Greening High-Temperature Manufacturing: Toward an RD&D Agenda

Discussion document for BU-ISE/ITIF workshop on January 27, 2021

The Challenge

Manufacturing sectors that rely heavily on high-temperature heat—including cement, iron and steel, and chemicals—are generally recognized as more challenging to decarbonize than other sectors. Together, these sectors account for about 16 percent of global energy demand and 17 percent of direct global carbon dioxide emissions ($GtCO_2$).[1] For decades, the research community has focused on relatively minor modifications to traditional processes. While these changes can increase productivity and improve efficiency, transformational approaches will be needed to achieve deep emissions reductions and meet climate goals.

Two technical barriers to decarbonization include high-temperature heat and process emissions resulting from chemical reactions. Calcination of limestone, reduction of iron ore, and steam cracking to produce ethylene—all rely on fossil fuel combustion to generate high temperatures. The chemical reactions in these sectors are a second source of emissions. These process emissions are independent of the source of energy and thus cannot be eliminated by switching to clean heat.

Many clean alternatives have been proposed, but all pose technical and/or cost challenges,[2] especially in an environment with readily available low-cost natural gas. A common question across sectors is whether to shift production to an all-electric system or whether to use synthetic fuels and non-fossil feedstocks. In recent years, a number of highly innovative technologies have been explored for producing steel and other products using electricity. Other alternatives propose shifting from conventional fossil fuels to hydrogen or other synthetic fuels that are produced with minimal greenhouse gas emissions.

Some proposed solutions can address both heat and process emissions. For example, electrolytic iron ore reduction avoids process emissions while using electricity for heat. Other technologies can address heat or process emissions but not both. Electrification of cement kilns avoids fossil fuel combustion for heat but is unable to eliminate process emissions from the calcining step. The relative merits and tradeoffs of these approaches, including the relative economics, is uncertain.

Additional challenges to industrial decarbonization include:

- Lack of focus on decarbonization objectives among researchers and engineers
- Exhaustion of near-term opportunities for greater efficiencies
- Difficulty and cost of scaling up promising pilot-stage technologies
- Lack of funding for demonstration and early commercial production facilities
- Bespoke manufacturing processes for emerging technologies such as electrolyzers
- Lack of end-use markets for clean products to stimulate private investments in innovation
- Thin profit margins and trade exposure that limit private investments

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1 IEA (2020) Energy Technology Perspectives, https://www.iea.org/topics/energy-technology-perspectives.

2 Thiel and Stark (2021) "To decarbonize industry, we must decarbonize heat" https://doi.org/10.1016/j.joule.2020.12.007.

Currently, other countries and regions are investing more heavily in clean manufacturing innovation, as evidenced by major first-of-a-kind pilot projects such as HYBRIT (Luleå, Sweden) and SIDERWIN (Maizières, France). These private decisions are the result of strategic planning and investments by foreign governments, especially in Europe, that have not yet been matched by the U.S. federal government.

Clean manufacturing is beginning to receive greater attention from domestic policymakers: The omnibus 2021 appropriations act creates a new DOE industrial decarbonization program and calls for a national smart manufacturing plan. The United States still has a window to establish a competitive position in emerging climate-responsive heavy manufacturing markets.

Issues for Discussion

- What are the most critical research priorities in high-temperature systems to meet US climate targets while creating opportunities to increase the competitiveness of US manufacturers in a global economy focused on climate goals?
  - Crosscutting approaches: clean (blue or green) hydrogen as a feedstock, reductant, or fuel, and electrification technologies for heating such as electric arc, resistance, induction, dielectric, and electron beam heating
  - Sector-specific approaches:
    - In cement and concrete? (e.g. clinker substitution w supplemental cementitious materials, kiln electrification, fuel switching to hydrogen or biomass, alternative low-carbon cement and concrete chemistries, carbon capture and storage, alternative materials)
    - In iron and steel? (e.g., hydrogen-DRI, direct low- or high-temperature electrolysis)
    - In chemicals? (e.g., PEM electrolyzers, artificial photosynthesis, electrochemical synthesis, resistive heating)

- What are the most promising opportunities to reduce GHG emissions and revitalize manufacturing in these sectors in the near-term (e.g. by 2030) and long-term (by 2050)?

- Should high-temperature processes be a part of an initiative in zero-carbon fuels (e.g. hydrogen or ammonia made from clean electricity.)

- Are there novel processes that avoid the need for high temperatures that we should pursue?

- What are major technology opportunities that are NOT currently being researched?

- How mature is each approach, and where (at what innovation stage) should government invest? What federal RD&D investments are most likely to realize these opportunities?
  - Publicly-funded, individual investigator-initiated basic research programs?
  - Publicly-funded, targeted applied research programs carried out at academic and government laboratories?
  - Cost-shared pilot-scale facilities run by public agencies?
  - Cost-shared commercial-scale demonstration projects carried out by manufacturers?
  - Publicly-supported, industry-led manufacturing consortia that focus on targeted challenges or sectors (e.g. roll-to-roll manufacturing of electrolyzers)?

- What other federal policies would be most important to enhance the payoffs of these investments (setting aside economy-wide carbon pricing or regulation)?
    - Tax incentives for manufacturers or investors? Contracts for differences?
    - Loans or loan guarantees for manufacturers?
    - Regulatory reform?
    - Standards and certifications?
    - Workforce development?
    - Government procurement of end products (e.g. through GSA, DOD, DOT, USACE)?

Greening High-Temperature Manufacturing: Workshop Agenda
January 27, 2021

Session 1: Cross-cutting Topics (10:00 AM – 11:20 AM EST)

- General Introduction: Colin Cunliff (5 min)
- Framing the Discussion
- Short talks
    - Electrification: Ali Hasanbeigi (15 min)
    - Hydrogen industrial applications: Mark Ruth (15 min)
    - H2 vs electrification tradeoffs: Mark Johnson (15 min)
- Facilitated Discussion (25 min)

5 min break

Session 2: Sectoral Topics (11:25 AM – 1:00 PM EST)

- Framing the Discussion (5 min)
- Short talks
    - Hydrogen production: Everett Anderson (15 min)
    - Chemicals: Karthish Manthiram (15 min)
    - Iron & Steel: Marlene Arens (15 min)
    - Cement: Maria Juenger (15 min)
- Facilitated Discussion (30 min)

Invited Speakers:

- Ali Hasanbeigi, Global Efficiency Intelligence
- Mark Ruth, National Renewable Energy Laboratory
- Mark Johnson, Clemson University, former DOE-AMO director
- Everett Anderson, Nel Hydrogen
- Karthish Manthiram, Massachusetts Institute of Technology
- Marlene Arens, Fraunhofer Institute for Systems Innovation
- Maria Juenger, University of Texas, Austin