Industrial Decarbonization Roadmap, Part 3, Chemicals

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1. Introduction

The first part of this post is described was an Overview and is linked below:

https://energycentral.com/c/cp/industrial-decarbonization-roadmap-part-1-overview

Part 2 was about Iron and Steel Production Industries. And is linked below.

https://energycentral.com/c/ec/industrial-decarbonization-roadmap-part-2-iron-steel

This is the third part of this series and is about Chemical Manufacturing. [1]

In this case I have previously posted one paper on the chemical manufacturing industry. I did not reference this in the body of this paper.

2. Research Development and Demonstration (RD&D)

The diversity, complexity, and deep capital investment of the chemical manufacturing subsector leads to parallel RD&D needs for the decarbonization pillars: energy efficiency, industrial electrification, low-carbon fuels, feedstocks, and energy sources (LCFFES), and carbon capture, utilization, and storage (CCUS). Electrification and LCFFES are highly connected and evaluated together for this roadmap. Key learnings and RD&D opportunities from the meetings include:

- *Crosscutting RD&D opportunities include improving the application efficiency for chemical separations, the use of hydrogen as a fuel or feedstock, and the integration of CCUS to improve economics.*
- *A portfolio of low-carbon process heat solutions should be developed that industry could use as a starting point to select options with the best fit (e.g., application, economics, and geography).*
- *Subsector-specific RD&D opportunities include improving the effectiveness of thermal energy use, plasma, hydrogen fuel effectiveness, materials efficiency, electrical transfer, data science, and energy storage to improve the efficiency of whole system energy use.*
- *Advancing capabilities, such as battery storage, to use variable energy to rapidly, effectively, and economically switch from current to low-carbon sources is an early-stage opportunity.*
- *To increase their deployment, the effectiveness of noncontact thermal heating and hydrogen combustion needs to be researched, improved, and deployed at an industrial scale.*
- *The diversity of needs and applications suggests a range of RD&D investments would be needed across a portfolio of solutions with active engagement with*

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[1] Full List of authors, reviewers and supporting groups is contained on this document's front-matter pages xi -- xiv, U.S. Department of Energy, "Industrial Decarbonization Roadmap," September 2022, https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

industrial companies in partnerships to test and scale-up the most promising technologies.

- *Strategies that use existing capital and infrastructure will be crucial for near- and mid-term progress (e.g., energy efficiency, materials efficiency, LCFFES, and electrification).*

3. U.S. Chemical Production

With more than 70 thousand products, 11 thousand manufacturing facilities, and deep supply chain interconnections, the U.S. chemical manufacturing industry is very diverse.[2] The dimensions of this subsector—which employs over half a million people[3]—signal a high potential for leveraged impact as the subsector transforms. Many contributions from the subsector are not highly visible, as many chemical companies are not directly involved in making consumer products. Numerous chemicals are precursors of other chemical products (about 24%), and downstream manufacturers use some 30% of production.[4] This last impact reflects that more than 96% of manufactured goods are directly touched by the business of chemistry.

Overall chemical production has grown 13% since 2009 as shown in Figure 19 (next page).[5] The U.S. chemical manufacturing industry saw demand growth along with dropping feedstock and energy costs in recent years due to the increased availability of inexpensive shale gas. That competitive advantage has led to investments of $209 billion in new assets.[6] Energy intensity for the industry improved between 2001 and 2007 at an average rate of 5% per year, but the trend reversed with energy intensity going back up until 2016 as the industry recovered from the Great Recession (2007–2008) and low utilization rates.[5] Since 2016, energy efficiency again has been improving at an average rate of 2% per year.

When the energy use in feedstocks and heat and power are combined, the chemical industry is the largest energy user in the U.S. industrial sector. Natural gas and hydrocarbon gas liquids (HGLs) (which includes ethane, propane, propylene, and butanes), are the dominant energy sources used in manufacturing chemicals when considering both heat and power and feedstocks (Figure 20, next page). For chemical manufacturing in 2018, natural gas accounted for 61% of the total heat and power consumption, electricity 13%, waste gas 11%, coal 3%, and other 12%. Boilers, furnaces, and related systems combust those fuels to provide 90% of the thermal energy

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[2] "Chemical Sector Profile," Cybersecurity & Infrastructure Agency, May 2019, https://www.cisa.gov/publication/chemical-sector-profile

[3] "The Business of Chemistry by the Numbers," American Chemistry Council, July 2021, https://www.americanchemistry.com/media/files/acc/chemistry-in-america/data-industry-statistics/the-business-of-chemistry-by-the-numbers/files/business-of-chemistry-by-the-numbers Note that the linked document is a pdf, but when I added ".pdf" to the end it would not open. It would also not open directly by clicking on the above link, but when I copied the link and pasted it into my browser, it downloaded the file. This also applies to the later "Chemicals Trade by the Numbers" link.

[4] U.S. Department of Energy Office of Industrial Technologies, Energy and Environmental Profile of the U.S. Chemical Industry, https://www.energy.gov/sites/prod/files/2013/11/f4/profile_full.pdf

[5] American Chemistry Council, 2020 Guide to the Business of Chemistry, December 2020, https://www.americanchemistry.com/chemistry-in-america/data-industry-statistics/resources/2020-guide-to-the-business-of-chemistry

[6] "U.S. Chemicals Trade by the Numbers," American Chemistry Council, June 2021, https://www.americanchemistry.com/media/files/acc/chemistry-in-america/data-industry-statistics/us-chemicals-trade-by-the-numbers/files/us-chemicals-trade-by-the-numbers

needs of industry. This is evident in Figure 21 (next page) where the process heating, CHP, and boiler categories all connect with process heat.

Overall, the GHG emissions footprint of the U.S. chemical manufacturing industry was 274 million MT CO_2 in 2020.

Across these basic product families, several chemicals dominate GHG emissions, including the large-volume chemicals (e.g., ammonia, ethylene, propylene, methanol, benzene, toluene, and xylenes (BTX), and polyethylene) that account for 80% of the subsector's energy demand and 75% of the industry's global GHG emissions.

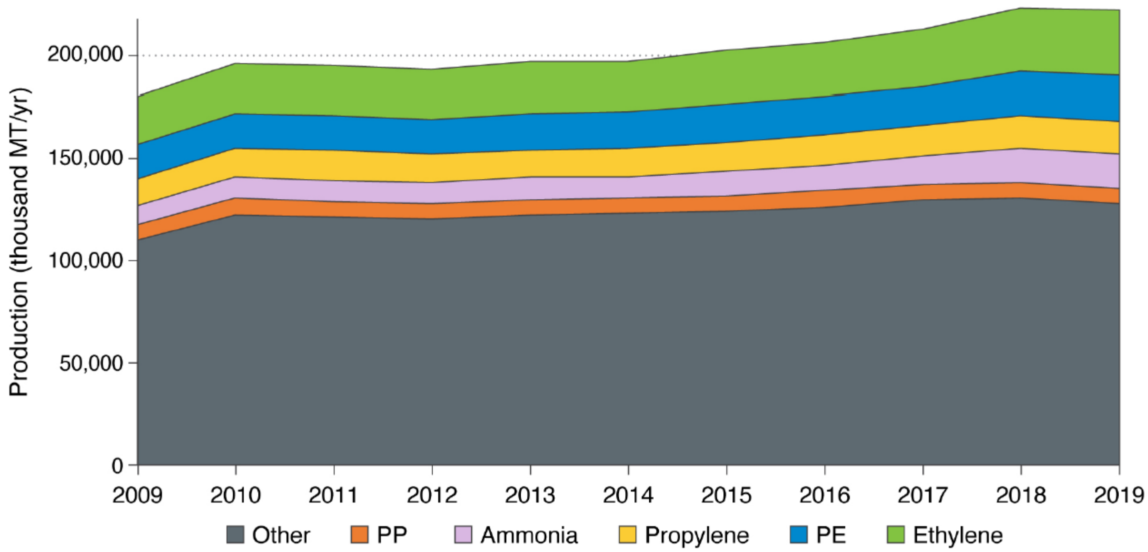

FIGURE 19. PRODUCTION VOLUMES FOR SEVERAL HIGH-VOLUME U.S. CHEMICALS 2009-2019 (THOUSAND MT/YEAR). PP – POLYPROPYLENE, PE – POLYETHYLENE. DATA SOURCE: ACC. [172]

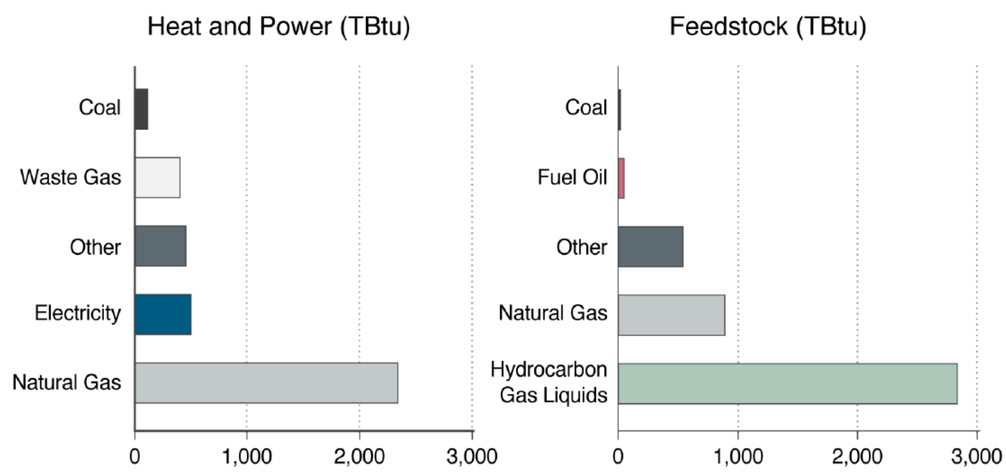

FIGURE 20. ENERGY SOURCES FOR THE U.S. CHEMICAL MANUFACTURING SUBSECTOR IN 2018.

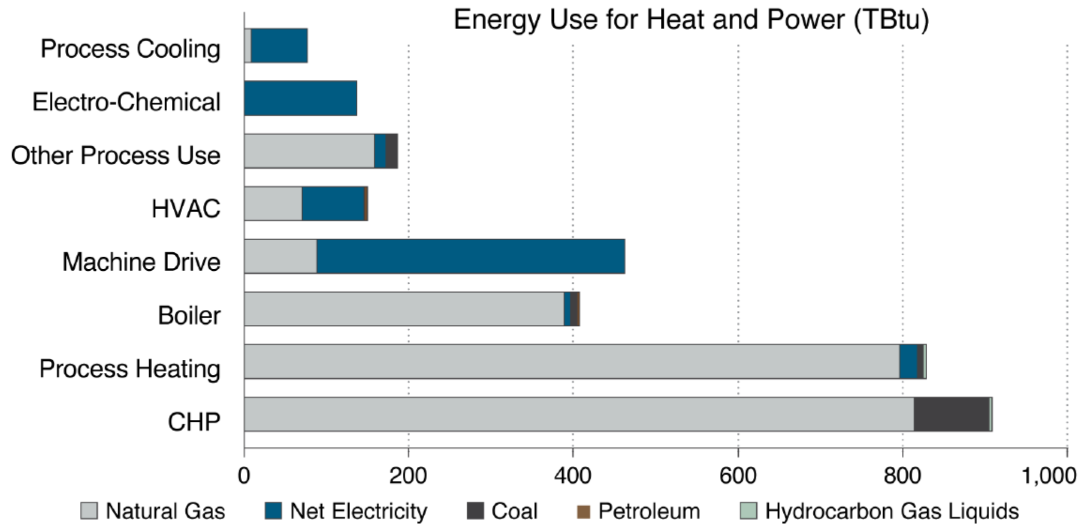

FIGURE 21. ENERGY USE FOR HEAT AND POWER IN THE U.S. CHEMICAL MANUFACTURING SUBSECTOR IN 2018.

3.1. Barriers and Opportunities

Several barriers and challenges specific to the chemical manufacturing industry were noted during the meetings. Those barriers with the strongest connections to RD&D needs are discussed here.

The very low prices of energy and fuel sources (e.g., natural gas and natural gas liquids) in recent years is a particular challenge for justifying low-carbon alternatives as the economics of these sources are a key factor in the U.S. chemical industry's market advantage. This presents RD&D opportunities to make transformative technologies as economically viable as possible. For example, the cost of hydrogen from electrolysis can be five to ten times the cost of incumbent sources. RD&D at a scale that lowers the capital and operations costs are vital to the deployment of these and other low-carbon solutions. Additional underappreciated challenges in this space when it comes to using electrolysis-hydrogen as a chemical feedstock are that modern Haber-Bosch plants are highly integrated with their numerous steam methane reforming (SMR)/water gas shift/methanation reactors, and will not be compatible with electrolysis-hydrogen feedstocks without substantial retrofitting.

The U.S. chemical industry has recently received an infusion of more than $200 billion in new capital investment connected with processing advantaged feedstocks from shale gas.[6] The new facilities made possible by such capital investment typically have the most energy efficient technologies available, are at large-scale, and could operate for 30–50 years making replacement with low-carbon technologies challenging. Research is needed on the best strategies (e.g., low-capital replacement approaches, transition to lower-carbon energy sources for heat and power, plug-in fuel replacements) to pursue considering the sunk capital and competitive economics of these newer facilities. The comparative benefits and drawbacks of CCUS versus retrofits, switching to low-carbon fuels or alternative carbon feedstocks such as CO_2, biomass, and waste should also be researched.

Production facilities, such as ethane crackers, which are older than this new shale gas-inspired wave may be candidates for energy efficiency upgrades, trials of new low-carbon solutions, or retrofits. Strategies that use existing capital and infrastructure will be crucial for near- and mid-term progress (e.g., energy efficiency, plug-in low-carbon fuels, *and electrification). At the opposite end of the efficiency distribution for production facilities from the new state-of-the-art facilities are the oldest, least efficient equipment, which could be considered for replacement by best available low-carbon technologies. There is a need to have low-carbon solutions and approaches across the distribution of process age and efficiency.*

Use of biomass, various waste streams (e.g., collected from municipalities, other industries, agriculture) holds a host of opportunities and RD&D challenges. These resources could serve as a source of low-net carbon emissions hydrocarbon feedstocks. RD&D to improve the quality of feedstock sources (e.g., separations), minimize carbon emissions associated with processing, and continued work to quantify the full life cycle impacts are some of the areas that need to be addressed.

The value return for recycling and materials efficiency in the United States has seen increased uncertainty because of supply chain shifts such as China's plastics ban, which prevents the import of all but the highest-quality plastics waste; persistence of low disposal costs; and lack of customer willingness to pay more for products with higher recycled content. More efficient processes for recycling, materials separations, and improvement in physical properties of products with higher recycled content are needed to attain higher recycling rates.

Supply and delivery of large quantities of competitively priced clean electricity are needed for chemical facilities to ramp up beneficial electrification, yet this electricity is not always available locally for the industry. The chemical manufacturing industry has not yet seen the advantage of using variable energy sources, current expertise is lacking, and process integration is not set up to tap into this resource. The RD&D opportunity is to enable opportunities where this resource could provide unique advantages, such as using onsite battery storage to ensure power quality and participate in wholesale markets.

There is a paucity of quantitative information on the non-energy benefits of various electric technologies (which makes capital justification difficult) and a lack of technical information about the application for low-carbon solutions. Improved information availability, transparency, access, and share-ability would aid justification arguments.[7]

Unfavorable thermodynamics for CO_2 *conversion to chemicals is a challenge in most paths to recycle or reuse captured* CO_2*. This does not exclude conversion, but it clarifies that the energy released when the* CO_2 *was formed during combustion must be added back to the process or material (and some more because of inefficiencies) to make products from* CO_2*. The* CO_2 *and energy burden will be part of the discussion even when the grid energy approaches a high level of clean electricity generation because of arguments that the low-carbon energy could be best used to displace high-carbon energy uses.*[8]

3.2. Pathways

To understand how the application of the decarbonization pillars could help phase out net GHG emissions, the potential GHG emissions reductions for several major chemical

[7] U.S. Department of Energy Advanced Manufacturing Office, Thermal Process Intensification: Transforming the Way Industry Uses Thermal Process Energy, May 2022, https://www.energy.gov/eere/amo/articles/thermal-process-intensification-transforming-way-industry-uses-thermal-process

[8] Scott A. Stevenson, "Thermodynamic Considerations of CO_2 Utilization," AIChE Journal 65, no. 9 (June 2019). https://doi.org/10.1002/aic.16695

products (ammonia, methanol, ethylene, and BTX (benzene, toluene, and xylenes)) were examined. This work was also pursued to provide guidance on where RD&D could significantly enable reductions. The topic of where to start on reductions, relative impact of the pillars, and RD&D priorities were also of common interest across the meetings.

The modeling results summarized in Figure 23 (next page) show that emissions could double in the BAU case considering the expected increase in demand for products and resulting emissions increases. Applications of the decarbonization pillars could level out the CO_2 emissions curve for the Moderate scenario and decrease emissions substantially by 2050 for the Advanced and Near Zero GHG scenarios. The Moderate scenario is largely achievable with commercially available technologies and current approaches, whereas the Advanced and Near Zero GHG scenarios assume ambitious application of transformative technologies and low-carbon approaches to the production of these major products. For the Moderate and Advanced scenarios, switching to electrification prior to decarbonizing the electric grid could result in higher GHG emissions through 2030. Similarly, for the expansion of hydrogen use, GHG emissions could go up if increased amounts of hydrogen were made with higher-carbon processes.

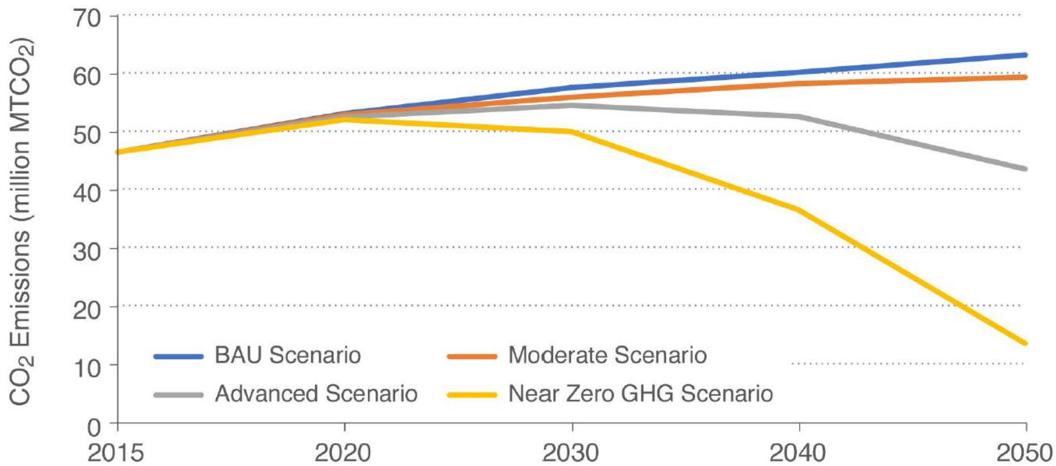

FIGURE 23. FORECASTED CO_2 EMISSIONS (MILLION MT/YEAR) FOR U.S. PRODUCTION OF AMMONIA, METHANOL, ETHYLENE, AND BTX BY DECARBONIZATION SCENARIO, 2015–2050.

The business as usual (BAU) scenario assumes slow improvement; moderate assumes higher rates of energy efficiency, switching to lower-carbon fuels, electrification adoption, and some CCUS; Advanced assumes even higher rates; and Near Zero assumes the most aggressive improvement and adoption rates.

The Moderate and Advanced scenarios show CO_2 emissions could increase in the short term which highlights the need for coordination on the timing of electrification and generation and use of low- or no- carbon electricity by the subsector. If industrial electrification occurs rapidly and locally supplied electricity has a relatively low proportion of low- or no-carbon electricity, the GHG emissions associated with the grid could cause increased emissions. This is due largely to the use of hydrogen made from electrolysis as a precursor for ammonia and methanol. If the locally supplied electricity has a relatively low proportion of clean electricity generation, the supplied hydrogen will have a higher carbon footprint than the incumbent process supplied by natural gas today. Hence, local generation of low- or no-carbon electricity that is reliable and suitable for industrial use (e.g., for hydrogen generation, process heat support, other) and increased adoption of electric technologies and processes needs to be coordinated and sequenced so that GHG emissions reductions are realized.

Even with the ambitious application of decarbonization technologies (i.e., under the Near Zero GHG scenario), some residual emissions would remain hard-to-abate (e.g., small dilute sources that are highly distributed across the chemical facility). Additionally, even if a significant portion of emissions were captured with CCUS, there would be some minor amount of residual CO_2 emissions because the capture efficiency likely would not be 100%. This suggests that there will need to be some intra-U.S. offsets or GHG emissions reductions in other subsectors or positive reductions of GHG emissions from other means.

Different factors contribute to the realization of significant CO_2 emissions reductions in each scenario. Figure 24 shows the contribution of each of the decarbonization pillars to CO_2 reduction for producing the combined set of product examples. The shared electrification and LCFFES pathways make the largest contribution to CO_2 emissions reduction, a large portion of which is related to a shift from conventional production routes for ammonia, methanol, and ethylene to processes that use hydrogen produced from clean energy. Electrification of process heat and power also makes a substantial contribution.

These simulations also show that energy efficiency approaches could make a significant contribution to decarbonization. Energy efficiency will continue to be important throughout this 30-year transition, and RD&D is needed to increase its relative contribution to CO_2 reductions and application to lower the implementation costs of the other decarbonization pillars.

Figure 24 (next page) shows the combined impact approaches that can be considered "electrification" within these heavy industrial subsectors (including using electricity for process heat, generation of hydrogen that is used as a fuel, and use of hydrogen as a feedstock or precursor in chemical reactions). It is instructive to briefly explore the impacts and timing of these approaches.

Impacts of electrification of process heat: Process heat accounts for 7.6 quadrillion Btu or 51% of U.S. manufacturing's onsite energy consumption; about 30% of that amount is in the low-temperature range (at or below 150°C). This temperature range and a growing portion of the medium-temperature range (150-300°C) are accessible by many commercial and electric technologies with the potential for both energy and non-energy benefits.

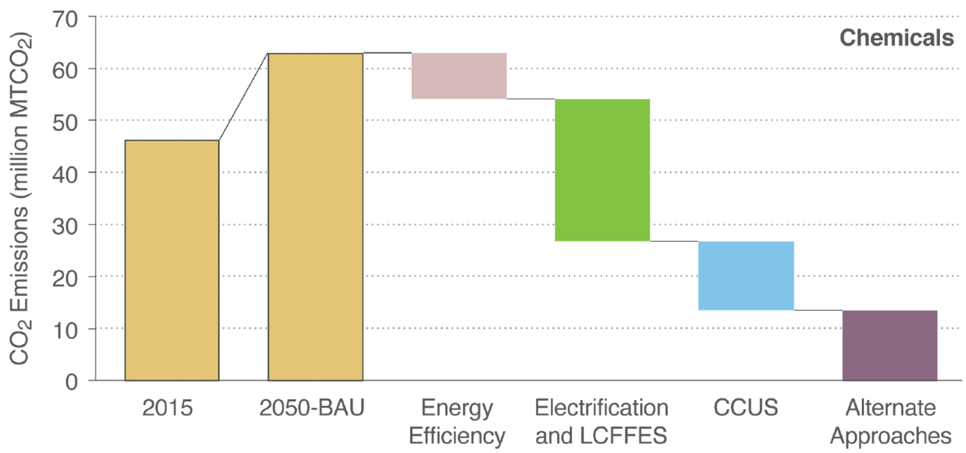

FIGURE 24. IMPACT OF THE DECARBONIZATION PILLARS ON CO_2 EMISSIONS (MILLION MT/YEAR) FOR U.S. PRODUCTION OF AMMONIA, METHANOL, ETHYLENE, AND BTX, 2015–2050.

Emissions are estimated for business as usual (BAU) and near zero GHG scenarios. Since industrial Electrification and LCFFES technologies and strategies are strongly interconnected, these pillars were grouped for scenario modeling. The "Alternate Approaches" band shows further emissions reductions necessary to reach net-zero emissions for the subsector. These alternate approaches, including negative emissions technologies, are not specifically evaluated in scenario modeling for this roadmap. The powering of alternate approaches will also need clean energy sources (e.g., direct air capture could be powered by nuclear, renewable sources, solar, waste heat from industrial operations).

In general, electric technologies have a lower energy intensity than conventional technologies. As the electric grid becomes decarbonized, this lower energy intensity will complement the lower-carbon impact of the energy source giving a lower CO_2 emissions factor as shown in Figure 25. The U.S. grid achieves emissions factor (kg CO_2/kWh) parity with coal between 2020 and 2030 in all scenarios[9] and with natural gas around 2030 in the Advanced and Near Zero scenarios. More aggressive assumptions on the rate of grid decarbonization from the BAU to Near Zero scenarios result in the emissions factor dropping more quickly below the emissions factors for coal or natural gas. For process heat applications, even if electrification occurs before the grid CO_2 emissions factor drops below the factor for natural gas and coal, there could be net reduction since electric technologies often have lower energy intensity (kWh/MT product) as shown in a recent study. Electrification of process heat then is a highly efficient way to achieve early CO_2 reduction while providing many energy and non-energy benefits.

***Impacts of electrification of hydrogen as a fuel:** The use of hydrogen as a fuel to replace coal, natural gas, or other fossil fuels could provide GHG emissions reductions, depending on the emissions factor difference between the hydrogen (and the way it is generated) and the fuel that it could replace.*

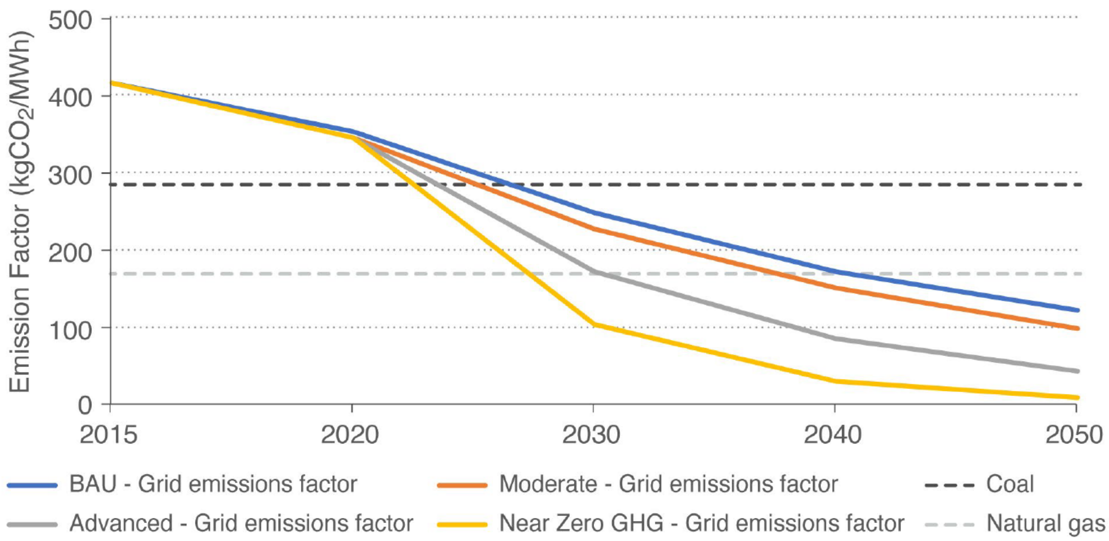

FIGURE 25. EMISSIONS FACTORS FOR SCENARIOS WHERE THE GRID IS DECARBONIZED COMPARED TO FUEL SOURCE EMISSIONS FACTORS FOR COAL AND NATURAL GAS (HORIZONTAL LINES).

For example, compared to coal the emissions factor difference versus hydrogen from clean energy would be the greatest, followed by hydrogen from steam methane

[9] This pertains to the emissions factor per unit of energy (kg CO_2/MWh) of coal and natural gas when they are used as fuel for industrial heating as opposed to the emissions factor of electricity grid (under different scenarios) when electricity is used for industrial heating.

reformers (SMR) with CCUS. This is illustrated in Table 3 (next page). Constant factors are assumed as we do not know the expected rate of improvement for the emissions factors for hydrogen with and without CCUS, but they will likely improve over time. RD&D that enables and lowers hurdles for the economic generation of clean hydrogen from low- or no-carbon-emitting processes at scale can help accelerate GHG emissions reduction via this approach. Also, RD&D that benefits implementing hydrogen as the replacement for fossil fuel sources with higher emissions factors would also be warranted.

Table 3. Emissions Factors for hydrogen produced using steam methane reforming (SMR), without and with varying levels of CCUS and electrolysis using renewable energy compared to coal and natural gas.

Fuel Sources	Emissions Factors Used for Scenarios (kg CO_2/MWh)
Coal	341
Natural gas	202
Hydrogen SMR without CCUS	364
Hydrogen SMR 53% CCUS	169
Hydrogen SMR 64% CCUS	130
Hydrogen SMR 89% CCUS	40
Clean hydrogen (low-carbon energy electrolysis H_2)	-

NOTE: FOR THIS ROADMAP, THE EMISSIONS FACTORS ARE ASSUMED TO REMAIN THE SAME FROM 2015 THROUGH 2050.
SOURCE: THIS WORK.

Impacts of electrification of hydrogen as a feedstock: *Hydrogen is a key reactant in several chemical reactions where it is incorporated directly (e.g., ammonia) or indirectly (e.g., methanol where organic matter from natural gas, biomass, etc., is converted to synthesis gas containing hydrogen). Intermediates (e.g., methanol, ethanol) made with low-carbon hydrogen could be an approach to make major chemical building blocks such as ethylene or propylene – from which a host of polymers and other downstream chemicals can be made. For this roadmap, a key question is whether this approach is a viable route to GHG emissions reduction and whether it should be a prime area for RD&D in the near-term.*

For the Moderate and Advanced scenarios, switching to hydrogen produced by electrolysis (referred to in this roadmap as "electrolysis-hydrogen") prior to decarbonizing the electric grid could result in higher GHG emission. For the expansion of hydrogen use, GHGs could possibly go up if increased amounts of hydrogen were made with higher-carbon processes (e.g., SMR without CCUS). Similarly, considering the generation of ammonia as an example, if electrolysis of hydrogen as a feedstock were to be pursued even modestly while produced using current projections for grid electricity, the scenarios show that CO_2 emissions could increase as shown in Figure 26 (next page). For clean electrolysis to be viable at scale, large-scale low-cost clean energy will be necessary as grid integrated electrolysis without a clean electricity grid will have more GHG emissions than hydrogen produced with SMR.

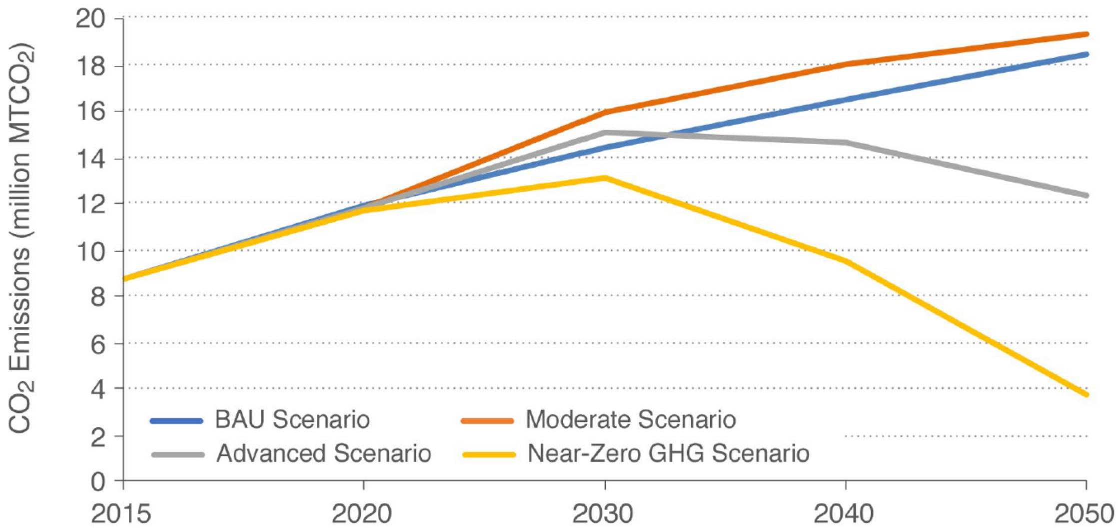

FIGURE 26. CO_2 EMISSIONS (MILLION MT/YEAR) FORECAST FOR THE U.S. AMMONIA INDUSTRY BY SCENARIO WHEN ELECTROLYSIS-HYDROGEN IS ADOPTED MODESTLY IN 2030–2050.

This increase is due to the high electric intensity for ammonia produced from electrolysis-hydrogen (181 kWh/MT ammonia for natural gas-based process versus 9,500 kWh/MT ammonia for the electric process). When using electrolysis-hydrogen as a feedstock instead of hydrogen produced from natural gas, DOE accounts for the emissions associated with the electricity used in electrolysis. However, there is no credit for displacing the natural gas because as a feedstock it is incorporated into the ammonia and does not result in direct emissions.

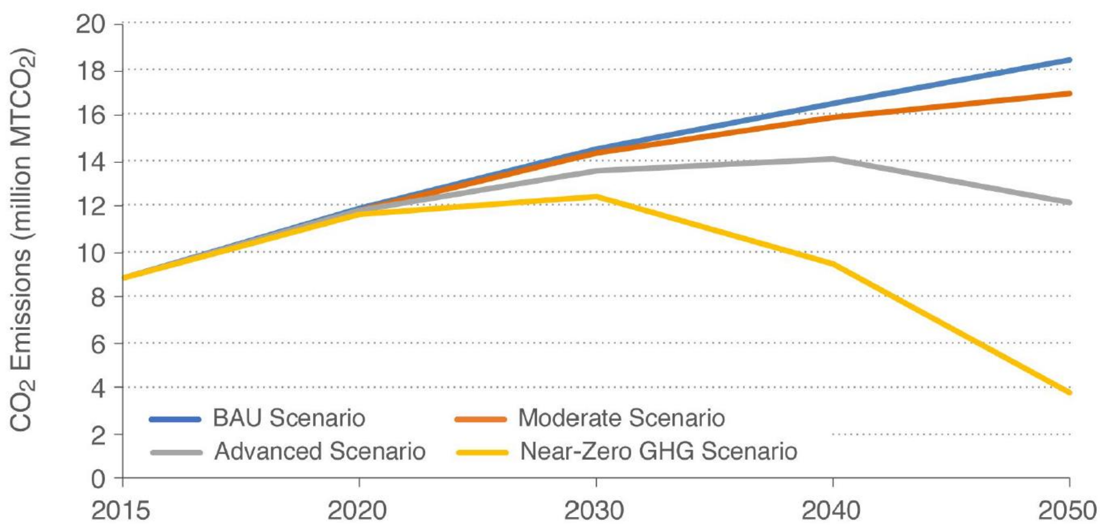

FIGURE 27. CO_2 EMISSIONS (MILLION MT/YEAR) FORECAST FOR THE U.S. AMMONIA INDUSTRY BY SCENARIO WHEN ADOPTION OF ELECTROLYSIS-HYDROGEN IS DELAYED UNTIL THE ELECTRIC GRID IS DECARBONIZED.

In the Moderate scenario, the balance point to keep CO_2 emissions from increasing above the BAU scenario (as shown in Figure 27) would limit U.S. ammonia production via the electrolysis-hydrogen pathway to about 1%, 3%, and 5% in 2030, 2040, and

2050, respectively. If the proportion of electrolysis-hydrogen is reduced in early years, this increase can be avoided (Figure 27).

This analysis showed that the use of electrolysis-hydrogen as a feedstock for major chemical products (e.g., methanol, polyethylene, polypropylene, ammonia) would require large-scale accessibility of clean electricity. Until the electric grid becomes 100% clean, the CO_2 emissions associated with grid-electricity generated hydrogen will hinder the use of electrolysis-hydrogen. Direct integration of non-carbon energy sources (such as wind or solar) with electrolysis could be an alternate route to clean-grid utilization and allow a higher level of production of chemicals via this pathway.

RD&D perspective learnings from this analysis include:

- *Electrification of process heat is a top early opportunity. RD&D that lowers barriers, improves economics, accelerates adoption should be a top priority.*
- *Use of clean hydrogen can reduce GHG emissions from industry by displacing high-carbon incumbent feedstock.*
- *Use of electrolysis-hydrogen has several hurdles for use as a feedstock in chemicals, since the replacement electric processes have much higher energy intensity, and viability would require a low-carbon grid. Electrolysis-hydrogen could be used in chemical processes without increased CO_2 emissions if it is produced using electricity from 100% clean generation sources…*
- *RD&D that lowers hurdles and aids implementation for the economic generation of clean hydrogen at scale can help accelerate CO_2 reduction.*

The combined electrification approaches—process electrification, switching to low-carbon energy sources, such as electrolysis-produced hydrogen, hydrogen with CCUS, and transformative processes—could reduce emissions to 2015 levels. Abatement technologies and activities, such as CCUS, biofuels or biomass, and negative emissions approaches (such as soil carbon sequestration) could further reduce GHG emissions. Although this simulation examines just a portion of the emissions for the subsector, by considering the three chemical products with the largest CO_2 emissions, it suggests a portion of CO_2 emissions from hard-to-abate sources would remain. Several other approaches and technologies could reduce GHG emissions further including carbon sinks (e.g., reforestation) and abatement technologies and activities (e.g., CCUS).

The relative contributions of the decarbonization pillars suggests additional RD&D in electrification would be crucial to realizing this impact. Also, the use of low-carbon hydrogen as a feedstock for the production of building block molecules (e.g., ethylene, propylene, and methanol), biomass, and other options are needed to further reduce CO_2. Efforts to accelerate the adoption and scaling of the cost-effective generation, transport, and use of renewably sourced hydrogen will be particularly important.

Understanding the best sources for CCUS application, combined with integration research to minimize costs and deployment hurdles, will also be important. Starting points for the capture of CO_2 from the highest-purity, highest-volume sources in industry have been studied, and those studies have shown that 123 facilities have the potential to avoid 68.5 million MT CO_2 per year at costs below \$40 per MT CO_2 delivered.[10] There are RD&D needs associated with the connection to potential CO_2 transport and storage

[10] Pilorgé, H., et al., Cost Analysis of Carbon Capture and Sequestration of Process Emissions from the U.S. Industrial Sector. 2020. Environmental Science & Technology 54, 12: 7524-7532. https://doi.org/10.1021/acs.est.9b07930

infrastructure. A build-out of trunk lines and an expanded national network would be needed to meet the CCUS needs of multiple industries. This includes early expansion along the Gulf Coast, where several petrochemical complexes are located.

Author's comment: I believe there is (perhaps) a lack of understanding in the above text. There seems be too much emphasis on the percentage of renewable / low carbon power on the electric grid. That is not the way the grid works.

When a large user contracts for power from one or more specific dedicated generation source(s), the delivered power (both the amount and the greenhouse gas (GHG) intensity) that is injected into the grid is assumed to be the same as delivered. A really good demonstration of this can be seen by reading the post linked below.

https://energycentral.com/c/cp/amazon-climate-moves

3.3. RD&D Needs and Opportunities

This section explores the RD&D challenges and opportunities of the decarbonization pillars and what should be the priority approaches. Across RD&D for the decarbonization pillars and crosscutting areas, stakeholders noted that low-carbon technologies are in various development stages. Four opportunities are presented here that extend across the breadth of chemical processes.

3.3.1. Process Heat

There are various temperature ranges to consider for process heat in the chemical industry, as shown in Figure 29. About 60% of the process heat demand is in the low-temperature range (less than 150°C categories), which is the best opportunity for several current technologies. An additional 15% of process heat is in the medium-temperature range (150–300°C). Only 2% of the process heat is in the 300–550°C range, but an additional 24% is in the 550–1,100°C range. The latter range could be accessible by advanced nuclear reactors including high temperature gas reactors (HTGR) and very high temperature reactors (VHTR) available in the near term, as well as molten salt reactors. Other technologies able to reach this range include electrolysis-hydrogen and electric heating.

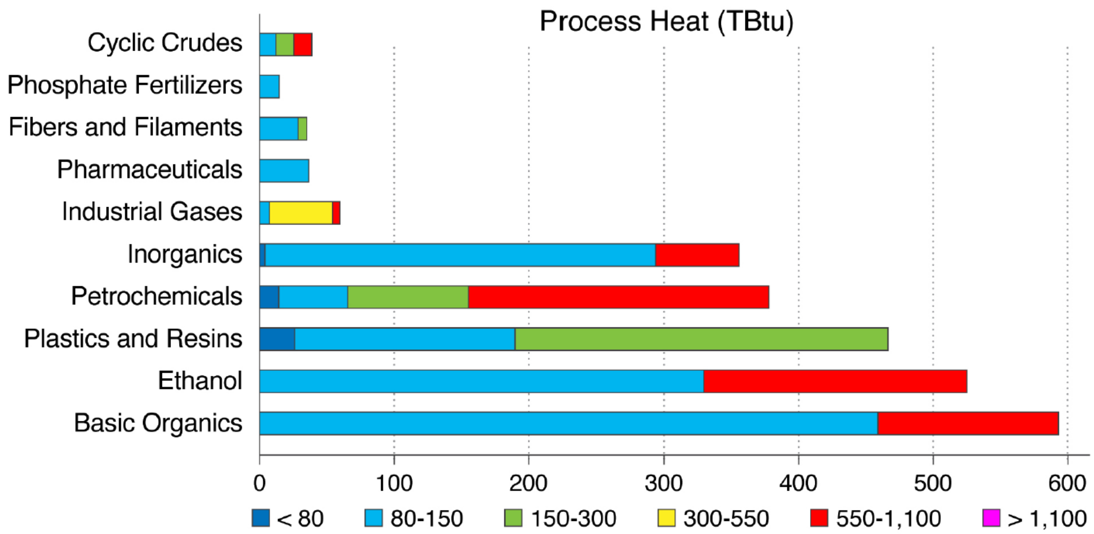

Figure 29. Distribution of process heat use across top product categories in the U.S. Chemical Industry by temperature range (°C).

3.3.2. Separations and Other Unit Operations

Thermally driven separations account for some 40% of the energy consumption of 25 top chemicals, including ethylene, acetic acid, ethanol, methanol, and xylene. In some cases, the introduction of alternative modes of energy transfer has shown promise for process enhancements. For example, electric fields applied to separations systems can control properties (e.g., transport and media structure), mitigate fouling, and help pre-concentrate input flows. The materials changes can extend porosity and the latter improvements could help with product cleanup, which is a route to waste reduction and energy savings. Retaining the performance of separations processes by minimizing degradation from unwanted chemical reactions is also vital. Research is needed on routes to minimize or control this degradation (e.g., reduced rates of change via operating conditions, additives, and chemical control to yield benign degradation products). A combination of electric and magnetic fields has been used in particle sorting and various triggers, including light, electric, and magnetic fields are being used to cycle separations materials…

3.3.3. Hydrogen

Hydrogen as a feedstock is an important option for decarbonizing industry. Clean hydrogen can serve as a precursor to chemicals production, providing a low-carbon route to methanol, ammonia, hydrazine, and other molecules that serve as feedstocks for other chemicals. Methanol is one of the most-produced commodity chemicals in the world, with a global demand in 2015 of 75 million MT. Renewable methanol can be produced using the hydrogen from renewable or nuclear electricity (clean hydrogen) or from sustainable biomass. Methanol can be used in many ways, including as a feedstock, energy carrier, and transportation fuel. Methanol can also be produced with CO_2*, such as by the proprietary Methanex process, and used as an automotive fuel...*[11]

3.3.4. Biomass and Waste Streams as Fuels and Feedstocks

The prospect that a variety of biomass and waste streams could provide low-carbon emissions hydrocarbons for fuels and chemical feedstocks is an area of continued interest. Studies have noted that biological production methods can lower the GHG emissions of producing many chemicals by 39% to 86%[12] *and a commercial partnership recently announced a joint venture to produced bio-based intermediates, with greater than 90% lower GHG emissions.* [13]

The chemical industry has invested in multiple waves of RD&D and commercial projects using biomass over decades. For example, chemicals manufacturers have recently developed and commercialized processes to make bio-based polyethylene from

[11] "About Methanol," Methanex, 2020, last modified 2020, https://www.methanex.com/about-methanol/how-methanol-made

[12] Felix Adom et al., "Life-Cycle Fossil Energy Consumption and Greenhouse Gas Emissions of Bioderived Chemicals and Their Conventional Counterparts," Environment, Science and Technology 48, no. 24 (2014): 14624-14631. https://doi.org/10.1021/es503766e

[13] "Cargill and HELM partner to build $300M commercial-scale, renewable BDO facility, first in the US, to meet growing customer demand," Cargill, June 8, 2021, https://www.cargill.com/2021/cargill-and-helm-partner-to-build-$300m-facility

sugarcane and bio-based butadiene from the fermentation of sugars.[14] *These and many other RD&D and commercial ventures show the interest of chemical companies and their partners in tapping bio-based routes to chemicals...*[15]

4. Major Chemical Industry Commitment

Sasol is a major player in the international chemical industry. It is based in South Africa, but is currently developing a major sustainable chemical plant in the U.S., the Lake Charles (Louisiana) Chemicals Project (LCCP). LCCP is well over the original budget, but basically is complete.

…Sasol is, however, a tough company to decarbonize. It uses a highly carbon-intensive process called Fischer-Tropsch to convert coal or natural gas into refined fuels that would otherwise more commonly be made from petroleum. The process that was developed by German scientists in the 1920s later helped fuel Hitler's war effort. Later, perfection of the process helped South Africa fuel its economy during the apartheid years. Sasol now makes nearly 150,000 barrels per day of synthetic diesel and jet fuels worldwide. [16]

The Fischer-Tropsch process needs two primary feedstocks: carbon monoxide and hydrogen. Traditionally it has relied on fossil fuels to make them. Cheap and plentiful shale gas continues to be Sasol's rationale for making chemicals at Lake Charles. If Sasol can find "green" sources for those feedstocks, then maybe it can succeed in its goal of reducing emissions 30% by 2030. "We don't need to put new steel in the ground to produce. We need to enable the front end."

There's a lot of hype about the future hydrogen economy, and why not? When you burn it, all you get is water vapor. But it is energy intensive to produce. Sasol makes "gray" hydrogen in its plants by gasifying coal. It costs $1 a pound. Sasol in 2023 will make its first batch of "green" hydrogen—using excess wind or solar power to run the electrolysis—but the initial cost will be on the order of $3 a pound. That will come down, especially in the U.S. thanks to the many flavors of federal green energy tax credits included in the recent Inflation Reduction Act. "Whether it happens in 2030 or 2040—with so much money invested, it's going to happen." Once they can make enough green hydrogen, they'll combine it with a source of sustainable carbon (i.e., from landfill gas, or sucked out of the air) to make sustainable jet fuel.

Sasol aims to reduce its coal use by 25%, or 9 million tons a year. That will mean finding new jobs for potentially thousands of miners. CEO Grobler sees plenty of opportunities emerging in the extraction of copper, platinum and diamonds. At Lake Charles, where Sasol still has land to spare, they are considering the construction of a plant with South Korea's Lotte Chemical that would make electrolyte solvents for lithium ion batteries. In September Sasol announced a partnership with Japan's Itochu Corp to scale up the

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[14] "INVISTA and Arzeda enter agreement to develop bio-derived raw materials," BusinessWire, February 6, 2013, https://www.businesswire.com/news/home/20130206006354/en/INVISTA-and-Arzeda-Enter-Agreement-to-Develop-Bio-Derived-Raw-Materials

[15] Melody M. Bomgardner, "Biobased Chemicals and Fuels Face Growing Pains," Chemical and Engineering News 91, no. 26 (2013). https://cen.acs.org/articles/91/i26/Biobased-Chemicals-Fuels-Face-Growing.html

[16] Christopher Helman, Forbes, "Back From Brink, Sasol Gets On The Path To Greener Chemicals," Oct 3, 2022, https://www.forbes.com/sites/christopherhelman/2022/10/03/back-from-brink-coal-giant-sasol-gets-on-the-green-path/

manufacture of green hydrogen into more easily transported green ammonia. Already in their German operations Sasol makes bio-ethylene out of plant-based biomass and waste.

The green dreams must find fruition if Sasol is to grow. Grobler swears that Sasol is done building big new projects that rely on coal, oil, or natural gas. In his eyes the fossil fuel era simply won't last long enough for Sasol to generate a good return. "If you put steel in the ground you have to run it 30-50 years to get the true value out of the investment." The petroleum economy, and the internal combustion engine, he says, "is now plateauing and there is going to be a decline. Why would you invest in a declining market?"