Direct Air Capture as an Enabler of Ultra-Low Carbon Fuels

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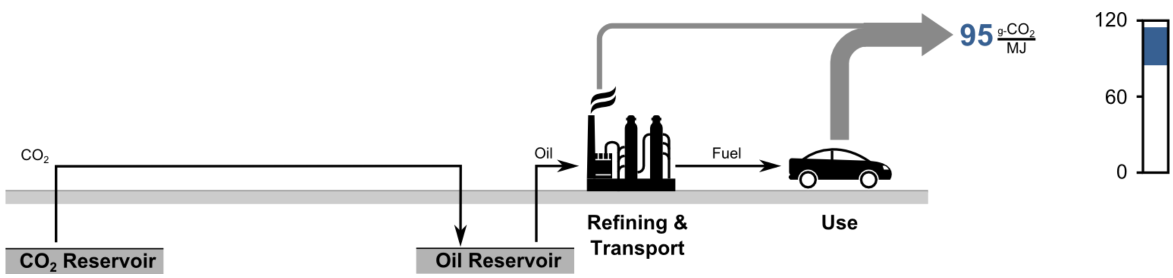
This document summarizes the differences between direct capture of CO_2 from the atmosphere (DAC) and CO_2 capture and storage (CCS) as competitive pathways to producing low-carbon transportation fuels.

DAC does not compete with CCS in reducing emissions from large fixed sources such as electric power or by being cheaper on a $/ton basis. Rather, DAC competes by providing an atmospheric – rather than geological – CO_2 source, which when used to produce fuels, can result in a lower life-cycle carbon intensity (CI) than fuels produced from CCS CO_2. Low CI fuels command a premium value in carbon-constrained transportation markets, such as California's Low Carbon Fuel Standard. The business model for commercializing DAC is *different* than that for CCS, and there are sizable markets where it can succeed.

The *origin* of CO_2 that is used to produce fuels – whether embodied in petroleum, mined for enhanced oil recovery (EOR), or captured from the air - is crucial to determining the *net flow* of CO_2 from the sub-surface to the atmosphere, and thus in determining the life-cycle carbon intensity of the fuel. If, for example, one were to supply an algal pond with CO_2 from a geologic reservoir—often the lowest cost CO_2--the resultant algal biofuel would have a CI very similar to that of conventional oil because the net transfer of carbon from geologic reservoirs to the atmosphere would be the same. The following scenarios illustrate the role of CO_2 source in determining the carbon intensity of fuels produced from EOR.

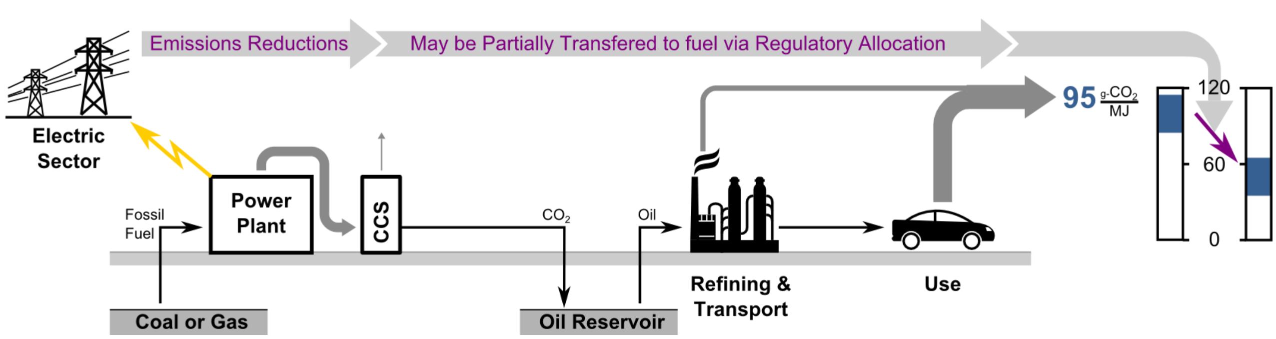
Scenario A: Conventional EOR Fuel Production

A geologic CO_2 reservoir supplies CO_2 for EOR to produce petroleum, and ultimately fuel. The carbon intensity (CI) can vary depending upon the specifics of the EOR field and the petroleum in the reservoir, but a typical value is **95 g-CO_2/MJ** as represented by the bar to the right of the image below.



Scenario B: Power Plant CCS to EOR

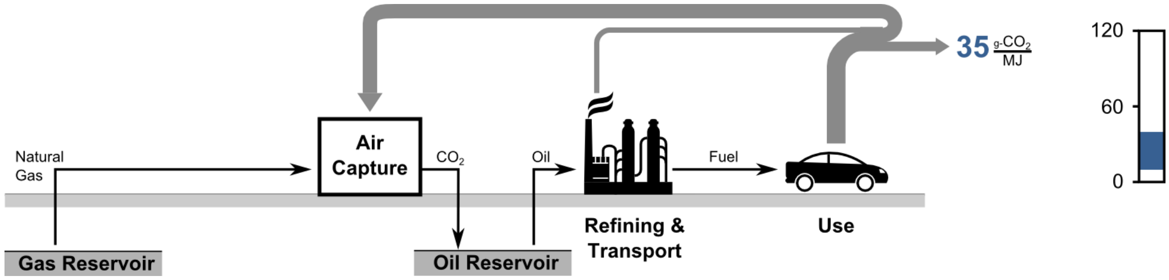
In this scenario the source of CO_2 is still geological. Coal or gas—which embody geologic carbon—are extracted and used in a power plant with CCS and the resulting CO_2 is used to produce fuel using EOR. A simple interpretation is that the fuel has *the same* **95 g-CO_2/MJ** CI as in the first scenario, although the system has produced low-carbon electricity. Under some regulatory regimes any emissions reductions in the electricity sector be partially allocated to the fuel, but one cannot claim both low carbon fuel and low carbon electricity.



Assuming the low-carbon electricity displaces U.S. grid average carbon intensity, and *all* electric-sector emissions reductions are allocated to the fuel, the resulting fuel CI may be of order 40 g-CO_2/MJ (right hand bar of the figure). Note that as natural gas and renewables gain in the generation portfolio the grid average intensity decreases and so do the reductions obtained by replacing grid electricity with CCS electricity, so that in a fully de-carbonized grid CCS-EOR produces fuel with exactly the same CI as conventional oil.

Scenario C: Air Capture to EOR

DAC captures CO_2 from the air, which compensates for the CO_2 released in fuel use, and in effect *recycles* the emissions for *reuse* in fuel production. Fossil fuel is used to power DAC and both the combustion CO_2 and atmospheric CO_2 are captured and injected for EOR. The CO_2 delivered to the oil reservoir is permanently sequestered, resulting in a *low CI fuel*, roughly **35g-CO_2/MJ** or lower (depending on the oil to CO_2 "lift ratio").



Summary

DAC enables the direct extraction of CO_2 from the atmosphere, which cannot be accomplished by CCS. This enables revenue streams and associated business models that are distinct from those available to CCS. These revenue streams can be much larger per ton of CO_2 from the atmosphere than the revenue streams available per ton of CO_2 avoided in the electric sector.

DAC is harder and more expensive than capture from power plants. Likewise cutting carbon in the transportation sector is harder and more expensive than cutting carbon in the electricity sector. One should therefore think of DAC as competing with biofuels and electric vehicles, not with power-plant CCS and wind power. Finally, regulators have often chosen to impose higher effective carbon prices on the transportation sector than they have on electricity. DAC is more expensive than CCS but it competes in a different market with a different incentive structure CCS.

The per barrel cost of DAC-EOR fuel is about 20% higher than the cost of conventional oil and it has a carbon intensity that is lower than most biofuels. DAC thus provides a near-term scalable technology that can supply low-carbon transportation fuels at a lower cost (and a lower land use footprint) than most biofuels. This gives DAC near-term markets where it can compete despite having higher cost per ton than power-plant CCS.

Algal biofuels require CO_2 enriched air. This can be supplied from a power plant only if the two plants are collocated, a requirement that severely restricts the scope for algal biofuels which also require water, cheap land and high insolation. Moreover a power-plant/algal-biofuel system can claim low carbon electricity or low carbon fuels but not both.

Successful commercialization of DAC will add to our ability to make deep reductions in economy-wide emissions, and meet critical long-term climate change goals.