the chemical industry. Nearly $3.5 billion will be devoted to carbon capture demonstration and pilot projects, and another $500 million to industrial emissions demonstration projects by 2026. In addition, $8 billion will support the development of regional hydrogen hubs, along with funding to support hydrogen manufacturing technologies. Industrial demonstration funding received another big boost with the passage of the Inflation Reduction Act (IRA) in August 2022, which allocates $5.8 billion over five years to this end.

The Department of Energy (DOE) is responsible for implementing these programs. Initial program documents confirm DOE's inclusion of the chemical industry within its scope. Project developers have begun to put together proposals in response to this opportunity. For instance, both the nascent Houston and Corpus Christi hydrogen hubs are likely to emphasize chemical production as a significant intended end-use.[7]

While public funding for demonstration projects would fill the most important gap in the RD&D policy domain, enhanced tax incentives for private R&D spending may also be helpful. Companies developing CCS and hydrogen technologies will need to invest in product development, problem-solving, and adaptation. These investments may spill over to benefit other firms, and tax incentives compensate the R&D investor for this loss. The United States has long had such an incentive, but the 2017 Tax Cuts and Job Creation Act weakened it considerably. Rob Atkinson of the Information Technology and Innovation Foundation (ITIF) has proposed doubling the value of the main provision of the tax code, along with other changes that would restore the incentive's effectiveness.[8] In addition, firms carrying out energy-related R&D can take advantage of a little-used 20-percent tax credit for work carried out in collaboration with academic institutions and federal laboratories.[9]

Infrastructure

CCS and hydrogen solutions are not stand-alone. They require infrastructure to operate. Carbon dioxide (CO_2) must be taken away from capture sites and either used elsewhere in the economy or permanently sequestered in underground geological formations. Hydrogen must be produced and, in many cases, transported to the plant site to be combusted. Some methods of hydrogen production involve CCS as well.

Hydrogen is currently produced by "reforming" natural gas under high heat and pressure. This process yields CO_2 as a byproduct, which is typically released. As a result, conventional hydrogen production is very carbon-intensive, emitting on a global basis as much as the nations of United Kingdom and Indonesia combined (equivalent to about 830 million metric tons of carbon dioxide (MMT CO_2-e) per year).[10]

Our modeling assumes that hydrogen will be produced in a similar fashion as today, but with improved reforming technology and CCS systems installed. The price of hydrogen in the model thus fluctuates with the price of natural gas. Electricity can also be used to produce hydrogen by splitting water into its constituent elements. If the electricity used for this purpose is generated without emissions, the process is without emissions as well, because little heat is needed and oxygen is the main byproduct.[11]

The United States produces about 10 MMT of hydrogen per year, some 15 percent of the world's total.[12] Industry roadmaps suggest that this figure could grow several-fold by 2050, even as production is cleaned up.[13] For these ambitions to be achieved, hydrogen must be made and moved to the point of use at a reasonable cost. Pipelines are likely to be the predominant mode of transport because they are the cheapest way to transport hydrogen across land.

Hydrogen pipelines are a mature technology. About 1600 miles are already operating in the United States, primarily in the Gulf Coast region, serving the oil and gas industry. They are different from natural gas pipelines, which are far more extensive. Hydrogen is harder to compress and leaks more easily than natural gas, and it is more corrosive. Hydrogen pipelines are more expensive to build as a result.[14]

Carbon dioxide pipelines are also mature and even more common than hydrogen pipelines in the United States, with a little over 5000 miles in operation. They serve a variety of industries, including chemicals and oil and gas. For instance, CO_2 is piped to oil fields and injected to enhance output.[15]

The hydrogen and CCS pipeline systems would likely need to be expanded considerably if the US economy is to approach net-zero emissions. For instance, the high electrification scenario in Princeton University's Net-Zero America report estimates that over 55,000 miles of CO_2 pipelines would be required, for a wide variety of purposes.[16] While new and extended pipelines might become profitable, uncertainty about the uses of both gases and about sequestration of CO_2 creates a classic "chicken and egg" problem. As with other forms of infrastructure, public funding can overcome this problem for these types of pipelines.

Such funding could be provided by a variety of means. Direct funding on a cost-shared basis may flow through the regional hydrogen hubs and similar federal programs. Low-cost loans or loan guarantees to pipeline developers, such as those provided by DOE's Loan Programs Office, are another way to subsidize them. Tax incentives could reduce the costs of pipeline construction and operation indirectly, although it is unclear whether pipelines would qualify under current provisions, which favor CO_2 sequestration and hydrogen production and energy storage. Other provisions of tax law, such as accelerated depreciation and private activity bonds, might also be utilized.[17]

Like other major infrastructure projects, CO_2 and hydrogen pipelines must run the gauntlet of federal, state, and local environmental review, which can be time-consuming and costly. Using existing rights-of-way and repurposing older infrastructure, such as natural-gas pipelines, may lower these hurdles. The IIJA contains provisions aimed at accelerating the federal review process, and a side deal that enabled the passage of the IRA may lead to legislation that furthers this objective. However, many observers see permitting as a major barrier to infrastructure projects, even those that would accelerate decarbonization.[18]

Finally, infrastructure operations must be safe and perceived by the public to be so. Hydrogen is explosive, corrosive, prone to leakage, and an indirect greenhouse gas (GHG). CO_2 is also corrosive, can be toxic, and is, of course, a GHG itself. Federal regulations for pipeline safety must be extended and enforced to ensure that new infrastructure serves its intended purposes and accidents are avoided.[19]

Grid Decarbonization

One of the unexpected findings of the "Pathways" study is that on-site power from CHP plants predominates among plants that contribute to the PVC value chain. Our 2020 baseline reveals that over 50 percent of emissions from the chain are from CHP and less than 15 percent from the grid. Our model assumes that the grid will decline further in importance as older plants retire and highly efficient CHP-based systems take their place in the chain.

Nonetheless, if the abatement pathways that we have modeled are pursued, a considerable portion of residual emissions (approximately 40 percent) will be due to the grid. If the grid can decarbonize more quickly than projected by the Energy Information Administration (EIA), whose forecasts we have incorporated into the model, the PVC value chain's carbon footprint will diminish more quickly as well.

The passage of the IRA is likely to have this effect. Models of its impact forecast that the power sector will be the largest source of emissions reductions during the 2020s, thanks to generous support for renewables, energy storage, nuclear power, and more.[20] The Biden administration has called for further reductions, setting a 2035 target for fully decarbonizing the grid.

The carbon-intensity of the grid varies dramatically from region to region, and the pace of decarbonization will certainly vary by region as well. Louisiana and Texas, where the PVC value chain is concentrated, have moderately carbon-intensive grids today. Some utilities in the region, have made net-zero pledges, such as Entergy's for 2050. An April 2022 report from the University of Texas notes that that state is blessed with abundant low-carbon energy resources and charted numerous pathways to net-zero emissions across the economy by 2050, including one that leads to a zero-emission grid by 2035. However, the state has by no means reached a consensus on pursuing decarbonization, much less adopting an aggressive pathway.[21]

Incentives for Early Technology Adoption

Once the infrastructure to transport CO_2 and hydrogen (and, in the case of CCS, sequester CO_2) has begun to expand, and CCS and hydrogen combustion systems have been demonstrated for typical facilities within the PVC value chain, these systems must diffuse rapidly for the pathways modeled in the study to be followed. Whether they will diffuse rapidly is far from certain, especially in the absence of a carbon price or regulatory mandate. Managers considering adoption may find that conventional systems remain cost-effective, may lack information or harbor uncertainty about low-carbon systems, or may simply prefer to minimize risk. These classic market barriers to completing the innovation cycle through early adoption may be addressed by incentives.

Investment tax credits (ITC) provide an incentive to potential early adopters by reducing the effective cost of equipment for those who have or can access a sufficient tax liability. The ITC played a key part in accelerating adoption of solar power in the United States over the past decade. Our models show that CCS systems are particularly sensitive to capital costs and so might benefit from an ITC. Whether an ITC would accelerate cost reduction for CCS systems, triggering a virtuous cycle of further innovation and adoption, as it has in the case of solar panels, is unclear. Such a cycle is most likely if the targeted system can be commoditized, so that the growth enabled by the ITC creates economies of scale in production. But, if each system must be customized to its site, as may be the case with CCS retrofits, this pattern will not be realized.

The hydrogen pathways to decarbonize the PVC value chain have relatively higher operating costs and lower capital costs than the CCS pathways. The cost of low-carbon hydrogen fuel is the largest driver of this difference. The “45V” (named for the relevant section of the tax code) production tax credit (PTC), which was incorporated into the IRA, promises to cut this cost. 45V could be worth as much as $3.00 per kilogram (kg) of hydrogen if the producer can demonstrate very low lifecycle emissions and meets specified labor standards. (Hydrogen producers may also opt for an ITC that is tied to emissions intensity instead of taking the PTC.)

Our models assume the use of hydrogen produced from natural gas with CCS or from steam cracker furnaces with CCS. With modest improvements in abatement from current levels, this product could become eligible for a PTC of between $0.12 and $0.60 per kg, which would probably put it in the range of our hydrogen scenarios with low energy prices and thus could bring forward adoption slightly.[22] “Green” hydrogen produced through electrolysis with much lower lifecycle emissions would be eligible for higher incentives, potentially bringing within reach our hydrogen “stretch” scenario. This scenario has the largest cumulative emissions reductions of all our models and would also have lower residual emissions if realized with “green” hydrogen.

Many alternative designs for providing incentives are available. For example, Germany and the United Kingdom are pursuing a “contract for differences” model to subsidize hydrogen, rather than a PTC or ITC.[23] This approach uses an auction mechanism to identify the cost difference between “clean” and “dirty” products (the “green premium”) and makes up the difference with a subsidy. In addition, the specific design features of the ITC and PTC, which may be altered by Congress at any time, can have major impacts on their effectiveness. For instance, 45V may be taken through “direct pay” for the first five years a production facility is eligible. That means the producer need not have a tax liability to receive the incentive, reducing the transaction costs of the provision’s implementation and enhancing its impact.

“Clean” Procurement

A second policy that could accelerate early adoption of CCS or hydrogen in the PVC value chain once decarbonization pathways have been demonstrated is “clean” procurement. The public sector, along with its contractors and voluntary private participants, may require a product like PVC to meet specific standards, such as a low level of embodied carbon. By doing so, these buyers (which may include companies like Occidental and Shell that have made notable climate commitments) accept paying more than the market rate for the product. Ideally, rapid early adoption leads to cost reduction, and the green premium disappears over time.[24]

As our study notes, construction is the major end-use for PVC, making up about 70 percent of total usage.[25] The public sector is a major force in this industry in the United States, with tax dollars paying for nearly half of all cement and a fifth of steel.[26] Its role will grow as the IIJA and IRA are implemented. For instance, the IIJA includes $50 billion in spending on water infrastructure nationwide, which could lead to the purchasing of large quantities of PVC pipe. And, our modeling reveals a relatively small green premium, so buying “clean PVC” would not add much to the overall cost of any specific project.

The Vinyl Institute, a trade association, working in collaboration with the Carbon Leadership Forum, has begun to develop standards for embodied carbon in PVC that include emissions from its production.[27] This effort initially seeks transparency for end-users of the product as well as to support companies pursuing voluntary goals. It might ultimately create a tool for estimating embodied carbon in a wide range of products used in construction.

However, the complexity of the PVC production process will make the use of such standards in clean procurement challenging. The PVC value chain intersects with other chains, such as chlorine for water purification and ethylene for production of polyethylene and other materials. The same plants frequently serve multiple chains. Decarbonizing PVC production thus requires at least partially decarbonizing other value chains. Indeed, only a minority of the total costs of the system that we modeled are allocated to PVC and are thus included in our estimate of its green premium. A majority of the system costs, therefore, would not be defrayed by “buy clean” programs unless these programs pay much larger premiums than the model estimates.

A final complicating factor for clean procurement is that many public construction projects currently specify materials other than PVC, such as ductile iron or cement for pipes. These restrictions on competition among materials neglect the potential lifecycle GHG emissions advantages of PVC.[28] Until such procurement processes adopt technology-neutral “open competition” principles, “buy clean” may have little effect on PVC production.

Carbon Pricing

Our models envision nearly universal adoption of abatement technologies throughout the PVC value chain by 2050. Unless the cost of clean production matches or falls below conventional methods, market incentives alone will not achieve this outcome. Public policy will need to alter these incentives, either by sustaining incentives for clean production until it reaches this cost threshold or by disincentivizing conventional production.

Carbon pricing would do the latter. Producers who emit GHGs would pay the government for every ton. If the incremental cost of cleaner production is less than the carbon price, they will adopt abatement technologies. Carbon prices can be imposed through taxes or fees or by the creation of a market for a limited number of emissions allowances, known as a “cap-and-trade” system.

The study models a carbon price that starts at either $50 or $75 per ton in 2030 and rises 5 percent per year after that. Not surprisingly, starting at the higher level leads to more rapid emissions reductions across all the scenarios that we modeled. The carbon price variable is far more powerful in driving adoption of CCS or hydrogen than energy prices, which we also vary in our scenarios.

A predictable, rising carbon price is an attractive approach for decarbonizing the chemical industry. The industry will be faced with difficult decisions about long-lived, expensive capital assets. This approach would reduce one element of uncertainty and provide a long horizon for planning. Equally important, it would cover all stages of the value chain and allow compliance costs to be distributed in proportion to the emissions that are ultimately embodied in end products.

A deficiency of this approach is that the carbon price is set in advance and is not easily adjustable if abatement costs prove to be different than anticipated by policymakers. Cap-and-trade systems are less predictable but more efficient in principle, setting the price at the level demanded by emitters. The European Union’s Emissions Trading System uses this approach, and it covers basic chemicals used in PVC production, such as ethylene, ethylene dichloride, and vinyl chloride monomer. However, free allowances have largely blunted its impact on the European chemical industry.[29] A proposal to eliminate these allowances more quickly than currently planned is working its way through the EU’s policymaking process at the moment. California’s cap-and-trade system also encompasses chemical production, but no plants in the PVC value chain are located there (though the state is home to many downstream PVC product fabrication plants). Neither the federal government nor the states in which the bulk of the PVC value chain resides have shown an appetite for carbon pricing.

A final complication worth considering in carbon pricing policy is parity across materials. If substitute materials like concrete or ductile iron face a different carbon price per ton of emissions than PVC, investments in production will be distorted. Policymakers must be attentive to competition among materials in end-use markets in their carbon price designs.

Air Pollution Regulations

Carbon pricing provides a convenient variable to represent a range of public policies in our modeling, and it would likely be an effective policy to decarbonize the PVC value chain in practice. But it is not the only policy that could drive widespread adoption of abatement technologies. Point-source air pollution regulation is an alternative, one that has commonly been adopted for similar challenges in the United States in the past.

The US Environmental Protection Agency (EPA) has the authority under the Clean Air Act to impose restrictions on pollutants from point sources like power plants and industrial facilities. This authority extends to CO_2, as established by the Supreme Court in *Massachusetts v. EPA* (2007). The Court’s recent *West Virginia v. EPA* (2022) decision did not challenge this authority, but instead is likely to focus its application on each individual plant, rather than on broader "systems of emissions" like industries or states, as the Obama administration had proposed in its Clean Power Plan.

Cracker furnaces and CHP plants are the largest point sources of emissions in the PVC value chain and would be the logical targets for such regulations. Chemical industry sites with these facilities are already subject to federal regulation to control pollutants that impact local air quality or pose health hazards. More-stringent standards for currently regulated pollutants might reduce CO_2 emissions as a co-benefit. There are no regulations currently in place to control CO_2 because of its global warming potential, but the EPA has stated that it will soon issue such regulations for coal and natural gas power plants. It has not sought to control industrial CO_2 emissions.[30]

Were the EPA to pursue a point-source strategy to regulate new chemical-industry facilities to control GHGs, its standard would need to "reflect the level of emissions performance achievable through the best system of emission reduction, considering cost and other factors, that has been adequately demonstrated."[31] Whether either of the two main pathways, CCS or hydrogen fuel, would provide this benchmark for new sources will likely depend on the success of demonstration projects. Standards for retrofits are typically less stringent. Upgrades at existing sites dominate our models. Whether such upgrades would qualify as new sources or retrofits may be situation-dependent.

Our models provide rough estimates of the costs of imposing facility-based standards for CO_2 emissions that would force the adoption of CCS or hydrogen combustion under a variety of assumptions. Very large sites in the PVC value chain might be required to spend hundreds of millions of dollars. In the models, site owners choose to do so because it is cheaper than paying the carbon price. In a regulatory framework, they would need to face a credible threat of enforcement. A collaborative RD&D program pursued in the shadow such a threat might reduce the cost of compliance over time and induce a productive dialogue between the industry and regulators.[32] However, we should not be sanguine that the imposition of regulatory standards would go unchallenged, especially since *West Virginia* provides new grounds for such challenges.

International Trade Policies

Widespread domestic adoption of abatement technologies will depend on trade policies as well as carbon pricing or regulation. Our models assume that PVC production for both domestic consumption and export will continue to grow for the next three decades. But if higher prices caused by the green premium undercut the competitiveness of domestic production, these assumptions are unlikely to be realized. In the face of a carbon price or heightened regulation, production may move abroad instead.

An increasingly widely discussed option to level the playing field in the United States would be to assess a "border adjustment" on imported PVC that embodies more carbon per unit than the domestic product. The more carbon-intensive the production method, the higher the adjustment would be. For instance, PVC made with high-carbon feedstocks, energy-intensive methods, and high-carbon electricity without abatement technologies would face a very high adjustment. PVC made under conditions comparable to those in the United States, on the other hand, would not face one at all.

Other jurisdictions that pursue similar policies will seek to impose similar adjustments, but universal adoption of such a policy is improbable. To allow US producers to compete in the global market, the federal government could provide export incentives to compensate them for the green premium. These payments would enable domestic producers to lower their prices to match those offered by more carbon-intensive producers abroad.

At least two major challenges arise for such policies. One is the difficulty of estimating the amount of embodied carbon in any particular shipment of PVC resin. The carbon-intensity of grid power, for instance, may change over the course of each day. Many plants are capable of using multiple feedstocks with different levels of carbon-intensity. Standards for carbon transparency developed to support clean procurement will help solve this challenge for domestic production, but similar trusted standards would need to be implemented globally for “clean trade” policies to achieve their goals.[33]

A second challenge of clean trade policymaking is avoiding protectionism and favoritism unrelated to climate goals. Once the possibility of adjusting the industrial playing field is opened, producers everywhere will have a strong incentive to distort it to their own advantage. World Trade Organization (WTO) rules are intended to address this risk, but they are rarely effective, and their application to climate-related trade policies is confusing and untested. Where specific and demonstrable costs are imposed domestically, like the US Superfund excise tax (which covers the PVC value chain), export incentives can be WTO-compliant. But the legality of most clean-trade policies is much murkier. Border adjustments, for instance, may be incompatible with the WTO’s core principle of nondiscrimination among trading partners.[34]

Conclusion

Our study of the PVC value chain provides insights into public policies that might be employed to decarbonize the chemicals industry more broadly. The sequencing and combination of policies explored here, for instance, are likely to be generalizable. Abatement technologies must be demonstrated and an early wave of infrastructure deployed first, with policies to support early adoption to follow, and more stringent policies that induce widespread adoption, along with trade policies that ensure fair competition globally, enacted in the later stages.

The chemical industry is rightly considered hard-to-abate. It makes many products that are vital to the economy and to daily living. It is very complex, internationally networked, and technologically advanced. Yet, if the world is to reach the net-zero goals laid out in the Paris agreement, this industry cannot be neglected or ignored. The sooner we begin to tackle this hard-to-abate sector, the more time we have to find, refine, and implement solutions.

Endnotes

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