Carbon Capture, Utilisation, and Storage (CCUS) Technologies May Play a Larger Role in Fighting Global Warming

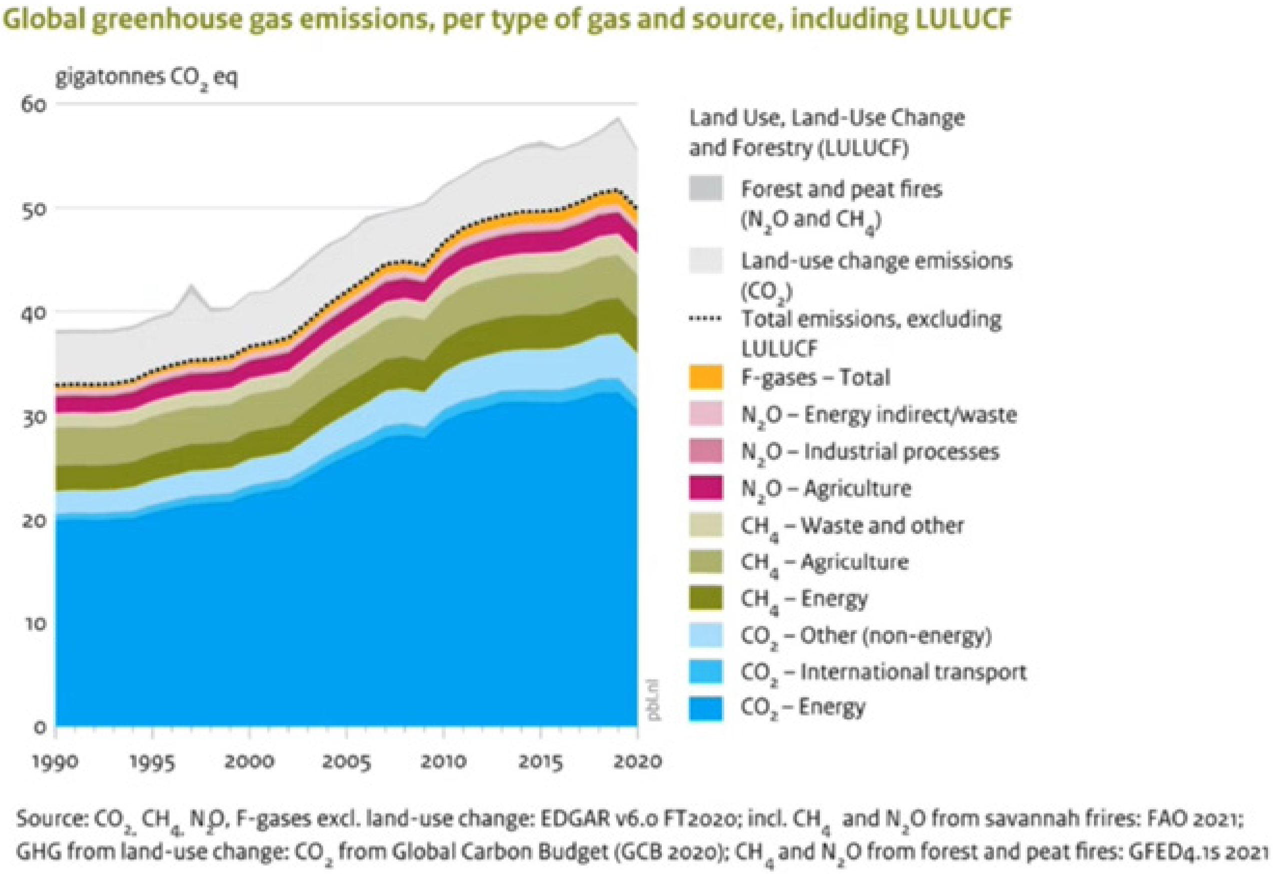
Chris Jones, Edwards Vacuum

There is broad consensus within the scientific community that human-generated greenhouse gas (GHG) emissions are causing global warming. If we can emit them, might we capture and remove them?

The answer is yes, though perhaps not as easily. But capture them we can, and we are. The real questions are, can we do it fast enough and big enough to make a difference, and can we afford it, in terms of dollars and energy? These questions fall within the purview of geoengineering, the third leg (in addition to mitigation and adaptation) of the framework within which most experts discuss as a response to climate change.

Carbon capture, utilisation, and storage (or sequestration) (CCUS) refers to various technologies that capture carbon dioxide at a source or from the atmosphere (direct air capture) and then either use it or store it so that it does not contribute to warming the planet. We are currently emitting about 55 gigatons of GHG (CO_2 equivalent – CO_2e) per year. CO_2 is the major component, but there are also major contributions from other gases (Figure 1).

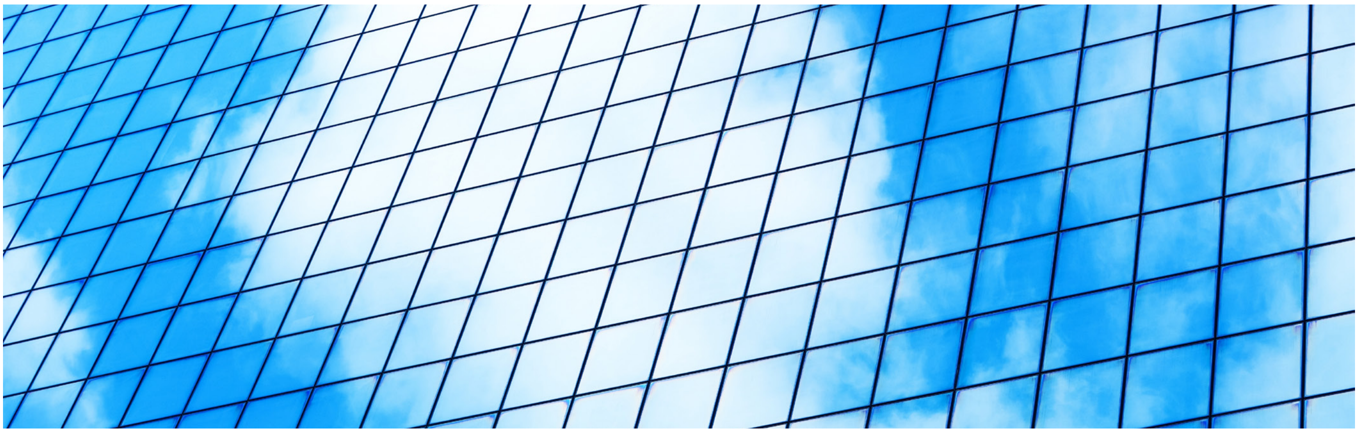
Methane (CH4) and nitrous oxide (N2O) emissions are smaller in volume but have much greater global warming potentials, ton for ton, over a 100-year period (GWP-100), 27.9X and 273X the GWP-100 of CO_2 (respectively).Fluorinated gases also contribute significantly to warming with GWP-100 as much as 25,000X CO_2. At the current rate of emission, we will exceed the budget required to restrict warming to less than 1.5°C before 2030.



Global greenhouse gas emissions, per type of gas and source, including LULUCF

Source: CO_2, CH_4, N_2O, F-gases excl. land-use change: EDGAR v6.0 FT2020; incl. CH_4 and N_2O from savannah frires: FAO 2021; GHG from land-use change: CO_2 from Global Carbon Budget (GCB 2020); CH_4 and N_2O from forest and peat fires: GFED4.1s 2021

Figure 1. Global GHG emissions by type of gas and source. CO_2 from energy production is by far the largest contributor. (https://www.pbl.nl/en/publications/trends-in-global-co2-and-total-greenhouse-gas-emissions-2021-summary-report)



In the 2015 Paris Agreement most countries in the world agreed to reduce GHG emissions enough to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. In 2018 the Intergovernmental Panel on Climate Change (IPCC) warned that we would see substantial impacts if the temperature increased by more than 1.5°C. The Science Based Targets initiative (SBTi) establishes reduction protocols and standards for companies to use to measure GHG emissions against targets that will limit warming to 1.5°C (Figure 2).

To do so we must approximately halve emissions each decade, i.e., 50% by 2030, then another 50% by 2040, before achieving net-zero emissions by 2050. Emissions from some sectors, such as air transport, may be difficult or impossible to eliminate. CCUS provides a means to remove residual CO_2 emissions that cannot be completely eliminated, especially as we come closer to the end of the journey where progress from reductions becomes harder to realize.

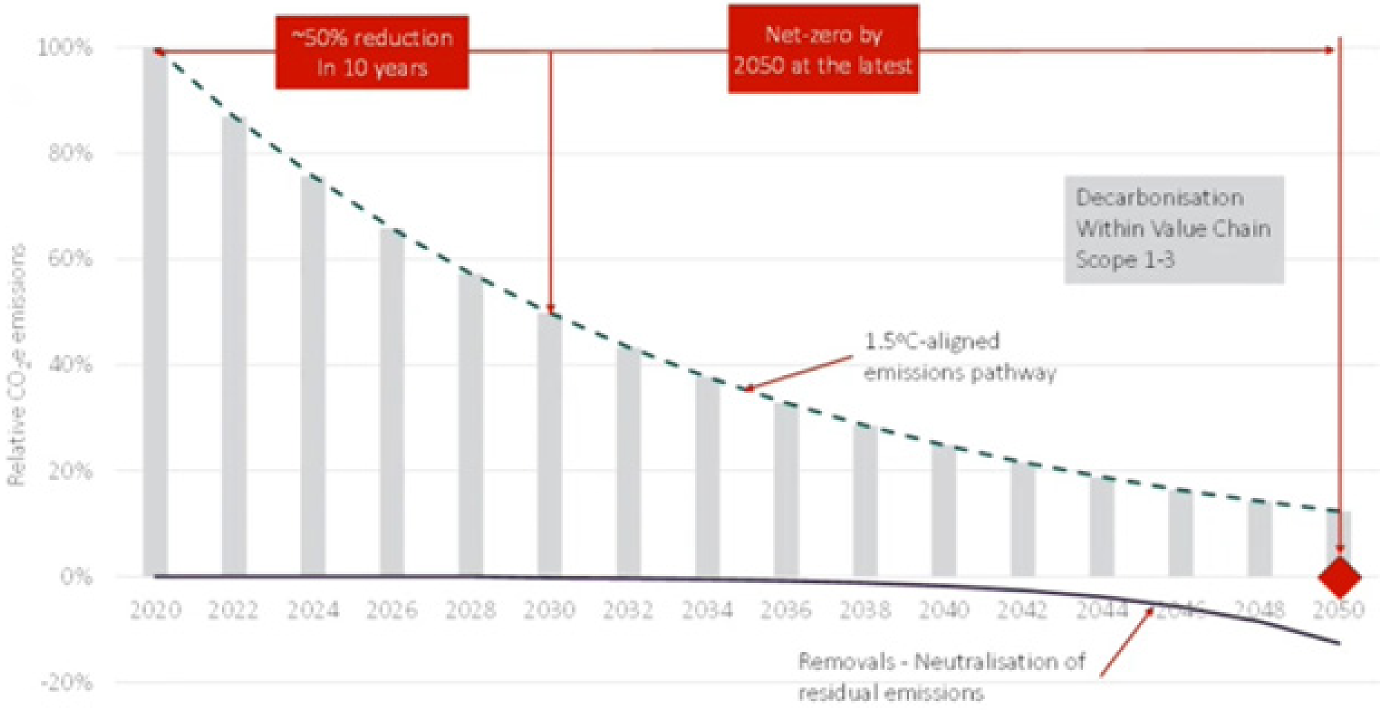
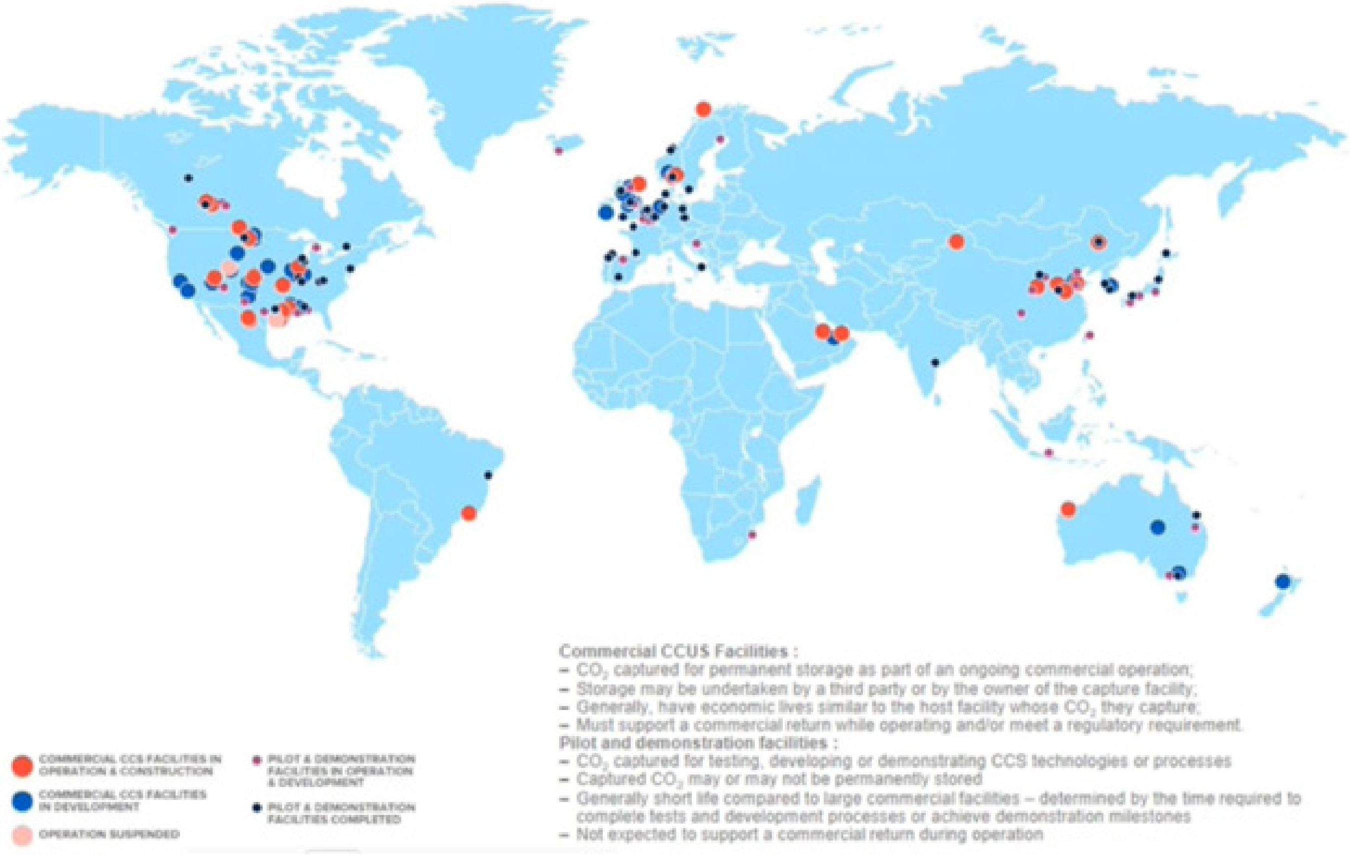


Figure 2. Reductions in GHG emissions needed to limit warming to 1.5°C

There has been accelerating growth in CCUS efforts around the world over the last few years. Early results from some innovative technologies are encouraging, and it may be that CCUS will play a larger role in the fight against warming than originally suggested. Figure 3 summarises CCUS projects in development or operation worldwide as of September 2021.

Both the number of projects and their geographical distribution are increasing. Net maximum capacity (not actual operating capacity) was 175 MMT per year. That is a respectable number, but it is less than 0.4% of global emissions.



Commercial CCUS Facilities :

- CO_2 captured for permanent storage as part of an ongoing commercial operation;
- Storage may be undertaken by a third party or by the owner of the capture facility;
- Generally, have economic lives similar to the host facility whose CO_2 they capture;
- Must support a commercial return while operating and/or meet a regulatory requirement.

Pilot and demonstration facilities :

- CO_2 captured for testing, developing or demonstrating CCS technologies or processes
- Captured CO_2 may or may not be permanently stored
- Generally short life compared to large commercial facilities – determined by the time required to complete tests and development processes or achieve demonstration milestones
- Not expected to support a commercial return during operation

Figure 3. Relative size, status, and location of commercial CCUS facilities (https://www.globalccsinstitute.com/news-media/events/the-carbon-capture-and-storage-101-webinars-introducing-a-ccs-project/)

Capture

Carbon capture can contribute in several ways to our efforts to achieve net-zero emissions. Most immediately, it can reduce emissions from fossil-fuel based electrical power generation that accounts for more than 60% of emissions in the U.S. We are making progress in developing green energy sources, including solar, wind, nuclear and geothermal, but capturing carbon from fossil fuel combustion would allow a slower phase out of fossil fuels while still meeting emission targets. In so doing it would ease the transitional impact on employment in the energy industry and avoid the cost of retiring fossil fuel facilities and infrastructure prematurely.

In other industries, carbon emissions come from the process itself. Examples include the production of cement and the manufacture of iron and steel. In the first step of the cement process, limestone (primarily calcium carbonate) is heated to form calcium oxide (lime) and CO_2. Although new cement formulations can reduce process emissions, capturing the carbon from this step is the only practical way to reach net-zero in this sector. Likewise, the initial step in the manufacture of steel involves the reduction of iron in iron ore (primarily iron oxide) by exposing it to heat and carbon monoxide, producing metallic iron and CO_2. There are other ways to reduce iron, such as using hydrogen instead of carbon monoxide as the reducing agent, but they are not yet widely used. Both cement and iron/steel making require high temperatures that are usually supplied by fossil fuel combustion.

The third option is capturing and storing carbon directly from the atmosphere. The primary challenge for direct air capture is the very low concentration of CO_2 in the atmosphere, which makes the capture process energy intensive. Unless the energy it uses is renewable, direct air capture can add more CO_2 than it removes. Still, it is the only option, of the three discussed here, that can actually take CO_2 out of the atmosphere.

Bioenergy with carbon capture and storage (BECCS) refers to energy pathways that capture and store biogenic carbon. For example, in the production of ethanol from corn, the growing corn captures CO_2 directly from the atmosphere and converts it to carbohydrates. A fermentation process converts the carbohydrates to ethanol and CO_2. The ethanol may be added to fuels and returned to the atmosphere when it is burned, or it may serve as feedstock for other industrial processes. The CO_2 generated by fermentation is highly concentrated and, therefore, easily captured and stored in geological formations. Other, more complicated BECCS processes show great promise for use in energy generation and carbon intensive industrial processes like cement and steel production. In all cases the energy produced is carbon neutral, coming from and returning to the atmosphere, and carbon stored or incorporated in long-lived products is removed from the atmosphere, i.e., carbon negative.

Utilisation

Of course, the value of carbon capture in reducing global warming depends on what is done with the carbon after it is captured. One option is to use it in place of carbon from fossil sources. Some uses keep the carbon out of the atmosphere for only a short time, such as synthetic jet fuel (Figure 4).

Still. If the carbon was extracted from the atmosphere to begin with, using renewable energy, then the net carbon contribution when it is burned can still be zero. It becomes a way to make green energy available to industries like aviation where finding a substitute for hydrocarbon fuels is challenging.

Other uses, such as building materials, retain carbon for a very long time. Synthetic aggregates made by mineral carbonation can provide essentially permanent storage of CO_2. The carbon dioxide may come from flue gas or other pure streams. Synthetic aggregates can also be used to dispose of industrial wastes such as fly ash, steel slag, and cement kiln dust Concrete is 60% to 80% mineral aggregate. In traditional concrete, the aggregates are mixed with water and cement.

The water converts the cement to interlocking crystals that bind the concrete together. CO_2-cured concrete uses non-traditional cements that cure when mixed with CO_2. This is a mature technology that can be cost competitive with traditional concrete, though it is currently used primarily for precast concrete blocks.

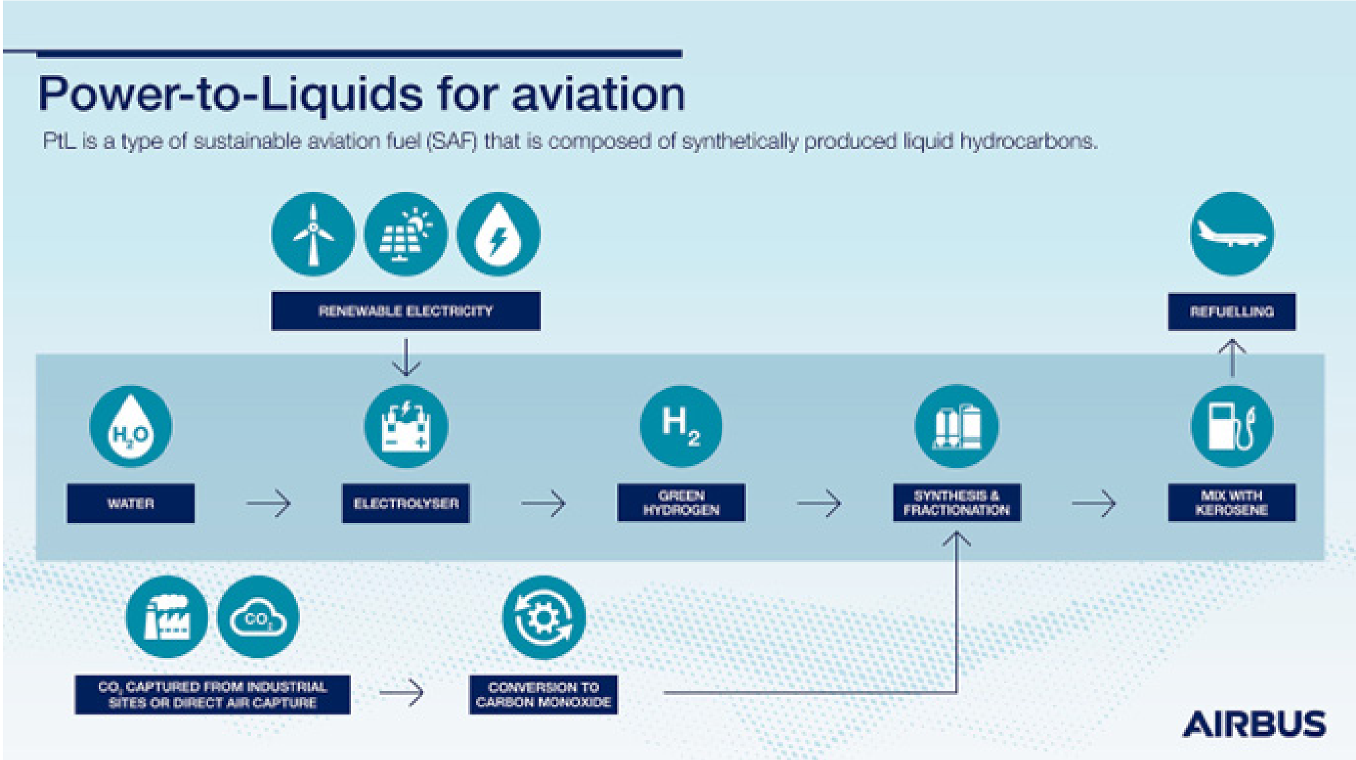


Figure 4. Energy pathway for producing sustainable aviation fuel (Source https://mediaassets.airbus.com/permalinks/551074/win/power-to-liquids-for-aviation-infographic-communication-media-ev.jpg)

Storage

Storage in geological formations, such as oil and gas reservoirs, unmineable coal seams, and deep saline reservoirs, is generally considered to be safe and secure when the storage facility is properly sited and operated. In nature, CO_2 remains trapped in these formations for millions of years. We have extensive experience storing CO_2 underground, with industrial scale projects dating back to the 1970's.

Oil and gas producers use CO_2 injection in advanced recovery techniques to force the last bit of oil from a deposit. This should not be taken as license to continue emitting GHG with the thought that it can simply be put back into the ground where it came from. Though known potential geological storage capacity is large, it is not unlimited. The ultimate solution remains the reduction of emissions.

Semiconductor Industry

What role does CCUS play in semiconductor manufacturing? Though we are not major direct emitters (scope 1 emissions), we do consume a lot of electrical power (scope 2 emissions). Our scope 1 emissions are roughly half our scope 2 emissions and consist mostly of non-CO_2 greenhouse gases such as PFCs, HFC, NF3, SF6, and N2O. Short-term, we will realise the greatest benefits, both environmental and financial, by reducing power consumption through improvements in energy efficiency. Longer term we must continue to advocate for conversion to renewable energy sources and the decarbonisation of the power grid. We must also remain vigilant in our efforts to capture and abate harmful GHG in the process exhaust stream, especially fluorinated gases, which are widely used for etching and chamber cleaning. Though the amounts may be small relative to global CO_2 emissions, F-gases are thousands of times more potent in their global warming potential, and often far longer-lived.