CLEARPATH

State of Play:
The Chemical and Refining Sectors

April 2025

Executive Summary

A 35% increase in demand for chemicals is expected globally by 2050. This is an exciting time for the American industrial base, with many opportunities to simultaneously drive down the cost of innovative technologies and to scale and deploy energy innovation. Several private companies have announced commitments to invest in hydrogen, advanced nuclear and carbon capture, utilization and storage (CCUS) technologies. Reducing the cost of these technologies will enhance America's position as a leader in energy and strengthen our manufacturing base, helping us overtake China as the largest exporter in the chemical and refining sectors. Investing in these innovative American technologies will increase the supply of key products that Americans use in their everyday lives, all while ensuring they are made cleaner.

Chemical production and refining are essential for producing fuels for power, heat and transportation. They also serve as vital inputs for a wide array of products, such as plastics, fertilizers, and pharmaceuticals, all of which are crucial to modern life.

This report aims to:

1. Identify the energy technologies that are most applicable to the future of American chemicals and refining.
2. Demonstrate the U.S.' competitive advantage in the chemical and refining sectors, which are not only cleaner than our competitors', but also have domestic growth opportunities.
3. Illustrate the significant contribution of these sectors to the U.S. Gross Domestic Product (GDP) and export competitiveness.
4. Outline policy recommendations to further the development and adoption of clean, innovative chemical production and refining technologies.

The best energy policy is to return American manufacturing to the U.S. where we have the highest environmental standards. This can be done by:

1. Reauthorizing the Clean Industrial Technology Act, with the inclusion of a dedicated research, development and demonstration (RD&D) initiative at the Department of Energy, which is essential for identifying and commercializing innovative American technologies. These technologies will provide cost-effective and clean solutions for industries, strengthen American manufacturers' competitive advantage and continue their steady contribution to U.S. GDP.
2. Bolstering the Section 9003 Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program, which is essential because the chemical and refining sectors account for 5% of global emissions, and alternative feedstocks like biomass are a key lever.

By investing in clean, cost-competitive and reliable technologies, the U.S. can ensure the continued growth and viability of the chemical and refining sectors to meet rising consumer demand for chemicals, while also advancing energy dominance goals by accelerating energy innovation to lower emissions.

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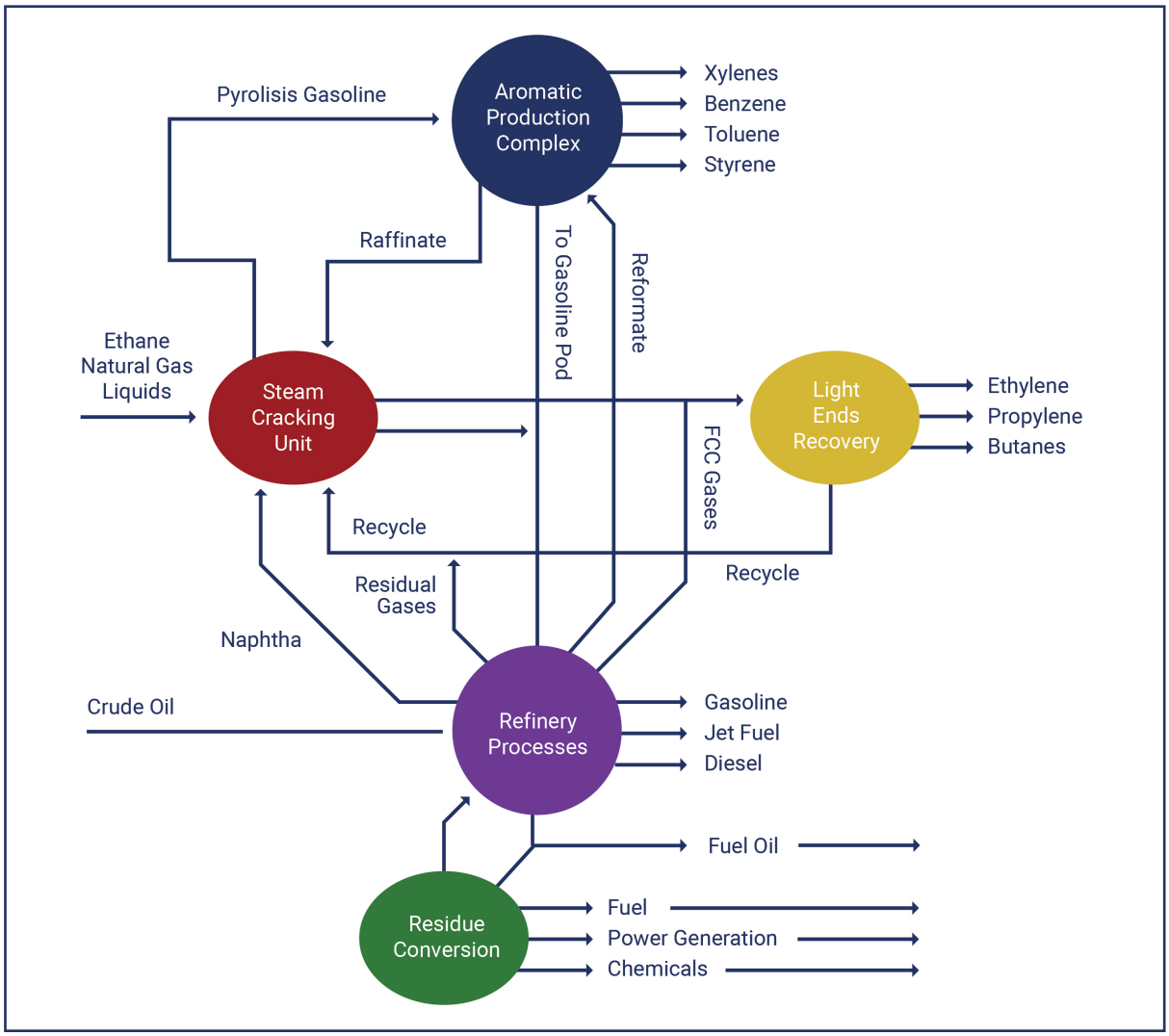
The Role of the Chemical and Refining Sectors in Emissions

A 35% increase in demand for chemicals is expected globally by 2050. This is an exciting time for the American The chemical and refining industries are the backbone of American manufacturing, with 96% of all manufactured goods involving products from these sectors.[1] These industries produce primary fuels for power, transportation and heat, while also providing essential inputs for widely used downstream products. Common household items like clothing, food containers, cars and TVs are all made with products from the chemical and refining sectors. As demand for these products increases, America must lead in developing clean, innovative solutions to decouple this demand from rising emissions. Projections indicate that emissions from chemical production and refining could rise by approximately 20% by 2050, driven by a 35% increase in demand.[2]

The largest sources of emissions in the refining sector are stationary fuel combustion units such as steam boilers and process emissions from catalytic cracking, reforming, flares, sulfur recovery plants and more.[3] The refining sector produces a wide variety of products, including gasoline, jet fuel and bitumen.[4] Additionally, the refining sector produces feedstocks for the production of chemicals, like naphtha. Across the U.S., many facilities integrate refineries with chemical production facilities to improve efficiency.



Source: Dr. Marcio Wagner da Silva, MBA

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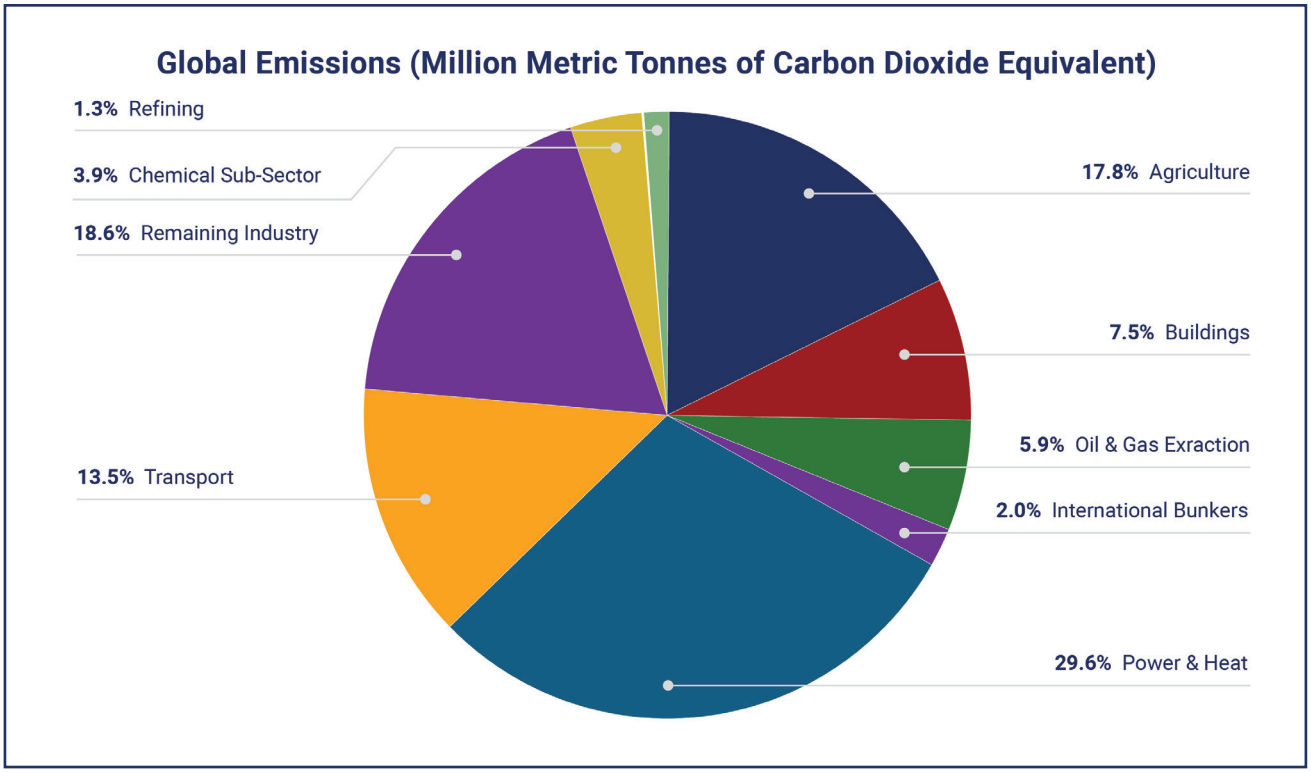
The primary sources of emissions in the chemical sector are the combustion of fossil fuels for industrial heat, process emissions and the use of electricity. Within the domestic chemicals sector, the production of ammonia, hydrogen and petrochemicals accounts for more than 75% of total emissions.[5]

Ammonia is a key input for nitrogenous fertilizers used in agricultural production.[6] Emissions from ammonia production increased by 39% from 2011 to 2021, largely due to the growth in the number of ammonia facilities. Ammonia is produced by combining nitrogen from the air and hydrogen through the Haber-Bosch process.[7] Approximately 70% of the ammonia produced is used for agricultural fertilizers.

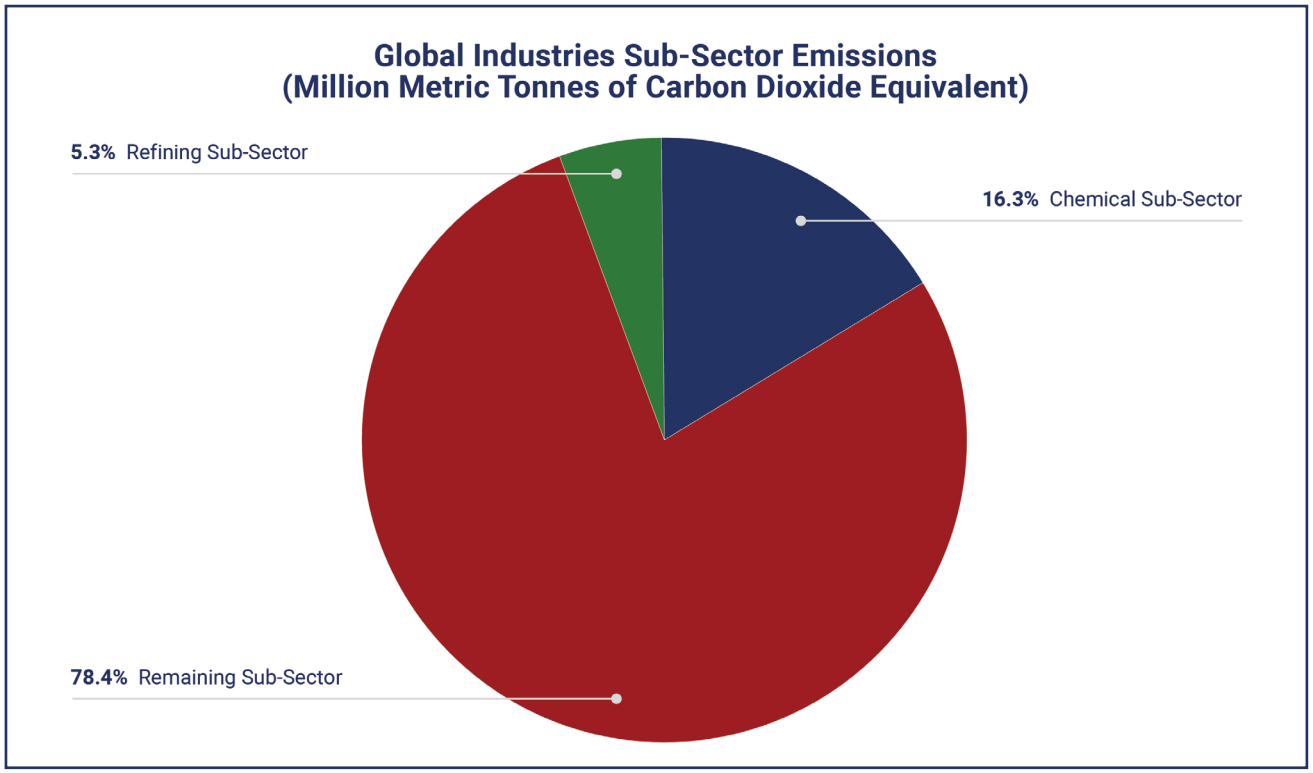
Petrochemical production emissions increased by 20% from 2011 to 2021, largely due to the increased number of petrochemical plants coming online.[8] This increase in production capacity was primarily driven by lower natural gas prices and a rise in demand for products that use petrochemicals (e.g., smartphones, medical equipment, toiletries). Petrochemical production creates emissions mainly from industrial heat, process emissions and electricity consumption.

Global Emissions from the Chemical and Refining Sectors

The industrial sector accounted for 24% of global emissions in 2021. The chemical and refining sectors contributed 5% of total global emissions, with the chemical sub-sector responsible for 4% and the refining sub-sector for 1%.[9] Within the industrial sector, the chemical and refining sector accounted for 22% of global emissions.



Data Source: Rhodium Group



Data Source: Rhodium Group

Technological Innovations for Clean Chemicals and Refining

Leading companies in the sector have identified innovative clean energy technologies such as hydrogen, nuclear power, carbon capture, utilization, and storage (CCUS), and low-emissions feedstocks (e.g., biomass, recycling) as potential pathways for reducing emissions and boosting America's competitive advantage. Major industry players have set emissions reduction goals and are working to demonstrate and deploy American technologies. For example, Dow, a major chemical company, reduced its carbon emissions by 15% between 2005 and 2020 while increasing the volume of manufactured products by 30%. Dow remains committed to achieving carbon neutrality and reducing Scope 1, 2, and 3 emissions by 2050.[10] ExxonMobil also intends to invest over $20 billion in low-carbon projects by 2027, marking the third increase in the past three years, up from an initial $3 billion in early 2021.[11]

Hydrogen

Today, 89% of all U.S. hydrogen production is used by petroleum refiners and nitrogenous fertilizer producers. However, affordable, widely available clean hydrogen is needed to replace the chemical and refining sector's demand for conventional hydrogen as low-carbon fuel and feedstock. Full adoption of clean hydrogen in ammonia production and significant uptake in refining is needed to decarbonize, with at least 7–8 million metric tonnes (MMT) of clean hydrogen per year by 2050. This is an increase of roughly 50% from expected levels in 2030.[12] To meet these levels, the cost-competitiveness of clean hydrogen must improve through advancing policies that further expand and decrease the cost of midstream and end-use infrastructure while supporting reliable offtake for hydrogen producers beyond 45V, the hydrogen production tax credit.

Nuclear

Many chemical processes require heat or steam with high-reliability factors, meaning they require high uptime and load factors. Nuclear energy can cleanly, affordably and reliably provide these inputs at the megawatt and gigawatt scales. Dow is building four high-temperature gas reactors in Seadrift, Texas, with X-energy, a developer of advanced small modular nuclear reactors. The Dow and X-energy project is expected to reduce the Seadrift site's emissions by approximately 440,000 MT CO2 equivalent per year.

Carbon Management

Carbon capture, utilization and storage (CCUS) for pure and dilute CO2 streams is an essential emissions reduction lever for the chemical and refining sectors. Significant scale-up is needed in the transport and storage of carbon dioxide and further research and development (R&D) of CCUS for dilute streams is required. ExxonMobil's Baytown refining and petrochemical facilities are partnering with Honeywell to install a CCUS project on the site capable of storing up to 10 MMT of CO2 per year and capturing 7 MMT of CO2 annually. This will result in a reduction of site-wide CO2 emissions by up to 30% compared to current operations.[13]
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Additionally, low-emissions biomass, waste, and captured CO2 feedstocks (i.e., forest residues, agricultural wastes, municipal solid wastes, recycled materials, etc.) can play an important role in decarbonizing the chemicals sector. The Department of Energy (DOE) Clean Fuels & Products Shot aims to source 50% of carbon-based chemicals from alternative carbon resources and anticipates that by 2050, there will be 1,050 MMT of biomass and waste and 450 MMT of CO2 resources as feedstocks to produce more than 400 MMT of fuels and chemicals. If this shot is successful, more than 650 MMT of CO2e emissions per year could be eliminated.[14] Another pathway to reducing emissions is recycling, also known as circularity. Recycling in this context means that plastic waste is reused as feedstocks for chemical processes, which reduces the need for virgin plastic – plastic produced for the first time – and displaces the need for other chemicals and fuels. There are multiple types of advanced recycling processes, with the main ones being mechanical, pyrolytic, and chemical recycling. Mechanical recycling reprocesses plastic by melting and can reduce production emissions by as much as 75%; however, the output material can have degraded material properties. Pyrolytic recycling is the thermal decomposition of materials in a low-oxygen environment and can increase overall production emissions by up to one-quarter. However, it generates a higher-quality alternative product. Chemical recycling processes like methanolysis are still in development and can potentially yield plastics with properties comparable to virgin plastics. Since 2017, companies from across the U.S. have announced 40 new projects in advanced recycling and recovery valued at over $7 billion with the potential to divert nearly nine MMT of waste from landfills per year.[15] Demonstration scale projects of methanolysis are underway and have the potential to make resins with recycled content that is 20-30% less emissions intensive than using virgin feedstocks.

Economic Impact

The chemical sector is an essential economic driver for the U.S. Federal engagement for research, development, demonstration and deployment should be bolstered and streamlined to maximize American innovation to maintain and grow the U.S.' competitive edge against geopolitical adversaries like China. Chemical manufacturing in the U.S. has seen steady growth in its contribution to GDP since the 1990s.[16] In 2023, it accounted for 1.9% of the nation's total GDP. Over the past 15 years, its share has remained relatively stable, peaking at 2% in 1997 and reaching a low of 1.7% in 2005.

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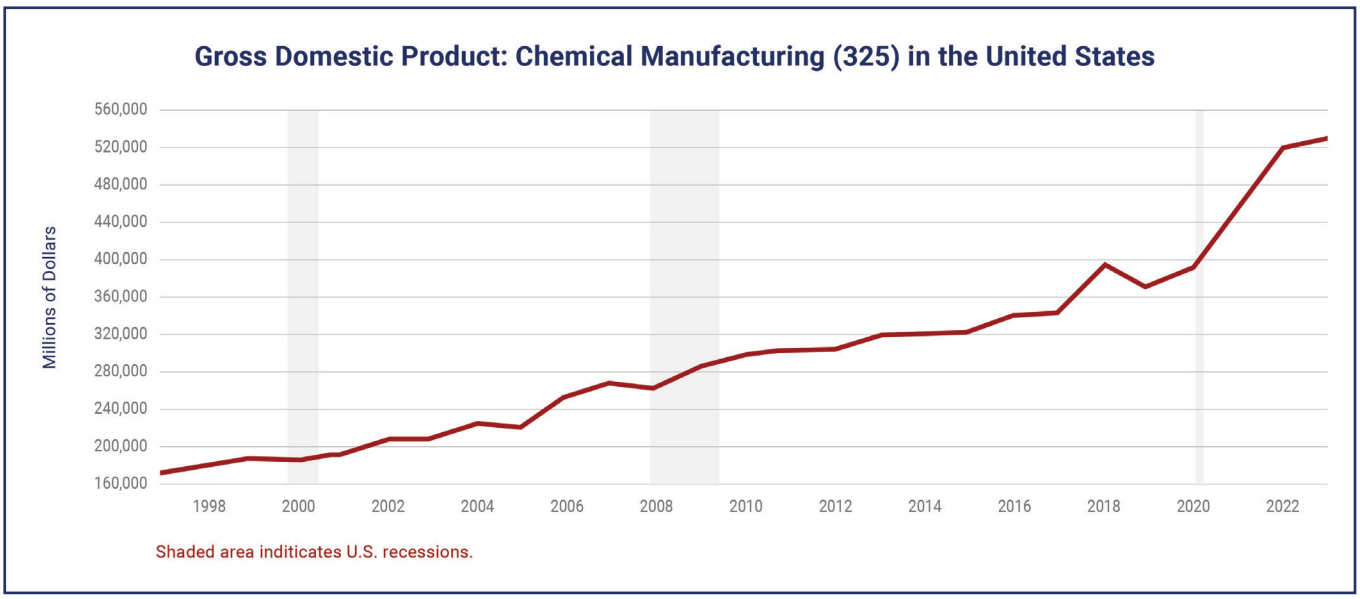


Source: FRED, U.S. Bureau of Economic Analysis

In 2023, the total domestic employment from the chemicals and refining sectors was approximately 1.9 million jobs made up of 918,000 chemicals manufacturing workers, 101,000 petroleum manufacturing workers and 751,000 plastics manufacturing workers. Additionally, the DOE anticipates that the chemical and refining industries' emissions reduction goals could create approximately 5.5 million job-years through direct and indirect jobs through 2050.[17]

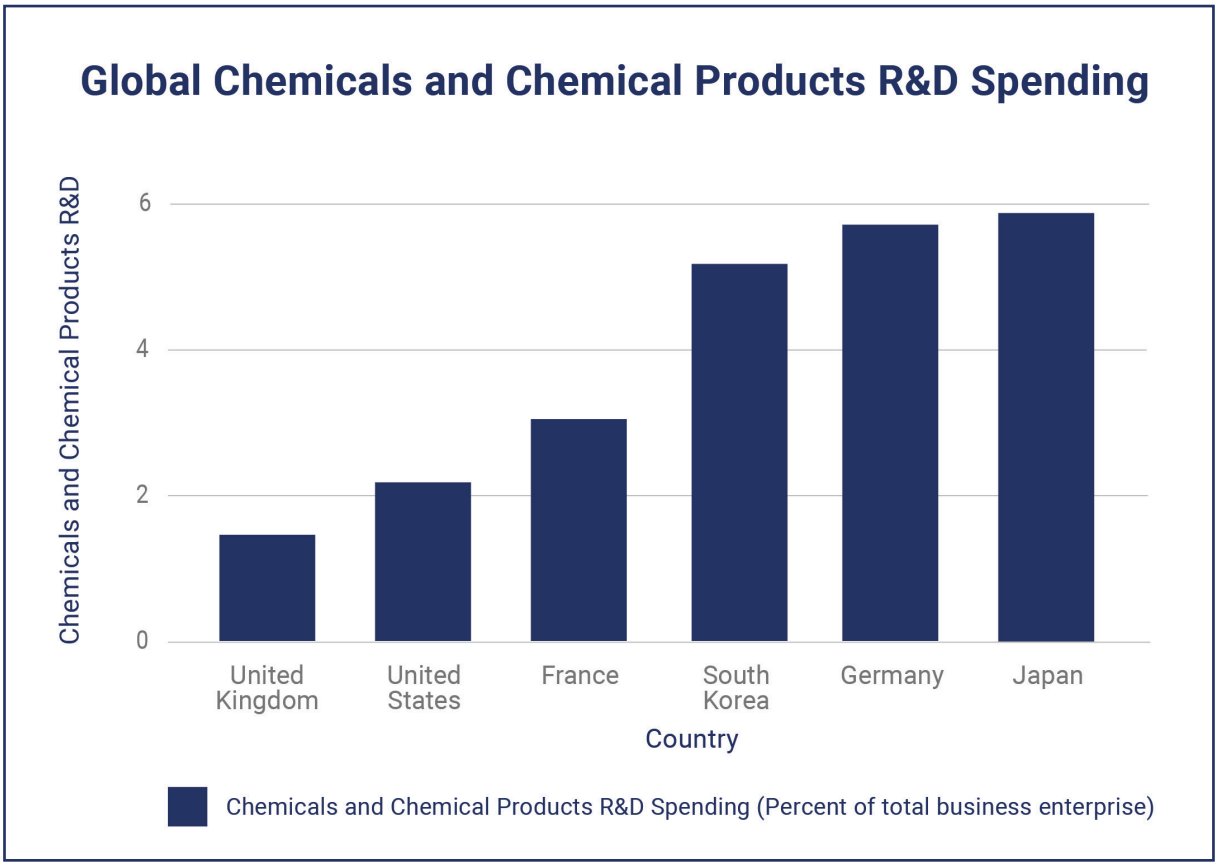
As demand for clean energy technologies continues to grow domestically and internationally, the chemical and refining sectors will play an important role in supplying components. U.S. chemical manufacturers produce materials used in batteries, hydrogen fuel cells and electrolyzers, small modular nuclear reactors and carbon capture, utilization and storage.

American Competitiveness for Global Chemical Exports

The U.S. is the second largest chemical manufacturer globally.[18] In 2023, the U.S. exported $159 billion and imported $213 billion in chemicals and related products.[19] Chemicals and related products account for 8% of U.S. goods exports and 7% of U.S. goods imports in 2023. The U.S. is the second-largest goods exporter and the largest goods importer globally. As of 2022, goods exports comprise 70% of total U.S. exports[20], with chemicals and related products representing roughly 5.5% of total U.S. exports.

The top 10 domestic export markets for the chemical and refining sector are Canada, Mexico, China, Belgium, Japan, the Netherlands, Germany, Brazil, South Korea and the United Kingdom.[21] Notably, these markets overlap significantly with regions that the International Energy Agency (IEA) predicts will contribute substantially to total global emissions.[22] Most of these countries are key partners and allies of the U.S. Furthermore, U.S. allies and trading partners are implementing demand signals toward lower-emissions products. For example, the European Union has implemented a carbon border adjustment that will cover fertilizers (i.e., ammonia) starting in 2026 and also has the registration, evaluation, authorization and restriction of chemicals (REACH) law to encourage the production of cleaner chemicals. This presents an opportunity for the U.S. to collaborate with its allies to continue exporting clean chemical products and innovative technologies designed to reduce emissions. Additionally, upgrading domestic capacity ensures these products will be manufactured in the U.S. instead of China, where environmental standards are weaker.

The Need for More R&D



Data Source: U.S. National Science Foundation

While the private sector has identified and committed to using these cutting-edge technologies, the U.S. is lagging behind other major players in research and development spending, especially China. By 2018, China spent around $24 billion annually on chemicals R&D, more than double that of American investments.[23] The U.S. is the second largest exporter of chemicals behind China.

The chemical sector is a significant contributor to U.S. exports and economic growth. However, U.S. companies' R&D investments lag at 2.2% of revenue compared to chemical manufacturers in other countries, including Germany (5.8%), Japan (5.9%), and China (6.6%). In other words, the U.S. ($9.5 billion invested) has invested $14.5 billion less than China ($24 billion invested) in R&D.[24] Further R&D investments are needed to keep American suppliers competitive against the Chinese for the forecasted increase in demand from sectors like household appliances to newer sectors like clean energy.

Federal Investments in Clean Chemical Production and Refining

The federal government engages in reducing emissions from the chemical and refining sub-sectors mainly through DOE. The Department of Defense (DoD) and the Department of Agriculture (USDA) also oversee programs that have the potential to reduce emissions from chemical production. Lanzatech, an innovative company pioneering biorefining and based out of Illinois, won an Advanced Research Projects Agency-Energy (ARPA-E) grant to convert waste CO2 into ethanol in 2021. Now, the company has five commercial-scale facilities that combined are abating approximately 515,000 MT of CO2 per year.[25]

While the existing programs are a step in the right direction, further federal engagement is needed. The DOE is doing this for other sub-sectors, like steel, cement and concrete, by investing in R&D. There is a high-impact opportunity for DOE to do the same with the chemical and refining sub-sectors. For example, in the $6.3 billion Industrial Demonstration Program (IDP) awards, which were established in the Energy Act of 2020, only one-sixth of the funds went towards the chemical and refining sub-sectors despite those sectors making up over a third of U.S. industrial emissions.[26] With further rounds of the IDP, targeted R&D funding can support innovative technologies for chemical manufacturing and refining.

The DOE, DoD and the USDA are all engaged in R&D programs that could help lower emissions from the chemical and refining sectors. Engagement at DOE spans from foundational research to demonstration projects. The DoD is mainly focused on foundational research. USDA hosts a loan guarantee program for biobased chemicals and refineries, as well as a labeling program for biobased products. See Table 1 in the appendix for a further breakdown of federal engagement and resources reducing emissions from refining and chemical production.

Policy Recommendations

While the federal government is investing in the chemical and refining sectors, there are opportunities to streamline efforts and provide targeted support to innovative American technologies. Technologies to reduce emissions from these sectors today are not affordable or widely adopted. Furthermore, breakthrough technologies that are in the early stages of R&D or not conceptualized yet are expected to be key solutions.

Reauthorize the Clean Industrial Technology Act

The manufacturing sector is expected to be America's top source of emissions by 2035, with the chemical and refining sectors making up over one-third of those emissions, expected to rise due to increasing demand. American R&D spending in the chemical and refining sectors is lagging behind global competitors like China and jeopardizing the U.S.'s potential for export growth.

The Clean Industrial Technology Act (CITA) was enacted into law in the Energy Act of 2020.[27] CITA provides direction for the DOE and federal investment in reducing emissions from the nonpower industrial sector through a competitive grant program. The Industrial Demonstrations Program (IDP) discussed above was created by CITA.

Congress can enhance the current program by improving research, development, and demonstration (RD&D) coordination for previously selected federal RD&D projects, including refining as a focus area, and providing targeted RD&D support for the chemical and refining sectors. Furthermore, Congress could reauthorize the IDP, which has invested in the competitiveness of America's manufacturing base, by continuing its funding profile through fiscal year 2025.

Reauthorizing this program, with updates to reflect President Trump's energy dominance agenda, will enable targeted investment with clear goals to unleash private investment and advance American manufacturing competitiveness.

Bolster the Farm Bill's Section 9003 Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program

The Section 9003 Program aims to solidify America as a leading manufacturer of advanced biofuels, renewable chemicals, and biobased products. The Section 9003 Program spurs innovation deployment in the bioproduct sector, through low-interest loan guarantees for the development, construction, and retrofitting of commercial-scale biorefineries and biobased product manufacturing facilities with new and emerging technologies. Facilitating the deployment of these technologies creates economic opportunities for America's rural communities and creates new markets for biobased feedstocks. This program can be modernized to reflect recent innovations and secure investments in the rural economy. Therefore, the Section 9003 program can be amended to:

- **Restore the pilot and demonstration-scale facility development grant program.** In conjunction with the loan guarantee program, USDA can offer grants to reduce risks associated with nascent technologies.
- **Include emissions reduction as a selection criterion.** Currently, the USDA must consider whether the applicant will have a positive impact on resource conservation, public health, and the environment, but does not specify reducing emissions as a positive impact.[28]
- **Specify obligated funds.** Since 2008, Section 9003 has seen a reduction in mandatory Farm Bill funding. The 2008 Farm Bill provided $320 million, $200 million in 2014 and $75 million in 2018. Specifying obligated funds is needed to reap the potential benefits of biomanufacturing.

Strengthening this program will unlock investment in biomanufacturing for chemical manufacturing and refining by reducing risks associated with early-stage technologies.

Conclusion

The chemical and refining sub-sectors are integral to the U.S. economy, accounting for a significant share of both exports and GDP. These industries are essential drivers of economic growth and are responsible for the products and materials that make modern life possible for the American people. They provide materials for various sectors, from manufacturing to agriculture, and support millions of jobs across the country. Without the chemical and refining industries, smartphones, modern medical equipment, clean energy technologies and so much more would not be possible. However, alongside their economic contributions, these sectors are also major sources of emissions.

To solve the global climate challenge, we need to bring manufacturing back to the U.S., where our environmental standards are better than in China. The federal government has a critical role to play by fostering innovation within the chemical and refining sub-sectors. By increasing support for R&D, the government can help develop efficient and affordable technologies that not only address the challenges of reducing emissions but also strengthen America's competitive position in the global market. Such investments could lead to breakthroughs in clean production processes and energy-efficient technologies, advancements that would both reduce emissions and bolster the long-term competitiveness of the U.S. chemical and refining industries.

Appendix

Table 1. Federal Engagement and Resources Supporting Clean Chemical Production and Refining

Agency	Program	Description
Department of Energy		
Bioenergy Technology Office (BETO)	Clean Fuels & Products Shot	The program aims to advance cost-effective technologies with a minimum of 85% lower GHG emissions by 2035. By 2050, the Shot aims to use sustainable carbon resources for 50% of carbon-based chemicals.
Office of Fossil Energy and Carbon Management (FECM)	Carbon Conversion Program	The program invests in the RD&D of technologies that convert captured carbon oxides into valuable products like chemicals.[29]
Industrial Efficiency & Decarbonization Office (IEDO)	Energy- and Emissions-Intensive Industries Program	The program includes a Chemical and Petrochemical Manufacturing research topic, which is focused on 'Sustainable Chemistry,' meaning designing and developing chemicals that have lower energy consumption and emissions, are less toxic to humans and the environment, reduced natural resource impacts, and are designed with circularity in mind.[30]
	Cross-Sector Technologies Subprogram	Research focuses on decarbonizing process heating, low-carbon fuels, feedstocks and energy sources (LCFFES), water and energy, and energy efficiency. Each of these research topics applies to the chemical and refining sub-sectors. The Cross-Sector Technologies subprogram completes applied R&D and pilot-scale demonstrations with the goals of electrifying industrial heat, fuel switching, reducing barriers for intermittent energy sources, energy efficiency, and reducing energy use for industrial water and wastewater treatment.[31]
	Rapid Advancement in Process Intensification Deployment (RAPID) Institute	The Institute is advancing modular chemical process intensification technology, including chemical commodity processes, natural gas upgrading, intensified process fundamentals, etc.[32]
Advanced Materials & Manufacturing Technologies Office (AMMTO)	Secure and Sustainable Materials Program	One of the program's focus areas is Circular Economy Technologies and Systems, which aims to extend the circulation of materials and products over multiple lifecycles. The RD&D portfolio for this program covers plastics.[33]

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	CESMII Smart Manufacturing Institute	The Institute is advancing the adoption of Smart Manufacturing techniques by integrating sensors, data, platforms, and controls. The Institute currently has one project investigating Smart Manufacturing for chemical processing.[34]
	Reducing EMbodied-energy And Decreasing Emissions (REMADE) Institute	The Institute is funding R&D projects that aim to reduce the cost of technologies to reuse, recycle, and remanufacture materials, like polymers.[35]
Advanced Research Projects Agency-Energy (ARPA-E)	High-Intensity Thermal Exchange through Materials and Manufacturing Processes (HITEMMP) Program	The program aims to develop new approaches and technologies for high-temperature, high-pressure, efficient, and compact heat exchangers. Heat exchangers are essential for efficient thermal energy exchange for industrial processes like petrochemical production.[36]
Office of Clean Energy Demonstrations	Industrial Demonstrations Program (IDP)	The IDP funds demonstrations for first- or early-of-a-kind projects that focus on the highest-emitting industries, including chemicals.[37]
Loan Programs Office (LPO)	Title 17 Clean Energy Financing	LPO can finance projects in the U.S. that support clean energy deployment and energy infrastructure reinvestment to reduce GHG emissions and air pollution.[38] Projects related to the chemical and refining sectors can qualify. For example, in June 2024, LPO announced a conditional commitment for a project that will produce chemicals.[39]
Office of Energy Efficiency & Renewable Energy	Electrified Processes for Industry Without Carbon (EPIXC) Manufacturing Institute	The Institute aims to develop and scale innovative electric heating concepts for clean manufacturing in support of DOE's Industrial Heat Shot.[40]

Office of Science	AMES National Laboratory Institute of Cooperative Upcycling of Plastics (iCOUP)	The members of iCOUP, led by AMES Laboratory, are performing R&D of new chemical pathways to reuse plastics.[41]
	Lawrence Berkeley National Lab Manufacturing Decarbonization Research Program	Research focuses on decarbonized industrial heat, energy management and efficiency, electrochemical refinery, and new polymers and systems modeling.[42]
	Oak Ridge National Laboratory Manufacturing Science Division	The Manufacturing Science Division focuses on developing and demonstrating advanced manufacturing technologies. The division includes a Chemical Process Scale-Up Group focusing on energy and industrial decarbonization. The Division is also home to a Manufacturing Demonstration Facility.[43]
National Energy Technology Laboratory	Center for Sustainable Fuels and Chemicals (CSFC)	The CSFCL is a technology incubation hub dedicated to helping the U.S. chemicals industry achieve net-zero emissions. It focuses on high-risk technologies that private sectors cannot develop alone. Utilizing NETL's expertise in computational sciences, the CSFC models low-emission manufacturing and simulates efficient scaling of production. Its innovations aim to accelerate market readiness, lower costs, and reduce environmental impact, creating a more agile supply chain for the chemicals industry.[44]
	Carbon Dioxide Conversion Program	The program focuses on the RD&D of a broad suite of technologies that convert CO2 into valuable products. One of the research focuses on the catalytic conversion of CO2 into chemicals.[45]
National Renewable Energy Laboratory	Advanced Manufacturing Research Division	The Division includes research topics like biomass manufacturing and combined heat and power. Furthermore, there is an onsite Integrated Biorefinery Research Facility available for testing and demonstration processes and technologies.[46]

Department of Defense		
United States Air Force	Bioindustrial Manufacturing and Design Ecosystem (BioMADE) Institute	The Institute funds innovative R&D projects that reduce barriers to commercializing bioindustrial manufacturing, including the chemical sector.[47]
Army Armament Research, Development, and Engineering Center	Environmental Security Technology Certification Program (ESTCP)	Funds validation and demonstrations of new sustainable chemistry technologies. The program collects cost and performance data to overcome the barriers to employing innovative technologies because of the Valley of Death. The program validates the performance of bio-based products as potential alternatives to petroleum-based products.[48]
The Office of the Assistant Secretary of the Army for Installations, Energy, and Environment	National Defense Center for Energy and Environment (NDCEE)	Demonstrates, validates, and transitions cost-effective validated technology solutions that meet DoD requirements, enhance mission readiness, and support sustainability and performance objectives. Preferred entry points for NDCEE-funded projects are TRL of 5 or 6 and an exit point of TRL 8 or 9.[49]
Department of Agriculture		
Rural Development Program	Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program	The program provides loan guarantees of up to $250 million to assist in the development, construction, and retrofitting of new and emerging technologies.[50]
	BioPreferred Program	The program aims to increase demand for biobased products. The program includes mandatory purchasing requirements for federal agencies and contractors and a voluntary labeling initiative.[51]

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