

CO₂ Utilization

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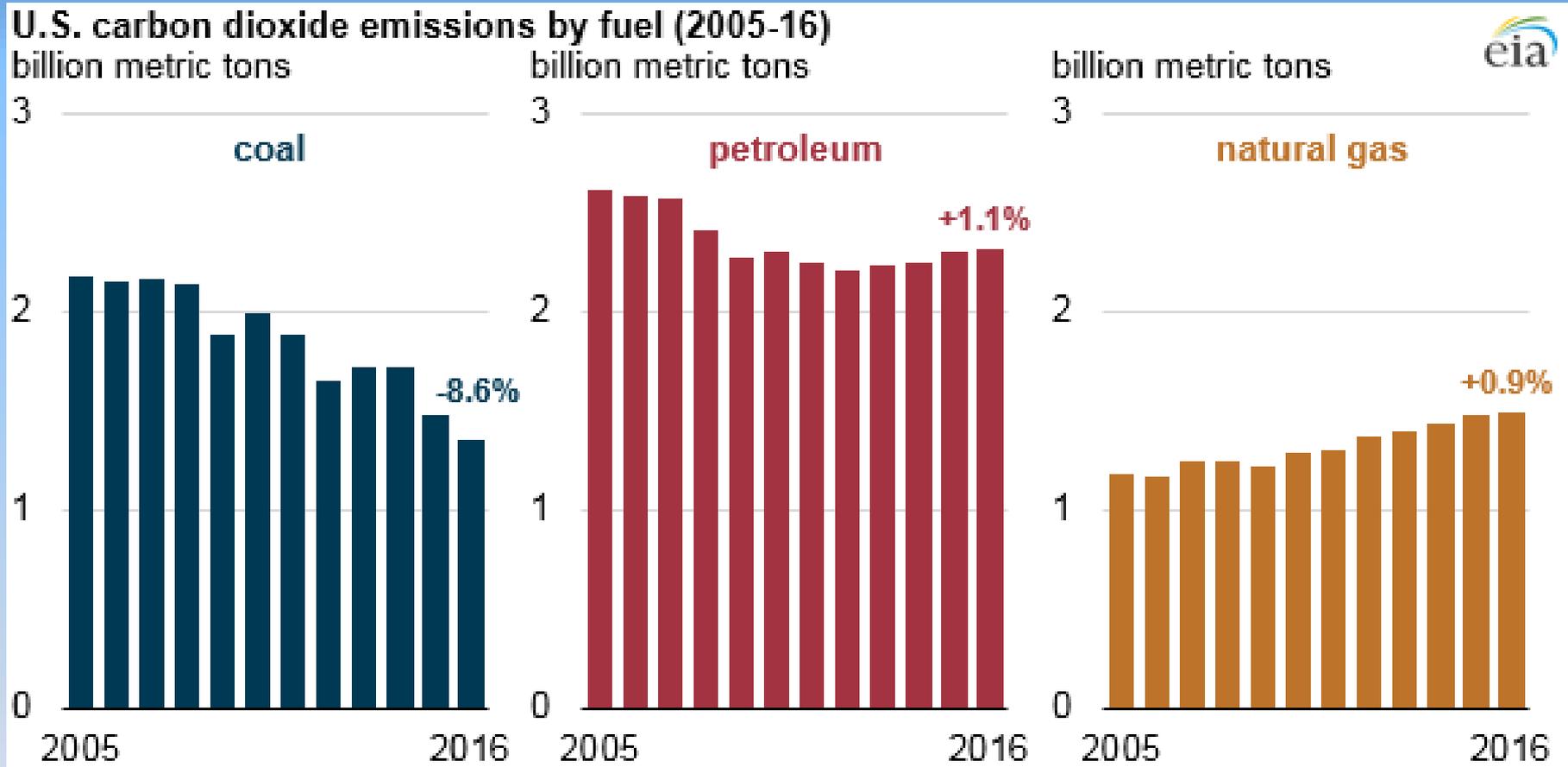
**Department of Petroleum Engineering Colorado
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At: University of Houston

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1. Evidence for global warming: overwhelming
2. Therefore: stop burning coal, and switch to natural gas as fast as possible
3. And: ensure that methane leakage from the NG industry is eliminated
4. Accelerate penetration of renewables
5. And utilize NG's combustion product, CO₂, as many ways as possible (CO₂ EOR, fuels, chemicals, materials – to create a market pull)

US CO₂ Emissions by Fuel. Past Decade



US CO₂ emissions in 2016, totaled 5,170 MMmt.

**This is 1.7% below 2015, and
14% below the Emissions in 2005.**

<https://www.eia.gov/todayinenergy/detail.php?id=30712>

Because CO₂ and CH₄ primarily come from our industry: oil and gas and coal, WE must solve the problem

- Renewable energy investment has more than tripled globally during the current decade compared to the prior 10-year period.
- Solar photovoltaic generation attracted the most investment dollars by far, followed by wind energy, between 2010 and 2019.
- More money was spent installing solar generation capacity than on new coal-fired power generating capacity.
- Still, most power delivered to the world's grids during the decade came from coal. Only 13% of global electricity is currently produced by solar! (Moslener, Univ. Frankfurt).
- China is leading in terms of GW of renewable energy installation, BUT: China is also leading in coal-fired energy generation!

Reference: "Global Trends in Renewable Energy Investment 2019" report was compiled by the Frankfurt School, Bloomberg New Energy Finance, and the U.N. Environment Programme, for this week's UN climate conference in NYC.

Near Term Needs/Opportunities: More Applications for CO₂

- CCUS – good, important and growing. Hence this Interdisciplinary CCUS Workshop at the University of Houston. The O&G industry can use growing amounts of CO₂ for EOR.
- CO₂ is good also for utilization in new materials, chemicals, fuels and other products. There is a rapid growth of creative industries, worldwide, to address this challenge/business opportunity!

Some examples of R&D on converting CO₂ to materials/fuels/chemicals and other products

One method is the use of solar photovoltaics in solar-to-fuel systems being developed at the [Lawrence Berkeley National Laboratory](#) (Berkeley Lab), in California. This method combines photovoltaic and electrochemical systems to allow the reduction of carbon dioxide to fuels such as ethanol, propanol and hydrogen.

Previous methods utilizing this technique suffered from low efficiency due to the large over-potentials required to enable the reduction of carbon dioxide. Researchers at Berkeley Lab, however, have overcome this by optimizing each component of the system and utilizing newly designed materials to minimize voltage loss.

Example 2: Carbon Engineering – Air to Fuels

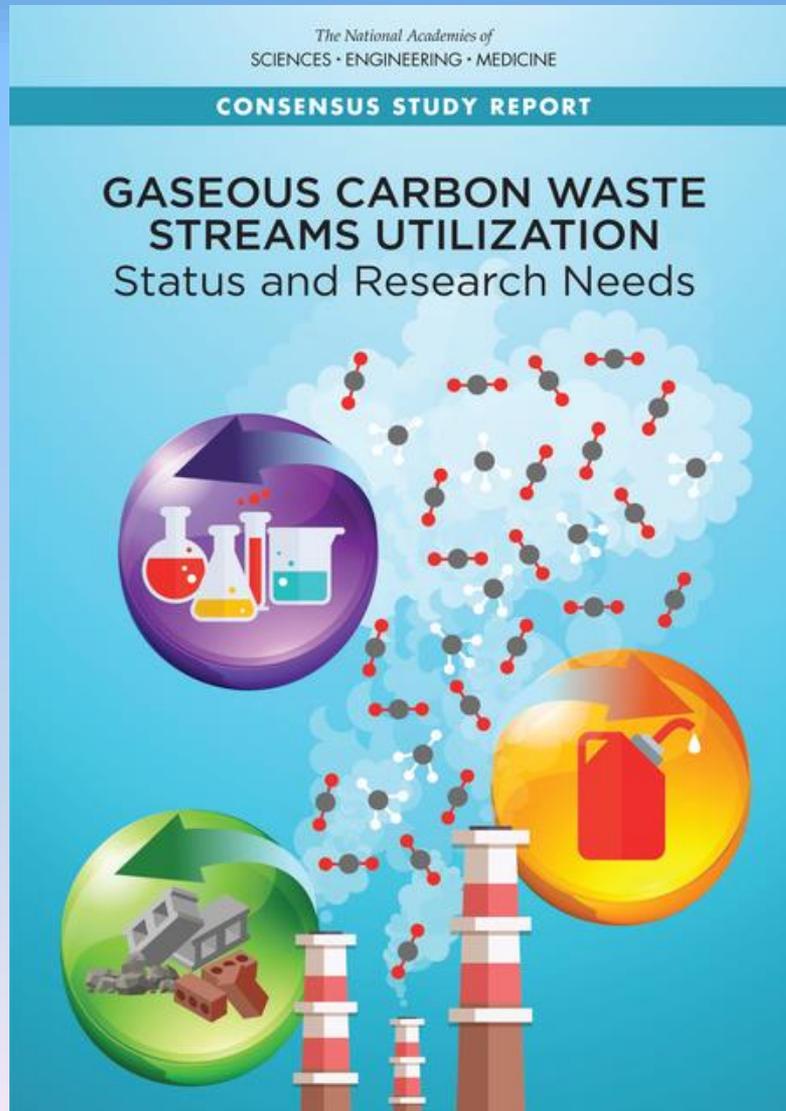
- Direct Air Capture of CO₂, and
- <https://carbonengineering.com/about-dac/>
- Air to fuels production
- Dire

Example 3/4: Climeworks, LanzaTech

- Zurich-based start-up [Climeworks](#), pumps the gas into greenhouses to boost the plants' photosynthesis and increase their yield, it hopes, by up to 20%. Climeworks says it will extract around 900 tonnes of CO₂ a year from the air.
- Chicago(Skokie)-based LanzaTech. <https://www.lanzatech.com/>

LanzaTech's carbon recycling technology is like retrofitting a brewery onto an emission source like a steel mill or a landfill site, but instead of using sugars and yeast to make beer, pollution is converted by bacteria to fuels and chemicals! Imagine a day when your plane is powered by recycled GHG emissions, when your yoga pants started life as pollution from a steel mill. This future is possible using LanzaTech technology.

Impactful Recent National Academy of Sciences Report



<https://www.nap.edu/catalog/25232/gaseous-carbon-waste-streams-utilization-status-and-research-needs>.

Published in 2018

Summary of NAS report

Gaseous Carbon Waste Characterization

Research is needed to map the detailed compositions and magnitudes of gaseous carbon waste streams, with particular attention to co-emitted species that could either hinder or enhance carbon utilization processes. This could increase opportunities for matching waste streams with appropriate utilization processes. Many companies, globally, are now getting into this. See, for example (and many others):

<http://www.lanzatech.com/> (Chicago) and Zurich-based start-up [Climeworks](#)

<https://carbonengineering.com/> a company set up by Bill Gates, physicist David Keith and oil sands magnate Norman Murray Edwards, and its partner, Canadian energy company [Greyrock](#), announced last December that they had made a vital breakthrough. Carbon Engineering had succeeded in using captured CO₂ to synthesize a mix of petrol and diesel.

Their process, known as “air to fuels” (or A2F) consists of three main steps. First, CO₂ is captured from the air and purified. The facility in Squamish already removes one tonne of CO₂ per day from the atmosphere, but previously, this was simply released back into the air as the rest of the process was not developed enough. Next, clean electricity, such as solar power, is used to split hydrogen from water. In the final step, the CO₂ and hydrogen are synthesized into fuel, such as diesel and jet fuel.

NAS Report Findings - 1

OVERARCHING FINDINGS

Previous assessments have concluded that in excess of one billion tons of carbon per year (roughly 3.6 billion tons of carbon dioxide or greater than 10 percent of current global anthropogenic carbon dioxide emissions) could feasibly be utilized within the next several decades if certain technological advancements are achieved and if economic and policy drivers are put in place.

While the eventual scale of carbon utilization will be determined by a variety of technical, economic, and policy drivers, over multiple decades, carbon utilization technologies could be instrumental in achieving a “circular carbon economy” in which waste is converted into resources, such as by capturing the products of hydrocarbon combustion and converting them back into hydrocarbon fuels. In the context of an envisioned economy based largely on solar and wind power inputs with no net carbon emissions, such technologies could enable hydrocarbon use while dramatically curbing greenhouse gas emissions.

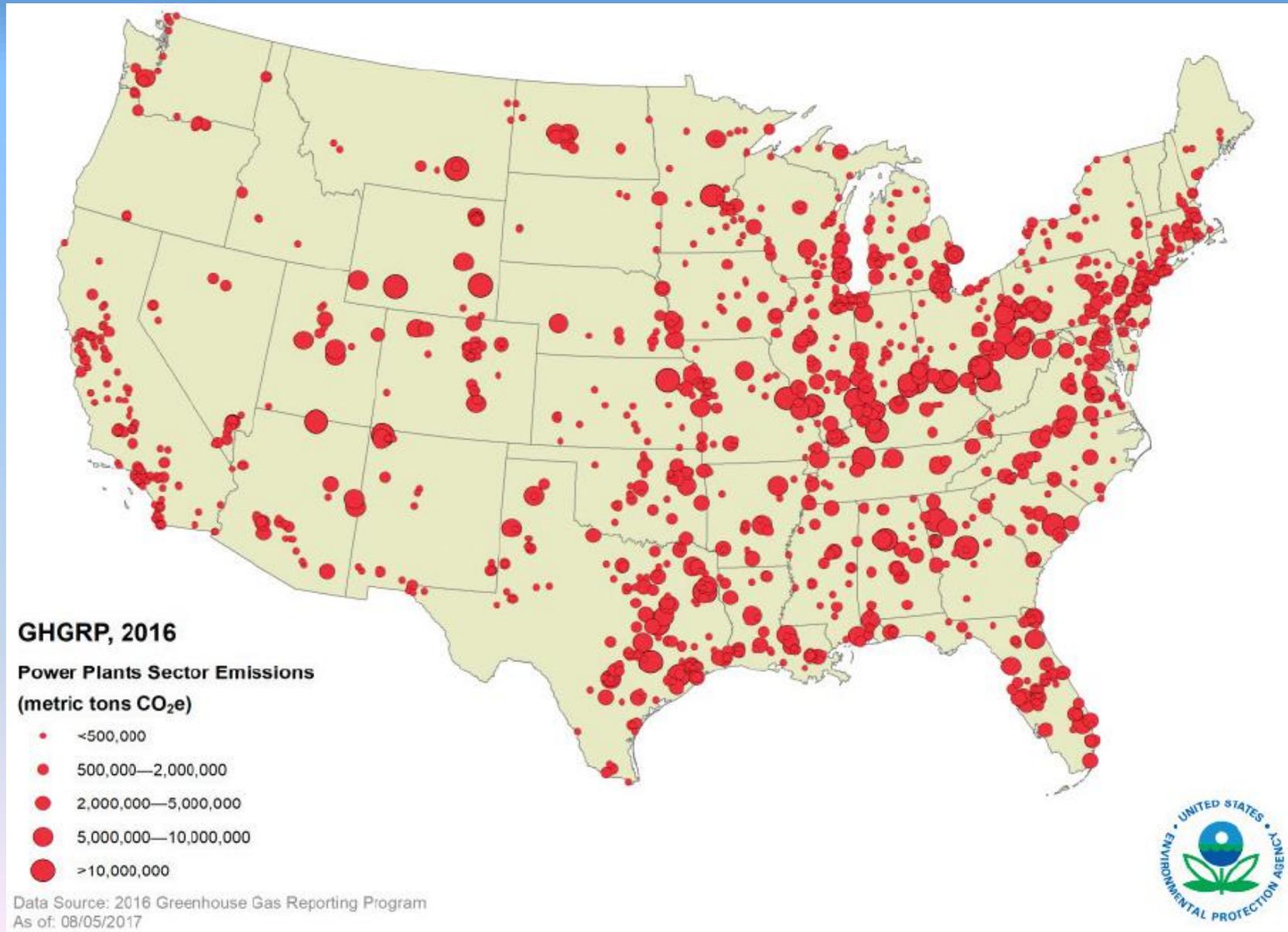
Finding 1: Carbon utilization technologies have a role to play in future carbon management and the circular carbon economy.

Finding 2: To play a meaningful role in carbon management, carbon utilization needs to be done at scale. The scale of carbon waste utilization will depend on the pace of technology development and future energy, market, and regulatory landscapes.

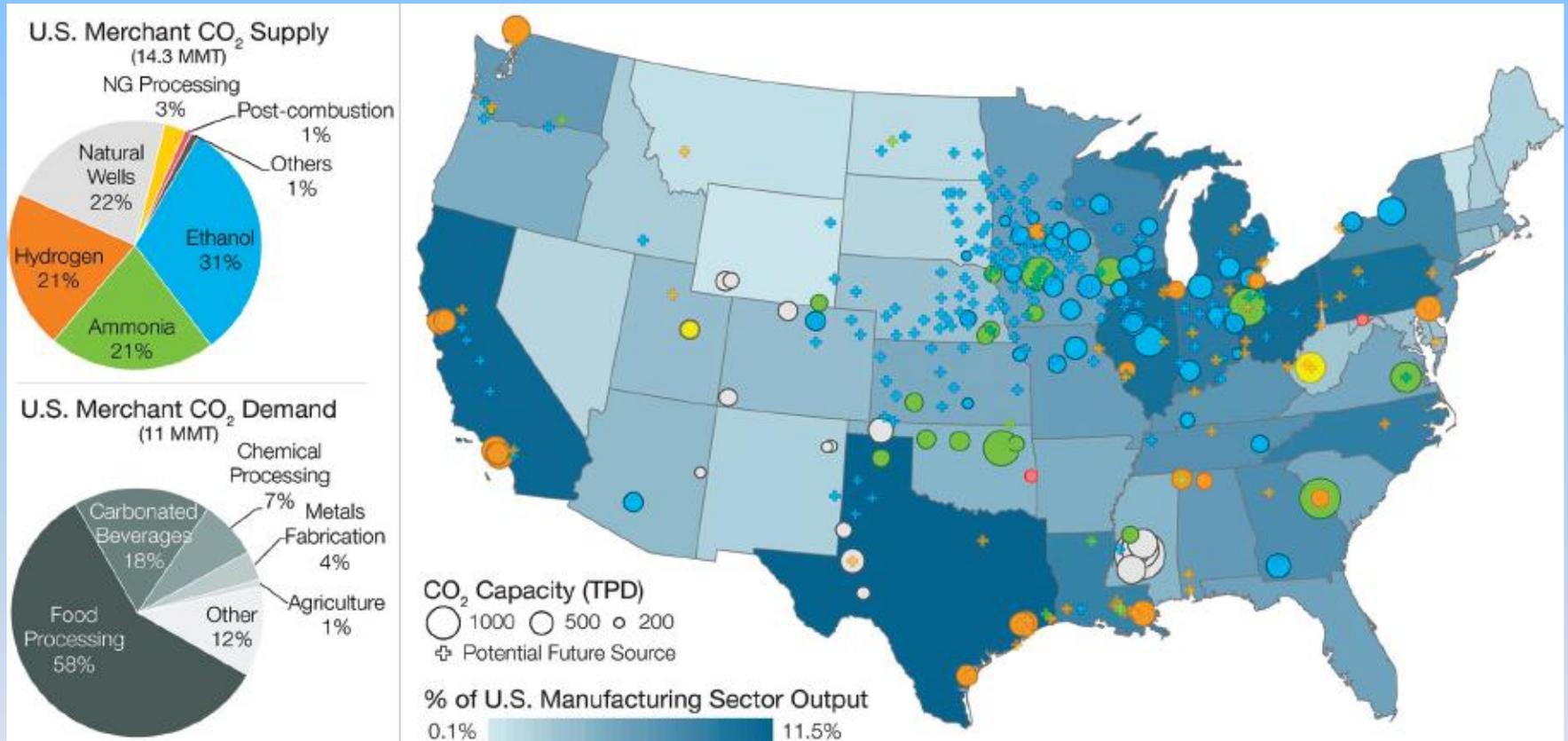
Broadly, carbon dioxide utilization can be categorized into three main pathways:

1. Mineral carbonation to produce construction materials
2. Chemical conversion to produce chemicals and fuels, and
3. Biological conversion to produce chemicals and fuels. Methane utilization pathways include chemical and biological conversion to produce chemicals and fuels, as well as the direct use of methane as a fuel.

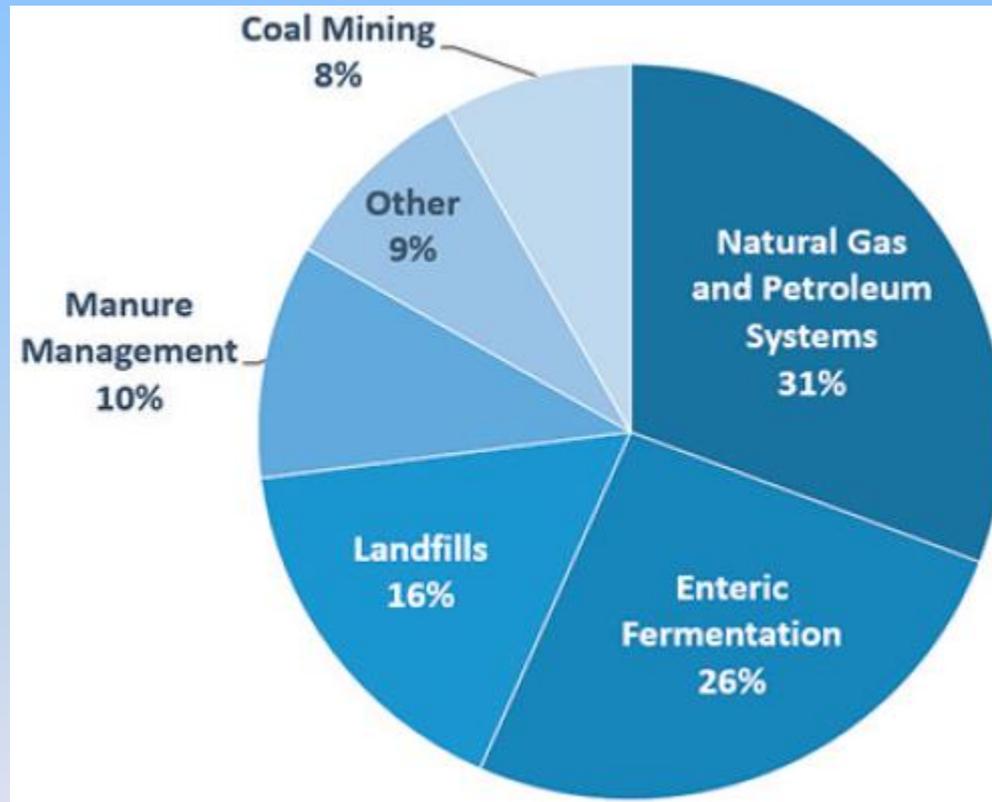
Distribution of US CO₂ Sources (currently: wasted!)



Distribution of US Users of CO₂



Methane emissions in the United States in 2016. Source: EPA, 2018.



The Major CO₂ Utilization Pathways

Pathways for carbon dioxide utilization include these:

- mineral carbonation
- chemical utilization
- biological utilization

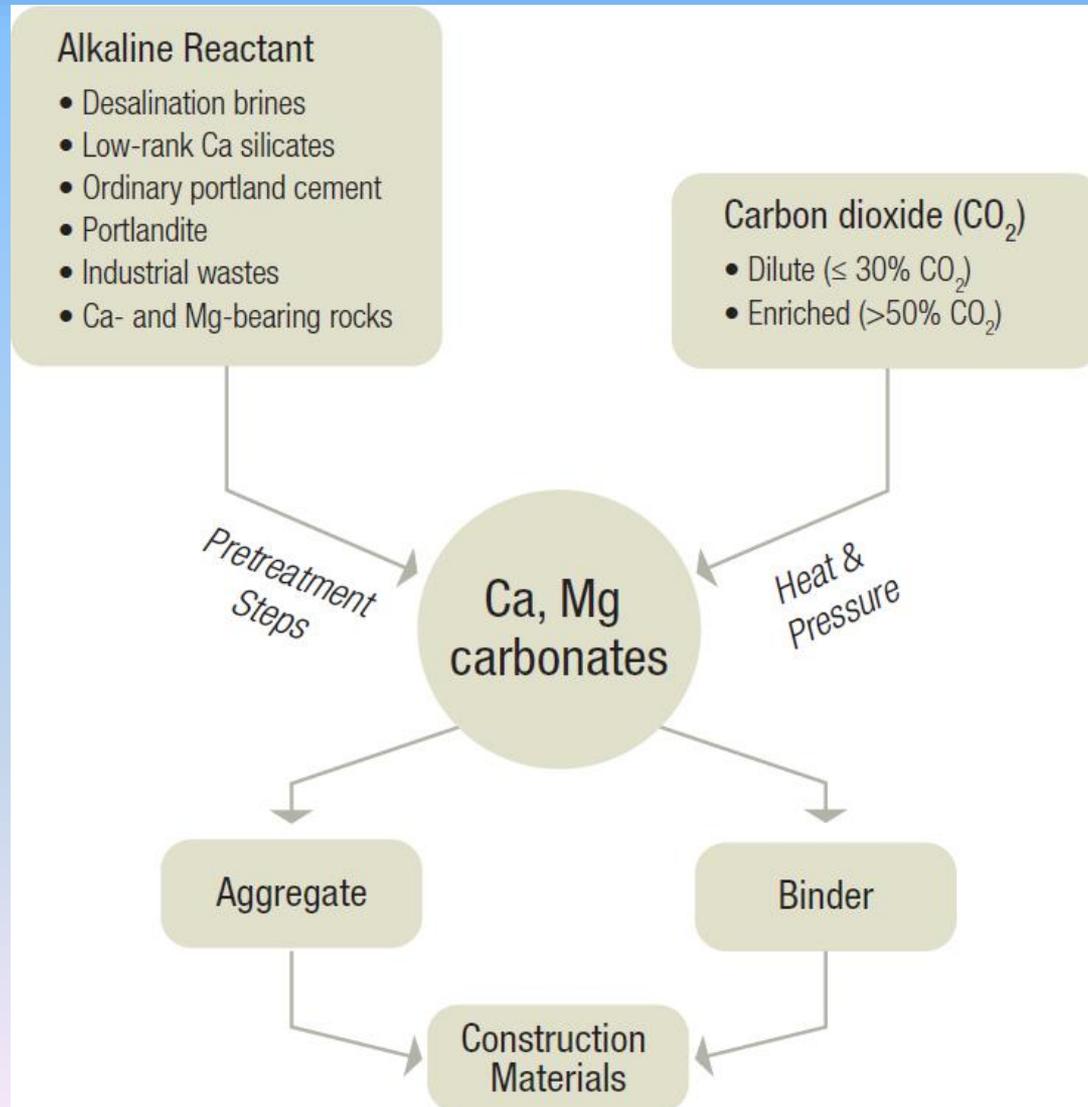
Pathways for methane utilization include all of the above AND direct use as fuel. These pathways involve multiple scales of operation, are at various stages of maturity, and require different energy inputs, feedstocks, and infrastructures.

Mineral carbonation pathway: Make Construction Materials

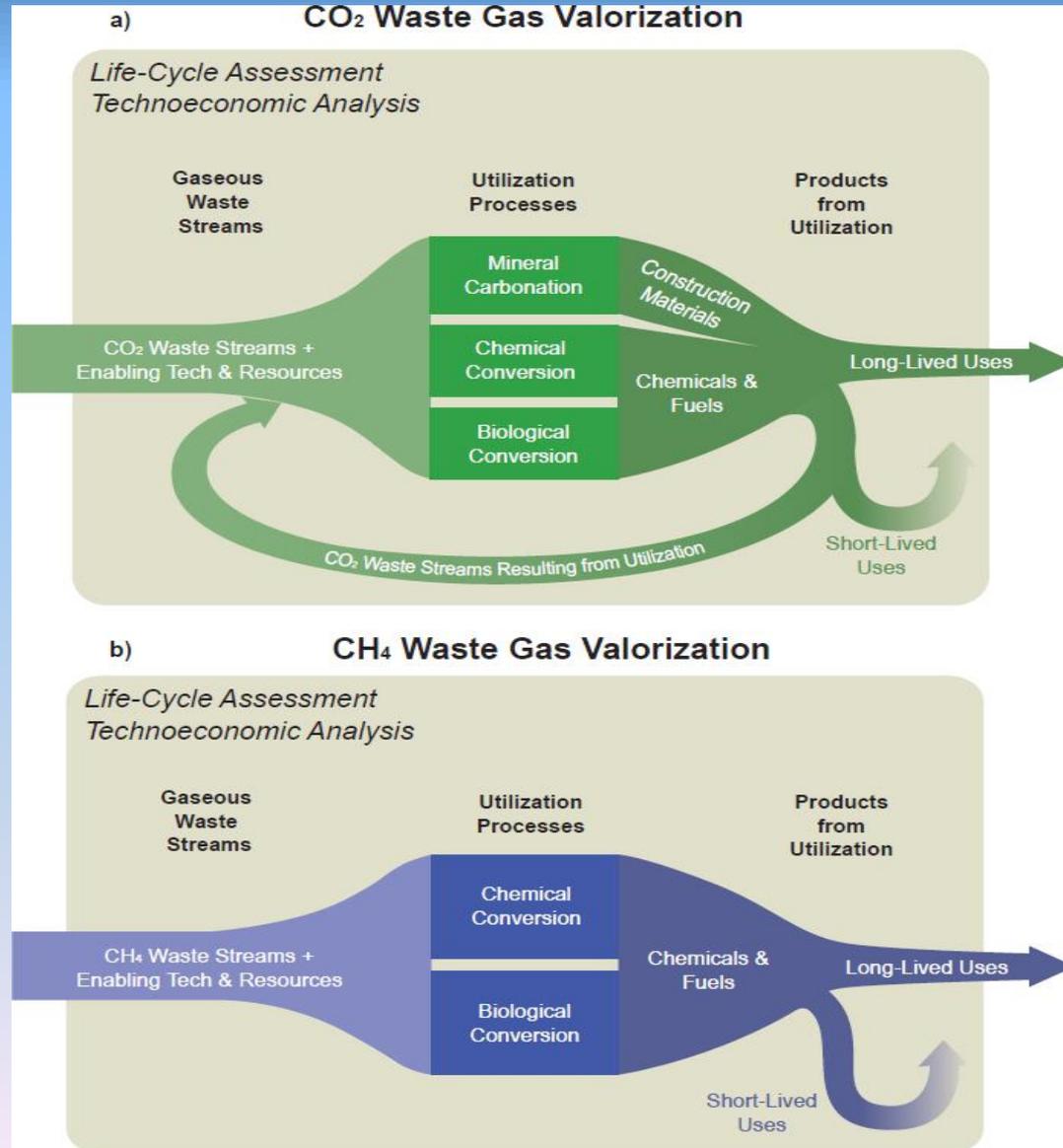
Mineral carbonation processes use waste carbon dioxide (CO_2) to produce construction materials. Mineral carbonation offers an attractive route to CO_2 utilization because

- (1) solid carbonates, the main products of mineral carbonation reactions, are already used in construction materials markets;
- (2) the chemistry involved in making carbonates based on calcium (Ca) and magnesium (Mg) is well known;
- (3) carbonation can consume large amounts of CO_2 by chemically binding it into stable, long-lived mineral carbonates; and
- (4) the reaction of CO_2 with alkaline solids is thermodynamically favored, thereby needing little, if any, extrinsic energy.

Mineral Carbonation Processes to Produce Many Kinds of Construction Materials



How to Create Value from wasted CO₂ (and CH₄)



Summary

We are seeing the start of another “disruptive technology” – one that may help dramatically reduce industrial greenhouse gases: turning CO₂ into value-adding products.

Great opportunity for the fossil fuels industry: we create the raw materials for such products.

Carbon utilization technologies have a role to play in future carbon management and the circular carbon economy.

To play a meaningful role in carbon management, carbon utilization needs to be done at scale.