A HOOVER INSTITUTION ESSAY

Making Demonstrations Effective

REPORT OF THE SHULTZ ENERGY AND CLIMATE TASK FORCE'S INDUSTRY DECARBONIZATION WORK GROUP

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Energy and Climate

SUMMARY

Compared to other energy sectors, decarbonization across the varied industrial subsectors will require systems that link technical innovations with industry operations, infrastructure, and markets:

- Individual facilities can implement subsector-specific process changes, efficiency measures, or technologies that offer moderate emission reductions at the margin.
- Crosscutting technologies, notably carbon capture and sequestration (CCS) and electrification with GHG-free electricity, GHG-free hydrogen, and nuclear heat and power can meanwhile potentially enable more significant economic reductions in emissions by meeting high-temperature heating requirements with fewer emissions, but they are risky for a single entity to deploy.
- Stand-alone industrial plants can be reconfigured within local clusters that integrate a variety of common energy and input suppliers with customers in a way that enables such deeper emissions reductions through shared infrastructure and logistics.
- Investment for the above approaches can be encouraged by a credible, long-term policy environment consisting of an emissions charge with border adjustments, regulatory mandates, or both, that hopefully could attract bipartisan support.
- Attention must also be paid to long-term energy-security issues that arise from international trade and supply of critical minerals.

But compared to other sectors, there is also widespread agreement that the transition to a near-net-zero industrial sector is not occurring sufficiently rapidly, and further, does not appear to even be on such a path. What might break through the inertia presented by these systems' interdependencies?

We believe that the current technological readiness levels in a variety of industrial decarbonization approaches now warrant a direct, yet still cost-limited and time-limited, government role in demonstration-phase projects that could reduce today's substantial private investment risks. The Work Group proposes creation of a portfolio of public/private independent corporations, drawing on lessons from the Synthetic Fuels Corporation of the Carter administration, but with a novel structure, to develop and demonstrate technically and economically sound near-net-zero integrated industry enterprises. There are many possible mechanisms for federal demonstration-phase support, and this report of the George P. Shultz Task Force on Energy and Climate explains why the proposed market-driven approach deserves favorable consideration.

Why Decarbonize Industry?

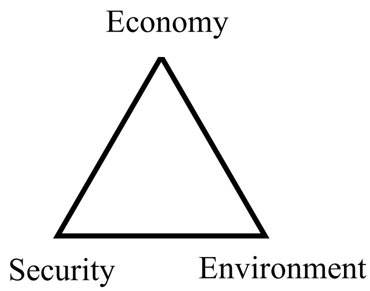
Any energy policy should strive to improve the health and growth of the economy, protect the domestic and international environment, and enhance domestic and international security. This applies to industrial sector policies as well. These three policy goals are summarized by the energy policy triangle, as shown in figure 1.

Security Issues

These include vulnerability to deliberate or accidental restrictions on oil or natural gas imports or other energy and materials supplies, and the limitations placed on US and European foreign policy options because of dependence on foreign energy sources. The current example is NATO allies balancing sanctions on Russia with their dependency on natural gas and oil imports from Russia.

Economic security issues also are raised by the great amount of international trade in all these sectors that determines where industrial production occurs and where industrial products are utilized. This situation creates a rationale for carbon border adjustment

Figure 1. The Energy Policy Triangle



mechanisms (CBAMs) to prevent domestic industries from losing competitiveness or relocating in response to climate policy.

Industrial decarbonization can be beneficial for international security. The United States has reduced net fossil fuel imports to near zero, but many of the European countries remain dependent on natural gas and oil imports, including large amounts from Russia. Industrial decarbonization that reduces use of fossil fuels is one way to strengthen the security of European and other nations over time by reducing or eliminating natural gas and oil imports from Russia.

There are important potential security benefits associated with industrial decarbonization. However, the security issues facing North America differ somewhat from those facing many European, Asian, South American, and African countries.

The Economy

Economic issues include growth of GDP and the costs of goods and services, the number and quality of jobs available for the population, and the distribution of wealth.

Industrial decarbonization could be either good or bad for the economy, depending on the costs of the alternative technologies and processes. In this paper we place particular emphasis on alternative methods of industrial decarbonization and steps to increase the pace of this deployment. We do not address other important demand-side macroeconomic issues that need to be addressed if any large-scale industry decarbonization effort is to gain public support. Assessing impacts on employment, communities, and income distribution is crucial. The Work Group believes its proposed creation of a portfolio of public/private independent corporations is the most economical way to move more rapidly toward deep industrial decarbonization.

The Environment

Energy-related issues of the environment include local and international impacts of energy production and use. Industrial decarbonation can protect the environment, not simply because of the reductions in atmospheric releases of greenhouse gases, but to the extent that the technology and operational changes reduce other environmental impacts of fossil fuels, such as the release of particulates from coal combustion. This paper focuses on one particularly important global environmental issue: emissions of greenhouse gases (GHGs) into the atmosphere, including carbon dioxide and methane.

To that end, carbon dioxide (CO_2) emissions from the primary production of iron and steel and from the chemical and cement industries are large contributors to the overall global and US greenhouse gas emissions. As with other emitters, the damages from the emissions are not paid for by the companies that emit; these are externalities of iron/steel and cement production.

The International Energy Agency (IEA) estimates that as of 2020, iron and steel production leads to global direct CO_2 emissions of about 2.6 billion metric tonnes, and cement production leads to about 2.3 billion metric tonnes.[1]

From the US component of the industry alone, based on US Environmental Protection Agency (EPA) estimates, in 2020 the US direct emissions from cement production were the equivalent of 66.4 million metric tonnes of CO_2 and emissions from iron/steel production were the equivalent of 62.1 million metric tonnes of CO_2. EPA reports a generally flat trend in GHG emissions from cement and from iron and steel for the period 2011 to 2021.[2]

Using an estimated social cost of carbon dioxide of $50 per tonne, the cost of these greenhouse gas externalities from the global iron and steel industry is $130 billion per year for iron and steel and exceeds $110 billion per year for cement. Each of these US industries—cement and iron/steel—has carbon dioxide global externalities that exceed $3 billion per year. Moreover, compared to some other sectors, the magnitude of these externalities relative to product value in these subsectors is large. For example, the global market for cement in 2022 was $340 billion, making the carbon dioxide externality alone nearly one-third the value of the entire output of this global industry.[3] Put another way, with a rule of thumb that every kilogram of cement produces about half a kilogram of CO_2, and a typical cost of cement of roughly $50 per tonne, incorporating the carbon externality would raise costs by half if using existing technologies and processes.

The magnitude of the externalities suggests that the benefits of decarbonization of the cement industry and of the iron/steel industry are large compared to the costs of a public assistance to reduce emissions. This underscores the need for private sector engagement through the public/private corporations that we propose. It also shows the importance of a strategy that preserves US industry competitiveness in these traded sectors so that entire industries do not shift to other countries, particularly China, leaving no net reduction in global carbon dioxide emissions. If success in the United States provided important information that allowed equivalent decarbonization around the world, the value of reducing these externalities would increase substantially.

Sources of Industry Carbon Dioxide Emissions

The International Energy Agency estimates of 2019 global carbon dioxide emissions and the US Environmental Protection Agency's 2019 estimates for the United States are presented in table 1.[4] The estimates are given for direct emissions (scope 1) and indirect emissions (scope 2), respectively, of carbon dioxide. Direct emissions are the result of combustion of fossil fuels by the sector or the releases of carbon dioxide from chemical processes in the

Table 1. CO_2 Emission Shares by Sector, 2019

		Global	*United States*
Industry	Direct	20%	21%
	Indirect	19%	9%
Transportation	Direct	26%	40%
	Indirect	1%	–
Res. / Comm.	Direct	9%	13%
	Indirect	19%	17%
Other	Direct	4%	–
	Indirect	2%	–

Sources: International Energy Agency, https://www.iea.org/data-and-statistics/charts/global-co2-emissions-by-sector-2019; and US EPA and US Energy Information Administration, https://www.eia.gov/totalenergy/data/monthly.

sector (scope 1). Indirect emissions are based on reallocation of emissions from electricity (and heat) to those sectors that use the electricity (scope 2).

In 2019, globally, the industrial sector was responsible for 39 percent of global carbon dioxide emissions, 20 percent of which were direct emissions and 19 percent of which were based on emissions in generating electricity and purchased heat used by the industrial sector. (Scope 3 indirect value-chain emissions are not included.) For the United States, the industrial sector was responsible for 30 percent of national carbon dioxide emissions in 2019, 21 percent of which were direct emissions and 9 percent of which were based on emissions from generating the electricity used by the industrial sector. The total global carbon dioxide emissions associated with the industrial sector could be roughly halved if all electricity and purchased heat used by the industrial sector were produced by zero-emissions sources; in the United States this would reduce industrial carbon dioxide emissions by almost one-third. These data show the enormous importance of electricity and high-temperature heat in the industrial sector.

Addressing industrial sector emissions is a global endeavor. Most of these emissions are concentrated in just a handful of countries and regions: the top five producers account for 76 percent of global capacity in steelmaking and 86 percent in cement (see table 2). China accounts for the largest share of production in both industries. Most of this production is consumed domestically, although many countries rely on exports from China to meet their steel and cement demands. The situation is similar for chemicals, aluminum, and pulp and paper. Collaborations focused on reducing industrial sector emissions will have much greater impact if they represent major markets beyond the United States.

Table 2. Global Total and Top Producers of Steel and Cement, by Output

Steel (2021): 1952 total million metric tonnes (MMT)	*Cement (2021): 3582 total million metric tonnes (MMT)*
1. China – 1033 MMT	1. China – 2500 MMT
2. EU – 153 MMT	2. India – 330 MMT
3. India – 118 MMT	3. Vietnam – 100 MMT
4. Japan – 96 MMT	4. United States – 92 MMT
5. United States – 86 MMT	5. Turkey – 76 MMT

Source: World Steel Association, *World Steel in Figures* (Brussels: April 2022), https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2022-1.pdf.

Industry sector–wide GHG emissions are influenced by assumptions about growth in economic activity and the trend in GHG intensity. The latter trend, in turn, depends on fuel pricing, the imposition of regulatory mandates, the development and deployment of new technology, and the pace of waste reduction and introduction of recycling. Section 5.5 of the Working Group III Technical Summary of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report AR6 gives a comprehensive account of the considerations encountered in the evolution and mitigation of industrial GHG emissions.[5] The report identifies the following industrial categories:

- iron and steel
- cement
- chemicals (petrochemicals and polymers)
- pulp and paper
- nonferrous metal, e.g., Al, Cu
- food processing
- textiles and leather
- mining

Each of these sectors has an entirely different operating process, and within each sector there is a large variation in the technology and operating parameters depending on plant location and plant vintage. The many detailed studies of industrial decarbonization encounter a wide range of technical, economic, regulatory, and policy uncertainties.[6] In the three key industrial areas—iron and steel, cement, and petrochemicals—investment continues to increase at an annual rate greater than depreciation, signaling an increase in output. The International Energy Agency presents technology road maps for iron and steel, cement, and petrochemicals.[7] The appendix of this report provides short, illustrative examples of these subsector-specific technology and systems dynamics.

Understandably, studies of industry decarbonization begin with a focus on the specific industry but quickly recognize that a much broader system view is needed to identify the best routes to global scale deployment. The IPCC AR6 Technical Summary scenario analysis estimates near-term and longer-term industrial GHG mitigation for the key industrial sectors of cement, steel, and primary chemicals from both direct and indirect emissions.

In IPCC's reckoning, *early improvements* come from (a) reduced carbon intensity of indirect electricity emissions; (b) energy efficiency; (c) material efficiency; and (d) recycling and reuse, such as the enormously successful trend over the past decades of aluminum recycling. *Later improvements* for achieving net zero come from (a) feedstock substitution, for example, hydrogen and biomass; (b) extensive use of electrification; and (c) carbon capture and storage or utilization.

Hydrogen (depending on how it is made), CCS, and negative-emission technologies such as direct air capture (DAC) have the potential to reduce carbon footprints across all sectors. Similarly, nuclear generation can produce both carbon-free electricity and the high-temperature heat that is necessary across the industrial sector.

Importantly, these latter improvements in industrial decarbonization will involve significant changes to large, complex, and costly manufacturing processes. These changes likely will require system redesign and new patterns of system integration, new business practices, and reconfigured supply chains involving different energy and material flows to take advantage of common infrastructure. These latter improvements cross industrial sectors: CCS will require an extensive new CO_2 pipeline and storage system; hydrogen will have cross-sector use for power, storage, and fuel; and reengineering high-temperature heat systems will contribute to decarbonization of all sectors. In contrast to today, much of industry will make use of a new *shared* infrastructure. It is hard to see such changes happening in a concerted way without clear, firm incentives and a stable, rational policy environment; imagine, for example, the changes needed to convert conventional petroleum refining and chemical manufacturing to a petrochemical process producing hydrogen with integrated CCS, and in a way that preserves or improves economic competitiveness. This is not done on a whim.

What Is Industry Doing, and Why Is Industrial Decarbonization Lagging?

Private sector organizations such as Mission Possible Partnership and the First Movers Coalition, consisting of major international banks and private firms, recognize the importance of accelerating decarbonization efforts of hard-to-abate industries by pledges of advance-purchase commitments and by advocating fast-track approval for key net-zero projects.[8] Industry generally has recognized the climate-change risks to the economy and has taken steps to reduce both emissions from its operations (scope 1) and emissions from suppliers (scope 2). Despite the growth in industrial output (52 percent) and in the overall US economy (96 percent) from 1990 to 2020, direct CO_2 emissions from fossil fuel combustion in the industrial sector decreased by 10.2 percent over the same time period. This divergence is attributed to (1) more rapid growth in output from less energy-intensive industries relative to traditional manufacturing industries, and (2) energy-intensive industries such as steel employing new methods, such as electric arc furnaces, that are less carbon intensive than the older methods.[9]

A number of companies have undertaken significant new projects, with and without federal assistance, to explore distinctly new net-zero technologies: carbon capture and sequestration activities are expanding with significant Department of Energy (DOE) support, Occidental Petroleum plans to build a direct-air-capture plant in the Permian Basin, and Chevron has announced a joint venture to provide hydrogen to produce electricity at the Utah Intermountain Power Plant.[10] Shell, backed by the European Union, is building a 100MW electrolyzer plant to produce hydrogen for its large-scale refinery in the Netherlands.[11]

But there are several reasons why the present private sector effort is not advancing more rapidly.

1. Clear and stable industry decarbonization policies, essential for private investors who make commitments based on anticipated future returns, are not generally in place. At present there is no experience with such changes at scale, and only a few scattered demonstration plants are being built and operated because of the absence of a firm policy framework.

2. The important benefits of industrial decarbonization do not accrue to the private sector investor and, therefore, are not incentives for investment. The external benefits from decarbonization are mitigation of climate damage; improved security of supply disruptions; and reduced uncertainty about international trade, border adjustments, and raw material scarcity.

3. The investment needed to decarbonize a large industrial facility is large, in the range of $1 to $10 billion, and represents a considerable fraction of a private firm's capital. It is high risk because it depends on changes taking place in neighboring industrial stacks. The investment decision is "betting the company." Moreover, the returns expected from external private risk capital are not well suited to the large scale and long time frames of such investments.

4. The transition of industrial sectors to deliver GHG emissions reductions of 50 percent or more will not happen by itself. The industrial sector structure will change fundamentally, requiring massive investments synchronized among many firms. This means that a risky decarbonization investment made by one firm within an industrial supply chain will rely on another supplier or customer firm's own risky decarbonization investment. It is a move to a shared infrastructure and supply chain. Synchronization of this shared infrastructure will not necessarily happen efficiently, even in the presence of an emission charge. Some public infrastructure investments will be necessary.

If governments expect their industrial sectors to meet ambitious economy-wide decarbonization goals without simply offshoring, they have a responsibility to go beyond establishing an emission pricing policy and stable regulatory framework. There are two broad modes of public assistance that have been proposed along these lines to break through the dynamics described above; the *first* is to provide public investment in shared infrastructure that encourages the formation of efficient integration of industrial decarbonization ventures. To that end, Congress has recently appropriated $8 billion for clean hydrogen hubs intended to enable different firms to access a central hydrogen production, storage, and distribution facility administered through a newly created DOE Office of Clean Energy Demonstrations (OCED).[12] This effort's successes or setbacks will warrant close attention to inform the merits of such a DOE-led approach.

The *second* mode of public assistance is to provide financial assistance to the private sector as it makes the transition along the innovations pathway from idea creation to deployment. The key step along this pathway is *technology demonstration*—realization of a project that successfully designs, constructs, and operates an initial integrated facility. The goal of the demonstration project is to establish the technical performance, cost, and regulatory compliance of the technology to convince the private sector—firms and lenders—that investment in large-scale deployment is commercially viable. A successful demonstration project can become the first-of-its-kind deployment facility with sufficient risk reduction to allow debt capital to replace expensive equity investment in *n*th-of-a-kind production facilities.

We believe that the current technological readiness levels in a variety of industrial decarbonization approaches now warrant this more direct, yet still cost-limited and time-limited, government role in this key demonstration phase. This government role goes beyond its traditional responsibility of supporting early-stage research and development to providing significant cost sharing for industrial decarbonization-related demonstration projects. Certainly, a stable regulatory and policy environment that could attract at least moderate bipartisan support would strengthen the market incentives for such projects by creating a more credible long-term framework for private investment.

A focus on successful demonstration projects would further lower the risk to private firms that such demonstrations could become commercial dead ends. A key component of such projects would be robust, data-driven modeling and simulation to define and assess alternative plans and to provide a capability to evaluate and transparently report progress or failures. The proposed initiative envisions that any public or private corporations that are created will have access to qualified analytic and communications support.

Different Approaches to Federal Assistance for Decarbonization-Demonstration Projects

Over the past half century, the government has adopted many different approaches to providing assistance for technology demonstration in the private sector (distinct from the technology development that goes on in the DOE national laboratories). These approaches include direct financial assistance for specific endeavors, for example, the Clinch River Breeder Reactor Project and the Kemper County "clean coal" project with precombustion CO_2 capture, and, more recently, for demonstration of advanced nuclear reactors. The federal government has also provided support for public/private partnerships such as the Partnership for a New Generation of Vehicles (PNGV), the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), and SEMATECH.[13] There have been many calls for greater private sector efforts on energy innovation, including from former secretary of state George Shultz through his leadership of this Task Force.[14]

The government's performance in managing and financing early-stage R & D is outstanding. However, the US government has had mixed success in its efforts to efficiently promote energy technology–demonstration programs such as those listed above. There are several reasons for this shortfall: the annual congressional budget cycle that often introduces disruptive changes to multiyear endeavors, the lack of government personnel with practical experience in project planning and management, and cumbersome federal procurement regulations that drive up costs.

A Proposal for the Creation of a Suite of Public/Private Independent Corporations

In light of the above, we propose the creation of a suite of public/private independent corporations to develop and demonstrate technically and economically sound near-net-zero integrated industry enterprises. Given the variety of barriers to effective public-project execution, we further recommend that these independent corporations should be managed by private sector entities to carry out technology-demonstration projects partially financed by the federal government.

It is sensible to involve private sector firms that have experience in designing, constructing, and operating large-scale industrial firms based on fossil energy in these demonstration projects. The involvement has the dual benefit of exploiting existing private sector experience and capabilities and preparing these private sector entities for playing a major role in future near-zero-emission industrial plant deployments. Participating firms could have a strong incentive to create and deploy the next generation of technologies that would underlie their future operations, thus giving them a competitive advantage over firms from other countries. The demonstration projects could address one of the important industrial sectors, such as cement, steel, and chemical manufacturing, or the role of the three crosscutting technologies in advancing industrial decarbonization. A few examples illustrate potential demonstration targets:

- the role of nuclear power in providing electricity and high-temperature heat in chemical manufacturing, vastly reducing the GHG emission of large plants;

- the development of an evolutionary role for hydrogen from blue steam–reformed methane to low-cost green hydrogen in steel manufacturing; and

- development and demonstration of a sequence of new cementitious materials to replace limestone ($CaCO_3$) in Portland cement manufacture to reduce CO_2 emissions.

Such demonstration projects can be quite costly and take several years to complete. The experience with present industrial enterprises suggests demonstration-plant projects (such as the two advanced nuclear reactor projects currently being supported by the Department of Energy) are in a cost range of $1 to $2 billion and have a project duration of up to five years. Despite broad public and political interest in decarbonization, however, the private industrial sector has made only a limited number of such investments given their distant and uncertain commercial benefit, as discussed earlier.

Over the years several proposals have been made to create quasi-public organizations to carry out demonstration projects that have a better chance of success than one that is government run.[15] In 1992 Harold Brown chaired a National Academy of Sciences panel that proposed creation of a Civilian Technology Corporation.[16] President Carter proposed creation of the Energy Security Corporation as a quasi-public organization to develop synthetic liquid and gaseous fuels from coal and oil from shale; this entity was included in the 1980 Energy Security Act as the Synthetic Fuels Corporation.[17] In contrast to these proposals for a single organization, members of the Shultz Energy and Climate Task Force here propose an operational construct for a suite of incentive-driven public/private corporations tailored to ten specific industry subsectors in order to allow for competition.

The Extent of the Proposed Public/Private Corporations Initiative

A menu of technology-demonstration projects that hold the promise of significant and low-cost industrial decarbonization should be drawn from the many existing climate studies. An ambitious program would establish two (or possibly more) public/private corporations for each of the five largest industrial sectors (with some likely involving crosscutting technologies)—each for a five-year period and with a federal budget of $1 billion to cover 50 percent of the total estimated cost required for a successful demonstration project. This amounts to a total program cost of the initiative of $20 billion over the five-year period. The precise number and budget for each public/private corporation would depend on the industry structure and the objectives set for the corporation.

Two efforts are proposed to be undertaken in each of the five industry sectors in order to encourage competition and increase the likelihood of successful innovation. An intellectual property licensing policy should be adopted to give firms participating in the demonstration project free use. The corporations would grant additional licenses under suitable terms to firms that came forward to participate in the deployment, thus fulfilling the policy's purpose to accelerate deployment of a decarbonized industry.

Governance and Operations of the Proposed Public/Private Corporations

Each corporation would be managed by a seven-member board of directors appointed by both chambers of Congress and the president—two together selected by the Senate majority and minority leaders, two together by the Speaker of the House and minority leader, and three by the president (one of whom would be designated chair).[18] Members would be selected based on expert knowledge and experience in the technical and commercial operations of the industry, its regulatory environment, and prospects for new low-carbon business configurations. Board members would be paid a nominal per diem stipend, with total annual compensation not to exceed a set cap.

The tasks of the board would be *first* to develop a five-year program plan for the demonstration project; *second* to obtain congressional approval and a one-time appropriation for the five-year cost of the project; *third* to prepare a solicitation for firms to design, construct, operate, and test the demonstration plant; *fourth* to select two winning teams and to monitor the technical progress, expenditures, and schedule of each effort; and *fifth* to deliver an annual progress report to the administration and Congress. In sum, the board of each public/private corporation would have the authority and responsibility for all its affairs.

Complementarity with Recent Federal Efforts

During the Biden administration, significant legislation has been enacted to invest in national infrastructure and to accelerate emission-reduction climate-control efforts.[19] The DOE is investing $21.5 billion focused on the demonstration phase, including $2.5 billion for advanced nuclear, $8 billion for hydrogen, and $2.5 billion for CCS demonstration projects.[20] In addition, there is a massive effort focused on strengthening US critical-mineral supply chains, a $40 billion loan and loan guarantee program, and a revival of a "permitting council" to streamline and coordinate permitting for, for example, early CCS projects.[21]

This is a large and ambitious federal effort, and its success is important. It will take some time for the DOE to assemble a staff of individuals with the technical knowledge and experience to solicit, select, and manage a set of documented and convincing industry decarbonization-demonstration projects. There are, however, some inherent difficulties with this DOE-led approach, perhaps surmountable with federal management of fifty-fifty cost-shared technology-demonstration projects intended to catalyze private sector adoption: required compliance with the Federal Acquisition Regulation (FAR) and intellectual property laws, and annual oversight by multiple congressional committees.[22] The DOE should consider whether the proposed public/private corporation initiative is not a more effective mechanism for accomplishing the meritorious objectives of accelerating industrial decarbonization.

Demand-Side Efforts

The Work Group believes that the proposal for public/private corporations supported by federal financing is a necessary step to achieving significant industrial decarbonization. Demand-side initiatives by consumers of industrial outputs, not considered in this report, also have an important role to play. There are three potential broad demand-side initiatives: imposition of emission charges, regulations that impose mandatory emissions reductions, and private financial and industrial firms that have made voluntary advanced purchasing commitments to reduce emissions in at least one sector (e.g., “green steel” purchasing commitments).[23] An analysis of the most economical balance between supply- and demand-side efforts is difficult.

Gathering Public Support

This proposed initiative is complicated, and one can expect many questions about the likelihood of its success compared to other possible schemes with which individuals have experience. To advance the political feasibility of such a proposal, we therefore believe that it would be important to begin by forming a dedicated organization to refine the initiative and to present and advocate to Congress, the executive branch, and the public. Presenting a bare-bones initiative to either Congress or the administration is unlikely to be successful. Moreover, specific public/private corporation proposals may or may not be successful. A capstone organization that advocates for significant public assistance for both public infrastructure projects and a palette of public/private corporation initiatives is needed. A Council for Accelerating Industrial Decarbonization led by a broad range of private sector firms is consistent with the character of the initiative. But the council must surely include a wide range of members that represent stakeholders in industrial decarbonization, including public-interest groups. State governments and organized labor organizations would be interested in the prospects of jobs, so their participation on the council would add political weight. There are many examples of motivated citizens forming organizations that have successfully attracted public attention and have led to government action; for example, the

Committee on the Present Danger has on several occasions since the 1950s raised the alarm about foreign policy developments, all of which have drawn significant official and public attention, and many that have resulted in government action. An effective current example is the Bipartisan Policy Center.[24]

The council would have two broad tasks. The first would be to describe the initiative to the public, and to members of Congress and executive branch officials who ultimately have the responsibility to appropriate necessary funding. The council would be saying: "We have a plan, we have a road map, and we need public funding for a fifty-fifty partnership."

If the response to the initiative is positive, the second task of the council would be to solicit expressions of interest from a wide range of groups that would self-assemble to form public/private corporations. Importantly, to avoid conflicts of interest, the council would *not* be responsible for assembling candidates for public/private corporations targeting either industry sectors or the four major crosscutting-enabling technologies (CCS, electrification, hydrogen, and nuclear energy).

Extensions

The initiative would initially be domestic, but the possibility of permitting international participation under similar financial and governance conditions should be kept open. There will be many opportunities for international cooperation, as suggested in the brief descriptions of industrial activities in the EU, China, and India in the appendices of this report.

Technical Appendices

The following three appendices illustrate the breadth of technologies, processes, and systems dynamics relevant to lowering the carbon emissions of the iron and steel, cement, and petrochemical industry subsectors. In general, we believe that the current landscape the appendices depict is one rife with technical opportunity, but as yet largely unexplored in practice given the highly competitive and traded nature of these subsectors. Lowering the risk to the private sector of exploring such opportunities is the key motivation for the public/private independent corporations recommended by this report.

APPENDIX A. LOW-CARBON OPTIONS FOR IRON AND STEELMAKING

Steel is a major input to construction and manufacturing. Demand for steel is growing and will continue to play an important role in a deeply decarbonized economy. As the world's largest industrial consumer of coal, the iron and steel industry accounts for roughly 8 percent of final energy demand and 7–9% of greenhouse gas emissions globally, releasing 2.6 billion tonnes of CO_2 in 2019.[25] The industry is highly concentrated: over 90 percent of production occurs in less than twenty countries.[26] In large part due to the rising demand for building construction during a period of rapid economic growth, China is home to more than half of the world's steel production; fully 85 percent of production capacity is located in developing countries.[27]

Steel production today involves one of two routes: integrated steelmaking using a blast furnace/basic oxygen furnace (BF/BOF), which starts with iron ore; or electric arc furnace (EAF) or minimill steelmaking, which uses recycled scrap alone or in combination with direct reduced iron (DRI, also called sponge iron) or pig iron (produced by melting iron ore along with charcoal and limestone at high pressure). The BF/BOF route accounts for 71 percent of production, the EAF route with scrap for 24 percent, DRI for 5 percent, and other routes for less than 1 percent.[28] The rapid expansion of global steelmaking capacity over the past two decades (with 75 percent of the growth located in China) has resulted in a relatively young blast furnace fleet (thirteen years old on average). The lower energy requirement of EAF steelmaking drives high scrap recycling rates of 80–90% globally.[29]

Decarbonization of steelmaking principally involves both displacing and decarbonizing the blast furnace process. The EAF process requires one-eighth as much energy as the blast furnace process, but it cannot replace integrated steelmaking in markets where scrap supply is limited. Each tonne of steel produced using the BF/BOF route results in emissions of between 1.5 and 3 tonnes of CO_2, most of which is associated with the blast furnace, while EAF CO_2 emissions are much lower and depend on the energy source used to generate electricity. While CO_2 emissions from both processes can be incrementally reduced with process-efficiency improvements, deep decarbonization will require reconfiguring processes to use different inputs. Raising material-input efficiency is also widely recognized as an important part of the solution, but it will not be sufficient in the face of growing steel demand.[30]

For the integrated BF/BOF process, there are several strategies for deep decarbonization. Substituting biomass for coke as a reductant could be important in places with abundant biomass resources, such as South America or Russia, although use is currently limited. Injecting green hydrogen into the blast furnace as an alternative to pulverized coal, an approach to raise efficiency, offers CO_2 emissions reductions of up to 20 percent; however, the need for coking coal is not eliminated. Retrofitting a blast furnace with carbon capture, usage, and sequestration (CCUS) combined with biomass offers the largest projected CO_2 reductions for the integrated process, but the cost is relatively high.[31] Switching to EAFs can further reduce CO_2 emissions, but its potential is limited in markets that lack a sufficient supply of scrap or zero-carbon electricity. The large number of relatively young blast furnaces in Asia also presents a challenge to any replacement strategy. Also, as scrap demand increases, the cost of EAF will also increase.

Currently, the most widely pursued approach to deeply reduce CO_2 emissions from steelmaking involves shifting to DRI in combination with scrap in the EAF process.

Today, coal and natural gas are the main fuels used in DRI. A traditional blast furnace is not required, and less fuel is needed. While DRI requires scrap to some extent, it can also be used when scrap is limited. India is the world's largest producer of DRI. Hydrogen is a potential alternative to coal or natural gas in the DRI process. If the hydrogen is produced with renewable or nuclear energy, steelmaking can be nearly emissions-free. All major European steel producers are currently developing hydrogen-based processes. At present, fourteen DRI projects are currently planned for blast furnace and EAF installations in Europe. Realizing the decarbonization potential of DRI in combination with EAF will require abundant electricity generated in ways that emit near-zero CO_2, from either renewables, nuclear, or fossil fuels with carbon capture and storage. China is also exploring hydrogen-based DRI as an alternative to its reliance on coal-intensive integrated iron and steel production, initially using coal gasification to make hydrogen, which is still a relatively CO_2-intensive process. Another potential but as-yet precommercial approach to zero-carbon steelmaking involves molten oxide electrolysis (MOE), in which an MOE cell converts iron ore into liquid metal and oxygen.[32]

Demonstration projects to reduce the CO_2 emissions from steelmaking are being announced around the world, focusing on the integrated, EAF, and DRI processes and many of them involving the production and use of hydrogen.[33]

APPENDIX B. DECARBONIZATION OF CEMENT MAKING

A crucial building material input, the global production of Portland cement, is about 4.3 billion tonnes annually. Its production requires high-temperature heat, produced today almost entirely by fossil fuels. This contributes to an average global emissions intensity of about 0.54 tonnes of CO_2 for each tonne of produced cement.[34] Responsible for about 8 percent of total global CO_2 emissions, the cement industry, if it were a country, would be the third-largest emitter in the world after China and the United States, and comparable to the total economy-wide emissions from India. Though only a small portion is traded internationally, production is highly concentrated alongside areas of construction demand: China alone represented 70 percent of total global cement production in 2021, while fourth-ranked United States was less than 3 percent. Energy historian Vaclav Smil once noted that China produced more cement for its building boom between 2011 and 2013 than the United States had in the entire twentieth century.[35]

Very little progress has been achieved in reducing CO_2 emissions from cement (and ensuing concrete) production and use. For climate stabilization goals outlined in the Paris Agreement to be met, both emissions that are fuel use related and those that are process related would have to be reduced. Those steps include the grinding, heating, calcining, and sintering of raw materials—typically limestone and clays—to form clinker in very-high-temperature kilns of 1450°C, often heated by coal. The chemical process of degradation of the limestone from carbonate to oxides, known as calcination, also directly releases CO_2 as a byproduct. This amount represents 60–70% of total CO_2 emissions in the overall production process. That reaction can take place in the high-temperature kiln itself, or in a special combustion chamber called a "precalciner" at a somewhat lower temperature of 600–900°C and representing about 50–60% of total production fuel use.[36] The ensuing clinker is then finely ground. There is a significant energy inefficiency in the overall process: of the 1 megawatt-hour energy input typically used per tonne of cement produced, only half is required by the thermodynamics, and the other half is waste. Despite these heat losses, cement has seen little improvement in energy efficiency over time—about 0.5 percent a year for the last six years.[37]

Given the strategic and critical use of cement and concrete in the building industry, there is an understandably conservative, slow uptake of any innovation that aims to replace or change the composition of the current product with products that would not require such high temperatures or that might require less resource input for the same-quality output product. Any change either in product composition or in manufacturing process would require significant changes in quality assurance processes, all the way to possible building code changes. This is not to say that innovations should not be stimulated. Indeed, there are roughly three types of innovation that could be explored:

1. *Design of a new manufacturing process*, for example, electrochemical processes based on direct electrolysis of the limestone into carbon and oxygen rather than CO_2, which would allow manufacturing at much lower temperatures, and possibly in smaller units with a smaller footprint.

2. *Reducing or changing the input resource for the same-quality output*, for example, mixing cement with carbon wires or pellets, with the potential to achieve the same quality (strength and durability) but with much less product, leading to lighter constructions. Also, development of alternative cement binders offers a viable pathway for reducing CO_2 emissions. Miller and Myers (2019) estimate that about a 25 percent emission reduction can be achieved solely through increased use of alternative binders.[38]

3. *Add novel, high-value functionality* to cement products that can offset the increased costs of cleaner production processes. For example, the manufacturing of carbon wires to fill the pore space in concrete may allow for resistive radiant heating through building walls or even the accumulation of large amounts of static electricity, as in a capacitor, offering the potential for power storage through concrete in walls, road pavement, or parking lots.[39]

All such innovations are likely to require significant changes in building codes. As such, in the longer term, such innovations may be crucial for sustained reduction of the carbon footprint, but they are less credible to be scaled in a Paris Agreement time frame (i.e., by 2030).

In that shorter time frame, substantial decarbonization in cement will likely only be achievable at scale through carbon capture and storage (CCS)—the only midterm option to reduce both energy emissions and process emissions in cement production. There are a number of such CCS options that could be used: postcombustion capture, oxy-combustion capture, and cryogenic carbon capture offer the most promising pathways for the cement industry. Postcombustion capture is likely the most straightforward option of the three in that it can conceivably be retrofitted onto existing cement plants without significant change to the production process. Oxy-combustion capture, on the other hand, would require the use of a nearly pure oxygen environment in the clinker kiln, or just in the precalciner (for partial capture). This is a less mature approach but could potentially still reduce overall emission reduction costs by providing a resulting purer stream of CO_2 and water vapor to capture. Cryogenic capture is even more conceptual, but proffers to remove CO_2 from a cement plant's flue gas by freezing the gas into a solid at –140°C, eventually delivering the resulting CO_2 stream at pipeline pressure.[40] Each approach represents somewhat different technology-readiness levels, and each offers varying packages of cost-reduction pathways across elements of a complete capture and storage system. They could therefore be considered as credible candidates for subsidized pilot or demonstration-scale plants in a commoditized industry that otherwise faces little private incentive to incorporate the emission externalities of its product.

APPENDIX C. DECARBONIZATION OF THE PETROCHEMICAL SECTOR

The petrochemical sector entails the use of hydrocarbon inputs for the production of building-block industrial chemicals, including the olefins ethylene and propylene, ammonia, aromatics such as benzene, and methanol. Those key chemicals in turn can be used to produce a broad set of thousands of consumer products, spanning from plastics to fertilizers, from synthetic fabrics to tires, and from polystyrene to detergents. Accordingly, inputs, processes, and technologies also vary widely. The sector consumes roughly 10 percent of global fossil fuels—more than the iron and steel and the cement subsectors combined—but primarily as a "nonenergy" feedstock input itself to provide the carbon and hydrogen atoms that are arranged into useful chemicals, and secondarily to provide heat and electricity needed to power that production process. As such, actual CO_2 emissions are only about 1.5 billion tonnes, or roughly 5 percent of global CO_2 emissions from energy. Demand for petrochemical products is rapidly rising, however, especially in developing economies where per capita use of plastics, for example, may be just one-tenth the level of developed economies; the International Energy Agency expects that this subsector alone will drive more oil demand in coming years than the entire transportation sector.[41]

Given the level of "nonenergy" feedstock use of hydrocarbons in the sector, emission-reduction strategies both are individually challenging and carry implications beyond the sector itself. This suggests the importance of few key dynamics for any decarbonization strategy of this sector:

1. *The need for integration of fuel and product manufacturing*. The focus of the sector will have to shift to more integrated (carbon-based) products and synthetic fuels. In particular, extraction and processing techniques of carbon from feedstocks other than fossil resources need to be more developed, such as carbon from bio/agricultural and municipal waste as well as from CO_2 captured from the point sources or ambient air, or seawater. This may lead to a different positioning of base molecules such as hydrogen, ammonia, and methanol production in petrochemical value chains driven by new low-carbon, circular manufacturing systems.

2. *The importance of clean thermochemical routes to hydrogen*. Much attention is given to the production of hydrogen from clean sources of electricity, such as renewables. But given this subsector's high rate of growth, it is probably more credible to sustainably (that is, economically) accelerate its decarbonization along the nonfossil input model described above by focusing more on thermochemical routes to hydrogen production (e.g., reformation or pyrolysis). This approach could be combined with new, clean sources of dispatchable heat, both for direct use in high-temperature petrochemical production process steps as well as for storage, combined with renewable power. Thermochemical routes to hydrogen scale faster than first decarbonizing a separate electric grid and then producing clean hydrogen from it through electrolysis; they are in essence independent of that broader infrastructure development. In this context, the role of new, advanced nuclear energy (both for power and directly for higher-temperature heat) would also be an attractive complement to renewables-based solutions.

3. *The relative value of government-supported collaborative frameworks*. More so even than in the steel and cement industries, the decarbonization of the petrochemical subsector is more involved and more interconnected with a variety of other industrial subsectors using petrochemical products and resources. In this highly optimized and integrated system of today, it is particularly difficult for one player in the value chain to unilaterally move toward a cleaner process. As such, we can expect that any emission-reduction progress here will be relatively opportunistic absent coordination, and probably not optimal from an engineering-system perspective. In this sector, there is particular promise in major firms in key regions such as the United States and Europe collaborating with government to drive pilots and demonstrations.

4. *The regional and adjacent industry implications of adopting new resources and processes*. One dynamic to watch could be that the expected growth of the petrochemical subsector globally, combined with the exploration of new processes and resources to reduce CO_2 emissions, could impact regional manufacturing competitiveness in the manufacture of these highly traded products. For example, the unexpected advent of fracking in the United States set off hundreds of billions of dollars of associated private sector petrochemical investment in the US Gulf Coast over the past decade

> to produce the plastic precursor ethylene from cheap gas, which was not previously considered economical. Going forward, were biomass-based feedstocks to become preferred industry inputs instead of fossil fuels, the US Midwest or Brazil could see the emergence of more distributed biochemical refineries to complement their existing bioethanol production.[42] Along similar lines, some have speculated that the Middle East, already a petrochemical production locus due to cheap fossil fuels, could transition to a low-cost global green hydrogen producer given solar renewable resources. Even that may be preceded, however, by production of clean hydrogen and ammonia driven by a diversification of existing natural gas businesses and the opportunity for (likely similarly cheap) large-scale carbon capture and storage, while ramping up renewable production of hydrogen and ammonia and other base chemicals using CO_2 as a feedstock. The more widespread adoption of ocean-water desalination may even enable colocation of clean hydrogen and methanol production (with CO_2 extracted from ambient air or even infrastructure-sharing seawater), thus leading to new and different industrial synergies.

Each of these dynamics illustrates the potential for integration of various petrochemical production processes made possible by low-carbon feedstocks and other resources—as well as the industrial codependencies that have largely dissuaded independent private investment to this end.

• • •

This Shultz Energy and Climate Task Force Industry Decarbonization Work Group report reflects the variety of input offered by Task Force participants through a series of structured roundtable discussions at the Hoover Institution and other consultations through the spring and summer of 2022. David Fedor of the Hoover Institution was instrumental in support of this essay's development.

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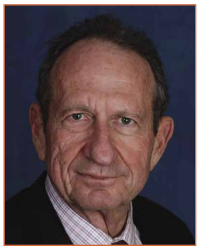

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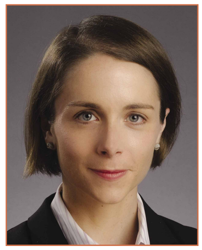

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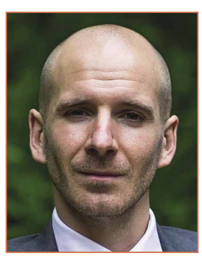

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The George P. Shultz Task Force on Energy and Climate

The George P. Shultz Task Force on Energy and Climate takes a balanced approach toward sustaining the economic, environmental, and security dimensions of energy policy. The Task Force's goal in carrying forward Secretary Shultz's legacy, as established more than fifteen years ago, is to continue his nonpartisan, temperate, and problem-solving approach toward energy and climate questions of US national importance: with balance, so that policies can be sustained over political cycles to match the large scale and long time frames at which the energy world operates; with clarity—both analytical and moral—in appraisals of complex systems; and with a constructive voice, favoring pragmatic steps in the right direction today so as to not get lost in the distance of time or rhetoric. Cochaired by Arun Majumdar and Amb. Thomas F. Stephenson, the task force convenes as needed to respond to emergent energy problems. And it organizes regular, ad hoc expert and practitioner work groups to identify sector-specific midterm risks in the energy transformation and propose novel policies to address them.

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