An Atlas of Carbon and Hydrogen Hubs for United States Decarbonization

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About the Great Plains Institute

A nonpartisan, nonprofit organization, the Great Plains Institute (GPI) is transforming the energy system to benefit the economy and environment. Working across the US, we combine a unique consensus-building approach, expert knowledge, research and analysis, and local action to find and implement lasting solutions. Our work strengthens communities and provides greater economic opportunity through creation of higher paying jobs, expansion of the nation's industrial base, and greater domestic energy independence while eliminating carbon emissions.

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Executive Summary

The industrial sector, which is a major component of both the United States economy and emissions profile, faces challenges to decarbonization due to reliance on on-site fuel use and chemical processes for product manufacturing. Increased renewable electricity and an electrified transportation sector can help reduce emissions from industrial use of grid electricity and product distribution, but there remains a large fleet of existing equipment used for on-site generation of energy, heat, and mechanical production. In some cases, the production of industrial commodities like cement and ethanol involves the inherent release of greenhouse gases as part of a basic chemical process.

Decarbonizing these processes, fuel use, and installed equipment will require new or alternative forms of low-carbon fuels, advanced technologies, and modified equipment or production configurations. Given the vast number of active industrial facilities that contribute to the economy of local communities and the nation, solutions to industrial emissions will need to be deployed at scale and at considerable speed in order to achieve alignment with international climate modeling scenarios and United States midcentury goals. Many of the technologies and advanced production processes needed for industrial decarbonization are still in the research and development or pilot demonstration phases.

Meanwhile, it has become increasingly clear that achieving global climate modeling scenarios that limit temperature increases to 1.5–2°C will require significant amounts of negative emissions through carbon capture, biomass-based energy, and carbon removal via direct air capture. Like industrial decarbonization solutions, carbon removal remains a nascent technology that is just now growing into the commercial demonstration phase. Negative emissions through carbon capture and carbon removal will also require the transport of carbon dioxide (CO_2) to locations with access to permanent and secure geologic storage.

There exist numerous areas of concentrated industrial activity within the vicinity of geologic storage formations throughout the United States that, along with existing commodity transport infrastructure, form potential carbon and hydrogen "hubs." These hubs would act as early launching points for investment in carbon removal and hydrogen production that can minimize financial and logistical barriers to market development. The regional clustering of industrial activity within these hubs would enable decarbonization solutions to achieve commercial demonstration and economywide deployment at the scale needed to achieve climate goals.

The Great Plains Institute presents this atlas of potential carbon and hydrogen hubs across the United States that offer the capacity to accelerate industrial emissions reductions and carbon removal through focused coordination, deployment, and policy.

The Great Plains Institute identified the following as major components of a carbon and hydrogen hub:

- High concentration of large **industrial emitters**
- High quantities of **fossil fuel use** for on-site industrial energy production
- Presence of **45Q tax credit-qualifying** facilities for carbon capture retrofit, as well as identified near- and medium-term **capture opportunities**
- Current reported production of **hydrogen** and **ammonia**
- Large geologic saline and fossil formations for **permanent and secure CO_2 storage**
- Existing multimodal **commodity distribution infrastructure** such as freight railroads, barge waterways and ports, and interstate highway freight truck routes
- Existing conventional fossil fuel distribution infrastructure for hydrogen blending and established rights-of-way for low-impact CO_2 transport infrastructure

Executive Summary
GPI's Carbon and Hydrogen Hubs

GPI has identified 14 hubs across eight regions of the United States. These are by no means exclusive, as industrial emissions occur throughout the country, and carbon removal or direct air capture will need to be deployed wherever beneficial. Three illustrative pages of components and opportunities are provided for each hub within this atlas.

Identified potential carbon and hydrogen hubs

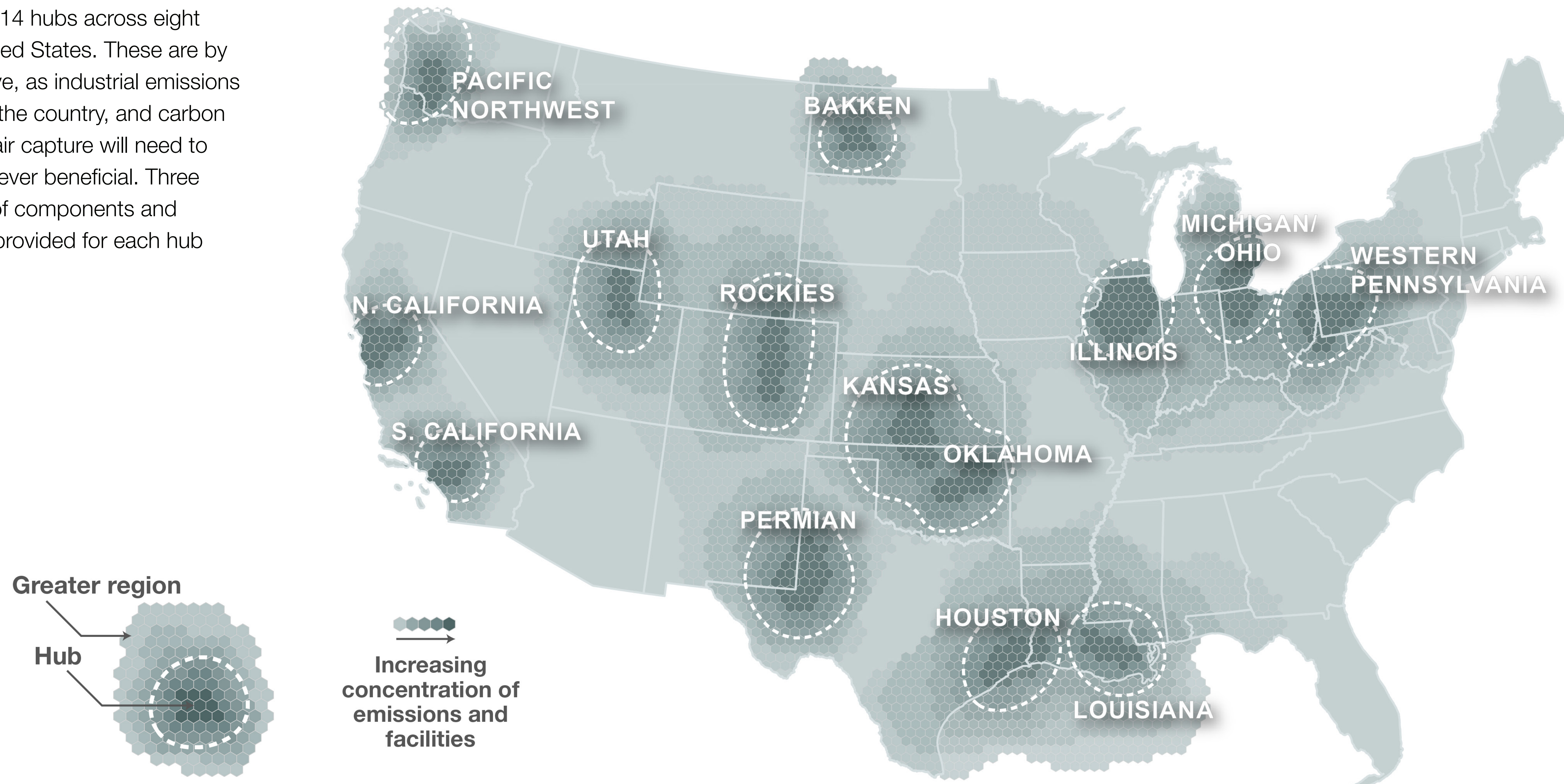

Figure authored by GPI, 2021.

Methodology and Data Sources

The atlas draws on federal and state data sources and analysis by GPI and others, including the following:

Industrial facility characteristics, locations, emission profiles, and historic hydrogen or ammonia production were gathered from the US Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP).[1]

Facility fuel use is based on the National Renewable Energy Laboratory (NREL) *2018 Industrial Energy Data Book*.[2]

Section 45Q-qualifying facilities and near- and medium-term carbon capture retrofit opportunities are based on the Great Plains Institute's (GPI) 2020 whitepaper on CO_2 transport infrastructure.[3]

Geologic storage potential is based on the US Department of Energy (DOE) *Carbon Storage Atlas (Fifth Edition)*[4] and the SCO_2T storage model developed by Carbon Solutions, LLC.[5]

Existing transportation infrastructure and routes are sourced from data published by the US Department of Transportation, Tele Atlas, and the US Bureau of Transportation Statistics.[6]

Data on existing fossil fuel distribution infrastructure are published by the US Energy Information Administration (EIA).[7]

Finally, the following topics have also been identified as key enablers of low-carbon fuels and carbon dioxide removal but are not included in this version of the atlas: renewable and zero-carbon electricity generation, electric capacity for new load presented by electrolysis-based hydrogen production, industrial equipment electrification, biomass resource availability for low-carbon fuel and product feedstock, and direct air capture facilities. These will be topics of future study on carbon and hydrogen hubs by GPI.

Acronym Guide

45Q	—	Section 45Q tax credit for carbon oxide sequestration
Btu	—	British thermal units
CCUS	—	Carbon capture, utilization, and storage
CO	—	Carbon oxide
CO_2	—	Carbon dioxide
CO_2e	—	Carbon dioxide equivalent
DOE	—	US Department of Energy
EIA	—	US Energy Information Administration
EPA	—	US Environmental Protection Agency
GHG	—	Greenhouse gas
GHGRP	—	Greenhouse Gas Reporting Program
GPI	—	Great Plains Institute
Gt	—	Gigatonne (billion metric tons)
IEA	—	International Energy Agency
IIJA	—	Infrastructure Investment and Jobs Act
IPCC	—	United Nations Intergovernmental Panel on Climate Change
Mt	—	Million metric tons
MMBtu	—	Million British thermal units
NATCARB	—	National Carbon Sequestration Database and Geographic Information System
NREL	—	National Renewable Energy Laboratory
RDD&D	—	Research, development, demonstration, and deployment
SCO_2T	—	Sequestration of CO_2 Tool

Components of a Carbon and Hydrogen Hub

A carbon and hydrogen hub provides the opportunity to develop decarbonization solutions and deploy them at scale. The industrial activity and geologic storage capacity located in a hub region provide a potential marketplace for producers and consumers of hydrogen and captured carbon. Components of carbon and hydrogen hubs include the following:

- High concentration of large **industrial emitters**
- High quantities of **fossil fuel use** for on-site industrial energy production
- Presence of **45Q tax credit-qualifying** facilities for carbon capture retrofit, as well as identified near- and medium-term **capture opportunities**
- Current reported production of **hydrogen** and **ammonia**
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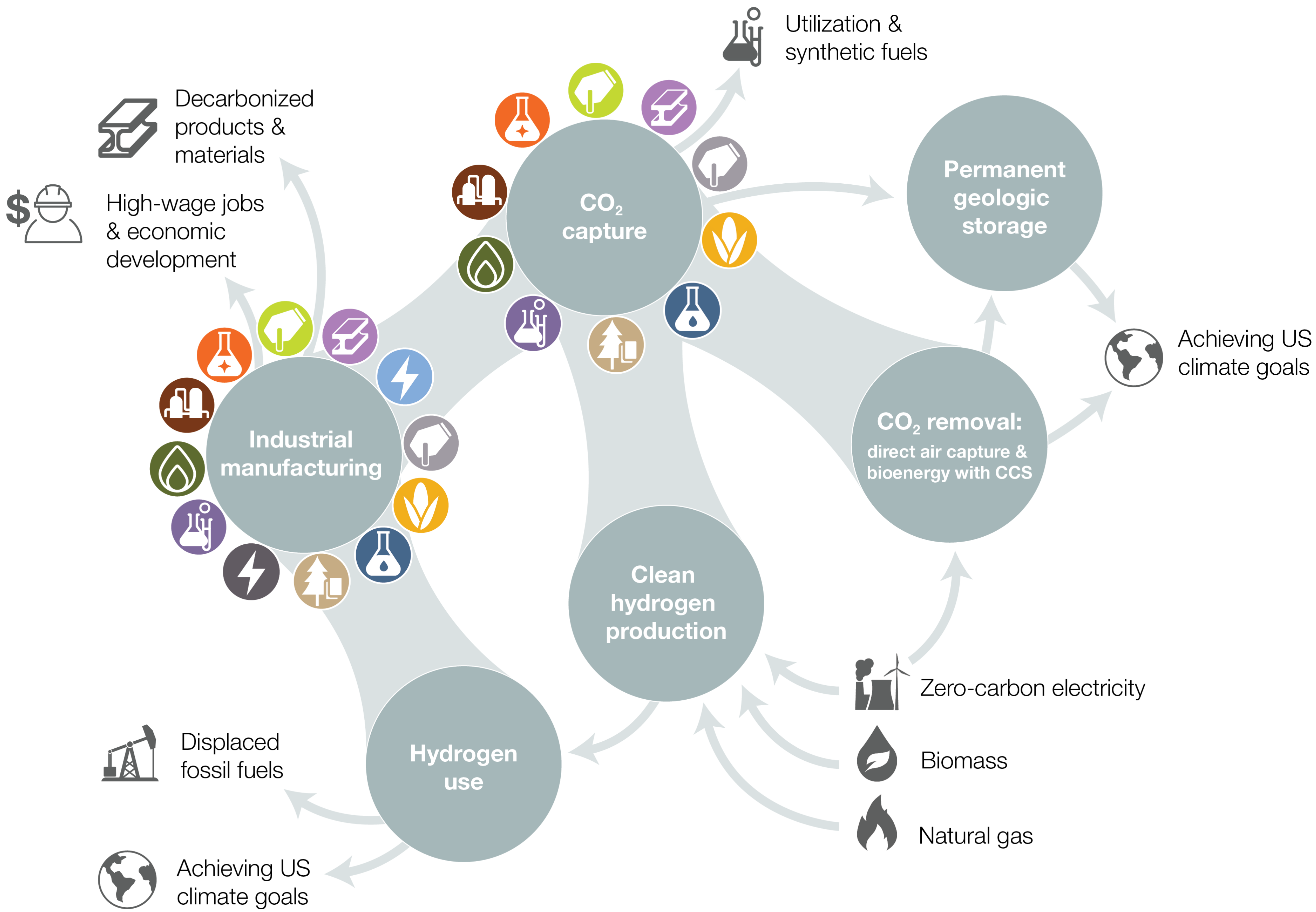


Figure authored by GPI, 2021.

Midcentury Decarbonization: US Industrial Emissions

According to global climate modeling scenarios by groups such as the United Nations Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), it has become clear that to keep global temperature rise below 1.5° to 2°C, **the world must reach net-zero emissions by midcentury** (2050 to 2060).[8] Nearly all global modeling scenarios require **economywide deployment of negative emissions** technologies such as carbon capture and storage, direct air capture, and bioenergy with carbon capture and storage. Biomass production, afforestation, and the coordinated tracking and carbon scoring of agricultural and land use practices are also needed. As the global population, land use, and energy demand continue to rise, negative emissions technologies are required to reduce emissions and draw down the current and projected atmospheric concentrations of greenhouse gases (GHGs).

Carbon management and hydrogen will play a vital role in meeting GHG reduction goals in the United States, particularly in hard-to-decarbonize sectors, such as industry and manufacturing. The US industrial sector provides high-wage jobs, economic investment, and tax revenue, and often forms the backbone of local and regional economies. The manufacturing sector, which includes the production of metal, mineral, chemical, and petroleum products, among many others, is currently the fourth-largest contributor to the United States' GDP.[9] In 2020, the manufacturing sector added $2.3 trillion to the nation's economy[10] while employing 12.2 million people.[11] Finding decarbonization solutions and technologies that maintain and create sustainable economic activity will be a vital part of the effort to reach net zero by midcentury.

Between 2015 and 2020, the global economy emitted **35.5 gigatonnes of GHG emissions per year**.[12] Approximately 17 percent of these emissions occurred in the United States, at a rate of about **6.56 gigatonnes per year** in 2019.[13] Within the United States, industrial production and manufacturing contributes 1.5 gigatonnes or 23 percent of the nation's GHG emissions.[14] The industrial sector is the third-highest emitting portion of the United States economy after transportation and electricity.[15]

Reaching net-zero emissions will require the United States to mitigate more than 6 gigatonnes of annual economywide emissions by midcentury, with annual mitigation of 1.5 gigatonnes required by the industrial sector. This level of industrial decarbonization is not expected to occur naturally or through foreseen market dynamics. Instead, US industry is projected to continue growing at 1.5 percent per year.[16] Current operations and energy inputs in this sector alone would lock in a temperature rise of at least 1.65°C, even without any additional facilities or expansion.[17] According to the IPCC, "emissions reductions by energy and process efficiency by themselves are insufficient for limiting warming to 1.5°C," indicating the need for carbon management and alternative fuels.[18] Through carbon-reducing and mitigating technologies, the US can decouple industrial production and growth from GHG-intensive energy consumption.

Number of jobs per industry within the manufacturing sector

Sector	US Jobs
Manufacturing sector total	12,200,000
Nonmetallic mineral products	398,000
Primary metals	351,000
Paper products	354,000
Petroleum and coal products	109,000
Chemical products	846,000
Plastics and rubber products	693,000

Source: US Bureau of Labor Statistics (December 8, 2021).

Midcentury Decarbonization: US Industrial Emissions

There are a number of challenges to decarbonizing the industrial sector, which is composed of a variety of complex processes and emission sources across industries. Manufacturing methods for industrial products often release CO_2 as a result of innate chemical reactions and cannot be decarbonized through electrification or fuel-switching alone. Industrial facilities also consume large quantities of fossil fuel to produce on-site electricity, heat, and energy for manufacturing processes, resulting in additional on-site emissions. Many facilities use large quantities of electricity, resulting in emissions either from either grid-connected power plants or on-site electricity generation.

Mitigating industrial emissions will require electrification and renewable electricity generation, energy efficiency, new technology, and alternative means of production. It will also require new feedstock supply chains and low-carbon hydrogen biofuel alternatives to medium- and high-grade fuels. Finally, carbon capture and permanent storage can act as a negative emissions technology that counteracts hard-to-reduce emissions in the industrial sector, allowing the United States to meet its midcentury GHG reduction goals.

Source of industrial emissions by sector

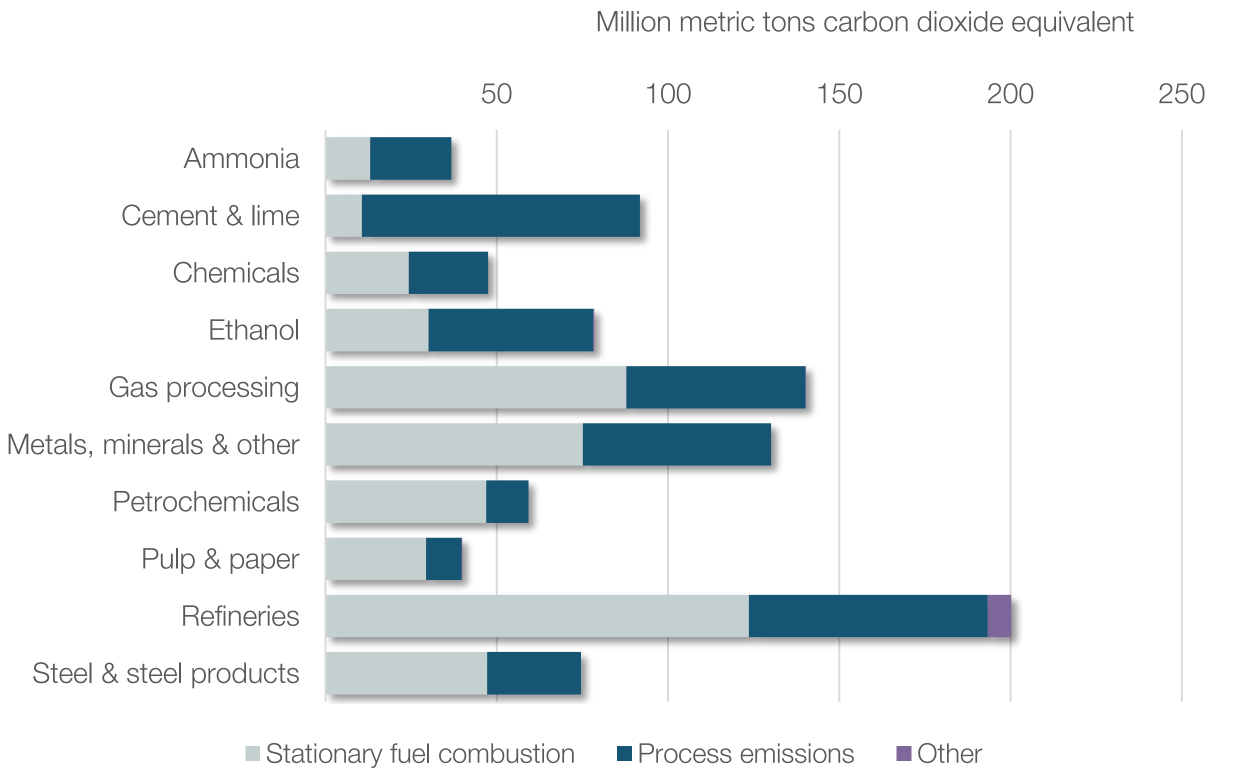


Figure authored by GPI based on EPA GHGRP 2019 data (as of August 7, 2021).

Reaching net-zero emissions will require the United States to mitigate more than 6 gigatonnes of annual economywide emissions by midcentury.

National Landscape of Industrial Fuel Use & Emissions

US industrial and power facilities emit roughly 2.5 billion metric tons of carbon dioxide equivalent (CO_2e) per year. Refineries and gas processing facilities are the highest emitters within the industrial sector, producing 200 million metric tons (Mt) and 140 Mt CO_2e per year, respectively. Other major emitters in the industrial sector include facilities that produce cement and lime, ethanol, and steel and steel products. Coal and gas power plants also account for a significant share of nationwide emissions totals.

The US is home to 1,197 facilities whose emissions meet minimum eligibility thresholds to qualify for the federal Section 45Q tax credit. Nationwide, 542 facilities have also been identified as near- and medium-term opportunities for capture retrofit over the next 10 to 15 years based on each facility's expected Section 45Q eligibility, operational patterns, and unique emissions profile.[19] Numerous facilities in the cement and lime, ethanol, refining, and gas processing sectors have been identified as near- and medium-term opportunities for retrofit with carbon capture equipment.

Number of facilities and carbon capture opportunities by sector

Sector	Number of Facilities	Annual Stationary Emissions million metric tons CO_2e	45Q-Eligible Facilities	Near- and Medium-Term Capture Opportunities
Ammonia	27	36.8	24	9
Cement & lime	142	91.8	130	89
Chemicals	298	47.5	17	2
Ethanol	180	78.5	173	170
Gas processing	1,361	140.3	92	52
Metals, minerals & other	1,322	130.1	29	3
Petrochemicals	81	59.3	35	4
Pulp & paper	224	40.0	17	2
Refineries	140	200.2	94	65
Steel & steel products	184	74.7	45	8
Coal power plant	295	1,029.1	216	65
Gas power plant	970	612.6	325	73

Source: EPA GHGRP 2019 data (as of August 7, 2021); Abramson, McFarlane, and Brown, *Transport Infrastructure for Carbon Capture and Storage*.

US industrial fuel use and emissions profile by sector

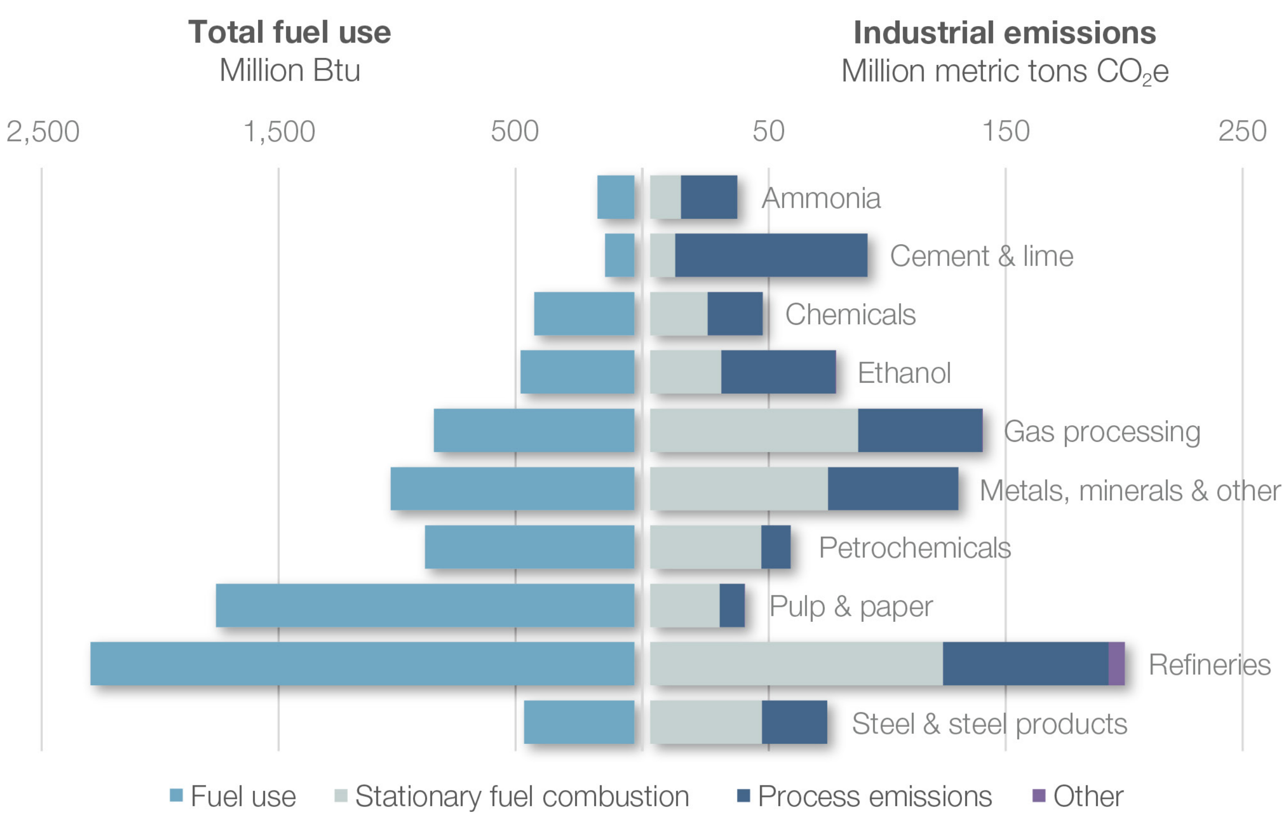


Figure authored by GPI based on EPA GHGRP 2019 data (as of August 7, 2021); McMillan (2019).

Natural gas, fuel gas, and wood and wood residuals are the leading fuels most commonly used to power US industrial activity. US industrial facilities utilize a total of 8.8 quadrillion British thermal units (Btu) generated from fossil fuels per year. Half of this total fuel use comes from combustion of natural gas, with 4.4 quadrillion Btu produced from natural gas per year. Fuel gas is responsible for 2.3 quadrillion Btu produced per year. Wood and residuals account for 1.2 quadrillion Btu per year. All other fuels, including coal, oil, and blast furnace gas, individually produce amounts of energy that are an order of magnitude smaller than natural gas, fuel gas, and wood and residuals.

Top 15 industrial fuels by total energy

Fuel	Total Energy	
Natural gas	4.4	quadrillion Btu
Fuel gas	2.3	quadrillion Btu
Wood & wood residuals	1.2	quadrillion Btu
Bituminous coal	269	trillion Btu
Subbituminous coal	155	trillion Btu
Blast furnace gas	96	trillion Btu
Mixed industrial fuels	69	trillion Btu
Coke oven gas	57	trillion Btu
Petroleum coke	38	trillion Btu
Coal coke	24	trillion Btu
Agricultural byproducts	24	trillion Btu
Tires	14	trillion Btu
Distillate fuel oil no. 2	13	trillion Btu
Residual fuel oil no. 6	13	trillion Btu
Landfill gas	11	trillion Btu
Total (all fuels)	**8.8**	**quadrillion Btu**

Source: McMillan (2019).

Carbon Management & Removal

A necessary tool to meet 1.5-2°C climate scenarios

For the United States to meet its decarbonization goals, new investment and significant efforts are required to retrofit carbon capture technology to industrial and power facilities that are unlikely to decarbonize or retire by midcentury. The chemical and mechanical aspects of the production processes for some industrial and power operations, such as in cement production, iron and steel manufacturing, refining, and some basic chemicals production, make it infeasible for emissions to be abated by switching to low-carbon energy sources. Such industrial processes often have limited or no abatement options beyond carbon capture retrofit.

Analyses from the IPCC and the IEA demonstrate how carbon capture deployment is essential to reaching net-zero global emissions by 2050. Carbon capture, utilization, and storage (CCUS) achieves capture of 7.5 gigatonnes (Gt) CO_2 in 2050 annually in the IEA net-zero scenario,[20] and a median level of 15 Gt CO_2 of capture in 2050 in IPCC climate scenarios.[21] Additionally, negative emissions through carbon removal from direct air capture and bioenergy with carbon capture and storage account for 1.9 Gt CO_2 in the IEA's net-zero 2050 scenario and a range of 3.5 to 16 Gt CO_2 in the IPCC 2050 scenarios.[22]

IPCC climate scenarios are described on the following page.

Carbon Management & Removal

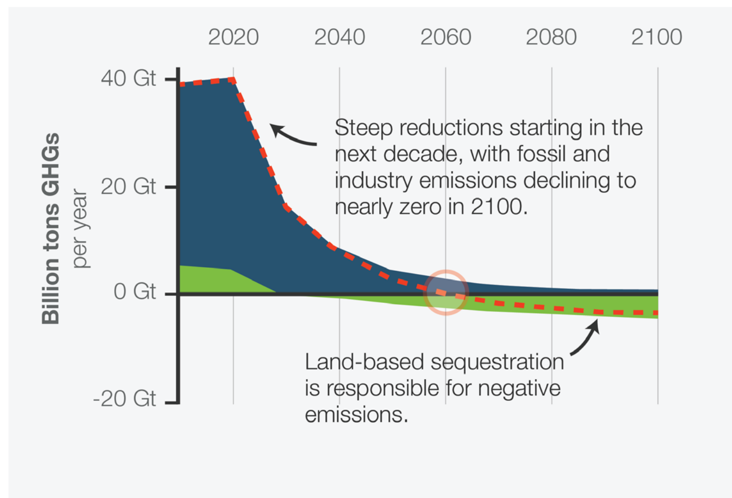
A necessary tool to meet 1.5-2°C climate scenarios

The IPCC outlines four scenarios where emissions reductions will limit global temperature rise to 1.5°C.[23]

In the IPCC's first illustrative scenario, Low Energy Demand, negative emissions are required for all major industries and agriculture, energy demand must decrease, widespread afforestation must occur, and general lifestyle changes must occur rapidly worldwide. Importantly, the agriculture and land use sector must completely invert its current net-positive emissions to net negative by 2030, becoming a carbon sequestering sector. Emissions across the global economy must be nearly halved from 2020 levels by the year 2030 in this scenario.

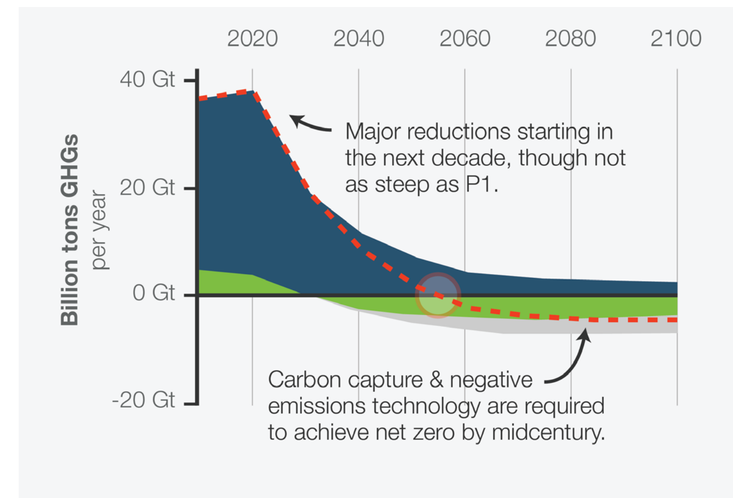
Low Energy Demand Scenario.

Steep and complete reductions



Scenario S1.

Steep reductions in the '20s and '30s



In the second illustrative scenario, S1, CCUS and bioenergy with carbon capture and storage are responsible for cumulative reductions of 348 Gt CO_2 through 2100. Agricultural methane emissions must decrease by nearly 70 percent by 2050 compared to 2010 levels, and nitrous oxide levels must decrease by 26 percent.

The third illustrative scenario, S2, includes 687 Gt CO_2 in cumulative reductions from CCUS and bioenergy with carbon capture and storage through 2100.

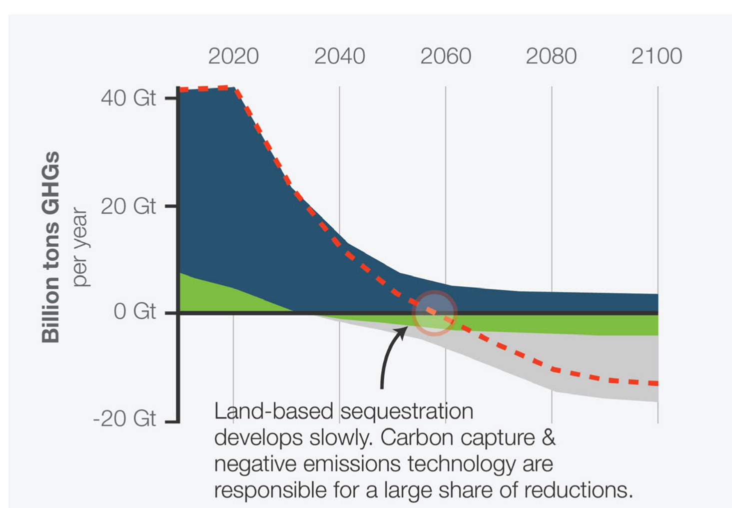
Source of GHG emissions or reductions

- Fossil fuel and industry
- Bioenergy & carbon capture, utilization, and storage
- Working lands: agriculture, forestry, and other land use
- Net GHG emissions
- Net-zero GHG emissions

Source: Figure authored by GPI based on Huppman et al. (2018).

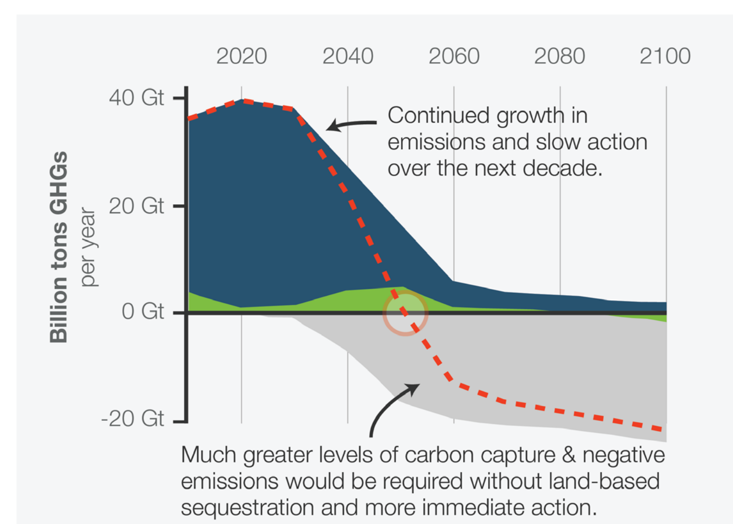
Scenario S2.

Moderate reductions and negative emissions



Scenario S5.

Delayed action



In the fourth illustrative scenario, S5, energy demand and emissions from the power and industrial sectors continue to increase over the next decade, resulting in delayed net decarbonization. This scenario, which may be the most likely given current energy and industrial trends, indicates that 1,218 Gt CO_2 cumulatively or an annual average of 15 Gt CO_2 per year are necessary for decarbonization through 2100.

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Carbon Management & Removal

A necessary tool to meet 1.5-2°C climate scenarios

Analysis by the Rhodium Group shows the potential for the deployment of carbon capture to create hundreds of thousands of high-wage jobs. Up to 107,000 jobs can be created over a period of 15 years through capital investment in retrofits and retrofit operations. Additional jobs would occur in the long term. After 2035, capital investment and retrofit operations could drive up to 131,000 jobs.[24]

Scaling up carbon capture and carbon removal is critical to achieving US decarbonization targets while maintaining and creating high-wage jobs in core sectors of the US economy. The hubs identified in this atlas represent initial focus areas of investment and coordination to achieve economies of scale through shared CO_2 transport infrastructure. By enabling clusters of capture sources to develop shared infrastructure to connect with markets for utilization and storage, the hub model enables the near-term economic feasibility needed to jumpstart eventual economywide deployment.

Carbon capture jobs and economic impact study results, 2021-2035

Industry	Number of Facilities	Annual Average Project Jobs	Annual Operations Jobs	Private Investment billion dollars
Ammonia	10	112 - 167	165 - 210	$0.4 - $0.6
Cement	87	2,840 - 4,250	2,560 - 3,515	$9.1 - $13.6
Coal power plant	62	21,820 - 32,730	13,890 - 20,780	$75.6 - $112.4
Ethanol	174	741 - 1,118	1,229 - 1,714	$2.6 - $3.9
Gas power plant	67	11,030 - 16,570	6,550 - 9,850	$35.6 - $56.4
Gas processing	22	91 - 137	112 - 159	$0.3 - $0.4
Hydrogen	61	1,081 - 1,605	1,105 - 1,543	$3.6 - $5.3
Petrochemicals	2	150 - 220	110 - 160	$0.5 - $0.7
Refineries	59	2,905 - 4,400	1,935 - 2,705	$7.4 - $11.1
Steel	9	1,720 - 2,590	1,610 - 2,340	$5.5 - $8.3
CO_2 transport	-	19,853	-	$38.2

Source: King, Herndon, Larsen, and Hiltbrand, *The Economic Benefits of Carbon Capture*.

Near- and medium-term carbon capture jobs potential, 2021-2035

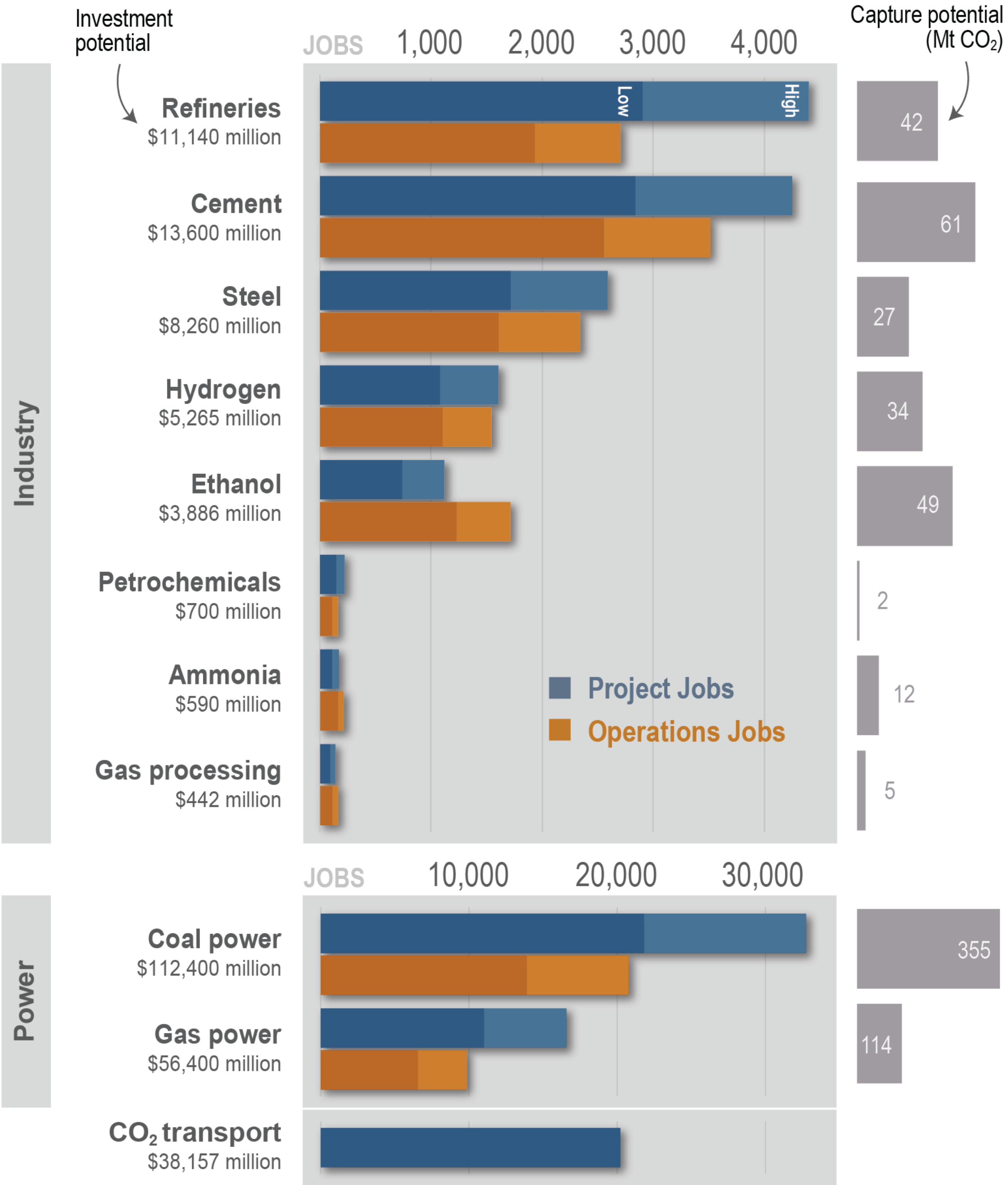


Figure authored by GPI based on Source: King, Herndon, Larsen, and Hiltbrand, *The Economic Benefits of Carbon Capture*.

Carbon Capture: 45Q Tax Credit-Qualifying Industrial and Power Facilities

Carbon capture will be a critical tool in decarbonizing the nation's diverse array of industrial and power facilities. While the power sector can be fully decarbonized by switching to renewable and zero-carbon energy sources and increasing energy efficiency, the industrial sector faces several unique challenges to decarbonization. Combustion of fossil fuels is the primary source of medium- and high-grade heat in major industrial production processes, such as steel and cement manufacturing, which cannot easily be substituted with renewable sources. In some cases, the release of CO_2 is inherent to chemical reactions in the industrial manufacturing process. Carbon capture and storage is one of the only ways to decarbonize process emissions such as these.

Near- and medium-term deployment of carbon capture equipment at the nation's largest industrial facilities, such as those with emissions sizable enough to meet current minimum thresholds for Section 45Q eligibility, can enable the greatest cumulative greenhouse gas reduction impacts over time. Section 45Q-eligible facilities can enable these major emissions reductions while taking advantage of the 45Q tax credit as well as natural economies of scale.

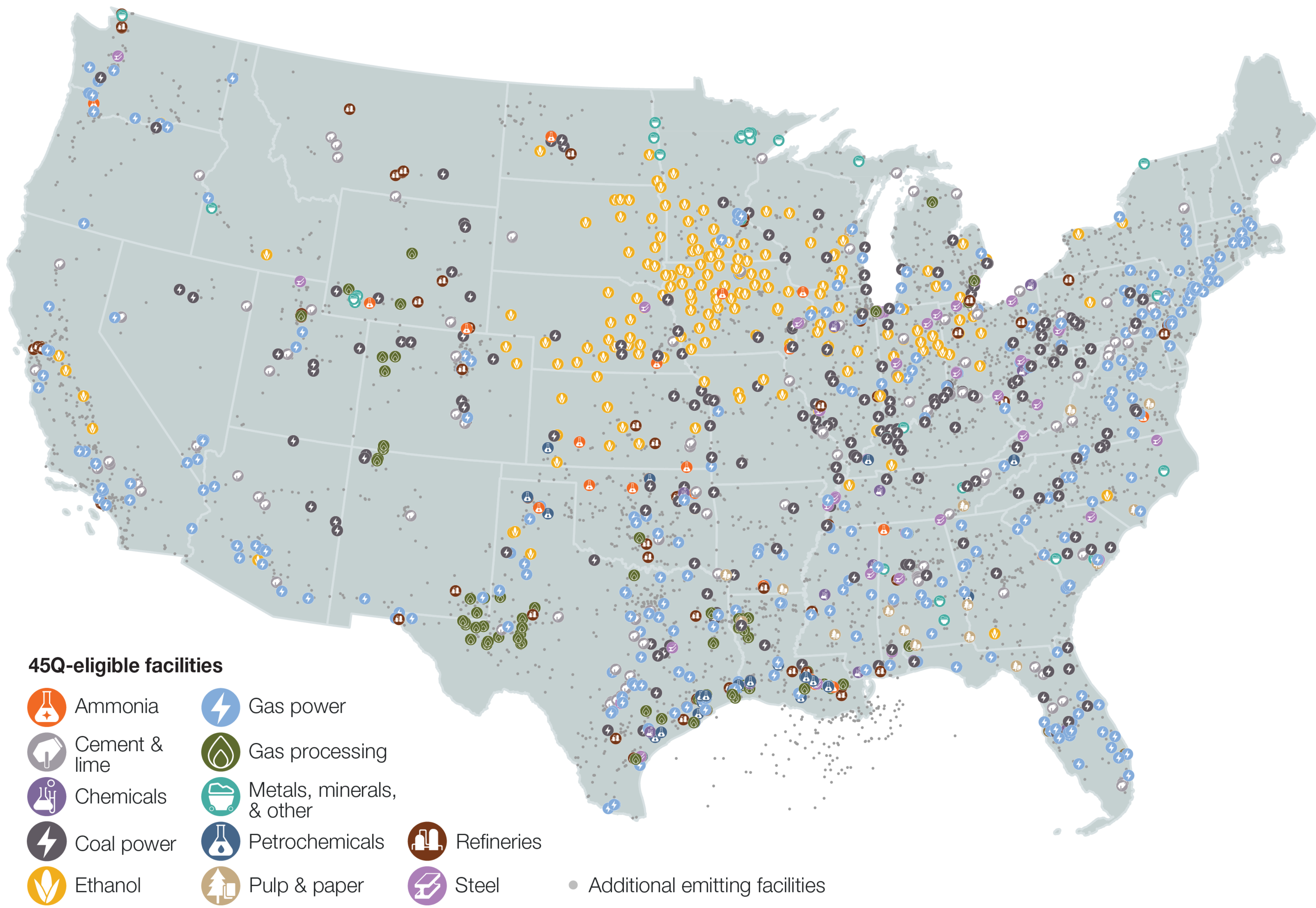


Figure authored by GPI based on EPA GHGRP 2019 data (as of August 7, 2021).

Identified Near- and Medium-Term Carbon Capture Retrofit Opportunities

GPI identified 542 facilities as prime candidates for carbon capture retrofit over the next 10 to 15 years. These facilities represent a launching point for investment in carbon capture, where the economics of capture appear favorable for near-term investment. Additional 45Q-eligible facilities that continue to operate and provide employment and investment by midcentury should also be considered opportunities for carbon capture retrofit at that point.

Near-term candidates for capture are largely clustered in the regional hubs identified in this atlas, further optimizing potential project economics by enabling coordination between facilities and subsequent economies of scale in transport and storage.

GPI identified 542 facilities where current technical, operational, and commercial factors provide a launching point for near-term investment in carbon capture.

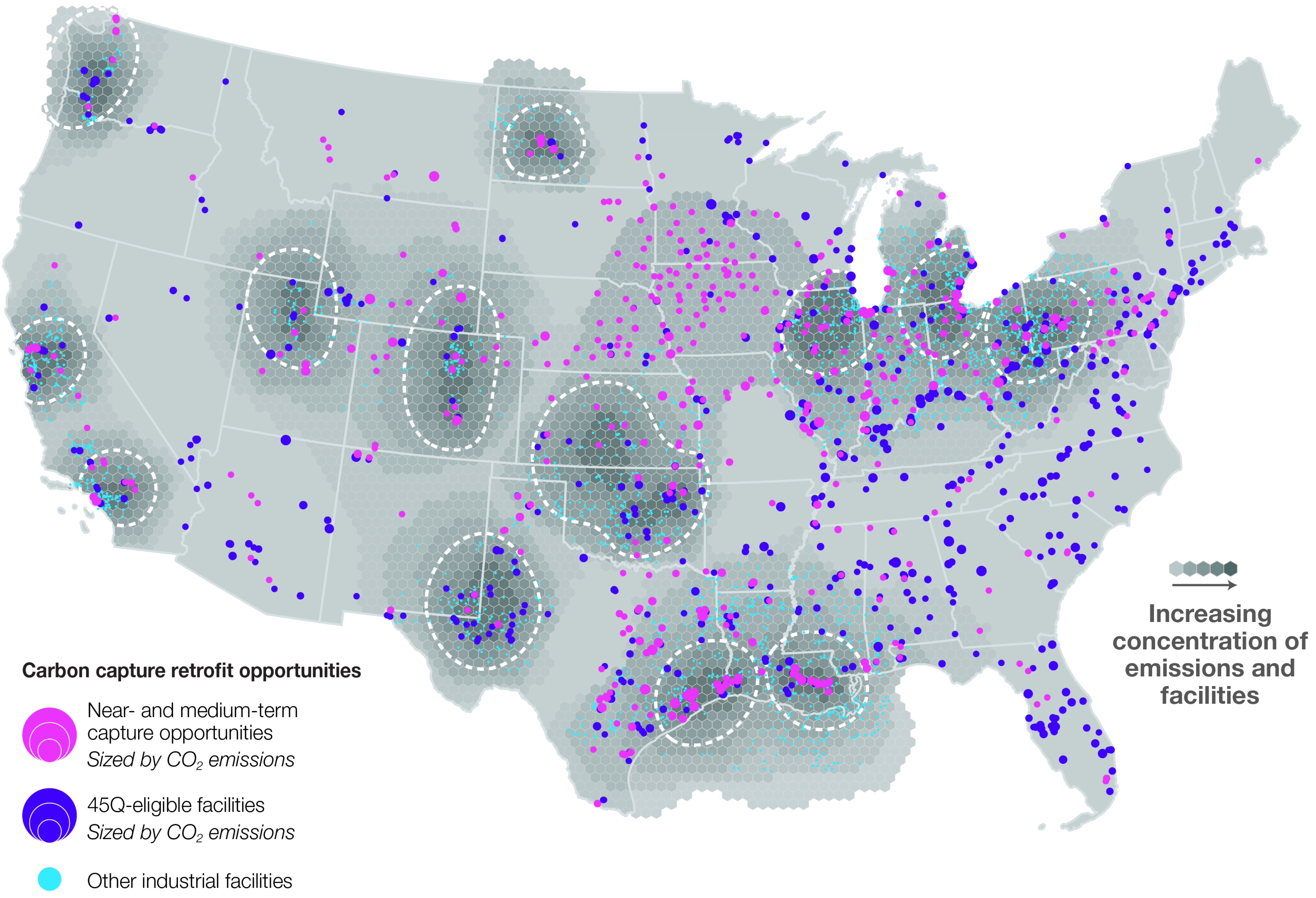


Figure authored by GPI based on Abramson, McFarlane, and Brown, *Transport Infrastructure for Carbon Capture and Storage*; EPA GHGRP 2019 data (as of August 7, 2021).

Permanent Geologic Storage

The US has ample physical capacity to permanently store thousands of years of US emissions at current levels in secure geologic saline formations.[25] However, local characterization will be needed to identify suitable CO_2 injection sites for project development. Site access and cost of injection also factor into geologic storage access for a given project.

Locating direct air capture and carbon capture hubs in areas with existing saline storage capacity can minimize transport costs, land use, and local impact. However, not all potential direct air capture and carbon capture hubs are co-located with geologic storage formations. Shared transport infrastructure can achieve beneficial economies of scale, enabling break-even on investments in industrial capture retrofit even when longer distance transport to a final storage site is required.

Estimated US geologic CO_2 storage capacity

	Low	Med	High
Saline	2.2 trillion	8.1 trillion	21.2 trillion
Fossil	72 billion	159 billion	188 billion

metric tons CO_2
Source: NATCARB (NATCARB_OilGas_v1502; October 30, 2015; NATCARB_Saline_v1502; October 30, 2015).

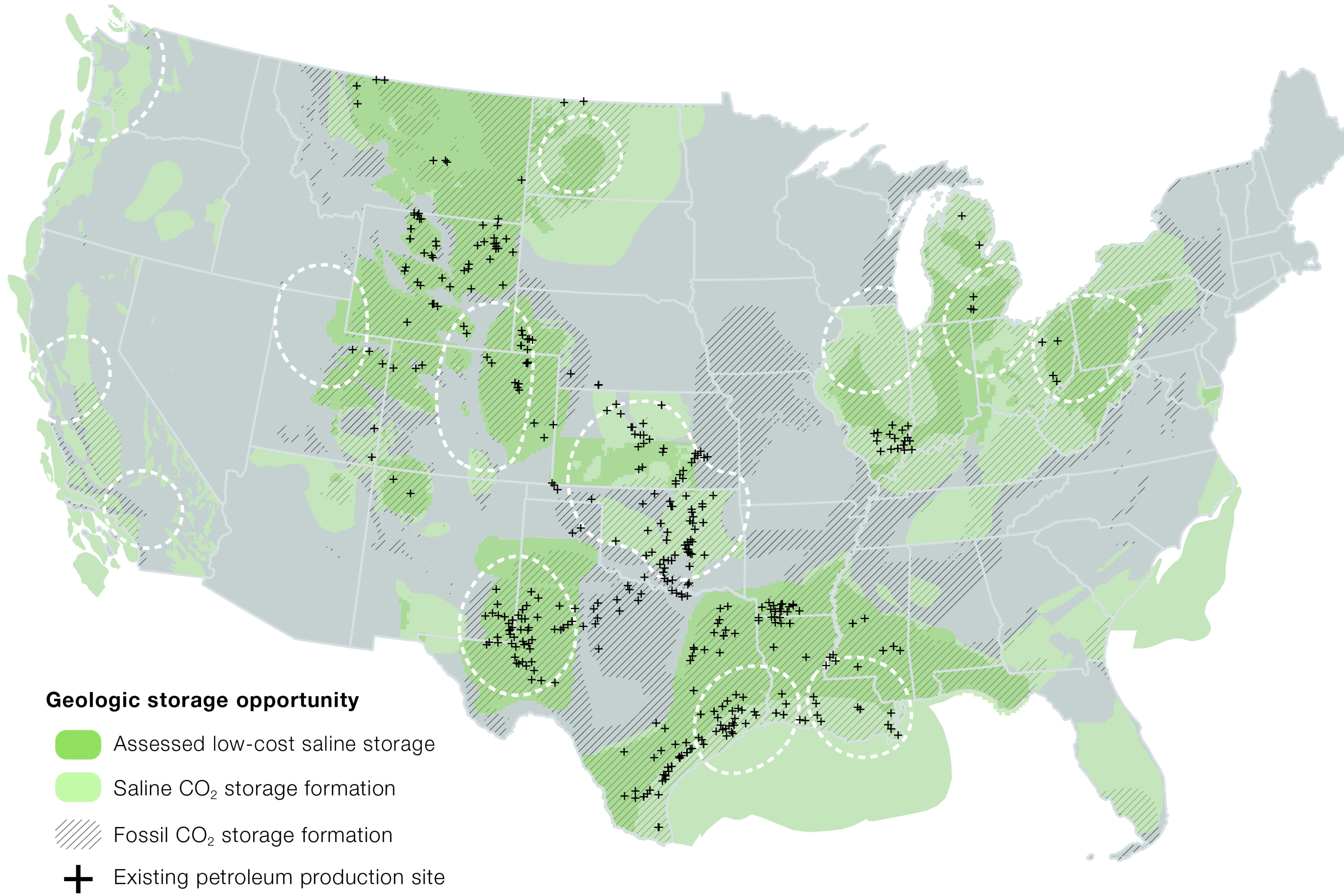


Figure authored by GPI based on ARI (September 2018), Middleton et al. (September 2020), NATCARB (NATCARB_Saline_v1502; October 30, 2015), HIFLD (September 21, 2017).

Hydrogen as a Decarbonization Solution

An increase in low-and zero-carbon hydrogen production and related technologies is needed to reach net-zero GHG emissions by 2050. Hydrogen is a versatile fuel source that can be stored for long periods of time and can reduce carbon intensity of power systems, heating systems, and industrial production. Hydrogen can also act as an energy carrier, be combusted for energy without emitting GHGs, and enable energy storage that can cover intermittent or seasonal periods of low energy production from renewable electricity generation.

When produced with zero- or low-carbon energy, hydrogen is a powerful decarbonization solution for multiple sectors and numerous end uses that are difficult to electrify, such as industrial process heat, heavy trucking, iron and steel production, and marine shipping. Hydrogen use can displace fossil-based medium- and high-grade heat in industrial applications that may be hard to electrify.[26] In the IEA's net-zero scenario, hydrogen-based fuels account for 13 percent of global energy demand in 2050.[27]

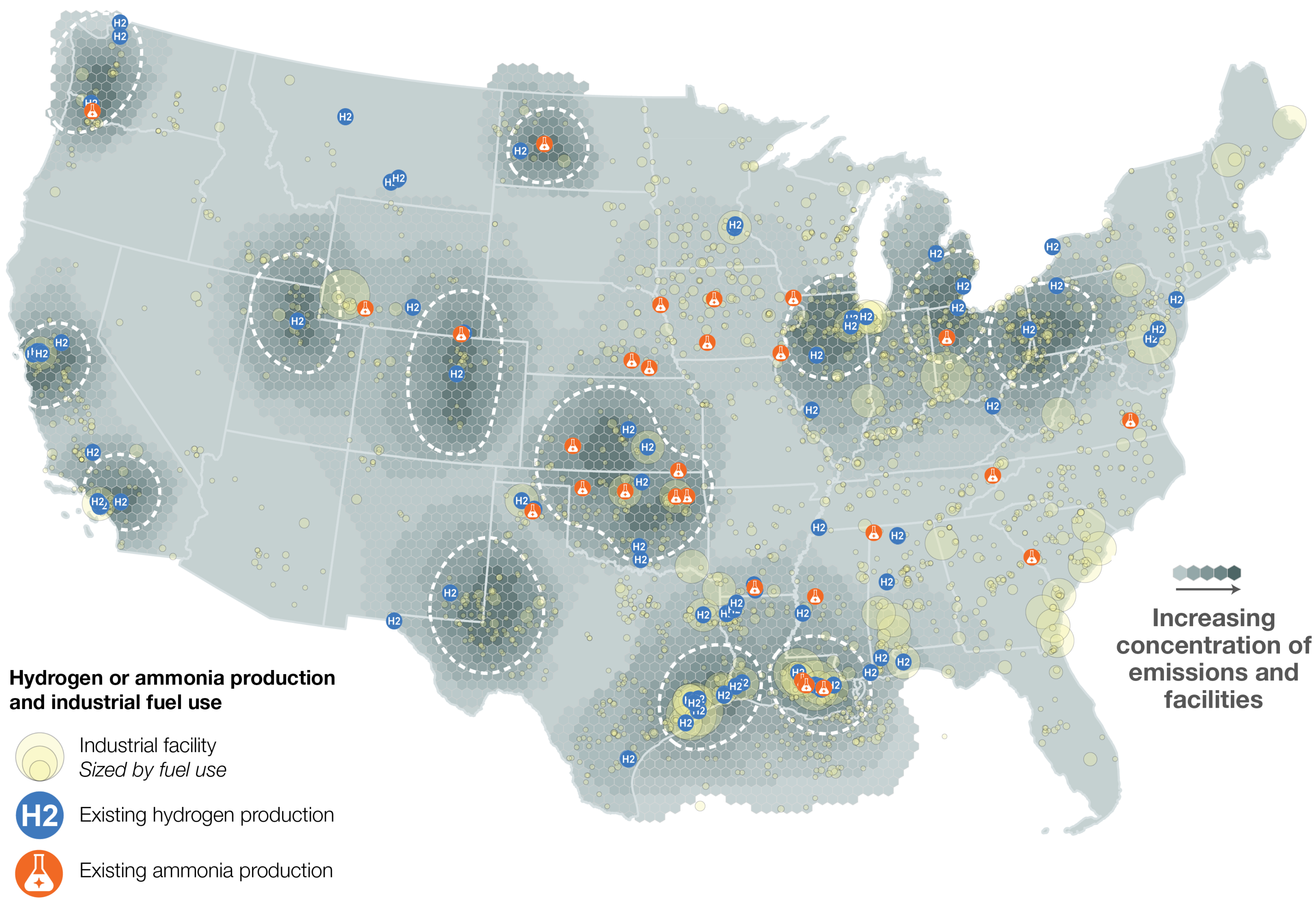


Figure authored by GPI based on McMillan (2019); EPA GHGRP 2019 data (as of August 7, 2021).

Hydrogen as a Decarbonization Solution

Hydrogen is currently a primary feedstock in the production of ammonia, a major agricultural fertilizer.[28] Although there are multiple methods of producing hydrogen, it is most commonly produced using the steam methane reforming process with natural gas or biomass acting as the primary feedstock. Currently, 95 percent of hydrogen is made from natural gas steam methane reforming, producing CO_2 as a byproduct.[29] Adding carbon capture equipment to this process can drastically reduce carbon emissions and result in low-carbon hydrogen.[30] In the IEA's net-zero scenario, nearly 40 percent of hydrogen in 2050 is produced at facilities using natural gas and carbon capture.[31]

In addition to natural gas-based steam methane reforming, hydrogen can also be produced through electrolysis, where electricity splits water into hydrogen and oxygen. Electrolysis can be powered with renewable or nuclear electricity, resulting in zero- or low-carbon hydrogen. Biomass gasification is another low-carbon technique used to produce hydrogen. Emissions from combusting biomass-based fuel are considered biogenic, or part of the natural CO_2 lifecycle, and can be carbon neutral or result in negative emissions with the right combination of technological processes and management. Carbon capture equipment can also be added to the biomass gasification process, potentially creating hydrogen with a net-negative GHG intensity. The complementary nature of hydrogen production and carbon capture demonstrates the benefit of establishing coordinated carbon and hydrogen hubs. Hydrogen and CO_2 can also be used to produce synthetic methane, further reducing emissions associated with natural gas use and methane leakage. In the IEA's net-zero scenario, synthetic fuels and synthetic methane production meets 10 percent of the demand for network supplied gas in the buildings, industry, and transport sectors in 2050.[32]

As demand for hydrogen as an energy carrier, transportation fuel, and high-grade industrial fuel grows, new production facilities utilizing a variety of production configurations and feedstocks will be required throughout the country. The hubs identified in this atlas provide an opportunity to co-locate new hydrogen facilities in areas with existing hydrogen and ammonia distribution infrastructure, natural gas pipelines, biomass feedstock resource, and permanent geologic CO_2 storage potential. These hubs offer initial focus areas of investment and coordination to move low-carbon hydrogen production and use from small scale to commercial demonstration and eventually to economywide deployment.

New policies and investment are needed, such as hydrogen tax credits and the option to convert tax credits into a cash payment (direct pay), before it is feasible to launch hydrogen at the scale required to make an impact on United States emission levels. Policies should aim to reduce the cost of low- and zero-carbon hydrogen production, make transportation of hydrogen easier, and prepare to introduce hydrogen to the consumer market. Existing and proposed policies are listed in detail in the final section of this atlas. To truly be a decarbonization solution, new methods of producing low-carbon hydrogen must be demonstrated and deployed at a scale required to serve the level of demand for industrial fuels across the United States.

Biomass Availability for Hydrogen Production and Carbon Removal

In order to produce low-carbon hydrogen at the scale needed to address US climate goals, siting of new hydrogen production facilities must consider the availability of renewable resources, including biomass, wind, and solar. Biomass residues, which include materials left over as byproducts of crop harvesting and silviculture operations, can be used as material feedstocks in hydrogen production and other alternative chemical production. Biomass residues can also be collected for biomass-based electricity and heat generation and paired with carbon capture to produce negative emissions. Furthermore, these residues represent a way to collect biomass without significant change to current agricultural production and forestry management practices.

NREL's Biopower Atlas[33] is used here to demonstrate regional availability of biomass residues from agriculture and forestry. While biomass resource and bioenergy crop production are important factors to consider for low-carbon fuels and carbon removal, they are not examined in depth in the current release of this atlas. For additional reference, Princeton University's Net-Zero America study includes modeled projections of bioenergy crops, such as perennial grasses for use in biopower, pyrolysis, and biobased hydrogen production.[34]

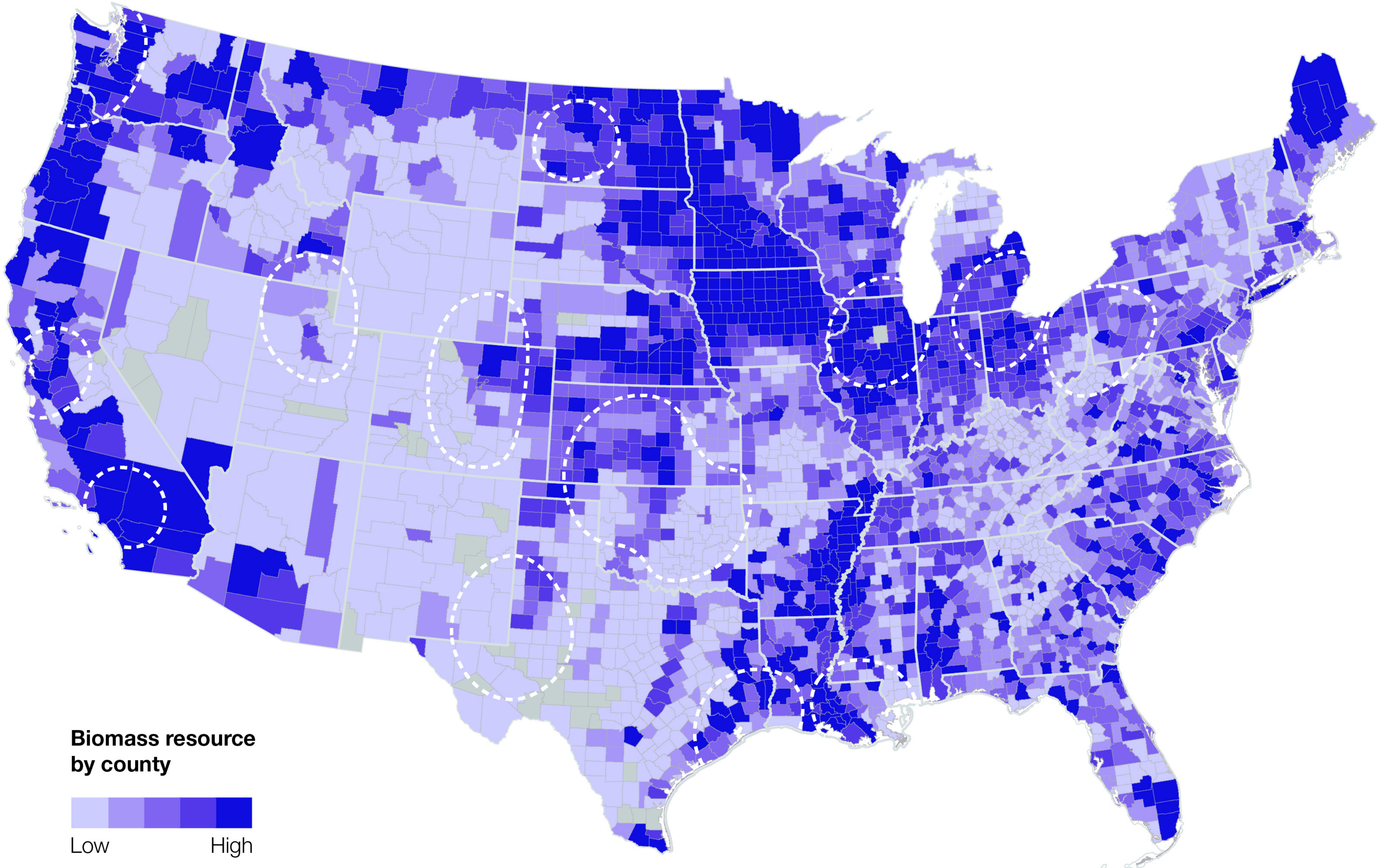


Figure authored by GPI based on NREL (2014).

Renewable and Zero-Carbon Electricity Availability for Hydrogen Production and Carbon Removal

At scale, industrial electrification, transportation electrification, and carbon removal through direct air capture will result in increased demand for renewable and zero-carbon electricity. The use of hydrogen as an energy carrier will also require large amounts of zero-carbon electricity for water electrolysis. Data from S&P Global Market Intelligence[35] and the US EIA[36] are used here to show the nation's potential for electricity generation from wind and solar, as well as existing nuclear power plants.

Given the electric intensity of direct air capture, it is strategically important to locate facilities in areas that can take on increased demand for reliable renewable and zero-carbon electricity. The capacity of regional balancing authorities and electric generation dispatch markets to take on new load must be considered. Transmission constraints and the projected retirement of nuclear and other baseload power plants are also important considerations.

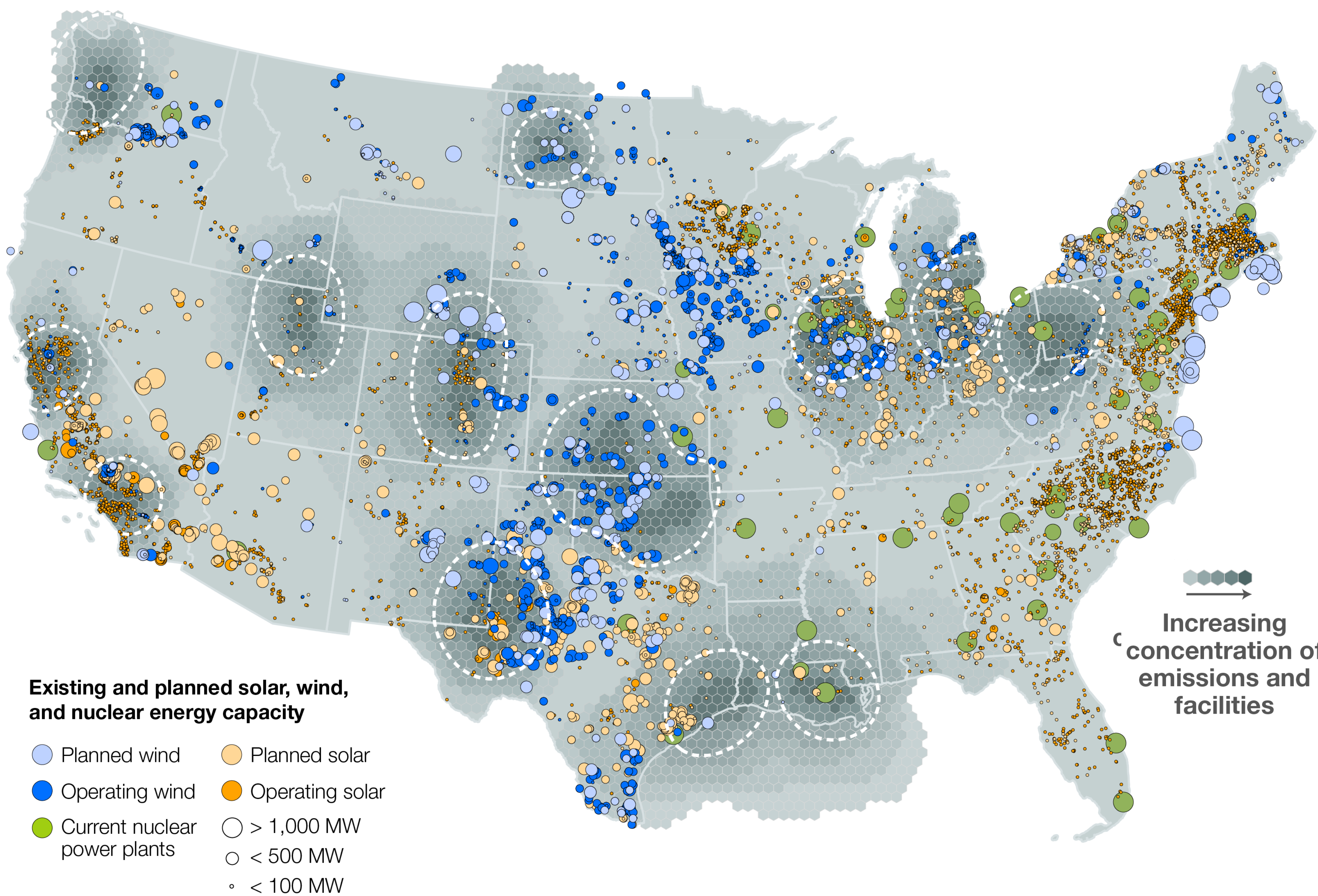


Figure authored by GPI based on S&P Global Market Intelligence; S&P Capital IQ (December 2, 2021); EIA Power Plants (July 10, 2020).

Economic Development Rationale for the Establishment of Carbon and Hydrogen Hubs

Scaling carbon capture and hydrogen infrastructure to the levels required to meet midcentury climate targets will require coordinated effort and achieving economies of scale. Carbon and hydrogen hubs present an opportunity to take advantage of existing co-location of industrial producers, commodity transport infrastructure, and geologic carbon storage capacity to overcome financial and logistical barriers to at-scale deployment.

The costs of transporting captured carbon from emitting facilities, or hydrogen from hydrogen-producing facilities, can pose barriers to project deployment. For example, the Section 45Q tax credit enables economic carbon capture from many sources, but the coordinated development of major new CO_2 transport infrastructure remains a logistical and financial challenge. Local and regional hubs concentrating producers and consumers can reduce financial and logistical barriers to development of transport infrastructure. GPI's 2020 whitepaper on CO_2 transport infrastructure found that developing shared transport infrastructure connecting industrial and power facility clusters to storage and utilization sites can maximize the amount of carbon captured and stored by a carbon capture and storage network while minimizing overall costs and land use impacts.[37] These benefits are observed in part because CO_2 transport infrastructure has strong economies of scale, whereby high-capacity infrastructure with greater CO_2 throughput has a lower unit cost per ton of CO_2. Shared infrastructure systems connecting multiple buyers and sellers of CO_2 or hydrogen also reduce demand or supply risk for any individual carbon capture or hydrogen project, reducing financing risk premiums and the total cost of individual projects.

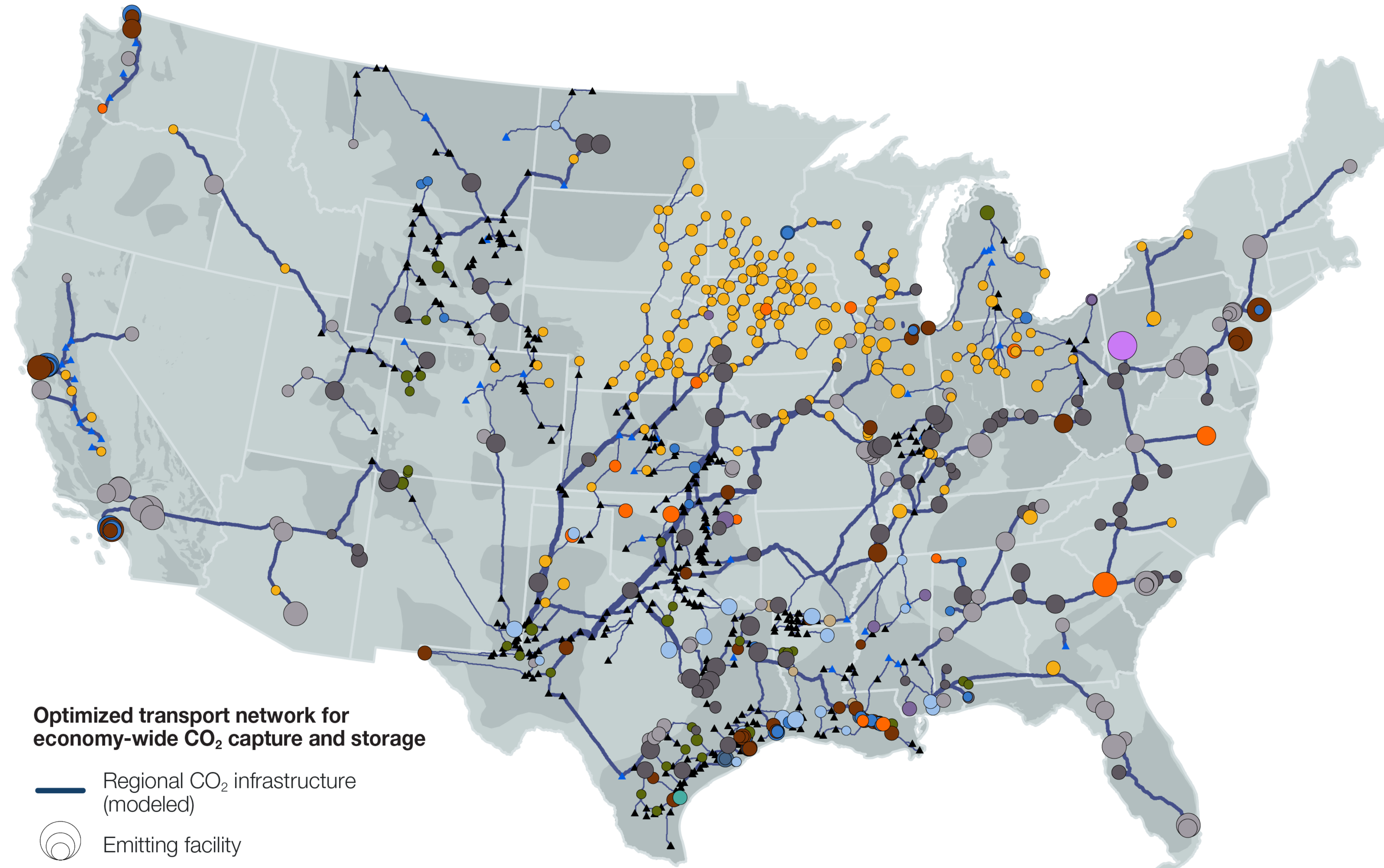
While costs of developing a CO_2 transport infrastructure network may be prohibitive for an individual facility to develop alone, costs can be shared when multiple facilities in a hub collaborate on developing shared infrastructure. Industrial facilities in a carbon and hydrogen hub can take advantage of their proximity to one another to develop shared transport infrastructure and achieve the associated financial benefits. In areas where industrial sources are co-located with suitable geology for CO_2 storage, overall transportation costs are further abated as the distance CO_2 must travel to its destination is reduced.

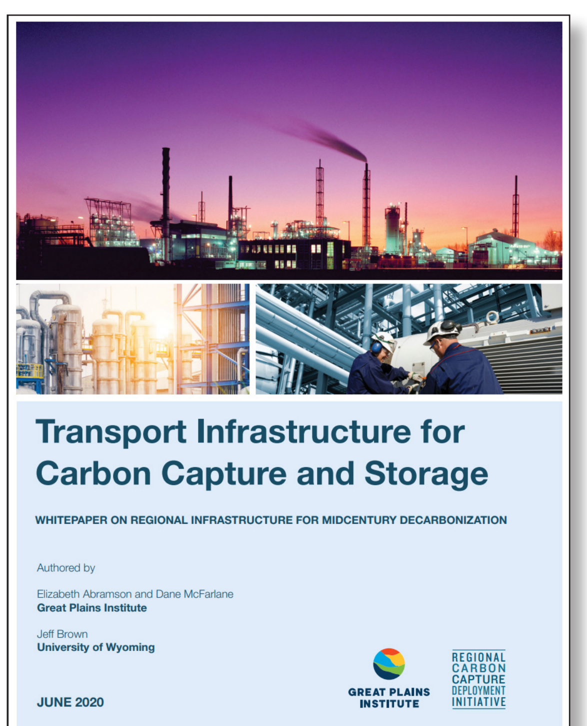
The establishment of carbon and hydrogen hubs can also sustain and create local economic investment, enabling the scale of development and deployment required for low-carbon technology and decarbonization solutions. Beneficial regional specialization can occur when a comparatively large concentration of a specific industry in a region produces from a resource that is abundantly available locally.[38] Resource-intensive industries using larger facilities are more efficient when located near their primary resources and can meet demand with fewer facilities.[39]

Ideally, carbon hubs concentrated in specific regions will increase the deployment of carbon capture by increasing efficiency and reducing cost through shared inputs, shared infrastructure, and proximity to areas of CO_2 storage or use. Carbon and hydrogen hubs can substantially reduce transportation costs and the need for additional distribution infrastructure compared to more broadly dispersed facilities.[40]

Regional Carbon Transport Infrastructure

GPI and the Regional Carbon Capture Deployment Initiative conducted a three-year analysis on transport infrastructure for carbon capture and storage, published in June 2020. GPI collaborated with Los Alamos National Laboratory and the Indiana Geological Survey to determine optimized regional transport infrastructure to deliver CO_2 from capture sources to storage locations using the SimCCS model. A primary finding of the study was that long-distance regional pipelines that aggregate CO_2 from multiple sites maximize economies of scale, resulting in minimized transport costs and greater feasibility for capture retrofit.





GPI's Transport Infrastructure whitepaper, published June, 2020. Download the report at carboncaptureready.org.

Figure authored by GPI based on results from the SimCCS model, 2020.

Transport Infrastructure: Railroads

Before regional carbon and hydrogen pipeline networks are built, existing multimodal transport networks such as railroads can play an important role in transporting carbon and hydrogen to sites of utilization or storage. An extensive network of freight rail lines runs throughout the US, connecting ports, manufacturing hubs, and other areas of economic activity. These rail lines are widely used for long-distance transport of bulk commodities, including energy products and chemicals.[41] With many transport nodes intersecting waterways and interstates, commodities may travel by a combination of rail, truck, and water.

An extensive network of freight rail lines running throughout the US is already widely used for long-distance transport of bulk commodities, including energy products and chemicals.

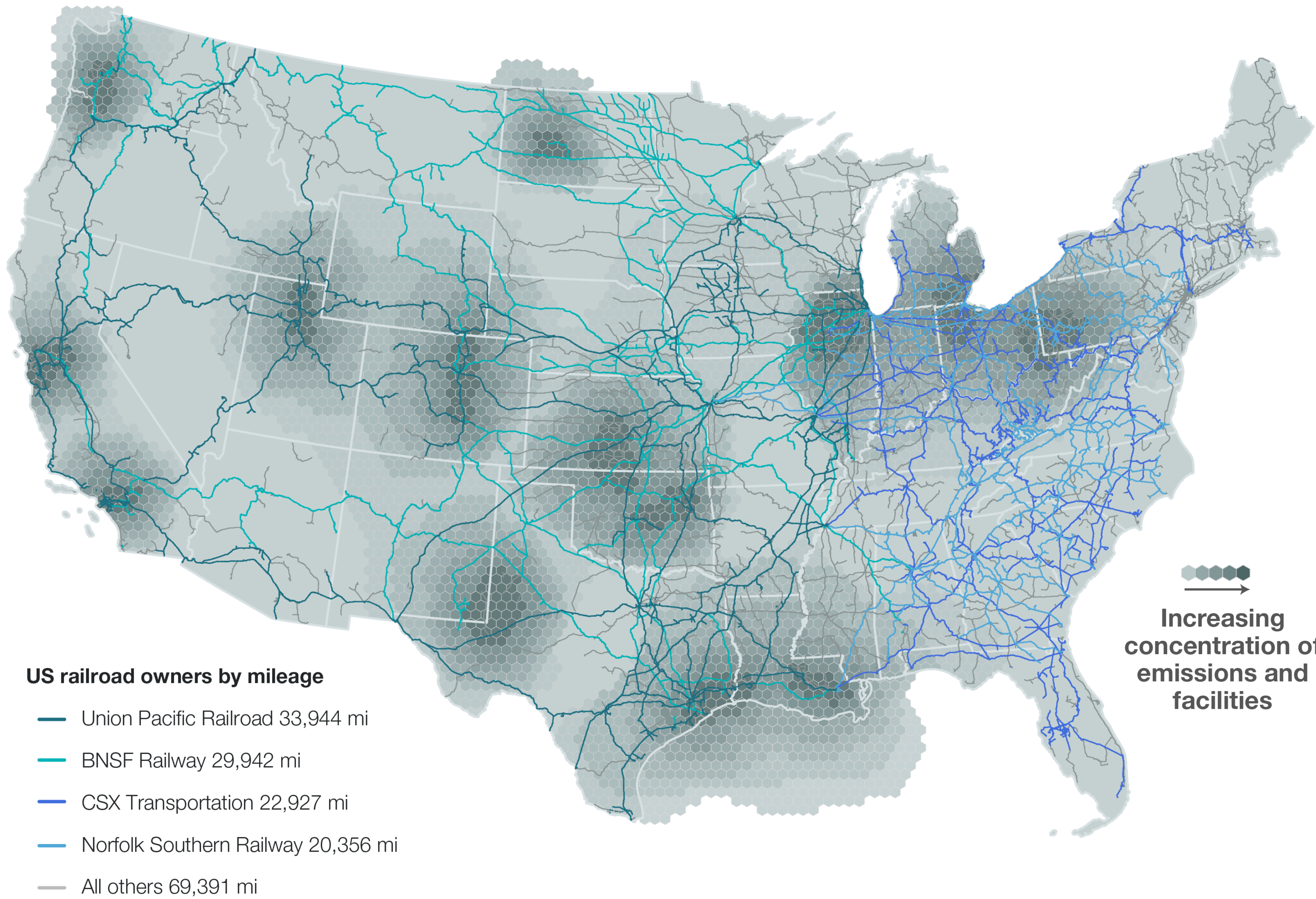


Figure authored by GPI based on Bureau of Transportation Statistics (October 6, 2021).

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Transport Infrastructure: Barge Waterways & Freight Highways

Barge waterways and freight highways can play an important role in near-term carbon and hydrogen transport networks. Like railroads, interstate routes and freight waterways are well-established modes of transport for bulk commodities, such as energy products and fuels. Trucks, barges, and trains can connect local facilities to one another, as well as facilitating connection to distant markets. These multimodal transport options also offer flexibility, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported.

Interstate highways and freight waterways are well-established modes of transport for bulk commodities, such as energy products and fuels.

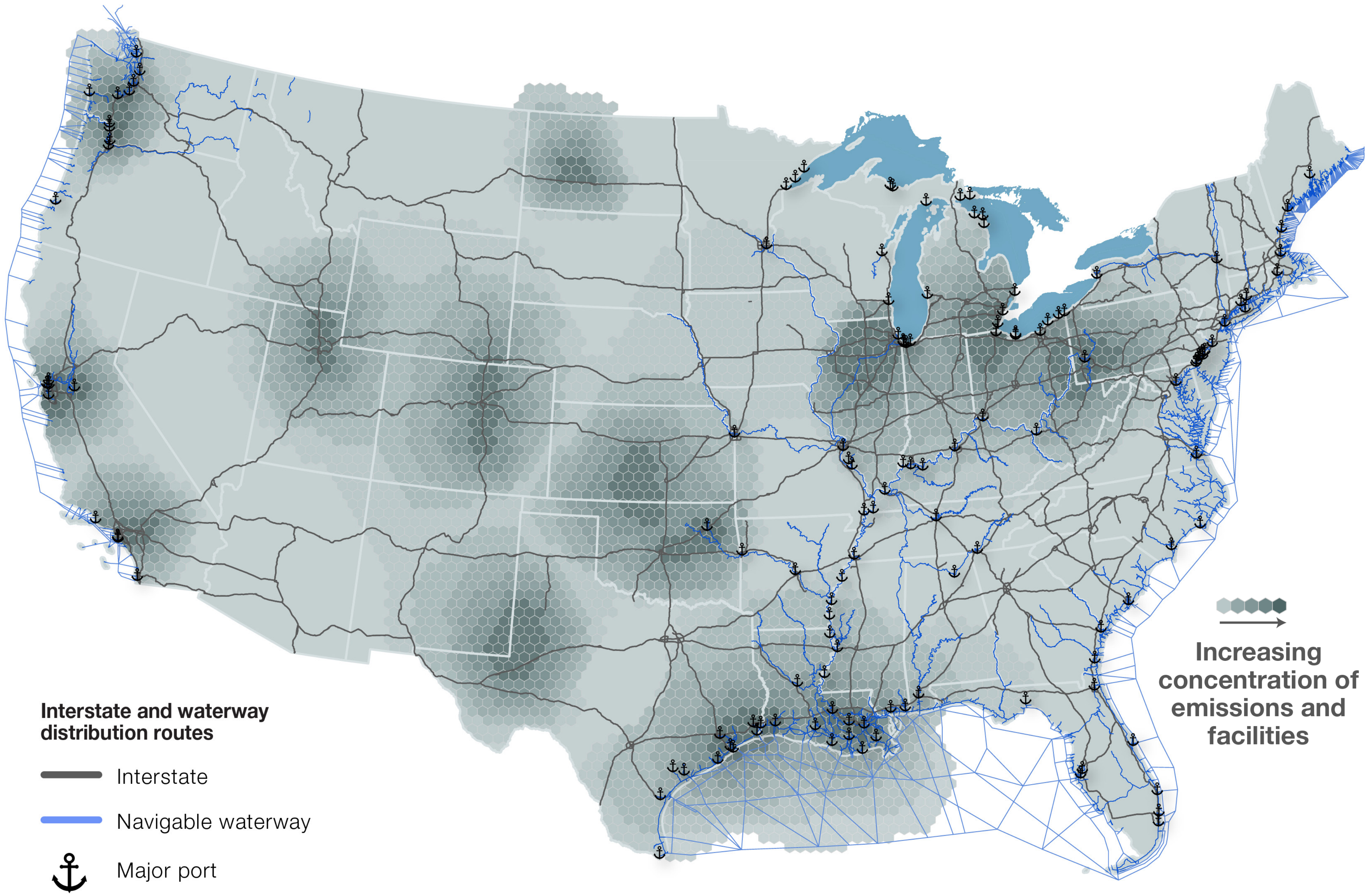


Figure authored by GPI based on Tele Atlas (October 6, 2021); National Transportation Atlas Database (Major Ports; December 17, 2019; Navigable Waterway Lines; June 26, 2019).

Transport Infrastructure: Natural Gas Pipelines

The nation's existing pipeline networks can serve multiple purposes in the development of carbon and hydrogen transport networks. Routing new carbon and hydrogen pipelines along existing pipeline routes can maximize efficiency in infrastructure buildout, as existing natural gas and other pipelines can provide an adjacent right-of-way that reduces land use, logistical challenges, and planning costs for new carbon and hydrogen transport infrastructure. To a certain extent, hydrogen can also be blended into the existing natural gas distribution system for co-firing. However, greater utilization of existing pipeline infrastructure may not be feasible due to unique pressure and corrosion considerations for CO_2 and hydrogen.

Routing new carbon and hydrogen pipelines along existing pipeline routes can maximize efficiency in infrastructure buildout.

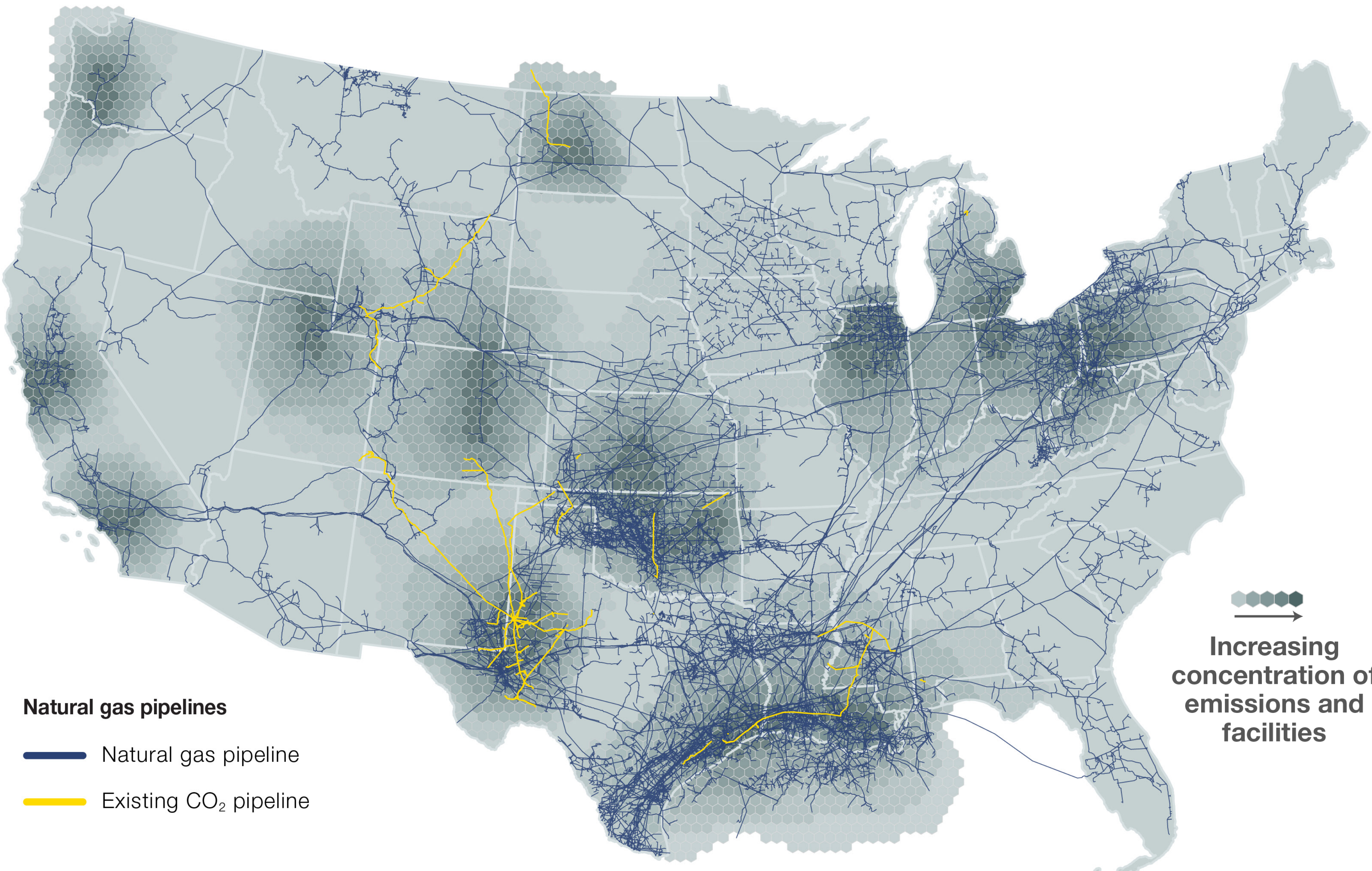


Figure authored by GPI based on EIA Natural Gas Interstate and Intrastate Pipelines (April 28, 2020).

Transport Infrastructure: Petroleum Pipelines

Oil pipelines, like natural gas lines, can provide an adjacent right-of-way that maximizes efficiency in infrastructure buildout and minimizes land use for new carbon and hydrogen infrastructure. The regions identified as hubs identified in this atlas are often already operating as major interchanges of petroleum, fossil fuel, and other chemicals transmission. This highlights their position as central nodes of connection and distribution for fuel and commodity markets.

Existing oil and gas pipelines can provide an adjacent right-of-way for transport of zero-carbon commodities.

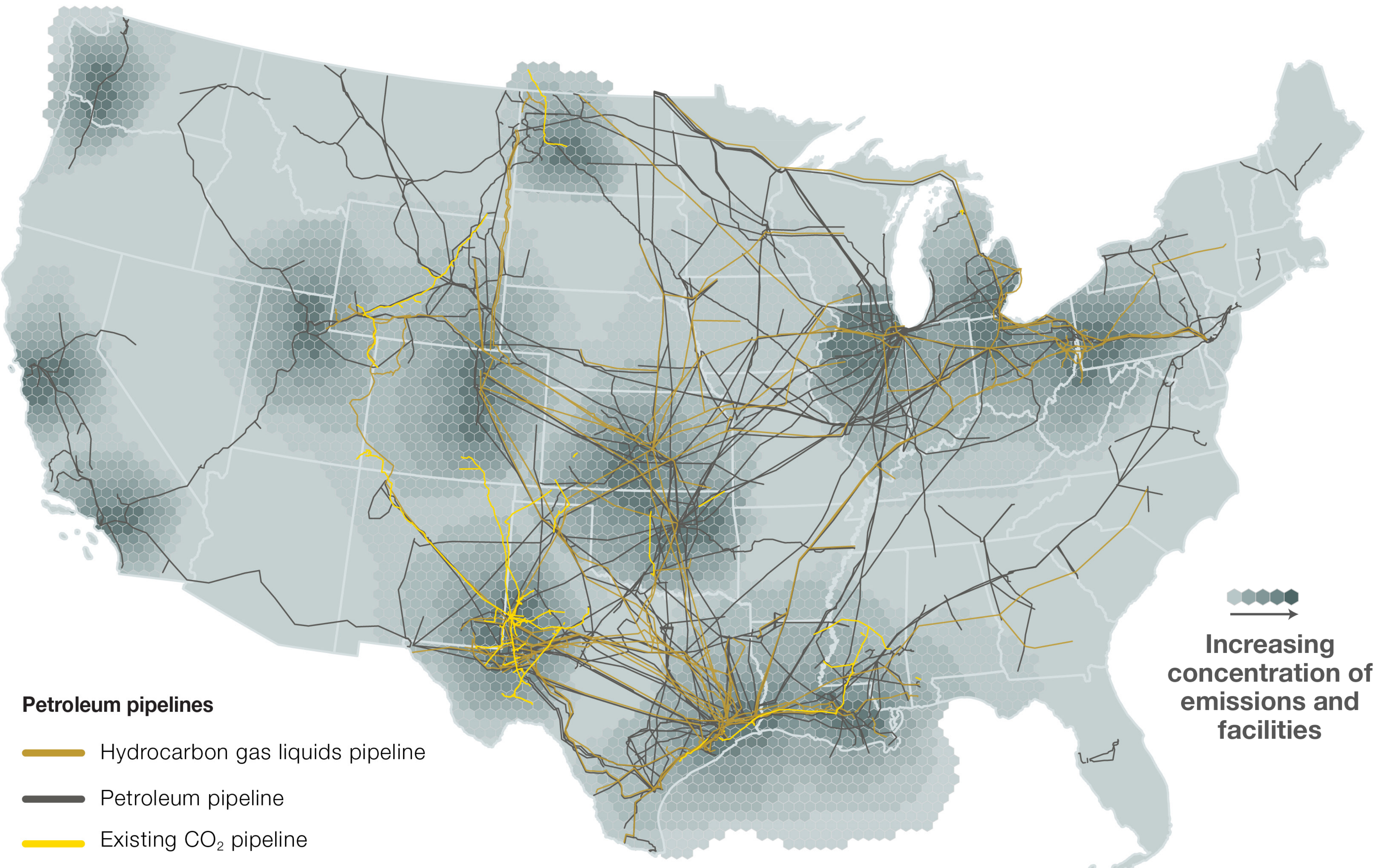


Figure authored by GPI based on EIA (Crude Oil Pipelines; April 28, 2020; HGL Pipelines; April 28, 2020; Petroleum Product Pipelines; April 28, 2020).

Regional Opportunities for Hub Development

This atlas identifies eight regions where concentrated industrial activity coincides with opportunities for permanent geologic carbon storage. Each region has unique advantages that can facilitate the near-term deployment of carbon capture, transport, and storage infrastructure and the development of a low-carbon hydrogen economy. With distinct industrial profiles and networks of existing commodity transport infrastructure, each region can play to its strengths in the development of carbon and hydrogen hubs.

The regions identified in this atlas emit a collective total of 1.7 billion metric tons CO_2e per year. On-site fuel combustion and process emissions account for 402 Mt CO_2e and 302 Mt CO_2e, respectively. The Gulf Coast and Midwest and Illinois Basin regions currently lead in total stationary fuel consumption and in total emissions.

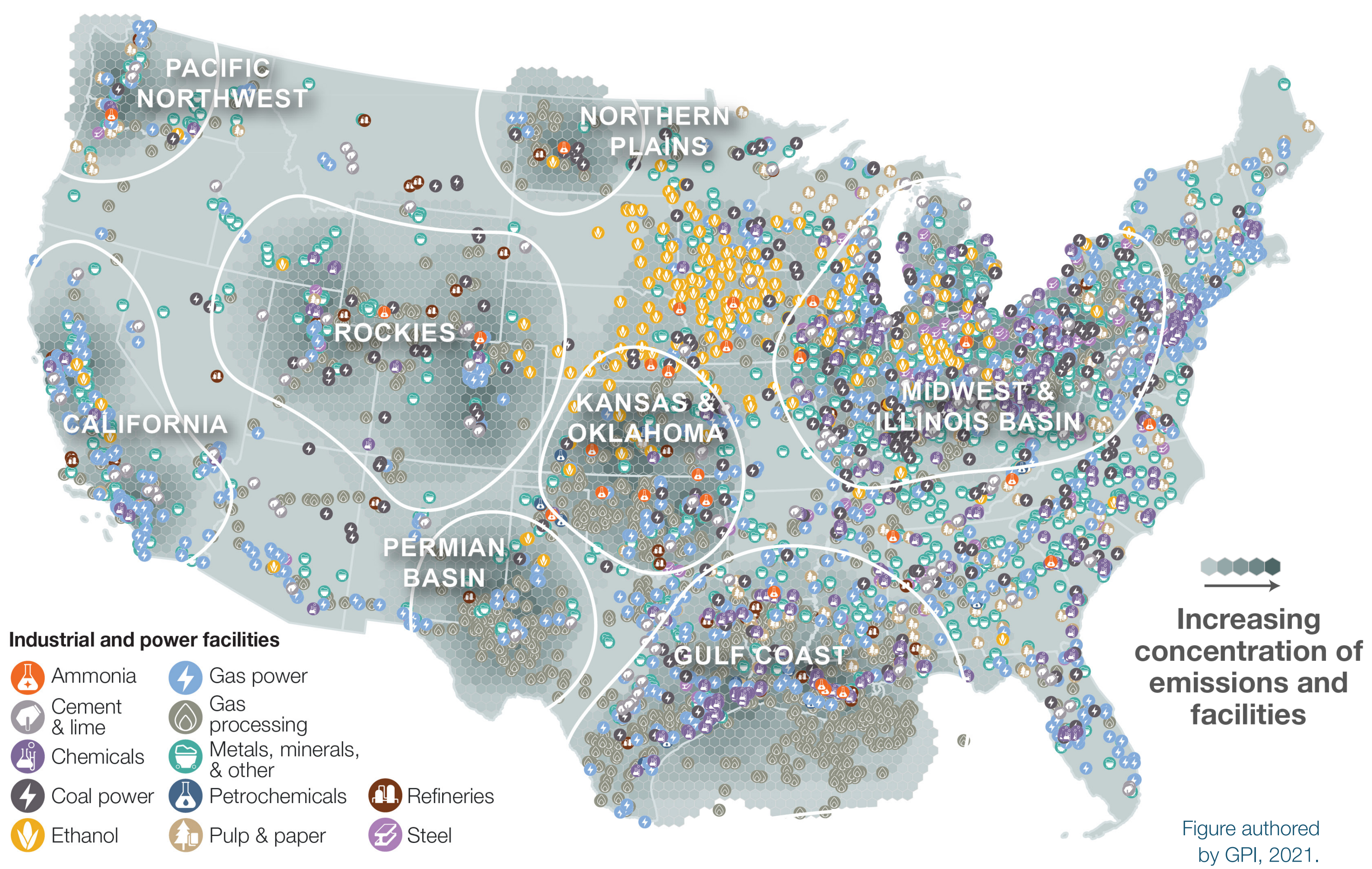


Figure authored by GPI, 2021.

Number of facilities and emissions profile by region

Row Labels	Number of Facilities	Total Emissions	Stationary Fuel Combustion	Process Emissions	Stationary Fuel Use trillion Btu
California	245	80.4	29.2	25.8	466.3
Rockies	228	146.8	20.3	17.1	276.2
Midwest & Illinois Basin	1,188	679.7	128.5	114.3	1,577.6
Kansas & Oklahoma	345	146.5	27.0	27.0	382.8
Gulf Coast	1,028	519.1	173.3	101.7	3,340.3
Northern Plains	45	35.0	5.3	1.2	23.9
Pacific Northwest	67	26.6	7.0	5.4	167.0
Permian Basin	186	44.2	11.6	9.3	138.8

Source: Analysis by GPI based on EPA GHGRP 2019 data (as of August 7, 2021). All emissions are in million metric tons CO_2e.

Regional Opportunities for Hub Development

The regions identified in this atlas include a total of 3,332 facilities across 12 primary sectors. Industrial sectors with a high total number of facilities across study regions include: gas processing; metals, minerals, and other; and ethanol production. The Midwest and Illinois Basin and the Gulf Coast are home to a particularly high concentration of industrial and power facilities, with over 1,000 facilities in each region. Coal and gas power plants currently in operation also account for a large number of facilities across the study regions.

Facilities in the study regions identified in this atlas emit a total of 1.7 Gt CO_2e per year, accounting for roughly two-thirds of the nation's total annual stationary emissions. With annual emissions of 680 Mt and 519 Mt CO_2e, respectively, the Midwest and Illinois Basin and the Gulf Coast are responsible for the greatest share of emissions among the study regions. The Rockies and Kansas and Oklahoma are the next highest emitters, each emitting around 146 Mt CO_2e per year.

Number of facilities by sector

Industry	California	Rockies	Midwest & Illinois Basin	Kansas & Oklahoma	Gulf Coast	Northern Plains	Permian Basin	Pacific Northwest
Ammonia	-	2	3	9	5	1	-	1
Cement & lime	9	10	34	8	11	-	3	2
Chemicals	5	7	80	7	109	-	-	2
Coal power plants	-	26	101	22	24	7	-	1
Ethanol	4	4	45	29	135	1	2	
Gas power plants	91	30	161	52	484	3	3	14
Gas processing	35	88	213	132	97	29	29	8
Metals, minerals & other	75	45	392	61	61	2	118	22
Petrochemicals	-	-	7	8	34	-	25	
Pulp & paper	4	1	39	5	50	-	1	10
Refineries	17	12	15	10	18	2	4	5
Steel & steel products	5	3	98	2	-	-	1	2
Total	**245**	**228**	**1,188**	**345**	**1,028**	**45**	**186**	**67**

Source: Analysis by GPI based on EPA GHGRP 2019 data (as of August 7, 2021).

Total stationary emissions

Industry	California	Rockies	Midwest & Illinois Basin	Kansas & Oklahoma	Gulf Coast	Northern Plains	Permian Basin	Pacific Northwest
Ammonia	-	0.81	3.9	7.8	13.7	3.1	1.3	0.18
Cement & lime	7.8	5.1	26.3	4.4	7.9	-	6.7	0.37
Chemicals	0.19	0.87	12.3	3.9	22.2	-	1.2	0.13
Coal power plants	-	98.5	364.0	74.8	119.2	27.9	17.5	8.0
Ethanol	0.99	0.8	27.9	9.5	127.5	0.26	12.9	-
Gas power plants	28.6	11.9	85.8	19.7	60.5	0.83	1.2	7.0
Gas processing	7.7	12.3	14.9	8.0	6.7	1.9	0.29	0.29
Metals, minerals & other	4.0	10.1	51.7	3.7	51.8	0.14	3.0	2.6
Petrochemicals	-	-	1.6	1.3	10.2	-	0.07	-
Pulp & paper	0.72	0.04	5.2	0.97	95.6	-	-	1.2
Refineries	30.0	5.7	24.4	12.5	3.9	0.83	-	6.6
Steel & steel products	0.3	0.61	61.8	0.14	-	-	-	0.28
Total	**80.4**	**146.8**	**679.7**	**146.5**	**519.1**	**35.0**	**44.2**	**26.6**

Source: Analysis by GPI based on EPA GHGRP 2019 data (as of August 7, 2021). All emissions are in million metric tons CO_2e.

Number of Facilities and Total Emissions
by Region and Industry

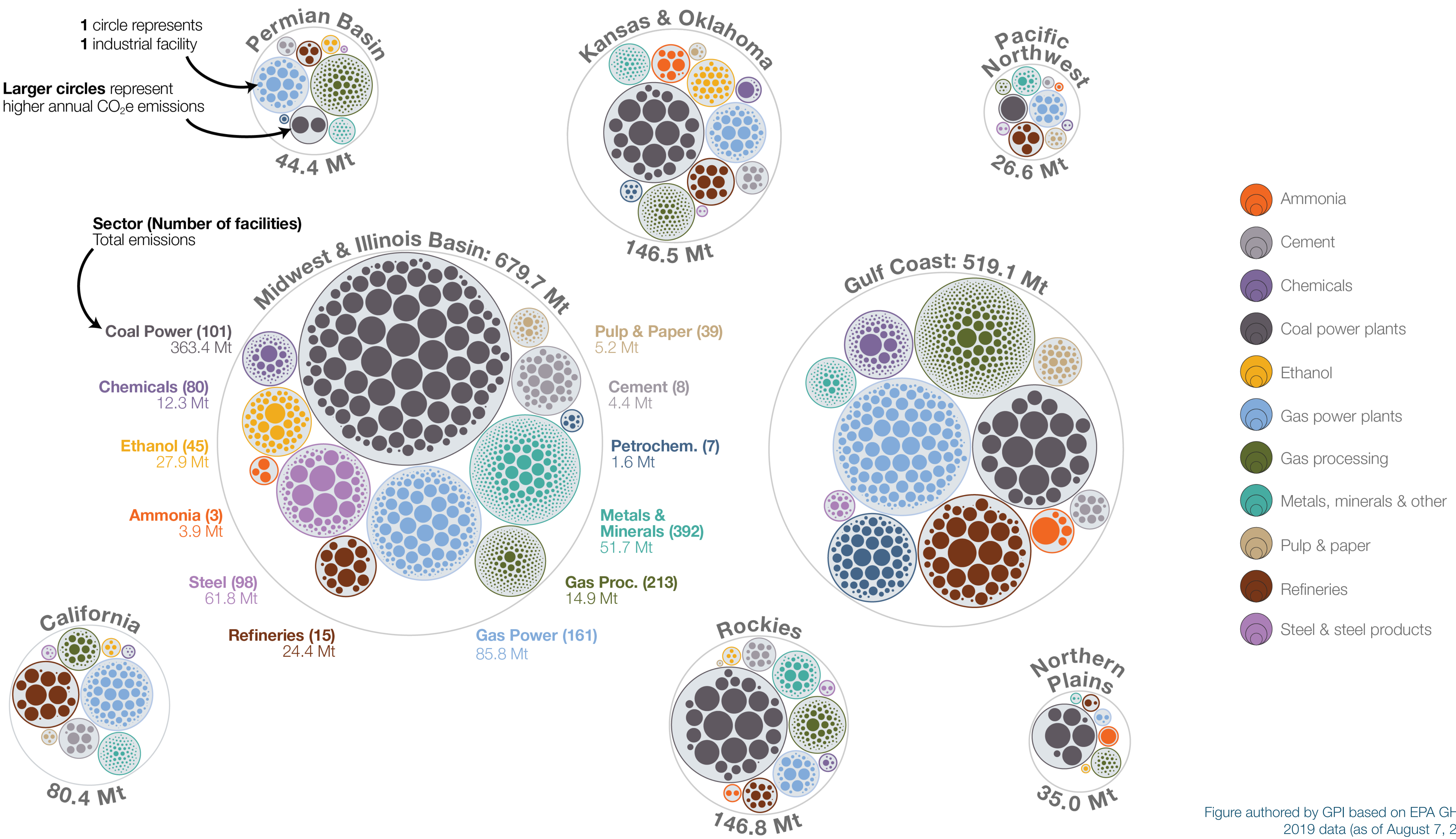


Figure authored by GPI based on EPA GHGRP 2019 data (as of August 7, 2021).

Carbon and Hydrogen Hubs

Identified potential carbon and hydrogen hubs

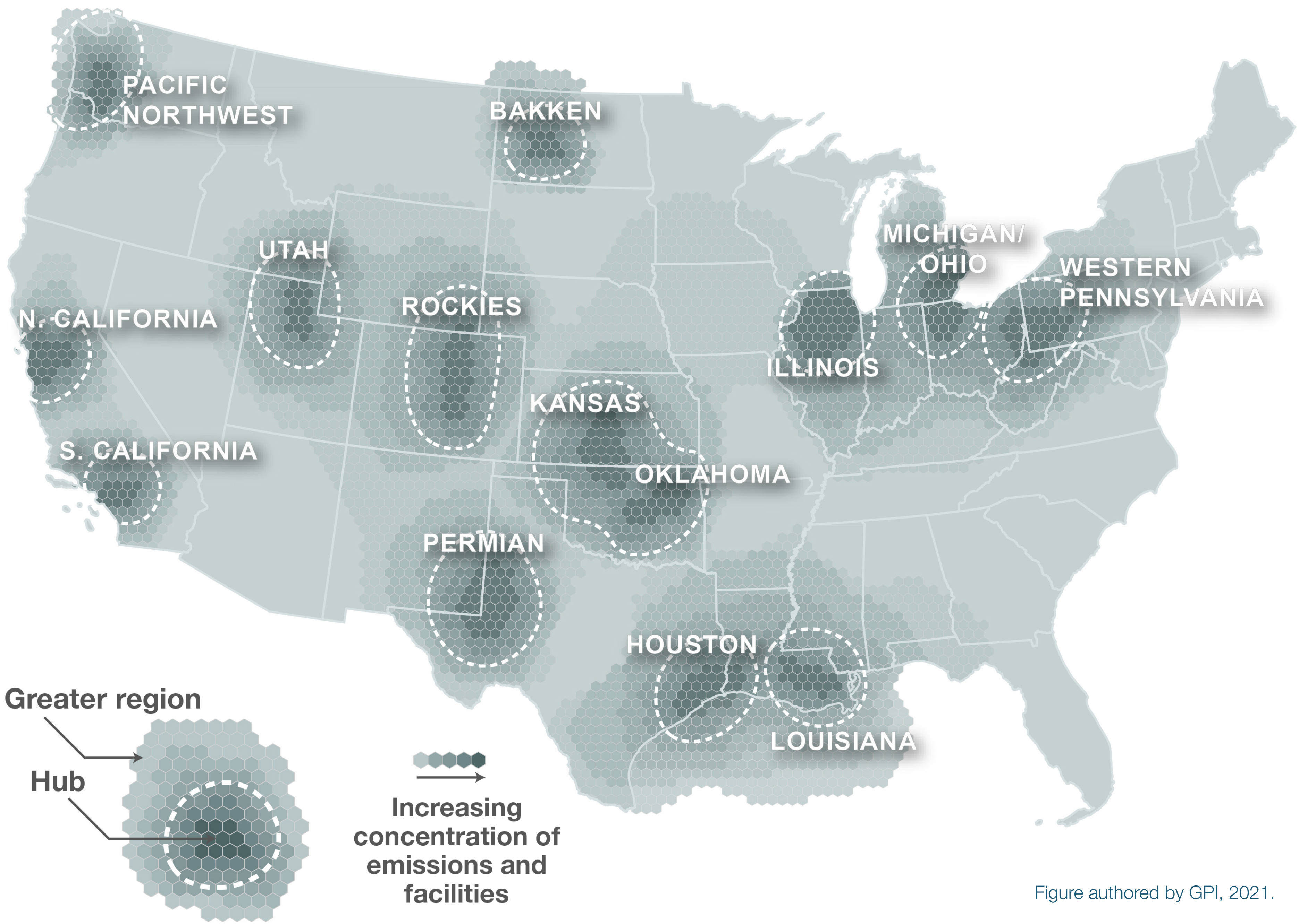


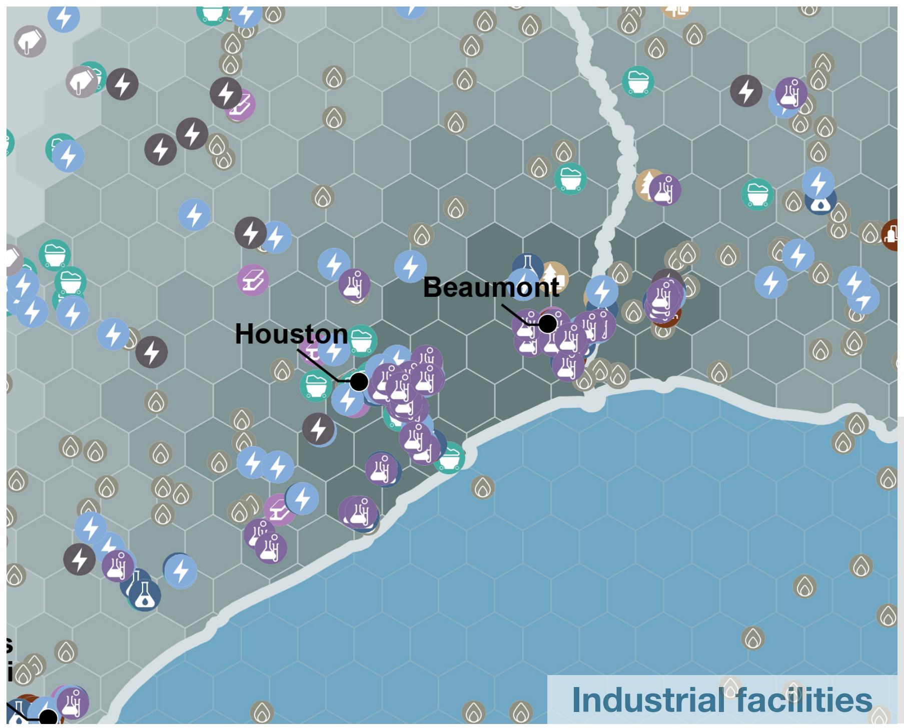
Figure authored by GPI, 2021.

This atlas identifies 14 regional hubs with high concentrations of key economic, geographic, and geologic factors that can catalyze development of carbon and hydrogen hubs. These hubs are profiled in the following pages of this atlas.

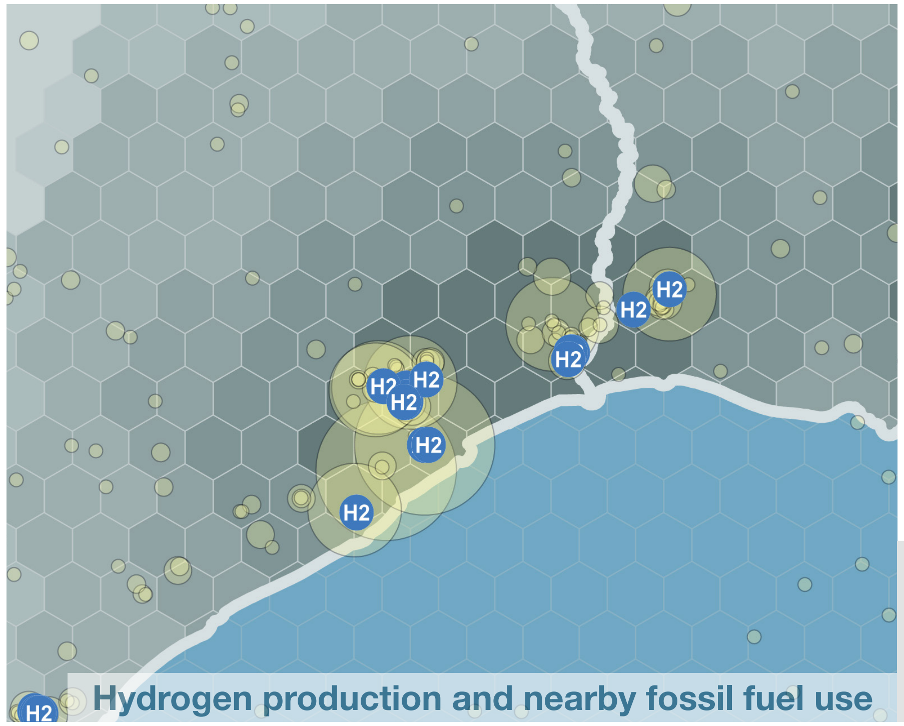
Houston

Houston is home to one of the largest industrial concentrations of petrochemical and fossil fuel-related operations in the nation. Its proximity to carbon utilization in Texas, the Midcontinent region, and the Gulf Coast make Houston a promising candidate for carbon capture, utilization, CO_2 transport infrastructure buildout, and industrial decarbonization.

Industrial Emissions and Fossil Fuel Use



Houston is home to a high number and concentration of diverse industries, including chemicals and petrochemicals production, natural gas processing, and petroleum refining. Facilities in the Houston hub emit 156.2 million metric tons (Mt) of CO_2e annually, including 77.4 Mt from stationary combustion and 31.0 Mt from process emissions. There are 57 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There are **14 hydrogen-producing facilities** in the Houston hub already co-located with the central corridor of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 1.4 billion MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

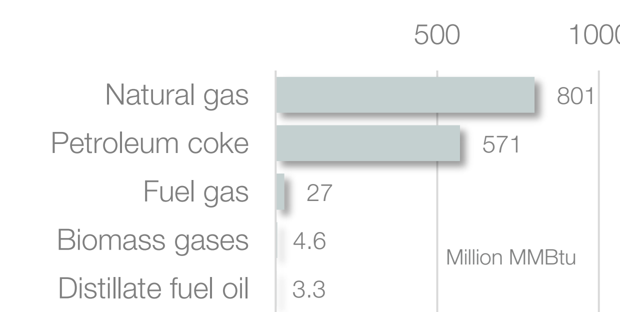
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Chemicals	53	6.3	5.3	1.0
Coal power plants	2	15.0	< 0.1	-
Gas power plants	24	31.2	3.8	< 0.1
Gas processing	42	22.0	10.8	11.2
Metals, minerals & other	18	0.8	0.8	< 0.1
Petrochemicals	34	28.8	23.6	5.2
Pulp & paper	2	0.7	0.4	0.3
Refineries	16	51.2	32.6	13.3
Steel & steel products	2	0.1	0.1	< 0.1
Total	**193**	**156.2**	**77.4**	**31.0**

All emissions are in million metric tons CO_2e.

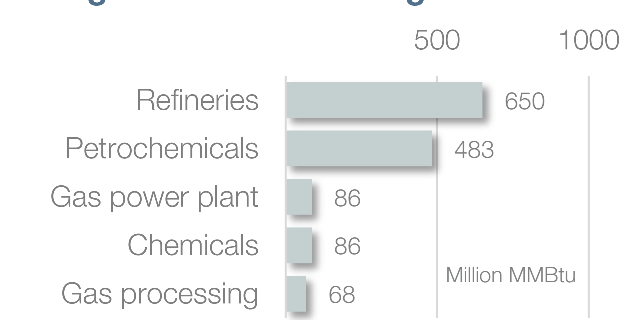
The top industrial fuels consumed in the Houston hub include natural gas at 801 million MMBtu per year and petroleum coke at 571 million MMBtu per year. Refineries and petrochemicals plants are the largest consumers of fossil fuels in this regional hub, consuming 650 million MMBtu and 488 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



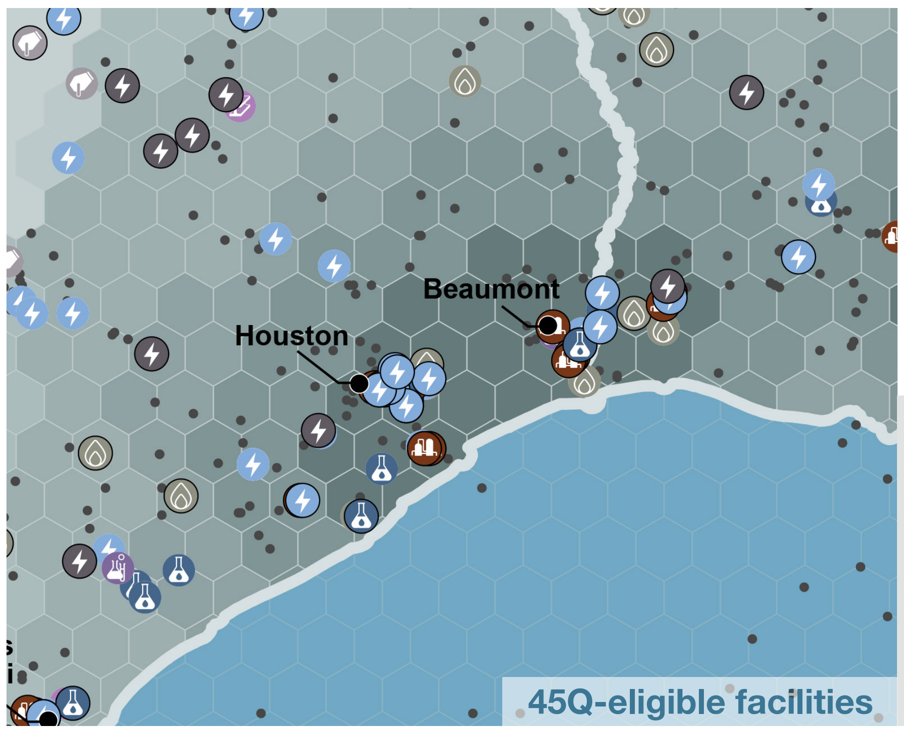
Largest fuel-consuming industries



Houston

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

Carbon Capture and Storage

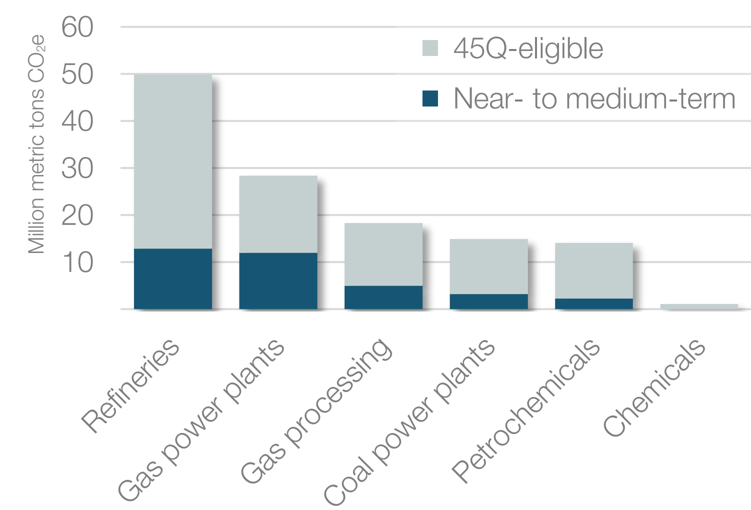


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 57 industrial and power facilities in the Houston hub that meet emissions thresholds for Section 45Q eligibility, 39 have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

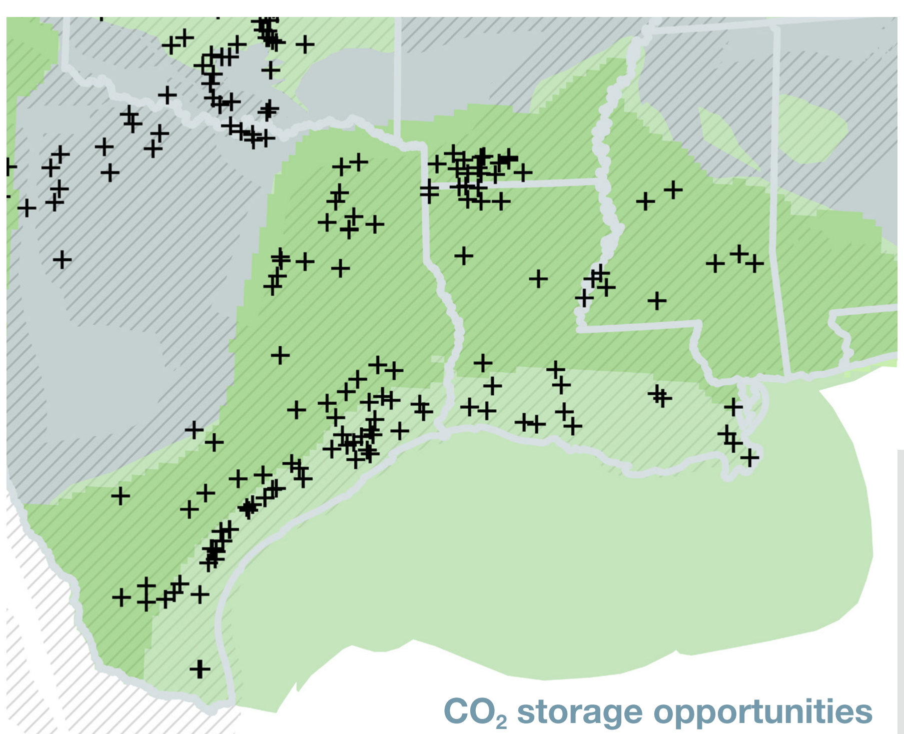
45Q-eligible facilities by industry

- Chemicals
- Petrochemicals
- Coal power
- Refineries
- Gas power
- Near- to medium-term
- Gas processing
- Additional emitting facility

Carbon capture opportunities



- Industrial and power facilities emit **156.2 Mt CO_2e per year**
- **45Q-eligible** facilities emit **127.4 Mt CO_2e per year**
- **35.3 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

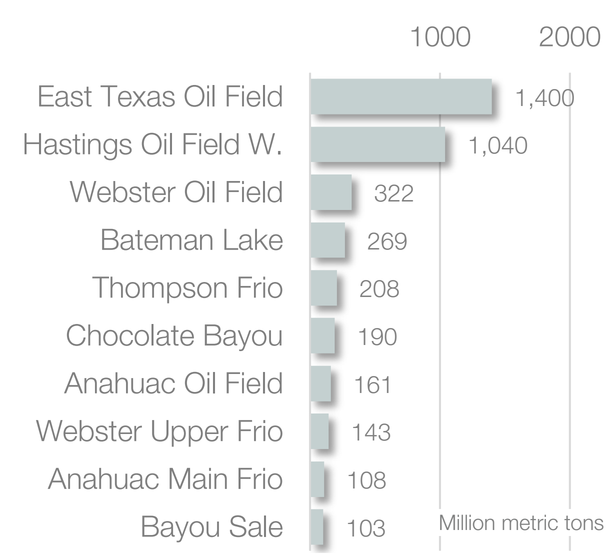


The area surrounding Houston has potential to act as a major carbon storage destination for capture facilities and carbon removal throughout the country. The Texas gulf has potential to store 1.6 trillion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins such as oil and gas fields. The Houston hub can also access storage elsewhere in Texas, Louisiana, and the Gulf.

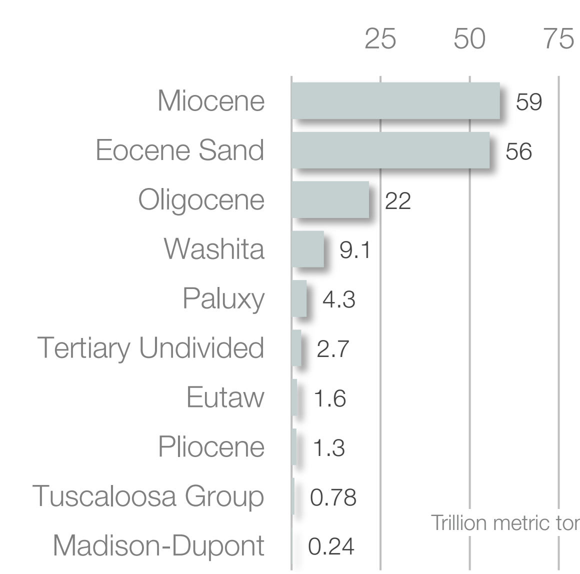
Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

Fossil storage formations
by CO_2 storage capacity



Saline storage formations
by CO_2 storage capacity



Houston

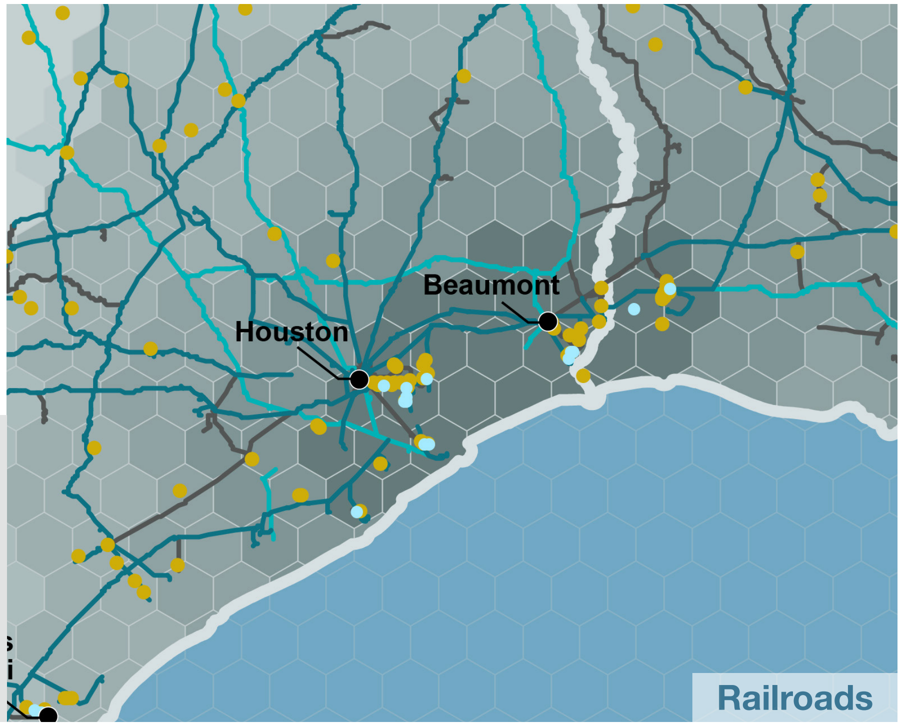
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

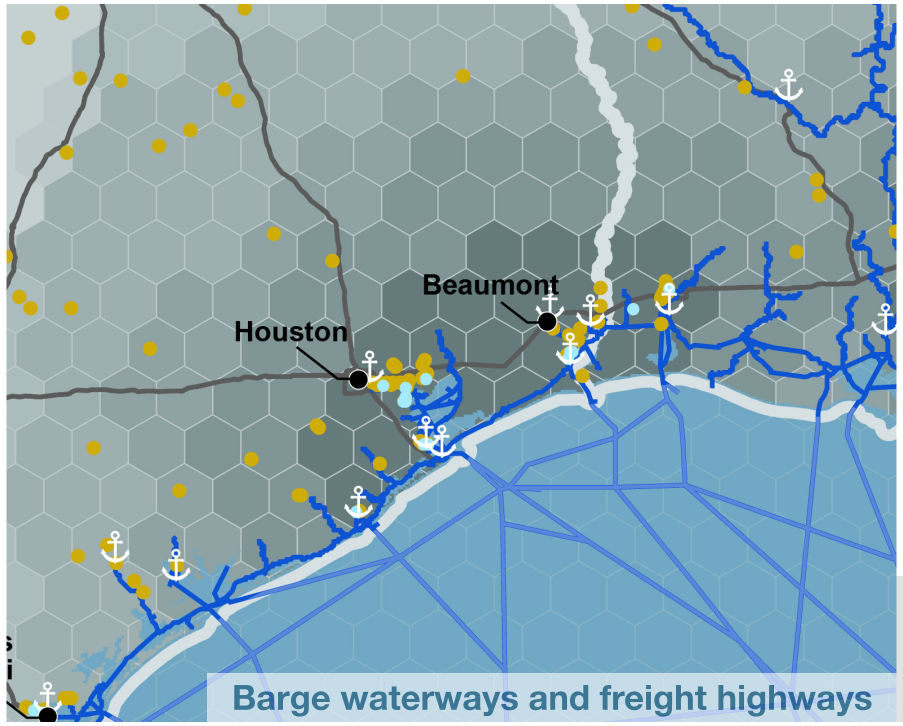
Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Houston hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





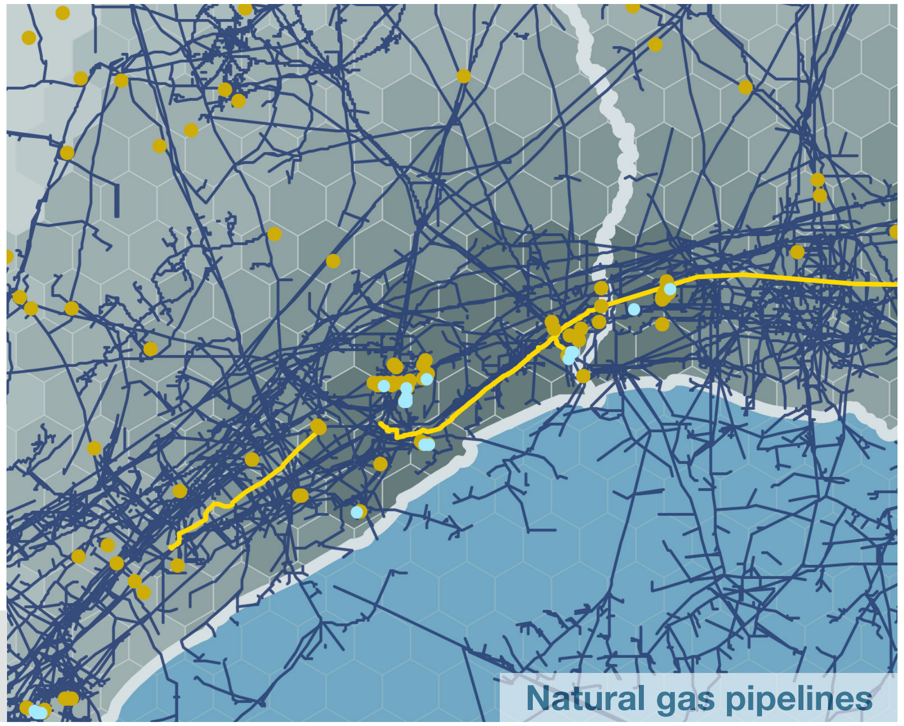
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With several major ports and extensive access to shipping channels, Houston has unique access to global and domestic markets for carbon and hydrogen.

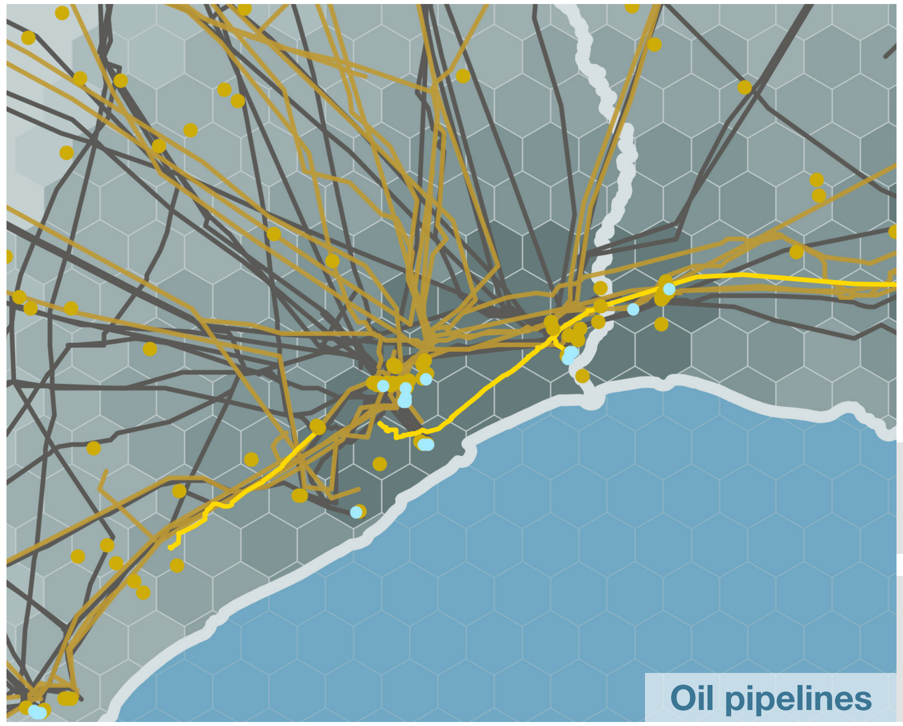
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Houston hub currently has 7,892 miles of natural gas pipelines and 171 miles of CO_2 pipelines.

Infrastructure	Miles
Natural gas pipelines	7,892
Oil pipelines	11,494
Existing CO_2 pipelines	171

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Houston hub's 11,494 miles of oil pipelines to achieve efficient buildout.

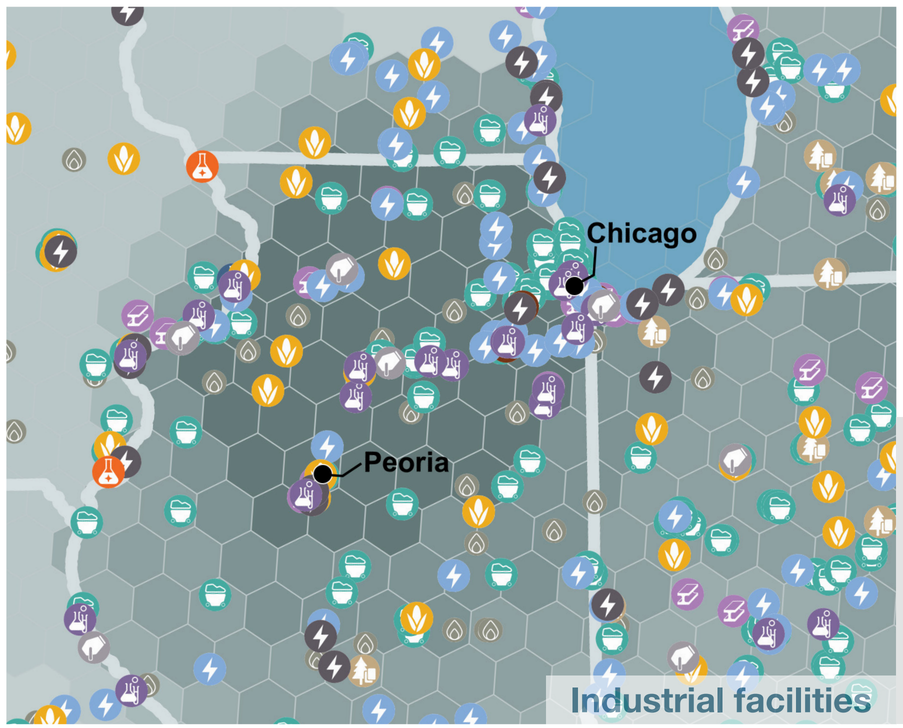
- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

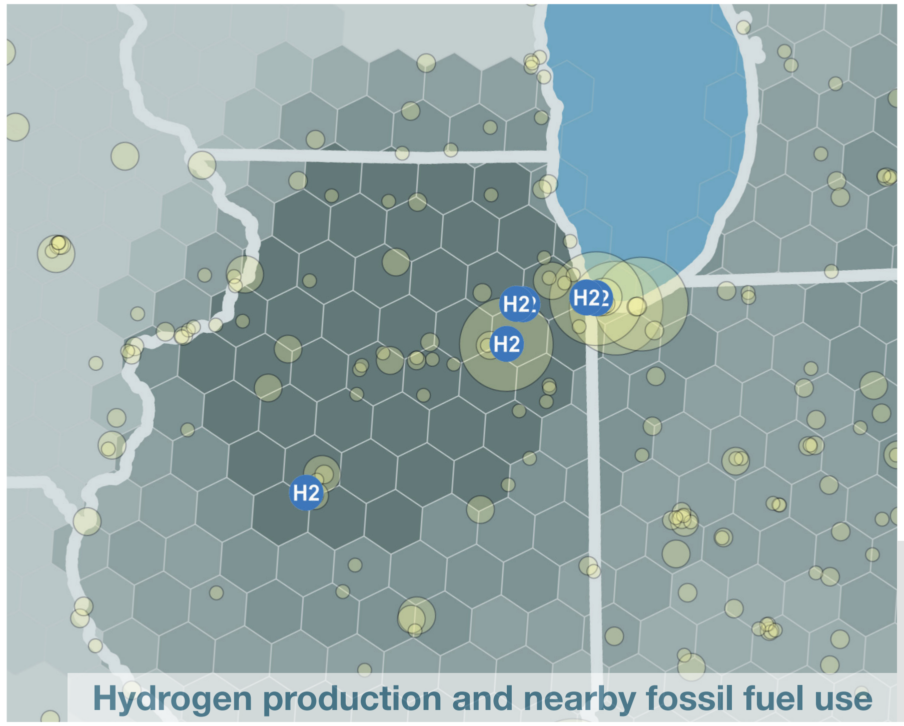
Illinois

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity make Illinois a potential launching point for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use



Illinois is home to a high number and concentration of diverse industries, including steel and steel products manufacturing, ethanol production, and chemicals production. Facilities in the Illinois hub emit 78.1 million metric tons (Mt) of CO_2e annually, including 33.6 Mt from stationary combustion and 21.6 Mt from process emissions. There are 43 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There are **six hydrogen-producing facilities** in the Illinois hub, five of which are co-located with the area's central cluster of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 367 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

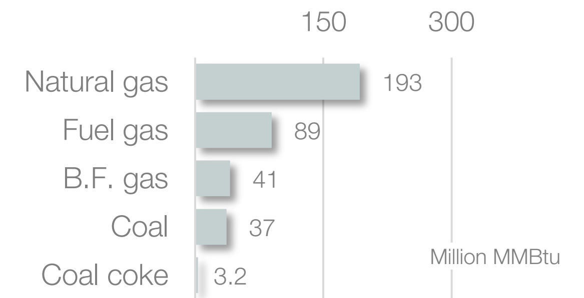
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ammonia	2	2.4	0.8	1.6
Cement	5	2.7	0.8	1.8
Chemicals	16	1.5	0.7	0.9
Coal power plants	7	13.9	< 0.1	-
Ethanol	13	10.5	5.0	5.5
Gas power plants	27	10.0	0.9	0.0
Gas processing	18	3.1	0.7	2.4
Metals, minerals & other	50	3.4	3.1	0.4
Petrochemicals	2	0.7	0.7	-
Refineries	3	9.2	5.0	2.9
Steel & steel products	14	22.0	15.9	6.1
Total	**157**	**78.1**	**33.6**	**21.6**

All emissions are in million metric tons CO_2e.

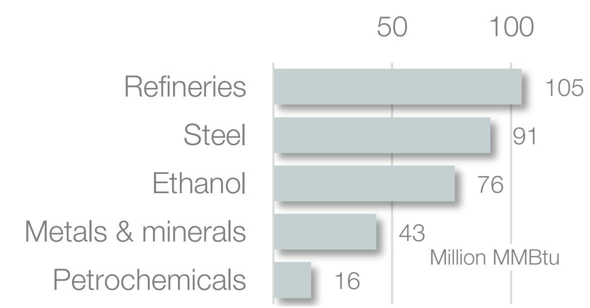
The top industrial fuels consumed in the Illinois hub include natural gas at 193 million MMBtu per year and fuel gas at 189 million MMBtu per year. Refineries and steel plants are the largest consumers of fossil fuels in this regional hub, consuming 105 million MMBtu and 91 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



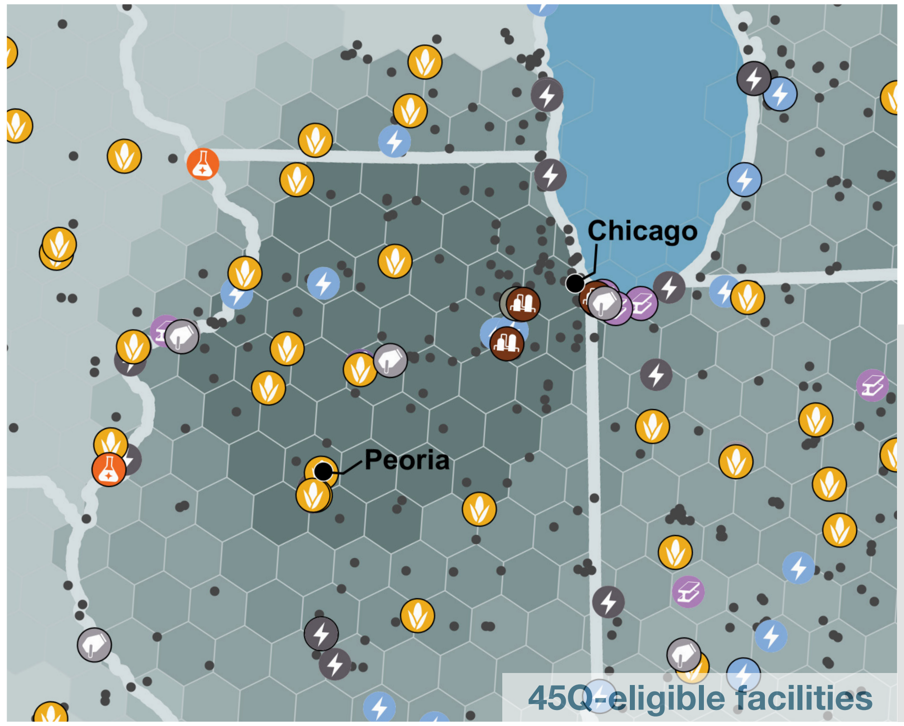
Largest fuel-consuming industries



Illinois

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

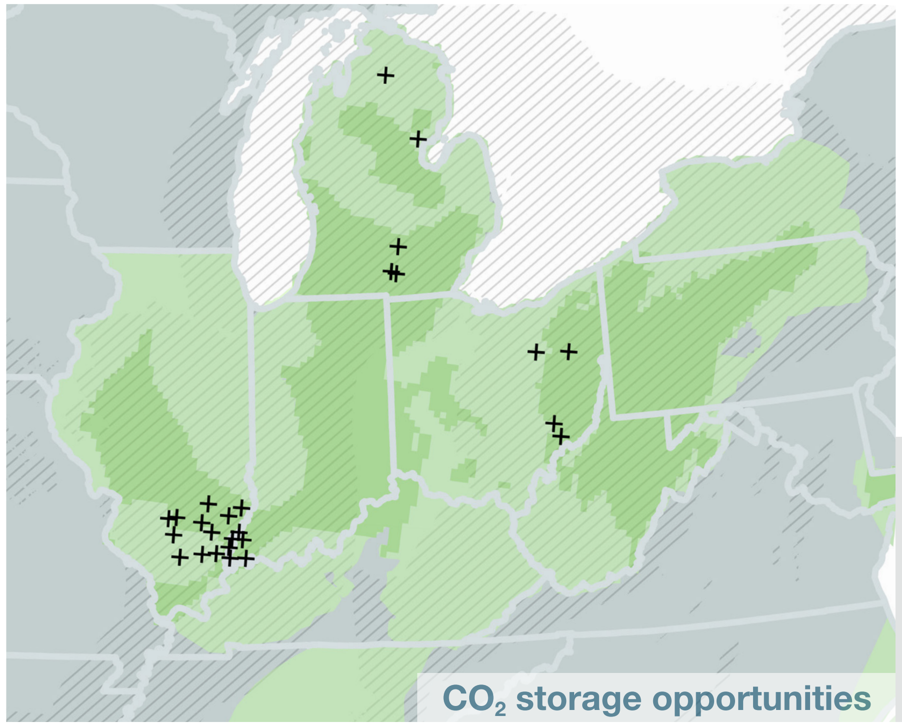
Carbon Capture and Storage



The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 43 industrial and power facilities in the Illinois hub that meet emissions thresholds for Section 45Q eligibility, 25 have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

45Q-eligible facilities by industry

- Ammonia
- Cement & lime
- Chemicals
- Coal power
- Ethanol
- Gas power
- Gas processing
- Refineries
- Steel
- Near- to medium-term
- Additional emitting facility

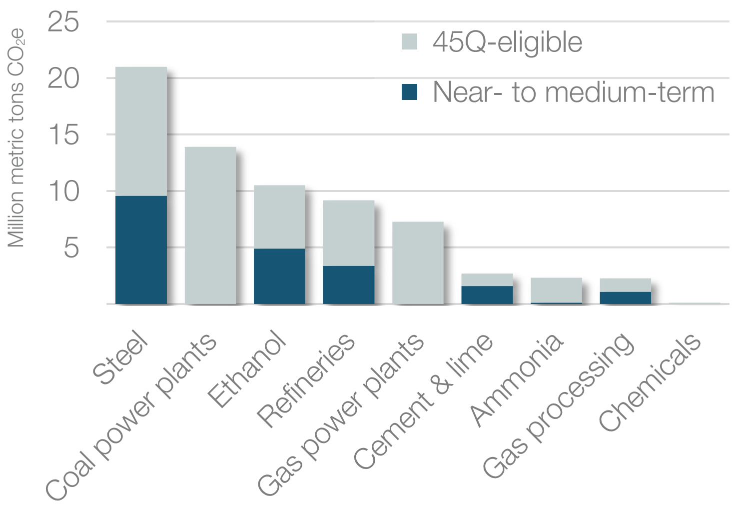


Illinois has potential to act as a major carbon storage destination for capture facilities and carbon removal throughout the Midwest and Mid-Atlantic regions. The state of Illinois has potential to store 87 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins.

Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

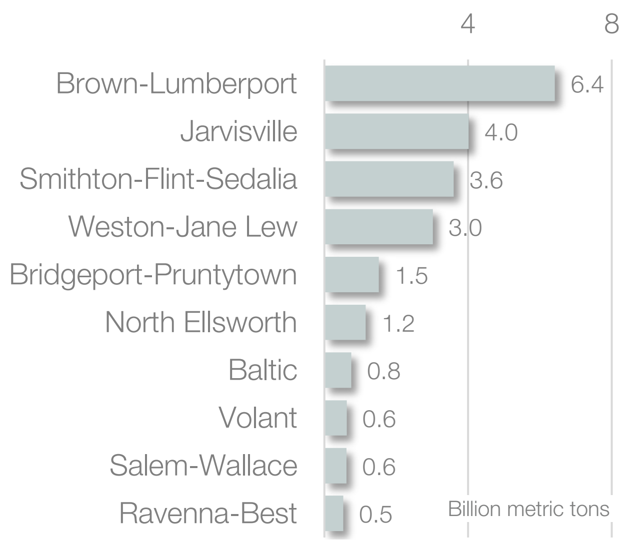
Carbon capture opportunities



- Industrial and power facilities emit **78.1 Mt CO_2e per year**
- **45Q-eligible** facilities emit **69.1 Mt CO_2e per year**
- **21.4 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

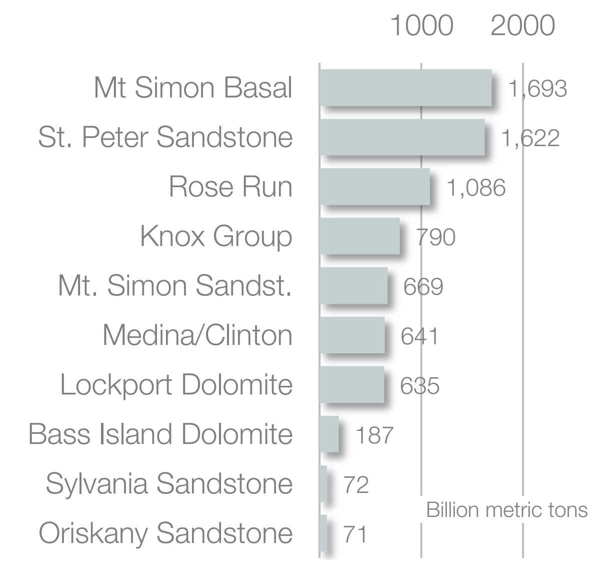
Fossil storage formations

by CO_2 storage capacity



Saline storage formations

by CO_2 storage capacity



US CARBON AND HYDROGEN HUBS ATLAS GREAT PLAINS INSTITUTE

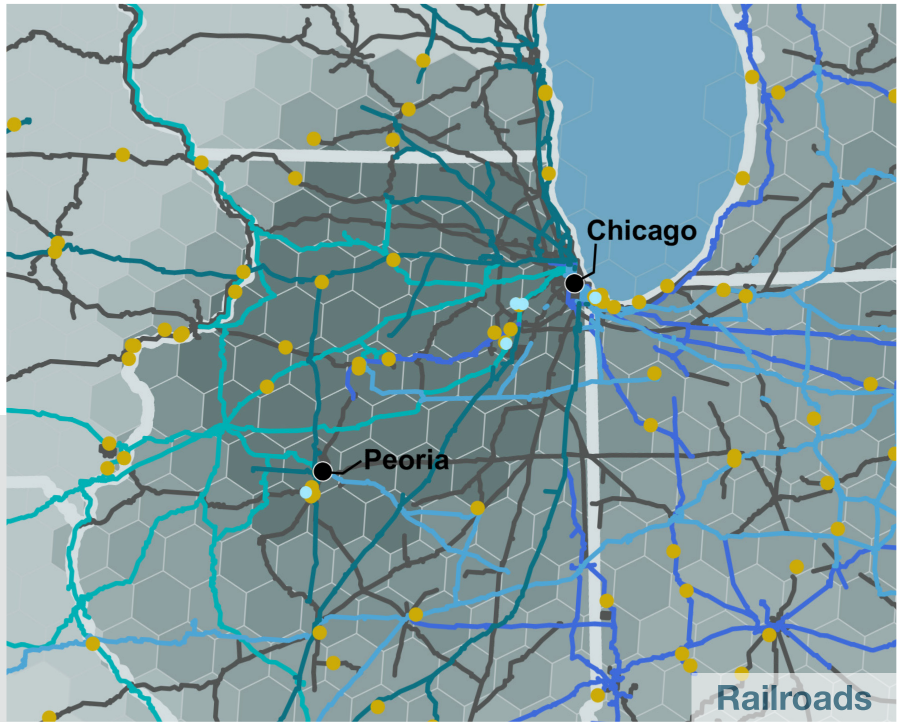
Illinois

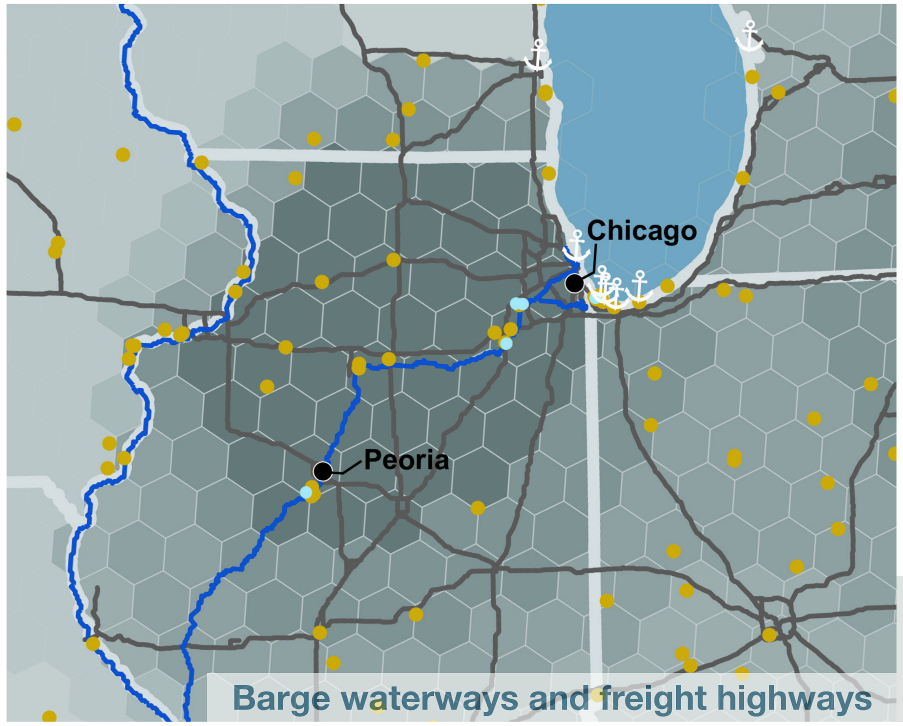
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Illinois hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks
- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





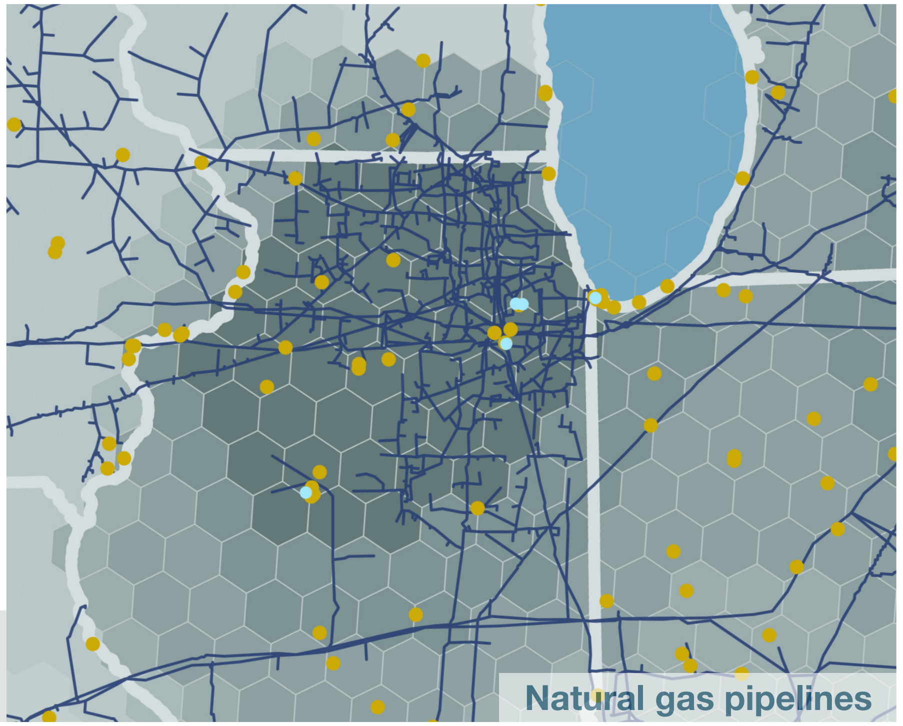
Freight trucks and barges are both flexible carbon and hydrogen transport options, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With major ports on Lake Michigan and access to key shipping channels along the Mississippi and Illinois rivers, Illinois is well-positioned to access domestic and international markets for carbon and hydrogen.

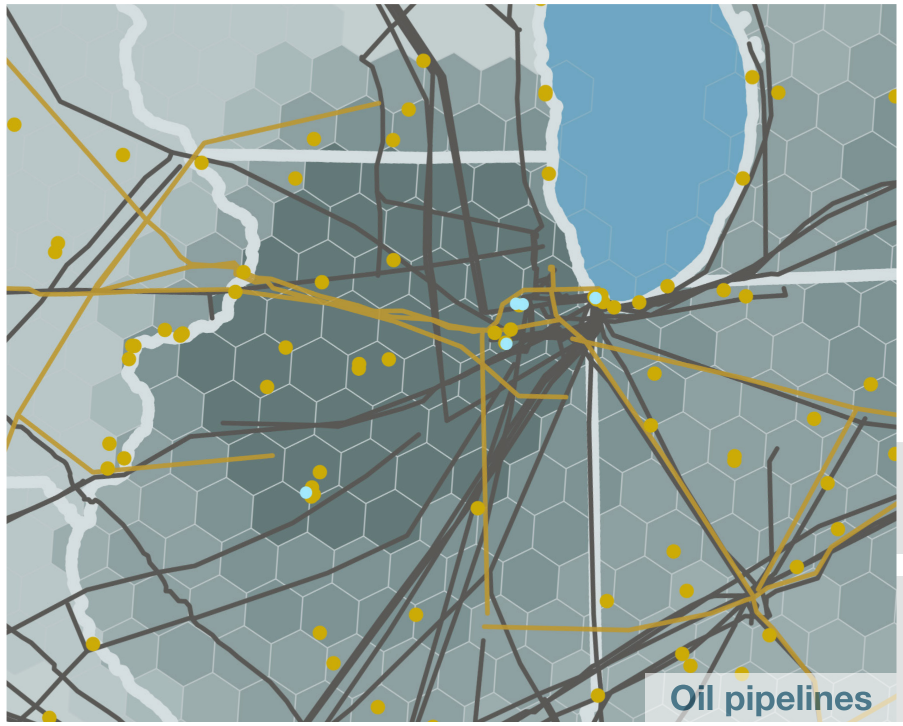
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Illinois hub currently has 5,188 miles of natural gas pipelines.

Infrastructure	Miles
Natural gas pipelines	5,188
Oil pipelines	8,664

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Illinois hub's 8,664 miles of oil pipelines to achieve efficient buildout.

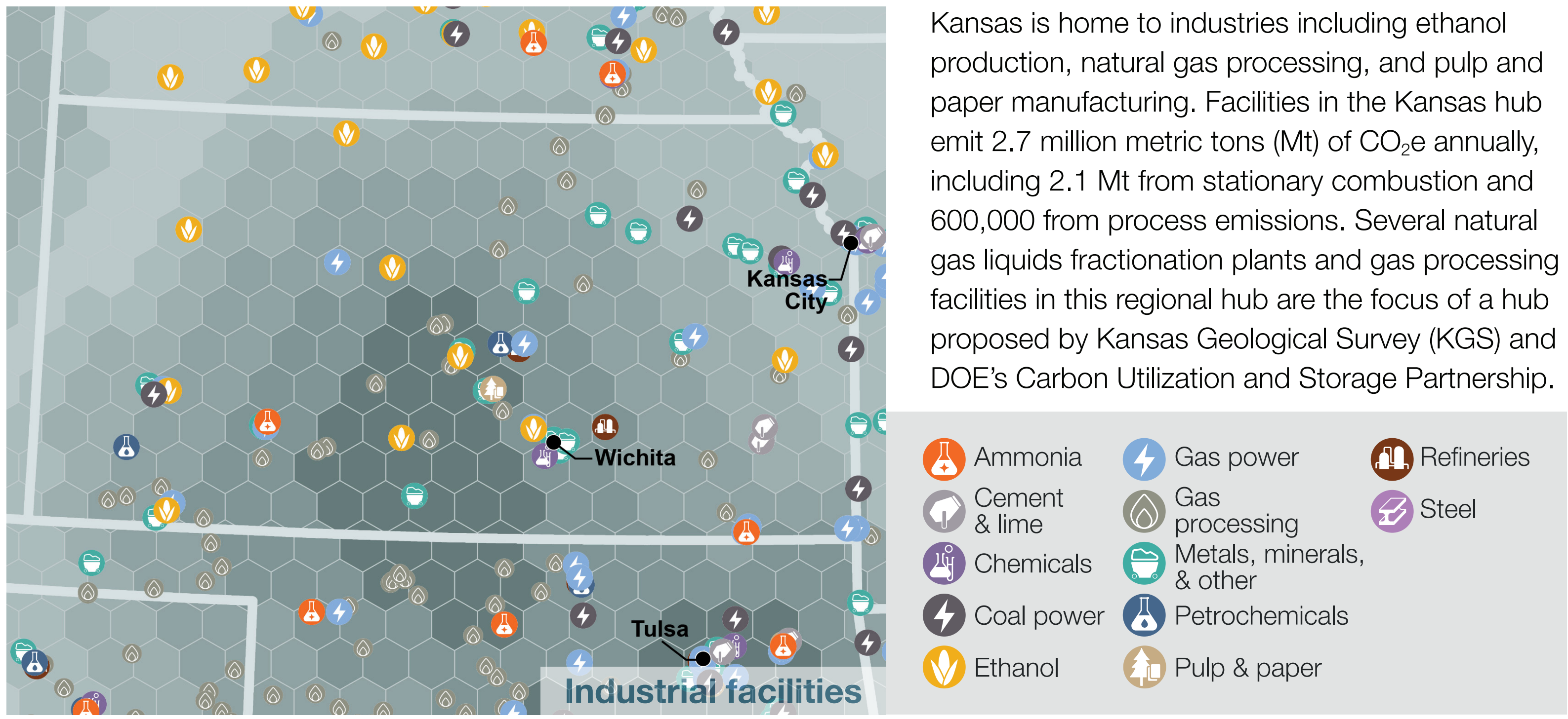
- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

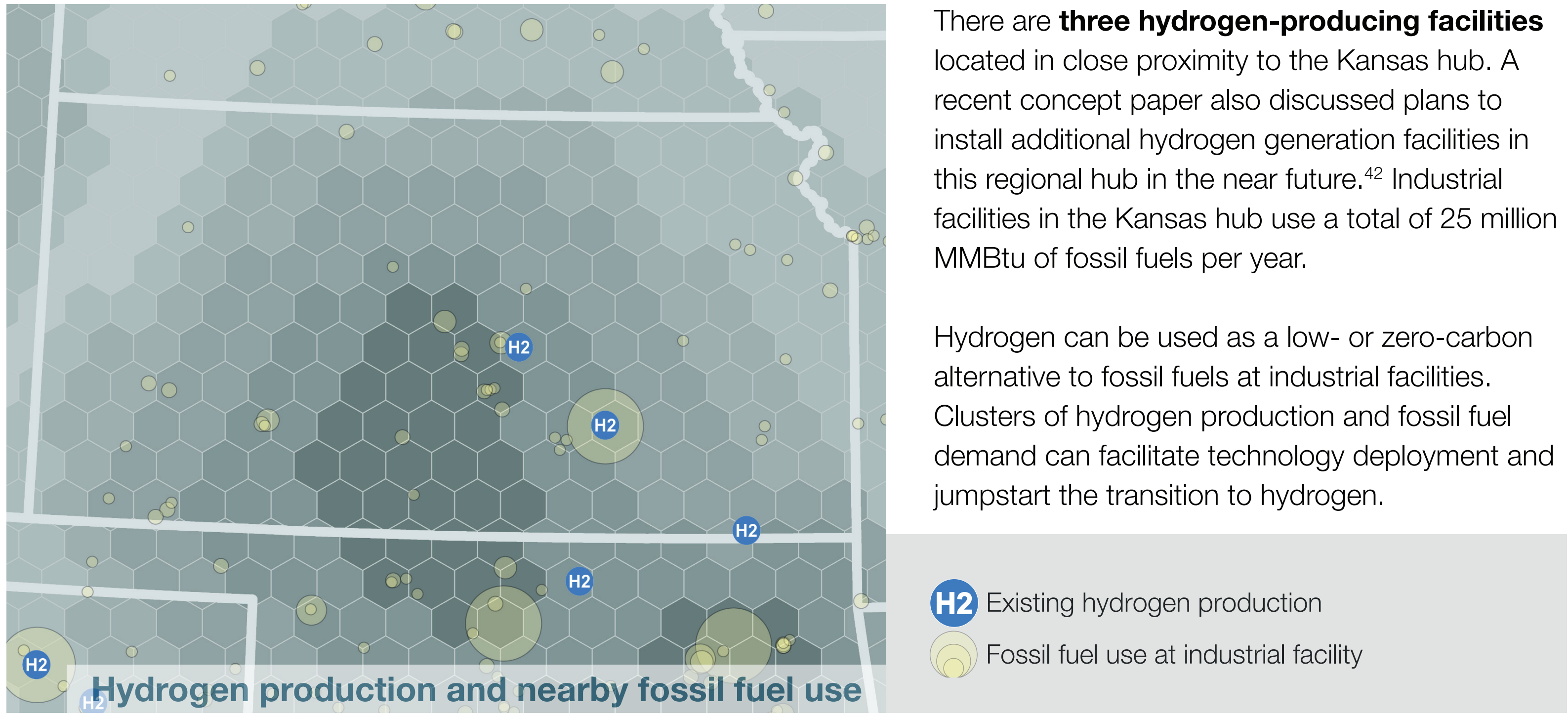
Kansas

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity give Kansas unique advantages in jumpstarting investment in carbon capture and low-carbon hydrogen deployment. The geographic extent of the Kansas hub is based on the CCUS hub proposed by Kansas Geological Survey and DOE's Carbon Utilization and Storage Partnership.

Industrial Emissions and Fossil Fuel Use



Kansas is home to industries including ethanol production, natural gas processing, and pulp and paper manufacturing. Facilities in the Kansas hub emit 2.7 million metric tons (Mt) of CO_2e annually, including 2.1 Mt from stationary combustion and 600,000 from process emissions. Several natural gas liquids fractionation plants and gas processing facilities in this regional hub are the focus of a hub proposed by Kansas Geological Survey (KGS) and DOE's Carbon Utilization and Storage Partnership.



There are **three hydrogen-producing facilities** located in close proximity to the Kansas hub. A recent concept paper also discussed plans to install additional hydrogen generation facilities in this regional hub in the near future.[42] Industrial facilities in the Kansas hub use a total of 25 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

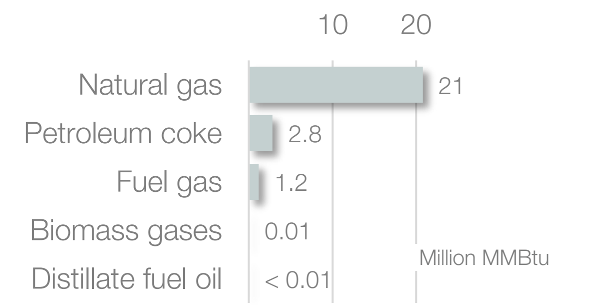
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ethanol	2	0.6	0.1	0.4
Gas processing	18	2.0	1.7	0.2
Metals, minerals & other	4	0.2	0.2	-
Pulp & paper	1	< 0.1	< 0.1	-
Total	**25**	**2.7**	**2.1**	**0.6**

All emissions are in million metric tons CO_2e.

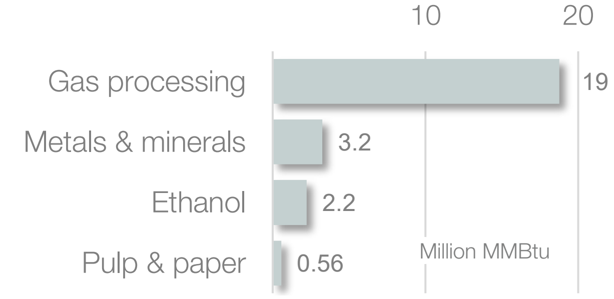
The top industrial fuels consumed in the Kansas hub include natural gas at 21 million MMBtu per year and petroleum coke at 2.8 million MMBtu per year. Gas processing plants are the largest consumers of fossil fuels in this regional hub, consuming 19 million MMBtu of fossil fuels per year.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



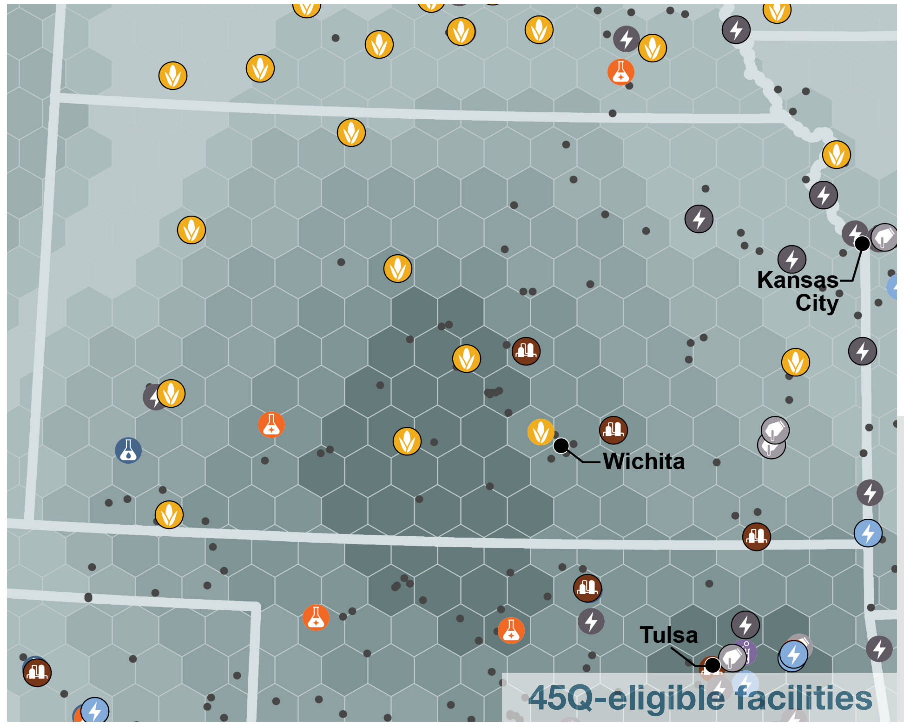
Largest fuel-consuming industries



Kansas

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

Carbon Capture and Storage

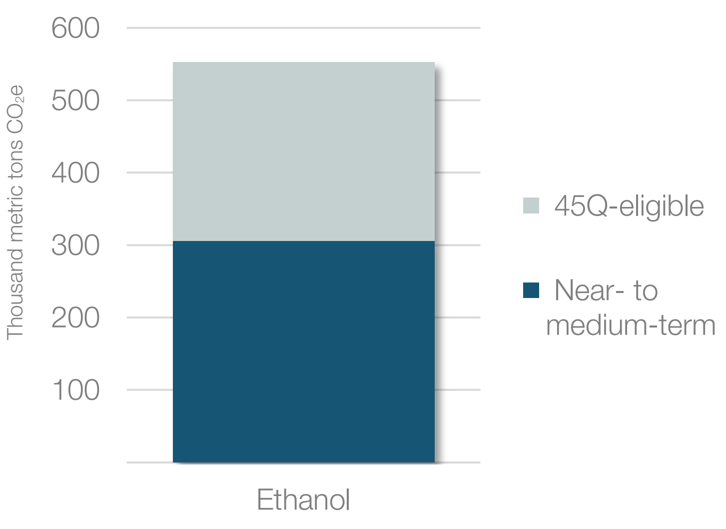


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. There are two industrial facilities in the Kansas hub that meet emissions thresholds for Section 45Q eligibility. Both facilities have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

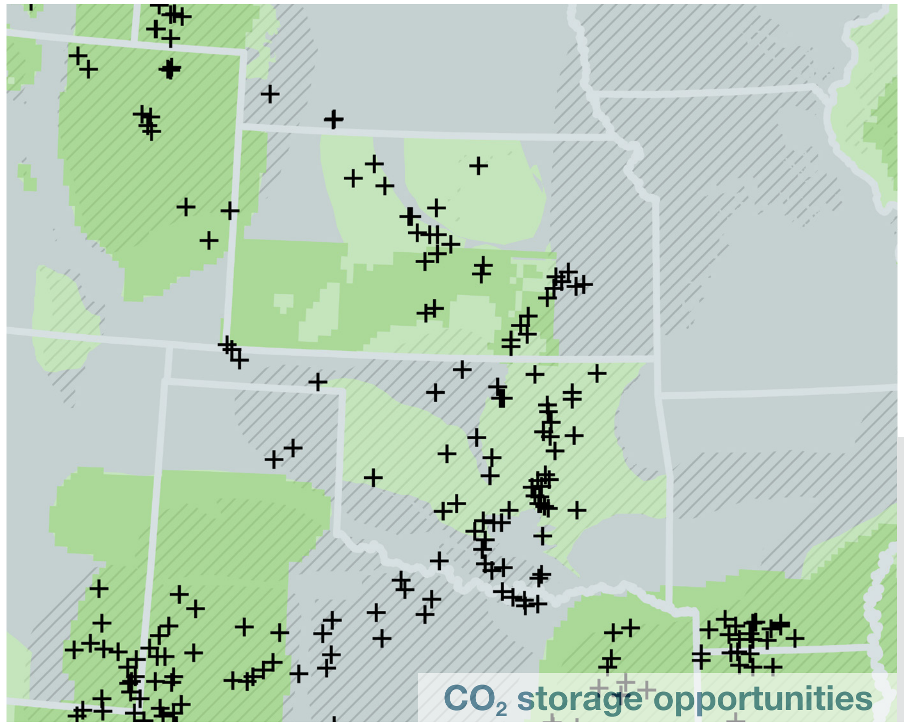
45Q-eligible facilities by industry

- Ethanol
- Near- to medium-term
- Additional emitting facility

Carbon capture opportunities



- Industrial and power facilities emit **2.7 Mt CO_2e per year**
- **45Q-eligible** facilities emit **600,000 mt CO_2e per year**
- **300,000 mt CO_2 per year** are **capturable** in the **near- to medium-term**



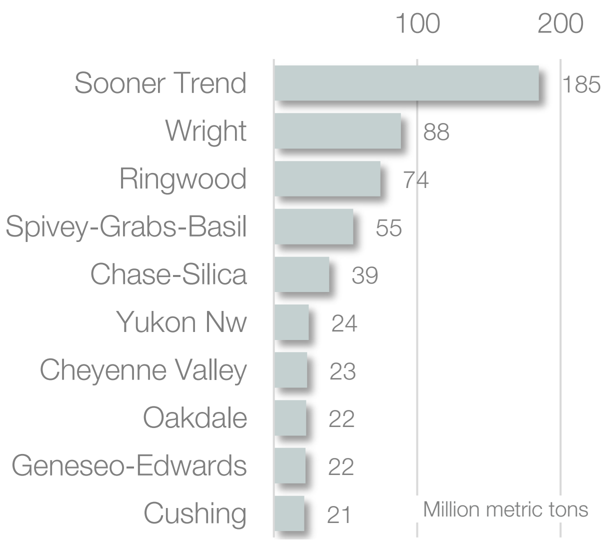
Kansas has potential to act as a major carbon storage destination for capture facilities and carbon removal. The state of Kansas has potential to store 37 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins such as oil and gas fields. The Kansas hub is the focus of a KGS and DOE study aiming to identify potential CO_2 reservoirs for long-term geologic storage.

Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

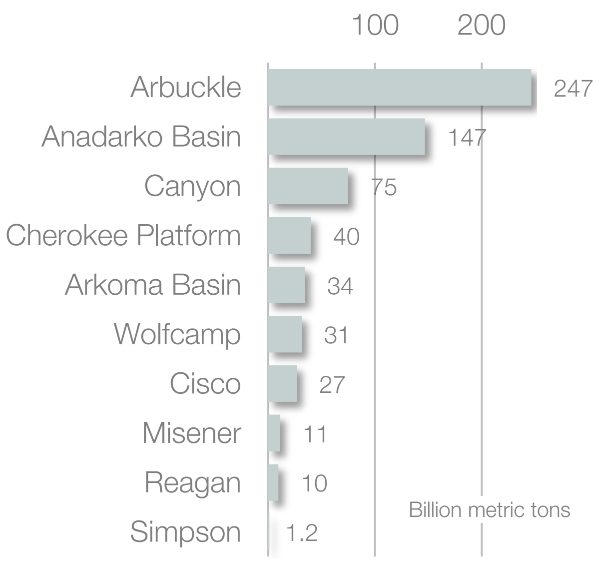
Fossil storage formations

by CO_2 storage capacity



Saline storage formations

by CO_2 storage capacity



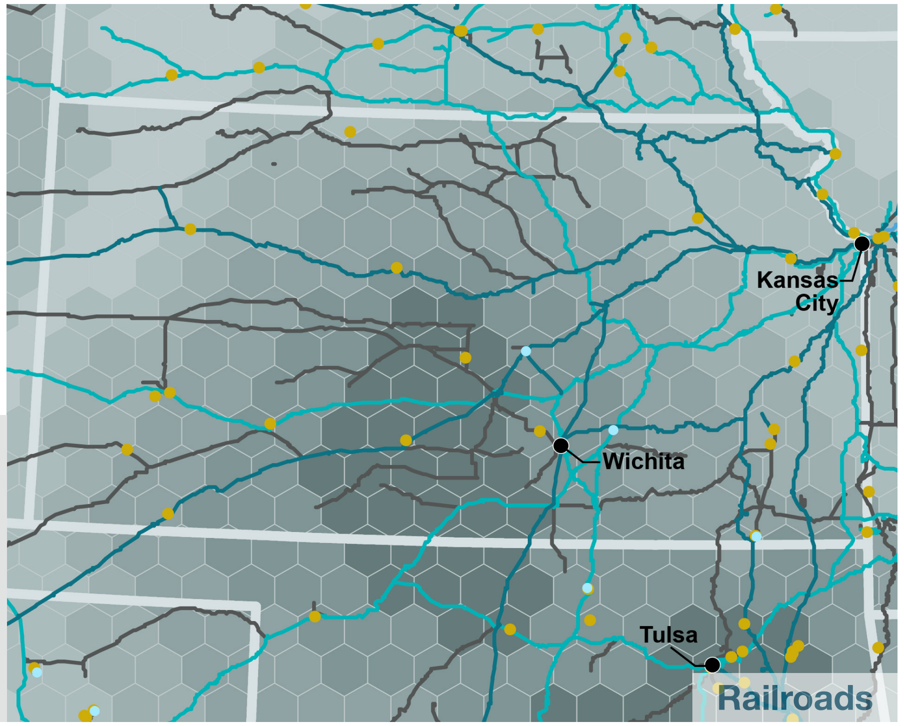
Kansas

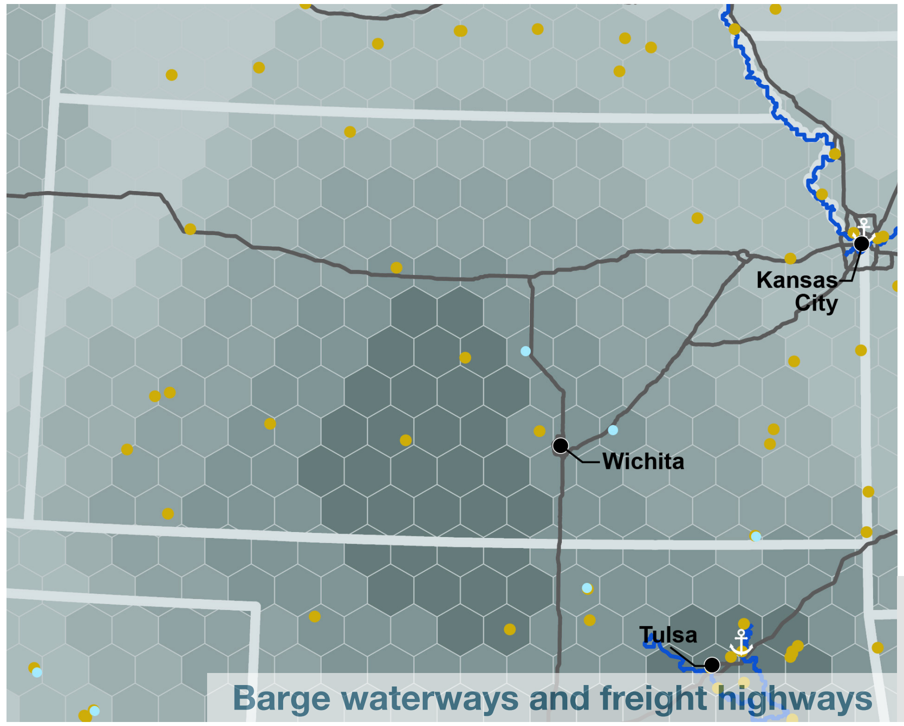
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Kansas hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks
- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. Major ports along rivers in the Midcontinent region can connect Kansas with broader markets for carbon and hydrogen.

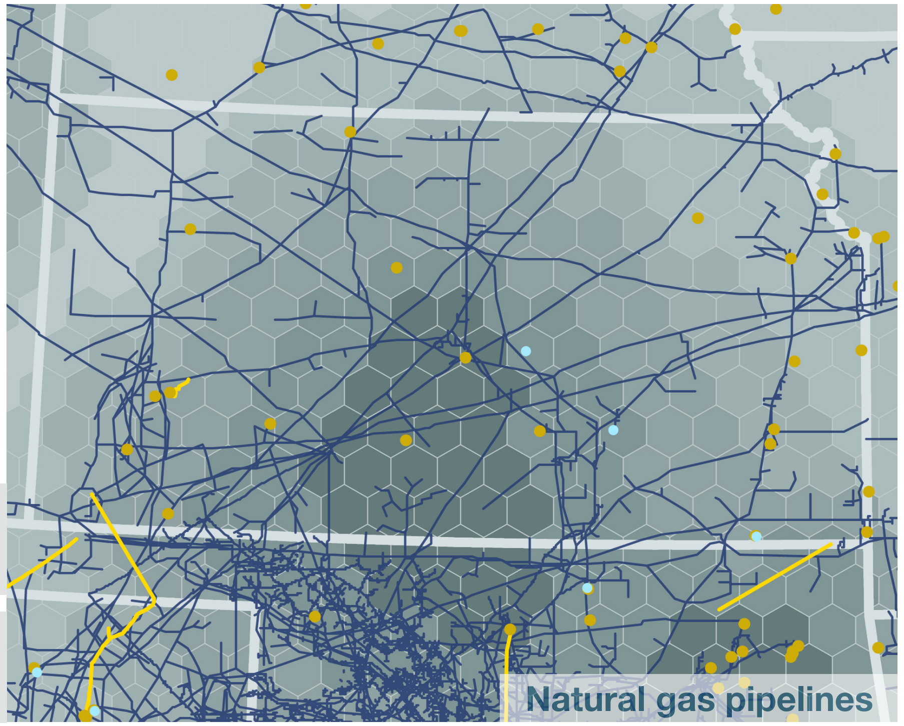
- Interstate highway
- Navigable waterway
- Major port

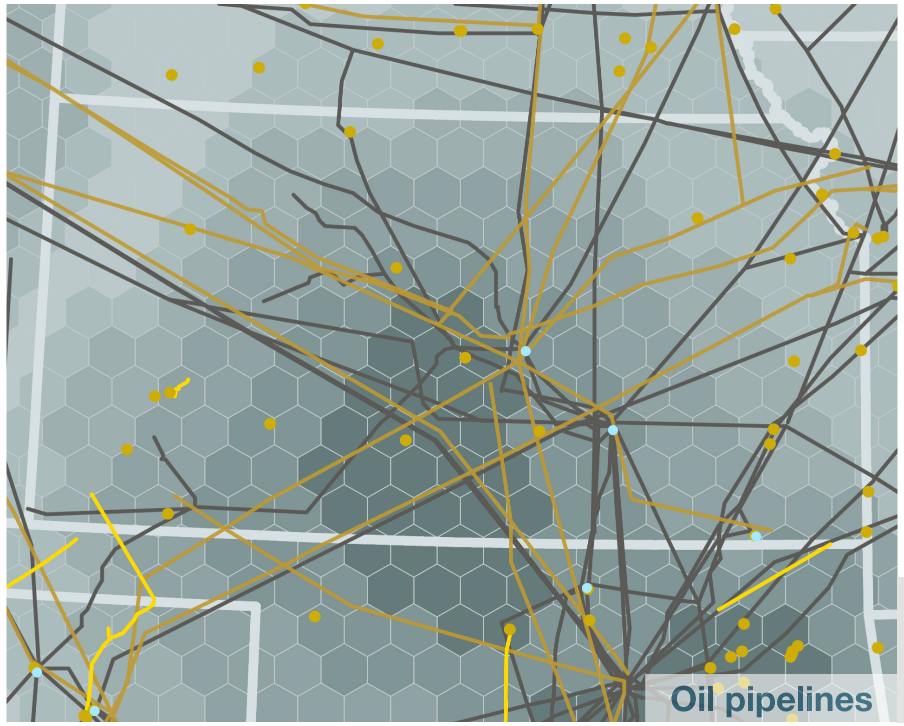
Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas and oil lines. The Kansas hub currently has 6,178 miles of natural gas pipelines and 3,421 miles of oil pipelines.

Infrastructure	Miles
Natural gas pipelines	6,178
Oil pipelines	3,421

- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Natural gas pipelines





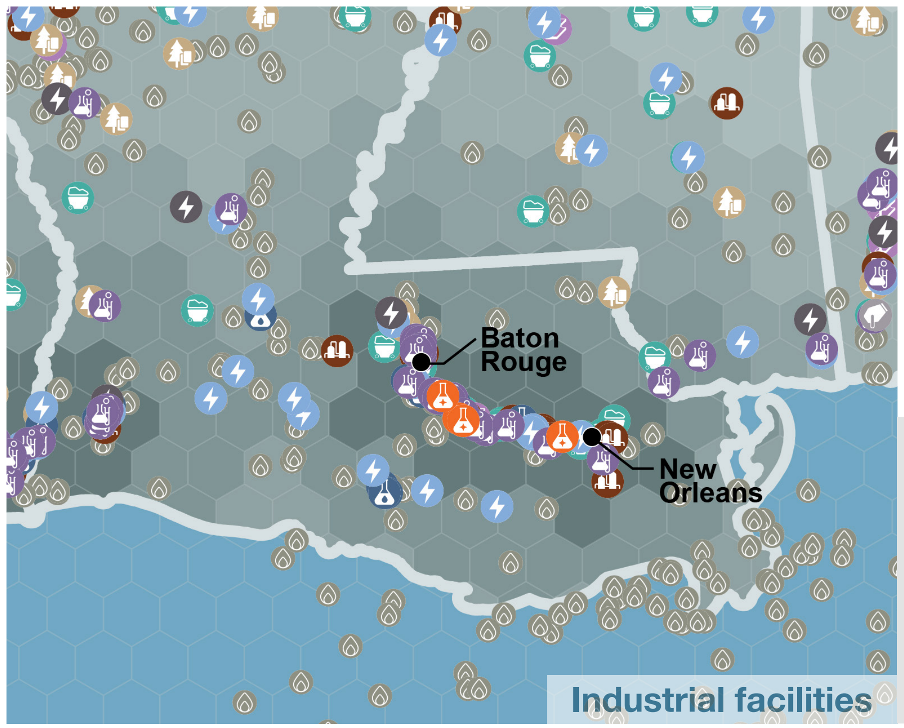
Kansas is centrally located between areas of rich geologic storage resource and existing CO_2 utilization. This offers potential for the state to become a nexus of long-distance CO_2 transport corridors under future scenarios where major CO_2 capture, transport, and storage occurs in accordance with US decarbonization goals. The state of Kansas has 14 miles of existing CO_2 pipeline, and unlike most other states, is adjacent to a major concentration of the nation's existing CO_2 pipelines.

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

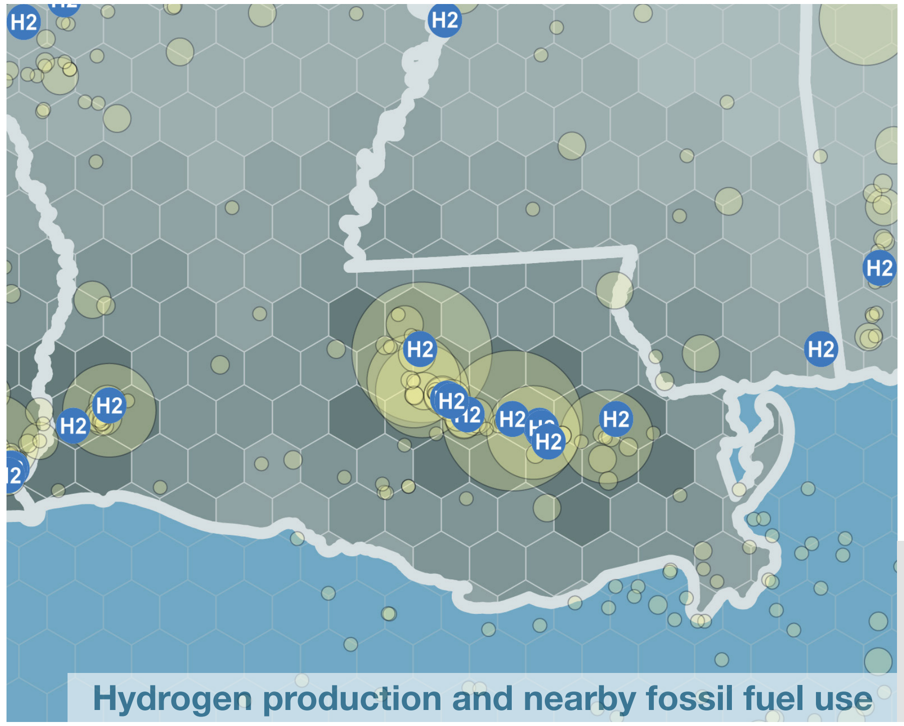
Louisiana

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity make Louisiana a natural launching point for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use



Louisiana is home to a high number and concentration of diverse industries, including petrochemicals production, natural gas processing, and petroleum refining. Facilities in the Louisiana hub emit 86.1 million metric tons (Mt) of CO_2e annually, including 36.3 Mt from stationary combustion and 29.4 Mt from process emissions. There are 42 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There are **10 hydrogen-producing facilities** in the Louisiana hub already co-located with the central corridor of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 755 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

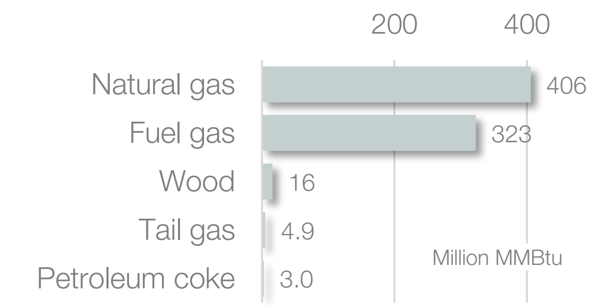
Industrial facility emissions

Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ammonia	4	12.9	3.9	9.0
Chemicals	22	2.1	1.6	0.5
Coal power plants	1	2.9	< 0.1	-
Gas power plants	11	15.6	0.2	-
Gas processing	35	8.2	2.0	6.3
Metals, minerals & other	11	1.6	1.6	-
Petrochemicals	19	13.5	10.3	3.3
Pulp & paper	2	0.5	0.4	0.1
Refineries	10	24.5	16.3	8.2
Steel & steel products	1	1.0	< 0.1	0.9
Total	**117**	**85.1**	**36.3**	**28.3**

All emissions are in million metric tons CO_2e.

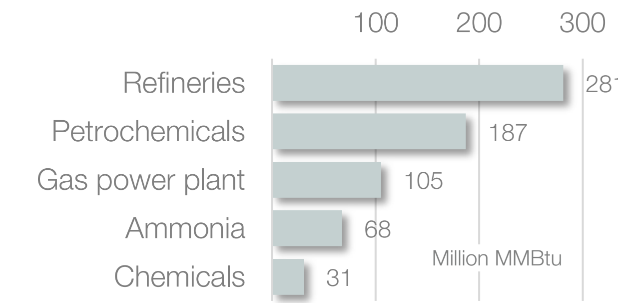
The top industrial fuels consumed in the Louisiana hub include natural gas at 406 million MMBtu per year and fuel gas at 323 million MMBtu per year. Refineries and petrochemicals plants are the largest consumers of fossil fuels in this regional hub, consuming 281 million MMBtu and 187 million MMBtu of fossil fuels, respectively.

Top industrial fuels consumed



Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

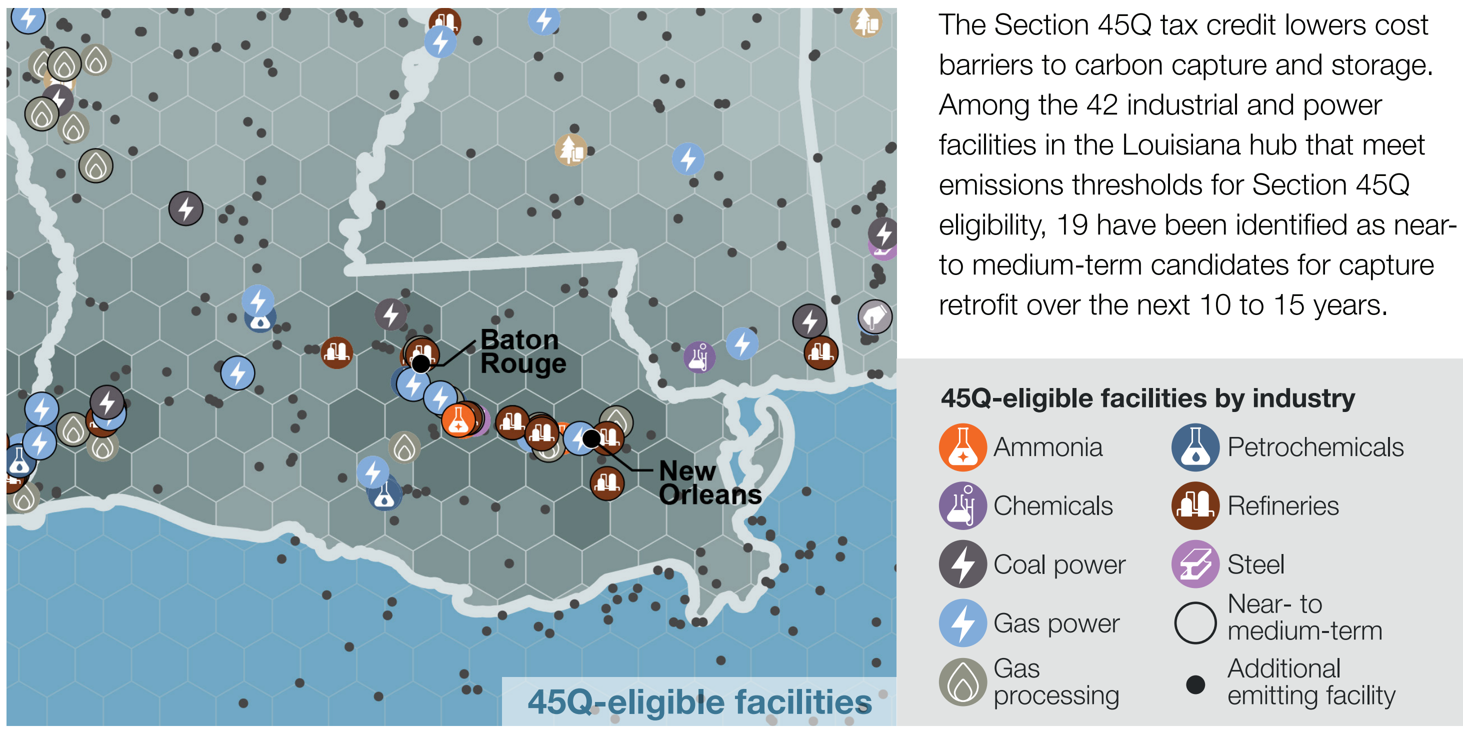
Largest fuel-consuming industries



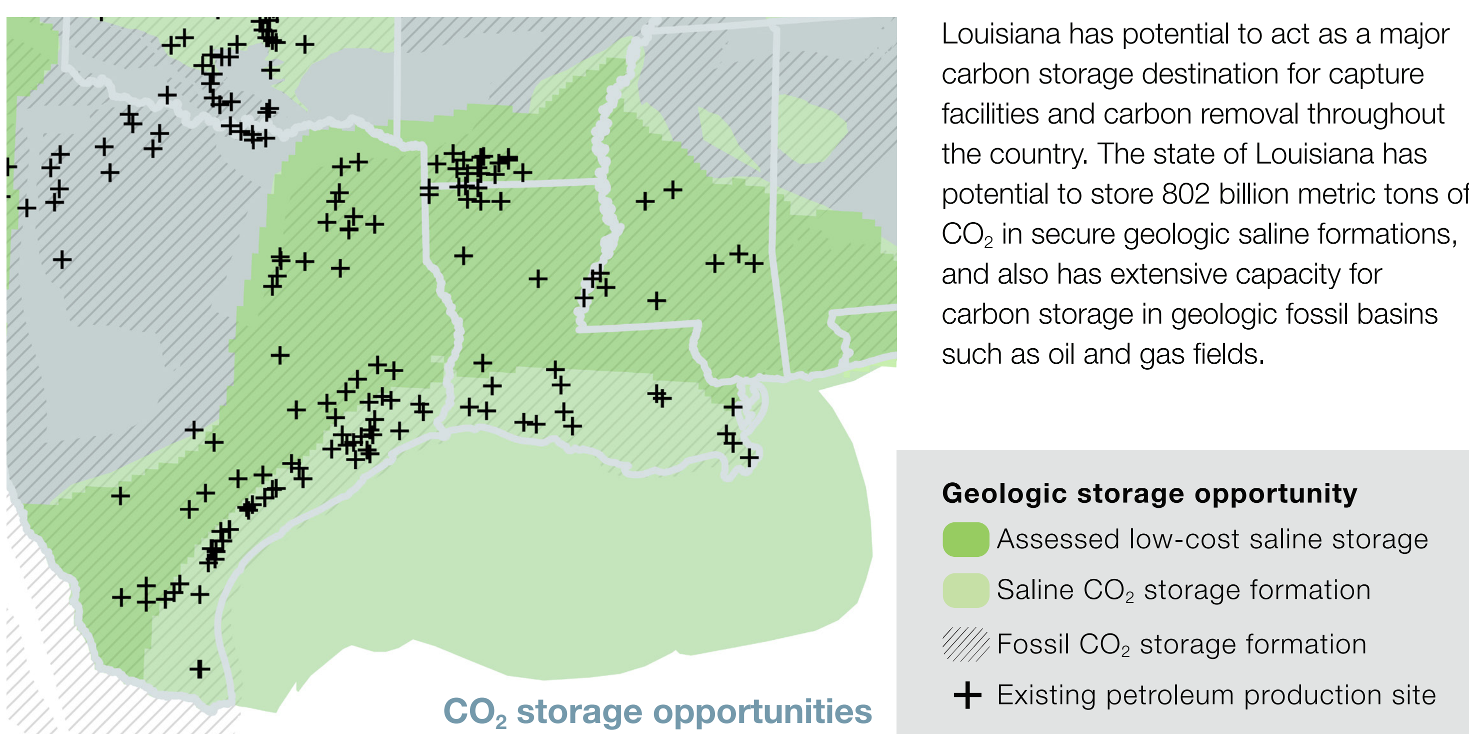
Louisiana

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

Carbon Capture and Storage

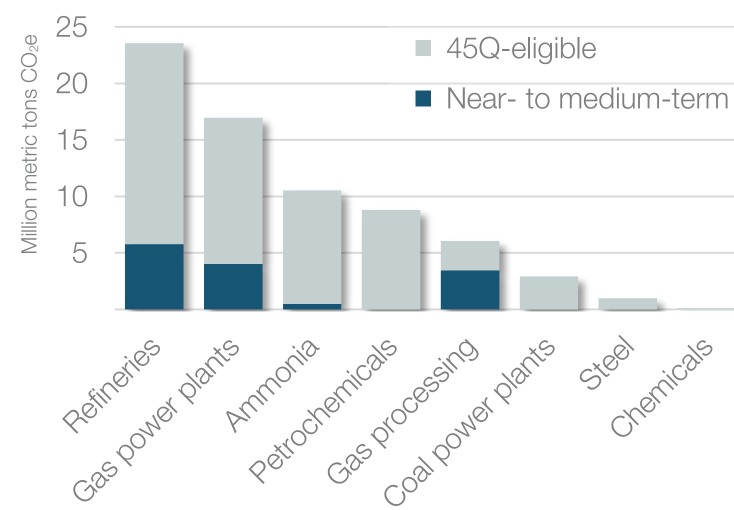


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 42 industrial and power facilities in the Louisiana hub that meet emissions thresholds for Section 45Q eligibility, 19 have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.



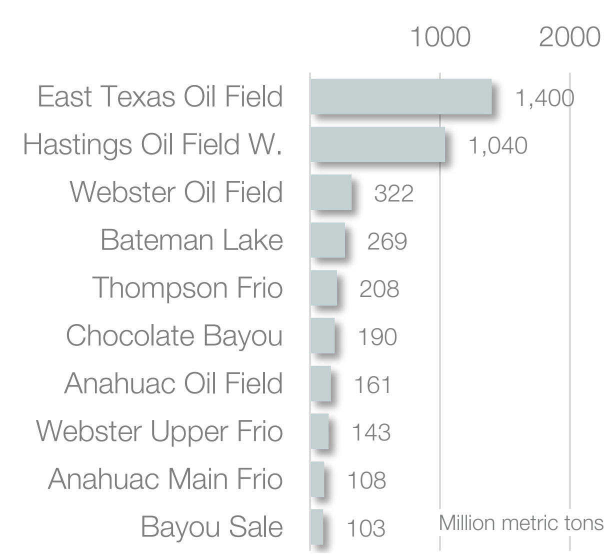
Louisiana has potential to act as a major carbon storage destination for capture facilities and carbon removal throughout the country. The state of Louisiana has potential to store 802 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins such as oil and gas fields.

Carbon capture opportunities

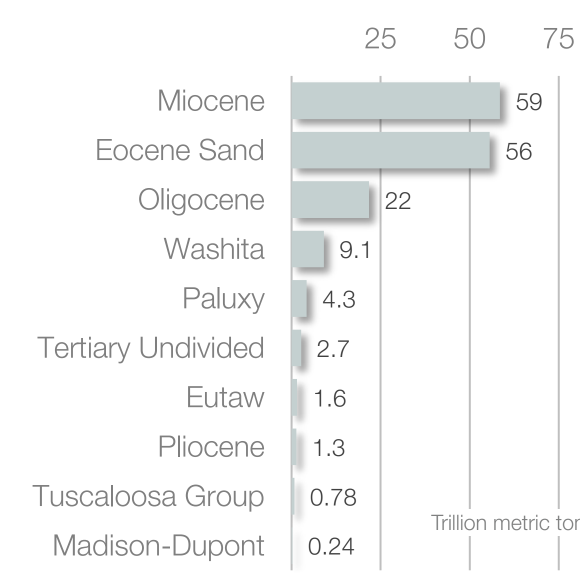


- Industrial and power facilities emit **85.1 Mt CO_2e per year**
- **45Q-eligible** facilities emit **73.1 Mt CO_2e per year**
- **13.7 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

Fossil storage formations
by CO_2 storage capacity



Saline storage formations
by CO_2 storage capacity



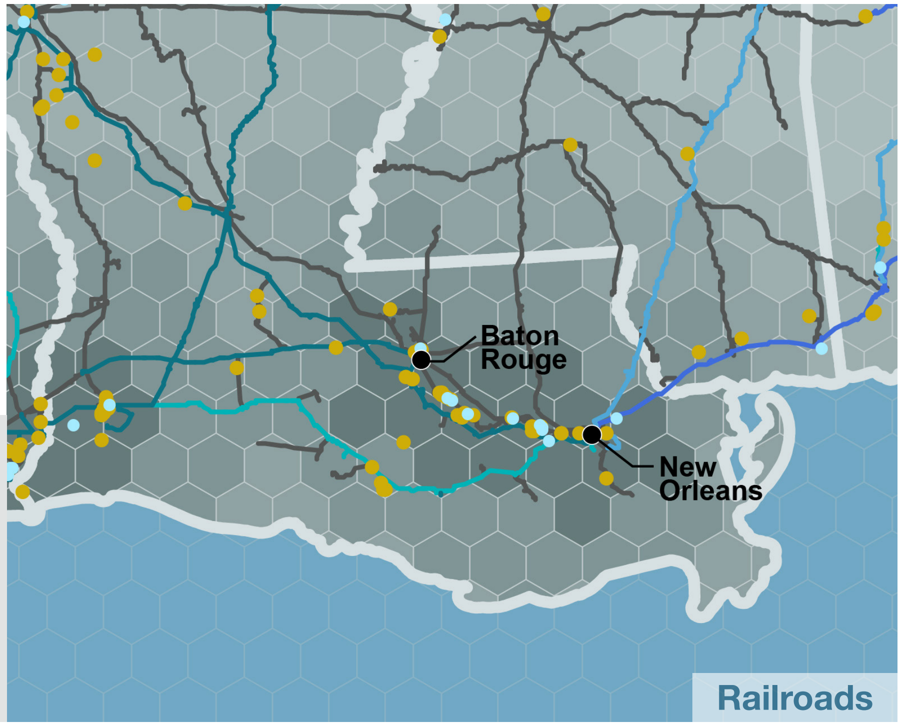
Louisiana

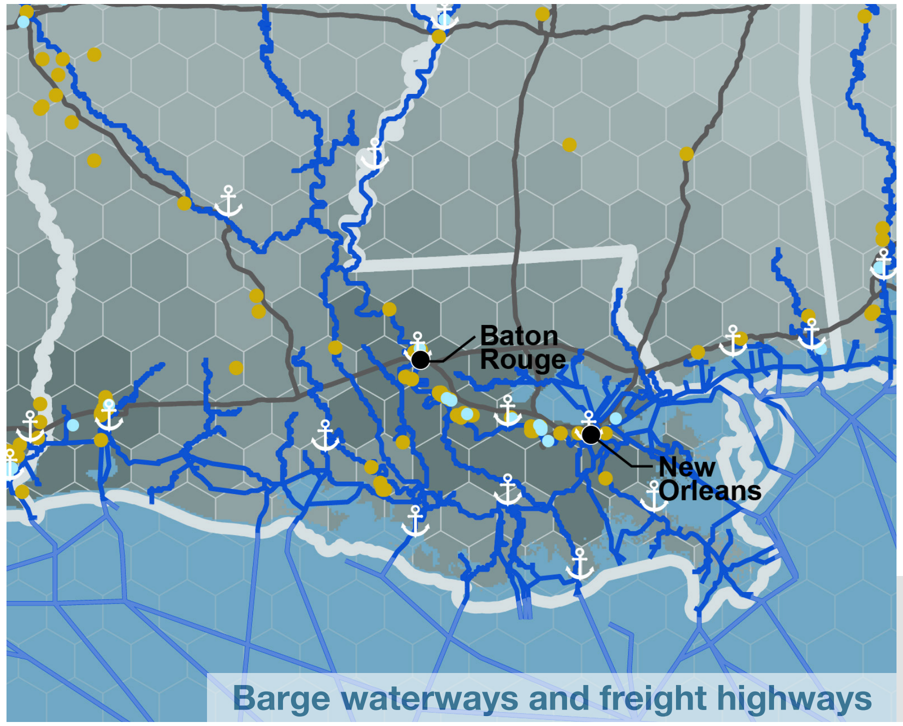
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Louisiana hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks
- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





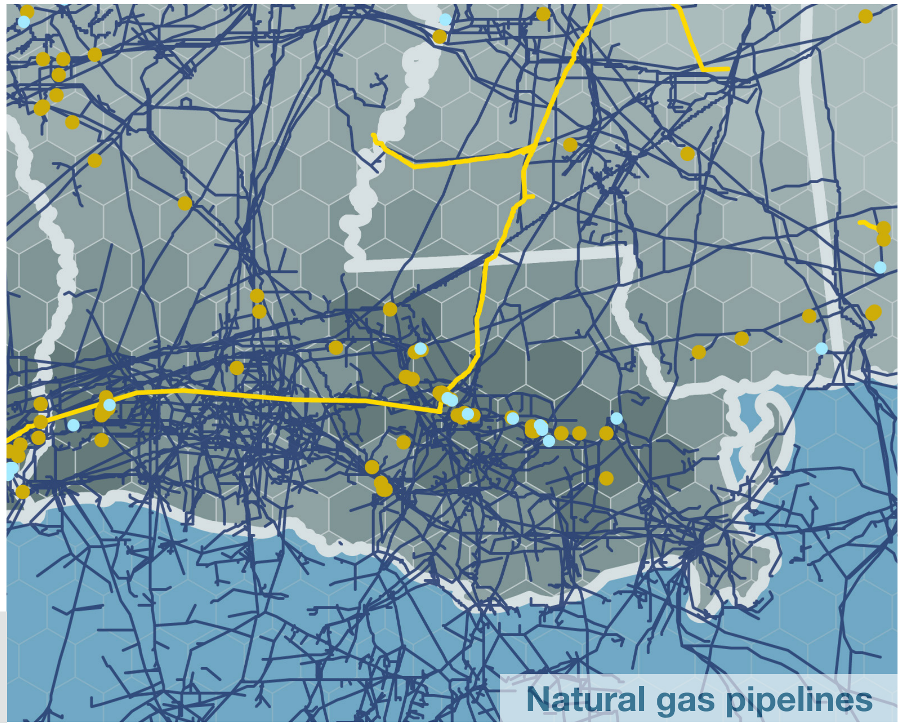
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With several major ports and extensive access to shipping channels, Louisiana has unique access to global and domestic markets for carbon and hydrogen.

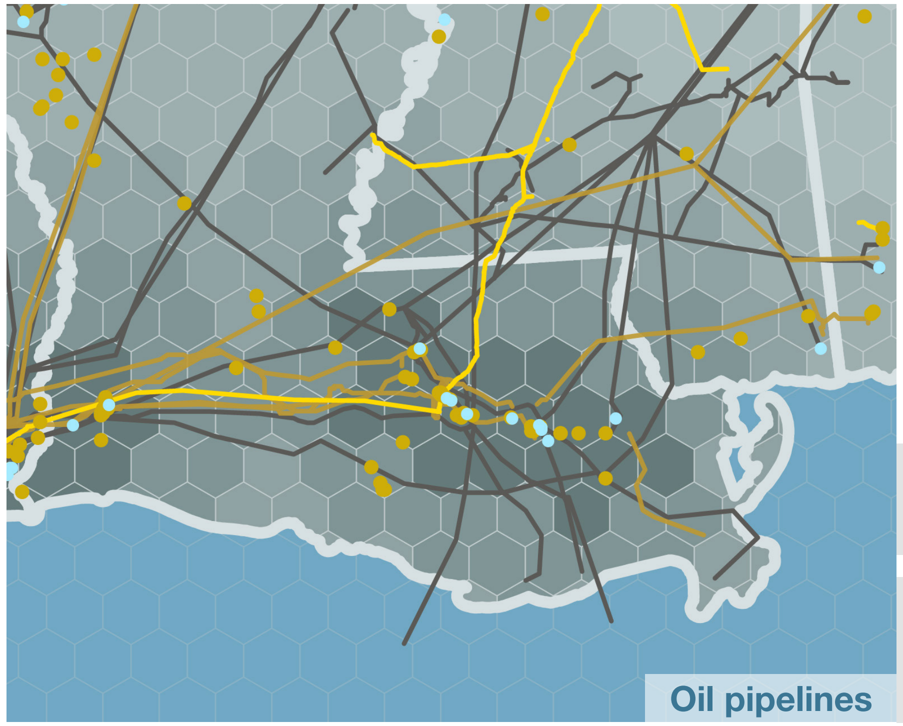
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Louisiana hub currently has 4,475 miles of natural gas pipelines and 77 miles of CO_2 pipelines.

Infrastructure	Miles
Natural gas pipelines	4,475
Oil pipelines	5,145
Existing CO_2 pipelines	77

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Louisiana hub's 5,145 miles of oil pipelines to achieve efficient buildout.

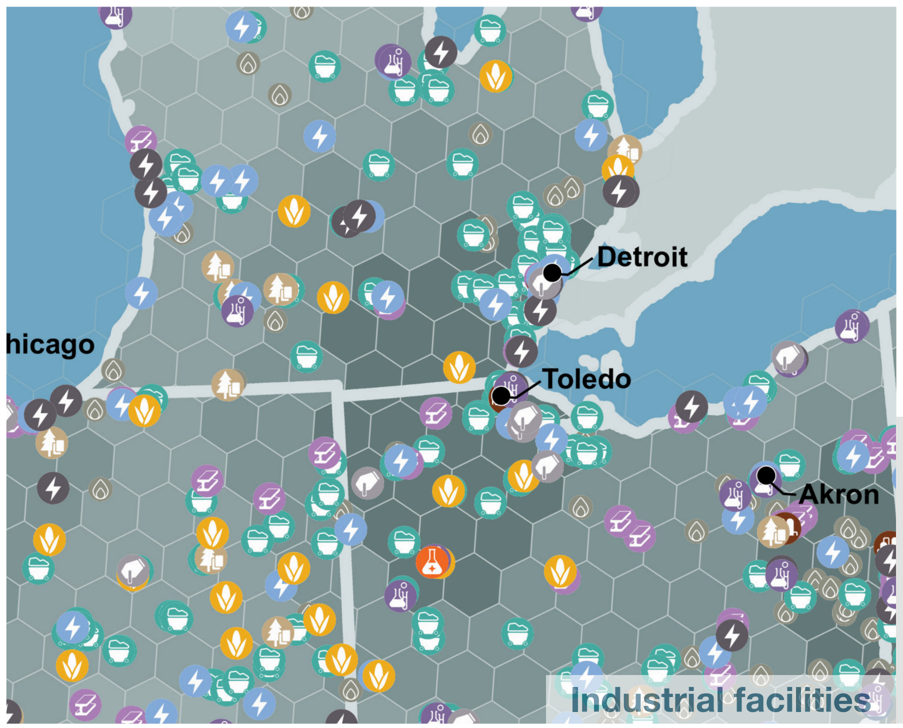
- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

Michigan & Ohio

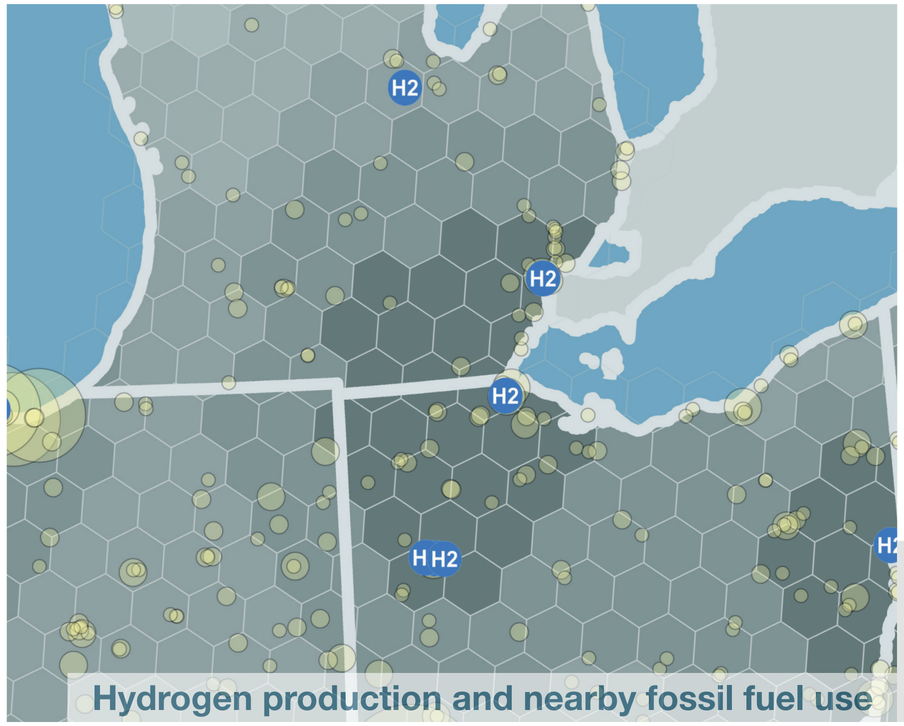
The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity in Michigan and Ohio provide a key opportunity for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use



The Michigian and Ohio hub is home to a high number and concentration of diverse industries, including steel and steel products manufacturing, ethanol production, and cement production. Facilities in this regional hub emit 47.0 million metric tons (Mt) of CO_2e annually, including 12.7 Mt from stationary combustion and 9.2 Mt from process emissions. There are 28 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.

Ammonia
Cement & lime
Chemicals
Coal power
Ethanol
Gas power
Gas processing
Metals, minerals, & other
Petrochemicals
Pulp & paper
Refineries
Steel



Industrial activity and fuel use is distributed throughout Michigan, Ohio, and Indiana, and includes **hydrogen five production facilities**. Industrial facilities in this regional hub use a total of 155 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Existing hydrogen production
Fossil fuel use at industrial facility

Industrial facility emissions

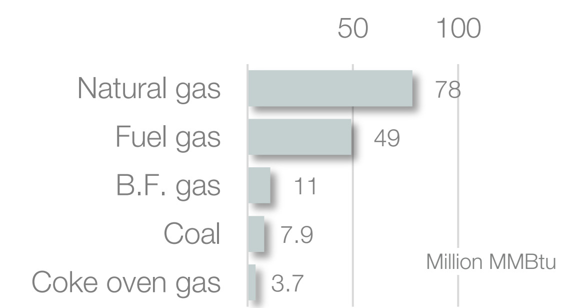
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ammonia	1	1.5	0.5	1.0
Cement	5	2.9	1.1	1.8
Chemicals	3	0.1	0.1	-
Coal power plants	4	18.2	< 0.1	-
Ethanol	4	1.1	0.4	0.8
Gas power plants	10	8.6	1.7	-
Gas processing	6	1.2	0.0	1.2
Metals, minerals & other	38	2.2	2.0	0.2
Petrochemicals	1	0.1	< 0.1	0.1
Refineries	4	5.1	3.5	1.6
Steel & steel products	9	5.9	3.3	2.6
Total	**85**	**47.0**	**12.7**	**9.2**

All emissions are in million metric tons CO_2e.

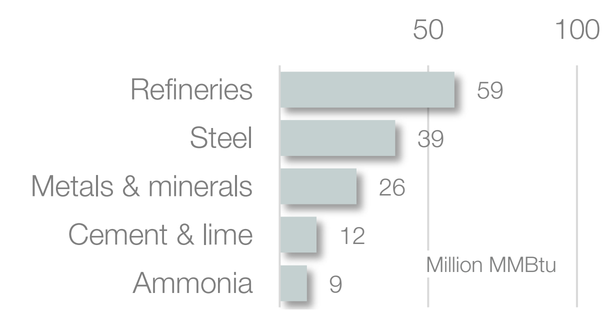
The top industrial fuels consumed in the Michigan and Ohio hub include natural gas at 78 million MMBtu per year and fuel gas at 49 million MMBtu per year. Refineries and steel plants are the largest consumers of fossil fuels in this regional hub, consuming 59 million MMBtu and 39 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



Largest fuel-consuming industries

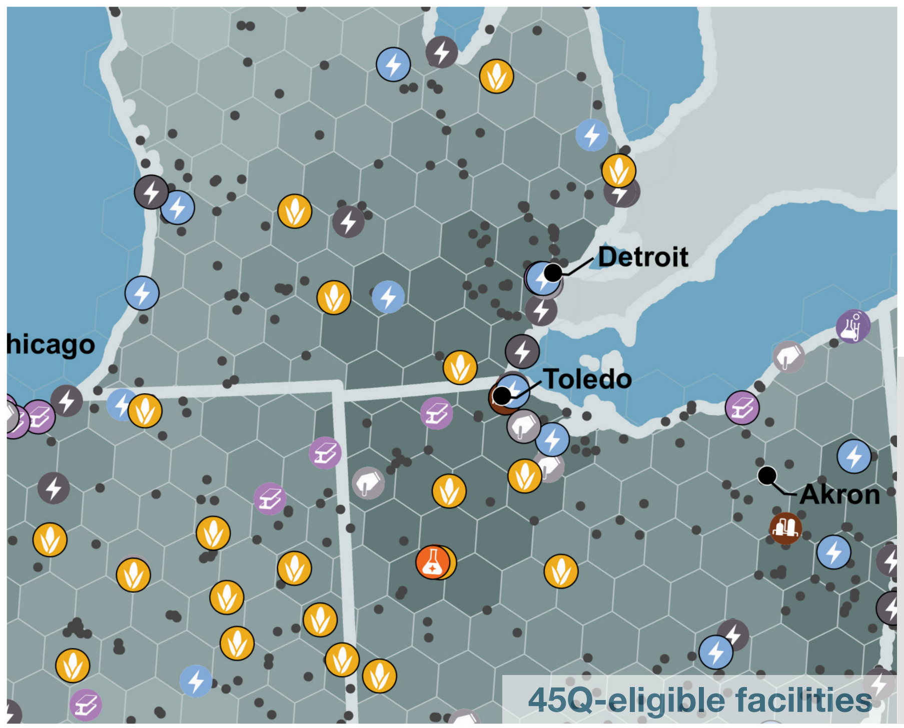


US CARBON AND HYDROGEN HUBS ATLAS GREAT PLAINS INSTITUTE

Michigan & Ohio

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

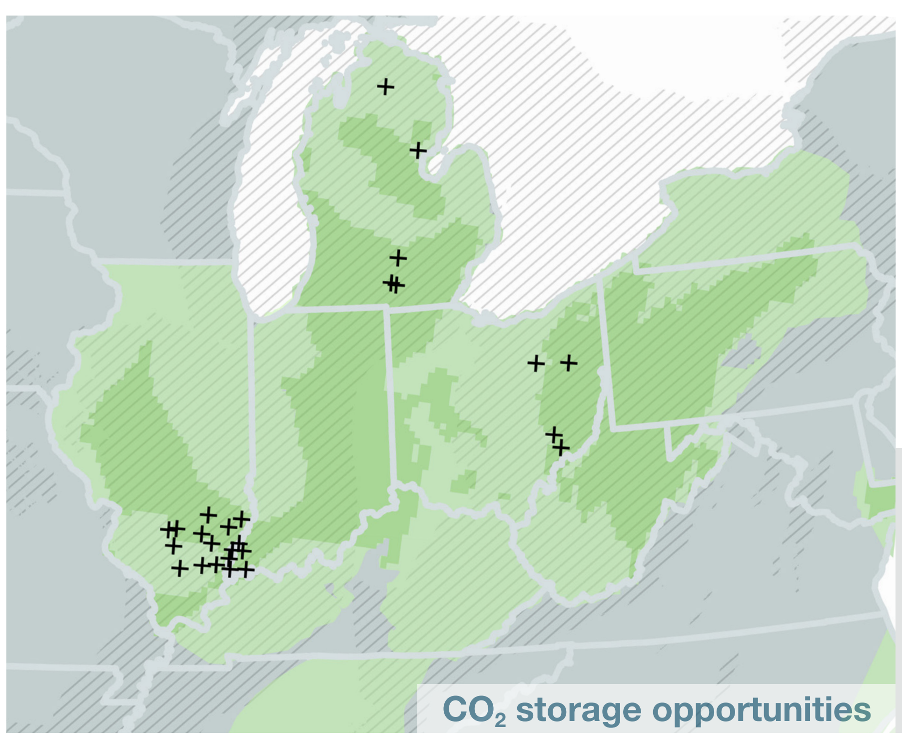
Carbon Capture and Storage



The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 28 industrial and power facilities in the Michigan and Ohio hub that meet emissions thresholds for Section 45Q eligibility, 13 have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

45Q-eligible facilities by industry

- Ammonia
- Cement & lime
- Coal power
- Ethanol
- Gas power
- Gas processing
- Refineries
- Steel
- Near- to medium-term
- Additional emitting facility

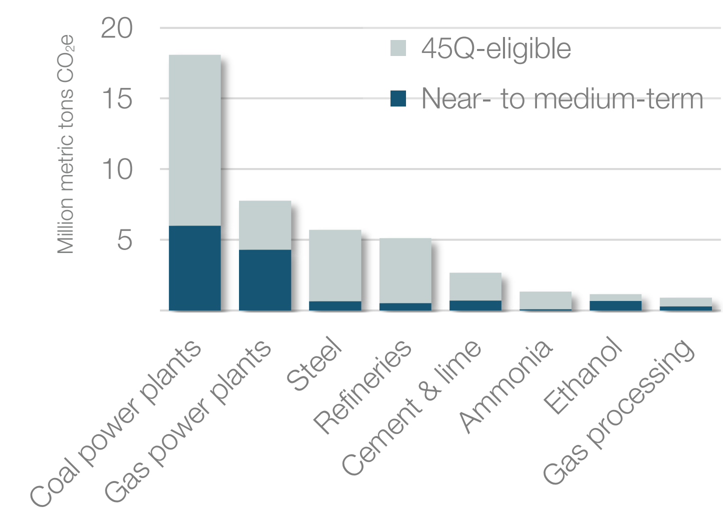


Michigan and Ohio have potential to act as a major carbon storage destinations for capture facilities and carbon removal. The states of Michigan and Ohio have the combined potential to store 57 billion metric tons of CO_2 in secure geologic saline formations, and also have extensive capacity for carbon storage in geologic fossil basins.

Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

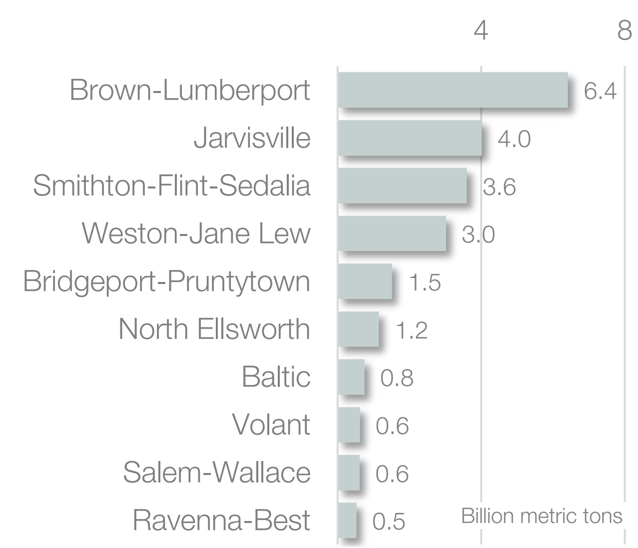
Carbon capture opportunities



- Industrial and power facilities emit **47.0 Mt CO_2e per year**
- **45Q-eligible** facilities emit **43.0 Mt CO_2e per year**
- **13.2 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

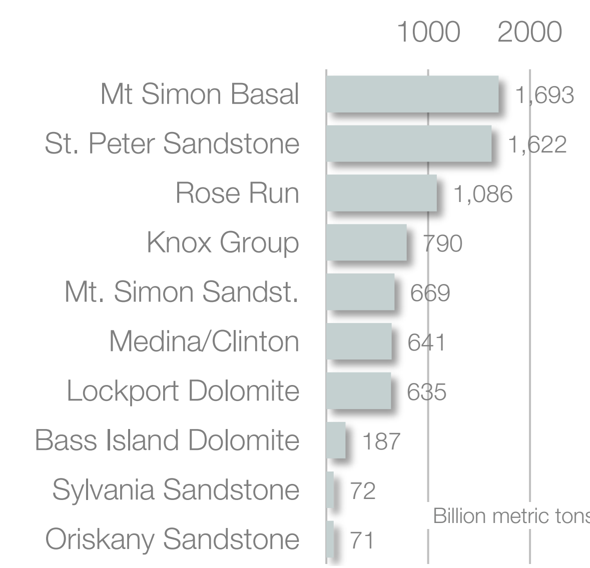
Fossil storage formations

by CO_2 storage capacity



Saline storage formations

by CO_2 storage capacity



Michigan & Ohio

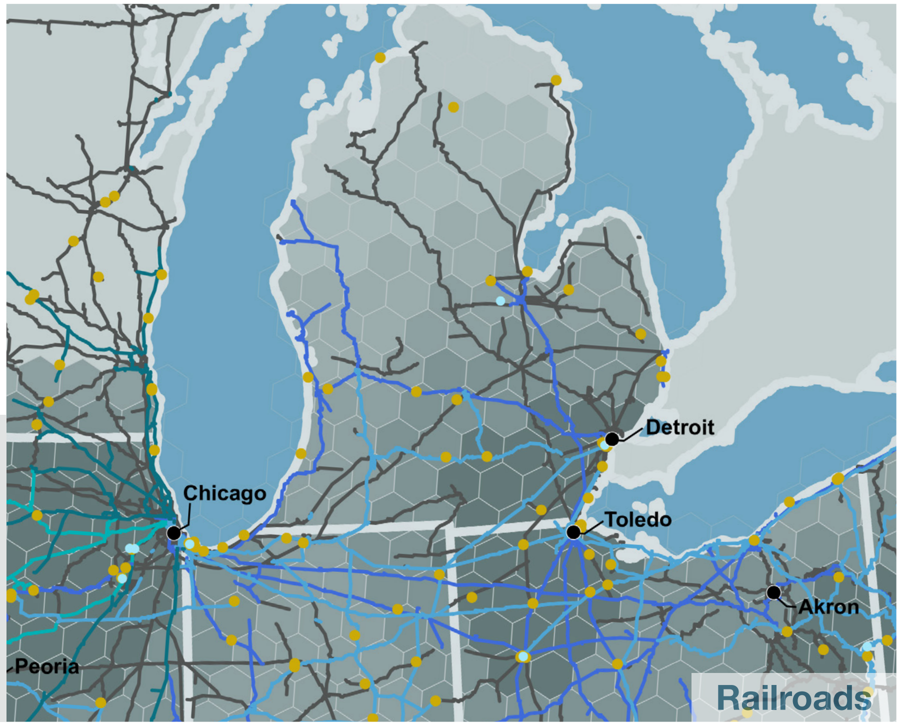
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

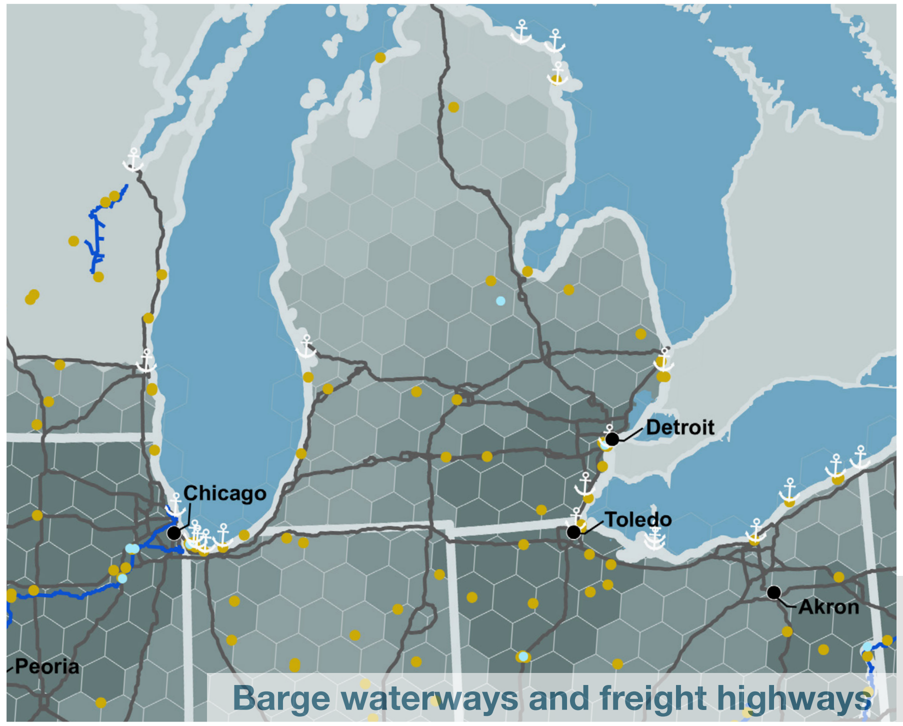
Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Michigan and Ohio hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





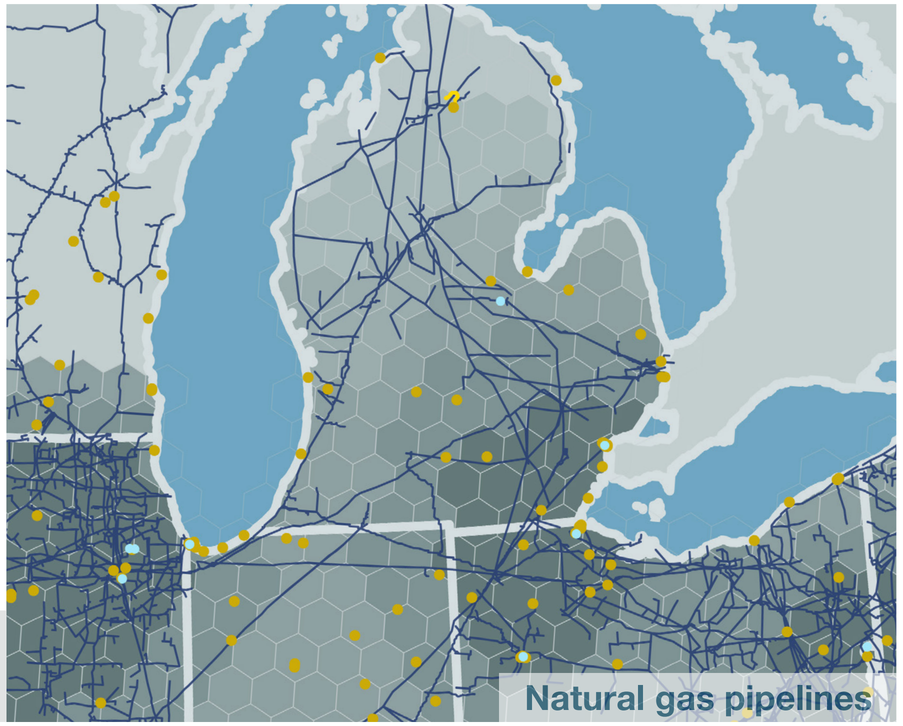
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With major ports on Lake Erie, the Michigan and Ohio hub is well-positioned to access domestic and international markets for carbon and hydrogen.

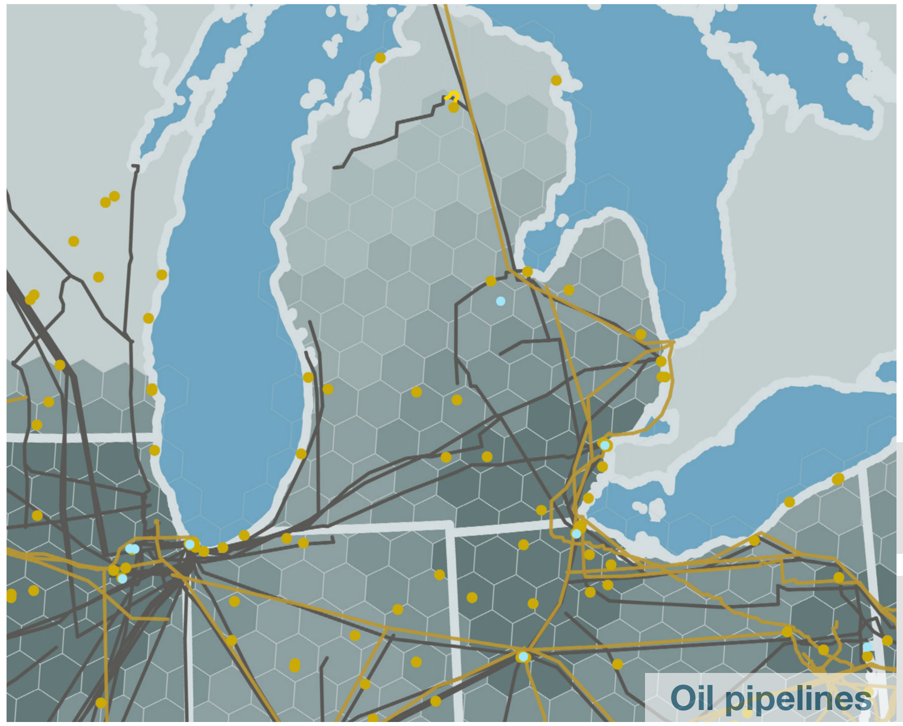
- Interstate highway
- Navigable waterway
- ⚓ Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Michigan and Ohio hub currently has 2,148 miles of natural gas pipelines. Northern Michigan is already home to proven CO2 utilization and storage, with existing transport infrastructure.

Infrastructure	Miles
Natural gas pipelines	2,146
Oil pipelines	4,128

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Michigan and Ohio hub's 4,128 miles of oil pipelines to achieve efficient buildout.

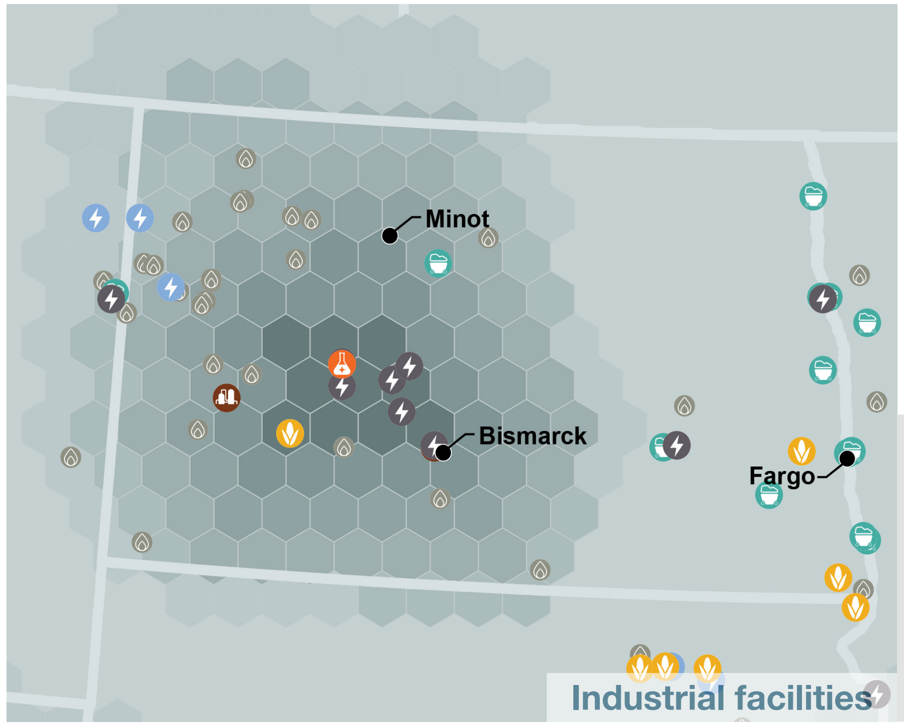
- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

North Dakota: Bakken Hub

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity make North Dakota a potential launching point for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use

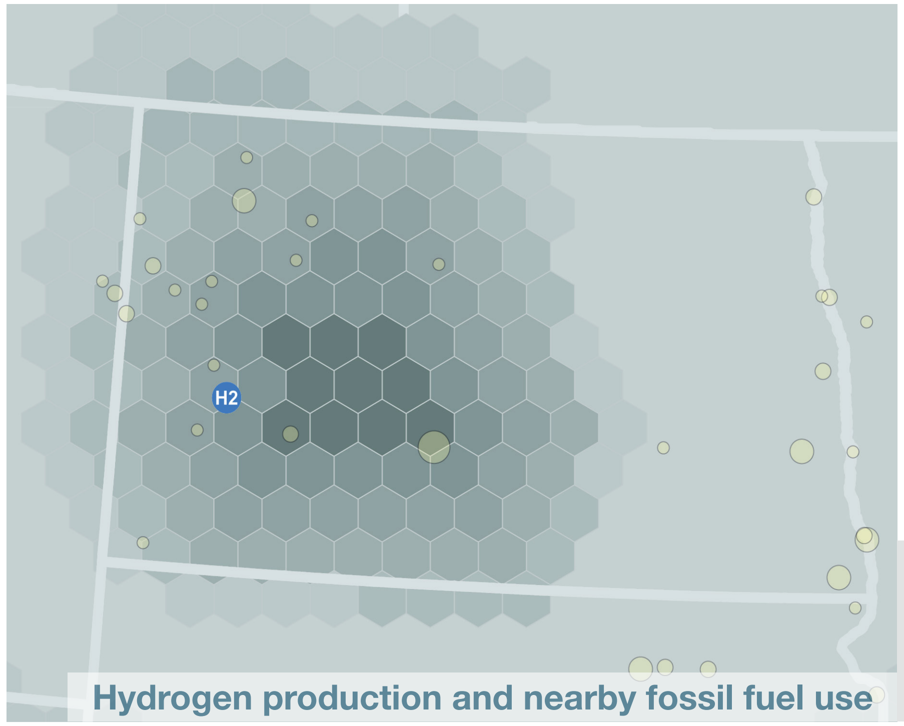


North Dakota is home to industries including natural gas processing, petrochemicals production, and ammonia production. Facilities in the North Dakota Bakken hub emit 35.0 million metric tons (Mt) of CO_2e annually, including 5.3 Mt from stationary combustion and 1.2 Mt from process emissions. There are 7 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.

Industrial facility emissions

Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ammonia	1	3.1	2.8	0.4
Coal power plants	7	27.9	0.1	-
Ethanol	1	0.3	0.1	0.2
Gas power plants	3	0.8	0.1	-
Gas processing	29	1.9	1.5	0.4
Metals, minerals & other	2	0.1	0.1	-
Refineries	2	0.8	0.6	0.3
Total	**45**	**35.0**	**5.3**	**1.2**

All emissions are in million metric tons CO_2e.



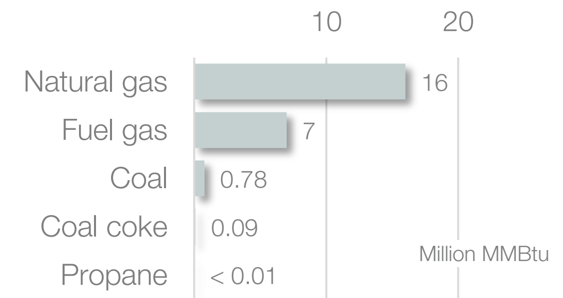
Industrial activity and fuel use is distributed throughout the Bakken hub and includes hydrogen prduction at at least **one facility**. Industrial facilities in this regional hub use a total of 24 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

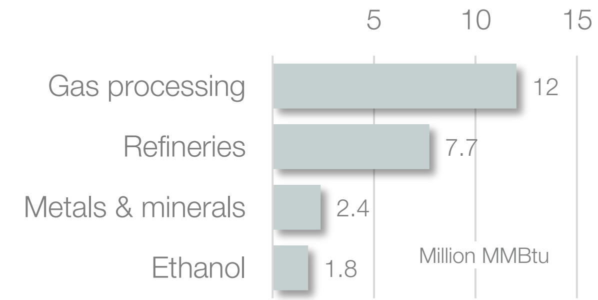
The top industrial fuels consumed in the Bakken hub include natural gas at 16 million MMBtu per year and fuel gas at 7 million MMBtu per year. Gas processing plants and refineries are the largest consumers of fossil fuels in this regional hub, consuming 12 million MMBtu and 7.7 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

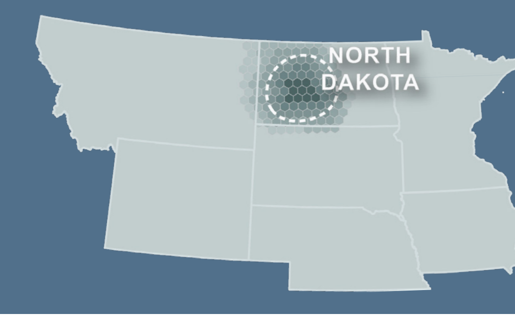
Top industrial fuels consumed



Largest fuel-consuming industries

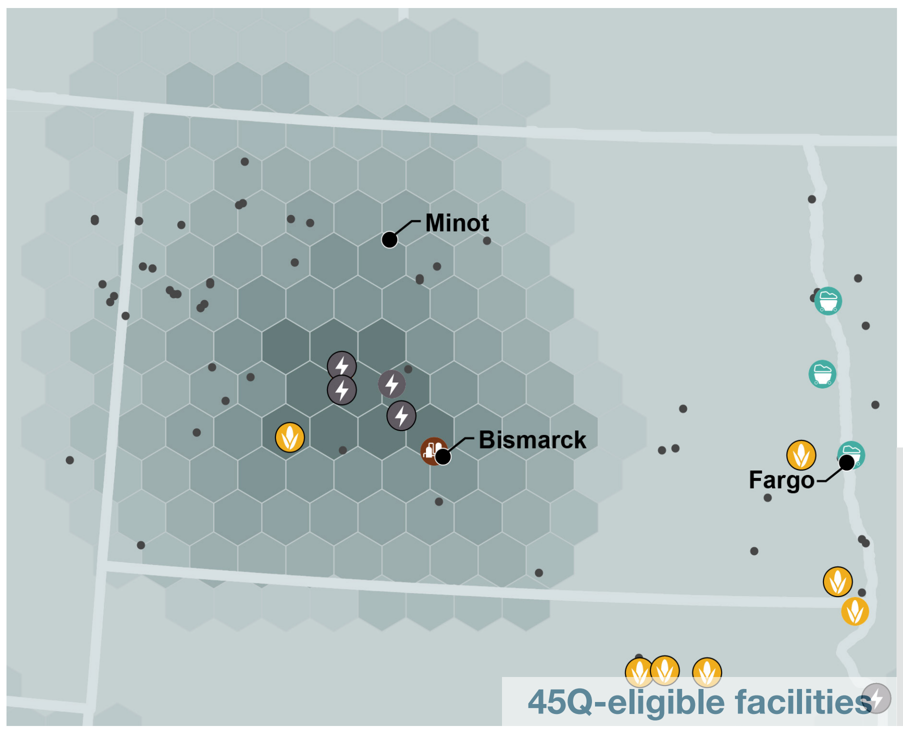


North Dakota: Bakken Hub



Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

Carbon Capture and Storage

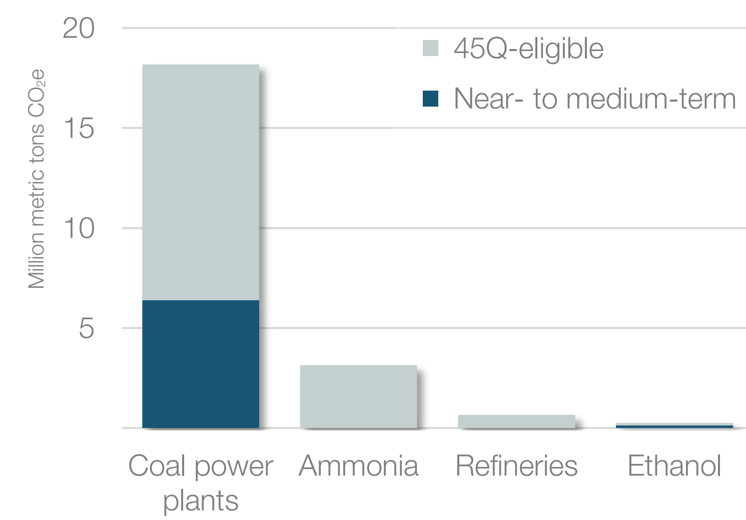


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the seven industrial and power facilities in the Bakken hub that meet emissions thresholds for Section 45Q eligibility, four have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

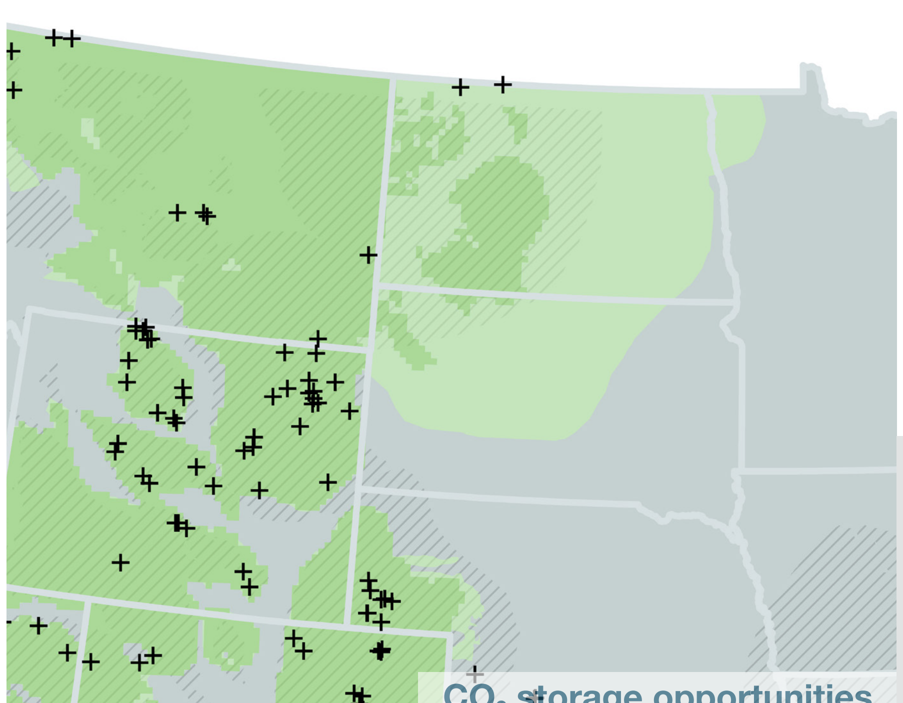
45Q-eligible facilities by industry

- Ammonia
- Refineries
- Coal power
- Near- to medium-term
- Ethanol
- Additional emitting facility

Carbon capture opportunities



- Industrial and power facilities emit **35.0 Mt CO_2e per year**
- **45Q-eligible** facilities emit **22.4 Mt CO_2e per year**
- **6.5 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

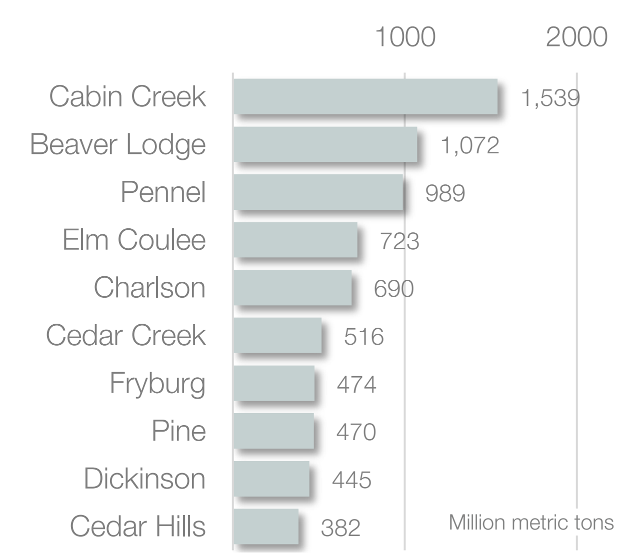


North Dakota has potential to act as a major carbon storage destination for capture facilities and carbon removal. The state of North Dakota has potential to store 146 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins.

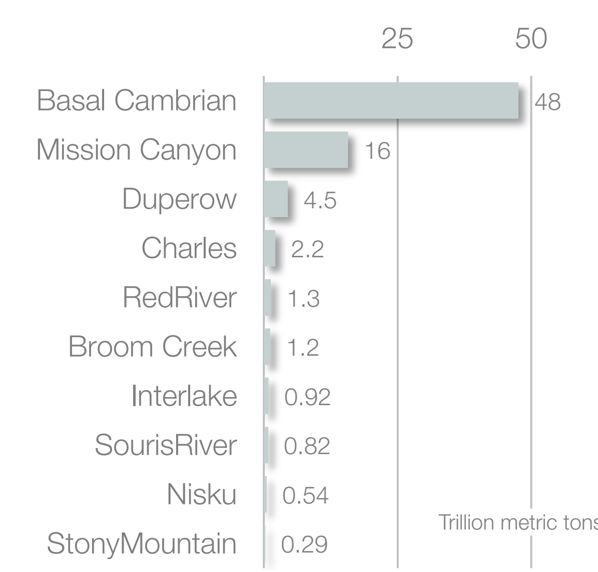
Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- + Existing petroleum production site

Fossil storage formations
by CO_2 storage capacity



Saline storage formations
by CO_2 storage capacity



US CARBON AND HYDROGEN HUBS ATLAS GREAT PLAINS INSTITUTE

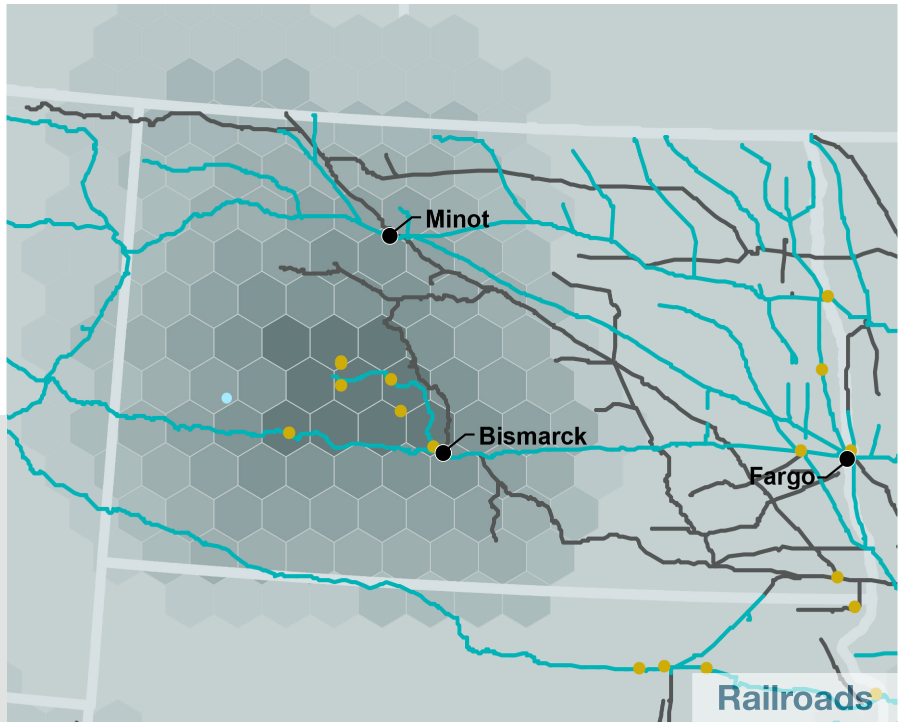
North Dakota: Bakken Hub

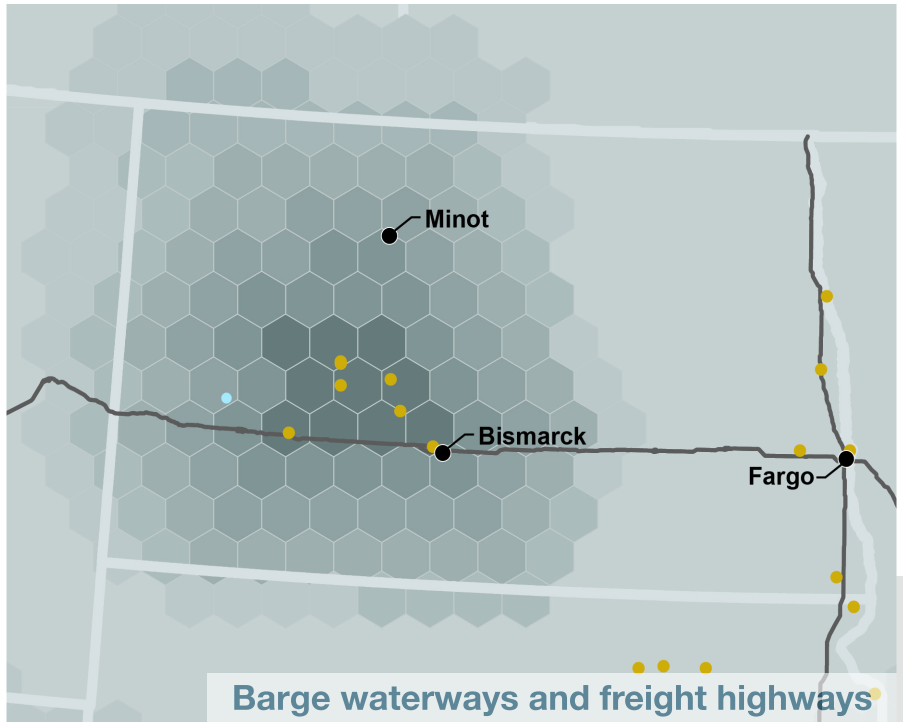
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

Transport Infrastructure

Many industrial facilties are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Bakken hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks
- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





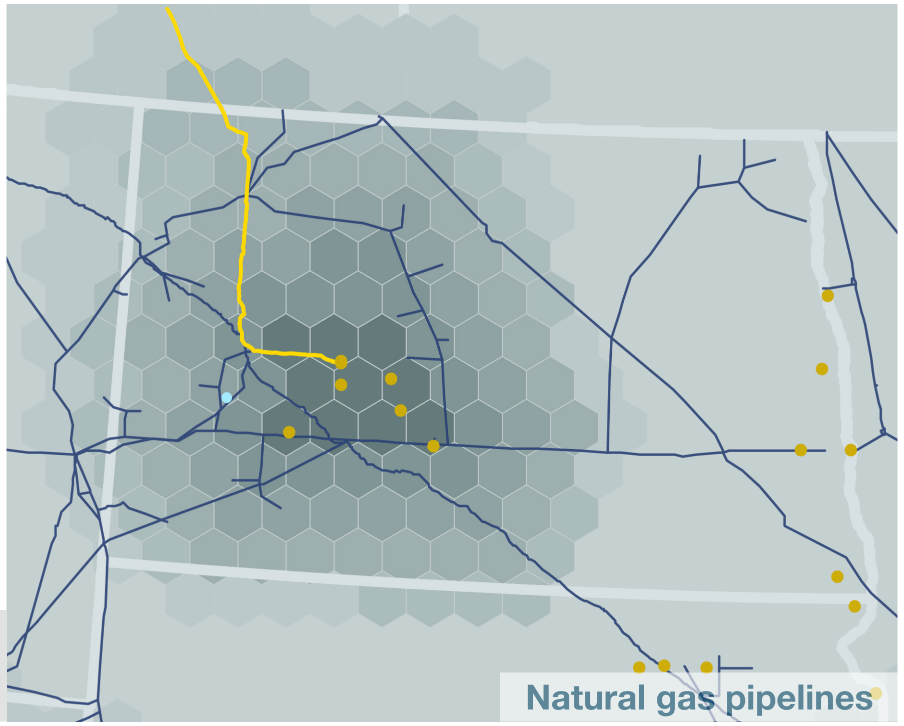
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. Freight trucking can connect the Bakken hub to broader markets for carbon and hydrogen.

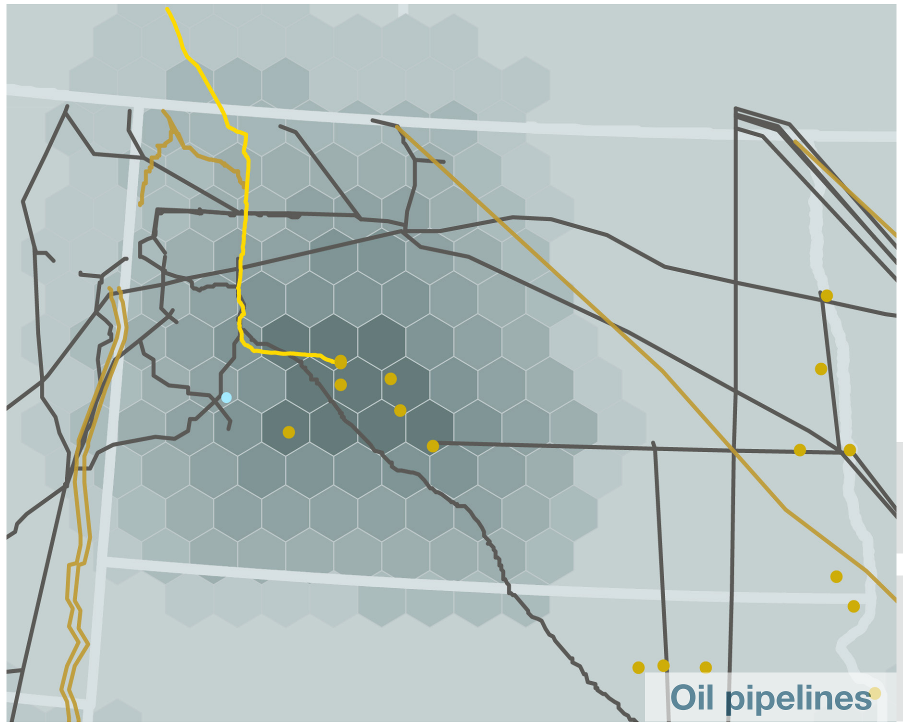
- Interstate highway
- Navigable waterway
- ⚓ Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Bakken hub currently has 2,130 miles of natural gas pipelines and 220 miles of CO_2 pipelines.

Infrastructure	Miles
Natural gas pipelines	2,130
Oil pipelines	4,071
Existing CO_2 pipelines	220

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Bakken hub's 4,071 miles of oil pipelines to achieve efficient buildout.

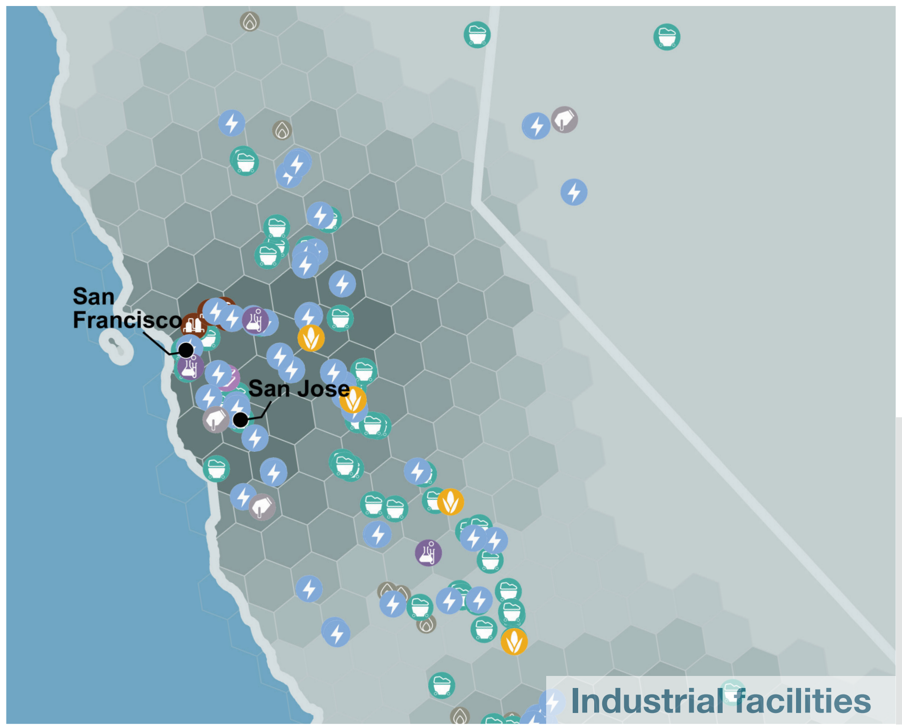
- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

Northern California

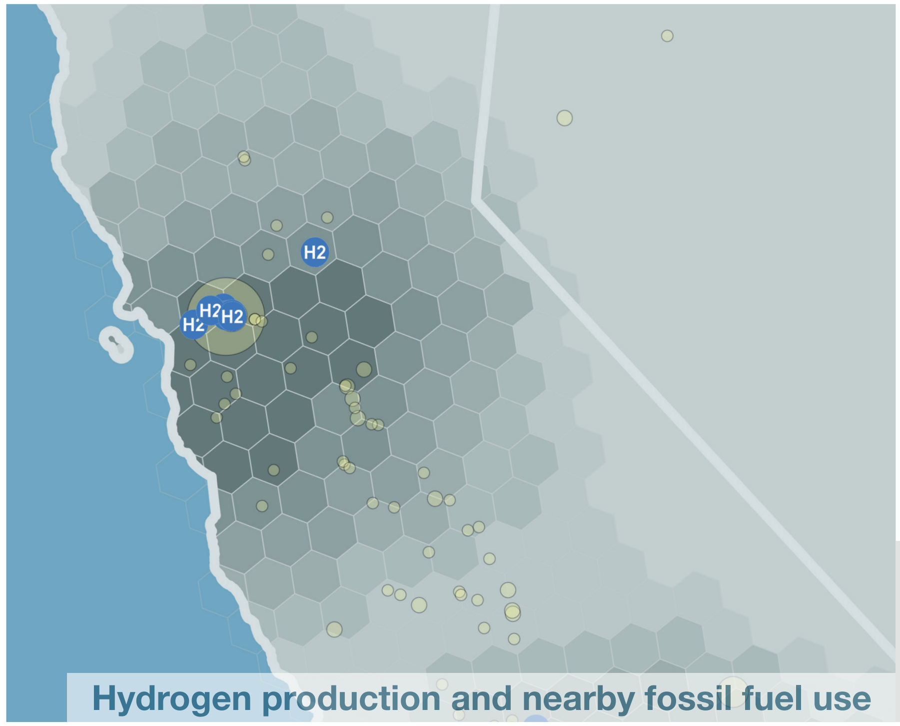
The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity make Northern California a potential launching point for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use



Northern California is home to a high number and concentration of diverse industries including petroleum refining, natural gas processing, and ethanol production. Facilities in the Northern California hub emit 29.6 million metric tons (Mt) of CO_2e annually, including 9.8 Mt from stationary combustion and 9.6 Mt from process emissions. There are 17 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.

Ammonia
Cement & lime
Chemicals
Coal power
Ethanol
Gas power
Gas processing
Metals, minerals, & other
Petrochemicals
Pulp & paper
Refineries
Steel



There are **eight hydrogen-producing facilities** in the Northern California hub already co-located with the area's central cluster of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 143 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Existing hydrogen production
Fossil fuel use at industrial facility

Industrial facility emissions

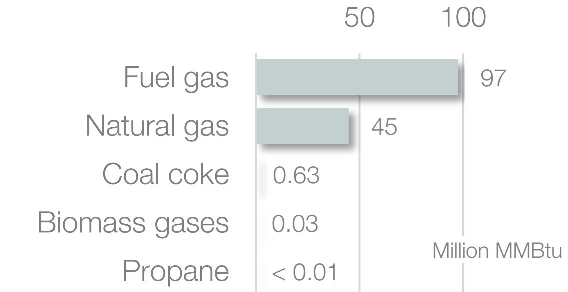
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Cement	1	0.8	< 0.1	0.8
Chemicals	2	0.1	0.1	-
Ethanol	2	0.5	0.1	0.4
Gas power plants	27	11.5	1.3	-
Gas processing	3	1.8	0.0	1.8
Metals, minerals & other	20	1.1	0.9	0.2
Refineries	5	13.8	7.3	6.5
Steel & steel products	2	0.1	0.1	-
Total	**62**	**29.6**	**9.8**	**9.6**

All emissions are in million metric tons CO_2e.

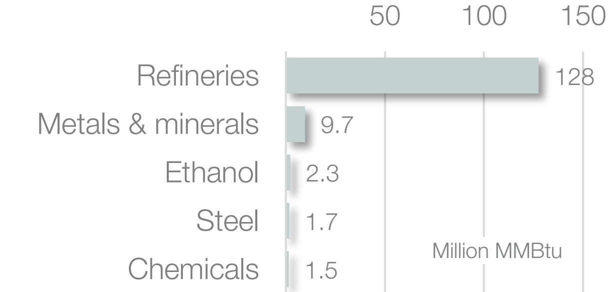
The top industrial fuels consumed in the Northern California hub include fuel gas at 97 million MMBtu per year and natural gas at 45 million MMBtu per year. Refineries are the largest consumers of fossil fuels in this regional hub, consuming 128 million MMBtu per year.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



Largest fuel-consuming industries

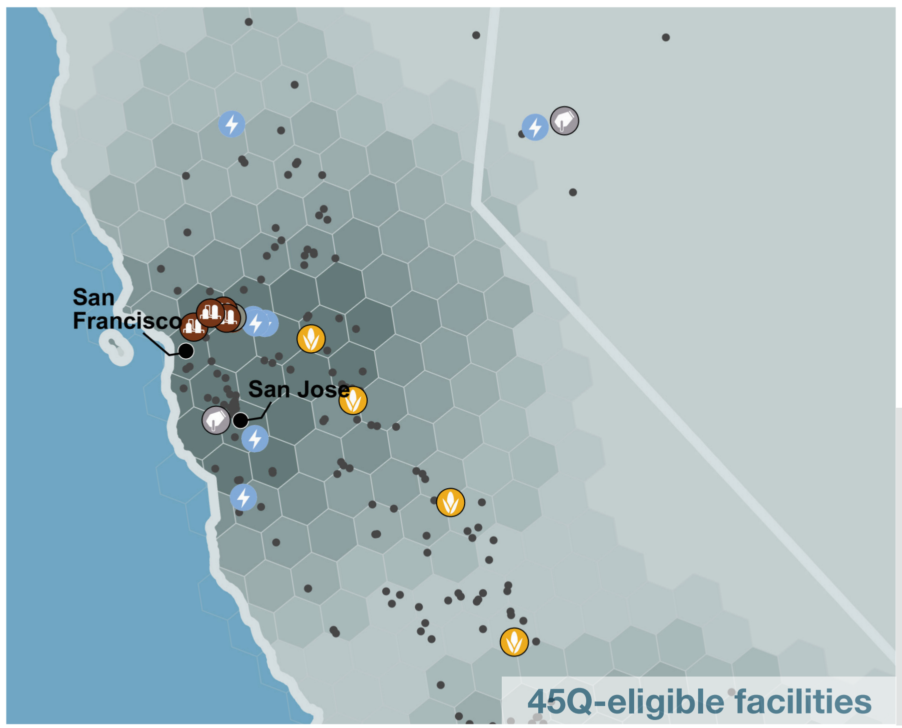


US CARBON AND HYDROGEN HUBS ATLAS GREAT PLAINS INSTITUTE

Northern California

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

Carbon Capture and Storage

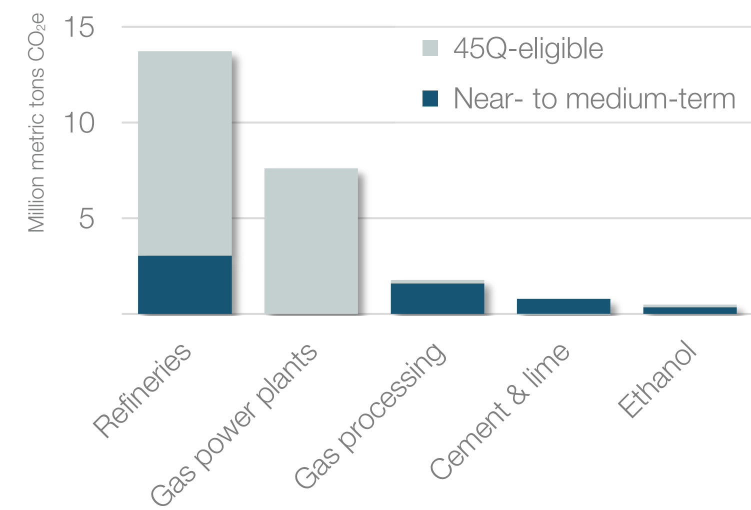


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 17 industrial and power facilities in the Northern California hub that meet emissions thresholds for Section 45Q eligibility, ten have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

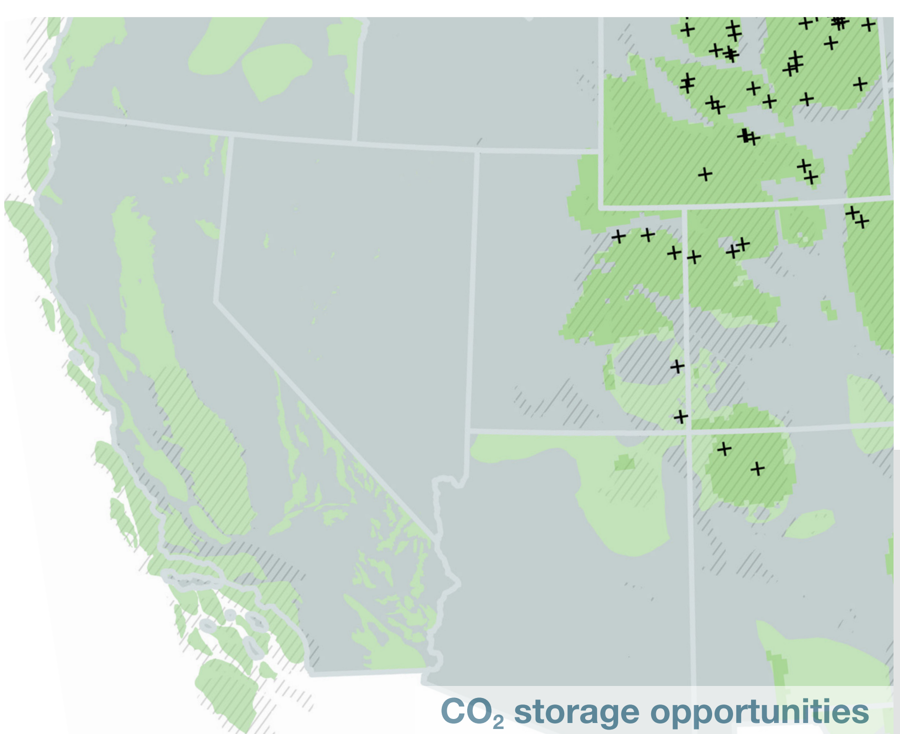
45Q-eligible facilities by industry

- Cement & lime
- Ethanol
- Gas power
- Gas processing
- Refineries
- Near- to medium-term
- Additional emitting facility

Carbon capture opportunities



- Industrial and power facilities emit **29.6 Mt CO_2e per year**
- **45Q-eligible** facilities emit **24.5 Mt CO_2e per year**
- **5.8 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

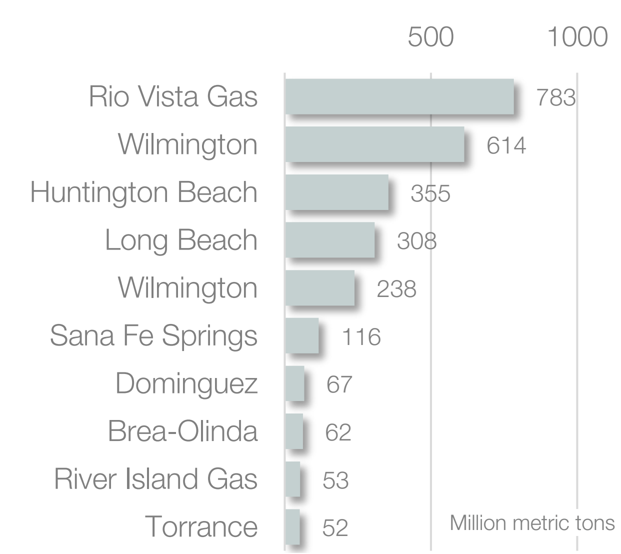


Northern California has potential to act as a carbon storage destination for capture facilities and carbon removal. The state of California has potential to store 148 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins.

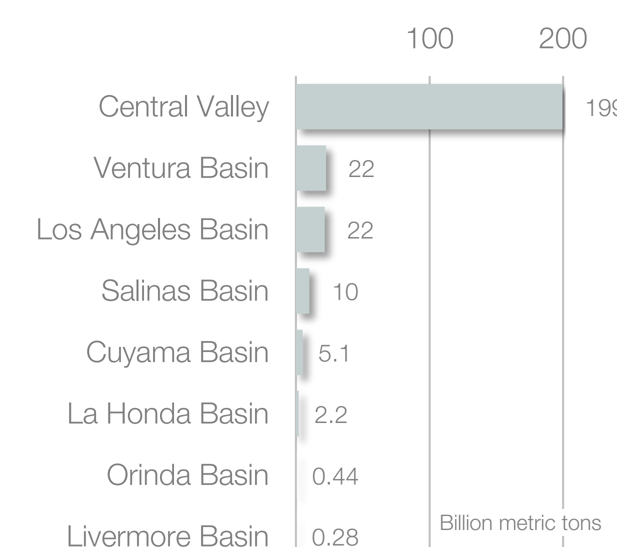
Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- \+ Existing petroleum production site

Fossil storage formations
by CO_2 storage capacity



Saline storage formations
by CO_2 storage capacity



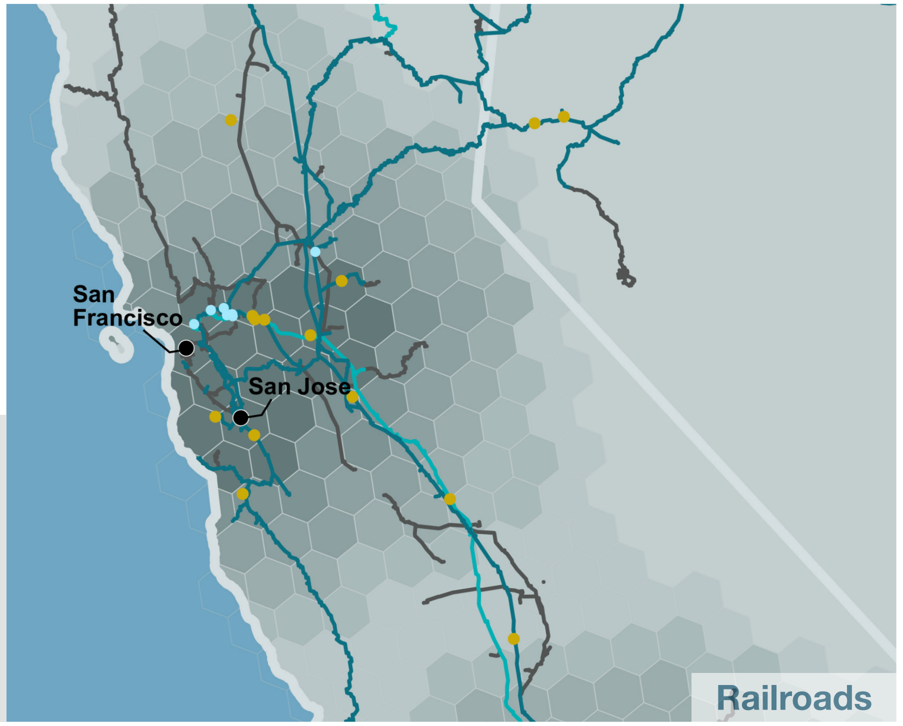
Northern California

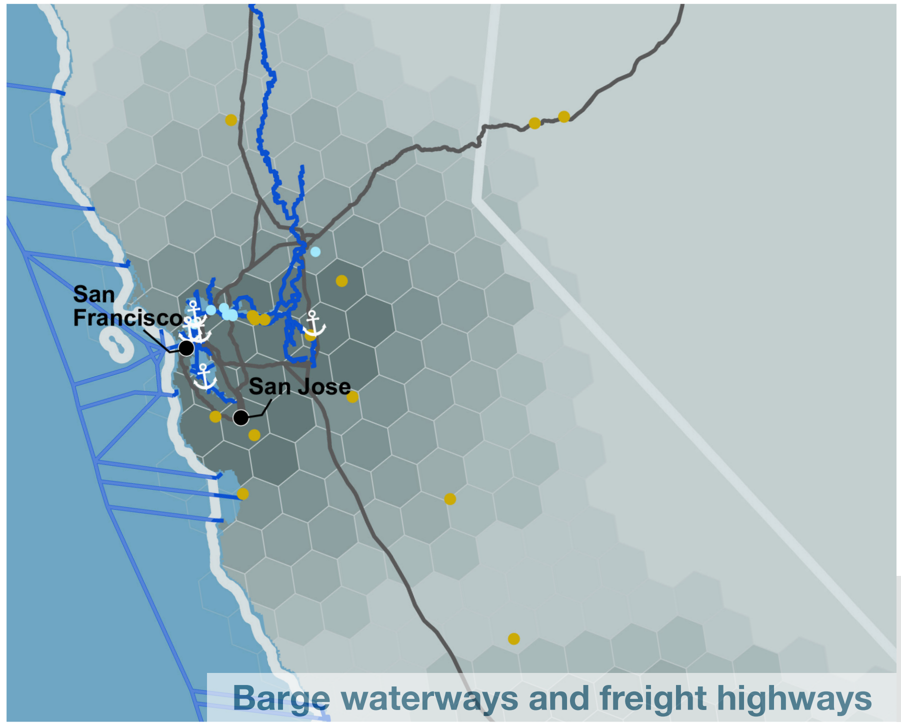
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Northern California hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks
- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





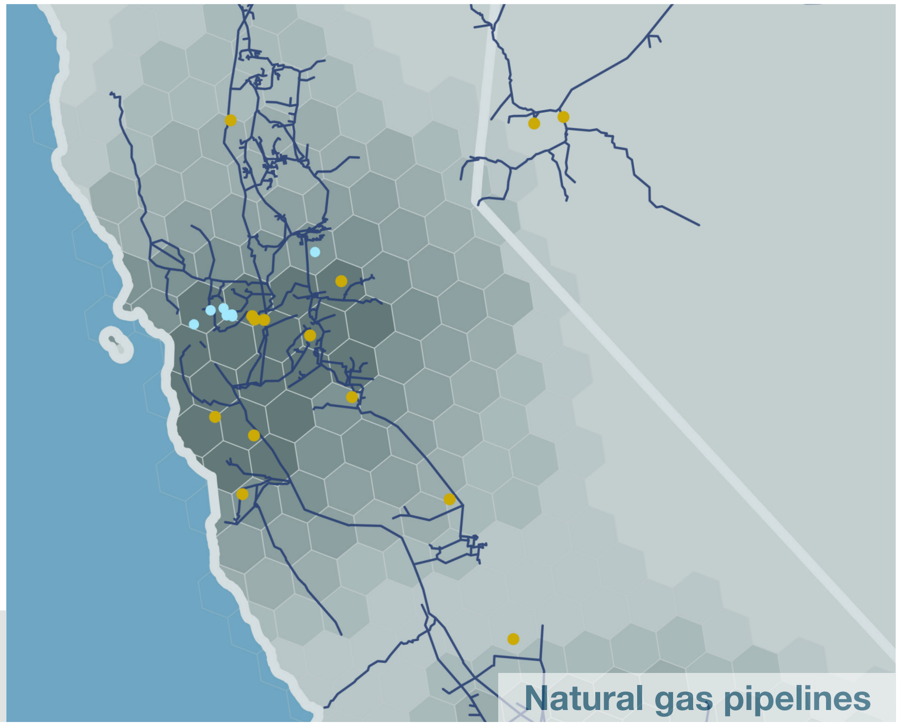
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With several major ports and extensive access to shipping channels, Northern California has unique access to global and domestic markets for carbon and hydrogen.

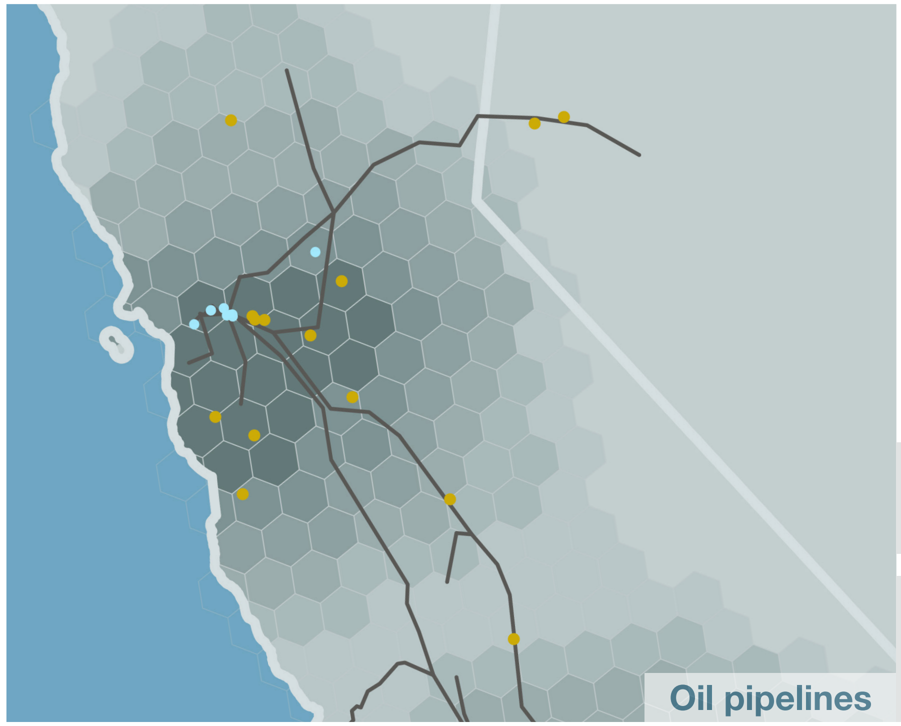
- Interstate highway
- Navigable waterway
- ⚓ Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Northern California hub currently has 937 miles of natural gas pipelines.

Infrastructure	Miles
Natural gas pipelines	937
Oil pipelines	906

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Northern California hub's 906 miles of oil pipelines to achieve efficient buildout.

- 45Q-eligible facility
- Existing hydrogen production

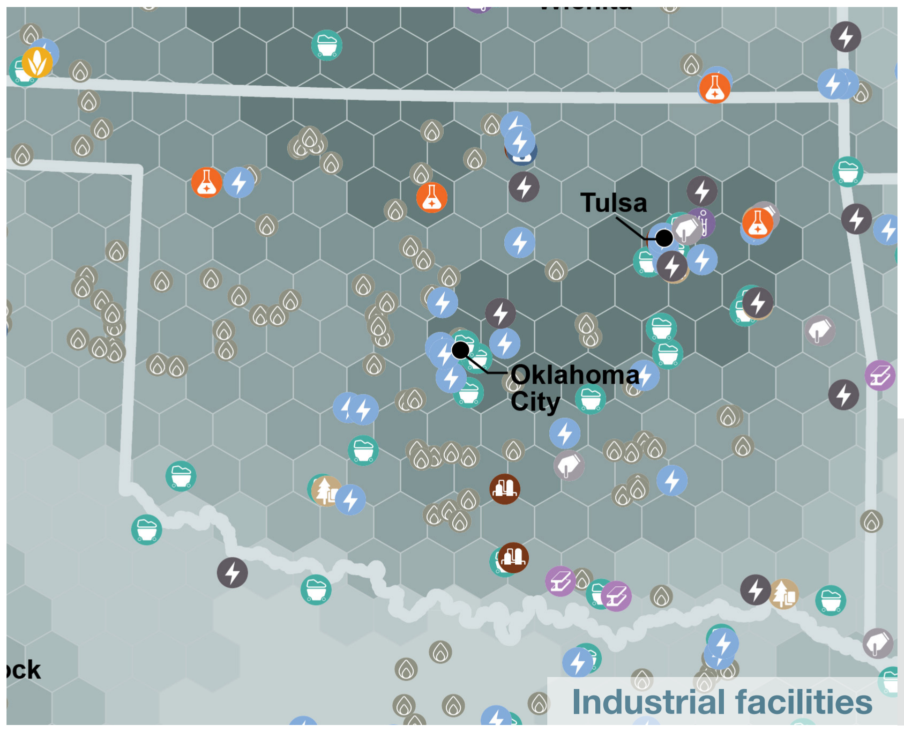
- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

US CARBON AND HYDROGEN HUBS ATLAS GREAT PLAINS INSTITUTE

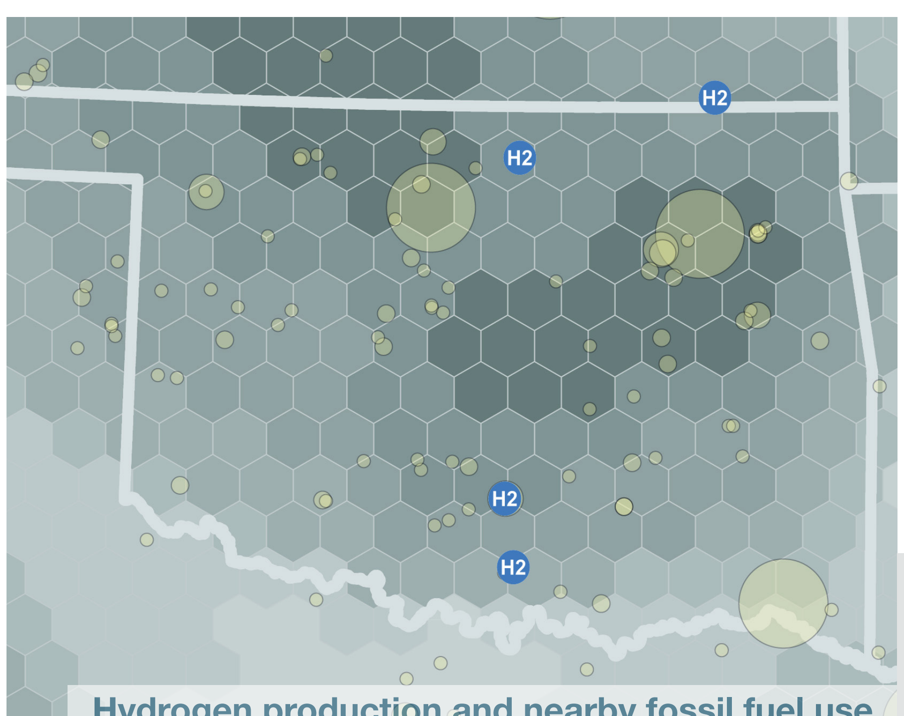
Oklahoma

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity give Oklahoma unique advantages in jumpstarting investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use



Oklahoma is home to a high number and concentration of diverse industries, including natural gas processing, pulp and paper manufacturing, and petroleum refining. Facilities in the Oklahoma hub emit 25.8 million metric tons (Mt) of CO_2e annually, including 3.8 Mt from stationary combustion and 3.8 Mt from process emissions. There are 16 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There are **four hydrogen-producing facilities** located in proximity to the Oklahoma hub. Industrial facilities in this regional hub use a total of 62 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

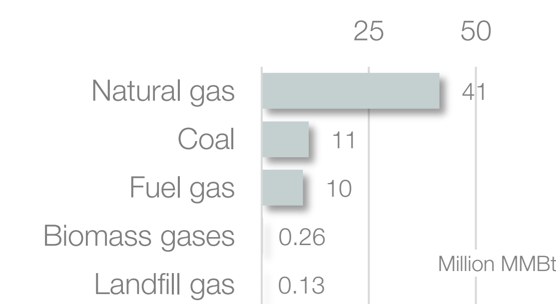
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ammonia	1	0.3	0.1	0.2
Cement	2	0.8	0.2	0.6
Chemicals	2	3.7	1.0	2.7
Coal power plants	4	9.4	< 0.1	-
Gas power plants	10	8.9	0.2	-
Gas processing	5	0.2	0.2	< 0.1
Metals, minerals & other	11	0.7	0.6	0.1
Pulp & paper	3	0.9	0.8	0.1
Refineries	2	1.0	0.9	0.2
Total	**40**	**25.8**	**3.8**	**3.8**

All emissions are in million metric tons CO_2e.

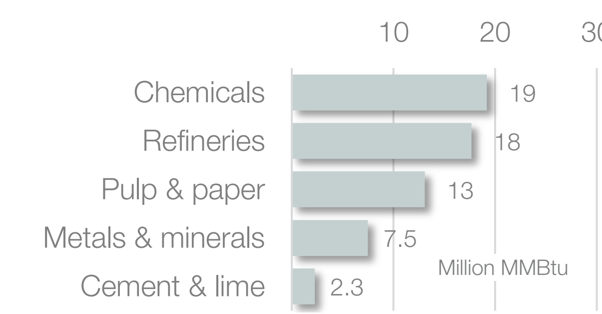
The top industrial fuels consumed in the Oklahoma hub include natural gas at 41 million MMBtu per year and coal at 11 million MMBtu per year. Chemicals plants and refineries are the largest consumers of fossil fuels in this regional hub, consuming 19 million MMBtu and 18 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



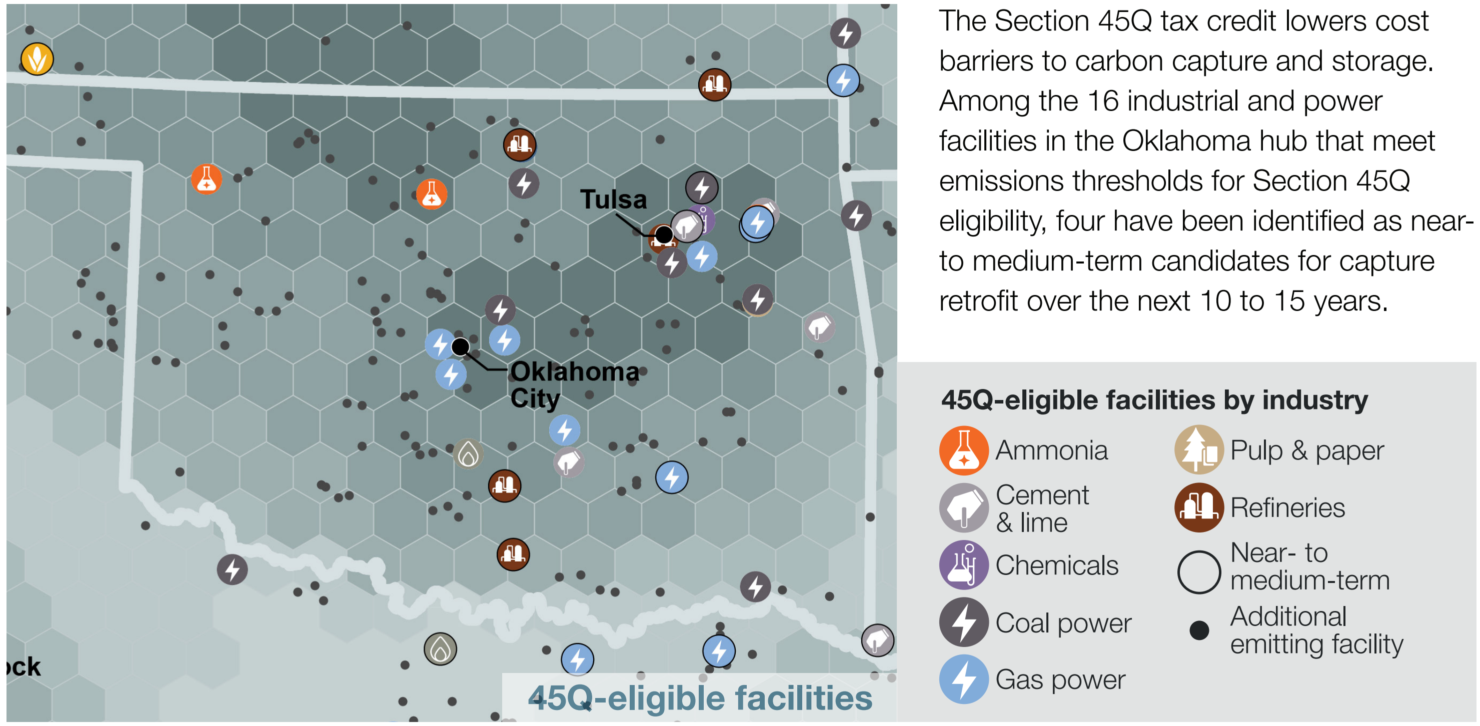
Largest fuel-consuming industries



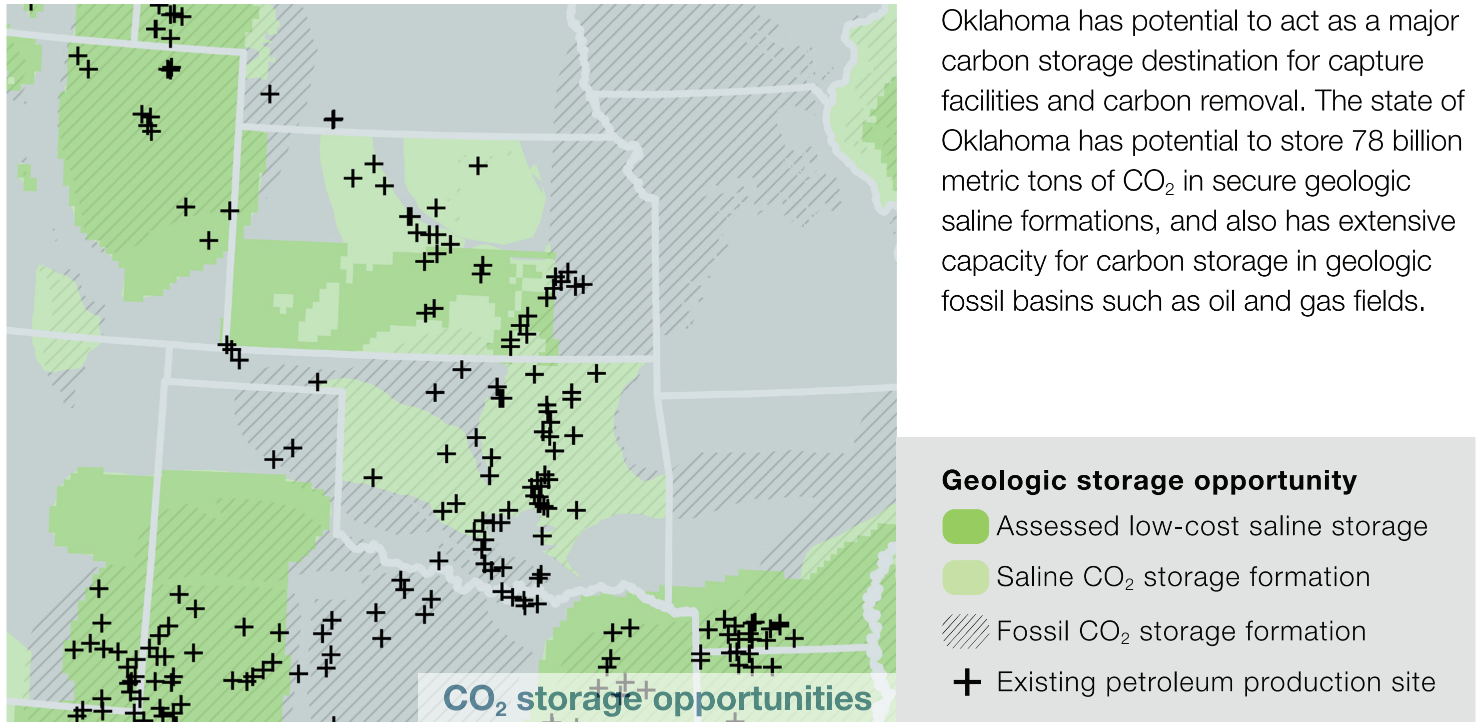
Oklahoma

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

Carbon Capture and Storage

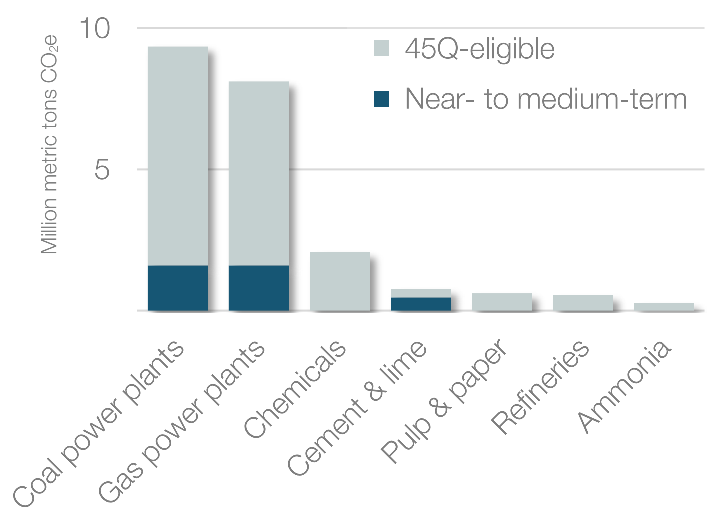


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 16 industrial and power facilities in the Oklahoma hub that meet emissions thresholds for Section 45Q eligibility, four have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.



Oklahoma has potential to act as a major carbon storage destination for capture facilities and carbon removal. The state of Oklahoma has potential to store 78 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins such as oil and gas fields.

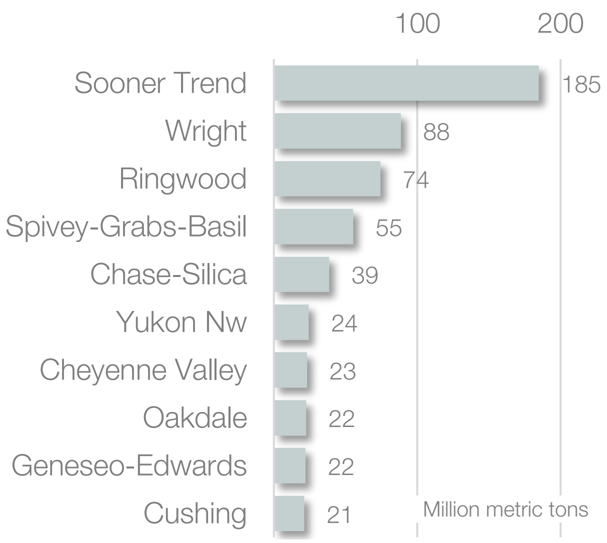
Carbon capture opportunities



- Industrial and power facilities emit **25.8 Mt CO_2e per year**
- **45Q-eligible** facilities emit **23.4 Mt CO_2e per year**
- **3.7 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

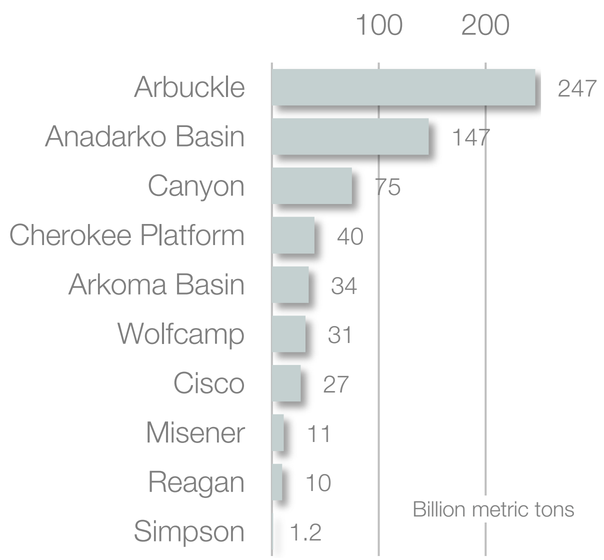
Fossil storage formations

by CO_2 storage capacity



Saline storage formations

by CO_2 storage capacity

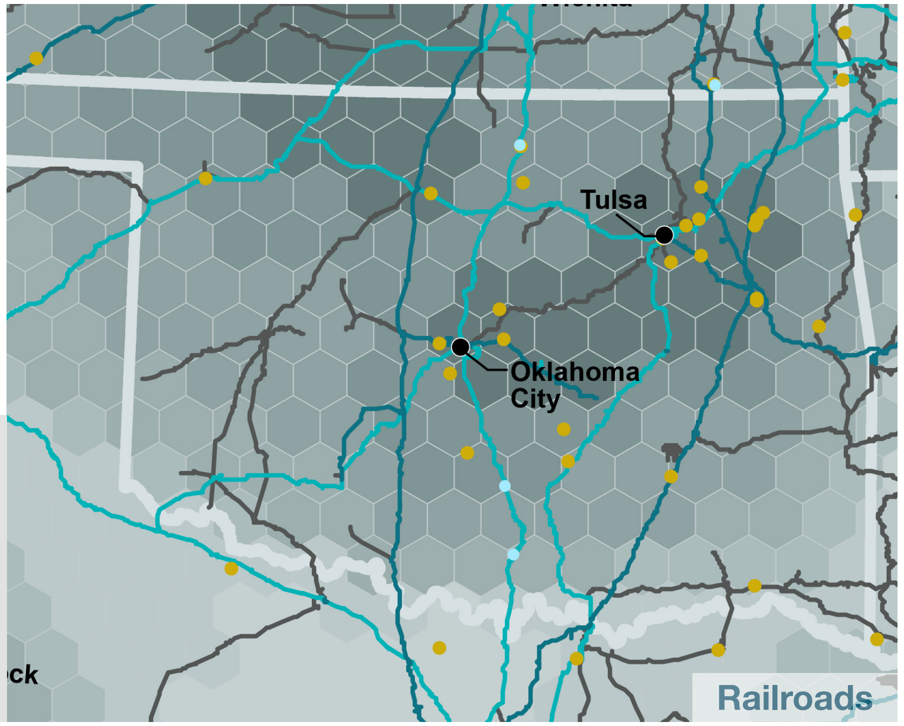


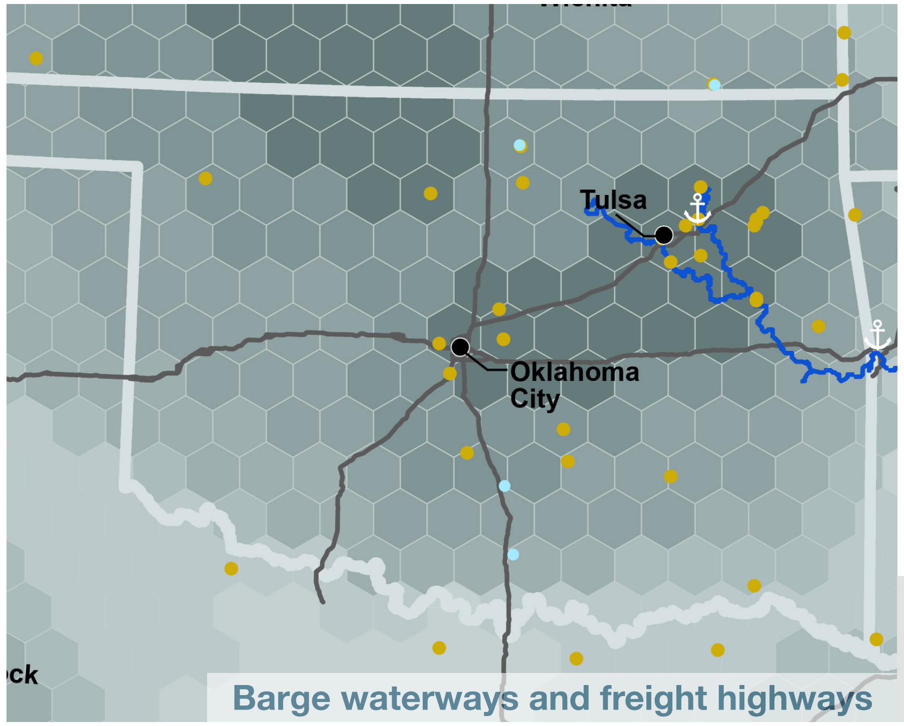
Oklahoma

Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Oklahoma hub are located along major rail lines, facilitating connection to markets across the US.

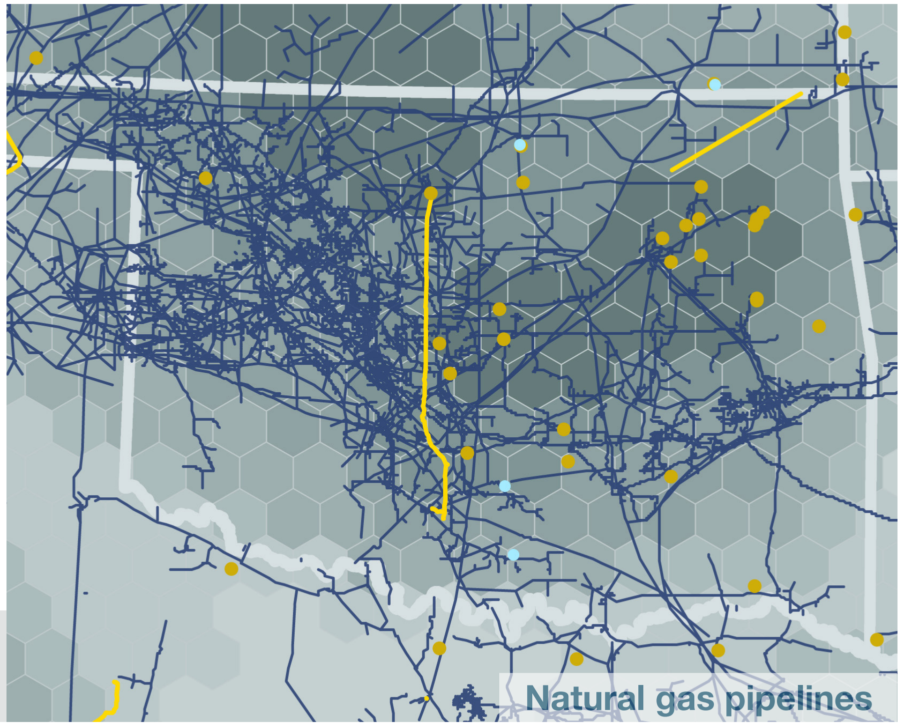


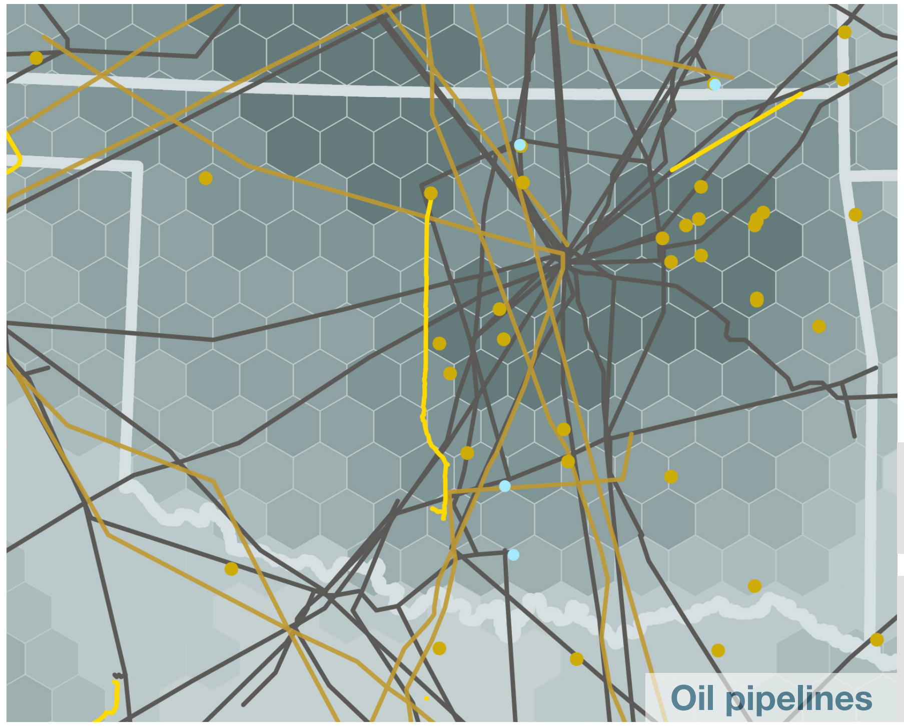


Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With major ports along the Arkansas River and interstate connection to other regional hubs, Oklahoma is well-situated as a transport nexxus for carbon and hydrogen markets.

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Oklahoma hub currently has 2,399 miles of natural gas pipelines, 8,800 miles of oil pipelines, and 211 miles of nearby CO_2 pipeline.

Infrastructure	Miles
Natural gas pipelines	2,399
Oil pipelines	8,800



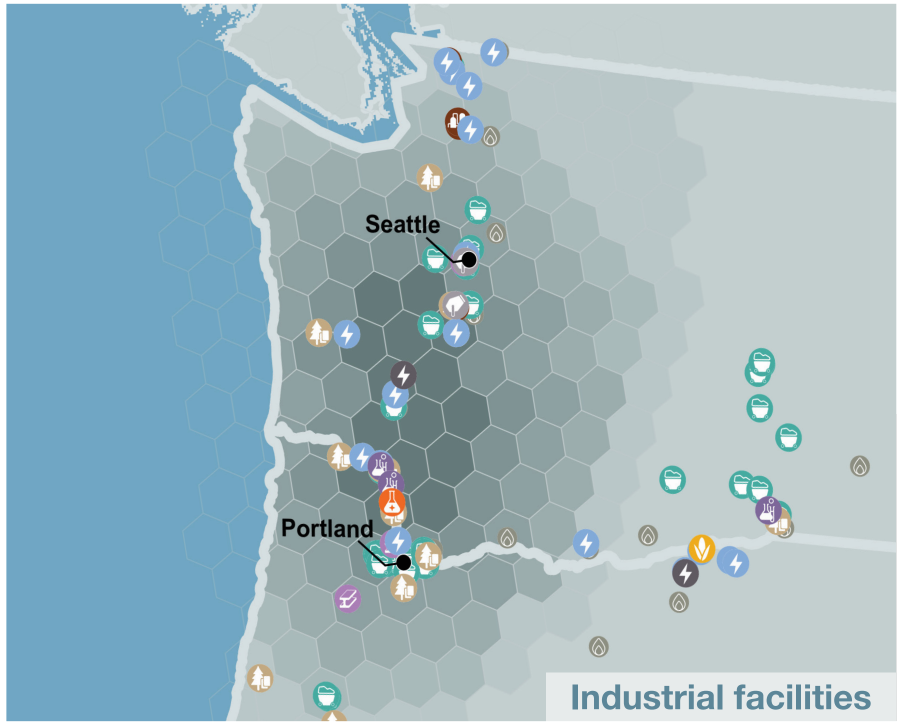


Oklahoma is centrally located between areas of rich geologic storage resource and existing CO_2 utilization. This offers potential for the state to become a nexus of long-distance CO_2 transport corridors under future scenarios where major CO_2 capture, transport, and storage occurs in accordance with US decarbonization goals.

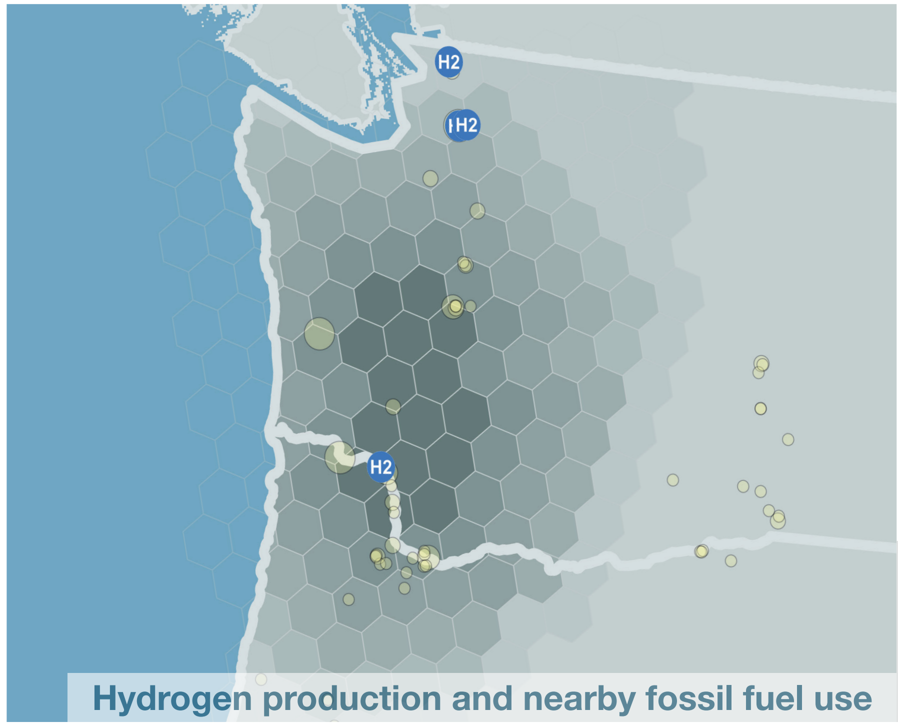
Pacific Northwest

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity in the Pacific Northwest provide a key opportunity for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use



The Pacific Northwest is home to a high number and concentration of diverse industries, including natural gas processing, pulp and paper manufacturing, and petroleum refining. Facilities in the Pacific Northwest hub emit 26.6 million metric tons (Mt) of CO_2e annually, including 7.0 Mt from stationary combustion and 5.4 Mt from process emissions. There are 15 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There are **four hydrogen-producing facilities** in the Pacific Northwest hub already co-located with the central corridor of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 167 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

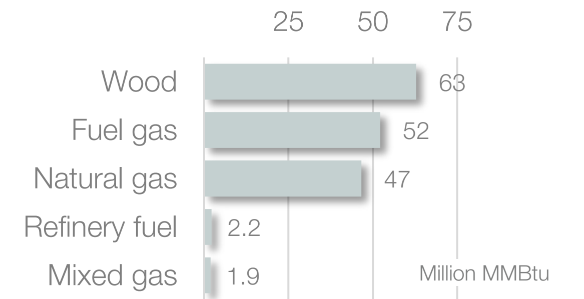
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ammonia	1	0.2	0.1	0.1
Cement	2	0.4	< 0.1	0.4
Chemicals	2	0.1	0.1	< 0.1
Coal power plants	1	8.0	< 0.1	-
Gas power plants	14	7.0	0.8	-
Gas processing	8	0.3	0.2	0.1
Metals, minerals & other	22	2.6	0.8	1.8
Pulp & paper	10	1.2	0.9	0.3
Refineries	5	6.6	4.1	2.5
Steel & steel products	2	0.3	0.1	0.1
Total	**67**	**26.6**	**7.0**	**5.4**

All emissions are in million metric tons CO_2e.

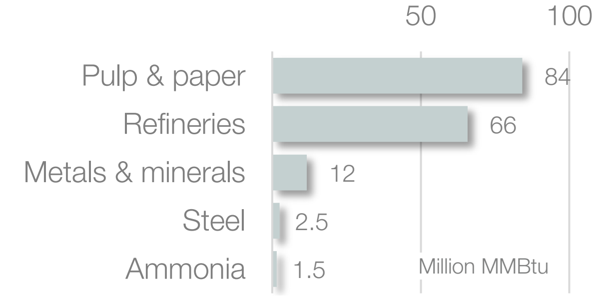
The top industrial fuels consumed in the Pacific Northwest hub include wood at 63 million MMBtu per year and fuel gas at 52 million MMBtu per year. Pulp and paper plants and refineries are the largest consumers of fossil fuels in this regional hub, consuming 84 million MMBtu and 66 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



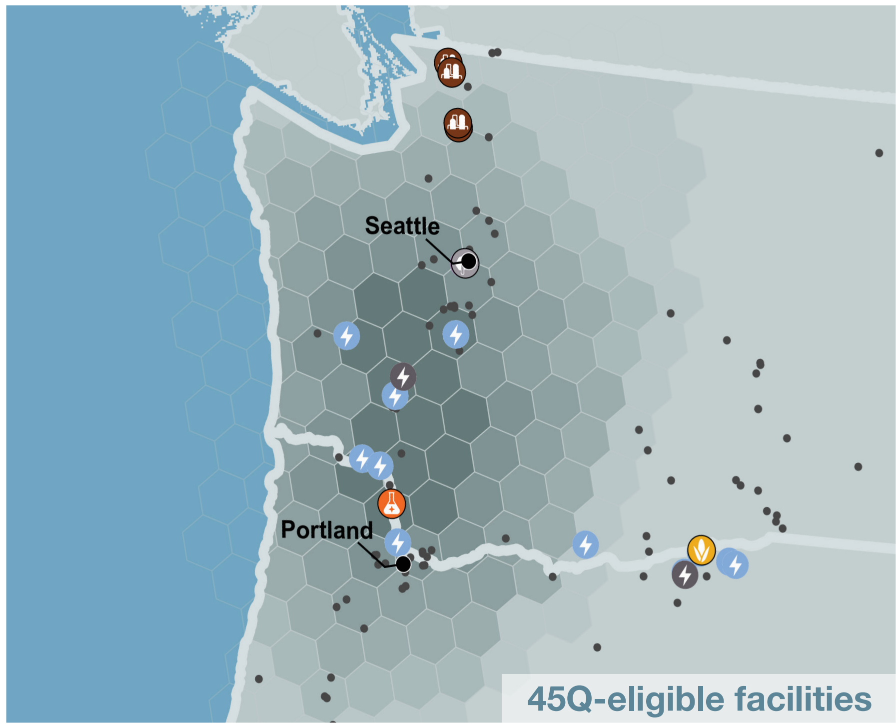
Largest fuel-consuming industries



Pacific Northwest

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

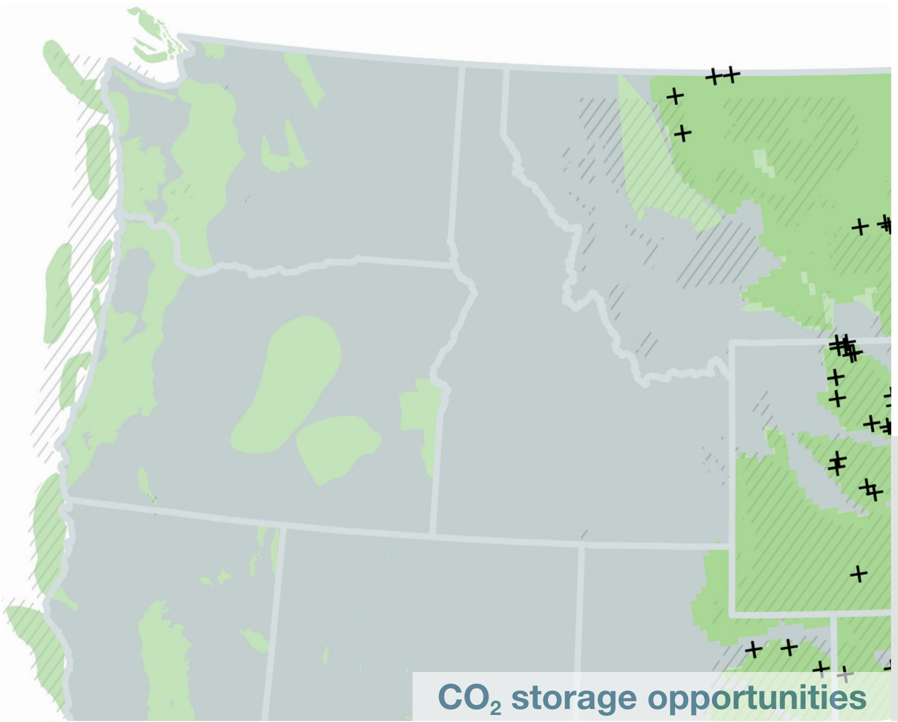
Carbon Capture and Storage



The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 15 industrial and power facilities in the Pacific Northwest hub that meet emissions thresholds for Section 45Q eligibility, six have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

45Q-eligible facilities by industry

- Ammonia
- Refineries
- Cement & lime
- Steel
- Coal power
- Near- to medium-term
- Gas power
- Additional emitting facility
- Metals, minerals, & other

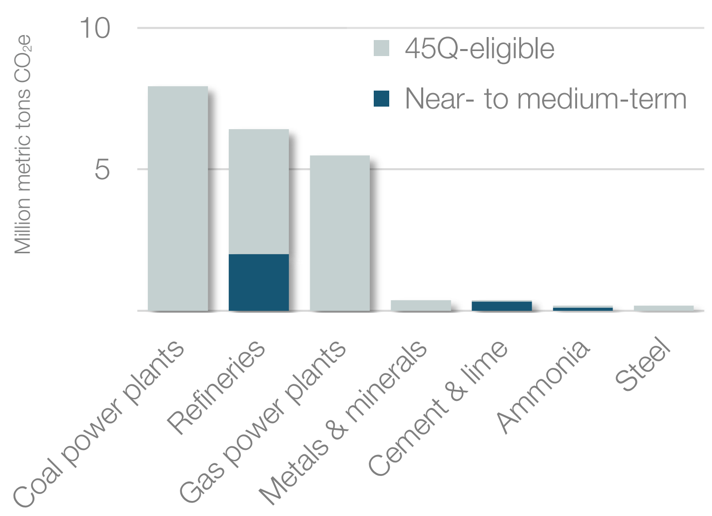


The Pacific Northwest has potential to act as a carbon storage destination for capture facilities and carbon removal. The states of Washington and Oregon have the combined potential to store 214 billion metric tons of CO_2 in secure geologic saline formations, and also have capacity for carbon storage in geologic fossil basins.

Geologic storage opportunity

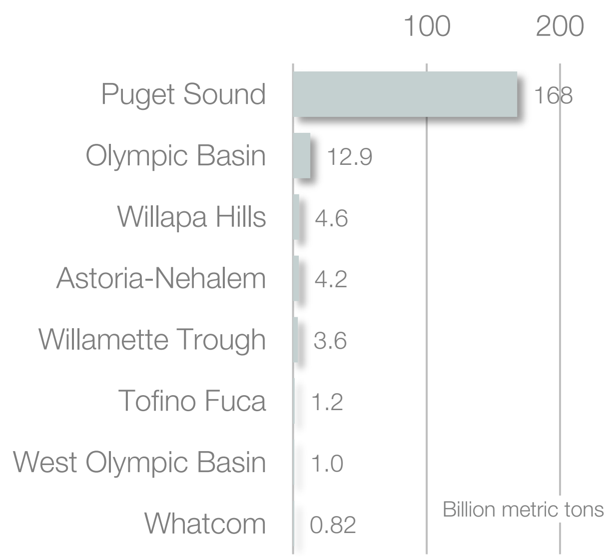
- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

Carbon capture opportunities



- Industrial and power facilities emit **26.6 Mt CO_2e per year**
- **45Q-eligible** facilities emit **21.7 Mt CO_2e per year**
- **2.4 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

Saline storage formations
by CO_2 storage capacity



Note: Offshore fossil storage formations not yet classified for storage potential.

Pacific Northwest

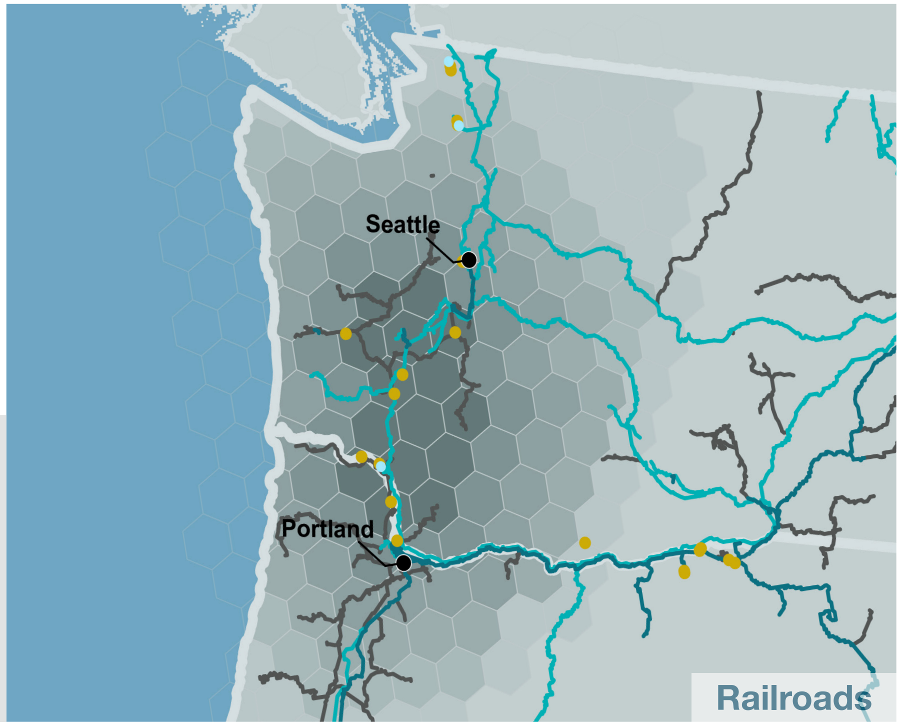
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

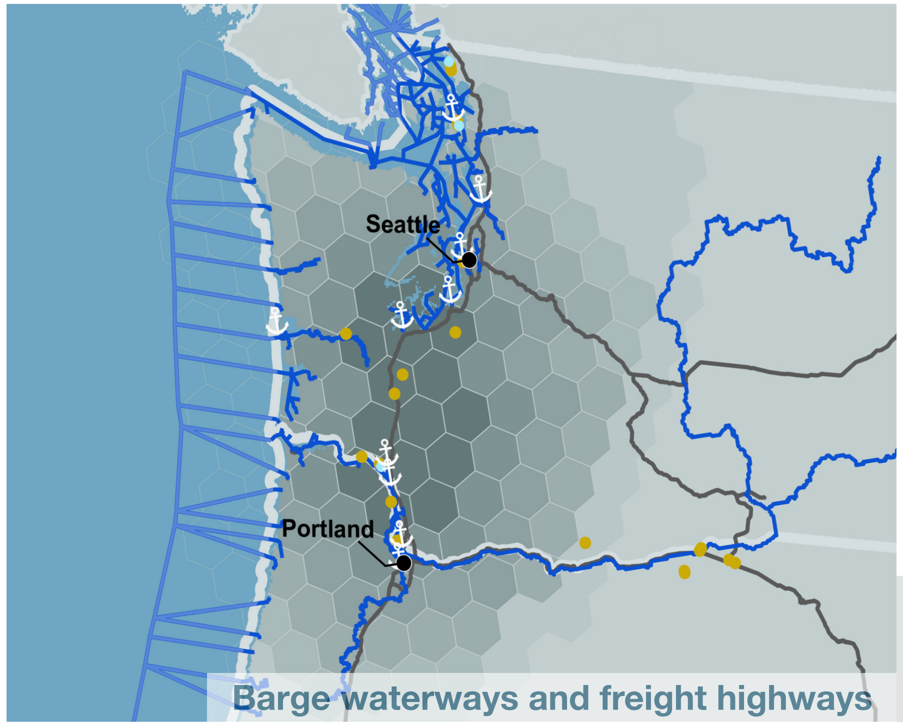
Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Pacific Northwest hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





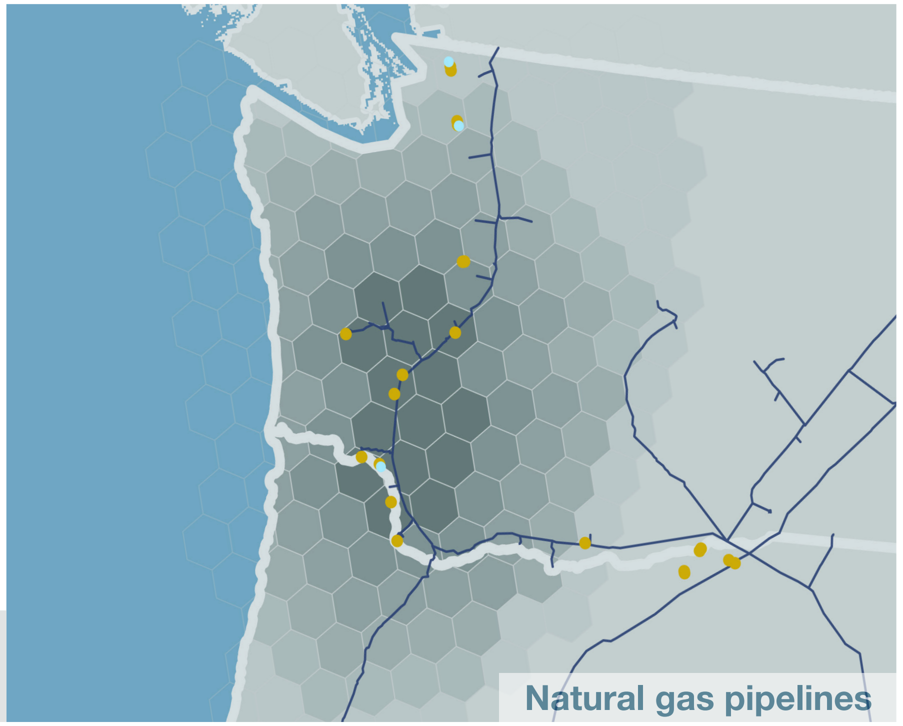
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With several major ports and extensive access to shipping channels, the Pacific Northwest has unique access to global and domestic markets for carbon and hydrogen.

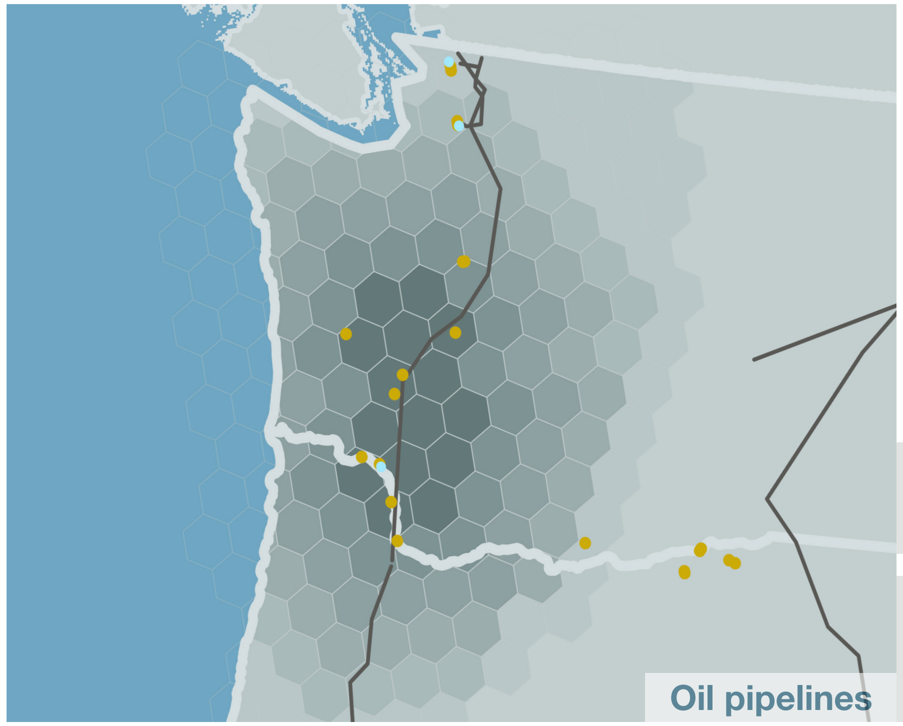
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Pacific Northwest hub currently has 512 miles of natural gas pipelines.

Infrastructure	Miles
Natural gas pipelines	512
Oil pipelines	438

- Existing CO_2 pipelines
- Natural gas pipelines





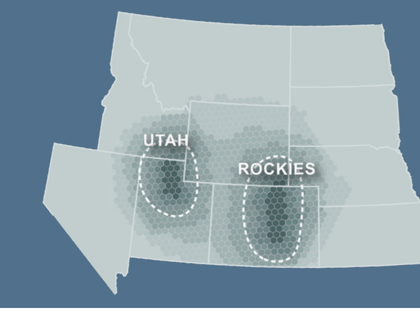
Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Pacific Northwest hub's 438 miles of oil pipelines to achieve efficient buildout.

- 45Q-eligible facility
- Existing hydrogen production

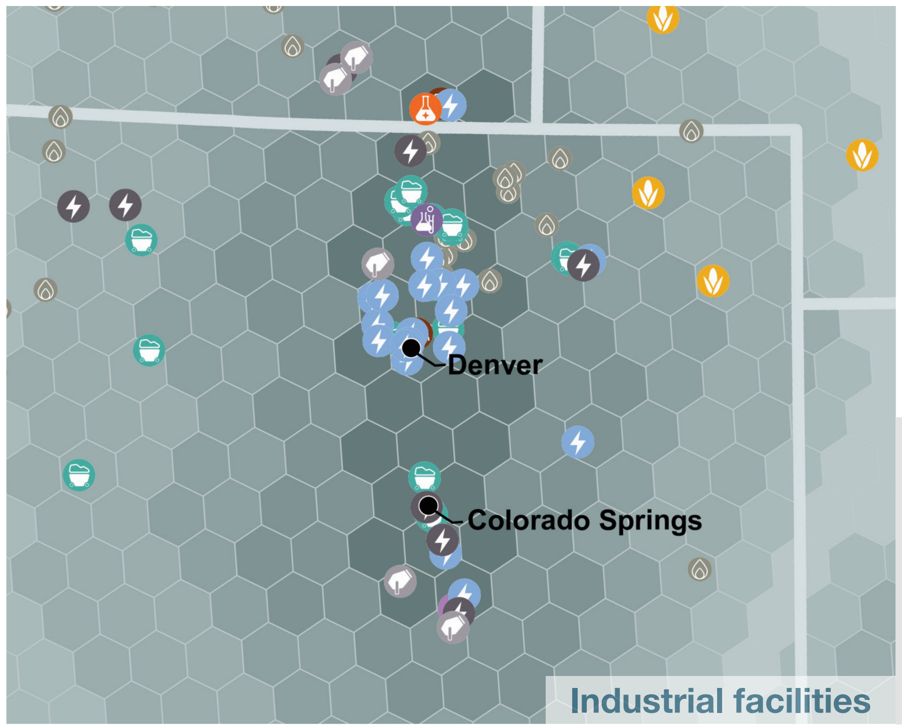
- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

The Rockies: Denver

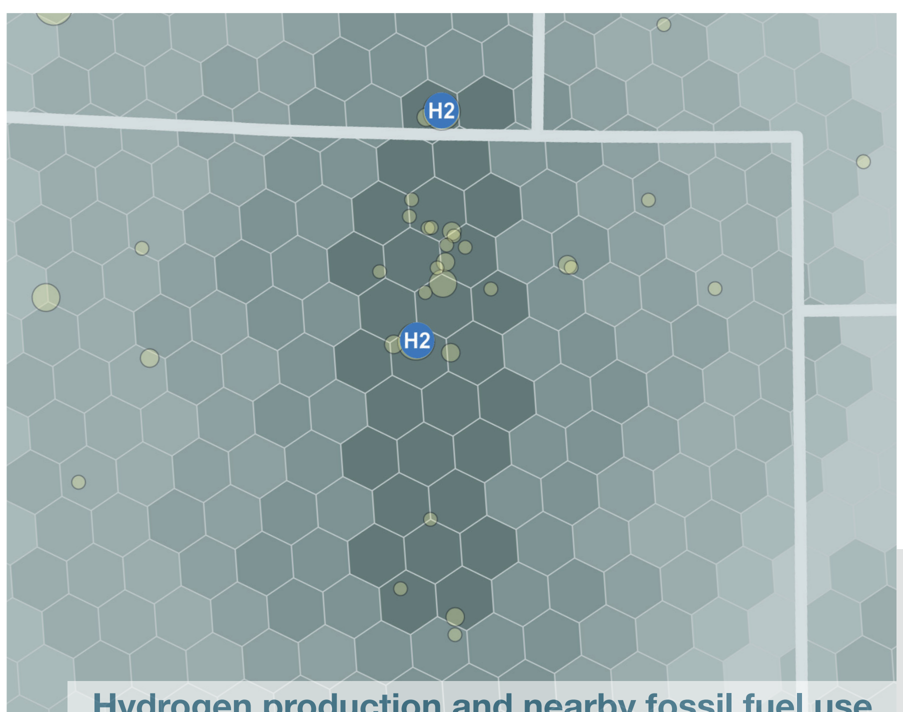
The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity make the Rockies a natural launching point for investment in carbon capture and low-carbon hydrogen deployment.



Industrial Emissions and Fossil Fuel Use



The Rockies are home to a high number and concentration of diverse industries, including natural gas processing, cement production, and petroleum refining. Facilities in the Rockies Denver hub emit 26.6 million metric tons (Mt) of CO_2e annually, including 3.3 Mt from stationary combustion and 3.7 Mt from process emissions. There are 15 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There are **two hydrogen-producing facilities** in the Denver hub already co-located with the central corridor of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 46 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

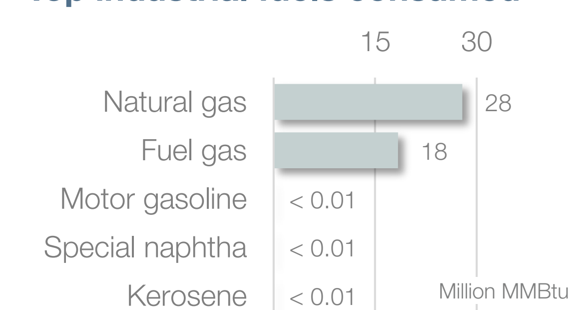
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Ammonia	1	0.4	0.2	0.3
Cement	3	2.0	< 0.1	2.0
Chemicals	1	0.0	< 0.1	-
Coal power plants	4	12.1	< 0.1	-
Gas power plants	19	7.9	0.4	-
Gas processing	12	1.3	1.0	0.2
Metals, minerals & other	12	1.0	0.5	0.5
Refineries	2	1.6	1.0	0.6
Steel & steel products	1	0.3	0.2	0.1
Total	**55**	**26.6**	**3.3**	**3.7**

All emissions are in million metric tons CO_2e.

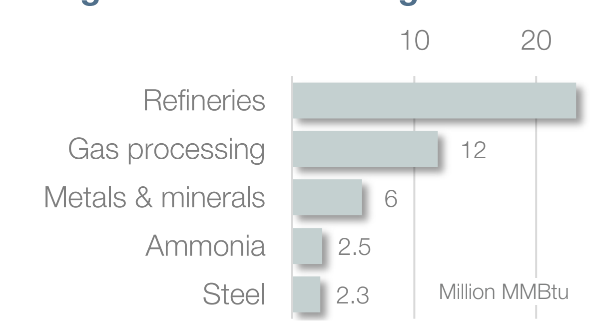
The top industrial fuels consumed in the Denver hub include natural gas at 28 million MMBtu per year and fuel gas at 18 million MMBtu per year. Refineries and gas processing plants are the largest consumers of fossil fuels in this regional hub, consuming 23 million MMBtu and 12 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed

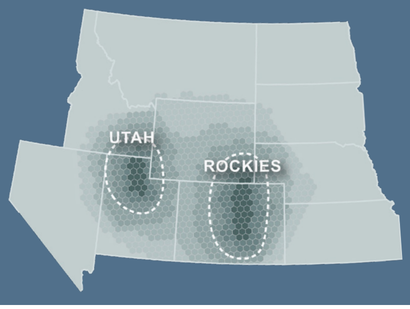


Largest fuel-consuming industries

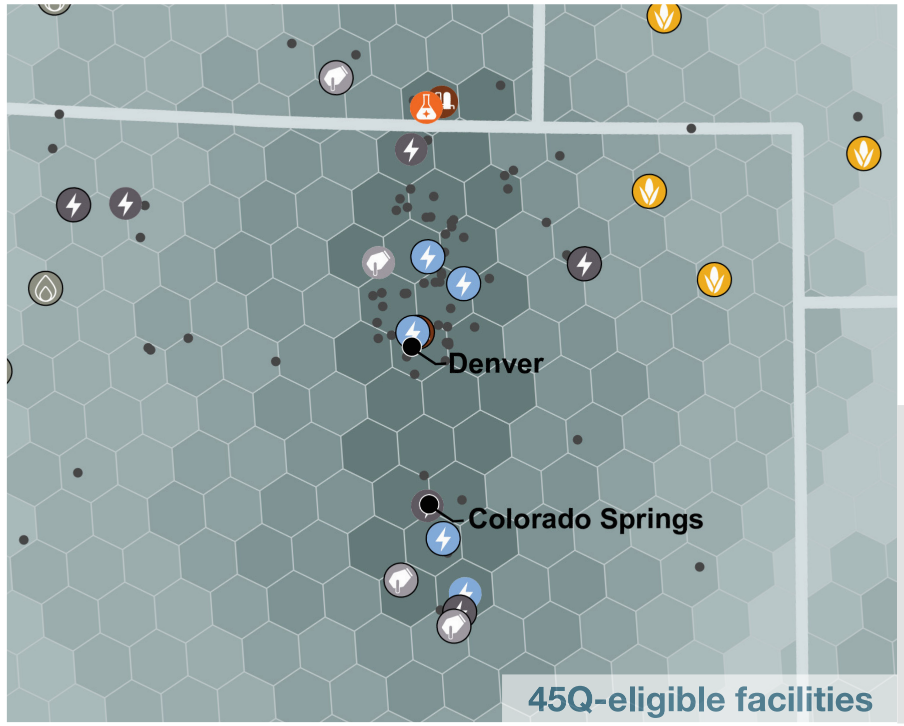


The Rockies: Denver

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.



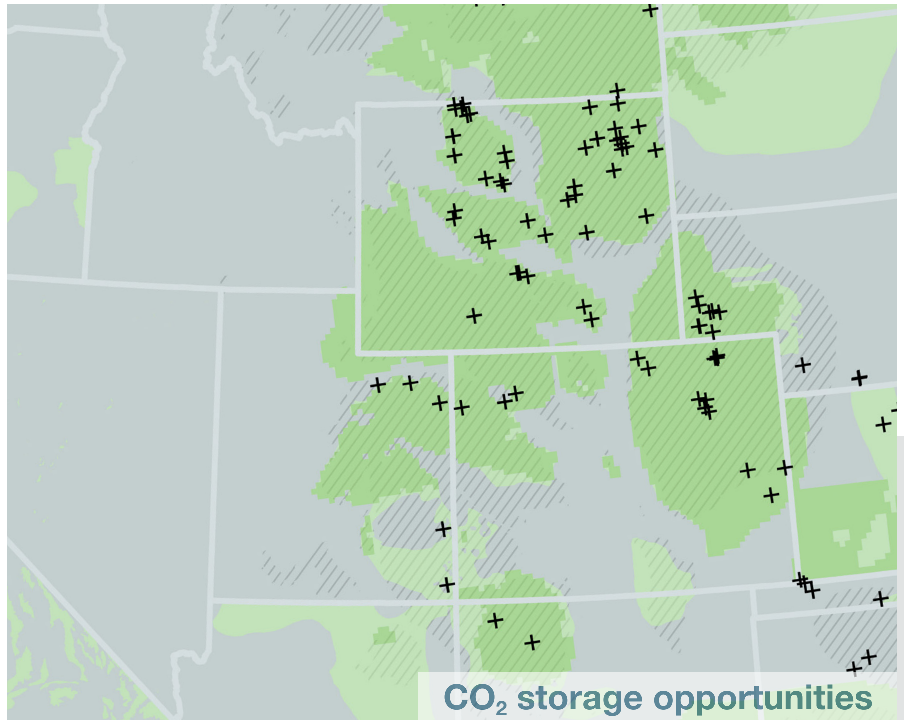
Carbon Capture and Storage



The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 15 industrial and power facilities in the Denver hub that meet emissions thresholds for Section 45Q eligibility, eight have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

45Q-eligible facilities by industry

- Ammonia
- Refineries
- Cement & lime
- Near- to medium-term
- Coal power
- Additional emitting facility
- Gas power

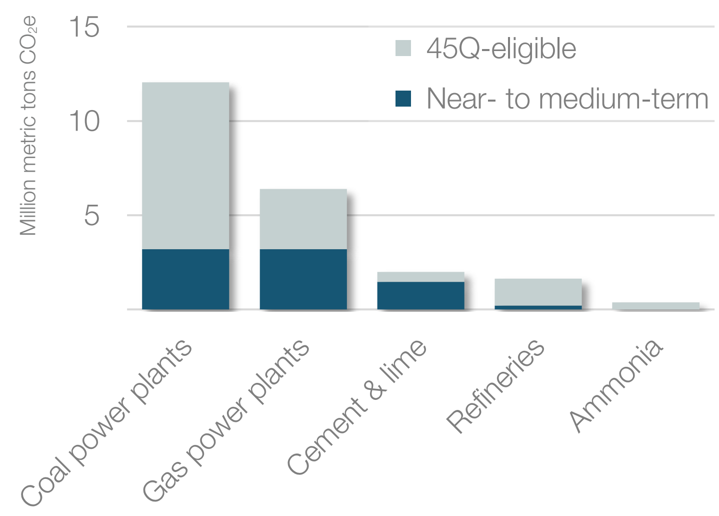


The Rockies have potential to act as a major carbon storage destination for capture facilities and carbon removal. The states of Wyoming and Colorado have the combined potential to store 773 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins such as oil and gas fields.

Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

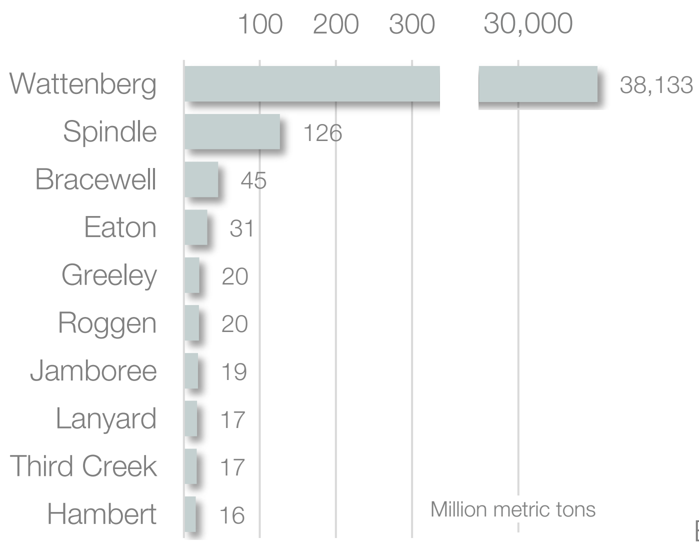
Carbon capture opportunities



- Industrial and power facilities emit **26.6 Mt CO_2e per year**
- **45Q-eligible** facilities emit **22.6 Mt CO_2e per year**
- **8.1 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

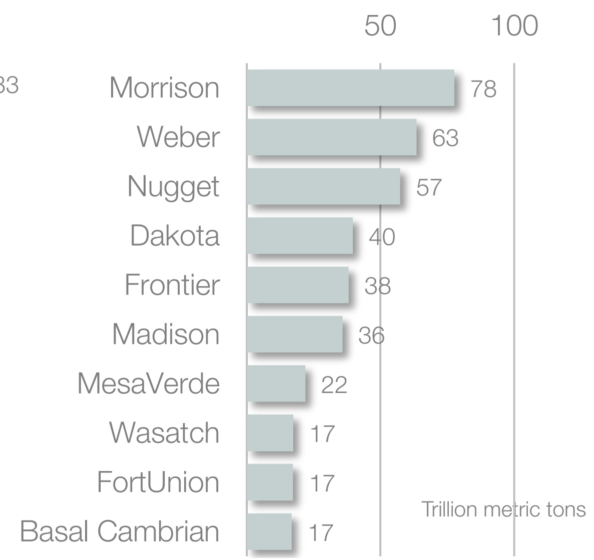
Fossil storage formations

by CO_2 storage capacity

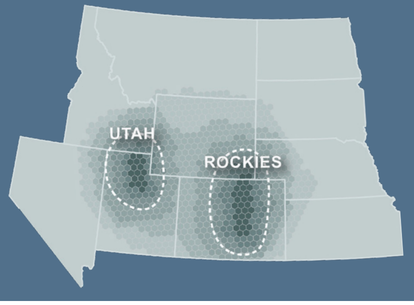


Saline storage formations

by CO_2 storage capacity



The Rockies: Denver



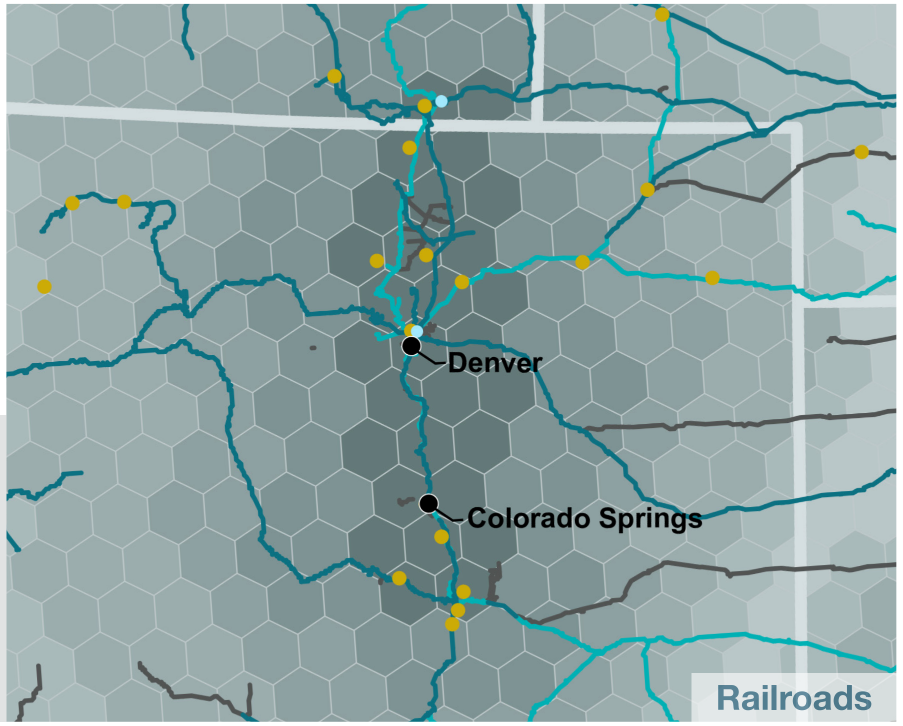
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

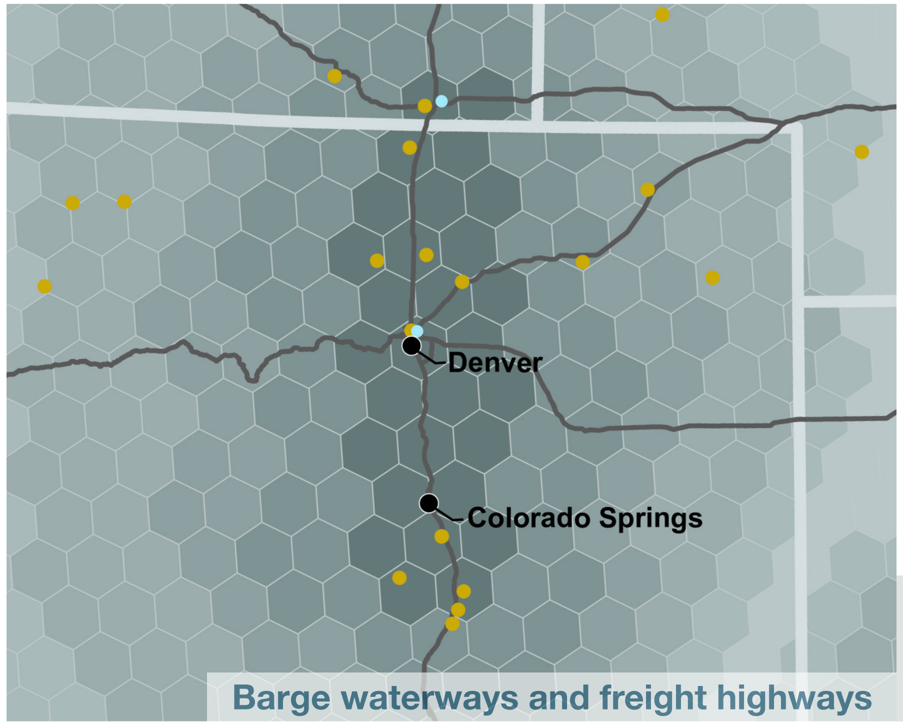
Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Denver hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





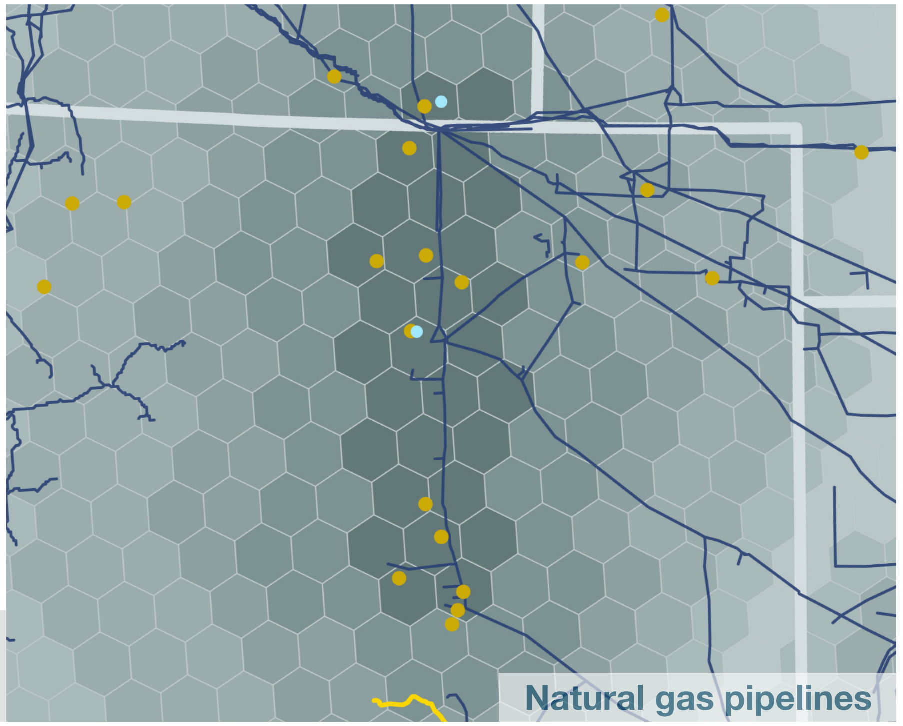
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. Freight trucking can connect the Denver hub to broader markets for carbon and hydrogen.

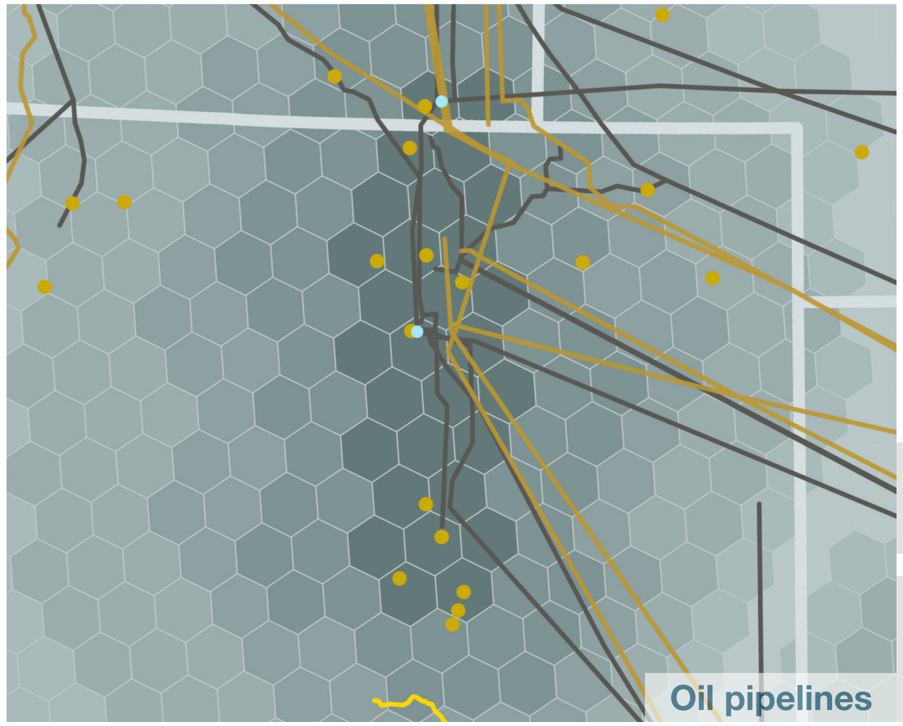
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Denver hub currently has 4,703 miles of natural gas pipelines. This regional hub is also adjacent to major existing CO_2 pipeline networks in Wyoming and the Permian Basin.

Infrastructure	Miles
Natural gas pipelines	4,703
Oil pipelines	3,066

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Denver hub's 3,066 miles of oil pipelines to achieve efficient buildout.

- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

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Southern California

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity make Southern California a potential launching point for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use

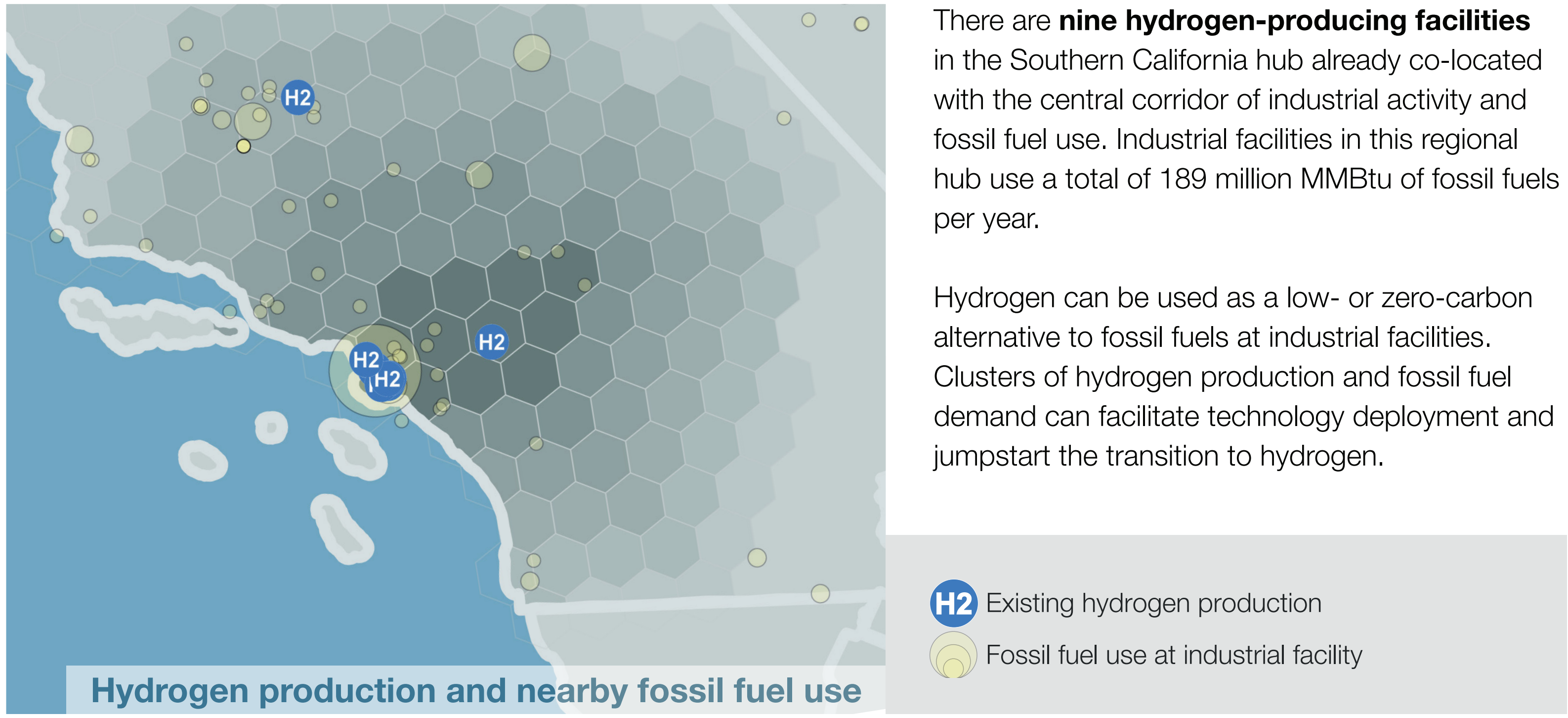
Industrial facilities

Southern California is home to a high number and concentration of diverse industries, including petroleum refining, natural gas processing, and cement and steel manufacturing. Facilities in the Southern California hub emit 31.7 million metric tons (Mt) of CO_2e annually, including 11.3 Mt from stationary combustion and 12.7 Mt from process emissions. There are 18 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.

Industrial facility emissions

Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Cement	3	4.2	< 0.1	4.2
Chemicals	2	0.1	0.1	-
Gas power plants	23	7.9	0.3	-
Gas processing	6	2.3	0.1	2.2
Metals, minerals & other	14	0.8	0.7	0.1
Pulp & paper	2	0.3	0.3	-
Refineries	8	15.9	9.7	6.2
Steel & steel products	3	0.2	0.2	< 0.1
Total	**61**	**31.7**	**11.3**	**12.7**

All emissions are in million metric tons CO_2e.



Hydrogen production and nearby fossil fuel use

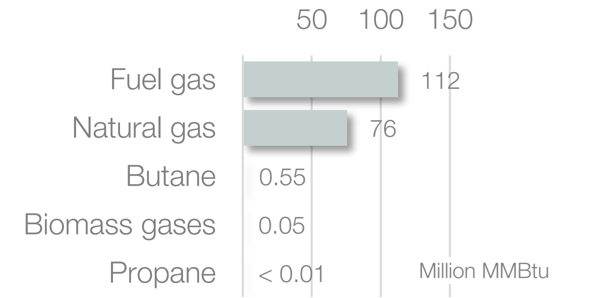
There are **nine hydrogen-producing facilities** in the Southern California hub already co-located with the central corridor of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 189 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

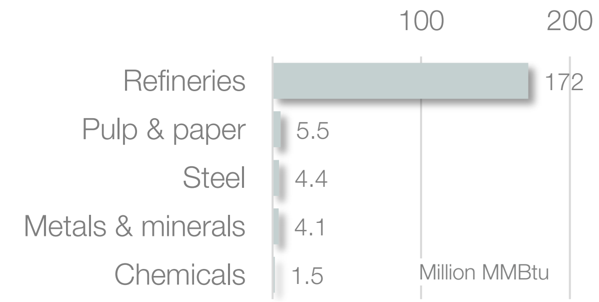
The top industrial fuels consumed in the Southern California hub include fuel gas at 112 million MMBtu per year and natural gas at 76 million MMBtu per year. Refineries are the largest consumers of fossil fuels in this regional hub, consuming 172 million MMBtu of fossil fuels per year.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



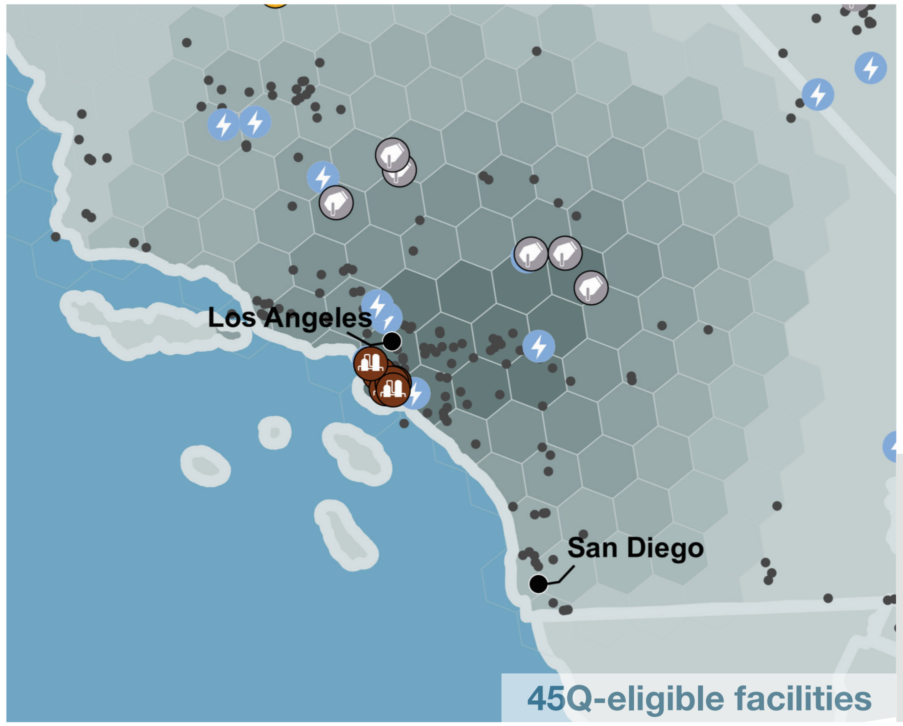
Largest fuel-consuming industries



Southern California

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

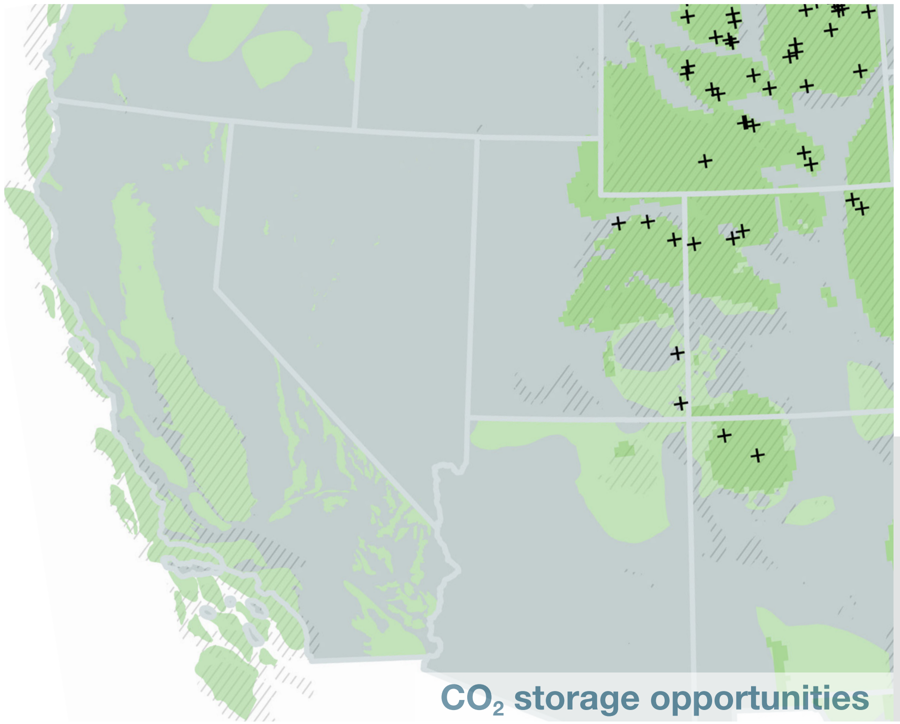
Carbon Capture and Storage



The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 18 industrial and power facilities in the Southern California hub that meet emissions thresholds for Section 45Q eligibility, 12 have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

45Q-eligible facilities by industry

- Cement & lime
- Gas power
- Gas processing
- Refineries
- Near- to medium-term
- Additional emitting facility

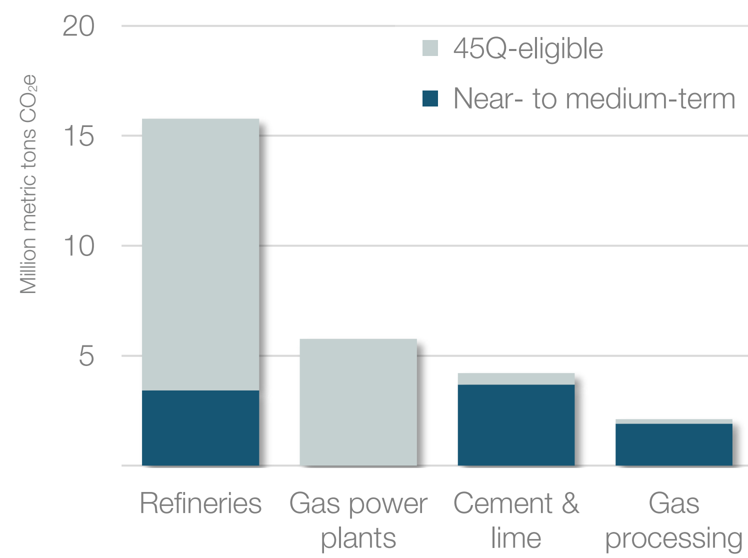


Southern California has potential to act as a carbon storage destination for capture facilities and carbon removal. The state of California has potential to store 148 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins.

Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

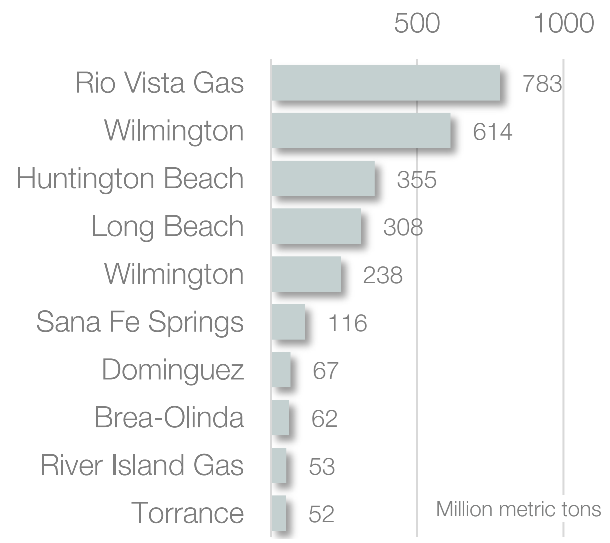
Carbon capture opportunities



- Industrial and power facilities emit **31.7 Mt CO_2e per year**
- **45Q-eligible** facilities emit **28.0 Mt CO_2e per year**
- **9.0 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

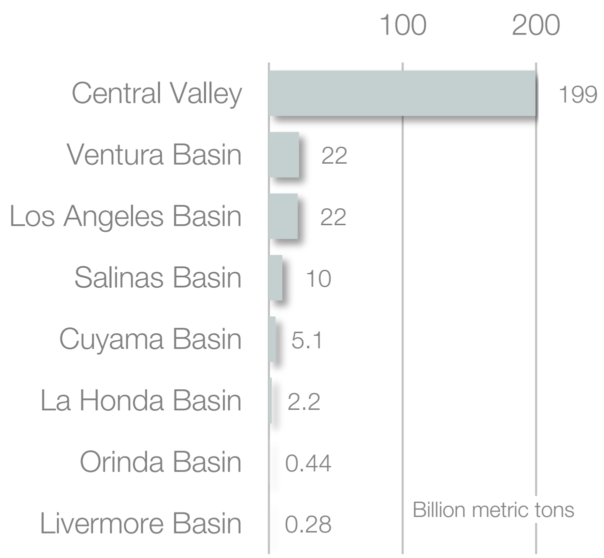
Fossil storage formations

by CO_2 storage capacity



Saline storage formations

by CO_2 storage capacity



Southern California

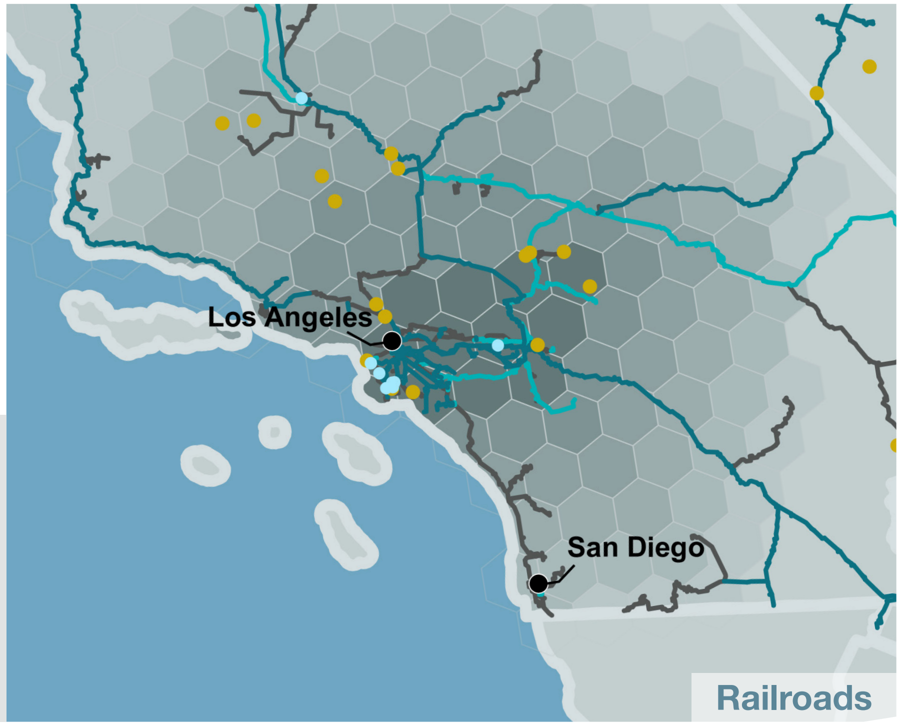
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Southern California hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others



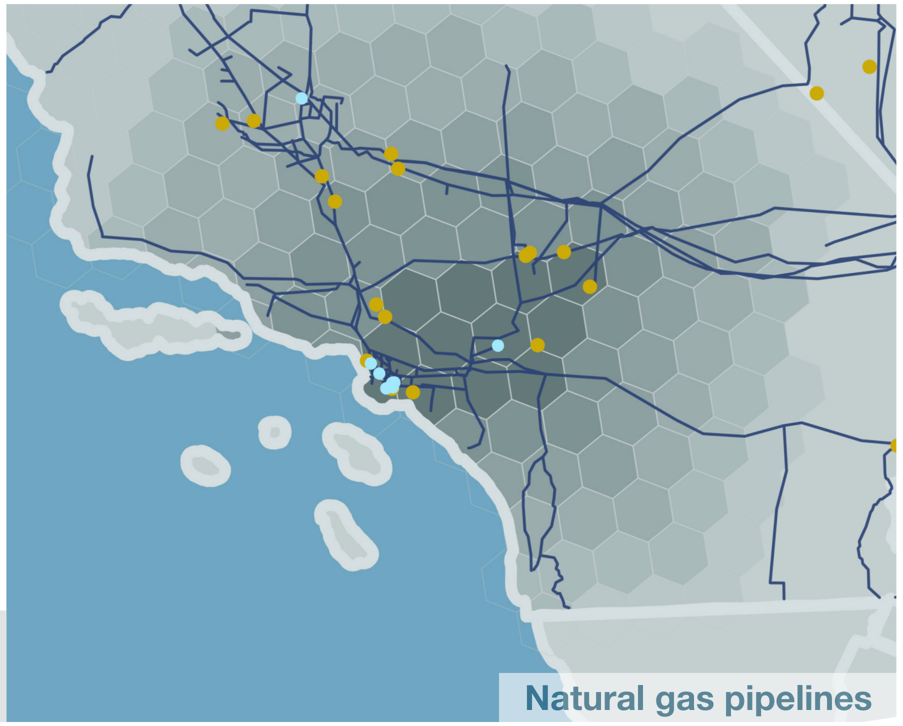
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With several major ports and extensive access to shipping channels, Southern California has unique access to global and domestic markets for carbon and hydrogen.

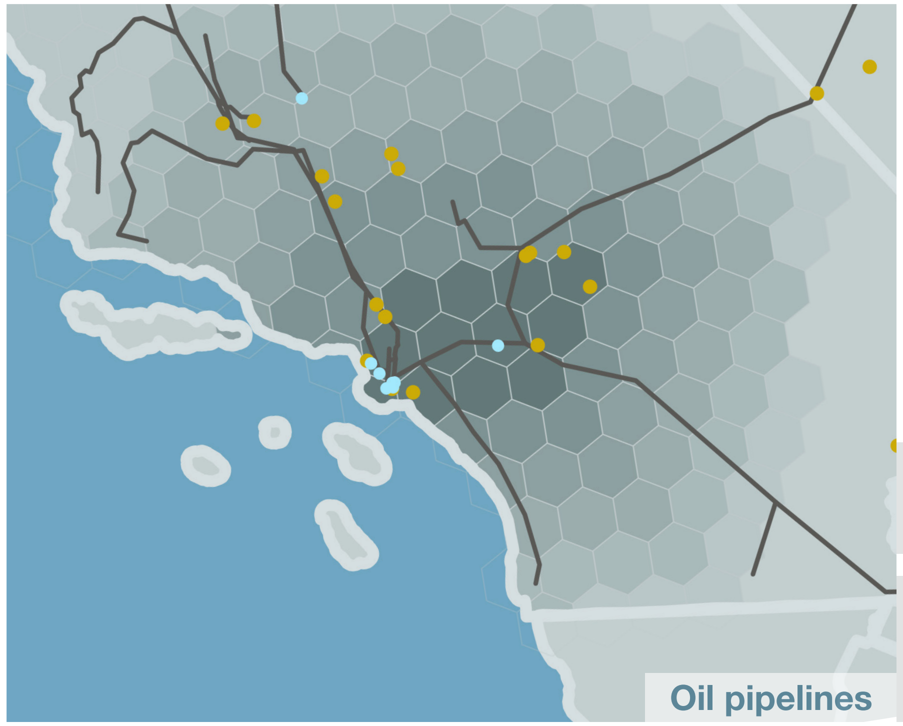
- Interstate highway
- Navigable waterway
- ⚓ Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Southern California hub currently has 750 miles of natural gas pipelines.

Infrastructure	Miles
Natural gas pipelines	750
Oil pipelines	1,596

- Existing CO_2 pipelines
- Natural gas pipelines





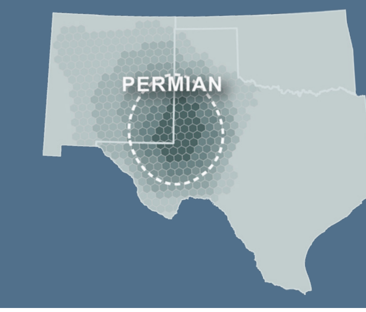
Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Southern California hub's 1,596 miles of oil pipelines to achieve efficient buildout.

- 45Q-eligible facility
- Existing hydrogen production

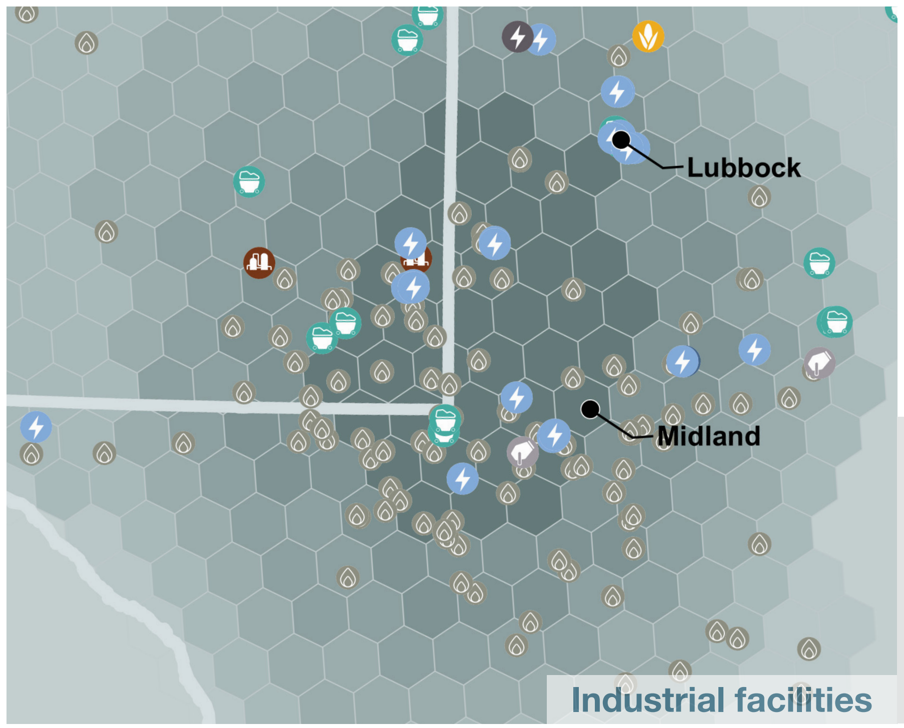
- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

Texas: Permian Basin

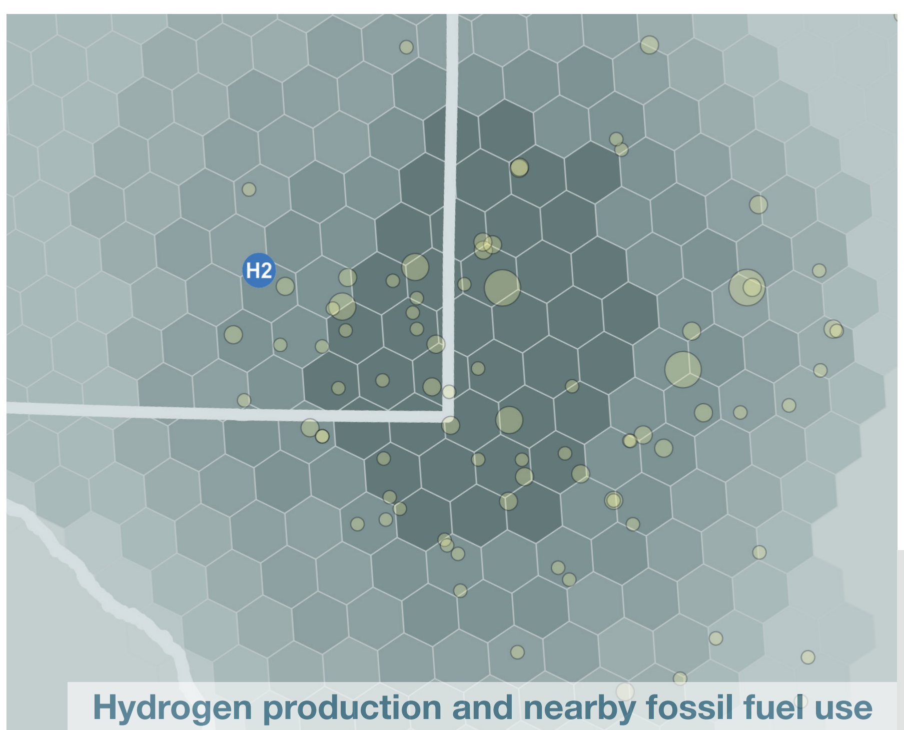
The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity give the Permian Basin unique advantages in catalyzing investment in carbon capture and low-carbon hydrogen deployment.



Industrial Emissions and Fossil Fuel Use



The Permian Basin is home to a high concentration of natural gas processing facilities as well as industries including petroleum refining and cement production. Facilities in the Permian Basin hub emit 30.5 million metric tons (Mt) of CO_2e annually, including 8.4 Mt from stationary combustion and 6.8 Mt from process emissions. There are 35 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



Industrial activity and fuel use is distributed throughout the Permian Basin hub and includes hydrogen prduction at at least **one facility**. Industrial facilities in this regional hub use a total of 95 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

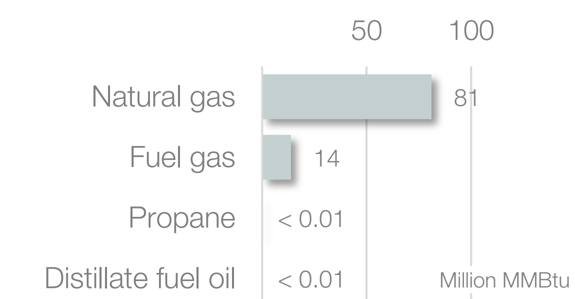
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Cement	1	0.4	< 0.1	0.3
Coal power plants	1	2.9	< 0.1	-
Gas power plants	19	13.3	0.9	-
Gas processing	97	11.5	6.0	5.5
Metals, minerals & other	7	0.3	0.2	< 0.1
Petrochemicals	1	0.3	0.0	0.3
Refineries	3	1.9	1.2	0.7
Total	**129**	**30.5**	**8.4**	**6.8**

All emissions are in million metric tons CO_2e.

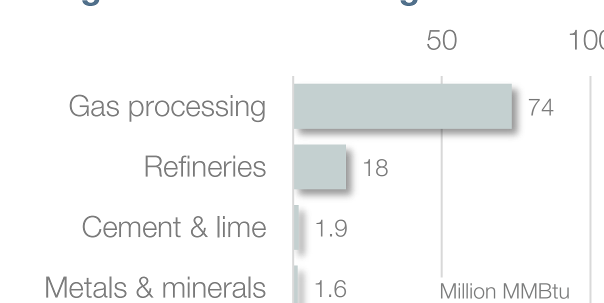
The top industrial fuels consumed in the Permian hub include natural gas at 81 million MMBtu per year and fuel gas at 14 million MMBtu per year. Gas processing plants and refineries are the largest consumers of fossil fuels in this regional hub, consuming 74 million MMBtu and 18 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed

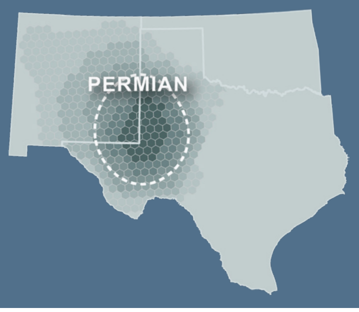


Largest fuel-consuming industries

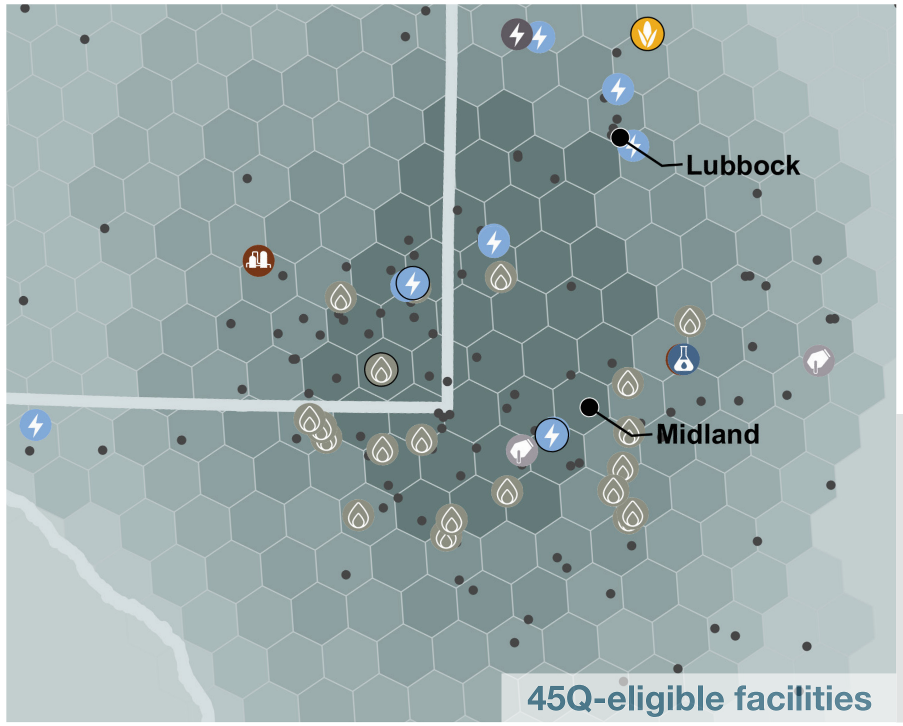


Texas: Permian Basin

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.



Carbon Capture and Storage

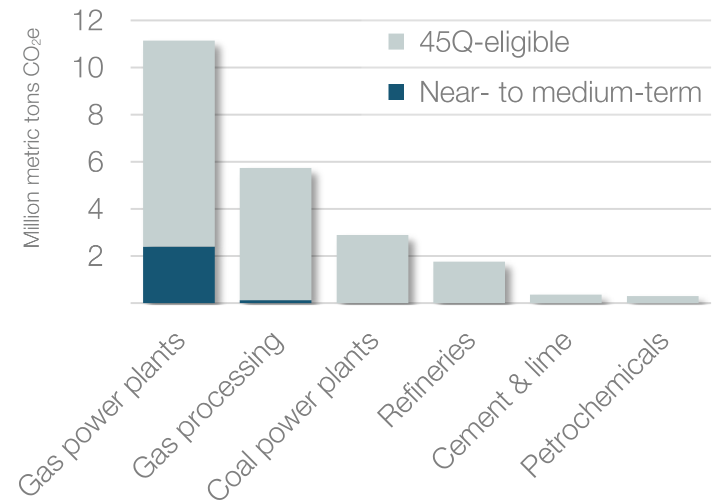


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 35 industrial and power facilities in the Permian hub that meet emissions thresholds for Section 45Q eligibility, three have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

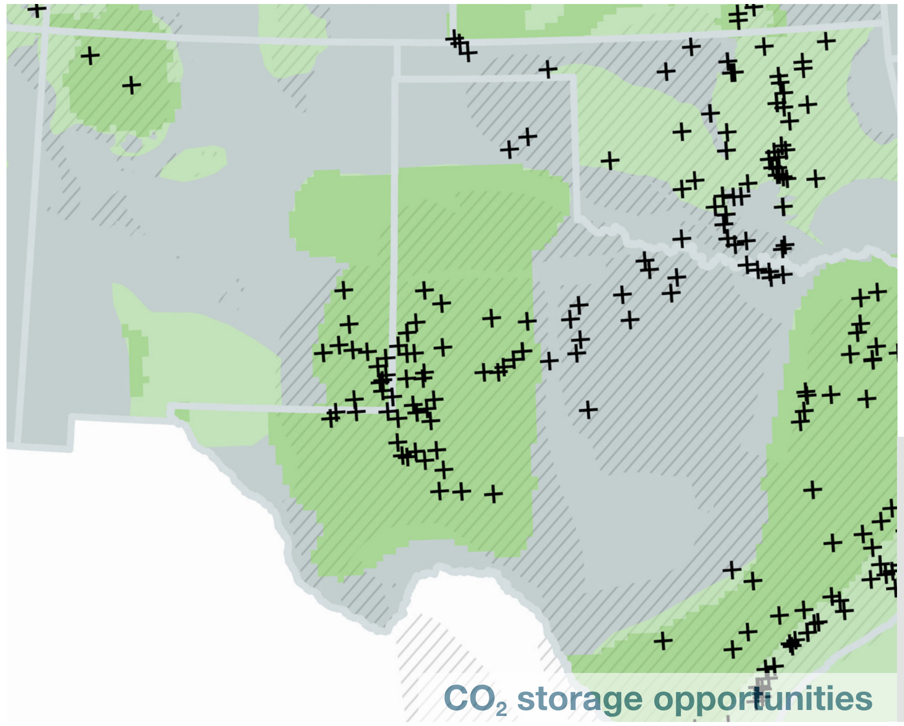
45Q-eligible facilities by industry

- Chemicals
- Petrochemicals
- Coal power
- Refineries
- Gas power
- Near- to medium-term
- Gas processing
- Additional emitting facility

Carbon capture opportunities



- Industrial and power facilities emit **30.5 Mt CO_2e per year**
- **45Q-eligible** facilities emit **22.6 Mt CO_2e per year**
- **2.5 Mt CO_2 per year** are **capturable** in the **near- to medium-term**



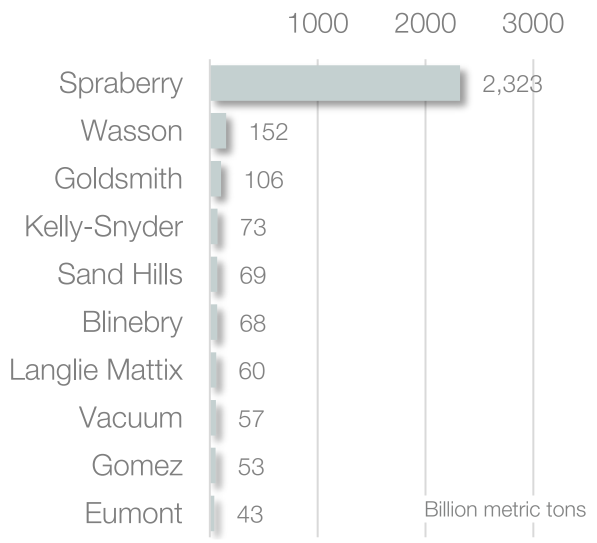
The Permian Basin has potential to act as a major carbon storage destination for capture facilities and carbon removal throughout the country. This regional hub has potential to store 533 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins such as oil and gas fields.

Geologic storage opportunity

- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

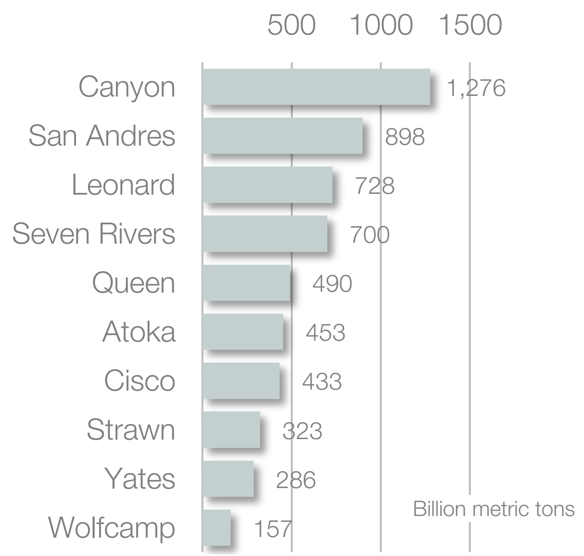
Fossil storage formations

by CO_2 storage capacity



Saline storage formations

by CO_2 storage capacity



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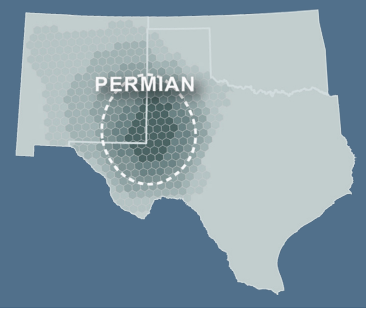
Texas: Permian Basin



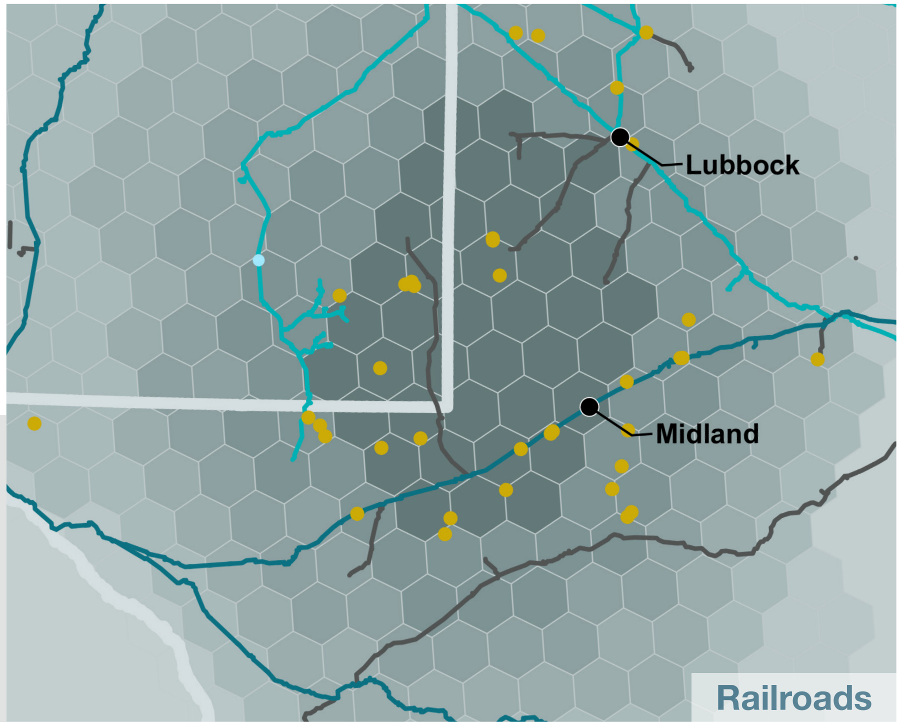
Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

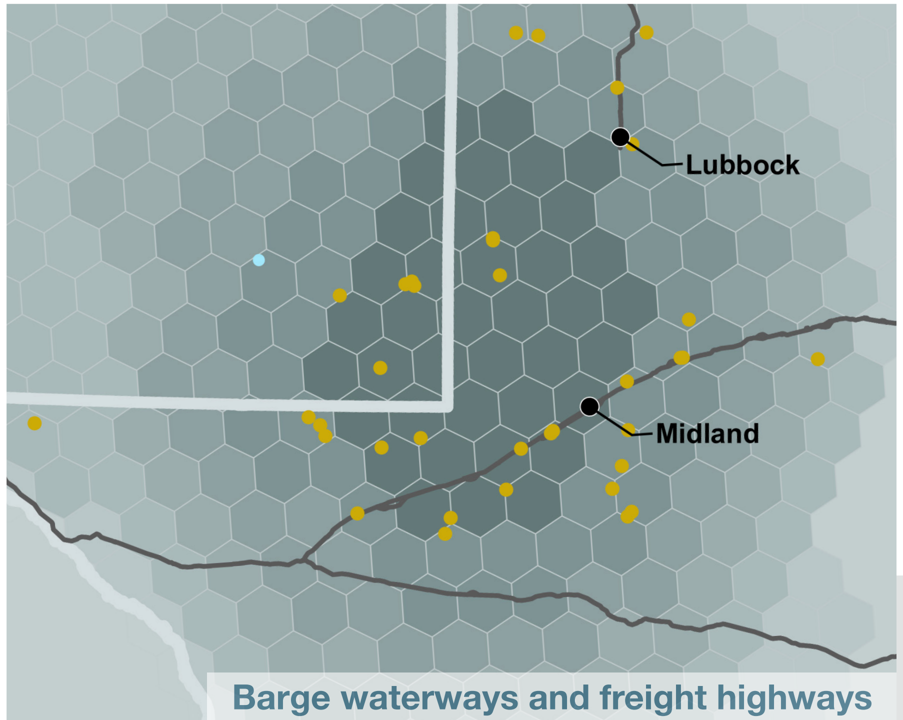
Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Permian hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





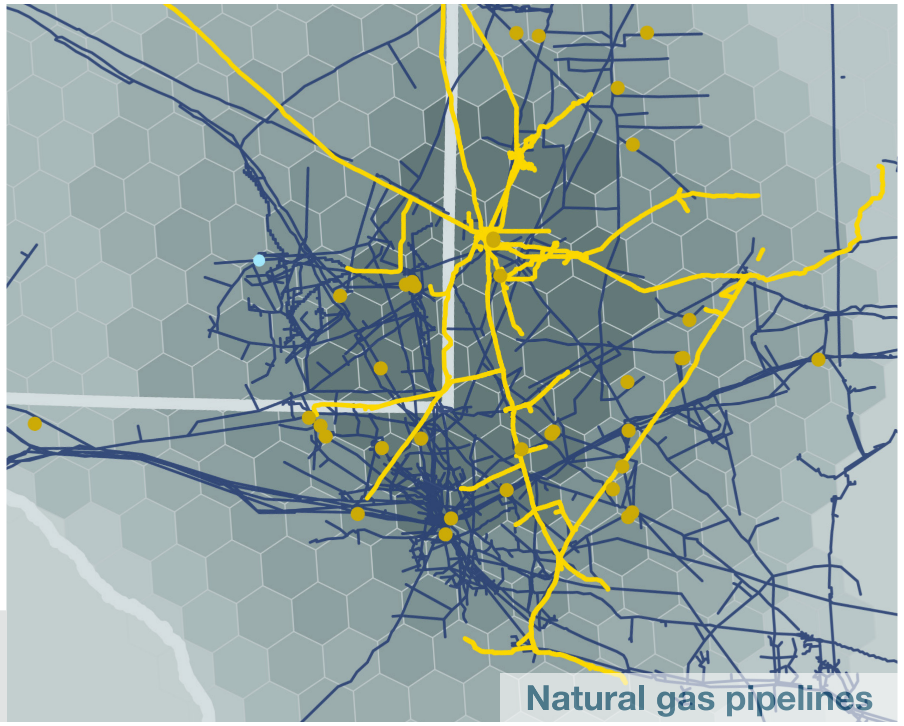
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. Freight trucking can connect the Permian hub to broader markets for carbon and hydrogen.

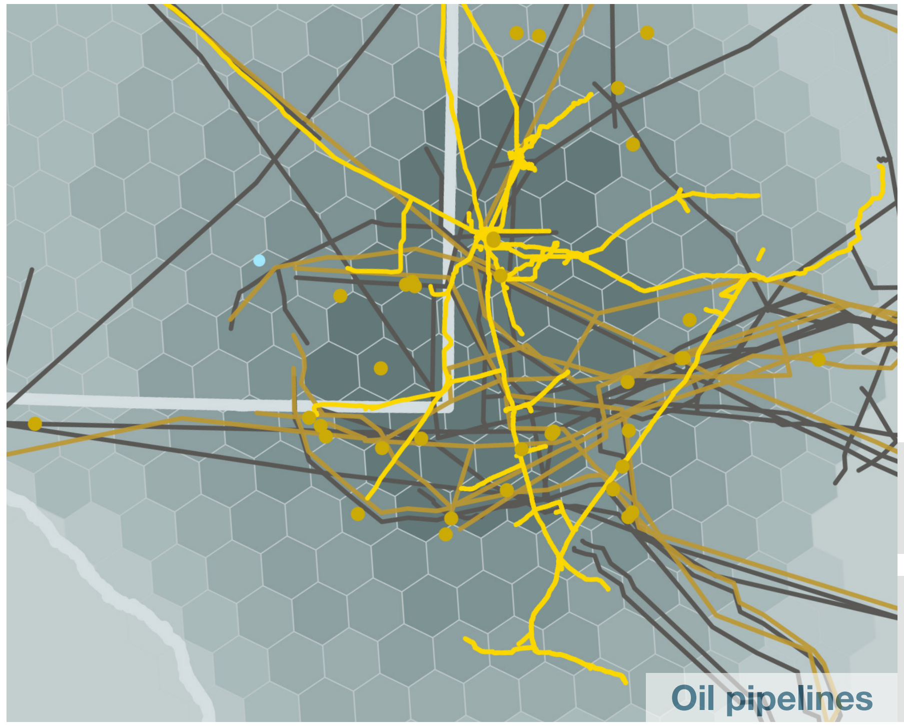
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Permian hub currently has 10,197 miles of natural gas pipelines and 1,795 miles of CO_2 pipelines.

Infrastructure	Miles
Natural gas pipelines	10,197
Oil pipelines	9,896
Existing CO_2 pipelines	1,795

- Existing CO_2 pipelines
- Natural gas pipelines





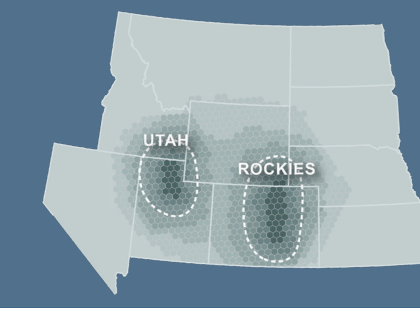
Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Permian hub's 9,896 miles of oil pipelines to achieve efficient buildout.

- 45Q-eligible facility
- Existing hydrogen production

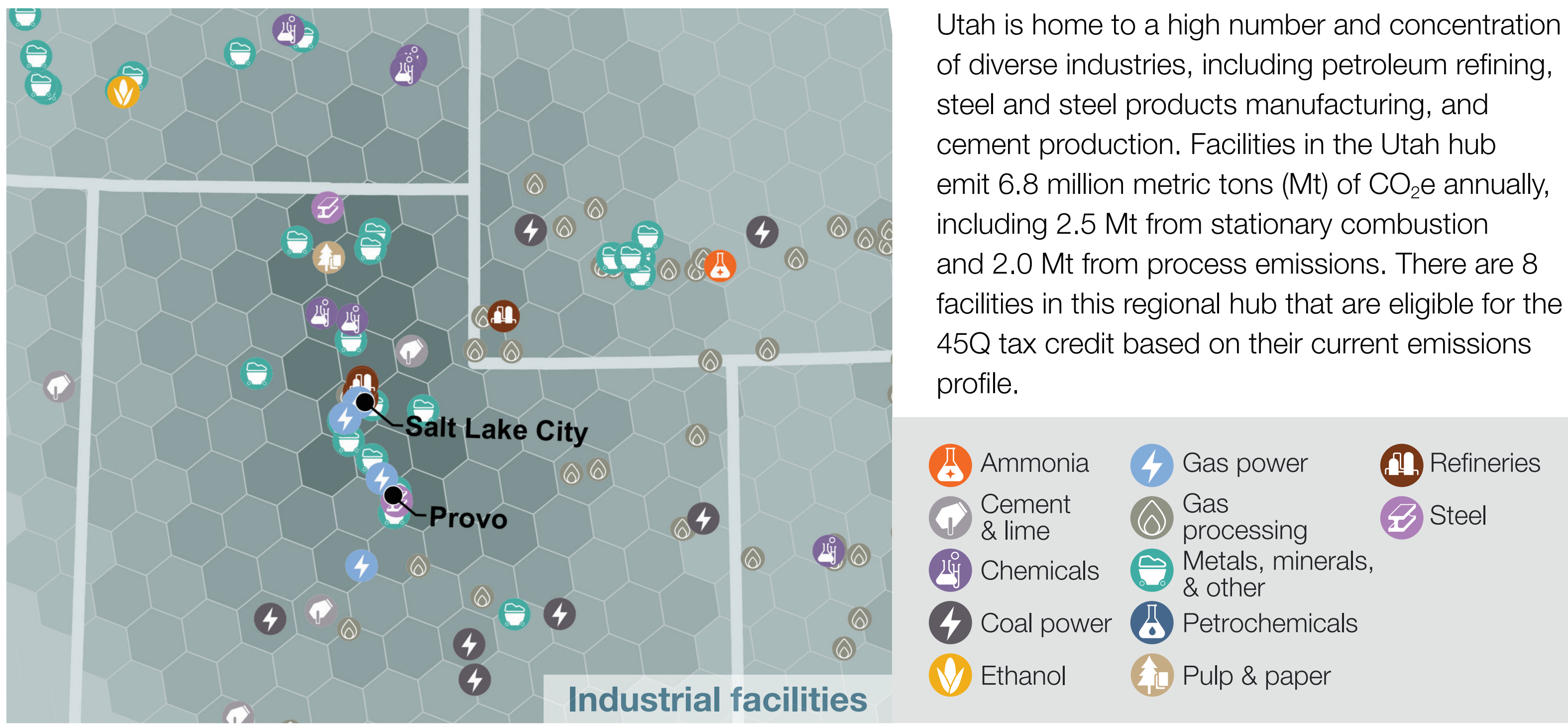
- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

Utah

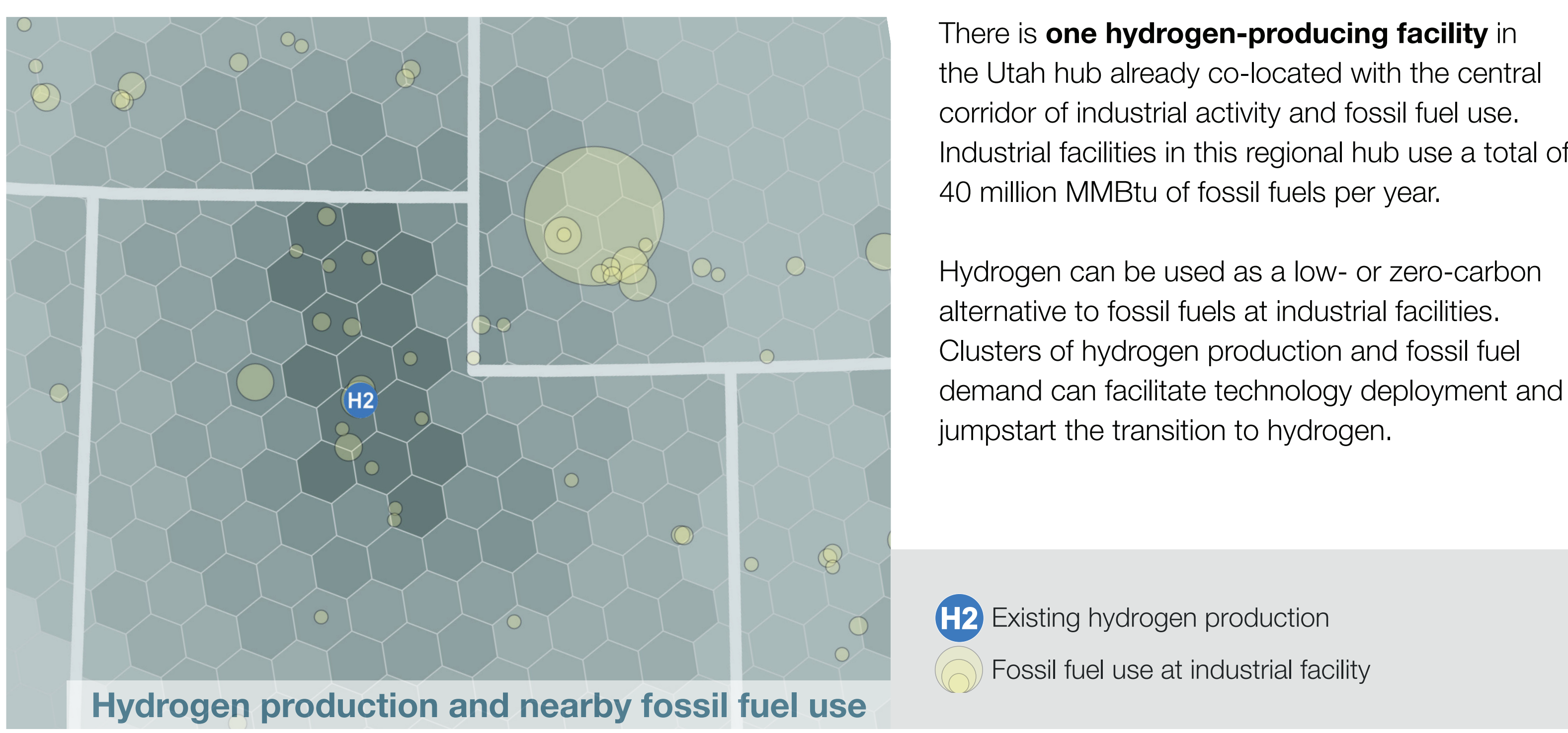
The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity in Utah provide a key opportunity for investment in carbon capture and low-carbon hydrogen deployment.



Industrial Emissions and Fossil Fuel Use



Utah is home to a high number and concentration of diverse industries, including petroleum refining, steel and steel products manufacturing, and cement production. Facilities in the Utah hub emit 6.8 million metric tons (Mt) of CO_2e annually, including 2.5 Mt from stationary combustion and 2.0 Mt from process emissions. There are 8 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There is **one hydrogen-producing facility** in the Utah hub already co-located with the central corridor of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 40 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

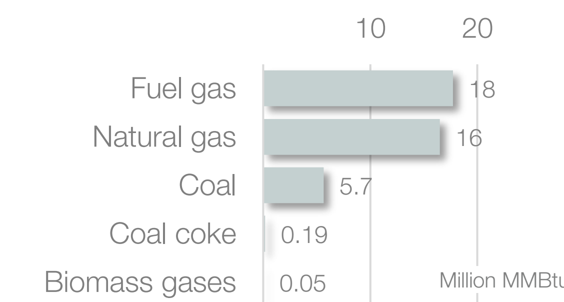
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Cement	1	0.7	< 0.1	0.7
Chemicals	2	0.2	0.2	-
Gas power plants	3	2.3	< 0.1	-
Gas processing	2	0.2	< 0.1	0.2
Metals, minerals & other	11	1.1	0.8	0.3
Pulp & paper	1	< 0.1	< 0.1	-
Refineries	5	2.0	1.4	0.7
Steel & steel products	2	0.3	0.1	0.2
Total	**27**	**6.8**	**2.5**	**2.0**

All emissions are in million metric tons CO_2e.

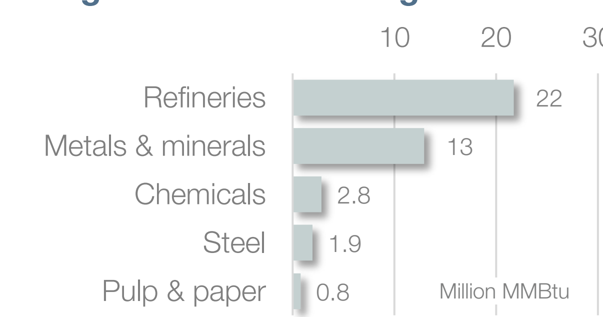
The top industrial fuels consumed in the Utah hub include fuel gas at 18 million MMBtu per year and natural gas at 16 million MMBtu per year. Refineries are the largest consumers of fossil fuels in this regional hub, consuming 22 million MMBtu of fossil fuels per year.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed

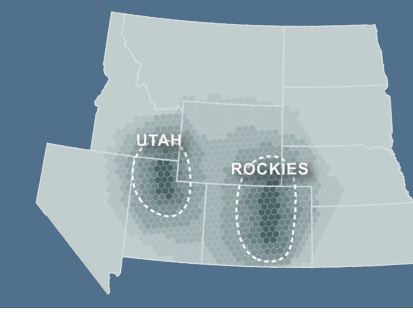


Largest fuel-consuming industries

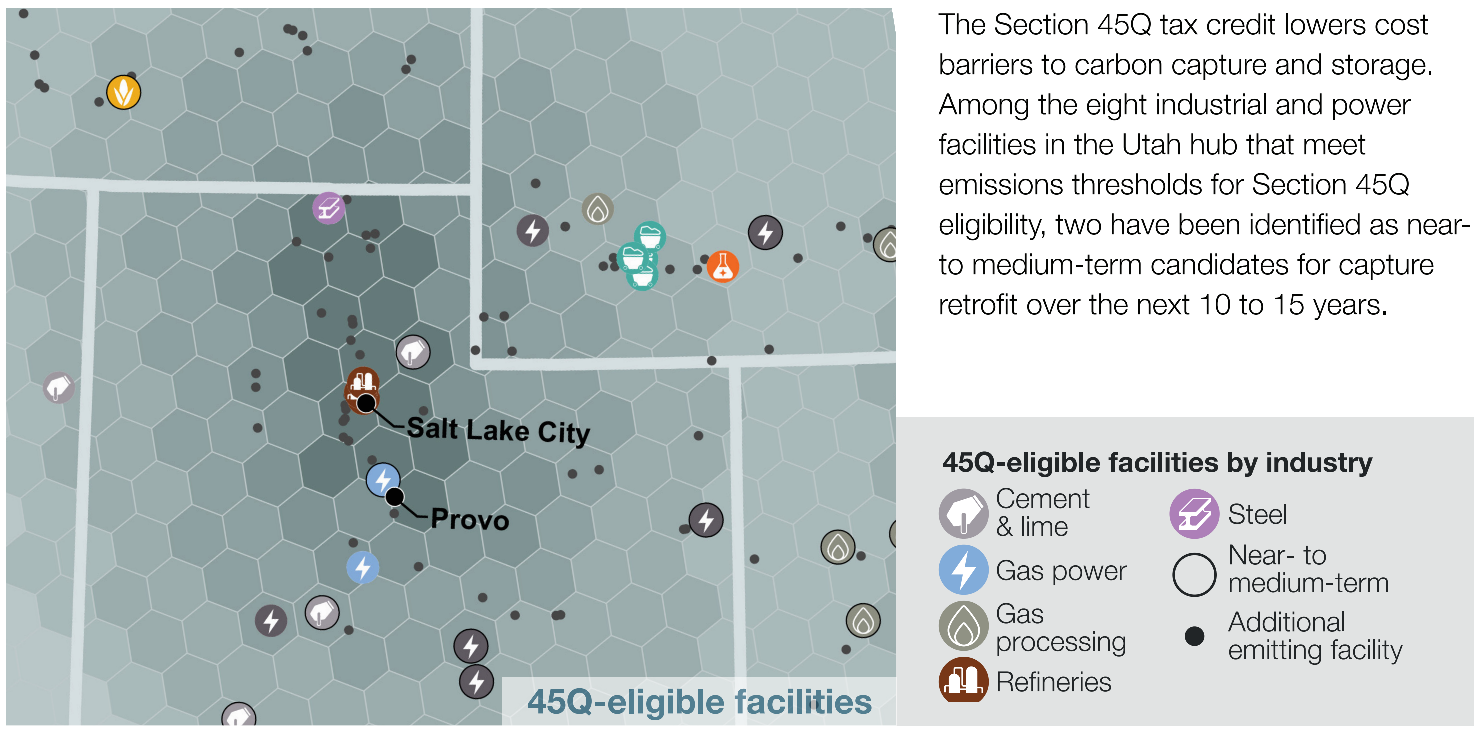


Utah

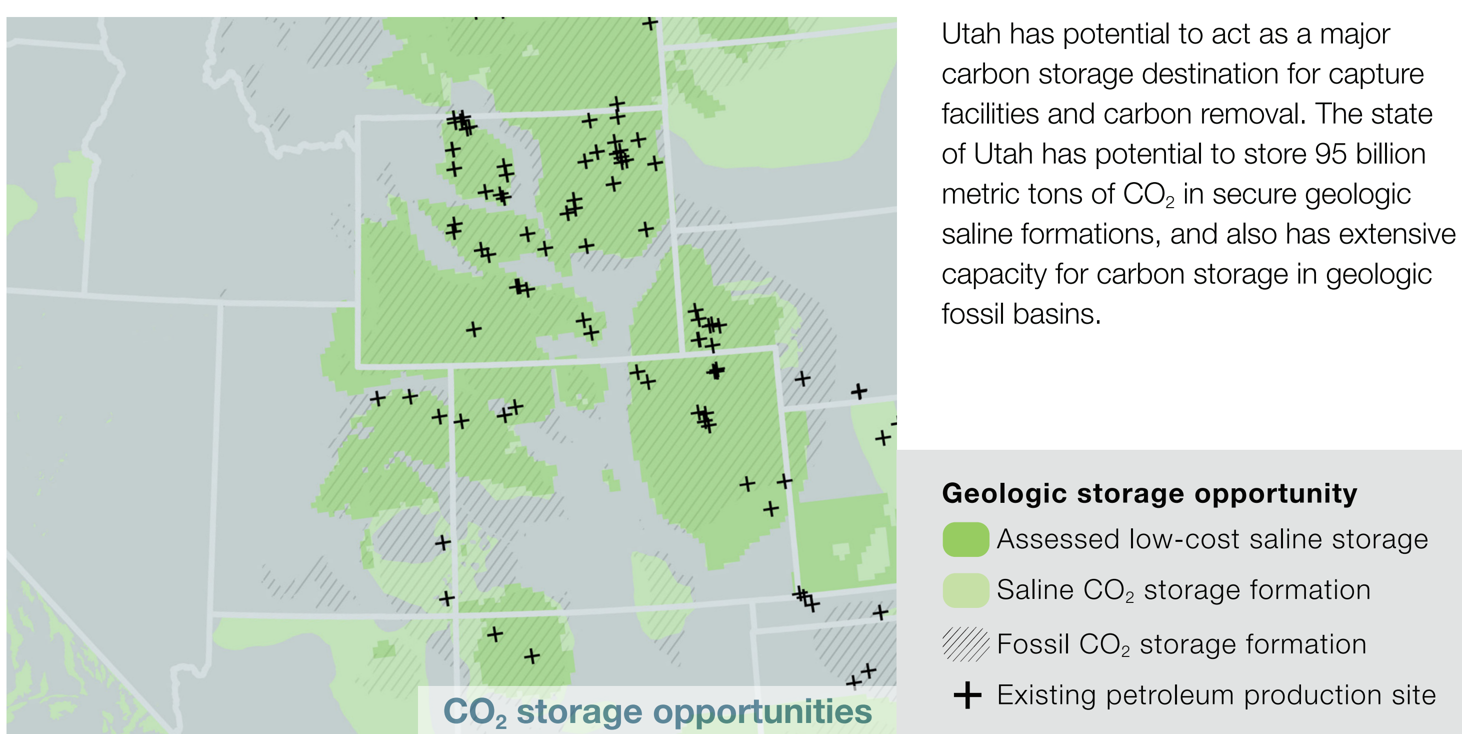
Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.



Carbon Capture and Storage

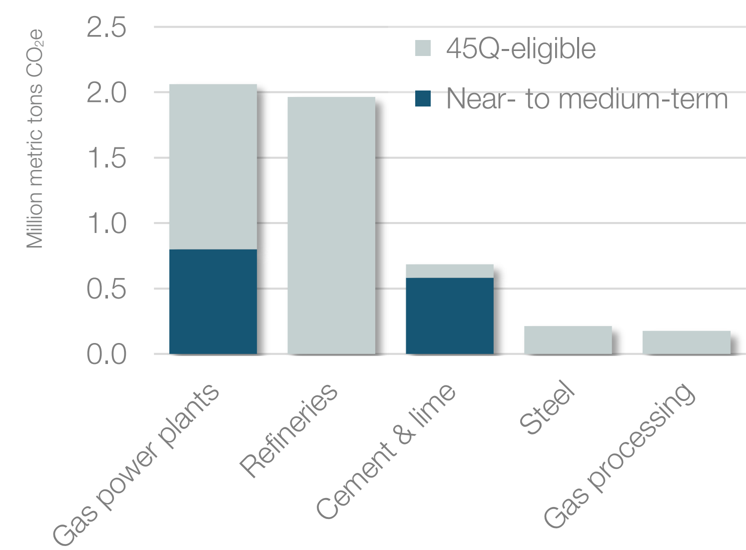


The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the eight industrial and power facilities in the Utah hub that meet emissions thresholds for Section 45Q eligibility, two have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.



Utah has potential to act as a major carbon storage destination for capture facilities and carbon removal. The state of Utah has potential to store 95 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins.

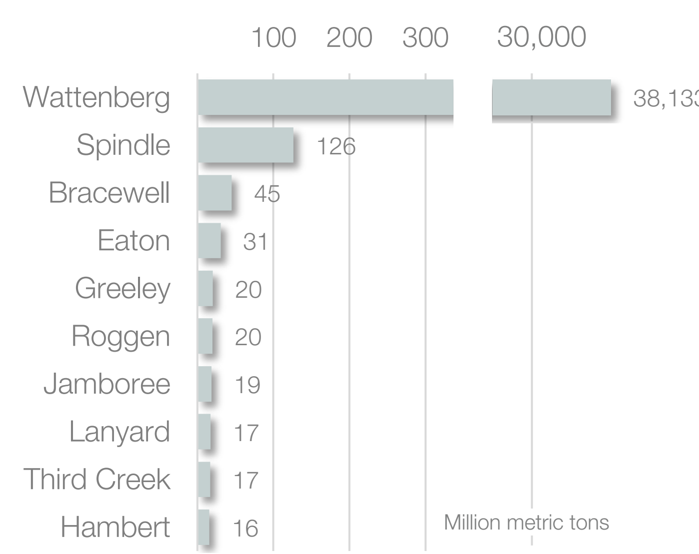
Carbon capture opportunities



- Industrial and power facilities emit **6.5 Mt CO_2e per year**
- **45Q-eligible** facilities emit **5.2 Mt CO_2e per year**
- **1.4 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

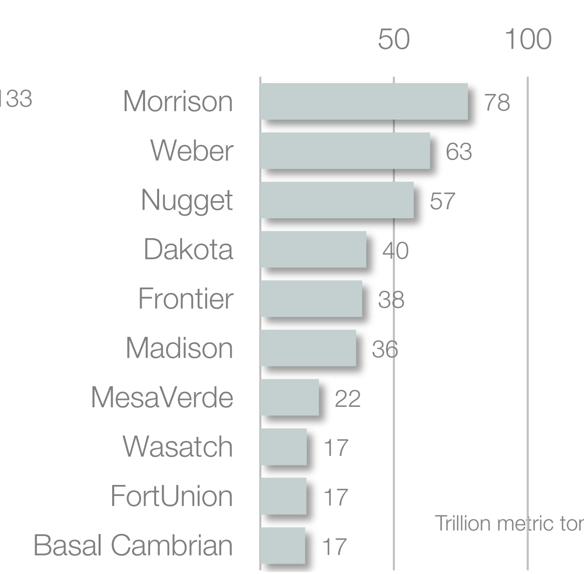
Fossil storage formations

by CO_2 storage capacity



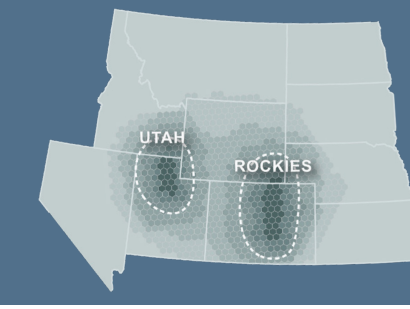
Saline storage formations

by CO_2 storage capacity



Utah

Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

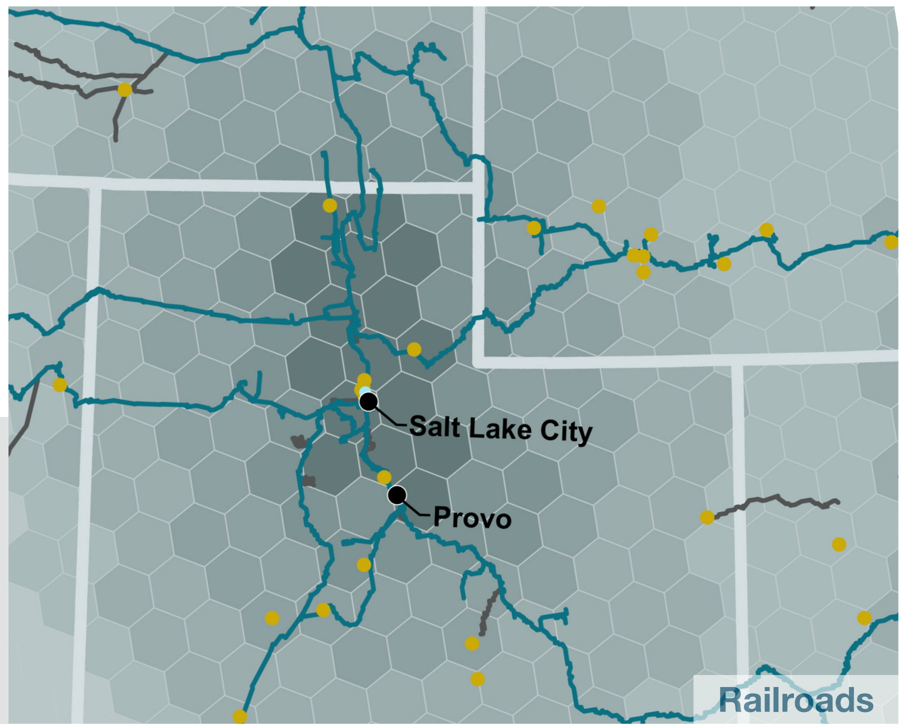


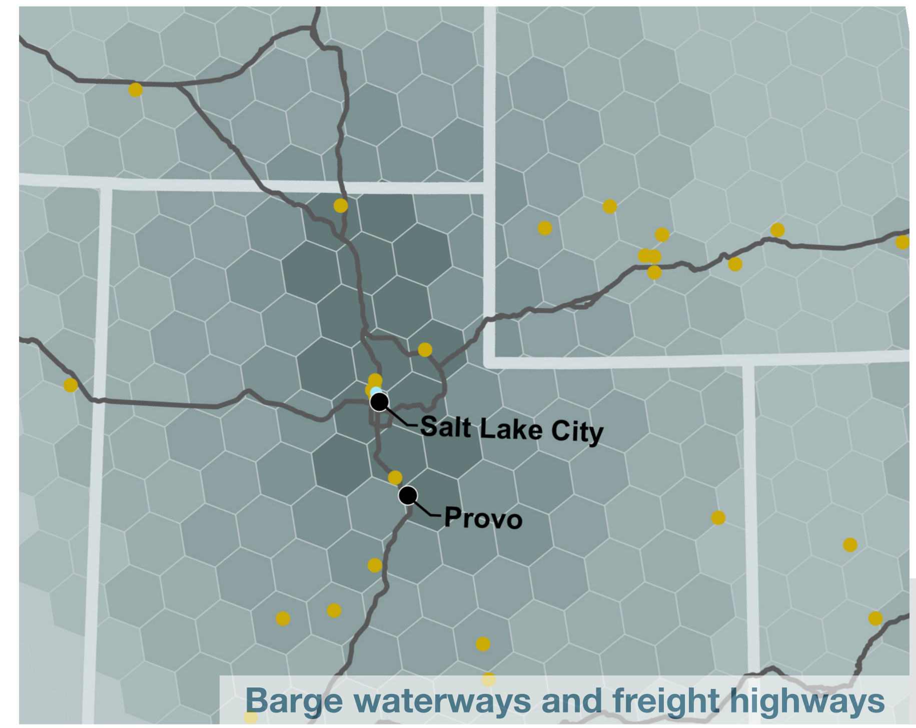
Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Utah hub are located along major rail lines, facilitating connection to markets across the US.

Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others





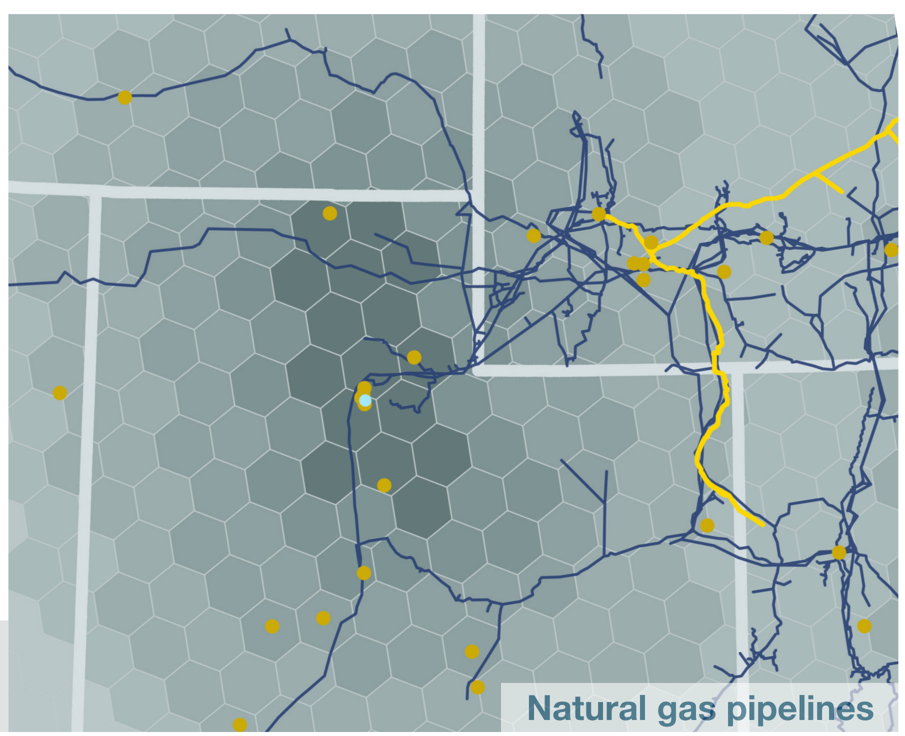
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. Freight trucking can connect the Utah hub to broader markets for carbon and hydrogen.

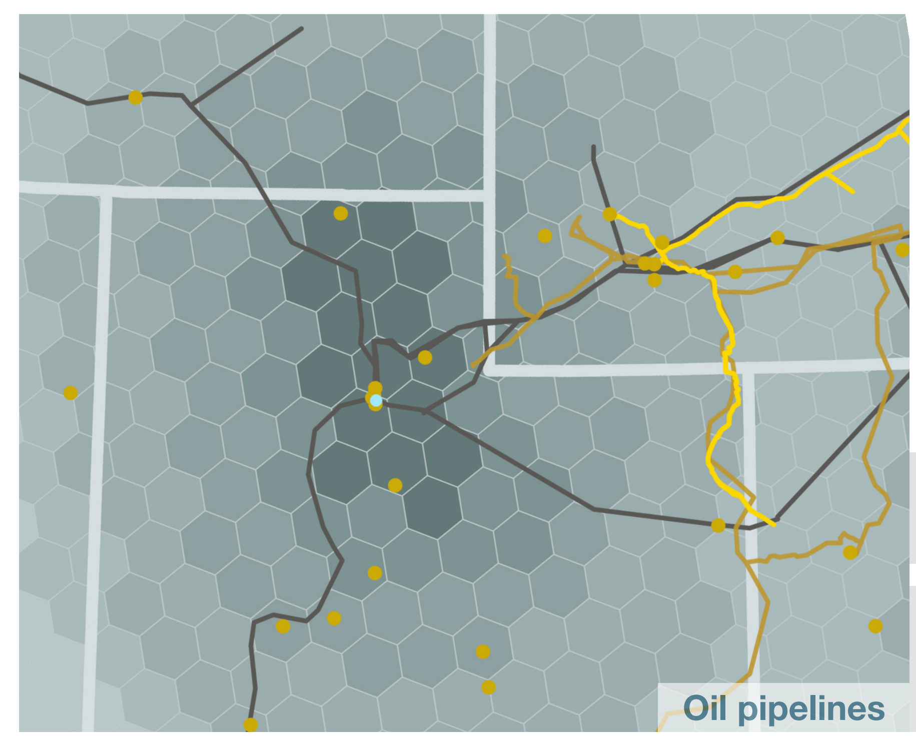
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Utah hub currently has 448 miles of natural gas pipelines. This regional hub is also adjacent to an extensive existing CO_2 pipeline networks that runs across Wyoming.

Infrastructure	Miles
Natural gas pipelines	448
Oil pipelines	1,966

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Utah hub's 1,966 miles of oil pipelines to achieve efficient buildout.

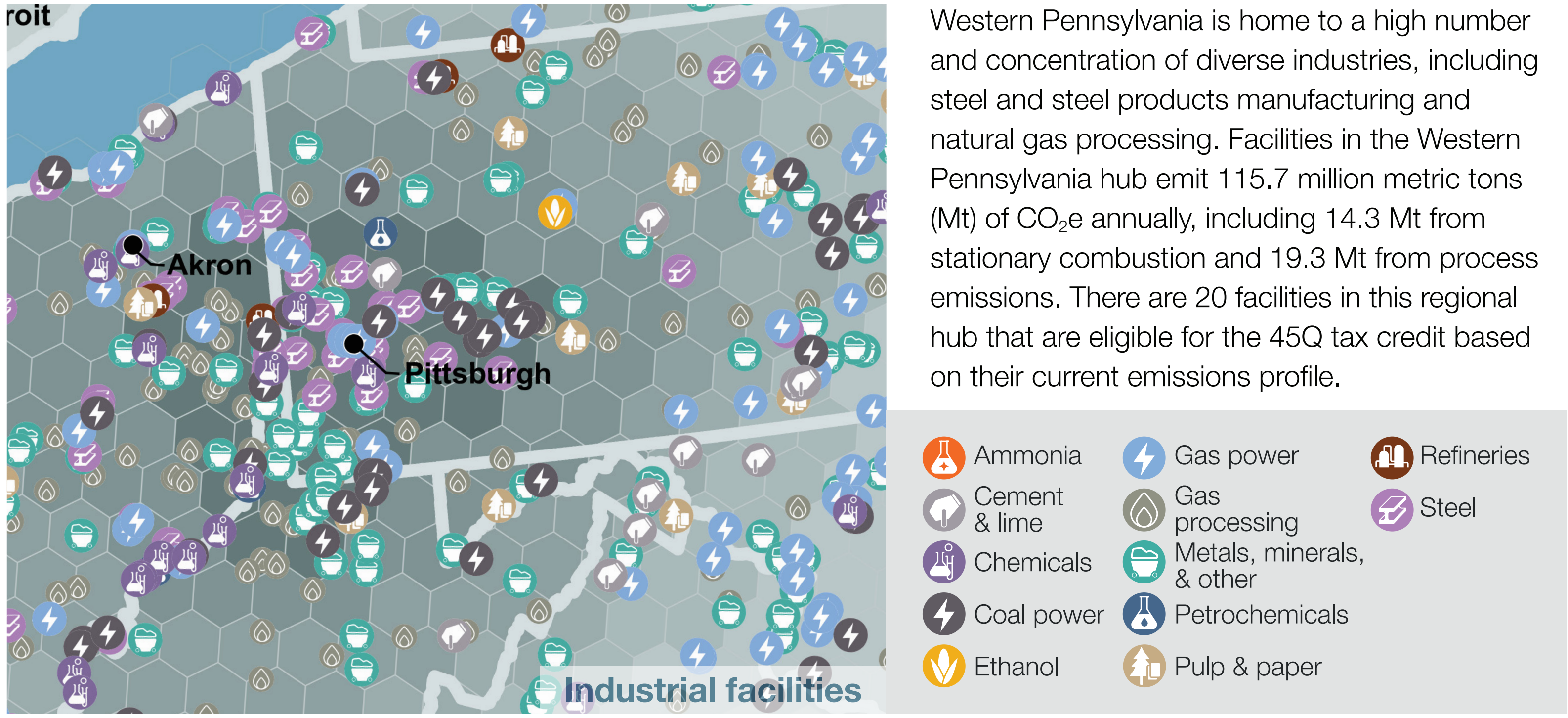
- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

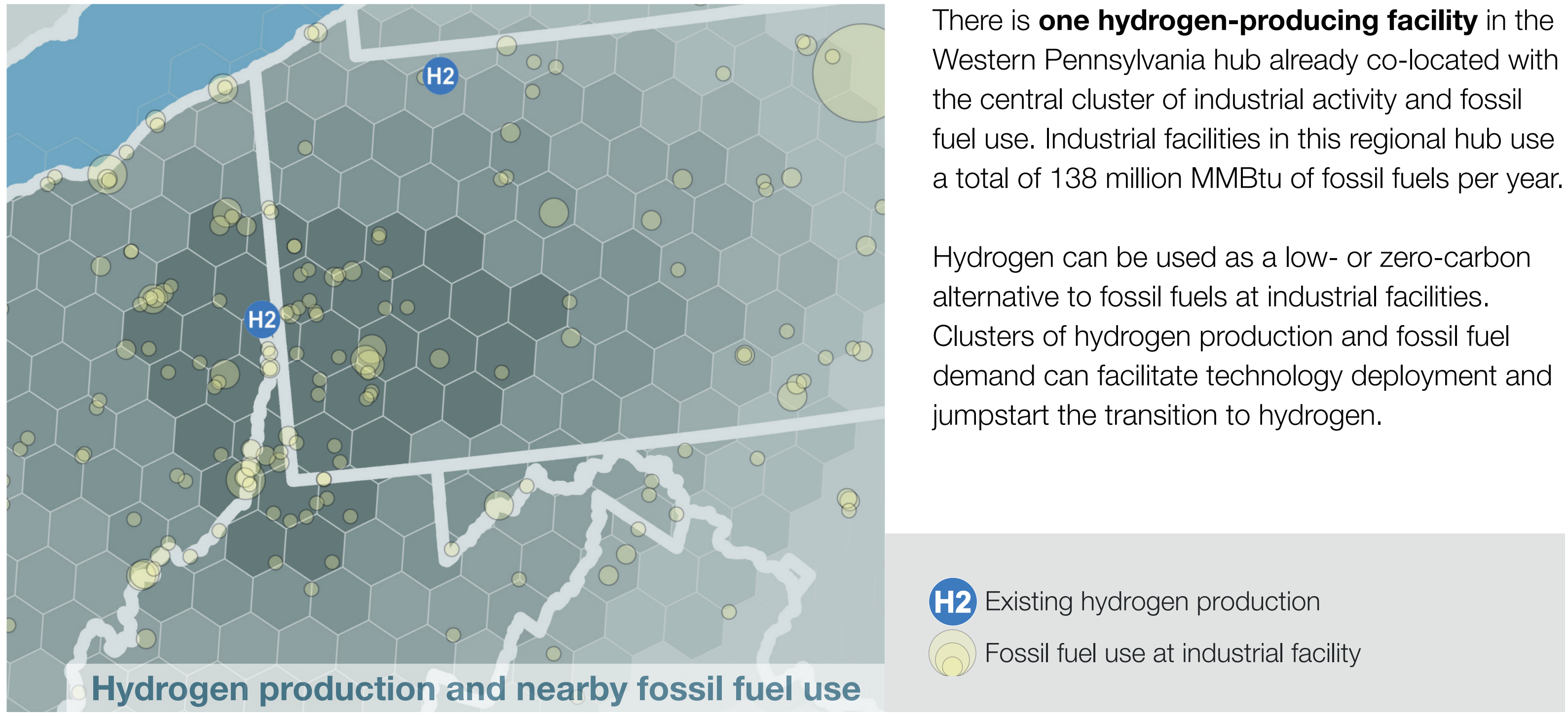
Western Pennsylvania

The existing landscape of industrial production, commodity transport infrastructure, and geologic carbon storage capacity make Western Pennsylvania a natural launching point for investment in carbon capture and low-carbon hydrogen deployment.

Industrial Emissions and Fossil Fuel Use



Western Pennsylvania is home to a high number and concentration of diverse industries, including steel and steel products manufacturing and natural gas processing. Facilities in the Western Pennsylvania hub emit 115.7 million metric tons (Mt) of CO_2e annually, including 14.3 Mt from stationary combustion and 19.3 Mt from process emissions. There are 20 facilities in this regional hub that are eligible for the 45Q tax credit based on their current emissions profile.



There is **one hydrogen-producing facility** in the Western Pennsylvania hub already co-located with the central cluster of industrial activity and fossil fuel use. Industrial facilities in this regional hub use a total of 138 million MMBtu of fossil fuels per year.

Hydrogen can be used as a low- or zero-carbon alternative to fossil fuels at industrial facilities. Clusters of hydrogen production and fossil fuel demand can facilitate technology deployment and jumpstart the transition to hydrogen.

Industrial facility emissions

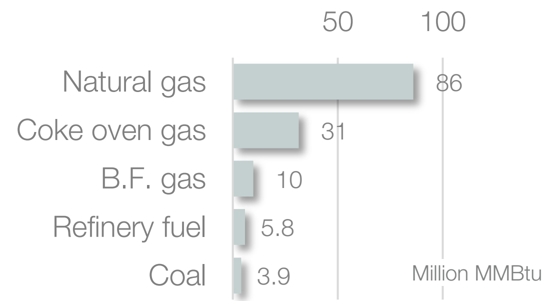
Sector	Total # of Facilities	Total Emissions	Stationary Combustion Emissions	Process Emissions
Cement	1	0.2	< 0.1	0.2
Chemicals	5	0.8	0.8	-
Coal power plants	18	75.8	2.5	-
Gas power plants	13	9.0	0.2	-
Gas processing	44	2.9	2.6	0.3
Metals, minerals & other	37	18.5	0.9	17.6
Petrochemicals	2	0.1	0.1	-
Pulp & paper	2	0.1	0.1	-
Refineries	2	0.8	0.6	0.2
Steel & steel products	28	7.5	6.5	1.0
Total	**152**	**115.7**	**14.3**	**19.3**

All emissions are in million metric tons CO_2e.

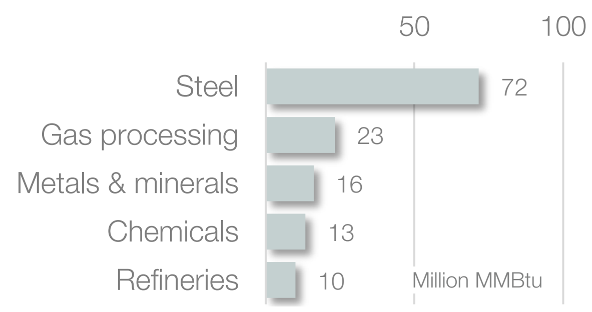
The top industrial fuels consumed in the Western Pennsylvania hub include natural gas at 86 million MMBtu per year and coke oven gas at 31 million MMBtu per year. Steel and gas processing plants are the largest consumers of fossil fuels in this regional hub, consuming 72 million MMBtu and 23 million MMBtu of fossil fuels, respectively.

Using hydrogen as a medium- and high-intensity energy source to displace conventional fossil fuels can reduce combustion emissions alongside other solutions like electrification and renewable energy. Process emissions from product manufacture are another major source of GHGs at industrial facilities. These production processes may not involve fuel combustion and would require other solutions such as carbon capture to fully decarbonize.

Top industrial fuels consumed



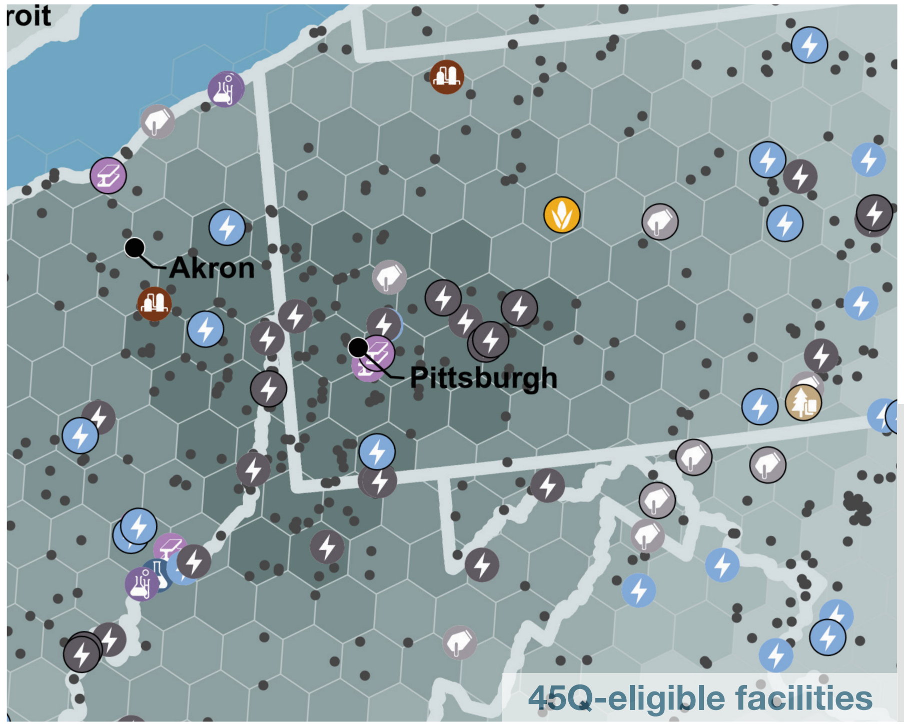
Largest fuel-consuming industries



Western Pennsylvania

Carbon capture and storage is an essential tool for achieving midcentury climate goals, maintaining the competitiveness of US industry, and protecting and creating high-wage jobs. Carbon capture is crucial in decarbonizing key carbon-intensive industries where CO_2 emissions are inherent to the chemistry of production processes and cannot be eliminated solely by switching to low-carbon electricity. The US has capacity to safely and permanently store thousands of years of carbon emissions in geologic saline formations.

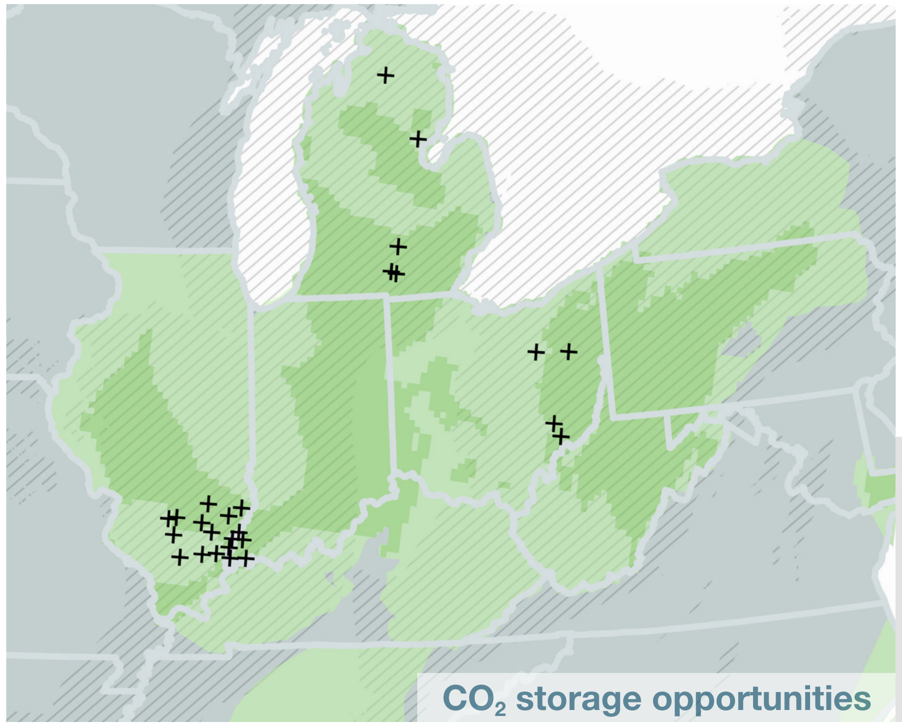
Carbon Capture and Storage



The Section 45Q tax credit lowers cost barriers to carbon capture and storage. Among the 20 industrial and power facilities in the Western Pennsylvania hub that meet emissions thresholds for Section 45Q eligibility, nine have been identified as near- to medium-term candidates for capture retrofit over the next 10 to 15 years.

45Q-eligible facilities by industry

- Cement & lime
- Coal power
- Gas power
- Refineries
- Steel
- Near- to medium-term
- Additional emitting facility

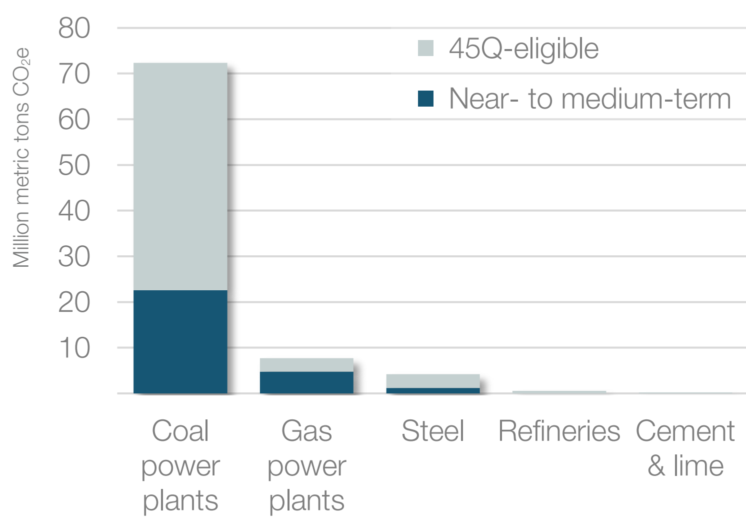


Western Pennsylvania has potential to act as a major carbon storage destination for capture facilities and carbon removal. The state of Pennsylvania has potential to store 18 billion metric tons of CO_2 in secure geologic saline formations, and also has extensive capacity for carbon storage in geologic fossil basins.

Geologic storage opportunity

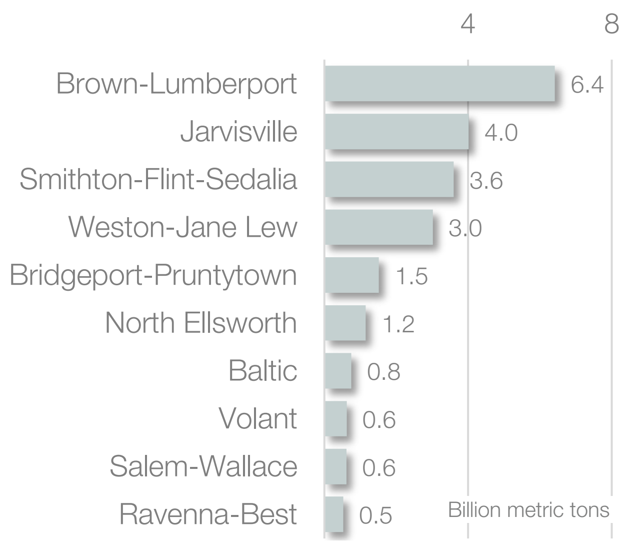
- Assessed low-cost saline storage
- Saline CO_2 storage formation
- Fossil CO_2 storage formation
- Existing petroleum production site

Carbon capture opportunities

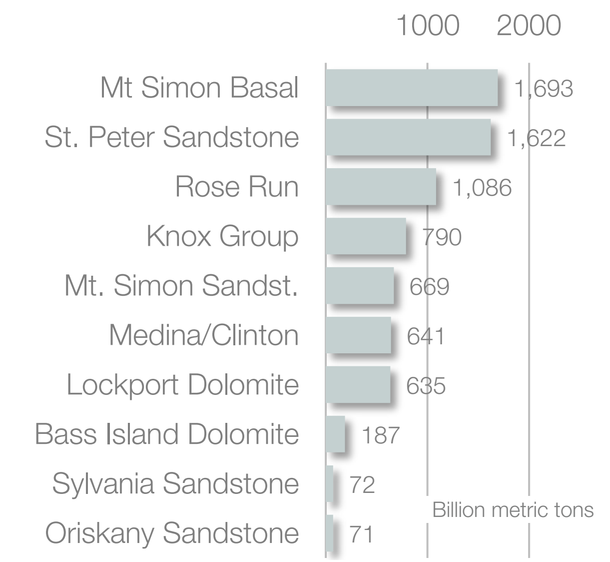


- Industrial and power facilities emit **115.7 Mt CO_2e per year**
- **45Q-eligible** facilities emit **85.5 Mt CO_2e per year**
- **28.6 Mt CO_2 per year** are **capturable** in the **near- to medium-term**

Fossil storage formations
by CO_2 storage capacity



Saline storage formations
by CO_2 storage capacity

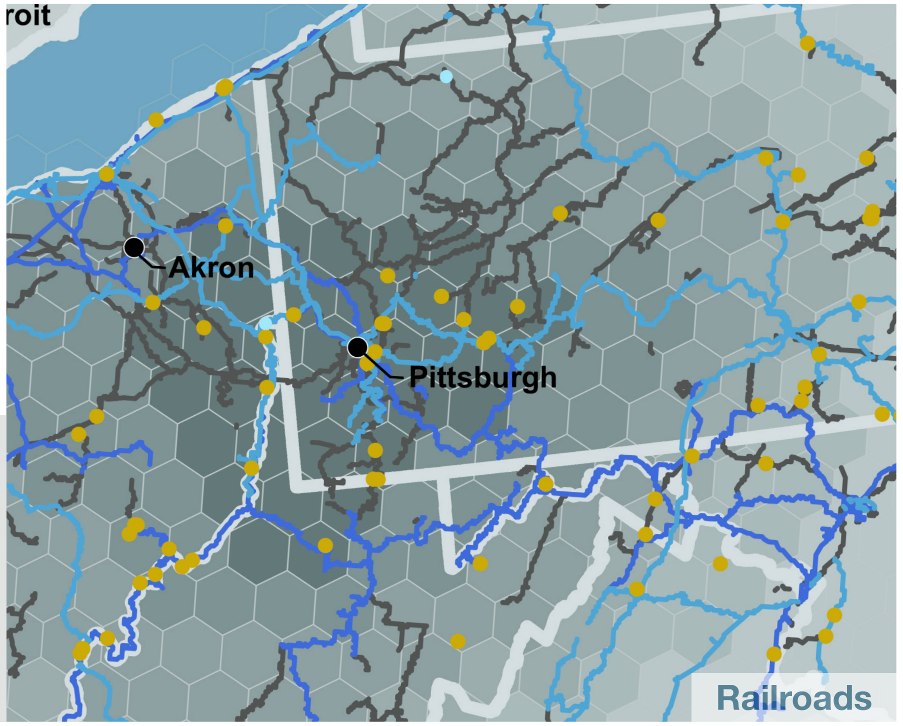


Western Pennsylvania

Industrial hubs can offer existing transportation infrastructure, delivery routes, and distribution networks needed for the efficient supply of feedstocks and delivery of products. Hydrogen may be blended into existing natural gas pipelines for co-firing, and both carbon and hydrogen could be transported by rail, freight trucking, or barge. Existing pipeline rights-of-way may be crucial for efficient and equitable routing of new CO_2 pipelines for utilization and permanent storage.

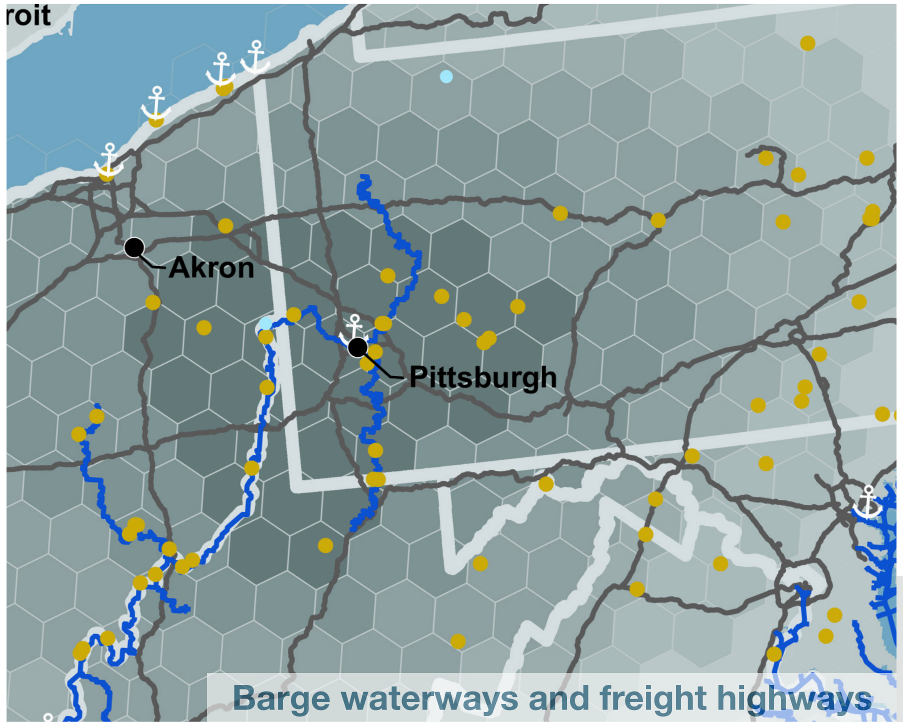
Transport Infrastructure

Many industrial facilities are located along rail lines and often use rail transport to import and export goods. Railroads can also play a role in transporting captured carbon and hydrogen. Many of the facilities in the Western Pennsylvania hub are located along major rail lines, facilitating connection to markets across the US.



Railroad networks

- Union Pacific Railroad
- BNSF Railway
- CSX Transportation
- Norfolk Southern Railway
- All others



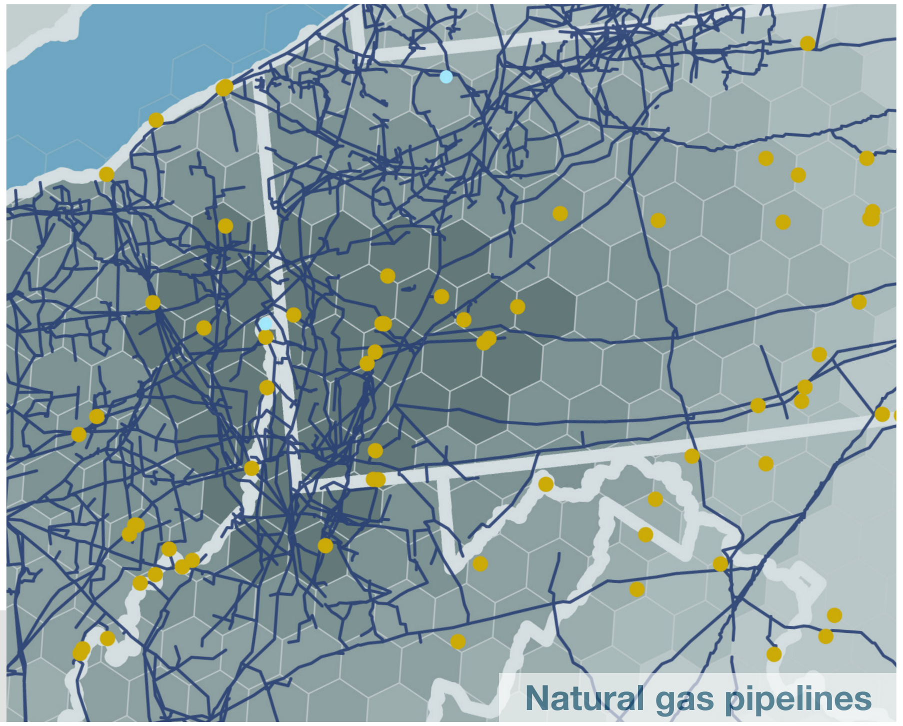
Freight trucks and barges can each play a role in the development of carbon and hydrogen transport networks. Both transport options are flexible, enabling routes to evolve over time and the frequency of transport to adapt in line with the volume of material being transported. With several major ports on Lake Erie and access to shipping channels along the Ohio river, Western Pennsylvania is well-positioned to access global and international markets for carbon and hydrogen.

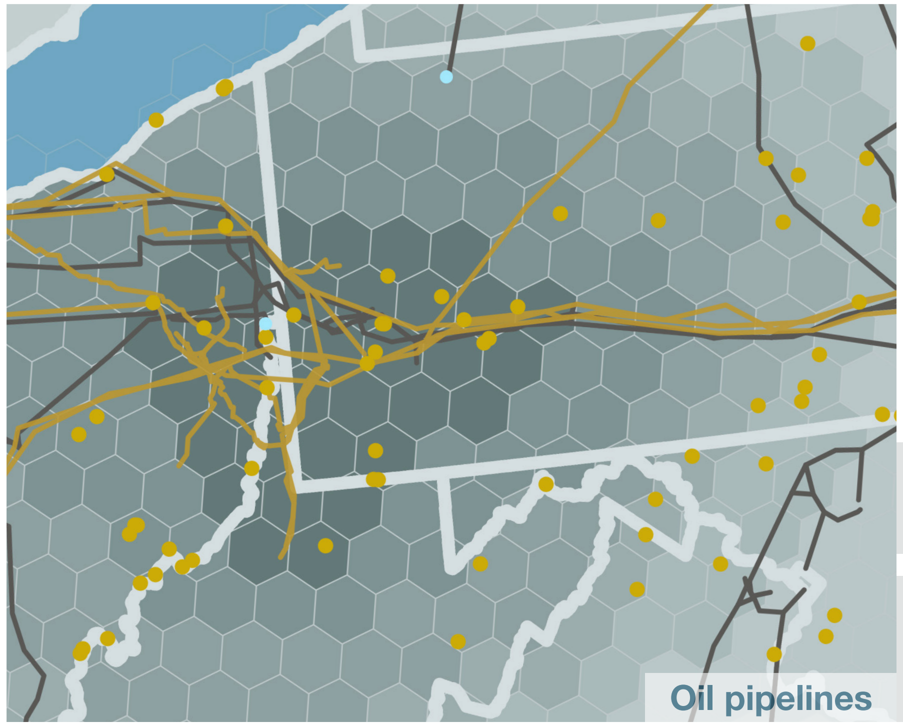
- Interstate highway
- Navigable waterway
- Major port

Logistical challenges to carbon and hydrogen pipeline deployment can be reduced by following existing right-of-way of natural gas lines. The Western Pennsylvania hub currently has 5,323 miles of natural gas pipelines.

Infrastructure	Miles
Natural gas pipelines	5,323
Oil pipelines	1,406

- Existing CO_2 pipelines
- Natural gas pipelines





Collocating new CO_2 and hydrogen pipelines along existing pipeline routes can maximize efficiency and reduce surface impacts. New CO_2 and hydrogen pipelines could follow existing right-of-way established along the Western Pennsylvania hub's 1,406 miles of oil pipelines to achieve efficient buildout.

- 45Q-eligible facility
- Existing hydrogen production

- Existing CO_2 pipelines
- Hydrocarbon gas liquids pipelines
- Petroleum pipelines

Carbon and Hydrogen Hubs Policy

Through the recent passage of groundbreaking bipartisan legislation, Congress has made a major down payment on federal policies needed to enable hydrogen and carbon hub development in the form of grants, loans, extensions, and improvements to existing tax credits. Going forward, a suite of additional, complementary federal and state carbon management and hydrogen policies is needed for the US to achieve technology and infrastructure deployment on a scale and timeframe consistent with meeting midcentury climate goals, while sustaining and expanding a high-wage energy, industrial, and manufacturing jobs base, and supporting existing and new domestic industries.

Supportive policies needed for at-scale deployment carbon and hydrogen hubs are detailed in this section.

Federal Policy

Recently enacted and pending legislation provides the federal policy framework of technology demonstration investments, deployment incentives and infrastructure support necessary for at-scale hub development. Outlined in the following pages are existing federal policies and programs and pending policy measures necessary to foster the development of carbon and hydrogen hubs.

Current federal policies & programs for carbon management

The past several years have witnessed tremendous progress in laying a foundation of broadly bipartisan federal legislation to facilitate carbon and hydrogen hub development.

In early 2018, Congress enacted the landmark reform expansion of the Section 45Q tax credit to support commercial deployment of carbon capture, direct air capture and carbon utilization projects.

This was followed by passage of the 2020 Energy Act as part of the Consolidated Appropriations Act of 2021 (fiscal year 2021 Omnibus), which authorized unprecedented investments in the commercial demonstration of a wide range of carbon management and other clean energy and industrial technologies.

Then, in 2021, the full Energy Infrastructure Act developed by the Senate Energy and Natural Resources Committee was incorporated into the Infrastructure Investment and Jobs Act (IIJA), the recently passed bipartisan infrastructure package. Over a five-year period, the IIJA will fully fund the ambitious technology research, development, demonstration, and deployment (RDD&D) investments authorized by the 2020 Energy Act, provide major additional funding for programs to develop clean hydrogen and direct air capture hubs, and establish a first-ever program of low-interest federal loans and grants to help the private sector finance associated CO_2 transport and storage infrastructure.

Finally, a robust and historic package of bipartisan enhancements to the existing 45Q tax credit, together with new tax credits such as one proposed for clean hydrogen production, has been included in budget reconciliation legislation known as the Build Back Better Act. While the Build Back Better Act failed to pass in its current form, broad political support remains for its suite of expanded clean energy and industrial incentives, and further legislative action is expected this Congress to advance these tax provisions that would leverage substantial private investment in carbon and hydrogen hubs.

Revamping the Section 45Q tax credit

The reform and expansion of the 45Q tax credit in 2018,[43] along with its two-year extension in the Consolidated Appropriations Act of 2021, provides foundational support for commercial-scale deployment of carbon capture, direct air capture and carbon utilization technologies.[44] The Internal Revenue Service finalized 45Q tax credit guidance and rulemaking in January 2021, assuring long overdue regulatory and investment certainty for carbon capture projects, which can now complete the planning, engineering, permitting, and financing required to begin construction by the end of 2025 and qualify for the credit.[45]

Crucial new programs in the Consolidated Appropriations Act, 2021

In passing the bipartisan Energy Act as part of the Consolidated Appropriations Act, 2021 in December 2020, Congress included in the year-end omnibus fiscal year 2021 appropriations, COVID-19 relief measures, and significant energy- and climate-related provisions.[46] In addition to the two-year extension of the 45Q tax credit, the legislation featured historic increases to authorization levels for carbon capture, removal, utilization, and storage RDD&D. The bill also incorporated key provisions from the Utilizing Significant Emissions with Innovative Technologies (USE IT) Act and established interagency efforts around the responsible planning, siting, and permitting of CO_2 transport and storage infrastructure. Finally, the bill also included a cross-cutting program at the DOE to fund decarbonization efforts for carbon-intensive industrial and manufacturing sectors and authorizations for research and development of nuclear-to-hydrogen, performance and cost targets for clean energy, and a study on blue hydrogen.[47]

45Q tax credit structure and eligibility requirements

Annual Carbon Capture Thresholds		
25,000 – 500,000 metric tons of CO_2 / carbon oxide (CO) For **carbon utilization** projects to convert CO or CO_2 into useful products (e.g., fuels and chemicals)	At least **100,000** metric tons CO_2 / CO **Industrial facilities** (e.g., ethanol, steel, cement, and petrochemicals) and direct air capture facilities	At least **500,000** metric tons CO_2 / CO **Electric generating** units (e.g., coal, natural gas, and biomass-fired power plants)
45Q Tax Credit Amounts		
$35 per ton For **secure geologic storage** of CO_2 through **enhanced oil recovery**	**$35 per ton** For **carbon utilization** projects to convert CO or CO_2 into useful products (e.g., fuels and chemicals)	**$50 per ton** For **secure geologic storage** of CO_2 in saline geologic formations

Timing: Projects must begin construction before January 1, 2026 and may claim the credit for up to 12 years after being placed in service.

Eligibility: Carbon capture and direct air capture projects that either capture and utilize or geologically store carbon oxides are eligible to claim the tax credit.

Groundbreaking investments in the IIJA

The bipartisan IIJA includes core carbon management measures for hubs development. In addition to supporting clean hydrogen and direct air capture hubs directly, the package includes funding to finance the buildout of large-scale commercial CO_2 transport and storage infrastructure (see SCALE Act below), robust funding of authorizations to support commercial-scale demonstrations, and front-end engineering and design studies for carbon capture, direct air capture technology prizes, carbon capture demonstration projects and grants for the commercialization of products and technologies utilizing captured CO_2 and its precursor carbon monoxide.[48] Carbon management provisions supporting hubs development are listed in the table at right (note that hydrogen hubs funding is included in the table on hydrogen investments).

Additionally, carbon management provisions in the IIJA include direct appropriations for large-scale carbon capture pilot projects and demonstration programs needed to deploy hubs. There is also significant funding for earlier stage research and development of carbon capture, direct air capture, and carbon utilization technologies.

Carbon management provisions in the Infrastructure Investment and Jobs Act

IIJA Carbon Management Provisions	Funding
Large-scale pilot projects	**$ 937 M** over four years
Demonstration programs	**$ 2.54 B** over four years
Direct air capture technologies prize competitions	**Pre-commercial: $15 M for FY2022** **Commercial: $100 M for FY2022**
Carbon Utilization Program	**$310 M** over five years
Carbon Capture Technology Program Front-end engineering and design program	**$100 M** over five years
SCALE Act Financing CO_2 transport and storage infrastructure	**$4.6 B** over five years
Direct air capture hubs Creates four regional hubs	**$3.5 B** over five years
Total funding for carbon management	**$12.1 B** over five years

Source: Infrastructure Investment and Jobs Act.

SCALE Act CO_2 transport and storage infrastructure investments in the IIJA

Congress authorized and funded first-ever federal financing and grants for deployment of large-scale commercial CO_2 transport and storage infrastructure as part of the IIJA, which included the bipartisan Storing CO_2 and Lowering Emissions (SCALE) Act in its entirety. Broadly, the SCALE Act supports the buildout of critical regional CO_2 transport and storage infrastructure networks for hubs deployment and includes the following components:[49]

Carbon Dioxide Transportation Infrastructure Finance and Innovation (CIFIA)

This financing mechanism provides flexible, low- interest grants and loans to cover common carrier CO_2 transport infrastructure development costs and lowers the risk of private sector investment. The Carbon Dioxide Transportation Infrastructure Finance and Innovation program emphasizes projects across industries and regions sited within or adjacent to existing pipeline or other linear infrastructure corridors to help minimize environmental disturbance and other siting concerns.

Carbon Storage Validation and Testing Program

This measure amends the Energy Policy Act of 2005 and establishes an RDD&D program for carbon storage, providing funding to develop new or expanded commercial, large-scale geologic storage projects and associated transport infrastructure. Projects with substantial CO_2 storage capacity or that store CO_2 from multiple carbon capture facilities will be prioritized.

Geologic storage permitting

The legislation increases funding to support permitting for dedicated CO_2 storage wells (Class VI wells) by the US EPA. It also provides grants for states establishing delegated Class VI permitting programs implemented at the state level according to federal standards.

Carbon Capture Technology Program

This program will provide front-end engineering and design grants for CO_2 transport infrastructure necessary to enable deployment of carbon capture, utilization, and storage technologies.

Carbon Utilization Program

This program will fund RDD&D for carbon utilization to develop standards and certifications to facilitate the commercialization of products derived from carbon utilization. The program will also provide grants to state and local governments to procure low- and zero-carbon products sourced from captured carbon emissions for use in infrastructure projects.

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Current federal policies & programs for hydrogen

In addition to providing support for carbon management more broadly, the passage of the IIJA substantially augments federal policy in support of low- and zero-carbon hydrogen production, transport, storage, and use, further contributing to the potential for carbon and hydrogen hubs development. Notably, the IIJA establishes a program and provides significant funding for the development of four regional clean hydrogen hubs. Other IIJA provisions include RDD&D to accelerate hydrogen production from low- and zero-carbon energy sources, defining “clean hydrogen” for policy purposes, establishing a hydrogen strategy and roadmap, establishing an intermediary for clean hydrogen program information at the National Energy Technology Laboratory, developing a clean hydrogen supply chain and workforce by prioritizing demonstration projects in major shale gas regions, and funding the DOE’s Hydrogen Program Plan.[50]

Hydrogen provisions in the Infrastructure Investment and Jobs Act

IIJA Hydrogen Provisions	Funding from 2022 - 2026
Regional clean hydrogen hubs	$8 B
Clean Hydrogen Manufacturing and Recycling Program	$500 M
Green Hydrogen Demonstration, Commercialization, and Deployment Program	$1 B
Industrial research and assessment centers	$550 M
Smart manufacturing leadership	$50 M
Total funding for hydrogen	**$10.1 B**

Source: Infrastructure Investment and Jobs Act.

Regional clean hydrogen hubs

The IIJA authorizes $8 billion for the establishment of at least four regional clean hydrogen hubs, defined as “a network of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in close proximity.” In establishing hydrogen hubs and connecting these networks of stakeholders, the IIJA aims to accelerate clean hydrogen commercialization and support the development of coordinated clean hydrogen production, processing, delivery, storage, and end-use through demonstration.

The DOE will select hydrogen hubs based on several criteria, ensuring hubs support employment and are diverse in feedstocks, end-uses, and geography. Hydrogen hubs will demonstrate the ability to produce clean hydrogen from fossil fuels, renewable energy, and nuclear energy, as the DOE will select at least one project which derives its feedstock from each. Similarly, at least one regional clean hydrogen hub will be selected to demonstrate the viable end-use of clean hydrogen in electric power generation, industry, commercial and residential heating, and transportation sectors. Geographic diversity aims to spread the investment and benefits of regional clean hydrogen hubs across different regions of the US, using energy resources most abundant in each region, while siting at least two hubs in regions with abundant natural gas resources. Further, priority will be given to hubs likely to create the greatest amount of long-term, skilled employment.

In January of 2022, the DOE launched a voluntary tool called H2 Matchmaker for hydrogen users and suppliers to self-identify, increasing regional project awareness. The tool will be used to populate an interactive map and database of hydrogen stakeholders to help facilitate hub formation. Solicitation of regional clean hydrogen hub proposals are to begin by May 14, 2022, with selection one year later.

Hydrogen strategy and roadmap

The IIJA also calls for developing a “technologically and economically feasible national strategy and roadmap to facilitate widescale production, processing, delivery, storage, and use of clean hydrogen.” The DOE will develop this roadmap to help ensure a cohesive national strategy for maximizing the environmental and economic benefits of hydrogen development while prioritizing geographical and industry diversity. The roadmap will evaluate opportunities to use existing infrastructure, including natural gas and CO_2 pipelines, along with existing industrial, residential, and commercial consumers of natural gas. The roadmap will also identify the barriers and resources needed for developing clean hydrogen hubs, including those co-located with carbon capture, utilization, and storage hubs across the United States.

Hydrogen research and development program

The IIJA establishes a clean hydrogen research and development program to advance hydrogen research and development and to commercialize its use and production by 2040. The program will support clean hydrogen produced from diverse energy sources and used in electric power generation, industrial applications, and fuel sources. The program further supports manufacturing commercially available hydrogen technologies and standardizes clean hydrogen production.

Hydrogen manufacturing and technology recycling

The IIJA creates clean hydrogen manufacturing and technology recycling initiatives that will advance equipment manufacturing technologies and techniques for clean hydrogen production, processing, delivery, storage, and use through multiyear grants, contracts, and agreements for RDD&D projects. The initiatives will also provide grants to projects developing strategies to increase the reuse and recycling of clean hydrogen technologies.

Federal Policy Recommendations

Building on the recently enacted bipartisan legislation described above, additional improvements to federal policy would help complete the full portfolio of federal policies needed to support and accelerate the development and deployment of carbon and hydrogen hub projects and infrastructure.

Further enhancements to the Section 45Q tax credit

The following additional bipartisan improvements to the 45Q tax credit have been included in pending budget reconciliation legislation and represent a central plank of the remaining federal carbon management policy agenda:

- o Providing a direct pay option for carbon capture, direct air capture, and carbon utilization projects to eliminate the substantial loss of incentive value to costly and burdensome tax equity transactions undertaken by project developers that otherwise lack the capacity to fully monetize 45Q credits;
- o Extending 45Q to ten years, for all projects beginning construction by the end of 2031, to increase the investment horizon for carbon and hydrogen hubs to be planned, developed and scaled up;
- o Increasing 45Q credit values for carbon capture projects in industry and power generation and for direct air capture projects to close remaining cost gaps, expanding feasibility to additional technologies and sectors critical to meeting emissions reductions goals and accelerating near- and medium-term deployment;[51] and
- o Significantly reducing arbitrary annual carbon capture thresholds to increase the number of facilities eligible for the credit and increase the technology innovation and emissions reduction potential of the 45Q program.

If enacted, these enhancements to the 45Q tax credit outlined above, in conjunction with the measures already passed as part of the IIJA, would deliver an estimated 13-fold scale-up of carbon management capacity and 210–250 million metric tons of annual CO_2 emissions reductions by 2035. Additionally, analyses by the Rhodium Group highlight the potential to create hundreds of thousands of high-wage jobs and generate hundreds of billions in investment from carbon capture and direct air capture deployment in states around the country.[52]

Scaling up commercial geologic storage

The evolution of carbon and hydrogen hubs at a degree and pace that achieves economies of scale and meets climate goals fundamentally hinges on expanding and accelerating the development and permitting of large-scale geologic storage across the country. This commercial scale-up of geologic storage must be accomplished while the federal 45Q tax credit remains available to help finance coordinated and ramped-up deployment of carbon capture, direct air capture, and carbon utilization projects, in concert with the stepwise buildout of shared regional CO_2 transport infrastructure linking carbon management projects to newly-permitted storage sites. Toward that end, federal action on multiple fronts—reviewing and finalizing Class VI permits for geologic storage projects, delegating primacy for Class VI permitting of geologic storage to states, commercial geologic storage permitting and deployment on federal lands, and the development and permitting of offshore geologic storage—is urgently needed to provide confidence and clarity for broader hub planning efforts, as well as financial certainty for the development and financing of individual projects.

Critical actions to scale up commercial geologic storage include the following:

Helping states achieve Class VI primacy

States achieving Class VI primacy is a crucial component of scaling up geologic storage to levels needed for midcentury decarbonization. North Dakota and Wyoming have set an important precedent in being awarded primacy by the EPA, giving those two states the right to undertake Class VI permitting of geologic storage projects in accordance with federal standards. However, if the anticipated demand for geologic storage permits is to be met in a timely fashion, many more states will need Class VI primacy.

The IIJA provides $50 million in grant funding to award Underground Injection Control grants and to support states' efforts to develop programs leading to primacy. Separately, the law includes $25 million in funding for the EPA to permit Class VI storage projects in those states that do not yet have Class VI primacy or choose not to pursue it. These additional government resources will help the EPA boost staffing capacity, permit Class VI wells in a timely manner and reduce the timeframe needed to complete states' primacy applications. Finally, the funding provided to the EPA's Underground Injection Control program by the IIJA will help the EPA and states process Class VI permit applications more efficiently, ensure effective implementation of the Class VI program by providing additional resources to states undertaking Class VI primacy applications, and help those states prepare for the expanded permitting responsibilities that come with that delegated authority.

Permitting storage projects on federal lands

Given that the federal government owns and manages a large proportion of land in many western states, the development and permitting of CO_2 transport and storage infrastructure on federal lands will be necessary for long-term carbon and hydrogen hub deployment at the scale needed to meet climate goals. However, the current federal permitting process presents formidable challenges of time and cost to the development of commercial-scale projects. Federal land managers do not have adequate guidance to allow projects on lands they administer, including urgently needed rules and regulations to address pore space ownership and permanent storage of CO_2.

These critical policy gaps can be addressed through current legal structures, such as the National Environmental Policy Act, Federal Land and Policy Management Act, and National Forest Management Act. Management of projects on federal lands should be delegated to the Department of Interior, which manages surface and subsurface resources. The completion of such guidance, combined with greater prioritization by agency leadership and the allocation of additional resources, can empower federal land managers to process project applications efficiently.

Establishing regulations for offshore storage

For the first time, the IIJA establishes authority for permitting CO_2 storage on the offshore continental shelf to the Bureau of Offshore Energy Management, which also manages offshore subsurface resources, such as oil and gas. This authority includes issuing leases, easements, and rights-of-way in federal waters. The Department of Interior must now work in consultation with the EPA to establish regulatory frameworks for pore space ownership, pore space utilization procedures (e.g., leasing), and long-term liability for offshore storage of CO_2.

Carbon hubs must accommodate the storage needs of multiple capture facilities, necessitating the development and permitting of large-scale geologic storage sites capable of receiving many millions of tons of CO_2 every year. Global assessments suggest that the total potential carbon storage resource associated with appropriate deep geologic formations in offshore settings in the US represents 32 percent of total US carbon storage potential.[53] Offshore transportation and storage of CO_2 faces many of the same challenges as onshore projects proposed on federal lands. Now that management of offshore projects is delegated to the Bureau of Offshore Energy Management, once a federal framework is established, federal managers will require adequate resources to develop and implement offshore projects.

Fostering hydrogen production and markets

Deployment of competitive clean hydrogen and associated hubs will require additional federal policies that lower the cost of low- and zero-carbon hydrogen production, invest in research and demonstration, and facilitate the buildout of transport and storage infrastructure. These policies include the following:

Providing hydrogen tax credits

Production and investment tax credits reduce the upfront and operating costs of hydrogen production, and a clean hydrogen tax credit has been included in the Build Back Better Act budget reconciliation bill. Tax credits should be neutral towards the type of hydrogen production technology, chosen energy feedstock, and end use once it meets a minimum standard of emissions reduction relative to conventional production methods. Additionally, higher credit amounts that reward technologies with lower carbon intensities, as compared to conventional hydrogen production, are powerful tools to incentivize newer, cleaner technologies.

Scaling hydrogen transport and storage infrastructure

Access to federal low-interest loans and grants for hydrogen pipelines and rail and maritime transport will incentivize the construction of infrastructure linkages between regionally dispersed producers and consumers and avoid the higher costs and emissions associated with truck transport.[54] Further developing storage infrastructure will enable hydrogen to be sold and dispatched when needed, which can help overcome production variability. Hydrogen's ability to provide long-term storage enables dispatchable low- and zero-carbon electricity to support the integration of variable renewable generation resources on the grid. Finally, clear federal guidelines for safe transport, storage, and use of hydrogen will also be necessary to build out the requisite infrastructure for a nationwide hydrogen market.

Ensuring additional financing mechanisms for hydrogen

Additional financing mechanisms can provide the final push to make a hydrogen project viable by incentivizing capital investment or enhancing revenue. These tools include a direct pay option for tax credits as provided for in the Build Back Better Act, contracts for differences to ensure producers receive a minimum price, tax-exempt private activity bonds, and master limited partnerships. A project's eligibility for these mechanisms and their relative contribution will likely vary by project type, but their availability provides more optionality for financing projects and increases developer and investor confidence.

State Policy

Supportive state policies can complement and leverage federal policies to accelerate the deployment of regional carbon and hydrogen hubs by increasing project feasibility, bridging remaining project cost gaps, enabling shared infrastructure systems, and creating economies of scale. There are three broad categories of policies that states can consider: regulatory policies and planning, financial incentives, and market development. Outlined on the following pages are policies and incentives that states have used, are under consideration, or are suggested for states with carbon management and hydrogen potential.

State Regulatory Policies and Planning

State regulation and planning efforts can facilitate the development of hubs projects and associated CO_2 and hydrogen transport and storage infrastructure. Key state-level regulation and planning efforts include the following:

Regulating pore space ownership

State initiatives to establish pore space ownership, efficient project permitting processes, and long-term stewardship programs will be critical for project deployment. Appropriate legal frameworks are necessary to establish pore space ownership for permanent geologic storage. Ownership and long-term stewardship of CO_2 are issues that need to be established before hub development in a state or region can occur. Additionally, states should develop frameworks that allow for amalgamation of pore space to ensure that geologic storage projects can be developed at the scale required to anchor broader regional hub development.

Establishing Requirements for CO_2 responsibility

Federal Underground Injection Control program rules provide flexibility to states that have been granted primacy in establishing specific requirements for CO_2 injection and storage at the state level. This flexibility allows states to designate specific pathways for projects to meet federal requirements.

Facilitating hydrogen project permitting

Permitting is a necessary step in the process of project and hub deployment. To encourage hydrogen production, transport, storage, and end-use projects within a state, an enabling regulatory framework for permitting should be established or clarified to minimize any unexpected delays or unnecessary costs and challenges to project development. The permitting process should include information from initial project scoping to final emissions testing after construction and provide clear safety standards for hydrogen producers, retailers, transport, and storage. Facilitating a predictable and timely permitting process will help attract project development and investment to a state, benefiting local economies and industries and contributing to state-level decarbonization goals and plans.

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Financial Incentives

State level incentives can help drive private investment in carbon and hydrogen hub projects. Key state-level financial incentives to support hub development include the following:

Ensuring eligibility for state low-carbon and clean fuel programs

Ensuring eligibility of carbon management and hydrogen projects for state incentives and other policy support can drive project developer and investor interest in hydrogen and carbon hub projects with associated geologic storage. The incorporation of appropriate eligibility in line with state and regional needs can foster commercial project deployment.

Establishing favorable state tax policies

States can tailor their tax policies to provide incentives for carbon and hydrogen hubs. Exemptions or reductions in property and sales taxes on machinery and equipment can reduce costs for hub development. Temporary and targeted reductions in production and severance taxes can encourage the use and geologic storage through enhanced oil recovery of CO_2 captured from industrial facilities, power plants, and ambient air. The eligibility and prioritization of existing lending, loan guarantees, and grant programs can be expanded to include the development and deployment of hydrogen and carbon hubs. While state programs do not tend to reach the scale of federal incentives, the impact of state financing and grants can be significant. Notably, these programs can cover costs incurred in the initial stages of project development, such as front-end engineering and design studies, which are challenging to finance with private dollars.

Leveraging utility cost-recovery mechanisms

Utility cost recovery mechanisms can reduce costs for hub development. State legislatures can provide utility regulatory commissions with the statutory authority to offer timely reimbursement of expenses incurred during construction and operation, as well as favorable rates of return for regulated utilities' investments in projects to capture and manage carbon emissions. Some states have explicitly included carbon capture as an eligible technology for utility cost recovery.

Offering financing and grant programs

Offering financial incentives for low- and zero-carbon hydrogen production and use to complement existing and anticipated federal incentives can also encourage project development within a state. These incentives could include demonstration grants, tax benefits, or other financial incentives for hydrogen production and projects retrofitting energy and heat sources for hydrogen use.

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Market Development

The development and financing of projects to produce low- and zero-carbon industrial products, fuels and electricity occur when project developers and investors are confident in future markets for such products. States have therefore established procurement standards and programs, portfolio standards, and other policies to build markets that can work in synergy with supply-side financial incentives for private investment. Beneficial policies for market development include the following:

Instituting state procurement programs

State procurement standards and programs are useful for hubs deployment because the construction and ongoing operation and maintenance of state buildings, facilities, fleets, and other infrastructure projects can help provide reliable markets to help justify private investments in carbon management and clean hydrogen projects. These programs include:

- Policies establishing standards for low- and zero-carbon products;
- Common disclosure and reporting frameworks; and
- Procurement programs requiring state agencies and contractors to purchase all or a percentage of industrial products, fuels, and electricity from low- and zero-carbon sources.

Procurement policies can span a wide range of industrial sectors and ensure eligibility for the full carbon management value chain in industry, including carbon capture, carbon utilization, direct air capture, CO_2 transport infrastructure, and geologic storage, as well as hydrogen production, transport, storage, and end-uses. Policies can further prioritize products with lower lifecycle emissions and greater community benefits.

Establishing off-take agreements

Off-take agreements can provide financial and investment certainty before a future market and larger functioning carbon or hydrogen hub evolves. State legislatures and regulatory commissions can provide a guaranteed buyer for electricity, fuels, and industrial products produced with carbon capture, direct air capture, carbon utilization, and geologic storage.

Ensuring inclusion in electricity generation portfolios, clean energy standards, or economic plans

Including carbon capture and storage and clean hydrogen in an electricity generation portfolio or clean energy standard can help reduce costs for hub deployment as producers can earn compliance credits and facilitate utility cost recovery approval from regulatory commissions. States can also prioritize hydrogen through legislation addressing hard-to-abate industries along with transportation, as hydrogen use will help build the market in both sectors. Including hydrogen in state economic development plans would also spur regional hubs and coordination with other relevant economic policies and planning. For already enacted plans and policies, states should expand the definition of hydrogen and provide eligibility, where necessary, to include all low- and zero-carbon pathways of production. Definitions of transportation electrification should include low- and zero-carbon hydrogen as well.

Interstate Collaboration

Interstate collaboration, including planning and policy alignment, will accelerate the full implementation of CO_2 transport and storage infrastructure needed for hubs deployment. Industrial and power plant emissions and suitable storage locations are geographically dispersed across the US, indicating that future CO_2 transport and storage networks will need to be regional and interstate in scope. Also, federal implementation of the USE IT Act provides valuable opportunities for states to develop collaborative regional approaches to planning, regulation, siting and permitting of CO_2 transport and storage infrastructure. Finally, state collaboration can help to reduce environmental, social, and other impacts and improve economies of scale that reduce the future costs and increase the benefits of projects and infrastructure.[55]

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