MIT CLIMATE GRAND CHALLENGES

Massachusetts Institute of Technology

Center for Electrification and Decarbonization of Industry (CEDI)

Addressing climate change will require decarbonizing the industries that manufacture the material world around us. Industrial carbon footprints arise from the manufacturing of products that are essential to modern life; they are responsible for a staggering 33% of global anthropogenic greenhouse gases (GHG) emissions, the vast majority (>90 percent) of which is carbon dioxide.

The lion's share of industrial emissions can be traced back to four specific products that form the industrial pillars of our society: cement, steel, ammonia, and ethylene. Today they represent 45 percent of industrial carbon dioxide emissions and 15% of global emissions, but increased demand for industrial products is projected to amplify industrial emissions by 2.2% per year, far outpacing the rate of emissions growth in other sectors, such as buildings, power, and transportation.

The primary use and origin of the carbon footprint for each of these industrial products is as follows:

- **Ammonia** is predominantly used as a fertilizer and has enabled stunning improvements in agricultural productivity since large-scale methods for its production were devised in the early 1900s. Ammonia (NH_3) is produced using nitrogen and hydrogen, the latter sourced from hydrocarbon feedstocks, leaving behind a stoichiometric carbon dioxide footprint.
- **Ethylene** is a precursor for the manufacturing of polyethylene, a ubiquitous plastic commonly used in packaging. It is produced primarily by steam cracking, a process in which larger hydrocarbons are combined with steam at 800°C to produce smaller hydrocarbons. The high temperatures require a cheap source of thermal energy, which comes from burning fossil fuels.

- **Steel** is an iron alloy produced through the reduction of iron ore to metallic iron with carbon from coal at 1200°C, which produces a stoichiometric carbon dioxide footprint. Additional emissions from coal or electricity production are incurred in melt-processing the steel at 1650 °C.
- **Cement** is a binder used in both mortar (cement + sand) and concrete (mortar + aggregate). Lime (CaO) is a key constituent of cement, generated by firing ground limestone ($CaCO_3$) with aluminosilicates at >1450°C, leading to the stoichiometric emission of carbon dioxide as well as thermal emissions from burning fossil fuels, primarily coal.

BARRIERS TO DECARBONIZING INDUSTRY

Any credible plan to decarbonize industry must impact the production of these four pillars. However, this is extremely difficult for several reasons:

1. A large share of these pillars' associated emissions is stoichiometric in nature, arising unavoidably from the carbon in hydrocarbons and minerals used as feedstocks.
2. Industrial processes are highly integrated, meaning that changes to decarbonize one step of processing impacts upstream and downstream steps.
3. Capital investments in industry are amortized over decades, such that decisions made decades ago continue to impact present and future emissions.
4. These products are commodities with small profit margins and for which externalities are not valued, making investments in innovation challenging.

Taken together, these factors make clear that decarbonization of industry will require a bold, expansive strategy that moves beyond minor investments in process efficiency at the margins. It is without question a Climate Grand Challenge.

OUR SOLUTION: THE CENTER FOR ELECTRIFICATION AND DECARBONIZATION OF INDUSTRY (CEDI)

A broader technological trend that is enabling decarbonization in other industries, such as power and transportation, is electrification, which we see as a compelling pathway to decarbonization of chemicals and materials production as well. Electrification in the form of replacing conventional electrical power with renewable electricity in manufacturing is relatively easy, while achieving electrically driven routes for rearranging chemical bonds is much more challenging. Achieving progress in the grand challenge of decarbonizing industry will require that we master the ability to use electricity to make and break chemical bonds that are involved in manufacturing ethylene, ammonia, steel, and cement.

In each of these four industries, there are credible, early examples of electrical decarbonization developed in individual labs across MIT, but that have not yet been brought together as an integrated and accelerated vision. And, beyond the four pillars, there exists a cascade of other chemicals and materials industries that have individually smaller but collectively huge GHG emissions, and which can be reinvented following similar methodologies. The mission of the proposed **Center for Electrification and Decarbonization of Industry (CEDI)** is to accelerate the development and implementation of these solutions.

OBJECTIVES AND TEAM LEADERSHIP

We envision the CEDI as an innovation hub that will unify the efforts of different research groups, departments, and schools within MIT, as well as a broad range of external stakeholders. The CEDI will carry out targeted fundamental research with urgency, to push the technological envelope on electricity-driven chemical transformations, in parallel with engineering efforts to pilot the most promising projects to demonstration. In our proposal, we identify cross-cutting themes that will serve to unify these directions within the proposed center. We present a plan for accelerating impact through prototyping and piloting of new technology in collaboration with a broad range of stakeholders, from mission-oriented venture investors to government agencies and small and large corporations.

We believe that this must be a physical as well as intellectual center, a dedicated lab and meeting space where experimental and computational tools are shared and all participants have the opportunity to interact.

The team is led by **Yet-Ming Chiang** (Materials Science and Engineering) and **Bilge Yildiz** (Nuclear Science and Engineering, Materials Science and Engineering), and consists of 14 other faculty.