Gaps and Opportunities for an **Economic, Resilient, Lower-Carbon Energy System for Base Chemicals** in the Gulf Coast

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HOUSTON ENERGY TRANSITION INITIATIVE

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EXECUTIVE SUMMARY

BACKGROUND

The U.S. Gulf Coast ranks among the top chemical manufacturing regions in the world. Hundreds of chemical plants in Texas and Louisiana produce millions of tons per year of base chemicals such as ammonia, ethylene, propylene, and chlorine. Altogether, the Gulf Coast accounts for over 50% of base chemicals and over 90% of primary petrochemicals (a subset of base chemicals made from crude oil or natural gas) made in the US.[1] These chemicals and their derivatives are critical for health care, agriculture, clean drinking water and thousands of commercial products such as construction materials, packaging, detergents, and textiles.

For the United States' national security and economic growth, it is critical that the Gulf Coast retains and strengthens its incumbent leadership in base chemical manufacturing. The Gulf Coast not only has the concentration of industrial assets for base chemical manufacturing, it also has the technical ability to develop and deploy new technologies needed for the next generation of base chemical manufacturing that is more resilient, efficient and lower-carbon. Through strong partnerships between academia, the U.S. Department of Energy's (DOE) national laboratories, and the oil, gas and petrochemical derivatives industry, the Gulf Coast is well positioned to be the launchpad for new technologies in lower-carbon base chemical manufacturing.

ESSENTIAL PARTNERS

The Greater Houston Partnership (Partnership) through its Houston Energy Transition Initiative (HETI) builds on the best of traditional energy skills and systems, leveraging industry leadership to accelerate global solutions for an energy-abundant, low-carbon future. The Partnership is the principal business organization for the greater Houston region, and HETI convenes industry, academia, government agencies and offices, nonprofits and environmental nonprofits to collaborate on shared low-carbon challenges.

In November 2024, HETI and a coalition of national laboratories, industry leaders, and U.S. Gulf Coast academic institutions planned and launched a series of annual workshops to address mutual scientific challenges and grow the connectivity between academic institutions, national laboratories and industry. These three groups were chosen to build relationships, share learnings and leverage their collective strengths.

National Laboratories: The 17 U.S. DOE laboratories conduct scientific research and development to address complex challenges in areas such as energy, critical material supply chains, national security and advanced manufacturing technologies. There is no national laboratory located in the Gulf Coast, but the labs' research has broad application for the base chemicals industry.

U.S. Gulf Coast Academic Institutions: Academic institutions are a hub of early scientific research alongside national laboratories leading to scale-up and deployment for industry. These higher education institutions build the pipeline of researchers and technicians through cross-sectoral education, starting as early as high school and 2-year and 4-year institutions.

U.S. Gulf Coast Base Chemicals Industry: The Gulf Coast chemical manufacturing industry produces products and derivatives critical for health care, agriculture, clean drinking water and thousands of commercial products such as construction materials, packaging, detergents, and textiles. The concentration of industrial assets, technical knowledge of manufacturing at scale and decision-making authority along the Texas Gulf Coast is unparalleled and ripe for scaling the next generation of lower-carbon chemicals.

The workshop was held at the Greater Houston Partnership under Chatham House Rules to identify research and development opportunities for a more efficient, resilient and lower-carbon energy system for base chemicals across the Gulf Coast. Attendees included technical and business leaders from chemical manufacturing and energy companies with Gulf Coast-based assets or corporate offices, academic institutions located along the Gulf Coast, and national laboratories, with the University of Houston, Louisiana State University, Rice University, Argonne National Lab, the National Energy Technology Lab (NETL), National Renewable Energy Lab (NREL), and Oak Ridge National Lab serving as co-hosts with HETI.

Students from the University of Houston served as scribes for the meeting and collected key findings and recommendations made by the workshop's participants. The Partnership thanks Dr. Ramanan Krishnamoorti, Vice President of Energy and Innovation, and Dr. Suryanarayanan Radhakrishnan, Managing Director of Energy, at the University of Houston, and the following University of Houston students for their contributions to this paper:

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[1] Council, A. C. *2023 Guide to the Business of Chemistry;* American Chemistry Council: 700 2nd Street NE, Washington DC 20002, **2023.**

AREAS OF IMPACT

The workshop included presentations and panel discussions focused on the following areas of opportunity to unlock the Gulf Coast's continued leadership in low carbon base chemical manufacturing. These opportunities were identified through interviews with industry, academic institutions, and national laboratories as key for a more efficient and lower-carbon energy system for base chemicals in the Gulf Coast.

Resilience: Building collaboration between the national labs, academia and industry for predictive, standardized models to enhance disaster preparedness and cybersecurity.

Economics: Promoting transparent carbon accounting and standardized cost models to drive low-carbon innovation and enhance market participation.

Energy and Process Integration: Advancing electrification, carbon capture, and renewable energy integration to optimize resource use.

Emerging Technologies: Scaling energy infrastructure, leveraging artificial intelligence (AI) and machine learning in process design, and validating manufacturing processes to commercialize new innovations.

SUMMARY OF FINDINGS

A hypothesis emerged – if the Gulf Coast could boost its resilience to natural and economic challenges and work through the systems of systems challenges posed by process integration and the manufacturing process scale-up of new technologies, it would retain and strengthen its leadership position in low-carbon base chemical manufacturing. Attendees made it clear that this can only be achieved by partnerships between industry to scale and deploy low-carbon solutions and national labs and academic institutions which can support technology development and de-risking. Through a series of small group discussions, attendees illuminated the following recommendations and opportunities for the Gulf Coast to lead new technology commercialization in base chemicals.

RECOMMENDATIONS

1. **Resilience:** National labs and academic institutions should jointly develop and test predictive, standardized models for resilience to stress-test assets virtually. Industry should validate and shape these models to guide investment in systems that can anticipate and respond to incidents – both national security related cyber threats and natural disasters. A joint advisory committee of national labs, academic institutions and industry would be an appropriate vehicle for this collaboration.

2. **Energy and Process Integration:** Companies often have to compare and contrast different approaches to resiliency, efficiency and lower-carbon intensity operations, such as hydrocarbon fuel replacement with low-carbon intensity hydrogen or nuclear energy. National labs, academic institutions and industry should advance electrification, point-source carbon capture, and renewable energy integration by utilizing public, standard models that allow users to compare industrial processes. These models should be built by national labs and academic institutions with input from industry and include public, transparent assumptions to allow for ease of comparing multiple processes and technologies. A first step is for a representative working group of industry, academia and national labs to review existing process integration models, identify gaps and needs for further access and data analysis.

3. **Economics:** National labs and academic institutions should develop a transparent, carbon accounting methodology, tested and validated by industry to promote awareness of carbon intensity and foster consumers' willingness to pay for lower-carbon intensity products. Development of a business-focused, transparent carbon accounting methodology that provides consumers and decision makers with the ability to assess choices associated with their chemical products is an opportunity for the Gulf Coast to lead. A first step is for a representative working group of industry, academia and national labs to audit existing carbon accounting methods, identify gaps and needs for further transparency.

4. **Emerging Technologies:** National labs and academic institutions should help industry to develop pathways to scale lower-carbon hydrogen and small modular nuclear infrastructure, leverage artificial intelligence (AI) and machine learning (ML), and establish pre-pilot scale assets as a national lab operated and shared resource, leveraging their fundamental science to validate manufacturing processes for commercializing innovations. A first step is to conduct a series of interviews of companies' pre-competitive needs, laboratory and academic research as well as a review of existing assets in the Gulf Coast to identify and act upon shared resource needs. The Greater Houston Partnership is prepared to lead this effort based on its existing relationships within the Gulf Coast innovation ecosystem, academia and national laboratories.

To support the competitiveness of base chemical manufacturers, the Greater Houston Partnership recommends that the Department of Energy (for example through its Advanced Materials and Manufacturing Technologies Office, Industrial Efficiency and Decarbonization Office and/or Fossil Energy and Carbon Management Office) fund the national labs in the recommended activities above and related procurement of equipment to fill a critical fundamental science gap in the discovery-to-deployed-solution process that impedes the commercialization of innovations that will benefit the United States' national security and economic growth.

GULF COAST LEADS THE NATION'S BASE CHEMICALS MANUFACTURING

The US Gulf Coast ranks among the top chemical manufacturing regions in the world. Hundreds of chemical plants in Texas and Louisiana produce millions of tons per year of base chemicals such as ammonia, ethylene, propylene, and chlorine. Altogether, the Gulf Coast accounts for over 50% of base chemicals and over 90% of primary petrochemicals made in the US.[1] These chemicals and their derivatives are critical for health care, agriculture, clean drinking water and thousands of commercial products such as construction materials, packaging, detergents, and textiles.

Chemical manufacturing is energy intensive. Approximately 50% of the total energy consumption of Texas and 70% of the total energy consumption of Louisiana is dedicated to industrial uses.[2] Most of this energy comes from natural gas and is delivered as heat for high-temperature reactors (e.g., ethylene cracking, Haber-Bosch ammonia synthesis) or is used to produce electricity and steam at onsite cogeneration utilities. Industrial usage of natural gas in Texas and Louisiana is estimated to be over 3 trillion standard cubic feet per year,[2] or nearly 100 GW of heat and electricity.

The Gulf Coast chemical manufacturing complex includes chemical plants, international shipping ports, rail lines, and thousands of miles of high-pressure pipelines for natural gas, ethylene, propylene, ammonia, hydrogen, and carbon dioxide. The net economic impact of chemical manufacturing is estimated to contribute nearly $100 billion per year to the economies of Texas and Louisiana and over 250,000 direct and indirect jobs with high salaries.[3] At a national level, chemical manufacturing is estimated to contribute roughly one quarter of the US GDP.[4]

Base chemicals made along the Gulf Coast are essential in everyday life and important for national security. For example, ammonia production in Texas and Louisiana represents roughly one-third of US production.[5] Ammonia, in various forms, such as urea, is used as fertilizer, which is critical to crop yields. Thus, a disruption in ammonia production in the Gulf Coast could have significant impacts on domestic food production and over $170 billion in annual US agricultural exports.[6] Over 95% of U.S. ethylene and propylene is made in Texas and Louisiana. These olefins are the basic building blocks used to make thousands of common polymer and oligomer products including plastic packaging, residential pipes, textiles, adhesives, insulation, detergents, and medicines, packaging and antiseptics critical to health care. The Gulf Coast produces over 70% of the domestic chlorine supply.[7] Chlorine is essential for clean drinking water, construction materials, and medical packaging.

BUILDING RESILIENCE – EXISTING INFRASTRUCTURE IS A NATIONAL SECURITY ISSUE

Historically, the combination of a relatively low-cost energy source combined with unparalleled infrastructure, a strong and generational workforce have been compelling factors for growth in the Gulf Coast chemical manufacturing. In the last few decades, flooding and hurricanes along the Gulf Coast have increasingly resulted in supply chain disruptions. In 2005, Hurricane Katrina devastated industries in the Lower Mississippi River Delta, while in 2017 Hurricane Harvey disrupted much of Southeast Texas. These natural disasters damage chemical plants, pipelines and electrical grids and cause other problems such as the inability of employees to return to work. Further, because of the interwoven nature of chemical manufacturing and the multiple reactions used to make chemical derivatives, the net effect on supply chains compounds.[8]

LIMITED PROCESS ELECTRIFICATION ADOPTION

The challenges of reducing the carbon intensity of the chemicals industry in the U.S. Gulf Coast region are complex, influenced by various interrelated factors, including the competition for lower-carbon electricity. The chemicals sector is characterized by its high energy demand, necessitating a substantial and continuous electricity supply. As the demand for lower-carbon energy surges across multiple sectors, including transportation, residential applications, and data centers, securing an adequate supply of renewable energy sources is becoming increasingly competitive and potentially cost-prohibitive. Fortunately, the wait times for permits and interconnections in the Gulf Coast are shorter, by nearly two years, than in other parts of the country, as shown in Figure 1.

[2] U.S. Energy Information Administration (EIA), *State Energy Data System.* **2024.**
[3] U.S. Department of Commerce, Bureau of Economic Analyses, https://www.bea.gov/.
[4] Cybersecurity & Infrastructure Security Agency, Chemical Sector Profile, **2022.** https://www.cisa.gov/sites/default/files/2023-02/chemical_sector_profile_final_508_2022_0.pdf
[5] USGS 2019 Minerals Yearbook NITROGEN [ADVANCE RELEASE]. https://pubs.usgs.gov/myb/vol1/2019/myb1-2019-nitrogen.pdf
[6] Federal Reserve Economic Data (FRED), St. Louis Fed, https://fred.stlouisfed.org/series/B181RC1Q027SBEA.
[7] U.S. Department of Energy, Office of Industrial Technologies, Energy and Environmental Profile of the US Chemical Industry. *Prepared by Energetics Incorporated. Columbia, Maryland*, USA **2000.**
[8] Ehlen, M. A.; Sun, A. C.; Pepple, M. A.; Eidson, E. D.; Jones, B. S., Chemical supply chain modeling for analysis of homeland security events. *Computers & chemical engineering* **2014**, 60, 102-111.; Misuri, A.; Moreno, V. C.; Quddus, N.; Cozzani, V., Lessons learnt from the impact of hurricane Harvey on the chemical and process industry. *Reliability Engineering & System Safety* **2019**, 190, 106521.; Ehlen, M.; Downes, P.; Scholand, A., A Post-Katrina comparative economic analysis of the chemicals, food, and Goodyear value chains (OUO). *DHS, Albuquerque, NM* **2007**.; DeRosa, S. E.; Kimura, Y.; Stadtherr, M. A.; McGaughey, G.; McDonald-Buller, E.; Allen, D. T., Network Modeling of the U.S. Petrochemical Industry under Raw Material and Hurricane Harvey Disruptions. *Industrial & Engineering Chemistry Research* **2019**, 58 (28), 12801-12815.

Energy Resource Interconnection Service (ERIS) requests are not significantly faster to process than Network Resource Interconnection Service (NRIS) requests, though ERCOT requests are

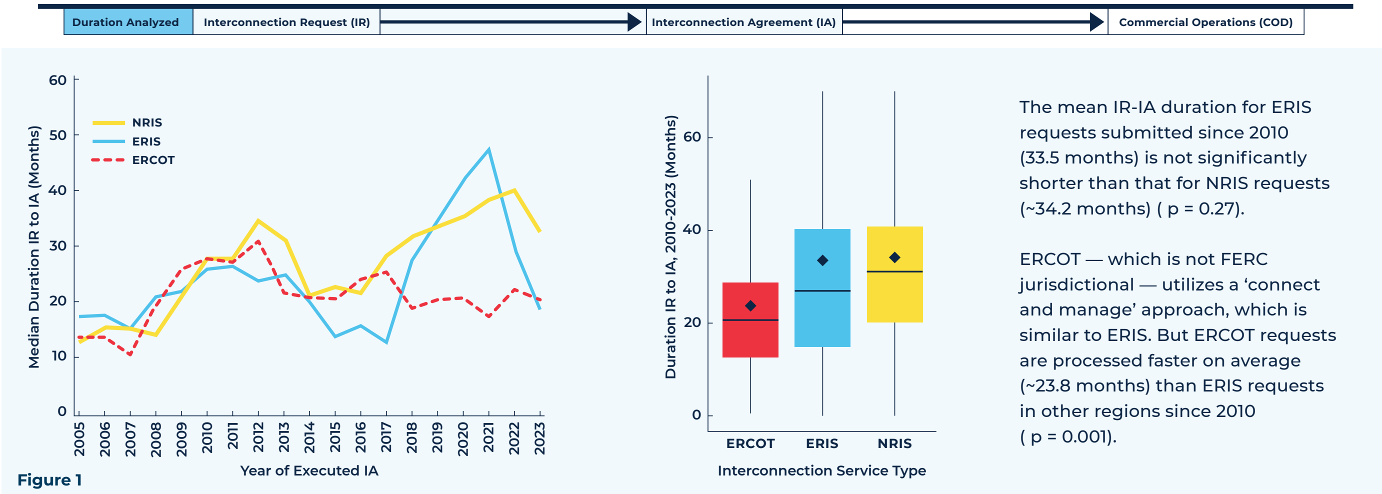


Figure 1: ERCOT requests are significantly faster to process by nearly two years. Source: Lawrence Berkeley National Laboratory[9]

FINDING #1 – PARTNERING ON MODELS FOR IMPROVED RESILIENCE

The resiliency of energy and manufacturing systems, especially with extreme weather events expected, is not included in predictive modeling. Industry, academia and national laboratories would benefit from collaboration on a standard 'resiliency index' to help identify the weakest links in the infrastructure value chain that are prime for investment.

Additionally, cyber security of the grid remains a concern. If all facilities are powered by the grid, the nation loses diversification of energy sources, making assets more vulnerable to attack. These problems are exacerbated when analysts fold in the anticipated increase in the number of data centers. The energy needs of data centers is very high,[10] expected to surpass 35 GW by 2030.[11]

RECOMMENDATION #1 – GULF COAST RESILIENCE

Resilience tools help model how infrastructure systems function under duress. Many tools have been released including the North American Energy Resilience Model (NAERM),[12] Technical Resilience Navigator,[13] and the Argonne Low-Carbon Electricity Analysis Framework.[14] A repository for multiple resilience models has been assembled here by the U.S. DOE.[15]

It is important to note that models can create new challenges while solving others. For instance, models may not translate well from one model to another. There may be differences in resolution times or timescale matching, and data may be needed from industry for higher resolution. Collaborative partnerships between industry, academia and national laboratories can ease some of these challenges.

National labs and academic institutions should jointly develop and test predictive, standardized models for resilience to stress-test assets virtually. Industry should validate and inform these models to guide investment in systems that can anticipate and respond to incidents – both national security related cyber threats and natural disasters. A joint advisory committee of national labs, academic institutions and industry would be an appropriate vehicle for this collaboration to develop models and ensure that they do not develop some of the common new problems discussed above in an effort to cure others.

PROCESS AND ENERGY INTEGRATION TO BUILD AT SCALE

Beyond the resiliency challenges above, there is a strong business need to remain globally competitive, especially in light of the growing demand for lower-carbon products. The region has an enormous capacity to permanently store carbon dioxide (CO_2) via geologic sequestration. According to a NETL Carbon Storage Atlas report, the combined capacity of Texas and Louisiana, including offshore capacity in the Gulf of Mexico, is over 2 trillion metric

[9] Queued Up: 2024 Edition; Lawrence Berkeley National Laboratory https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_R2.pdf
[10] AI is poised to drive 160% increase in data center power demand, Goldman Sachs, May 14 2024, https://www.goldmansachs.com/insights/articles/AI-poised-to-drive-160-increase-in-power-demand
[11] AI is poised to drive 160% increase in data center power demand, Goldman Sachs, May 14 2024, https://www.goldmansachs.com/insights/articles/AI-poised-to-drive-160-increase-in-power-demandi-driven-data-center-boom/
[12] U.S. Department of Energy, North American Energy Resilience Model, https://www.energy.gov/oe/north-american-energy-resilience-model-strengthen-power-system-planning
[13] U.S. Department of Energy Federal Energy Management Program, Technical Resilience Navigator, https://trn.pnnl.gov/
[14] U. S. Department of Energy, The Argonne Low-carbon Electricity Analysis Framework, https://www.anl.gov/esia/a-leaf
[15] U. S. Department of Energy, Argonne National Laboratory, Resilience Resources Gateway, https://resilience.anl.gov/

tons of CO_2.[16] Within the next two decades, the construction of CO_2 capture facilities and pipelines could enable sequestration for most of the two states' combined 400 million metric tons per year of industrial CO_2 emissions.[17] At present, there are about 160 pending Class VI well applications for Texas and Louisiana, each well with capacities near 1 million metric tons per year.[18]

Beyond carbon capture and sequestration, there are new opportunities to leverage CO_2 as a feedstock (utilization) and to reduce emissions through electrification including the increased integration of renewable energy. The potential for steady production of electrical and thermal energy, including high temperature heat, from modular nuclear reactors is well-matched with the needs of chemical manufacturing. For example, in 2023 Dow and X-Energy announced the selection of Dow's UCC Seadrift Operations manufacturing site in Texas for its proposed advanced small modular reactor nuclear project. The project is expected to provide the Seadrift Site with safe, reliable, zero-carbon-emissions power and steam, reducing the Seadrift Site's emissions by approximately 440,000 MT CO_2e/year.[19]

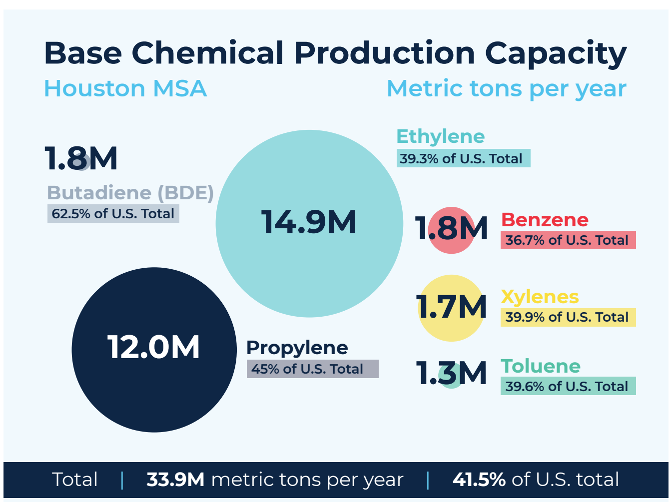
Accelerating the growth of lower-carbon products while maintaining resilient chemical plants with reliable and secure energy sources present several new challenges for energy and process integration in the chemical industry. There is a compelling need for innovation, collaboration, policies, and strategies and these were considered as the subjects of this workshop.

The world will continue to need more products made from base chemicals both as the global population grows and as emerging markets develop.[21] Population growth drives both greater demand for consumer and industrial goods, and greater energy demand for building and transportation sectors. As a result, competition for electricity among industry, buildings and transportation will continue to increase.

FINDING #2 – THE SCALE OF THE CHALLENGE IS VAST

Base chemical production is difficult to decarbonize due to the breadth and complexity of facilities and operations. Facilities are operated continuously year-round where any disruption in energy and materials supply can impact the productivity of other industries. The industry's scale demands significant energy to operate the factories, and with current technology, large tracts of land are needed. A significant amount of existing infrastructure is both aging and hard to retrofit for lower-carbon intensity. To switch to lower-carbon manufacturing at scale, new estimated capital is required at 2-3 times the value of the current invested infrastructure.[22]

Process electrification is an expected near-term solution for lower-carbon energy systems for base chemical production in limited and appropriate applications. Point-source CO_2 capture is also proven and essential, yet nascent. Biomass and other renewables are promising but also include challenges with matching feedstocks and a product's long development time. Waste heat allows for synergies in productivity but also requires process optimization and added infrastructure costs.



Source: CAS Registry via IHS Markit, June 2024

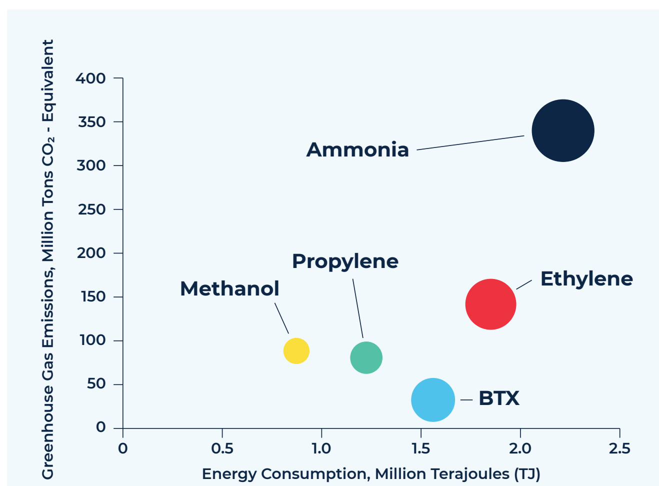


Figure 2

Figure 2. Energy consumption and greenhouse gas (GHG) emissions of base chemicals, which include ammonia, ethylene, propylene, methanol, and aromatics — benzene, toluene, and xylene (BTX). The sizes of the bubbles shown above are relative to production volume.[20]

[16] Hills, D. J.; Pashin, J. C. *Task 15–NATCARB Atlas Update–CO2 Sequestration Capacity Offshore Eastern Gulf of Mexico (SECARB CO2 Capacity Assessment for Delineated State Waters);* Southern States Energy Board, Peachtree Corners, GA (United States): **2021**.
[17] U.S. Energy Information Administration, *Energy-Related CO2 Emission Data Tables*, Oct 29. **2024**, https://www.eia.gov/environment/emissions/state/
[18] U.S. Environmental Protection Agency, *Underground Injection Control Class VI Permit Tracker,* April. **2025**, https://www.epa.gov/uic/current-class-vi-projects-under-review-epa
[19] X Energy, *Advanced Nuclear Reactor Project in Seadrift, Texas,* https://x-energy.com/seadrift
[20] Schiffer, Z. J., and K. Manthiram, "Electrification and Decarbonization of the Chemical Industry," Joule, 10, 2017. Figure from CEP "Decarbonizing the Basic Chemicals Industry Using Sustainable Finance", March 2024, https://www.aiche.org/resources/publications/cep/2024/march/decarbonizing-basic-chemicals-industry-using-sustainable-finance
[21] Chief Investment Officer, *"What Science Tells Us About Investing in the Energy Transition"*. Feb **2024** https://www.ai-cio.com/news/what-science-tells-us-about-investing-in-the-energy-transition
[22] International Energy Agency, *The Future of Petrochemicals,* **2018**. https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf

Several challenges with regards to process integration, including space and the scale of process electrification were discussed. Capital cost, competition for electricity, integration into existing assets, land and water were all identified as challenges that need to be addressed.

While there is a significant amount of available land for industrial development in the Gulf Coast region, co-locating new energy infrastructure to serve existing industrial sites has challenges. Land in desired locations may not be available or readily acquired.

RECOMMENDATION #2 – IMPROVED ENERGY AND PROCESS INTEGRATION

Companies must often assess different approaches to resiliency, efficiency and lower-carbon intensity operations, such as hydrocarbon fuel replacement with low-carbon intensity hydrogen or nuclear energy. National labs, academic institutions and industry should advance electrification, point-source carbon capture, and renewable energy integration by utilizing public, standard models that allow users to compare industrial processes. These models should be built by national labs and academic institutions with input from industry and include public, transparent assumptions to allow for ease of comparing multiple processes and technologies. A first step is for a representative working group of industry, academia and national labs to review existing process integration models, identify gaps and needs for further access and data analysis.

Existing national-lab-developed models for review include the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model, the Jobs and Economic Development Impact (JEDI), and the Demand Resources Energy Analysis Models (DREAM). Comprehensive system-of-systems modeling efforts through collaborative data sharing is an immediate opportunity.

While the public electrical grid, especially in the Gulf Coast region, has been detailed with fine precision, a unique opportunity to build, share and use a detailed model through a working group of industry, academia and national labs exists for the natural gas and base chemicals network in the Gulf Coast. Such a model could significantly address resilience and supply-chain security and further develop opportunities for synergizing lower-carbon initiatives especially those focused on carbon emissions reduction and use of alternate fuels, lower-carbon intensity hydrogen, nuclear energy and waste heat.

COHESIVE ECONOMICS AMIDST A LACK OF COMMON DATA AND CONSUMER UNDERSTANDING

The workshop participants discussed three main challenges related to 'standards.' The first is that there is no standardized global database or cost model to drive adoption of new technology. There is not a common source to determine levelized costs of abatement for various technologies. There is no standardized dataset or collaborative test bed that combines resources across power, water and chemical production using a system of systems approach.

The second challenge is that consumers generally do not understand the carbon intensity of their product choices. The energy consumption in and carbon intensity of consumer products made from base chemicals are less visible than those of the transportation industry. More transparent carbon accounting could help.

The third challenge is that emerging technologies, policies and regulations tend to develop concurrently and there is a lack of policy and regulatory certainty. These three challenges all tax the ability of investors and operators to manage project economics to commercial viability.

Upcoming tariffs, such as the European Union's Carbon Border Adjustment Mechanism (CBAM),[23] pose a substantial threat to the competitiveness of the U.S. chemical industry in international markets. Maintaining market access necessitates a multifaceted strategy. Directly mitigating the impacts of CBAM requires a significant reduction in carbon emissions.

Effective compliance with CBAM and similar tariffs demands thorough understanding and preparation. This includes developing robust and transparent systems for precisely tracking and reporting GHG emissions throughout the entire supply chain, a critical component for accurately calculating CBAM payments and ensuring full compliance. Moreover, close collaboration with suppliers to guarantee their products meet CBAM requirements is essential, highlighting the importance of supply chain transparency and collaboration for successful compliance.

Active engagement with policymakers is also critical. This involves participating in negotiations to ensure a fair and equitable CBAM design and implementation, potentially working through industry associations to advocate for needed adjustments to the CBAM and respond with similar tariffs applied to products imported from Europe and other sources. Simultaneously, advocating for supportive domestic policies is essential, including incentives such as tax credits and grants to foster the development and deployment of lower-carbon technologies within the U.S. chemical industry.

FINDING #3 – COMPETITION PREVENTS COLLABORATION

The lack of standards can influence how the industry behaves. The industry must balance risk management and competitive interests. Being a fast adopter can be more appealing than being a first-of-a-kind deployment in an uncertain environment that incurs more cost and risk. Additionally, protecting a competitive advantage limits knowledge sharing between companies and industry, academia and national laboratories, where intellectual property ownership takes time to come to agreement.

In addition, the analysis of technology options is siloed where different organizations have different views of the whole system but are not motivated to share information. There can be an absence of a holistic analysis for emerging technologies.

There can be a sentiment that people working in national labs and academia do not understand the scale constraints and real-world challenges that industry faces, further inhibiting collaboration.

[23] European Commission, *"Carbon Border Adjustment Mechanism (CBAM)"*, **2023**, https://trade.ec.europa.eu/access-to-markets/en/news/carbon-border-adjustment-mechanism-cbam

RECOMMENDATION #3 – COLLABORATION FOR IMPROVEMENTS TO LOW-CARBON SOLUTIONS ECONOMICS

While the immediacy of a domestic need for standardizing and implementing measurement and verification of carbon intensity is likely to be absent, potential measures stemming from global trade and implementation of border adjustments for carbon intensity are likely to spur the development of carbon intensity evaluations for the U.S. Gulf Coast chemicals industry.

National labs and academic institutions should develop a transparent carbon accounting methodology that industry would inform and validate to promote awareness of carbon intensity to foster consumers' willingness to pay for lower-carbon-intensity products and compliance with emerging carbon border adjustment mechanisms. Development of a business-focused, transparent carbon accounting methodology that effectively communicates to consumers and decision makers the choices associated with their chemical products is an opportunity for the Gulf Coast to lead. A first step is for a representative working group of industry, academia and national labs to audit existing carbon accounting methods, identify gaps and needs for greater transparency.

FINDING #4 – ENABLING THE GROWTH OF EMERGING TECHNOLOGIES

The Gulf Coast, with its significant base chemicals industry, has a broad range of solutions that can be integrated in the short term and several emerging technologies that in the longer term can lower-carbon intensity and increase resilience.

There are complementary resources available across national laboratories, the Gulf Coast academic institutions and industry to drive the sustainable growth of the base chemicals industry. Engaging the three groups in meaningful collaborations through a framework such as a consortium to promote collaborative modeling especially for resilience and enhanced data sharing is an immediate opportunity.

The Gulf Coast base chemicals industry has many existing facilities that could be repurposed to create shared pre-pilot scale assets to deploy the fundamental science capabilities of national labs to test the integration of emerging, scalable materials manufacturing technologies. There is a lack of intermediate scale (between lab and full pilot volume) facilities with open access to support chemical companies that do not operate their own facilities due to the specialized nature of the equipment.

These proposed shared manufacturing facilities could also underpin the development of consortia of industry partners, national labs, and academic institutions under a joint development agreement (JDA). Such JDAs are commonplace in the upstream energy industry where there is a need for de-risking of complex projects to advance the next projects through the innovation pipeline. The impending retirement of aging chemicals and refining assets provides a timely and cost-effective opportunity to repurpose them to expand the unique fundamental science capabilities of the national labs, such as Argonne's Materials Engineering Research Facility (MERF) which partners with industry to derisk scale-up of innovative energy materials so they can be commercialized sooner. Financial support from the Department of Energy to transfer assets to national labs could spur engaged reconsideration for end-of-life decisions for the industry in the Gulf Coast.

RECOMMENDATION #4 – PRE-PILOT SCALE ASSET DEVELOPMENT

National labs and academic institutions should help industry develop pathways to scale lower-carbon hydrogen and small modular nuclear infrastructure, leverage artificial intelligence (AI) and machine learning (ML), and establish pre-pilot scale assets as a national lab-operated and shared resource leveraging fundamental science to validate manufacturing processes for commercializing innovations. A first step is to conduct a series of interviews of companies' pre-competitive needs, laboratory and academic research as well as a review of existing assets in the Gulf Coast to identify and act upon shared resource needs. The Greater Houston Partnership is prepared to lead this effort based on its existing relationships within the Gulf Coast innovation ecosystem, academia and national laboratories.

OTHER OPPORTUNITIES FOR JOINT DEVELOPMENT AGREEMENTS

Artificial intelligence (AI) has the potential to play a transformative role in the decarbonization of the chemical industry within the U.S. Gulf Coast region, operating through various critical pathways that enhance sustainability and operational efficiency.

AI can enhance process design and simulation, process optimization, predictive maintenance, supply chain management, discovery of advanced materials, carbon capture efficiency and emissions monitoring and reduction. These capabilities could improve compliance efforts with environmental regulations and reduce overall carbon output associated with chemical manufacturing on the Gulf Coast.

The Gulf Coast is also the world's leader in the hydrogen economy with over half of the nation's and one-third of the global capacity for hydrogen pipelines and more than one-third of the already existing hydrogen production in the nation. With federal and industry support, the region has an opportunity to lower the carbon-intensity of this existing hydrogen production. The region has substantial salt cavern storage capacity and the experience to safely store lower-carbon hydrogen subsurface,[24] expanding the use of lower-carbon hydrogen for fuel applications as well as for products such as sustainable aviation fuels and lower-carbon methanol.

Several new and emerging technologies such as the use of plasma and microwave, the electrification of processes especially for low and medium heat applications, lowering the cost and environmental impact of capturing CO_2, the integration of advanced geothermal and nuclear heat and electricity – focused on fission (through advanced nuclear and small modular reactors) in the short-term and focused on fusion in the long-term – are all significant opportunities for the Gulf Coast industry to lead. The integration of variable renewable energy into the production

[24] Leopoldo M. Ruiz Maraggi, and Lorena G. Moscardelli, *"Hydrogen storage potential of salt domes in the Gulf Coast of the United States"*, Journal of Energy Storage, 82, 110585, **2024**.
https://starr.beg.utexas.edu/sites/default/files/content/digital-tools/RM_M2024.pdf

of lower-carbon base chemicals requires rapid advancement of energy storage including electrochemical, chemical, and thermal storage.

Product suites to consider for JDAs include the manufacture of methanol from CO_2, the development of polymers using CO_2 as feedstock, and development of membrane technologies for gas separation including point-source carbon capture. Recycled plastics require advances in technology development for chemical deconstruction and for the entire value chain of collection, sorting, cleaning, and transportation to reduce costs and emissions associated. Scaled use of biomass to produce chemicals and fuels remains an important opportunity for Gulf Coast industry to consider and can significantly benefit from the expertise at national labs and the possibility of repurposing of brown-field equipment rather than new build.

Nuclear energy can significantly improve the efficiency and sustainability of various chemical processes in several ways. For example, nuclear reactors can provide a stable and high-temperature heat source essential for numerous chemical operations. This capability is especially beneficial for thermal processes such as distillation and chemical synthesis, which are energy intensive.

These and other technologies are examples of potential candidates for joint development agreements between the Gulf Coast base chemicals industry, Gulf Coast academic institutions, and the U.S. national laboratories.

NEXT STEPS

The increasing integration and collaboration of national laboratories with the Gulf Coast industry and academic institutions is crucial for the growth of a more resilient, secure and economically viable low-carbon base chemical infrastructure. The region has the potential to become the global leader in advanced chemical manufacturing technologies and low-carbon energy systems spurring several decades of strong economic and job growth.

The group of workshop participants agreed to continue to convene the national labs, academia and industry. Future topics may include materials circularity, membranes and separations and sharing lessons learned from successful demonstration projects. By collectively facilitating and analyzing large-scale demonstrations, this ecosystem can build a system of systems approach to the shared challenge of a value-added, lower-carbon supply chain. Future collaborations should focus on developing shared pre-pilot-scale assets with national labs, and shared models for driving the chemical manufacturing sector to a more secure, resilient and prosperous future. The Greater Houston Partnership will continue to serve as the convener for these discussions and will immediately advance the process of conducting a series of interviews of companies' pre-competitive needs, laboratory and academic research as well as a review of existing assets in the Gulf Coast to identify and act upon shared pre-pilot scale asset needs in the Gulf Coast base chemicals industry.

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