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CO_2 Utilization Market Study

HOUSTON ENERGY TRANSITION INITIATIVE

1. Introduction

CO_2 utilization report overview

Deloitte Consulting LLP (Deloitte Consulting) and the Houston Energy Transition Initiative (HETI) have worked together to explore the role of CO_2 utilization in Houston and how the industry can advance for the economic benefit of the greater Houston region.

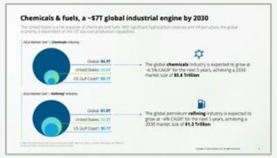
This report provides:

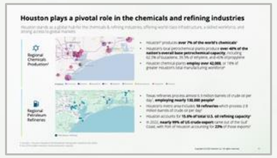
- Current state and potential of CO_2 utilization in industry, focusing on chemicals & fuels
- Benefits and challenges for the Houston region to grow CO_2 utilization

REPORT ORGANIZATION

00 **Section 0**: *Introduction*

01 **Section 1**: *Chemicals and fuels: Economic engines for Houston*

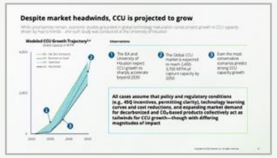


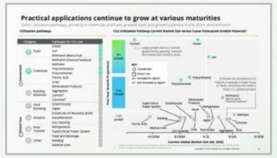


02 **Section 2**: *Houston's industrial carbon opportunity*

03 **Section 3**: *The current state of carbon utilization*

04 **Section 4**: *The future potential of carbon utilization*





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Introduction

Outlines key findings and explains why this report focuses on chemicals and fuels among other industrial sectors

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Chemicals and fuels: Economic engines for Houston

Reviews the importance of the Chemicals & Fuels subsectors from a global to regional perspective

02 *Slides 11–14*

Houston's industrial carbon opportunity

Explores Houston's unique advantages for becoming the nexus of the future carbon capture industry

03 *Slides 15–20*

The current state of carbon utilization

Summarizes the current carbon capture and utilization (CCU) landscape and explores examples of successful utilization projects

04 *Slides 21–27*

The future potential of carbon utilization

Explores the practical applications of CCU and two key product segments that are best poised to capture value from CCU implementation in the near term

Executive summary

- **Houston and the Gulf Coast are well positioned to scale US carbon utilization**
  The region combines the nation's highest density of industrial CO_2 emissions with world-class infrastructure and globally integrated markets in fuels, chemicals, and construction materials.

- **CO_2 utilization presents a potentially attractive opportunity for Houston to nurture and lead through the energy transition**
  Emerging product pathways such as sustainable aviation fuel and e-methanol align with Houston's industrial competitive advantages and global customer base. Technology readiness levels are maturing, and some applications will be ready for scale with coordinated support.

- **Carbon capture and sequestration (CCS) is advancing, but CCU remains underdeveloped**
  World-class, CO_2-ready geology CCS projects seem to be gaining momentum; however, CCU likely faces policy, market, infrastructure, and input challenges that may potentially slow deployment and financing. Unlocking CCU is essential to develop low-carbon-intensity value chains and products.

- **Four systemic barriers will need to be addressed to unlock CCU at scale:**

  - **Policy and measurement, reporting, and verification (MRV) misalignment** – Complex MRV standards highlight opportunities for policy alignment to help reduce long life cycle assessment (LCA) approval timelines.
  - **Demand and financing uncertainty** – Limited offtake, price guarantees, or credit stacking.
  - **Fragmented infrastructure** – Missing modular pipelines, shared inputs, and swing access to sequestration.
  - **Technology and input constraints** – Hydrogen, power, and catalyst bottlenecks; low technology readiness level (TRL) for some products.

- **CCU projects are entering the pipeline—including some already operational in Texas (e.g., Fairway Methanol)**—and the industry should consider leveraging these early proof points and partnerships to accelerate market scale-up.

Chemicals and fuels companies will likely lead CCU efforts in industrials

Industrials like chemicals, fuels, and aggregates remain essential to global economic growth and are significant sources of industrial CO_2 production. Chemicals and fuels sectors provide outsized economic impact to the Gulf Coast and should be prioritized as advantages for near-term carbon utilization.

Houston's industrial impact by market size[†]

Refining industry: **$40- $45B**

Chemical industry: **$40- $50B**

Construction materials: **$3- $5B**

Industry advantages for CCU

Point source density
Well-defined, fixed-location point sources allow cost-effective CO_2 capture and facility-specific retrofits

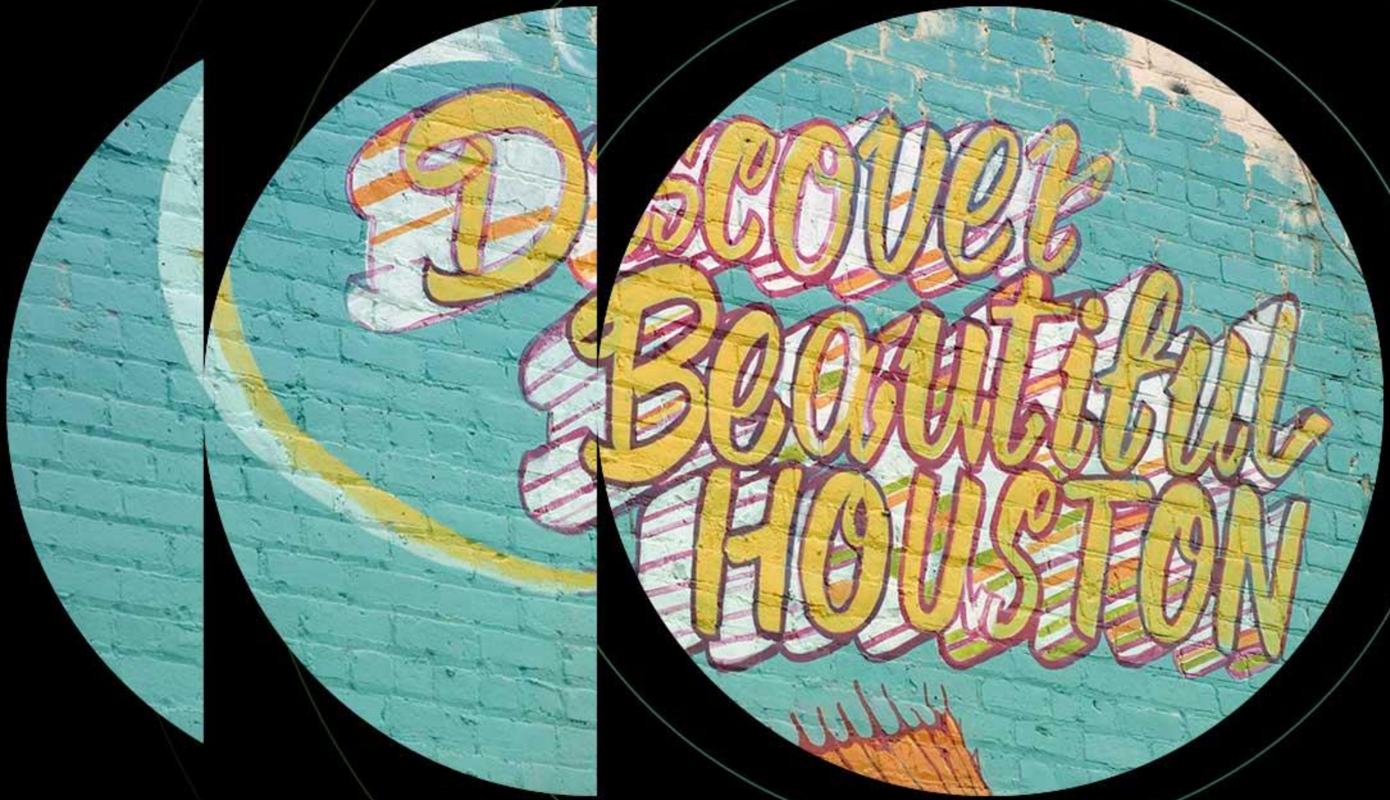
Equipment readiness
Process units *(e.g., reformers, crackers)* often emit CO_2 under pressure and temperature conditions favorable for capture

Inherent product impact
Carbon is embedded in nearly all chemical products, creating a large target for both capture and circular carbon pathways

Existing chemical pathways
Tested CCU pathways (e.g., CO_2-to-methanol, syngas) integrated into existing chemical infrastructure and markets

1 *For market sizing purposes, Houston = Houston MSA + Houston's Gulf Coast industrial corridor counties (e.g., Jefferson, Brazoria, Galveston, Chambers, etc.)*

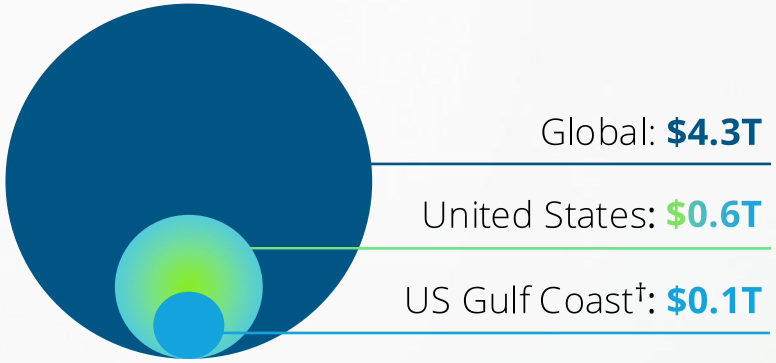
2. Chemicals and fuels: Economic engines for Houston



Chemicals and fuels, a ~$7T global industrial engine by 2030

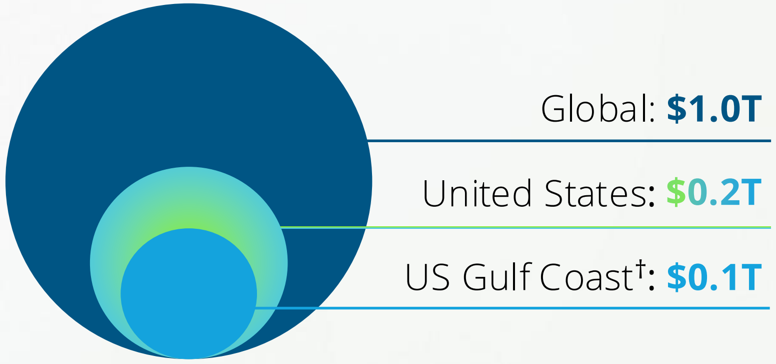
The United States is a net exporter of chemicals and fuels. With significant hydrocarbon reserves and infrastructure, the global economy is dependent on the US's low-cost production capabilities.

2024 market size[1] | **Chemicals** industry



The global **chemicals** industry is expected to grow at ~6.5% CAGR[2] for the next 5 years, achieving a 2030 market size of **$5.8 trillion**

2024 Market Size[1] | **Refining**‡ Industry



The global petroleum **refining** industry is expected to grow at ~4% CAGR[2] for the next 5 years, achieving a 2030 market size of **$1.2 trillion**

† Within this report, the US Gulf Coast includes the coastal regions of Texas, Louisiana, Mississippi, and Alabama
‡ Refining industry market size shown as a proxy for fuels

Advancement on a global scale is facilitated by chemicals and fuels

The chemicals and fuels industry helps promote economic prosperity, create end products that often elevate living standards, and supply materials critical to the energy transition.

Economic development

The chemicals industry contributed over $554B[3] to the US GDP in 2024. Fuel industries add further value through exports, domestic use, and industrial support.

Quality of life improvement

End products often improve quality of life by supporting health through pharmaceuticals, sanitation, and hygiene products and by enabling affordable transport, heating, and electricity access.

The benefits of the chemicals and fuels industry

Job creation

The US chemical manufacturing industry directly employed ~900,000 people in 2024,[4] with a 6x job multiplier.[5] The fuel sector added millions more jobs across upstream, downstream, and supporting industries like logistics and engineering, procurement, and construction.

Emissions reduction

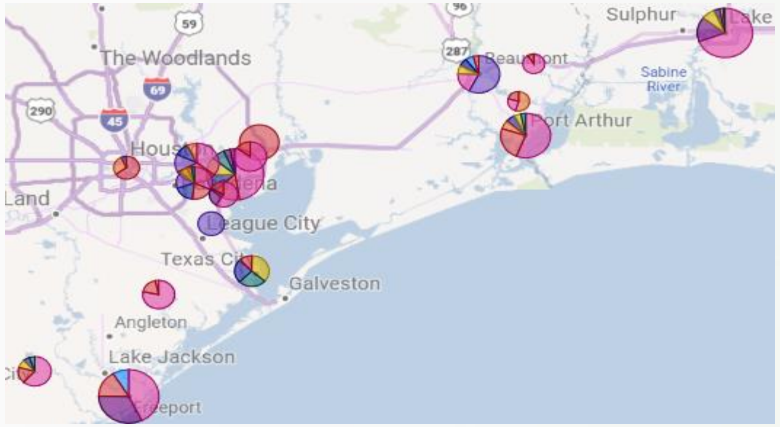
The industry enables the energy transition through advanced materials like carbon fiber blades, platinum alloys, and battery systems. Fuels are also shifting toward low-carbon options such as biofuels, including renewable natural gas, diesel, and sustainable aviation fuel.

Sources [1]Oxford Economics

Houston plays a pivotal role in the chemicals and refining industries

Houston stands as a global hub for the chemicals and refining industries, offering world-class infrastructure, a skilled workforce, and strong access to global markets.

Regional chemicals production‡10



Product Ammonia Benzene Butadiene ECU Ethylene Methanol Mixed Xylenes Propylene Toluene

- Houston† produces **over 7% of the world's chemicals**[6]
- Houston's local petrochemical plants produce **over 40% of the nation's overall base petrochemical capacity**, including 62.5% of butadiene, 39.3% of ethylene, and 45% of propylene
- Houston chemical plants **employ more than 42,000**, or 18% of greater Houston's total manufacturing workforce[6]

Regional petroleum refineries[11]

Petroleum refinery

- Texas refineries process almost 6.3 million barrels of crude oil per day,[7] **employing nearly 130,000 people**[8]
- Houston's metro area includes **10 refineries,** which process 2.8 million barrels of crude oil per day[6]
- Houston accounts for **15.6% of total US oil refining capacity**[6]
- In 2022, **nearly 99% of US crude export** came out of the Gulf Coast, with Port of Houston accounting for **23%** of those exports[9]

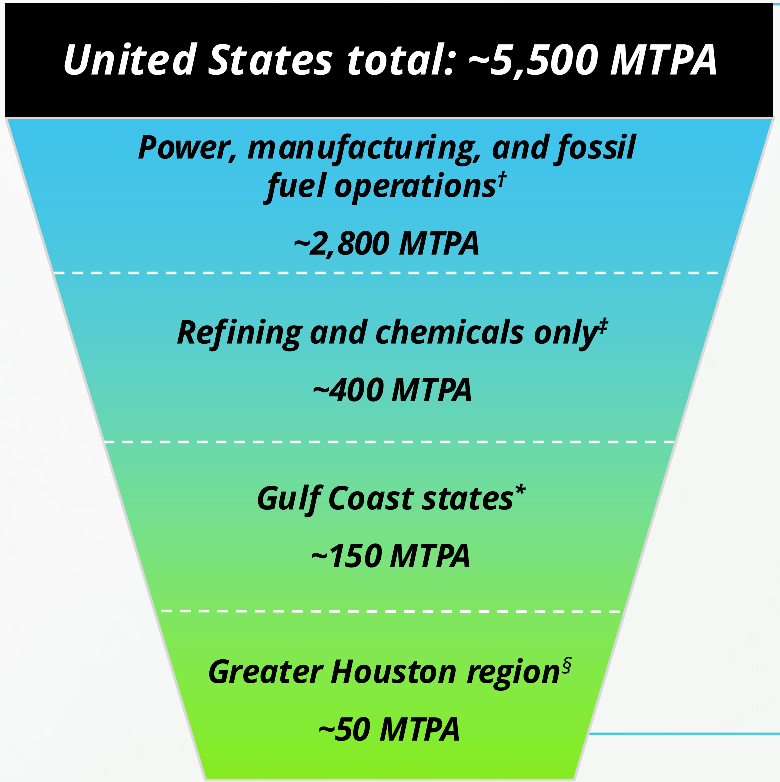
† Houston = Houston-Pasadena-The Woodlands metropolitan statistical area (MSA)
‡ Size of the bubble indicates relative production capacity

3. Houston’s industrial carbon opportunity

Greater Houston holds ~13% of US industrial refining and chemicals emissions

Throughout the nation, especially in the Gulf Coast region, the chemicals and refining industries are meaningful contributors to CO_2 emissions. The production of CO_2 presents an opportunity for the sector to capture waste material streams to deliver lower-carbon-intensity products.

Annual CO_2 emissions *(2024)*[1]



The challenge:

Without carbon capture utilization and sequestration (CCUS), CO_2 emissions will likely remain a substantial byproduct of the chemicals and fuels sectors for the foreseeable future

The opportunity:

By capturing and reusing CO_2, Houston may be better positioned to unlock growth in chemicals and fuels production, while reducing the carbon intensity of each ton produced and continuing to deliver economic benefit (e.g., employment) to the region

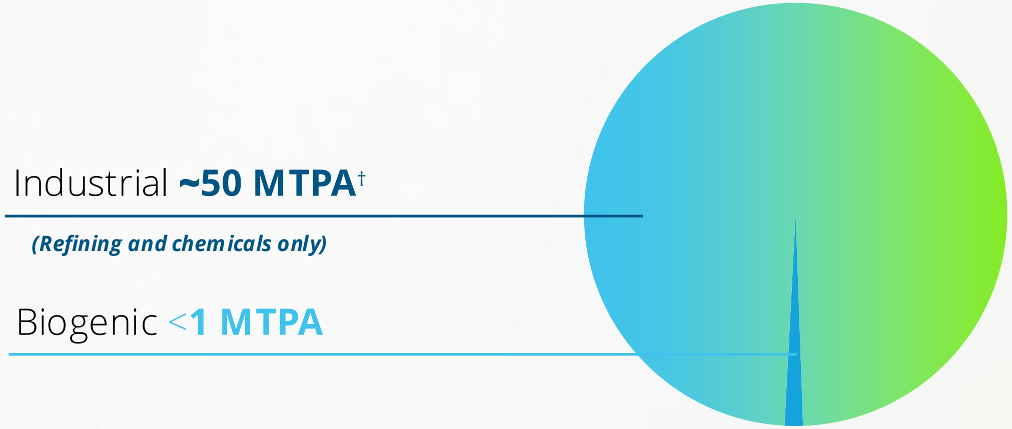
† Sector filters in climate trace filters used
‡ Sector sub-filters: chemicals, other chemicals, petrochemical steam cracking, and oil & gas refining
* Key coastal MSAs in the following states were included: Texas, Louisiana, Mississippi, and Alabama
§ Harris County + Galveston County

Industrial carbon sources provide the greatest opportunity

In the greater Houston MSA, sources of industrial carbon not only significantly exceed those of biogenic CO_2 sources but also provide concentrated, high-volume feedstocks that may significantly reduce capture costs.

CO_2 emissions by origin (MTPA)

Greater Houston region 2024



	Origin	Cost of capture‡	Examples *(CO_2 concentration vol%)*
Industrial CO_2 emissions	Fossil carbon	• High purity[2]: \$15–\$25/tCO_2 • Dilute[2]: \$40–\$120/tCO_2	• Refineries (8–12%)[4] • Cement plants (14–33%)[5] • Steelmaking (20–30%)[6] • Petrochemical plants (7–10%)[7]
Biogenic CO_2 emissions	Biological carbon	• High purity[3,*]: \$25–\$35/tCO_2 • Dilute[3,*]: \$50–\$150/tCO_2	• Biomass power (10–15%)[8] • Ethanol (~99%)[9] • Biogas (30–45%)[7]

† This report focuses on Industrial CO_2 emissions only; if filtering on power, manufacturing, and fossil fuel operations, the emissions double to 100 MTPA for Greater Houston
‡ Cost includes capture only, excluding transport, compression, purification, storage, etc. Also, DAC excluded; not linked directly to industrial or biogenic. Remains costly at \$134-\$342/tCO_2
* High purity streams most align with ethanol projects, whereas biomass power or pulp and paper mill capture are typically more dilute

Industrial carbon sources advantages

1. **Value chain and infrastructure**
   While the Greater Houston region has access to biogas and biogenic CO_2 from sources such as landfills, the supply-side value chain is limited in aggregation, processing, and transportation

2. **High-volume sources of potential feedstock**
   Industrial sources tend to produce large, continuous emissions from fixed point sources, while biogenic sources are generally smaller and more dispersed

3. **Capture technology readiness**
   Many industrial processes emit high-purity CO_2 *(e.g., natural gas processing, gas-to-liquids synthesis, steam methane reformers [SMRs])*, reducing capture costs and enabling viable commercial deployment

4. **CCS incentive synergy**
   Industrial emitters can stack 45Q tax credits, which provide federal incentives for capturing and storing or using CO_2, with CCU revenue streams, which adds economic appeal to emissions capture projects that would otherwise only rely on CCS

Houston is uniquely advantaged to both utilize and store carbon

Within the Gulf Coast, the Greater Houston region is well positioned to leverage the carbon supply based on the density of point sources, infrastructure, and naturally occurring geologic sequestration formations.

Houston's existing pipeline network closely aligns with major CO_2 point sources[10]

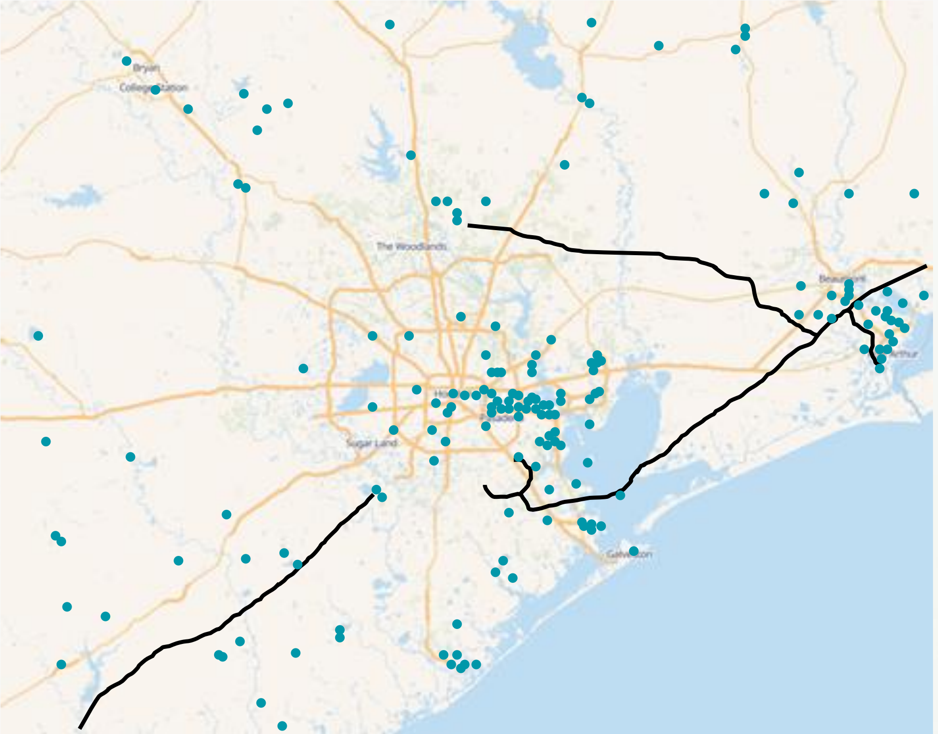


Figure 3: Point source and CO_2 pipeline map. Base Map © OpenStreetMap

Direct emitters — CO_2 pipelines

Houston hosts three critical siting advantages

1. **Density of emitters**
   Houston is home to one of the largest industrial clusters in North America where emitters often operate in close proximity, simplifying infrastructure needs for shared CO_2 collection, compression, and transport systems.

2. **Gulf geology for sequestration**
   Houston benefits from direct access to the Gulf Coast's extensive, high-quality saline formations that are ideal for storing large volumes of CO_2.

3. **World-class industrial infrastructure**
   Houston is a national hub for CO_2, oil, natural gas, and hydrogen pipelines, providing a strong infrastructure foundation that can be adapted or expanded for CO_2 utilization.

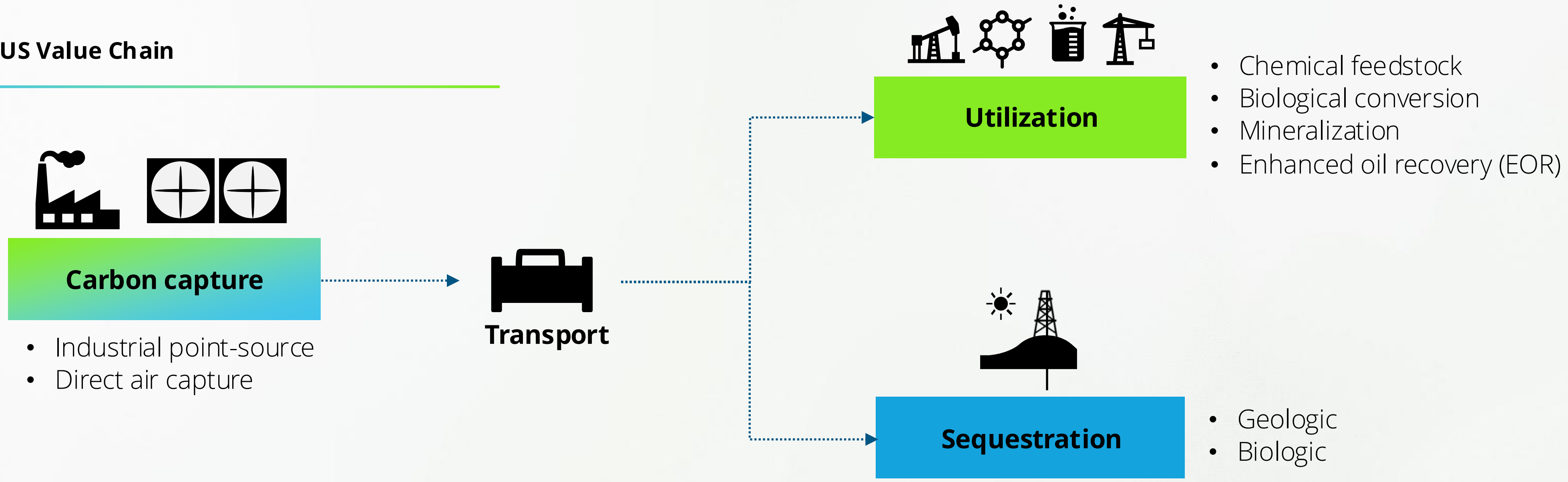
Despite these advantages, **Houston still needs increased infrastructure and flexible networks** to support both sequestration and utilization. Without this infrastructure, it may be difficult for **early movers to succeed and realize economies of scale.**

4. The current state of carbon utilization

CCUS capacity has been slow to expand, but the pipeline is growing

Scaling CO_2 utilization will require an integrated infrastructure system, from capture and transport to process inputs and data management to help ensure CO_2 and related feedstocks can flow reliably across industrial pathways.

Overview of CCUS Value Chain



US capacity[1,†]	Carbon capture *(MTPA CO_2)*	Utilization *(MTPA CO_2)*	Sequestration *(MTPA CO_2)*
2024 *(Operational facilities only)*	22	<1 without EOR *(21 with EOR)*	1
2030 *(Operational facilities, planned facilities, and under-construction projects)*	176	14 without EOR *(41 with EOR)*	186

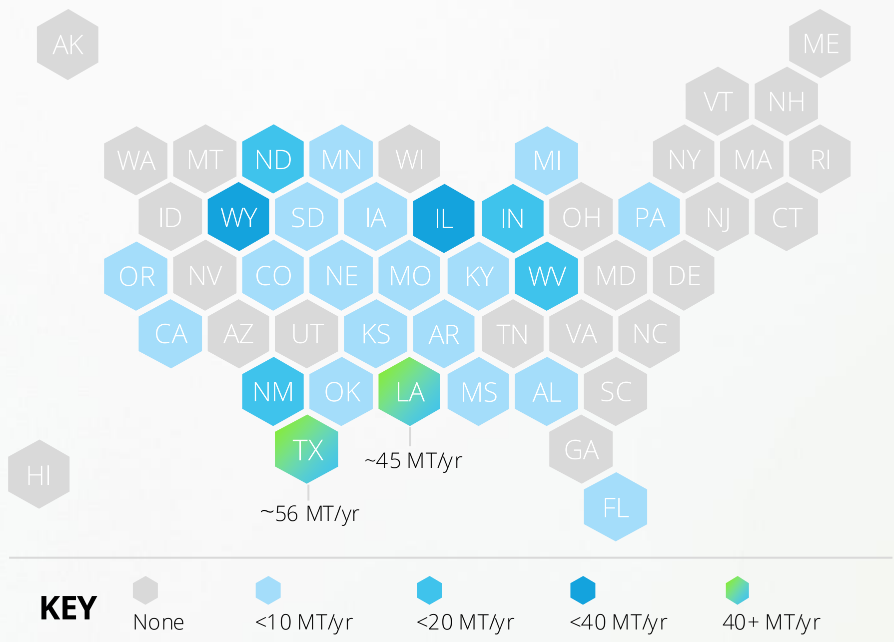
Although EOR absorbs nearly all captured CO_2 today, the US is rapidly expanding alternatives. Sequestration capacity rises from 1 to 186 MTPA by 2030, with utilization also growing. By decade's end, EOR will represent only a small share of total CO_2 use as large-scale sequestration comes online.

† The IEA CCUS database is a global data set of CO_2 capture, transport, utilization, and storage projects with ≥100 kt/yr capacity; includes commercial projects with defined capture sources and excludes EOR and DAC expansion scenarios. Data reflects project announcements as of March 2025, and if capacities are unknown, the projects must have a clear commercial scope. Where data gaps exist (e.g., estimated capacity, operation date), Deloitte does not assume what the values should be, and therefore the capacities and number of planned projects represented in this report may be less than reality. Additionally, the sum of utilization and sequestration volumes will not equate the capture amount, as the source of CO_2 from CCU or CCS projects is not defined in all cases.

CO_2 value chain | carbon capture

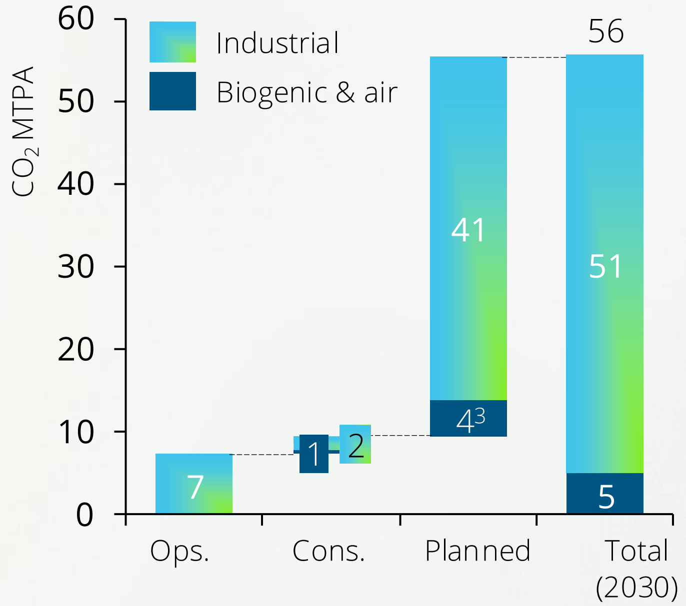
Texas is poised to be the leader in US carbon capture capabilities with announced projects today expected to reach 30% of all US capacity by 2030.

Announced capture capacity in the **US** (by 2030)[1,†]



	Projects	Capacity
Operational in 2024	23	~22
Under construction	14	~16
Planned by 2030	107	~138
Total by 2030	**144**	**~176 MTPA**

Announced capture capacity in **Texas** (by 2030)[1,†]



While Houston has abundant CO_2 supply potential, **aligning with utilization pathways will require targeted investment** in CO_2 conditioning, co-location planning, and market development for offtake

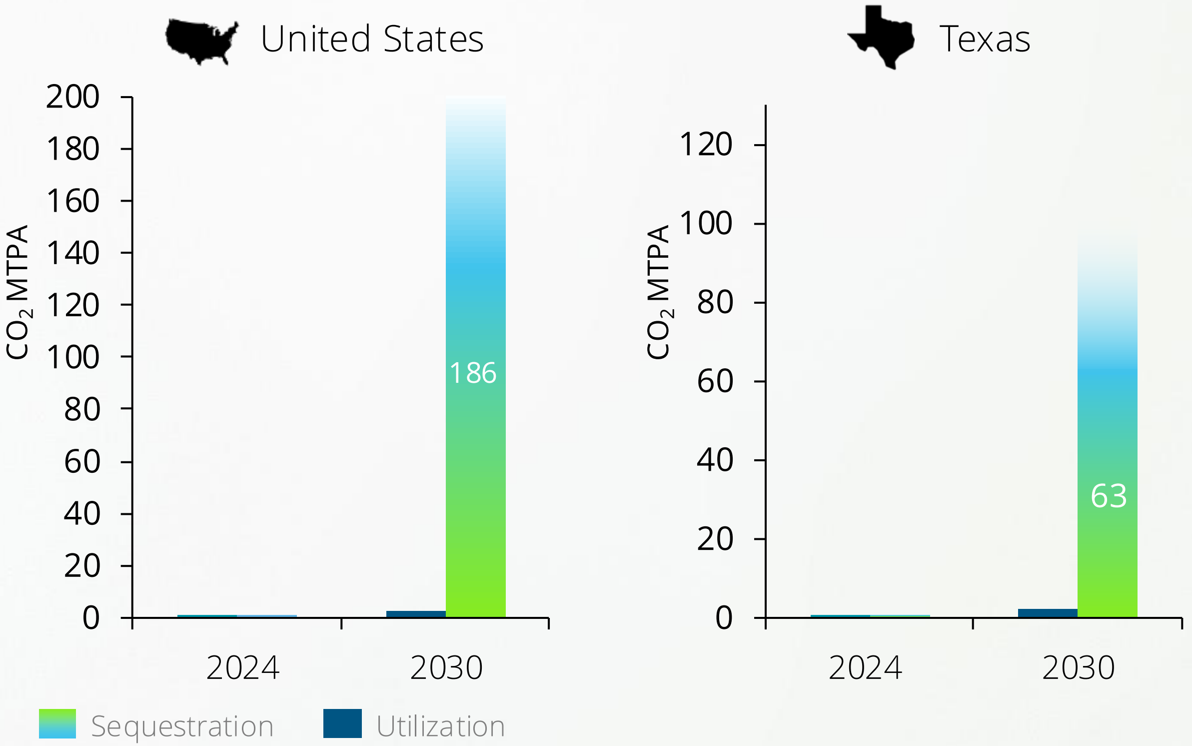
	Projects	Capacity	Example projects
Operational (2024)	6	~7	Campo Viejo Gas Processing Plant, Linde Clear Lake HyCO, Petra Nova
Under construction	2	~3	Linde-OCI Blue Ammonia Project, STRATOS
Planned (by 2030)	32	~46	Calpine Deer Park Energy Center, NextDecade Rio Grande LNG, Port of Corpus Christi Ammonia, ZEROS Project
Total (by 2030)	**40**	**~56 MTPA**	

† The IEA CCUS database excludes projects that do not meet the 100 kt/yr or commercial scope criteria, and thus additional, smaller-scale CCU or CCS projects that are operational, planned, or under construction are not included in the above tables. The projects represented above include full chain, capture, and CCU project types only, as storage and transport project types have unclear capture sources. Additionally, if the planned project's operational date was not provided, it was excluded and not assumed to be operational before 2030.

CO_2 value chain | Carbon sequestration and utilization

Sequestration capacity in the US has historically scaled faster than utilization, largely driven by former incentive structures favoring storage pathways.

Sequestration and utilization capacity †



Announced projects in Texas†

Utilization	Projects	Capacity	Example projects
Operational (2024)	1	<1	Celanese Clear Lake Project
Under construction	-	-	-
Planned (2030)	1	~2.0	HIF USA eFuels
Total by 2030	**2**	**~2 MTPA**	

Sequestration	Projects	Capacity	Example projects
Operational (2024)	1	<1	Campo Viejo Gas Processing Plant
Under construction	3	~2.7	Linde-OCI Blue Ammonia Project
Planned (2030)	23	~60.3	Bayou Bend CCS, Freeport LNG, Rose Carbon Capture and Storage Project, Cormorant Clean Energy
Total by 2030	**27**	**~63 MTPA**	

† The IEA CCUS database excludes projects that do not meet the 100 kt/yr or commercial scope criteria, and thus additional, smaller-scale CCU or CCS projects that are operational, planned, or under construction are not included in the above tables. The sum of utilization and sequestration volumes will not equal the capture amount, as the source of CO_2 from CCU or CCS projects is not defined in all cases. Additionally, if the planned project's operational date was not provided, it was excluded and not assumed to be operational before 2030.
‡ Excludes EOR utilization projects.

Both CCU and CCS have begun to establish their market presence

The carbon management landscape is growing in Texas, with several companies making investments.

	Celanese	HIF Global	Infinium	BP + Linde
Facility	**Texas** Clear Lake	**Texas** Matagorda	**Texas** Corpus Christi	**Texas** Greater Houston
Operations date	**Operational**[1]	**2030**	**Operational**	**2026**[10]
Processing throughput	• 0.18 MTPA CO_2 captured • 0.13 MTPA methanol produced for downstream production of acetyl chain and methanol-derived products	• 2 MTPA CO_2 capture (planned) • 1.4 MTPA e-methanol to be produced for **shipping industry**	• Unknown planned capacity • At full capacity, facility to produce 3 million liters of e-fuel annually[8]	• 15 MTPA CO_2 capture (planned) • Primarily a sequestration facility, with some captured CO_2 to be utilized for hydrogen production (undisclosed)
Additional details	• Operational since **2024** • **Fairway Methanol JV** with Mitsui[2] • Mass balance attribution with **ISCC-PLUS and RedCert** certification for third party validated sustainability impact[3] • **Sources CO_2 and hydrogen from nearby Linde facility**, highlighting how proximity between carbon sources and users reduces transport needs and enables a more cost-effective, low-carbon feedstock pathway[4]	• Will create 4,000 construction jobs and 140 direct jobs during operations[5] • **HIF Global, Bechtel Energy, Siemens Energy, and Topsoe** completed FEED • In March 2025, HIF was awarded first US **LCFS Tier II Design Pathway Certification**, allowing HIF to **apply and generate credits** for production of e-SAF, e-Naphtha, and e-Diesel[6,7]	• Infinium commenced its **Project Pathfinder in March 2024**, using a patented process of capturing CO_2 and generating green hydrogen to **produce low carbon e-fuels** • Drop-in fuels produced are the only ones in North America that are **ISCC PLUS certified**[9] • **Product portfolio** includes: ✓ e-Diesel ✓ e-SAF ✓ e-Naphtha	• **Announced in 2022**, expected to be operational in **2026**[10] • **Linde** will use its proprietary technology and operational expertise **to capture and compress the CO_2 from its hydrogen production facilities** for the project • BP's trading and shipping business aims to bring **renewable power and certified natural gas**, along with **commodity trading and price risk management** expertise

The Fairway Methanol project demonstrates a **circular and scalable business model** that transforms industrial emissions into mainstream, low-carbon products **today**

CCS projects support the development of CCU projects

Utilization and sequestration are complementary strategies that support and protect investment deployments. CCS acts as an early foundation while markets and infrastructure evolve toward broader CO_2 utilization.

How CCS helps

1. De-risks capture projects

Over **90%** of the 22 MTPA currently stored in the US **goes to saline or EOR reservoirs**. These large, proven sinks help **de-risk capture investments** before CCU markets fully mature.

2. Shared transport infrastructure

Shared compression and trunkline systems built for storage can also **support utilization needs** for purposes like synthetic fuel and concrete production facilities, reducing unit CO_2 transport costs by 40%–60% when moving from 3 MTPA to 10 MTPA (from $12 to $4), and then drops further at 30 MTPA to ~$2 per tCO_2 per 250 km.[11]

3. Blended portfolios

Coupling CCS and CCU enables stacked incentives to **diversify funding streams and reduce offtake-associated risks** (e.g., 45Q + 45V/SAF + LCFS) and combines the durable climate benefit of sequestration with local economic benefits like jobs and products from utilization projects.

Example projects integrating CCS and CCU

Dow's Net-Zero Ethylene & Derivatives Complex, Canada[12]

- Planned production of 3.2M MTPA of low-to-zero emissions polyethylene and ethylene derivatives
- Facility assets include a hydrogen-fueled ethylene cracker and a carbon sequestration facility
- Direct CO_2 pipeline integration to enable Day 1 carbon transfer to consumers

ArcelorMittal's Steelanol Project, Belgium[13]

- Announcement to produce ethanol at Steelanol plant
- Carbon-rich industrial **gases from steel production will be converted into ethanol** using LanzaTech's bio-recycling process
- Planned capacity to produce 80M liters of ethanol and reduce carbon emissions from the Ghent plant by 125,000 MTPA

CarbonFree's SkyMine, San Antonio[14]

- World's first industrial-scale carbon mineralization facility, creating over 250 construction jobs
- Planned to capture 75,000 tCO_2/yr from **cement flue gas, converting to carbon-negative baking soda**
- $125M project is expected to generate approximately $48 million in revenue and $28 million in annual earnings

5. The future potential of carbon utilization

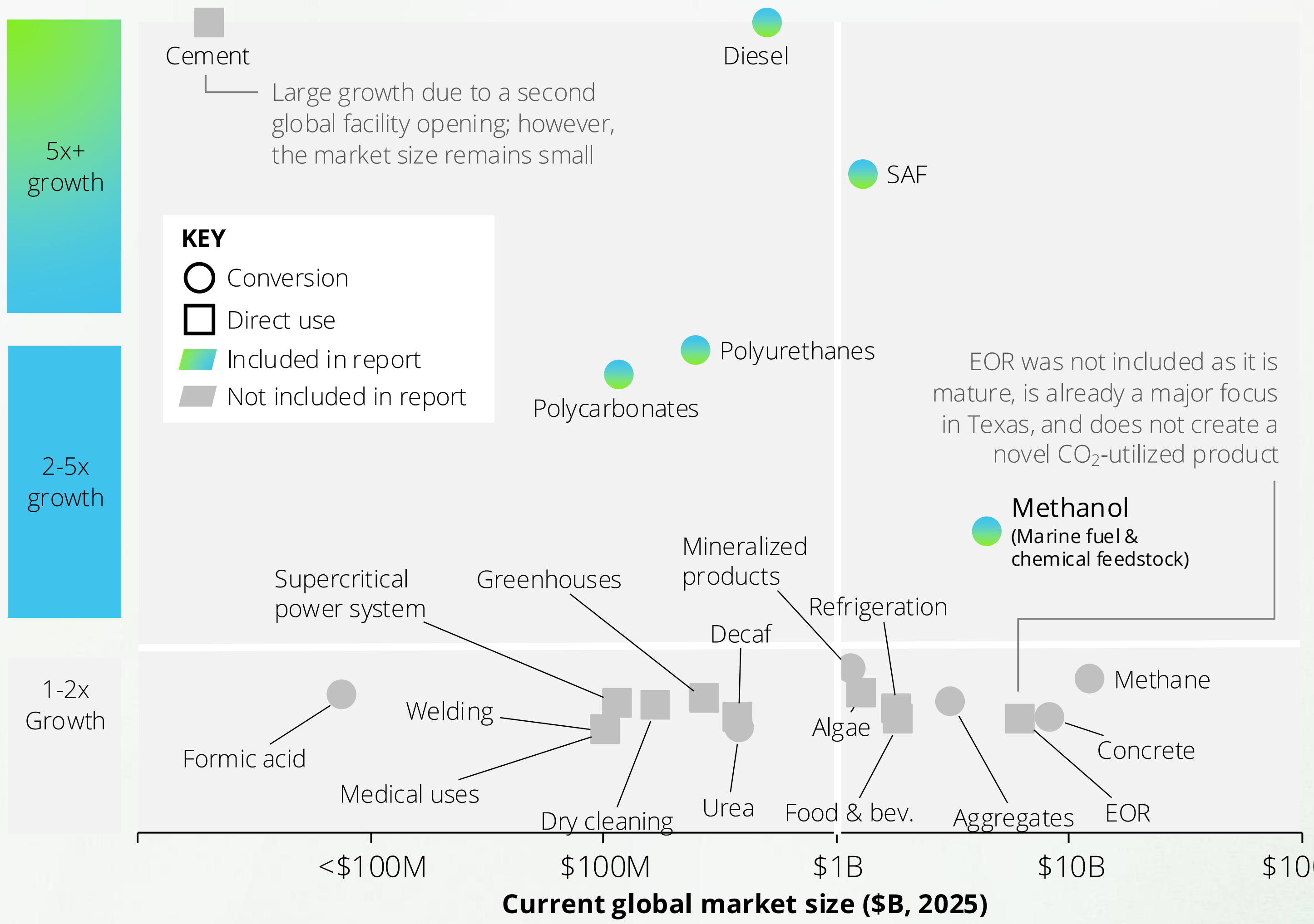
Practical applications continue to grow at various maturities

Select utilization pathways, primarily in chemicals and fuels, present scale and growth potential in the short- and mid-term.

Utilization pathways

Category		Pathways for CO_2 use
Conversion	Fuels	Diesel
		SAF
		Methanol *(Marine fuel)*
	Chemicals	Methanol *(Chemical feedstock)*
		Methane
		Polycarbonates
		Polyurethanes
		Formic acid
		Urea
	Building materials	Mineralized products
		Aggregates
		Cement†
		Concrete‡
Direct use	Yield boosting	Greenhouses
		Algae
	Solvents	Enhanced oil recovery (EOR)
		Decaffeination
		Dry cleaning
	Heat transfer	Refrigeration
		Supercritical power system
	Other	Food and beverage
		Welding
		Medical uses

CO_2 utilization pathway current market size versus 5-year forecasted growth potential[1]



‡ Cement includes only processes that utilize of CO_2 in the production process, which is minimal (total estimated 0.015 MTPA, 2025)

‡ Cement curing is included as part of the concrete process

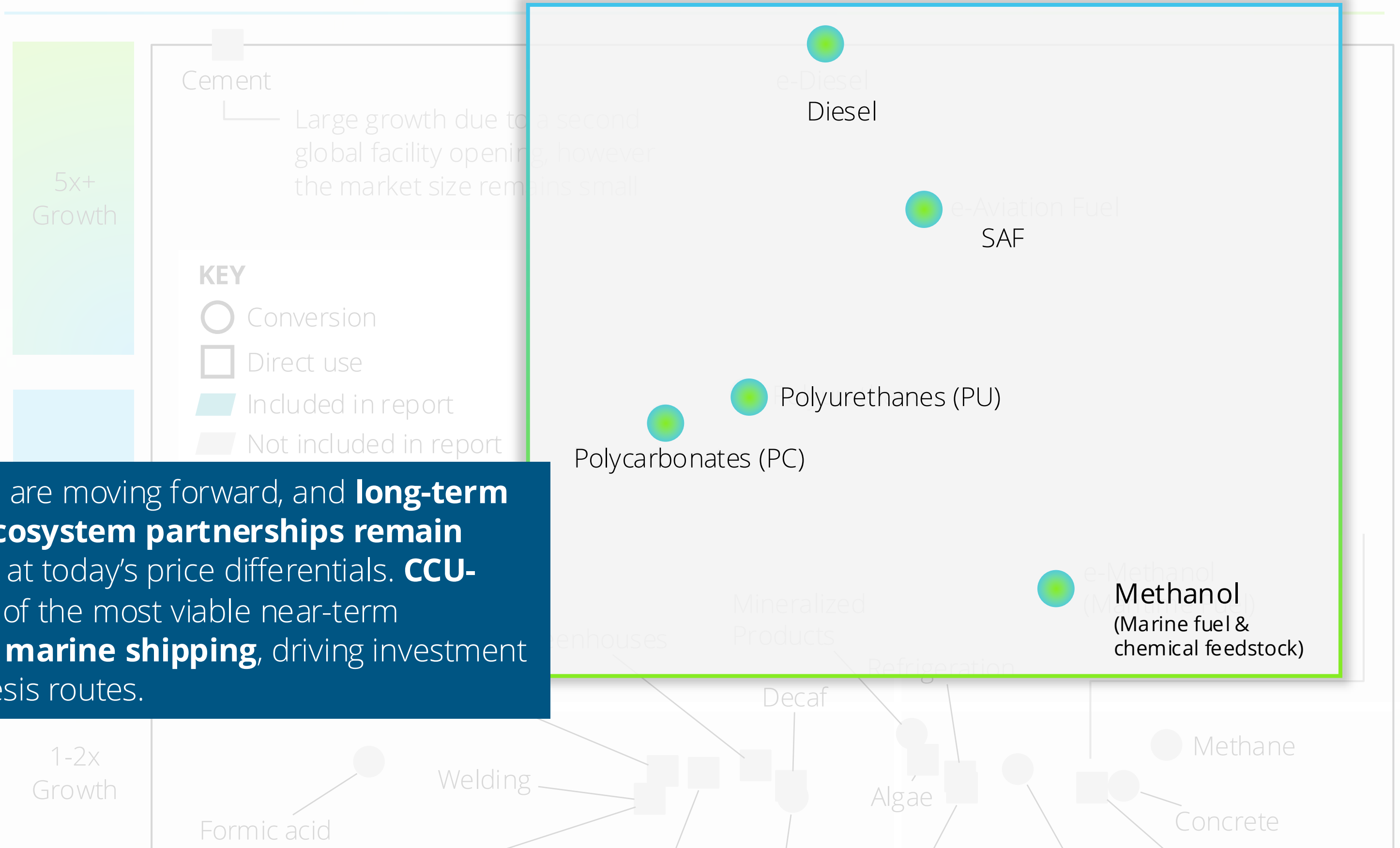
Fuels and basic chemical feedstocks can anchor early CCU market growth

These pathways combine proven technology readiness with meaningful market demand, positioning them as a strong foundation for future scale-up.

Utilization pathways

	Category	Pathways for CO_2 use
Conversion	Fuels	Diesel
		SAF
		Methanol *(Marine fuel)*
	Chemicals	Methanol *(Chemical feedstock)*
		Methane
		Polycarbonates
		Polyurethanes
		Formic acid
		Urea
	Building materials	Mineraliz…
		Aggregat…
		Cement[†]
		Concrete
Direct use	Yield boosting	Greenho…
		Algae
	Solvents	Enhanced oil recovery (EOR)
		Decaffeination
		Dry cleaning
		Medical uses

CO_2 utilization pathway current market size versus 5-year forecasted growth potential[1]



New, regional e-fuels projects are moving forward, and **long-term offtake agreements and ecosystem partnerships remain critical** to unlock investment at today's price differentials. **CCU-based methanol** offers one of the most viable near-term pathways for **decarbonizing marine shipping**, driving investment in scalable low-carbon synthesis routes.

While the pathways highlighted in blue demonstrate strong CCU potential and and rely on proven technologies, most still require greater industry momentum to achieve widespread adoption. **Near-term focus on fuels and chemicals** can help build the foundation for broader CCU deployment in the years ahead.

CO_2 utilization pathways technology readiness

CCU-based fuels are advancing from demonstration to large-scale deployment, though unit economics continue to constrain widespread adoption across the value chain.

Fuels[2,†]

Diesel's adoption is heavily limited by feedstock-related operational unit costs and significant CAPEX requirements for process units.

- **[7-9] Fischer Tropsch** FT is commercial, but capital intensive; CCU-syngas step is less mature and remains TRL 6–7
- **[5-6] Methanol-to-diesel** Demonstrated only at pilot scale; viability is constrained by green methanol costs and unproven long-term catalyst performance

SAF faces similar challenges but with added requirement to meet the needs of highly unit cost-sensitive customers operating on thin margins.

- **[7-9] Fischer Tropsch** FT-SPK is commercial, but capital intensive; CCU-syngas step is less mature and remains TRL 6–7
- **[5-6] Methanol-to-jet** Only pilot-scale demonstrations; early pilot stage with catalyst/selectivity limits and dependence on low-cost green methanol
- **[7-9] Alcohol-to-jet** ATJ is ASTM-approved; capital intensive due to multiple processing steps, and CO_2-derived alcohol is lower TRL

Hybrid[2,†]

Methanol's low-carbon pathways are limited both by access to low-cost feedstocks and the high energy consumption per unit product.

- **[7-9] Syngas reaction** Commercially mature; key challenges include lower conversion efficiency and heat-integration complexity
- **[6-8] Direct hydrogenation** First-of-a-kind (FOAK) and early commercial plants exist; green H_2 cost and catalyst stability are the major challenges
- **[3-5] Electro-catalytic reduction** Lab-to-pilot stage only; low yields, multistage downstream purification requirements, and high energy requirements

Chemicals[2,†]

Polyurethane & polycarbonates are limited by their need for energy-intensive processes to generate low-carbon methanol.

- **[8-9] Direct epoxidation** CO_2-polyols are commercial; CO_2-based epoxidation pathways remain at TRL 6–7 and are not yet cost-competitive
- **[6-7] Polyurethane/ polycarbonate via CO_2-MeOH/syngas** Polymer processes mature, but scale is constrained by limited availability and high cost of low-carbon intermediates

Legend
[X] = Technology readiness level

As CCU pathways mature, scaling low-carbon synthesis routes will depend on **continued reductions in renewable power costs, improved CO_2 feedstock availability, and commercialization partnerships** that de-risk FOAK deployments.

† *Not an exhaustive list of technology pathways*

CCU will need to overcome many challenges to be able to grow and scale

Addressing structural and market barriers is essential to help unlock scalable carbon utilization growth.

Key areas to overcome

POLICY LANDSCAPE & CHAIN OF CUSTODY

- **Updated tax incentives** *(under the One Big Beautiful Bill Act)* bring CCU and CCS closer to parity
- **MRV† and certification bottlenecks** Tracking emissions through to a final, CO_2-utilized product is more difficult than for high-volume sequestration
- **Regulatory environment** State or local regulatory drivers can evolve to incentivize demand for CO_2-derived products

MARKET DEMAND

- **Weak market pull** Limited buyer base, offtake risk, and uncertainty around green premiums
- **Financing gaps** Investors perceive CCU as high-risk due to low returns and unclear exit strategies
- **Complex business models** CCS projects avoid the complex market risks and uncertainties associated with selling CCU's CO_2-derived end products

INFRASTRUCTURE

- **Coordination challenges** CCU projects require alignment across capture sites, conversion tech, energy supply, and product offtake
- **Sequestration integration** Existing infrastructure prioritizes sequestration, lacking connectivity to utilization facilities or shared offtake networks
- **Permitting barriers** Utilization projects often face additional complexity related to product market entry and compliance

TECHNOLOGY & INPUTS

- **Low TRL and scale-up risk** Most CO_2-to-chemicals pathways remain at pilot or demo scale
- **Energy and H_2 intensity** Many processes depend on low-cost hydrogen or renewable power, raising operating costs
- **Equipment and catalyst bottlenecks** Long lead times for electrolyzers, compressors, membranes, and precious-metal catalysts slow project development

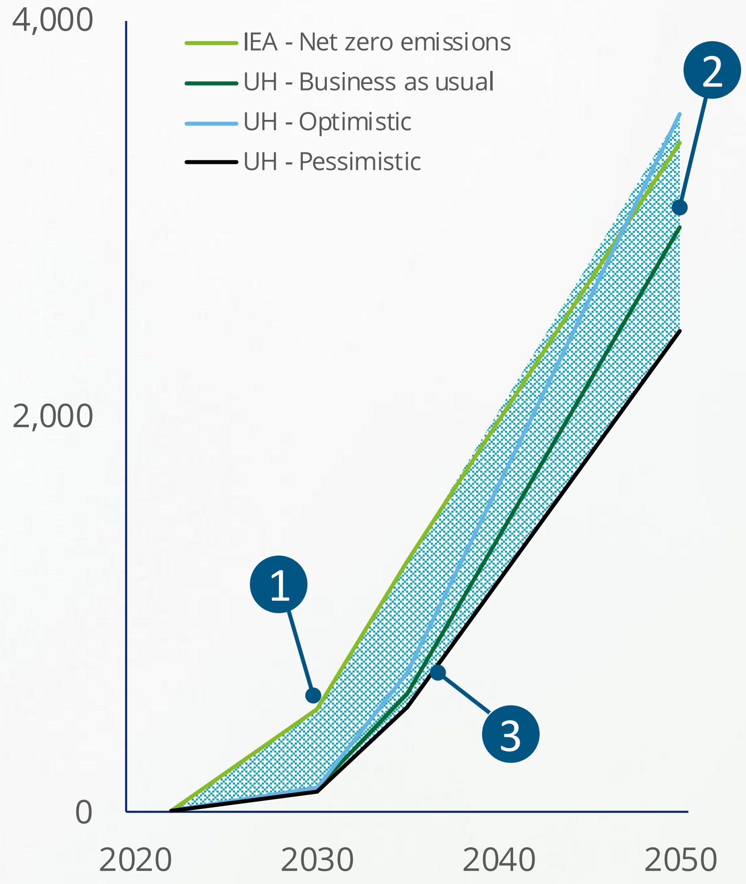
† *Measurement, reporting, and verification*

Despite market headwinds, CCU is projected to grow

While uncertainties remain, economic studies grounded in global technology maturation curves project growth in CCU capacity driven by macro trends—one such study was conducted at the University of Houston.

Modeled CCU growth trajectory[3,4]

Global capacity in MTPA



Observations

1. The IEA and University of Houston expect CCU growth to sharply accelerate beyond 2030
2. The Global CCU market is expected to reach 2,400-3,700 MTPA of capture capacity by 2050
3. Even the most conservative scenarios predict strong CCU capacity growth

All cases assume that policy and regulatory conditions (e.g., 45Q incentives, permitting clarity), technology learning curves and cost reductions, and expanding market demand for decarbonized and CO_2-based products collectively act as tailwinds for CCU growth—though with differing magnitudes of impact

Sources

Sources

Section

00

Introduction

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