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Office of Energy Efficiency & Renewable Energy
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

RE: DE-FOA-0002564: Request for Information on Establishing a New Manufacturing Institute

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INTRODUCTION

Thank you for the opportunity to provide insight into the establishment of a critical new Clean Energy Manufacturing Institute (CEMI). 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 industrial and manufacturing decarbonization strategies and policies.

ITIF strongly supports the creation of a new institute within the Advance Manufacturing Office that is focused on industrial decarbonization, particularly electrification of industrial processes and decarbonization of metal manufacturing.

Our comments focus on two high-priority applied technology sub-sectors that we believe show the most promise for significant decarbonization and would benefit from an Institute focused on them. These are high-temperature electrification for industrial processes and hydrogen-DRI steel production.

In addition, we provide comments on specific topic areas that would also benefit from continued research including low-temperature industrial heat technologies and low-carbon aluminum processes.

ITIF believes that a strong manufacturing base creates a more resilient and equitable economy, accelerates innovation, strengthens international competitiveness, and improves national security. The division between manufacturing and climate policy is counterproductive for both, and it overlooks a crucial opportunity to create an integrated national strategy. This Institute has the potential to bridge that gap.

The looming transformation of global manufacturing comes at a challenging moment for the United States. China's emergence as the world's factory, along with determined efforts by manufacturing powers such as Japan and Germany to sustain their industries, shrank the U.S. share of global manufacturing activity from 28 percent in 2002 to 18 percent in 2016. Real manufacturing value added fell by 20 percent as a share of the U.S. economy between 2007 and 2019 from 12.1 percent to 9.7 percent. U.S. manufacturing employment fell off a cliff during the 2000s and recovered more slowly than the rest of the economy in the ensuing years; it now accounts for just 8.5 percent of the workforce. [1]

To remain strong economically, the United States needs to rebuild its manufacturing sector. The sector's small share of the workforce is deceptive. Each manufacturing job generates about five to seven others in the supply chain and through spillovers, far more than a comparable job in the service sector**. Manufacturing is intimately connected with innovation as well. Manufacturing firms account for the vast majority of private research and development (R&D) spending and patents in the United States. And manufacturing is crucial to the U.S. position in the global economy.**[2]

As the request for information (RFI) notes, however, industrial processes account for almost one-third of total U.S. energy consumption and 28 percent of energy-related greenhouse gas (GHG) emissions. Meeting mid-century net-zero targets will require significant emission reductions across a wide swath of industrial sectors, ranging from chemicals and plastics refining to steel, cement, food processing, among others. While it is widely agreed that technologies are available to decarbonize the U.S. electric sector by up to 80 percent by 2035, the U.S. industrial sector is will be harder to decarbonize, due to the long lifecycles of industrial assets such as steel blast-furnaces and chemical refineries, the diverse array of energy inputs necessary, the high heat and chemical specifications for many processes, and the nascent state of many industrial decarbonization technologies.

Technology readiness is a crucial factor in the rate of industrial decarbonization between now and 2050. In fact, the International Energy Agency's (IEA) *2020 Energy Technology Perspectives* notes that the industrial sector has lower technology readiness levels (TRLs) than transportation and power generation. Many clean industrial technologies are still in the early concept and small prototype stage.[3]

The RFI's focus on electrification of industrial processes and decarbonization of metal manufacturing is appropriate, given the potential to reduce GHG emissions significantly while accentuating U.S. industrial innovation and technology advantage. **The United States must not lag international competitors in designing, developing, and deploying low-carbon industrial technological processes for vitally important industrial sectors.**

Category 1: Institute Scope

C1.1

The obstacles and challenges facing industrial sector decarbonization in general and the two topic areas of industrial electrification and metal manufacturing decarbonization in particular are diverse and complex. They can be organized into three broad categories.

First, there are **physical and chemical barriers** to full decarbonization that are difficult to overcome. Many industrial applications rely on fossil fuels as a feedstock. For example, virgin steel production requires a reductant to strip oxygen off iron oxide, which is currently supplied by either coke or natural gas. Plastics refining requires petroleum products as a feedstock. Portland cement emits carbon dioxide from the limestone used in the clinker process. All of these are examples in which the industrial process itself requires or emits carbon dioxide. Engineering out or reducing the carbon emitted is not impossible but poses technology and market risks.

Second, **technological barriers** are significant to both focus areas. While many processes can be electrified, a large number rely on natural gas consumed onsite in order to deliver the consistent, reliable high temperatures that are required for these applications. According to McKinsey, only half of all fossil fuel used today in industrial applications could be replaced with electricity using commercially available technologies.[4] **The Institute should prioritize the remaining 50 percent of high-temperature industrial processes that do not yet have viable electrification options**. Possibilities for Institute focus areas might include processes with temperature requirements above 1000^{o} Celsius for iron and steel, glass furnaces, and calcination of limestone for cement. As a test-bed for applied research, Institute can serve as a vital link between the development of these technologies in the lab and their application to real-world industrial processes.

Third, **market barriers** present challenges to industrial electrification and decarbonization of metal manufacturing. The first hurdle is that electricity, joule for joule, is still much more expensive than fossil fuels like coal, natural gas, and petroleum. 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. Finally, many industrial products are commodity goods such as steel and plastics. Increased fuel or production costs cannot easily be passed onto the consumer without significant risk of market share erosion.

Yet, the moment to invest in these technologies is rapidly nearing if the United States and the world are to meet decarbonization timelines. **The Institute should serve as a test bed for emerging low-carbon technologies that are nearing readiness in the coming decade. The Institute should facilitate innovation by filling gaps within and across the academic, federal, and private sectors as well as among diverse existing DOE programs.**

C1.2

A large swath of U.S. industry is interested in decarbonization of their processes to meet mid-century targets. This includes both producers of carbon-intensive industrial products and buyers of those products. The Renewable Thermal Collaborative, a coalition of companies, institutions and governments committed to growing demand and scaling technologies for low-to-zero carbon thermal needs, includes 15 industrial producers like Cargill, Kimberly-Clark, Mars, and Unilever.[5] The three largest U.S. steel producers, Cleveland-Cliffs[6], Nucor[7], and U.S. Steel[8] have all committed to significant carbon reductions through by 2030, with U.S. Steel committing to net-zero emissions by 2050. In 2020, Deloitte noted that the majority of manufacturing executives support improving environmental stewardship and that sustainability was critical to business operations.[9]

Although domestic corporate support for decarbonization exists, it faces hurdles including declining private expenditures on RD&D, a focus on short-term financial gains, robust international competition, and challenges to implementing new technology**. While the Institute cannot overcome all of the hurdles to developing and deploying low-carbon industrial technologies, it can serve as a trusted partner to private industry. In addition, the Institute can serve to bring in more corporate and industry partners who may not be actively engaged in this issue due to the lack of information or a trusted partner.**

C1.3

Many technologies currently exist for both proposed focus areas for the institute. However, adoption of those technologies is a different story. For instance, electrification technologies to supply low-to-medium temperatures (less than 300º Celsius), such as heat pumps, are available, but they do not meet all needs. A rough estimate of U.S. industrial heating needs suggests that as much as 16 percent of total emissions come from processes and systems that require temperatures that could be provided by heat pump technologies. Further development of new refrigerants and innovative alternate cycle technologies such as electrocaloric and electrocaloric systems for heat pumps, could bring these technologies to maturity. As noted above, we consider low-temperature electrification technologies to be a lower priority than high-temperature electrification opportunities. High-temperature heating technologies that are at a nascent stage of technological deployment, including radio-frequency heating, UV heating, electric infrared heating, and plasma melting (see Figure 1).[10] **By focusing on high-temperature electrification, the Institute could fill a gap by testing and piloting technologies and industrial applications.**

Figure 1: Characteristics of Various Electromagentic Heating Technologies[11]

Frequency	50 Hz - 500 kHz	10-100 MHz	200-3000 MHz	30-400 THz		1-30 PHz
Wavelength						
	Induction	Radio	Microwave	Infrared	Visible light	Ultra-violet
Max temp °C	3000	2000	2000	2200		N/A
Power density (kW/m²)	50,000	100	500	300		100
Efficiency	50-90%	80%	80%	60-90%		
Application	Rapid internal heating of metals.	Rapid internal heating of large volumes.	Rapid internal heating of large volumes.	Very rapid heating of surfaces and thin material.		Non-thermal curing of paints and coatings.

In the metal manufacturing sector, iron-ore reduction through a molten-oxide electrolysis process is at an early Technology Readiness Level (TRL), largely still in the small-scale pilot project stage. Hydrogen-direct reduced iron production is further along, in the demonstration phase. Technological barriers remain in both cases. These barriers include cost and feasibility concerns, but also fuel substitution away from traditional energy resources to lower-carbon alternative like clean hydrogen. There is ongoing research, for example, into the use of hydrogen plasma, or super-heated H_2 streams as a more suitable reductant.[12] The research indicates that it not be as simple as switching fuels from natural gas to hydrogen.

In the iron-ore refining process, the use of "green" or "blue" hydrogen as reductant is an emerging technology, but technical and economic hurdles remain to replace natural gas or "grey" hydrogen that need to be overcome. Similarly, in the primary aluminum production sector, low-carbon processes, such as the use of inert anodes and ceramic anodes, are emerging. However, traditional processes are well-entrenched.

Finally, there still exist some 'low-hanging' fruit that the industrial sector has not fully taken advantage of in the form of advanced electronics and energy efficiency improvements, including modifications at the system and plant level that can reduce the carbon intensity of many industrial processes. **These included 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. Incorporating AI and machine learning software technologies helps identify areas where increased automation and energy efficiency opportunities may exist.**

Category 2: Institute Organization

C2.1

The U.S. is a world leader in clean energy innovation and is well positioned to lead in the two sectors identified by the RFI. The U.S. industrial innovation landscape is a diverse and well-populated space that includes academia, government labs, start-up incubators, venture capital, industrial institutes, private foundations, think-tanks, and private finance and industry. **The Institute could serve as a critical node in the innovation cycle by connecting and collaborating with diverse partners across the innovation pipeline.** The Institute can collaborate with trusted international partners but must ensure that any cooperation does not undermine domestic intellectual property or lead to offshoring of manufacturing technology that is innovated here but produced elsewhere.[13]

C2.3

The location of the Institute will be key to determining its success in developing and supporting adoption of innovative technologies as well as helping to support local economies and developing a well-trained manufacturing workforce. **The Institute could maximize its impact by adopting an industrial cluster or hub approach, locating itself in an area of the country where a large percentage of metal manufacturing and industry are already located, such as the Ohio River Valley, Indiana/Illinois, or the Houston-Galveston-Louisiana Gulf Coast.** This approach would facilitate technology diffusion by building off a robust innovation ecosystem. By partnering with private industry, the Institute can help facilitate the speedy transfer of knowledge back and forth between stakeholders while building and an advance manufacturing workforce.

The areas of industrial electrification and decarbonization in the metal industries would benefit from cross-disciplinary collaboration by helping to connect energy innovators with industrial manufacturers who demand their products. Industrial firms are naturally risk averse and have tight product specifications. The Institute can serve as a trusted partner and act as a bridge between those who innovate the products, such as advanced electric heating technologies and new steel production processes, and industrial users. **The Institute can partner with both existing large and small firms that are developing and deploying these technologies as well as start-ups that are working to design, develop, and commercialize their technologies.** In the iron and steel decarbonization space, for example, there are only a handful of U.S.-based steel manufacturers and handful of start-ups focused on innovative new ways to reduce steel emissions.

Category 3: Institute Benefits

C3.1

The Institute's benefits in supporting electrified and decarbonized U.S. advanced manufacturing are numerous. In some cases, 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 process account for 20 percent of delivered energy, while for fossil fuels, energy losses were more than 50 percent.[14] 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.

The life-cycle energy benefits of electrification over natural gas or other fossil fuels are dependent upon the source of the electricity and difficult to generalize across geographic areas. However, as the U.S. electric grid becomes cleaner and industrial electrification improves, upstream emissions from the grid will likely decline. As the grid decarbonizes and switches away from fossil fuels, industry needs to be ready to take advantage.

The Institute, through applied research and expanded demonstration of innovative technologies, can highlight the many benefits of electrifying industrial processes.

Electrifying industrial processes also leads to faster start up times compared to fossil fuel combustion, which must first heat either water or air. Electric induction furnaces allow for precise temperature control as well, improving overall product quality. In addition, electrification may allow for increased industrial automation as it relies on precise and programable controls. Electrification also improves indoor air quality compared to fossil use, lowers factory waste heat, and provides for a quitter work environment than fossil fuel processes.[15]

Electrification of industrial processes requires improvements to the existing energy infrastructure, including upgrades to transmission systems and local distribution systems. Electrification could increase overall demand for electricity by four times or more by 2050.[16] This increase in demand will require significant investments in the transmissions and distribution infrastructure. Improvements in grid infrastructure improve overall grid resiliency and support further decarbonization of the U.S.

electric sector. **A focus on industrial electrification would spur greater investment in much-needed grid infrastructure, which would have wider decarbonization benefits for the economy and society.**

The greenhouse gas and air pollutant benefits of electrification of industry and decarbonization of metal manufacturing are immense. Industry is responsible for one-third of total U.S. emissions, with the iron and steel industry emitting 72 million metric tons of CO_2 in 2019. This total has declined over the last decade largely due to increased electrification, a decline in total steel capacity, and energy efficiency improvements. In addition, iron and steel blast furnaces produce significant quantities of carbon monoxide, particulate matter, and other air pollutants.

The use of blue and green hydrogen in industrial processes will be a critically important technology area for many industrial applications, including iron and steel. This market could grow dramatically if hydrogen becomes a major input for hard-to-decarbonize sectors. A recent National Renewable Energy Laboratory (NREL) report estimates that the technical potential for hydrogen use in the United States is an order of magnitude larger than today's, about 106 MMT per year, across a range of industrial, transportation, and storage applications.[17] An "ambitious" scenario in an industry roadmap finds that hydrogen demand in the United States could grow to 17 MMT per year by 2030 and 63 MMT per year by 2050, results that are consistent with several scenarios in Princeton University's Net-Zero America Project.[18]

Making hydrogen cheap, clean, and reliable will be important to the overall success of electrification of industrial processes and decarbonizing metal manufacturing. **The Institute could partner with emerging clean hydrogen hubs and work with existing and emerging DOE hydrogen programs that are supporting pilot-and commercial-scale demonstration projects to determine the best use and applications for clean hydrogen in industrial processes**. In addition, there will undoubtedly be challenges and hurdles to substituting clean hydrogen for fossil fuels such as natural gas. A new Institute could serve as a vital learning and knowledge hub to disseminate lessons learned.

Transportation of clean hydrogen from where it is produced to where it is consumed in industrial processes requires additional evaluation and study. An industrial hydrogen-focused institute might seek to identify where clean hydrogen is likely to be most economically and environmentally produced, how it might be transported through the existing natural gas infrastructure, and assess the potential drawbacks and challenges of distributing clean hydrogen through existing infrastructure.

Category 5: Institute Scope and Organization around Key Areas

C5.1

The potential scope of the Institute as detailed in section 4.2 of the RFI is a good starting point. It could be expanded to focus on key research and development needs to spur greater industrial electrification, including clean hydrogen substitution into industrial electrification and metal decarbonization, research into advanced heat exchanger technologies, and new methods for electrifying heat at high temperatures. The greatest decarbonization potential lies in the electrification of high-temperature industrial heating applications and fully decarbonizing the primary steel production. Lower priority, albeit still critical to U.S. manufacturing competitiveness, is the wide adoption and application of low-temperature industrial heating technologies and reducing the carbon intensity of primary aluminum manufacturing.

In addition, designing low temperature industrial heat pump systems that are flexible and diverse in their end use applications is critical to wider adoption and decarbonization. A one-size-fits-all approach will not work for majority of industry. An Institute might focus on how to build technology flexibility and substitution into its research, as well as heat pump integration opportunities through machine learning and artificial learning opportunities for diverse industries with a focus on food processing, paper, and chemical manufacturing. While much progress in industrial heat pump technology has been made a few key R&D areas include:

- new refrigerants, including the use of natural refrigerants, and highly innovative alternate cycle technologies such as electrocaloric and electrocaloric systems for heat pumps;
- next-generation heat exchangers exploring new materials, new designs, new fabrication techniques, and new design and simulation software;
- novel electric drying systems such as those that use mechanical methods and design software needed to achieve system efficiencies; and
- redesigning and reengineering low-temperature industrial processes to take advantage of the characteristics of heat pumps.[19]

The primary priority for consideration, however, should be high-temperature industrial heat applications. As noted above, an estimated 50 percent of processes that require high-temperature heat do not yet have viable electrification pathways. These technologies are less well-developed than low-temperature applications   The Institute should focus on innovative technologies for high-heat industrial applications which are harder to abate, do not have readily available technology pathways, and are energy- and emissions-intensive.

Category 8: Decarbonization in Metal Manufacturing – Productivity and Competitiveness

C8.1/8.2

The U.S. metal manufacturing sector is already less carbon-intensive than many of 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 U.S. cannot afford to fall behind international competitors in the development and deployment of these low-carbon metal manufacturing processes.

C8.1/C8.4

The Institute can be a critical node bridging the knowledge and application gap for decarbonized technologies by working with known industry partners, troubleshooting application hurdles, and by disseminating knowledge openly to stakeholders. The Institute can also help drive down technology costs for clean-but-expensive alternatives by working with the Manufacturing Extension Partnership and other partners to disseminate knowledge and best-practices.

Take hydrogen-DRI processes. 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.[20] **The Institute could remedy this gap by focusing on the development and deployment of hydrogen-DRI steel manufacturing.**

An alternative focus area for the Institute in the metals industry could be reducing emissions from primary aluminum production through advanced inert anodes and electrified heat. Aluminum requires less intensive temperatures than primary steel production (~1000º C compared to 1,600º C or greater). Such an Institute could focus on facilitating test-bed research on advanced inert anodes and carbothermic reduction processes, both of which have seen R&D progress but have not been widely adopted by the industry.[21] In addition, inert anodes have lower temperature requirements (~700º C), improving overall plant efficiency and reducing total electricity and emissions emitted from production.

Category 13: Disruptive Technology

C13.1

The most disruptive technological opportunities to decarbonize metal manufacturing are electrometallurgical techniques that rely only on a raw input, electricity and some non-pollutant reductant or solution. This approach results in reduced iron that can be further refined in existing electric arc furnaces.[22] The only waste product from such processes is oxygen; they do not emit CO_2. While this nascent technology area has not been commercially developed, it is one in which U.S. startups have been innovating in for many years. The technology, however, is not yet ready to scale beyond the small pilot projects currently being developed.

An institute focused in this area could leverage emerging technology companies that are pioneering innovative and yet-to-be commercialized low-carbon metal manufacturing techniques. **In addition, the Institute could play an important role by providing stringent testing and verification standards for new metal production processes. Through product testing and certification, the Institute could give would-be buyers of steel produced in novel ways confidence in the durability and safety of the product.**

Conclusion

ITIF thanks DOE for the solicitation of a request for information regarding the creation of a clean manufacturing institute to further decarbonization of U.S. industrial sector through electrification and advance metal production processes. **Ultimately, the Institute can have a significant impact by focusing on a few key test-bed technology and sectoral areas such as those identified in the RFI. Within those sectors, it will be crucial to rapidly develop high-temperature, zero-carbon technologies and decarbonization technologies within the iron, steel, and aluminum industries.**

The next decade is critical to the deployment of technologies that will either lock-in outdated and polluting technologies or will lead to the resurgence in U.S. manufacturing dominance. DOE has a long track record of supporting innovative and emerging industrial technologies through its institutes and research labs. This clean manufacturing institute is critical to building a robust clean industrial economy.

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