HYPERION METALS

23 September 2021

RFI ON ESTABLISHING A NEW MANUFACTURING INSTITUTE

Institution: **Hyperion Metals, Ltd**
Small: **1-50 employees**
NAICS Code: **212299 (All other metal ore mining)**
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Topic: (2) Decarbonization of Metal Manufacturing

Category 1 **Institute Scope**

The objective of this category is to solicit information on the scope of a potential Institute, as a public-private partnership, to advance industrial decarbonization. Responses should focus on the contributions that an Institute could make beyond that of private industry alone.

C1.1 What are key obstacles and/or challenges facing the development and deployment of technology supporting the proposed topic areas and how can the utilities of a Manufacturing Institute (see section 1.2) address these issues?

- Hyperion's response is limited to titanium ore reduction and metal powder production for energy and defense applications.
    - Hyperion believes that the scope of a Metal Manufacturing Institute would be too broad if it were to include multiple metals. For instance, manufacturing of steel and aluminum would likely dominate the work scope and squeeze financial resources for other metals (assumes Institute model of $70M/5 years).
    - If a Manufacturing Institute were to focus on titanium, a high strength-to-weight metal for energy and defense applications, it could bring significant national impact by incentivizing low carbon domestic titanium production capacity. There is no U.S. supply of primary titanium metal today. The scale of the funding, $70M Federal with non-Federal/industry matching, would be commensurate with the scale of the challenges to produce low carbon titanium.
    - A Manufacturing Institute could address the high energy and carbon intensity of today's Kroll process for titanium ore reduction. As discussed later, Hyperion controls proven technologies that lower the energy requirement and carbon footprint compared to titanium produced through via the Kroll process, developed in conjunction with ARPA-E and with Boeing and Arconic as industry partners.

C1.2 Is Industry sufficiently engaged and interested in the topic to invest?

- Yes. Hyperion's wholly owned subsidiary company TN Exploration, LLC is developing a mineral project to extract titanium ores in Camden, Tennessee. The mineral project combined with Hyperion's proven titanium technologies, secured through a license agreement with Blacksand Technologies, LLC, will enable the development of an ore to metal supply chain in the USA, for use in advanced industries and application including additive manufacturing.

  What key knowledge or capability is missing that prevents the private sector from adequately addressing the industrial decarbonization strategy by itself in the absence of public sector investment?

- A key capability missing is de-risking, both financially and technically, the scale-up of innovative low-carbon technology to replace the Kroll process to produce primary titanium metal.

If industry is currently not investing in this area, how might an Institute bridge the gap between the current state of technology and what industry is willing to invest?

- There is currently no domestic titanium metal capacity in the U.S., however, companies such as Hyperion Metals are willing to invest. For instance, Hyperion Metals is currently committing significant capital to progress its low-carbon titanium metal technologies, and would match Federal investment to scale their development. In addition, material science is needed to develop the appropriate titanium alloys and physical properties for various energy and defense applications. The Institute model at 50% cost share could help advance TRL 4 technology solutions already in the pipeline.

C1.3 What investments are currently being made to develop technology for a given topic area and can any of them be advanced by an Institute?

- Hyperion is committing significant capital to scale its titanium metal technologies, including the ***hydrogen assisted magnesiothermic reduction*** process and the ***granulation-sintering-deoxygenation process*** developed at the University of Utah. This innovative titanium ore reduction process was developed with DOE ARPA-E funding and related DOE Advanced Manufacturing Office funding.
- Hyperion also has an approved DOE User Agreement with Oak Ridge National Laboratory to characterize and performance test titanium powders and alloys produced using its technologies. Prior to, and under this agreement, significant laboratory investments have been made.
- An Institute could assist to accelerate the scaling and commercialization of the technologies which result in much lower energy and carbon reduction in the

production of titanium and ultimately have the potential to yield net-zero carbon emissions.

Are there sufficient early Technology Readiness Levels (TRL) technologies to advance and develop through an institute? Are the technologies in pre-competitive space or at a TRL appropriate for an Institute to advance?

- Yes, there are sufficient early TRL technologies and integration challenges in the pre-competitive space.

C1.4 Would an Institute be a more effective mechanism for reducing GHG emissions, advancing the energy efficiency, environmental stewardship, productivity, and competitiveness than other methods of technology development?

- The Institute model with a laser-like focus on sustainable titanium production could be very effective in lowering energy and carbon intensity. Hyperion and its partners' ultimate vision is to create domestic capacity and reduce the economic vulnerabilities associated with Russia and China controlling the global titanium market. A focused effort with DOE matching funds could make the U.S. a world leader in sustainable titanium production with net-zero carbon footprint.

Category 2 Institute Organization

The objective of this category is to solicit information on the potential for strategic structuring and organization to foster collaboration through a Manufacturing Institute.

C2.1 What stakeholders or collaborators should the Manufacturing Institute engage with and what are their roles?

- Targeted collaborators would be titanium powder producers, additive manufacturing equipment providers, component manufacturers and aerospace, industrial and vehicle OEMs (ultimate customers). While it is recognized that mining is out of the scope of an Institute, mining companies would be important collaborators to develop sustainable solutions across the whole domestic supply chain.
- Other technology providers in small to medium sized companies (e.g., hydrogen providers or electrolyzer manufacturers, specialty alloys, process controls, high temperature furnace/equipment providers, industrial systems integrators and engineering, procurement and construction contractors).
- A separate National Laboratory and university consortium should be established in parallel to the Institute. This consortium would provide pre-competitive R,D&D and systems integration expertise through digital engineering and physical testbeds.

C2.2 How should the scope of the Institute be focused to maximize its impact? What are the appropriate bounds of the scope?

- The scope of this institute needs to be focused on critical minerals where U.S. production capacity does not currently exist but is expected to be formed due to their strategic nature to the nation, including titanium and rare earths. This will allow decarbonization to be a focus from inception, rather than re-engineering existing operations. The probability of success is higher if the Institute scope is focused on one strategic metals area so that collaborators are unified in achieving success and not competing for resources. Broadening the scope to include vast areas such as steel and aluminum would likely dilute the funding which would result in minimal impact.

C2.3 What would be the most effective manner to structure an Institute to ensure the highest impact?

- An industry-led Institute in conjunction with a separate and parallel "hub-like" effort with universities and national laboratories would like result in early-stage pre-competitive R&D being licensed and transferred to industry. Because of their independence and FFRDC responsibilities, National laboratories would be ideal to set up process integration testbeds where technical and economic data needs to be openly published.

Provide any information on specific regional approaches that effectively merge innovation, economic activity, and high-skill jobs at all levels of the supply chain, as appropriate.

- Regions need to be selected that affiliate themselves with metals manufacturing. For instance, co-locating metals refining with the mining/ore extraction would generate more regional interest and create the critical mass level of jobs necessary for full regional and local support. This will enable greater direct and indirect economics benefits. Location of the Institute in the proximity of where the technology would be commercialized provides the political and community momentum for the overall Institute to endure and be well resourced. Tangible results would include more potential cost-share for facilities, equipment and workforce development programs. The Institutes already have established a track record of regional and/or State collaboration/support that supplements Federal funding. With TN Exploration's plans to mine titanium ores in Tennessee, a regional approach to the titanium minerals and titanium metal technologies would stimulate place-based innovation and adds jobs to a distressed area.

C2.4 How could this topic area benefit from cross-discipline collaboration and what would be the impact?

- Cross-discipline collaboration and solutions could lead to domestic, carbon-free titanium production. An example is agreements with Tennessee Valley Authority to provide carbon-free electricity to power operations and create hydrogen.

- Collaboration between the Department of Defense and DOE could enhance national and economic security around titanium sourcing. The U.S. imports almost all of its titanium needs. While current U.S. imports of primary metal are from Japan, China and Russia are the number 1 and 3 global producers, respectively, and can manipulate the worldwide titanium resources and market. This makes the U.S. very vulnerable for its defense needs (aerospace, armor, etc.). DOE would benefit by creating low energy and carbon intensity metals with high strength to weight ratios for various lightweighting applications such as vehicles.
- Another cross-discipline opportunity is to have a common testbed managed and operated by a national laboratory. Advantages of a test bed include:
    - Development of a common digital engineering simulation platform (enabling a "soft" integration of various technologies to validate their technical and economic performance);
    - Process integration expertise during scale-up; and
    - Independent results/data provided to DOE.

What are the barriers to cross-discipline collaboration in this area?

- IP protection can be a barrier to cross-discipline collaboration. Since DOE Institutes require 50% cost share, technologies being pursued tend to be mid to late stage TRLs where companies protect their IP where they have already invested their own internal resources. However, this barrier can be overcome for new Federal and non-Federal investments taking place under a newly created Institute as industry partners share a common goal to commercialize the technology.
- Cross-cutting lifecycle analysis around sustainability would not have major IP hurdles and would benefit DOE in evaluating decarbonization options across multiple metals refining processes for titanium.

C2.5 How would an Institute attract sufficient private sector investments and what metrics would provide short-term indicators of success within the first 5 years? Please include a discussion on long-term operations and the technical achievements needed to remain relevant to industry. Discuss the value proposition to the private and public stakeholders/members.

- Longer-term Federal support would bring more industry interest and investment.
- Metrics of success should be based on a standardized lifecycle analyses around sustainability.
- Major metrics shown in the table below could be established for the 5 year timeframe. Ultimately, net-zero titanium can be accomplished but it would take longer than 5 years since net-zero carbon is dependent on the carbon intensity of the grid and other energy resources. With TVA's current leading position relative to nuclear, renewables and plans for natural gas with carbon utilization/capture,

net-zero titanium is an achievable vision.

Primary Success Metric	Units	Baseline SOTA	5 year target (30% improvement)
Carbon emissions	Tonnes CO2/Tonne Metal	W	W'
Avoided carbon cost	$/Tonne CO2 avoided	X	X'
Process Energy Intensity	MJ/Tonne of metal	Y	Y'
Change in metal mfg. cost	Δ $/tonne metal or %	Z	Z'
Underrepresented persons trained/upskilled	# per demographic categories	0	N
Jobs created in disadvantaged areas	#	0	J
Technology Transfer	# of new commercial applications	n/a	a
IP: New Licenses/patents	#	0	b
Overall Persons trained	#		
Overall Jobs created			
Non-Federal funds	$	50%	50+%
Management & Operating costs	$/year	First year	15% of total R&D throughput

Category 3 Institute Benefit

The object of this category is to solicit information on the potential benefits of establishing an Institute, as a public-private partnership, to advance industry topics of importance to the DOE Mission. Responses should focus on the impact that an Institute could have beyond that of private industry alone.

C3.1 What are potential quantitative impacts of a Manufacturing Institute targeting a given topic area? Consider impacts on energy efficiency, life-cycle energy benefits, U.S. productivity, U.S. manufacturing base, economy, energy infrastructure, greenhouse (GHG) emissions, and/or related environmental impacts in manufacturing or use.

- Given that the U.S. has no titanium production capacity, an Institute investment could bring a domestic titanium industry and improve national security.
- Over the long term, investment in R&D will address climate and result in new economic opportunities for businesses and create jobs. If the U.S. businesses create new technologies, it can lead to greater domestic capacity to produce technologies and titanium metal with lower embodied energy and reduced criteria and GHG emissions over the lifecycle. If carbon intensity becomes an international trade metric, this could lead to greater global market share for U.S. titanium manufacturers.

What impact can an Institute have in 5 years, and beyond?

- In 5-years, the Institute can be up and running with technology demonstration at the scale necessary for industry to invest in production scale plants. The parallel digital platform can reduce permitting and licensing time, as well as validate plant economics.

C3.2 Industry uptake is critical to realizing the impacts of a Manufacturing Institute. What is the potential for industry to adopt innovative technologies developed through a Manufacturing Institute?

- If the Manufacturing Institute were to be co-located near the titanium ore resource, there is high potential for industry to develop the competitive processes necessary to produce titanium metal powders with low carbon and energy intensity. The Institute could also include additive manufacturers that would produce the components for defense and energy industries. In addition, aerospace and vehicle OEMs would also be Institute members who would provide the application requirements necessary for technology transfer and commercialization success.

What are the R&D breakthroughs/milestones necessary to integrate specific decarbonization strategies at the industrial level?

- While no R&D breakthroughs are needed, process scale-up and integration are necessary to decarbonize titanium metal production and validate economics.
- Carbon-free electricity and hydrogen energy costs will play an important role in the market competitiveness of the titanium technologies. New processes such as the titanium technologies discussed earlier would cut energy by 50% and carbon emissions by 33% compared to the SOTA Kroll process.

What factors ensure U.S. manufacturing derives sustained benefits from a Manufacturing Institute beyond the 5 planned years of federal funding?

- Concentrating the supply chain in one region creates the critical mass necessary to obtain long term political and community support while delivering the most job impacts. If an institute is not devoted to the economic development priorities of the region, it has less chance of enduring beyond 5 years of Federal support. Therefore, an Institute on titanium refining located next to the titanium ore mining creates the regional pull for an Institute to endure and evolve its mission to serve the community over time.

C3.3 How could an Institute in this topic area provide opportunities for advancing environmental justice and Equitable Economic Opportunity?

- Institutes could provide opportunities for environmental justice and Equitable Economic Opportunity if they are located in distressed areas where jobs in traditional industries such as fossil fuels are now gone. Camden, TN is one such region. Siting model net-zero plants at brownfield sites or closed mills can provide employment and higher quality of life to those that have been impacted by past industrial pollution.
- Aligning an institute in a region impacted by that industry's downturn (e.g., plant closures (coal plant in nearby Johnsonville, TN), layoffs, etc.) would likely garner more local and State support, thus improving an Institutes success probability.

How could an Institute in this topic area benefit their community and communities they serve, particularly underrepresented communities?

- Institutes can provide benefit to the community by providing generic upskilling and job training to unemployed or underemployed persons. Certifications programs, such as in machine tools for additive manufacturing, would provide a more fungible benefit to job seekers.
- Require that minority-serving academic institutions and minority-owned companies in the community be part of the Institute.

How can an Institute engage with local leadership and organizations?

- Through workforce development programs.

How can diversity and inclusivity be leveraged as a source of strength while Manufacturing USA Institutes establish their science and technology communities?

- Require that minority-based companies and institutions be part of the Institute and hire unrepresented persons as part of the management and operations of Institute. Establish K-12 STEM programs in the communities.

What is the potential that an Institute in each topic area could have to lessen overall environmental impacts and to ensure those impacts are experienced more equitably in the community and across the nation?

- Potential is high if the Institute becomes an enduring institution. Decarbonization towards an economy-wide net-zero carbon by 2050 will take decades, not 5-years. For the institute to become enduring, it should be woven into the fabric of the economic development priorities of the region. Given the prospects of titanium mining extraction in Camden, TN, and Institute located in that region would have the best chance of being integrated into the community and serve its constituents in this distressed area.

What diversity, equity, and inclusion efforts can be incorporated into RD&D investments to foster a productive and inclusive environment, support people from underrepresented groups in STEM, and advance equity?

- Require plans that a certain percentage of the RD&D be carried by underrepresented groups and that Institute membership have underrepresented institutions and businesses. Establish FOA evaluation criteria and score proposals on this.
- Ask for diverse Institute management and operations leadership and staff to be inclusive of underrepresented groups. Establish FOA evaluation criteria and score proposals on this.
- Require a community STEM program for K-12 with Federal and non-Federal matching funds.

C3.4 If you are a minority serving organization, what are the barriers to joining a Manufacturing Institute? N/A

How can an Institute be leveraged to engage more diverse populations (racially, geographically, gender, SES, academic institutions (e.g., community colleges))?

- Establish expectations and evaluation criteria in the FOA and then score it.

Category 4 Education and Workforce Development

The objective of this category is to solicit information on education, workforce development, and training needs of the new and incumbent workforce facing each topic area. The deployment of any new technology and the growth of any manufacturing industry requires a supply of workers skilled in the unique aspects for producing, installing, and using that technology. This includes developing a diverse and inclusive pipeline in education and workforce. To ensure that any new innovations are not hampered by workforce needs, we seek input from stakeholders on the most important workforce challenges and the most promising education and workforce developments that could address them.

C4.1 Describe the workforce gap facing the specific industrial decarbonization strategy. How large is the gap? What training and education resources are needed to fill the gap? Who is the target audience? What other workforce needs are not currently addressed?

- The workforce gap is likely more generic than specific. Community college training, education and certification for skilled manufacturing jobs would fill most needs. The Institute's industry members can drive the agenda for building the necessary skills.

What organizations/programs exist to strengthen workforce pipeline in the specified area?

- Existing Institutes such as IACMI provide a good model for emulation. More funding is needed for AMO to network together all 6 Institute workforce development programs.

What role can a Manufacturing Institute have in workforce development to maximize long term impact?

- DOE can require that Institutes create partnerships with community colleges to establish workforce development programs with Federal assistance. The Federal assistance could be contingent on a commitment by the State or county to sustain and evolve the programs.

C4.2 How can an Institutes encourage the participation of underserved communities and underrepresented groups in clean energy education and manufacturing jobs?

- Locate Institutes in underserved communities. Institutes could offer technician apprenticeships and summer jobs to targeted high school students interested in trades.

.2 Questions Addressing Decarbonization of Metal Manufacturing

Category 8 Productivity and Competitiveness

The objective of this category is to solicit information on the challenges/opportunities in the metals industry, as they relate to productivity and global competitiveness. Responses should focus primarily on technical aspects of the topic and how establishing an Institute would address the topic; however, relevant supporting information should be included when applicable.

C8.1 What are the greatest opportunities for increasing productivity, without increasing energy consumption or carbon emissions? Provide a detailed description of the opportunities and challenges. How would a public-private Institute effectively address these opportunities/challenges to increase the productivity of the U.S. metals industry?

- Incremental productivity gains in metals manufacturing can be achieved in an institute model through better heat integration and smart process controls. The impact will be less energy and carbon intensity and more cost competitive products. However, productivity gains alone will not lead to net zero carbon.

Elimination or significant modification of established processing routes (e.g., robotics/automation, sensors, industrial controls, legacy systems/equipment).

- An Institute model could effectively address these leading to measurable productivity gains.

Incorporation of new processing routes and methodologies (e.g., hybrid processing, machine tools, near net shape processing, flexible/adaptable processing systems).

- An Institute model could effectively address these leading to incremental productivity gains.

Improved testing, experimental capabilities, and predictive capabilities (e.g., prototyping capabilities, empirical data sets, computational tools, design tools, material-process-structure relationships, visualization tools, artificial intelligence / machine learning (AI/ML)).

- An Institute model could effectively address these leading to incremental productivity gains.

What is the highest technical priority for the metals industry related to productivity?

- Highest technical priorities would revolve around decreasing labor and energy costs and reducing wastes. Smart controls and processing can reduce opex and wastes. Energy storage may decrease energy costs where time of use pricing is used. Utilizing carbon-free hydrogen for metals reduction would be a priority.

C8.2 What is the greatest opportunity to increase U.S. competitiveness? How would a public-private Institute effectively contribute to the competitiveness of the U.S. metals industry?

Investment in RD&D; specify technology areas and TRL level(s).

- Scale-up and demonstration of an integrated process train would establish the technoeconomic data for industry to invest in production scale titanium production.

Creating an innovation ecosystem with a focus on U.S. prosperity.

- The impact would be an industrial titanium metal ecosystem that establishes domestic production where there is none today.

Strengthened domestic supply chain through the onshoring of materials, processes, and support activities.

- Since the U.S. now imports all of its titanium, creation of a supply chain enhances national and economic security.

C8.3 Are there technology areas where international competitors are outpacing or have the potential to outpace the domestic metals industry? How would a public-private Institute effectively position the U.S. metals industry to close this technology/competition gap?

- Since most titanium metal is processed in China and Russia and the U.S. has no industry, an Institute's focus on titanium could create domestic capacity and increase U.S. national and economic security.

C8.4 Provide any additional information relevant to the productivity and competitiveness opportunities/challenges of the metals industry that do not fit into the previous questions in this Category. This could include various industry data (e.g., economic, import/export, trends), references, or technical information.

Category 9 Energy Efficiency and Energy Intensity

The objective of this category is to solicit information on the challenges/opportunities in the metals industry, as they relate to energy efficiency and energy intensity. Responses should focus primarily on technical aspects of the topic and how establishing an Institute would address the topic; however, relevant supporting information should be included when applicable. Note that information specifically related to decarbonization, environmental justice, and climate change is requested in **Category 11**, and not the focus of this question.

C9.2 Are there significant opportunities to reduce the embodied energy of metals using secondary feed stocks? This includes the quality of scrap and recycling (upcycling).

- Yes, there are significant sources of scrap titanium that can be upcycled.

C9.3 Are there opportunities to increase energy efficiency by collocating metals manufacturing facilities with other industrial facilities. This includes manufacturing and nonmanufacturing facilities (e.g., water treatment, infrastructure). How would a public- private Institute help the metals industry to realize these energy efficiencies?

- Yes, there opportunities for decreasing overall energy use and carbon footprint by collocating upstream ore mining, titanium processing and powder manufacturing, and the final shaping into components for the defense and energy applications.

Category 10 Material Performance and Alloy Development

The objective of this category is to solicit information on the challenges/opportunities for improving material performance and new alloy development, as it relates to reducing the carbon intensity of the overall U.S. economy. It is recognized that material performance and processing are interdependent, and that advancements in one area will impact the other.

C10.1 How will alloy development impact decarbonization of the metals industry? How would a public-private Institute effectively ensure that process development and alloy development occur in a synergetic manner?

To what extent will the evolution of metals production and processing to be less carbon intensive require modifications to existing alloys?

- This would be a good research area for universities and National Labs under a "hub" that could co-exist in parallel with an industry-led Institute.

Are there opportunities to develop alloys whose processing will be less carbon intense?

- It is not known. Lower carbon intense processes for alloying could be part of the Institute's scope. Aerospace companies, vehicle OEMs and defense agencies could drive these alloy requirements.

C10.2 Are there opportunities to design or produce alloys that are considered enabling or used to position other industries to innovate and become less carbon intensive (e.g., automotive/transpiration, renewable energy equipment, energy storage, sustainable agriculture)? Provide a high-level description of the material and application.

What are the most important aspects of improved alloy performance needed to expanded design space and/or operational envelope?

- Strength (tensile, modulus, etc.) and density can be optimized via alloys for specific applications.

Category 11 Decarbonization and Environmental Justice

The objective of this category is to solicit information on the challenges/opportunities associated with the decarbonization of the metals industry. Responses should focus primarily on technical topics but also include social aspects when applicable.

C11.1 What are the greatest opportunities for decarbonizing the metals industry? How would a public-private Institute effectively facilitate the metals industries transition to carbon neutrality?

- The greatest opportunities for decarbonizing the metals industry is to utilize carbon-free electricity and hydrogen. New processes such as the titanium technologies discussed earlier would cut energy by 50% and carbon emissions by 33% compared to the SOTA Kroll process.

- An Institute model could achieve measurable gains in five years at 50% cost share, but a much more long-term, comprehensive foundational R&D effort involving universities and national labs would be required for net-zero carbon emissions. A national-lab parallel effort using an Energy Innovation Hub model which includes early stage TRL 2-4, digital engineering and physical testing capabilities can provide the foundational R&D and systems integration expertise through digital engineering and testbeds to meet net zero carbon emissions by 2050.

What are the largest technical challenges to decarbonizing the metals industry? It is recognized that these challenges will vary across the industry depending on the alloys and processing routes.

- To enable cost-competitive sustainable titanium manufacturing, focused R&D and systems integration and scale-up are needed for de-risking the chemical processing and plant economics. The following four key challenges need to be addressed over the next 5 years:

1. Materials Science – Some carbon-free approaches require high-temperature, harsh environment (reducing atmosphere, abrasive particles, etc.) materials research to ensure that furnace linings and other components maintain structural and mechanical properties under high, pure hydrogen concentrations and elevated temperatures required for ore reduction. This materials science potentially applies to reduction of titanium ore and other critical metal oxides/ores.

2. Manufacturing R&D – New process development such as titanium ore processing, unwanted competing chemical reactions, impurities, process yields and selectivity, process control and automation including AI, and other variables affecting product quality need to be optimized for decarbonized titanium production.

3. Digital Engineering and Simulation – Integrated energy systems modeling establishes the digital design basis for seamless integration of carbon-free electricity generation with hydrogen production, thermal management and other unit operations (condensers, etc.,) and ensures optimum heat and mass balances. Digital engineering will accelerate process design and enhance the experimental productivity. Detailed technical and economic modeling determines the optimum unit operations design and impact with respect to hydrogen stoichiometry, reaction temperatures, unsteady operations, and other variables. In addition, digital engineering/simulation software represents a digital twin of the laboratory hardware for theory validations, optimization and new AI-based digital process controls.

4. Scale-up and Testbed Validation – Operating experience at a larger scale verifies the materials performance/durability, process design and operations and techno-

economic performance. This information and data under real operating conditions is critical prior to scale-up to the production plant with industry equipment manufacturers, sensor and controls developers, and others. Testbed plant validation would be needed before industry would invest in a first-of-a-kind production-scale plant. Given the large capital investment in titanium ore reduction, high confidence is required beforehand.

What are the most viable approaches to decarbonization of the metals industry and what approaches will have the greatest impact?

- For titanium production, the titanium technologies (previously discussed) are the most viable approach to low carbon intensity titanium, and will have the greatest impact through both replacement of Kroll-based titanium metals production capacity as well as replacing metals with shorter lifespan (and thus lifecycle cost and carbon intensity) such as stainless steel.

What are the opportunities to significantly reduce or eliminate the use of carbon- based fuels/energy in the metals industry?

- Revolutionary approaches involving carbon-free electrolytic and/or hydrogen are the best opportunities to eliminate carbon-based fuels (for heat and reductant) in the metals industry.

C11.2 What are the challenges/opportunities related to utilizing onsite carbon-free power generation (e.g., solar, wind)? What are the challenges/opportunities to collocating metals manufacturing facilities with carbon-free powergeneration stations (e.g., hydroelectric, nuclear, geothermal)?

- On-site power is not necessary if challenges can be solved with bilateral contracting in energy/capacity markets. In Camden, TN, contracting with TVA would be a strong possibility.

C11.3 What role does electrification have in decarbonizing the metals industry? What specific opportunities/applications are there in the metals industry for electrification.

- With the Administration's 2035 carbon-free grid target and likelihood of an EPA clean power rule, direct electrification or electricity-based hydrogen production can play a major role in decarbonizing metals industry. Direct electrification through electrolytic processes are still in the early research phase.

C11.4 What is the greatest opportunity for reducing or eliminating environmentally harmful by-products or co-products? This question is focused on technical solution to avoid the creation of harmful co/by-products, not finding alternative uses for the co/by-products.

- Minimizing wastes and maximizing recycling of chemical agents and process water provides the best opportunity for eliminating harmful environmental by-products. Carbon-free electricity for power and heat can eliminate many air emissions (oxides of carbon, nitrogen, sulfur, etc.).

C11.5 What is the greatest opportunity for advancing environmental justice [21], as it relates to the metals industry? How would a public-private Institute effectively advance environmental justice, as it relates to the metals industry.

- Revitalization of shuttered mills with sustainable metals manufacturing such as titanium can add manufacturing jobs since the U.S. produces no titanium. As DOE strives to accomplish environmental justice objectives, a broader regional approach is required where the Institute is integrated with the local regions economic development priorities.

C11.6 Provide any additional information relevant to the environmental stewardship opportunities/challenges of the metals industry that do not fit into the previous questions in this Category. This could include various industry data (e.g., equitable economy opportunities), references, or technical information (e.g., clean energy technologies or innovations).

- Environmental justice and advancing STEM in underrepresented demographic categories can be advanced through combining AMO programs with State Energy Programs that may be funded in the Bipartisan Infrastructure Bill. In addition, a "Hub" model that co-exists with an Institute model can better promote STEM opportunities through internships, post-doc fellowships, temporary research appointments and other opportunities available through a university/national lab-based hub.