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International Trade Administration
U.S. Department of Commerce
1401 Constitution Ave NW
Washington, DC 20230

RE: ITA-2021-0005: Request for Comments on U.S. Clean Technologies Export Competitiveness Strategy

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INTRODUCTION

Thank you for the opportunity to provide comments on U.S. clean technologies export competitiveness. The Information Technology and Innovation Foundation (ITIF) is a non-profit, non-partisan research and educational institute—a think tank. Its mission is to formulate, evaluate, and promote policy solutions that accelerate innovation and boost productivity to spur growth, opportunity, and progress. Clean energy innovation is one of ITIF's main issue areas and includes a specific focus on innovation to make energy both clean and competitive. The responses to questions in this request for comments are based on a series of recent ITIF reports.

RESPONSES TO SPECIFIC QUESTIONS ASKED IN THE RFI:

1. **Is there an established methodology for designating particular technologies as clean technologies or additional factors that the Government should consider for purposes of scoping this strategy?**

The federal government should designate technologies as clean based on their function in achieving deep decarbonization. *Energizing America: A Roadmap to Launch a National Energy Innovation Mission,* a report co-authored by ITIF and Columbia's Center on Global Energy Policy, presents ten pillars that group technologies based on their distinct decarbonization application.[1] For example, nuclear and renewable power generation are grouped under the clean electricity generation pillar. Energy storage and energy efficiency technologies are distributed across multiple pillars because they serve multiple decarbonization functions, including grid modernization, net-zero energy buildings, and clean electricity generation. A functionality-based approach, rather than a technology-based approach, would enable the federal government to assess opportunities for U.S. exports on a wide range of clean technologies that will be in high-demand worldwide to reach net-zero greenhouse gas emissions.[2]

1. **Clean manufacturing and industrial decarbonization**, including electrification of process heat, hydrogen applications, and carbon capture for industrial sources such as cement, steel, and aluminum.
2. **Advanced vehicles and transportation systems**, including battery and fuel cell electric vehicles, DC fast chargers, vehicle lightweighting, efficiency technologies for medium- and heavy-duty vehicles.
3. **Energy-efficient and net-zero energy buildings**, including advanced heat pumps, solid-state cooling, smart meters, alternative building materials, high-performance windows, and grid-integration.
4. **Clean electricity generation**, including advanced nuclear reactors, thin-film solar PV, floating offshore and high-altitude wind, run-of-river hydropower, and enhanced geothermal systems.
5. **Zero- and low-carbon fuels**, including next-generation electrolyzers, carbon capture, sustainable biofuels, hydrogen from electrolysis or biomass gasification, ammonia, and synthetic hydrocarbon fuels.
6. **Grid modernization technologies**, including long-duration grid-scale energy storage, power electronics, and digital technologies that enable grid integration of buildings and vehicles.
7. **Carbon capture, use, and sequestration (CCUS)**, including the Allam cycle for natural gas power generation; and carbon capture for industrial sources such as cement and steel.
8. **Carbon dioxide removal / negative emissions technologies**, including direct air capture and storage (DACS), carbon mineralization, and bioenergy with carbon capture and storage (BECCS).
9. **Clean agricultural systems**, including fertilizer management, precision agriculture, soil carbon storage, and biotechnologies to enhance carbon storage.
10. **Foundational science and platform technologies**, including advanced materials, electrochemistry, quantum computing, genomic sciences, 3D printing, smart manufacturing, and machine learning.

2. What clean technologies offer the most significant immediate opportunities for U.S. exports of associated goods and services?

Smart grid technologies: The United States is home to several major smart grid technologies manufacturers, including General Electric, Sensus, Aclara, and Itron.[3] Smart meters—a smart grid infrastructure that can track and communicate real-time energy usage—have been critical to expanding participation in demand response programs and giving utility customers greater insight and control over their energy consumption. Other smart grid technologies—e.g., technologies that allow for enhanced sensing and control of grid elements, use more powerful computer processing, and have finer control systems—can support renewables integration and enable increased energy efficiency, reliability, and security.

Domestic demand for smart grid technologies has grown in recent years. As of 2019, around 60 percent the electricity meters installed in the United States were smart meters with advanced two-way communications capability that would enable visibility of real-time prices and support flexible demand.[4] Global demand for smart grid technologies will likely increase, as utilities around the world seek more efficient, reliable, and secure ways to manage energy generation, transmission, and distribution.[5]

Carbon capture and sequestration (CCS) technologies for blue hydrogen production: The United States is a world leader in blue hydrogen production—making hydrogen using natural gas and capturing the resulting carbon dioxide emissions using CCS technologies. Four U.S. facilities that make blue hydrogen are in operation. They include a refinery in Texas and fertilizer plants in Kansas, Louisiana, and Oklahoma. The Great Plains Institute has identified 34 hydrogen production facilities and 3 ammonia facilities—which together emit over 15 MMT of carbon dioxide per year—as potential near-term candidates for CCS retrofits.[6]

Congress has incentivized blue hydrogen production with the 45Q tax incentive, which provides a credit of $35 or more for each ton of carbon dioxide a facility permanently sequesters.[7] Congress has also directed the U.S. Department of Energy (DOE) to begin commercial demonstrations of carbon capture technologies to test their viability for blue hydrogen production.[8] As governments and businesses around the world increasingly turn to blue hydrogen to cut emissions and meet climate targets, demand for CCS technologies will increase. With more large-scale CCS projects for hydrogen production coming online in the near-term, the United States is well-placed to lead exports of this important technology.[9]

3. What clean technologies do not currently offer significant immediate opportunities for U.S. exports of associated goods and services but may offer such opportunities within the next five to ten years?

Electrolyzers for green hydrogen production: The United States is less well-positioned for green hydrogen production—making hydrogen using electrolyzers powered by renewable energy—than it is for blue, although it is home to several leading electrolyzer manufacturers. The largest announced domestic project for green hydrogen is a partnership between Nel, (a Norwegian hydrogen company) and Nikola (a U.S. designer of zero-emissions truck) that will supply 1 gigawatt of electrolyzers to 30 hydrogen fueling stations across the country.[10] But most of the installed capacity of electrolyzers is abroad, particularly in Europe. The federal government has supported research, development, and demonstration (RD&D) with grants on the order of $1 million–$2.5 million per project, but this scale is too small to demonstrate and validate low-cost, high-volume production. The United States could capture this nascent and growing market for electrolyzers in the long-term with sustained investments in commercial-scale demonstration projects.[11]

Smart buildings technologies: Smart building technologies, including sensors, artificial intelligence (AI), and active controls, may offer opportunities for U.S. exports within the next decade. These emerging technologies gather data on energy use, automate various processes, from lighting and security to heating, ventilation, and air conditioning (HVAC), and enable better integration with the electric grid.[12] AECOM found that the deployment of smart building technologies across 120 commercial energy projects in Chicago and Detroit produced $60 million worth of kilowatt-hour reductions.[13]

The Building Technologies Office (BTO) leads DOE's research in smart buildings, smart appliances, and grid-integrated efficient buildings (GEBs). As part of a new research initiative to develop GEBs, DOE is exploring AI applications in whole building controls, sensors, modeling, and analytics, as well as applications in advanced lighting and HVAC systems. Furthermore, the Energy Act of 2020 directs DOE to establish a Federal Smart Building Program to demonstrate the cost and benefits of smart buildings and implement associated technologies.[14]

The market for smart building technologies will likely grow as countries around the world seek to improve building energy efficiency and reduce greenhouse gas emissions from the buildings sector by optimizing energy supply and consumption. Residential and commercial buildings account for one-third of global energy demand and 55 percent of energy consumption[15]. These numbers are even higher in the United States, where buildings are the largest electricity-consuming sector, accounting for 71 percent of the nation's electricity usage and 32 percent of U.S. greenhouse gas emissions.[16]

Power electronics: Power electronics are essential for a modernized grid and already exist in several stages of the U.S. grid design, including long-distance power transmission and grid edge applications like power quality. The vast majority of power electronics use semiconductors made from silicon. However, as power electronics have become more widely used, the appeal of using semiconducting materials that have a wider bandgap than silicon, such as silicon carbide (SiC) and gallium nitride (GaN), has grown. Wide bandgap semiconductors operate at higher temperatures, frequencies, and voltages than silicon semiconductors, thus allowing devices that use them to be made smaller and more efficient.[17]

PowerAmerica (also called the Next Generation Power Electronics National Manufacturing Innovation Instutute) has an overarching goal to make SiC and CaN cost-competitive with silicon semiconductors, and increase their adoption in new armetks and applications. Its roadmap toward this goal, which was developed in 2016 and released in 2017, entails 50-percent cost reduction every two years, and focuses on improving reliability, enhancing performance, and fixing deficiencies in the "ecosystem"—such as domestic manufacturing capacity, workforce knowledge, and advanced complementary technologies. In the near term, the roadmap focuses on applications in consumer electronics, data centers, and solar power; further down the road, it anticipates energy-efficient industrial motor drives and medium-voltage drives for power plants being key end use.[18]

Advanced heat pumps: U.S. manufacturers are not yet well-positioned to capture the rapidly growing domestic and international markets for heat pumps and other advanced electric heating and drying equipment. Global markets for heat pumps are highly competitive. Top heat pump manufacturers spanning both domestic and international firms include Carrier, UTC, and Trane, as well as Mitsubishi Electric, Fujitsu, Daikin, and Panasonic (Japan), and LG (South Korea).[19] Electrifying end-use heating processes increases energy efficiency due to the inherent efficiency of electricity over fossil fuels. Whereas thermal losses from on-site fossil fuel use can be large due to waste, more work can be done with an equivalent amount of electricity. Energy losses from electricity used in industrial processes account for 20 percent of delivered energy, while for fossil fuels, energy losses were more than 50 percent.[20] Air-source heat pumps can return up to four times more heat per joule of energy input than an equivalent gas furnace by minimizing waste heat.

U.S. demand for these products is weak, in large part because low U.S. natural gas prices have maintained strong markets for conventional equipment. In 2015, only about 10 percent of U.S. households used heat pumps for heating (although this figure was up from 2 percent in 2001).[21] Corporate investment in heat pump innovation may also have been limited by the fact that the United States has been much slower than most of the rest of the developed world to phase out refrigerants that contribute to climate change. Innovations leading to inexpensive heat pumps with high performance, however, could give U.S. producers a significant advantage in both domestic and international markets in the long-term.[22]

Biotechnology-based alternative proteins: The opportunity for U.S. leadership in biotechnology-based alternative protein production remains significant. Livestock and manure are responsible for about 6 percent of global greenhouse gas emissions. As incomes rise globally, demand for meat and dairy products is expected to rise, driving up emissions further. Proteins made by fermentation as well as meat grown in vitro could replace agricultural production if costs can be reduced and consumers are willing.[23]

Plentiful private venture capital has positioned the United States to take an early lead in the emerging alternative protein industry. Biotechnology-based alternative proteins are not generally cost-competitive with conventional products, however. The rapid advance of the biological sciences, progress in biomanufacturing, along with further progress in fermentation, cell culture, and other biotechnologies, should make alternatives to processed meats such as hamburger and milk products such as whey cost-competitive in the long-term. Seafood, egg, and poultry substitutes may be the next potential markets, approaching price parity with conventional products in the early 2030s, according to Boston Consulting Group.[24]

Chemical production and recycling technologies: The United States enjoys enormous strengths in chemical manufacturing. But it is lagging behind in exploring innovation pathways that could lead to replacements for fossil fuel-based chemical production. The chemical industry accounts for about 6 percent of global emissions and rising.[25] Bioengineers express confidence that they can build systems to produce virtually any organic molecule at the bench level. If biomanufacturing systems for major commodity chemicals can be scaled cost-effectively without requiring carbon-intensive inputs, they could radically disrupt this industry while slashing its emissions.[26]

Biomanufacturing startups spun out of U.S. research institutions frequently go abroad to scale up production. These private decisions are the result of strategic planning and investment by foreign governments, especially in Europe, that have not yet been matched by the U.S. federal government. The nascent state of the industry, however, suggests that the United States still has a window to establish a competitive position in emerging climate-responsive biomanufacturing markets. Some opportunities in the long term include technologies to cut the cost of recycling plastics and other chemical products (such as paints, textiles, and lubricants), and to manufacture chemicals from feedstocks, fermentation processes, and artificial photosynthesis.[27]

Decarbonized metal manufacturing technologies: The United States' metal manufacturing sectors are already less carbon-intensive than many of its global industrial peers, such as Japan, South Korea, China, and for some industries and countries, Europe. This advantage is due in large part to the reliance on electricity as a fuel source in both secondary steel production in electric arc furnaces and the use of low carbon electricity in aluminum production. However, there are emerging technological areas where international competitors are outpacing or have the potential to outpace advances in domestic metal manufacturing. These areas include the use of clean hydrogen as a reductant in the direct reduced iron (DRI) process and the use of inert, or non-consumable anodes in low-carbon aluminum production. The United States cannot afford to fall behind international competitors in the development and deployment of these low-carbon metal manufacturing processes.[28]

4. For sectors or technologies in which the United States currently has a competitive domestic industry, what are the main factors (i.e., economic, technical, regulatory, etc.) that could pose a significant risk to the U.S. industry's competitive position?

Smart grid technologies: There are no active federal programs that support the deployment of smart grid infrastructure. Current federal smart grid programs focus solely on RD&D of smart metering technologies rather than deployment. The 2009 American Recovery and Reinvestment Act (ARRA) included $3.4 billion for the Smart Grid Investment Grant (SGIG) program to modernize the electric power grid. The SGIG program provided funding for deployment of advanced metering infrastructure (i.e., smart meters), distribution automation systems, phasor measurement units for the transmission grid, and customer systems such as smart appliances and building energy management systems.[29] The SGIG program is credited with installing more than 16.3 million smart meters, nearly double the number of smart meters installed before the SGIG program began.[30] Since the end of the program, utilities have had to finance grid upgrades without federal support, which is an especially large burden on rural electric coops and some of the smaller utilities that have fewer customers who can support rate increases to fund infrastructure upgrades.[31]

Carbon capture and sequestration (CCS) technologies for blue hydrogen production: Most of the U.S. production is "captive;" in other words, it is produced by the user at the site of use, such as a fertilizer plant or oil refinery. "Merchant" hydrogen is made at a central facility and delivered to customers by pipeline, tanker, or truck. Captive hydrogen producers have no incentive to retrofit their facilities with carbon capture in the absence of a policy that fully addresses the high cost of cleaner production. Merchant producers face the same cost differential and also lack a mechanism to distinguish clean from dirty hydrogen in sales. All producers face infrastructure barriers, particularly access to pipelines that will carry captured carbon dioxide to sequestration sites.[32]

5. For sectors or technologies in which the United States does not currently have a competitive domestic industry, what are the main factors (i.e., economic, technical, regulatory, etc.) inhibiting U.S. industry competitiveness?

Advanced heat pumps: U.S. demand for advanced heat pumps is weak, in large part because low U.S. natural gas prices have maintained strong markets for conventional equipment and higher relative electricity prices. In 2015, only about 10 percent of U.S. households used heat pumps for heating (although this figure was up from 2 percent in 2001).[33] Corporate investment in heat pump innovation may also have been limited by the fact that the United States has been much slower than most of the rest of the developed world to phase out refrigerants that contribute to climate change. In addition, there are remaining technological barriers to adoption of high-temperature electric heat pump technologies.[34]

Smart building technologies: The scale of federal investments in smart building technologies is too small to take full advantage of all building technology decarbonization opportunities. When all greenhouse gas emissions, including from electricity generation, are distributed by end-use sector, buildings account for the largest share of gross emissions at 32 percent, ahead of the industrial and transportation sectors. Despite its prominence as an energy-consuming sector and leading source of emissions, the buildings sector accounts for only 4 percent of DOE's applied energy technology portfolio. ITIF and other prominent organizations, including the International Energy Agency, have recommended that government energy RD&D programs increase focus on end-use innovations.[35]

Electrolyzers for green hydrogen production: The scale of federal investments in green hydrogen production RD&D projects is too small to demonstrate and validate low-cost, high-volume production. The federal government has supported research and development (R&D) with grants on the order of $1 million–$2.5 million per project.[36] Other countries are already investing large sums in commercial-scale demonstration projects, which are intended to attract even greater private sector investment. For example, the state of South Australia has put the equivalent of US$26 million (out of a total project cost of $173 million) into the world's largest green ammonia plant, including a 75 MW electrolyzer.[37] Similarly, the EU and many of its member states are making major investments in the electrolyzer supply chain as well as in prototype and demonstration production plants.[38]

Chemical production and recycling technologies: At present, there is no cohesive U.S. strategy in the federal government or in key industries for managing a transition that will affect at least 10 percent of U.S. manufacturing jobs over the next three decades. U.S. producers will need to make significant investments in order to preserve domestic markets in a low-carbon world and to win markets abroad in countries with ambitious climate policies. Some international oil majors with significant U.S. chemical production footprints are beginning to take action. Shell, for example, has set a goal of reducing its "carbon intensity by 45 percent by 2035 and by 100 percent by 2050."[39] But the overall rate of change to date seems far short of what will be required.

Biotechnology-based proteins: Lack of public funding for intermediate-scale production facilities represent a key gap in the U.S. alternative protein innovation system. Production beyond the lab but short of full commercial scale is crucial for most food industry start-ups to establish their credibility and prove out their processes. While simulation technology can greatly facilitate scale-up, investors and customers typically want hard evidence that young companies have mastered engineering, as well as the science and, are able to meet product and market specifications.[40]

In addition to public support for R&D and demonstration, the societal dimensions of shifting protein consumption will require a significant amount of research and smart communication. With some justification, farmers and ranchers may fear displacement caused by alternative proteins. Consumer acceptance may also prove challenging, especially in export markets with rising middle classes that perceive meat and dairy products to be desirable luxuries.[41]

Decarbonized metal manufacturing: The major factors inhibiting the development of a robust domestic decarbonized metal manufacturing sector are the technological inertia of existing lower carbon technologies such as electric arc furnaces (EAFs) in the iron and steel industry and the use of carbon-based anodes in primary aluminum manufacturing. While the United States is a global leader in lower carbon-intensive metals manufacturing there are technological limits with existing technology as to how low sectoral carbon emissions can go. Take green hydrogen-DRI iron production, for example. While the technology deployment is currently in its infancy in Europe, there is no known effort in the United States to bring together major steel producers, purchasers, academia, or technology start-ups or providers to develop a comparable clean steel industry based on clean hydrogen and DRI. The lack of a domestic low-carbon hydrogen industry that can transport H_2 from where it will be produced most cost-effectively to where it is needed in industrial applications, such as iron and steel, remains a significant challenge.[42]

6. What are the most impactful new actions the Government could take domestically to reduce or remove challenges, risks, and barriers in order to help position U.S. clean technologies industries for competitiveness in the global market?

Power electronics: The federal government should prioritize funding for RD&D in high-voltage direct current (HVDC) transmission, including advancing power electronics and converter and conductor technologies, and demonstrating meshed networks of HVDC lines.

Smart grid technologies: ITIF's March 2021 report "How Congress and the Biden Administration Could Jumpstart Smart Cities with AI" makes recommendations to the federal government to accelerate the adoption of smart grid technologies:

R&D:

- DOE should update its Grid Modernization research plan to include AI applications identified in the Grid Modernization Multi-Year Program Plan. DOE has not updated its research plan since 2015, leaving the smart grid research agenda uncoordinated with different technology programs.

Deployment and market expansion:

- The federal government should revive the SGIG program to support deployment of advanced metering infrastructure and other smart grid investments. The first SGIG program, funded through ARRA, was responsible for nearly doubling the number of smart meters, and was a key program for other grid modernization investments. However, nearly half of U.S. customers still lack smart meters. Grid upgrades are especially challenging for rural electric coops and utilities serving low- and moderate-income communities to fund on their own without federal support.

Smart building technologies: ITIF's March 2021 report "How Congress and the Biden Administration Could Jumpstart Smart Cities with AI" makes recommendations to the federal government on grid-integrated buildings and smart building technologies:

R&D:

- The federal government should prioritize investment in RD&D of AI for building energy applications, including DOE programs in advanced grid RD&D, grid-integrated efficient buildings, and energy systems integration.

Demonstration:

- The federal government should urge city governments to pilot smart building and smart grid technologies on city buildings. Because they generally have more control over their own buildings than other buildings in the public sector, if city governments can pilot and demonstrate energy savings from AI applications on their own facilities, they can then share that information with commercial and industrial buildings managers. The Salt River Project, an Arizona public utility, for instance, is piloting GEB technologies on their facilities, which they intend to eventually offer as a service to large commercial and industrial energy users.

Deployment and market expansion:

- The federal government should urge city governments should include AI and smart city technologies in their climate plans. AI is an important but often overlooked tool in the decarbonization toolkit. For example, in the last couple years, four large U.S. cities—St.

Louis, Chicago, Pittsburgh, and Boston—developed citywide building energy benchmarking reports to inform city energy and climate plans. The St. Louis report was the only one that encouraged adoption of smart building technologies (automated building energy management systems, occupancy sensors, and smart thermostats). But the list of technologies included was not complete. And the other cities did not include any AI or smart building technologies in their energy plans.

Advanced heat pumps: While DOE has supported heat pump and dehumidification technologies for decades, given their importance for meeting climate goals and expanding U.S. manufacturing, much greater investment is needed. Detailed roadmap and investment plans should focus on developing high-efficiency, low-cost, highly reliable heating, cooling, and drying systems for buildings and industry. ITIF's Clean and Competitive report offers the following recommendations:

R&D: Key focus areas include:

- new refrigerants and highly innovative alternate cycle technologies such as electrocaloric and elastocaloric systems for heat pumps;
- next-generation heat exchangers exploring new materials, new designs, new fabrication techniques, and new design and simulation software;
- innovations that could cut the cost of drilling and piping for geothermal heat pump systems;
- novel electric drying systems such as those that use mechanical methods and design software needed to achieve system efficiencies;
- redesigning and reengineering low-temperature industrial processes to take advantage of the characteristics of heat pumps;
- innovative separation technologies with a focus on membranes; and
- new sensors, simulation, and modeling tools for designing and operating zero-emission production systems in specific industries, such as food processing and paper manufacturing, including redesigning processes to incorporate heat pumps and novel drying techniques.

Demonstration:

- In conjunction with industry, the federal government should fund pilots and first-of-a-kind demonstrations of zero-emission industrial processes that use innovative heating, cooling, and drying equipment.

- Federal loans and other financial assistance should be provided for manufacturing advanced heat pumps domestically.

Deployment and market expansion:

- Appliance standards should be expanded to include a wider range of commercial and industrial equipment and consideration of system efficiency, such as the costs of grid integration and efficient dehumidification.
- Highly efficient electric heating and cooling equipment should be mandated for all new buildings constructed in the United States and become an integral part of any building efficiency retrofit program.
- All federal buildings, including those owned by DOD as well as civilian agencies, should replace fuel-fired space and water heating water systems with efficient electric systems.

Biotechnology-based alternative proteins: A robust federal policy to accelerate biotechnology-based alternative protein innovation in order to secure U.S. global leadership and enable large-scale emissions reductions might include:

R&D:

- Expand support through existing USDA programs for applied research on all aspects of the alternative protein supply chain. Opportunities abound to improve feedstocks, develop new ingredients and processing methods, and create production systems that are well adapted to seasonal variations in the availability of biomass inputs.
- Create targeted R&D programs to tackle specific barriers within the Agriculture Advanced Research and Development Authority (AGARDA), an authorized but as-yet unfunded office modeled on the Defense Advanced Research Projects Agency (DARPA). Such entities seek to fill high-impact "white spaces" that have been neglected in their parent agency's technology portfolio.

Demonstration:

- Provide public funding to cover the capital gap that prevents testbed facilities from being built in the United States. These facilities should be funded in conjunction with and operated by companies or industry organizations, and facility users should be required to cover operating costs.
- Work with states, localities, and groups of firms to develop a new Manufacturing USA innovation institute to accelerate innovation in alternative protein production technology. Such an institute could house shared facilities, support research into industry-defined

problems, invest in workforce development, and assist small and medium-sized companies to join emerging supply chains.

Deployment and market expansion:

- Focus regulatory attention on potential risks posed by products, rather than singling out products made with biotechnological methods for particular scrutiny. In particular, the Food and Drug Administration (FDA), which will have oversight of important aspects of cultivated meat production, has taken an excessively risk-averse approach to biotechnology-based products in the past, ignoring an evidence-based, bipartisan consensus for a more balanced approach.
- Level the playing field by cutting back federal subsidies for meat and dairy products and ensuring fair labeling of all products. The milk industry, for instance, which already receives a substantial portion of its income from the government, has petitioned the FDA to forbid plant-based substitutes such as soy milk from using the word "milk" in their marketing. Biotechnology-based innovations will surely face similar opposition.
- Put alternative proteins on an equal footing with conventional products in federal food procurement and nutrition support programs. Every day, federal agencies subsidize meals for millions of people, from soldiers to students to the needy, and they could use this buying power to advance climate-friendly alternative protein innovations, emulating innovation policies employed in many other fields of technology.

Innovation ecosystem:

- Assist farmers, ranchers, and rural communities that depend on the livestock industry directly or indirectly to join alternative protein supply chains or shift to other industries. Those who take land out of production may provide soil carbon sequestration services, while others may be able to shift from growing grain to sell to feedlots to raising plants that serve as inputs used in fermentation or cell culture.

Electrolyzers and CCS for hydrogen production: A federal policy agenda for clean hydrogen production should set ambitious cost reduction targets and prioritize research, development, and demonstration projects aimed at realizing these targets. The federal government should also support deployment by encouraging its own agencies to become early adopters of clean hydrogen and enacting policies that bridge, narrow, and ultimately eliminate the cost differential between dirty and clean hydrogen. Key steps include:

R&D:

- Shifting the focus of DOE's Hydrogen and Fuel Cells Technology Office away from light-duty vehicles and toward hydrogen production and end-use applications in hard-to-abate sectors, such as industry, energy storage, and heavy-duty transportation. The office's authorization should be expanded to include these applications.
- Increasing appropriations for R&D funded by DOE's Hydrogen and Fuel Cells Technology Office by 150 percent over five years. This investment should be embedded in a broader effort to build strong linkages across DOE's hydrogen innovation pipeline from basic research supported by the Office of Science on one end to commercially oriented demonstration projects managed elsewhere in DOE or by other federal agencies on the other.
- Working with industry and state and local governments to establish a new Manufacturing USA innovation institute to carry out cost-shared R&D on PEM electrolyzer manufacturing and systems integration. Such an institute could support problem-solving projects of broad interest across the hydrogen value chain, provide shared infrastructure, and develop programs to train skilled workers and support small and medium manufacturers.

Demonstration:

- Authorizing and providing public funding for a portfolio of pilot- and commercial-scale demonstration projects or clean hydrogen "hubs" that are cost-shared with private investors and operated by commercial firms. These projects could encompass both blue and green hydrogen production in a range of configurations as well as diverse end uses, informed by a strategic analysis of the competitive advantage of U.S. locations.
- Authorizing and encouraging federal agencies to become early adopters of clean hydrogen by executing long-term contracts to buy the output of demonstration projects. DOD and the General Services Administration (GSA), for instance, manage large fleets of buildings and heavy-duty vehicles that might be converted to hydrogen technologies in the coming decades.
- Trialing a contract-for-differences model to support demonstration projects. This model would create a bidding process to establish the lowest price that clean hydrogen producers are willing to offer and then fund the difference between that price and the market price for high-emissions hydrogen.

Deployment and market expansion:

- Adopting a "Moon Shot" production cost target for clean hydrogen of $1 per kilogram, with additional specific cost targets for storage and distribution. That level is 50 percent lower than the current DOE target and the current price of dirty hydrogen and in line with market-based projections of green hydrogen production costs in 2050 (see figure 1).46 (Just as this report went to press, DOE announced a target of $1 per kilogram for clean hydrogen by 2030.)

- Establishing production tax incentives (beyond the existing credit for hydrogen fuel cells) that are authorized through at least 2035, are eligible for some form of direct payment, are received by producers based in part on the amount of hydrogen produced, and have maximum life-cycle carbon-intensity limits for eligibility, with greater incentives for cleaner production methods.

- Expanding the range of hydrogen production, infrastructure, and end-use technologies that are explicitly eligible for assistance from the DOE Loan Programs Office. Loans, loan guarantees, and other federal assistance can help worthy borrowers that are not able to secure full financing from risk-averse private lenders to establish the "bankability" of clean hydrogen production.

Innovation ecosystem and technical assistance:

- Expanding initiatives to evaluate the potential of the existing natural gas infrastructure to transport hydrogen, while controlling local air pollution as well as GHG emissions. Blending modest amounts of hydrogen with natural gas could allow the existing infrastructure to serve as a bridge to a dedicated hydrogen infrastructure as volumes rise over the longer term.

- Ensuring that federal safety standards for hydrogen pipeline and distribution systems are adequate, and developing standards and guidance for the safe integration of hydrogen, ammonia, and other hydrogen carriers with industrial, heating, transportation, and other end-use infrastructure. Hydrogen is corrosive as well as inflammable, and any dramatic expansion in its production, transportation, and use will entail risks that must be managed.

- Updating measurement and improving modeling of the hydrogen value chain across production pathways, including both merchant and captive producers. Significant gaps mar the current understanding of job and value creation in this rapidly changing industry.

Chemical production and recycling technologies: A successful strategy for domestic bio-based chemical production would include R&D, demonstration, and deployment programs. It should pursue a portfolio of technologies because the advantages of each approach are only beginning to be understood and the pace of innovation has been so rapid. It would be accelerated by the development of a comprehensive national roadmap that builds on existing roadmaps; involves several federal agencies, notably DOE, the U.S.

Department of Agriculture (USDA), DOD, and U.S. National Science Foundation (NSF); and covers the full innovation lifecycle.

R&D:

A national roadmap would include a coordinated and well-funded program of basic and applied research. Applied research on chemical production at DOE has traditionally focused on transportation fuels (primarily ethanol) as well as carbon sequestration and conventional petrochemical production. DOE's Office of Science has financed innovative work in synthetic biology, artificial photosynthesis, and other advanced topics. These priorities and strategies to manage them should be revised to include additional priorities:

- Plastics and other chemical products designed to be disassembled and recycled without sacrificing performance
- Improved methods for disassembling chemical products (and mixed wastes) and rebuilding the components into useful materials without loss of performance, including selective catalysts, nonselective gasification, and possibly biological systems
- Development of crops designed to produce feedstocks for bio-based chemical manufacturing
- Organisms engineered to make commodity chemicals on a large scale using inexpensive feedstocks that do not compete with food production
- Production systems that use electricity and hydrogen as major inputs, perhaps combining synthetic and biological resources
- Hybrid systems that combine abiotic production of hydrogen gas or carbon monoxide with biological processes for chemical production
- Post-processing technologies for separations and purification of bio-products
- Computational tools for designing biological systems, novel materials, and next-generation production facilities that use AI and other new tools to tackle genetic selection, process inhibitors, and other challenges involved in scale-up.

Demonstration: Moving novel processes for chemical production to the 100,000-liter (or larger) scale can cost $100 million or more and take six to eight years. This risk and cost profile make it very difficult to attract private investors to such projects. Federal policy should seek to de-risk them by supporting public-private partnerships to build and operate large-scale test facilities aligned with the R&D program previously outlined.

Deployment and market expansion: Potential investors in innovative chemical production technologies will be looking toward the growth of markets in both the United States and globally.124 The European Union has adopted an aggressive growth strategy in its Circular Economy Action Plan. It includes an array of incentives and regulations to create markets for durable, repairable products such as improved labeling, "green public procurement," and recycling strategies for specific end-use products like electronics and textiles.

New directions for the United States could include:

- Improve public infrastructure for recycling plastics and other products of chemical manufacturing, as proposed by the BOTTLE Consortium, among others.126 The effort would be enhanced if there were ways to combine the collection of recycled materials with chemical reprocessing facilities.
- Expand and make more effective use of USDA programs, such as BioPreferred, which includes requirements for federal procurement, sample purchasing contracts, training, and voluntary labeling programs for industry program across a wide range of products including "cleaners, carpet, lubricants, [and] paints." Three thousand private companies are already participating.
- Ensure that products labeled as "biodegradable" actually lead to environmental benefits. Many products currently labeled as such do not degrade rapidly, particularly in marine environments.
- Create product labeling systems that reflect climate impacts, including a detailed environmental impact analysis covering water and land-use impacts wherever possible. As in Europe, these systems could include national product databases and embedded materials (e.g., unique taggants) that verify a product's origins.
- Establish public procurement ("buy clean") programs for low-emission, bio-based chemicals. Federal procurement could accelerate the growth of markets for these products.
- Tighten emission standards and enforcement at conventional chemical production facilities.

Innovation ecosystem and technical assistance: The chemical industry is concentrated in specific geographical regions in the United States. Federal policy should explore ways of helping these communities transition to next-generation chemical production. Biomanufacturing opens particularly interesting opportunities for investment when chemical production located near biological resources provides an economic advantage. This rural economic development initiative should partner with states and localities to build on their investments, such as those in Louisiana and North Dakota, and take better advantage of existing USDA resources such as the Agricultural Research Cooperative

Extension Services as well as loan grants that could support the development of bio-based chemical production.

Decarbonized metal manufacturing: Decarbonizing the U.S. primary metal manufacturing sectors will require both significant R&D, alongside deployment and market expansion opportunities. The United States should not lag behind Europe in the development and deployment of metals technologies that will come to dominate the industry in the coming decades. To miss this opportunity would be to vital domestic industries at a global disadvantage and fail to lower emissions. ITIF recently submitted responses to DOE's request for information (RFI) on the establishment of a new clean energy manufacturing institute that focuses on the decarbonization of metal manufacturing. Some of the recommendations offered in the RFI include:[43]

R&D: The R&D needs for decarbonizing the primary metal manufacturing sector include both continued support for technologies that already have an advanced Technology Readiness Level, such as hydrogen-DRI and support for processes that are not yet as far along such as plasma-H_2-DRI, metal electrolysis that relies entirely on electricity, and advanced inert anodes. Some key R&D priorities to consider:

- Support for hydrogen-DRI iron and steel production;
- Research into high-temperature, plasma-H_2 use in DRI production;
- Focus on advanced metal production processes such as molten oxide electrolysis (MOE);
- Continued support for inert-non-carbon-based anodes for aluminum production.

Demonstration: The United States should not fall behind global partners that are significantly increasing funding for large-scale pilot and demonstration facilities (300,000 metric tons per year). These facilities can cost $100-$500 million and require significant support through loan guarantees and other financial de-risking strategies. High capital cost hurdles for advanced industrial equipment are also significant. Incumbency, long-lived assets, and the need to avoid stranded asset risks are additional financial concerns. Manufacturers are naturally risk-averse, trusting processes that have worked for decades while being wary of newer processes, even if there are significant financial and emissions benefits. By supporting demonstration projects, the United States can help a national decarbonized metal manufacturing sector begin to take root.

Deployment and market expansion: The market for decarbonized metals is beginning to increase as consumers demand lower-carbon alternatives. Already, vehicle manufacturers are beginning to purchase low carbon steel and aluminum, and the market is expected to go dramatically over the next decade. The United States can support the deployment and market expansion of these technologies by creating testbeds for new promising technologies.

New directions for the United States could include:

- Support for new metal decarbonization pilot and demonstration facilities;
- Product certification and standards for new low-carbon products;
- Creation of technology and start-up test beds for promising advanced material applications.

Innovation ecosystem and technical assistance: The innovation ecosystem is highly concentrated with a handful of areas and firms. There are only a few U.S.-based primary steel manufacturers and start-ups focused on innovative ways to reduce steel emissions. The same is true in the aluminum sector. These industries are located in concentrated geographic areas as well. Technical assistance in the form of pilot and demonstration pilot projects, advanced standards, and certification for advanced low-carbon metals, and continued efforts to reduce or eliminate the use of fossil fuels in metal manufacturing represent key areas of continued attention.

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