Carbon Capture and Storage:

Essential and Cost-Effective

Key Points

Stopping climate change will be hard. Deep cuts in global CO_2 emissions must occur soon, but rising energy demand will probably increase emissions.

- By 2050, the IPCC tells us that CO_2 emissions must fall to 60% to avert a 2-degree Celsius rise in the Earth's temperature. By the end of the century, CO_2 emissions must essentially fall to zero.
- But these cuts must take place while global energy demand rises. By 2040, global energy consumption is projected to increase 28%.

Carbon capture and storage (CCS) is vital and essential to meeting 2050 climate goals.

- CCS is the only technology with large-scale abatement potential for many industrial sources. Industrial sources account for about 25% of global CO_2 emissions.
- CCS works on both industrial and electric plants. Together, these sectors account for 54% of the total U.S. CO_2 emissions.
- Projections by the International Energy Agency show CCS will need to account for 6,000 million tonnes of CO_2 reduction worldwide by 2050. That's more CO_2 than emitted today in the entire U.S.
- CCS is among the least expensive options to cut carbon dioxide, especially when used with enhanced oil recovery (EOR).

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The Climate Challenge

Stopping climate change will be hard. Deep cuts in global CO_2 emissions must occur soon, but rising global energy demand at the same time may increase emissions.

The Intergovernmental Panel on Climate Change (IPCC) concludes that greenhouse gas emission must be reduced by 40 to 70% by 2050, and must be zero or below in 2100.[i] Cuts from the electric sector must be even deeper. The IPCC concludes that electric sector emissions must reach zero CO_2 emissions by 2050 and negative emissions by 2100.[ii]

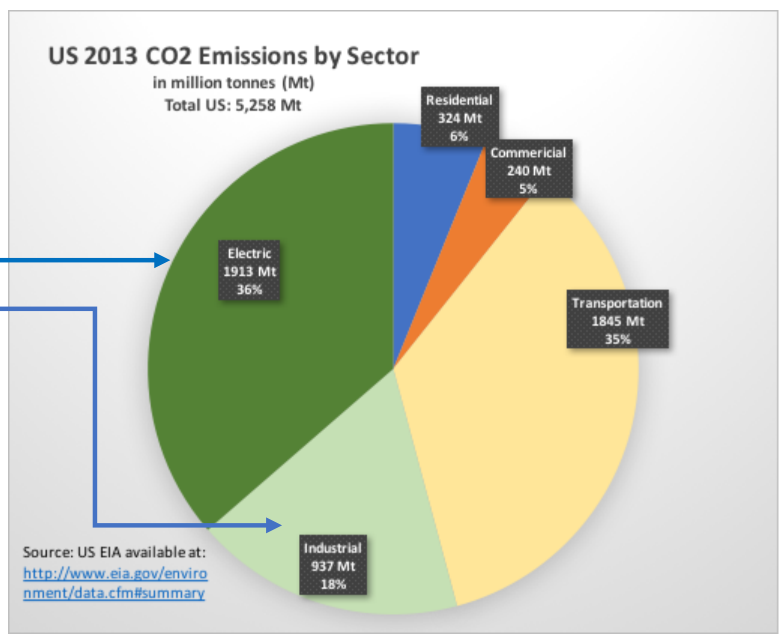
The International Energy Agency (IEA) also reaches a similar conclusion- we need a 50% reduction in CO_2 emissions from the total energy sector by 2050 while "the power sector becomes virtually decarbonized."[iii]

To complicate matters, these reductions must be achieved while total energy consumption rises. According to IEA, total global energy use is expected to grow 28% by 2040, including a 40% increase in the electric sector.[iv]

Emissions Sources and CCS

IEA calls carbon capture and storage (CCS) "vital" and "essential," accounting for about 14% of the CO_2 cuts (6,000 million tonnes) in 2050 needed to avoid temperature increases of 2 degrees Celsius.[v] CCS is important because it reduces CO_2 emissions from two of the largest sectors: industrial and electric. In the United States, these two sectors account for 54% of the emissions, as shown below.

Carbon capture works on both the electric and industrial sectors which together account for 54% of US CO_2 emissions.



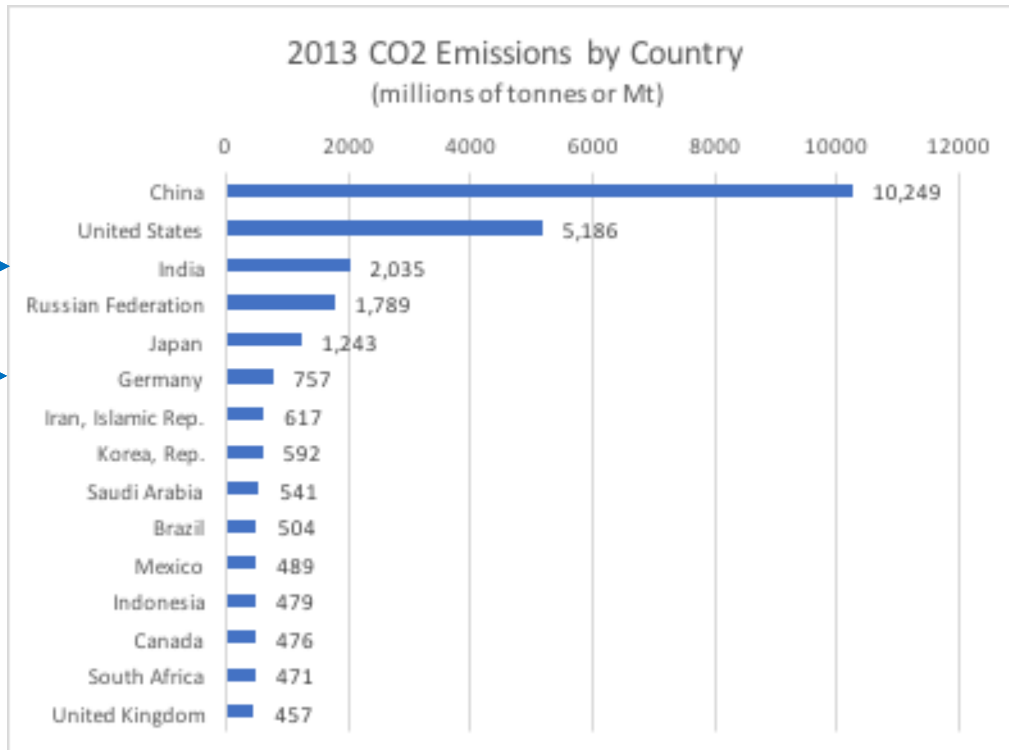
While many options are available to cut carbon dioxide in the electric sector, CCS is the only technology with large-scale abatement potential for many industrial sources. That's because the emissions from many critical industries arise not simply from burning a fossil fuel to produce steam or electricity to run the industrial plant, but because CO_2 is an inescapable by-product of the chemical reactions that manufacture glass, iron, steel, aluminum, fertilizers, cement, and paper.

CCS is the primary technology available for cement (8% of global CO_2 emissions[vi]), fertilizer production (3-5% of global CO_2 emissions[vii]) and steel (5% of global CO_2 emissions[viii]). Its importance is one reason why IEA concludes, "CCS represents the most important new technology option for reducing direct emissions in industry…"[ix]

The table below ranks CO_2 emissions by country, and shows the importance of industrial emissions. If China's industrial emissions (about 3,300 Mt) were their own country, they would rank 3rd overall. If the industrial emissions (937 Mt) in the U.S. could be separated into their own country, they would rank 6th.

If China's industrial emissions were a country, they would rank 3rd in the world.

U.S. industrial emissions would rank 6th.



Source: World Bank available at
http://data.worldbank.org/indicator/EN.ATM.CO2E.KT?year_high_desc=true

CCS Costs

The avoided cost of carbon dioxide is a standard measure used to compare the effectiveness of different carbon reduction options. It is defined as "the cost of reducing CO_2 emissions to the atmosphere while producing the same amount of product from a reference plant."[x]

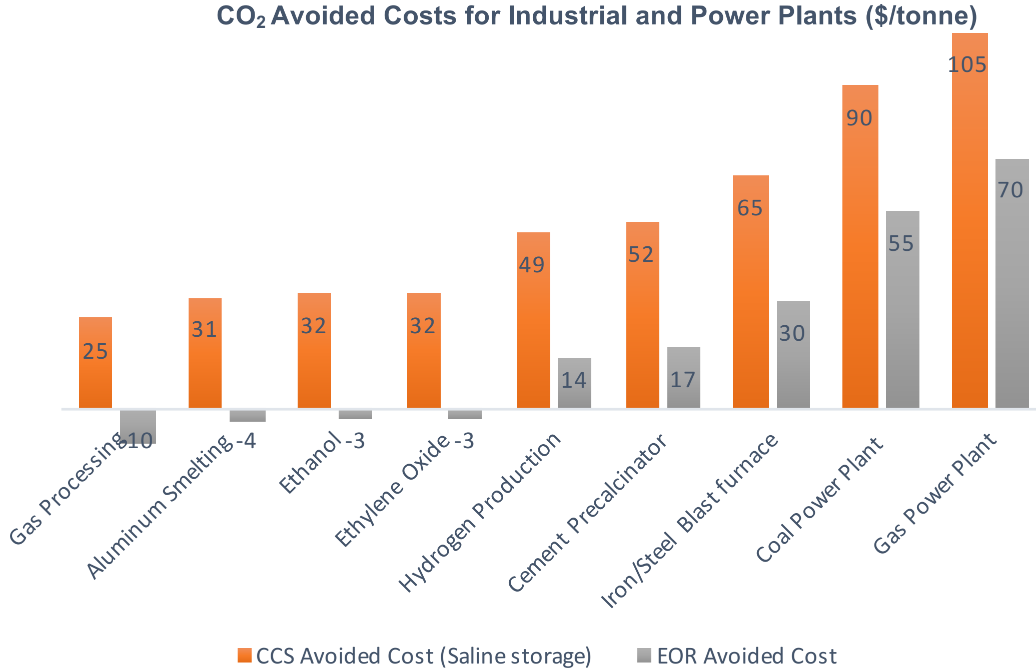
For CCS, the avoided cost of carbon dioxide is represented by more than one number. That's because CCS can be applied to different industries and fuels, and because the captured CO_2 can be stored in either saline formations or used to recover oil in aging petroleum fields.

Generally, it's cheaper to capture CO_2 when its concentration in the emissions is high. Therefore, in industries where the CO_2 emissions are relatively "pure" (e.g., ethanol, natural gas processing, ethylene oxide), the avoided cost of CO_2 is lower than in electric power plants where the CO_2 concentration in the flue gas is relatively low. Even within the category of electric power plants, natural gas plants have a lower CO_2 concentration in the flue gas than coal plants, and so the avoided cost of CO_2 is higher in gas plants than coal plants.

The choice of storage also impacts the avoided cost of carbon dioxide. When CO_2 is sold by a source for enhanced oil recovery, the revenue offsets some (but usually not all) of the costs of capture and transport. This lowers the avoided cost of carbon dioxide relative to saline storage.

The figure below shows the avoided cost of carbon dioxide for selected industrial and electric power plant applications. From left to right, the bars representing the avoided cost of CO_2 grow larger as the concentrations in the emissions become more dilute. The figure below also shows two cost bars. The smaller bars reflect CO_2 sales for EOR (assuming $60 per barrel oil) while the larger bars reflect the avoided cost of CO_2 if the source must pay to store the CO_2 in saline formations. As the figure shows, EOR can reduce CCS costs significantly.

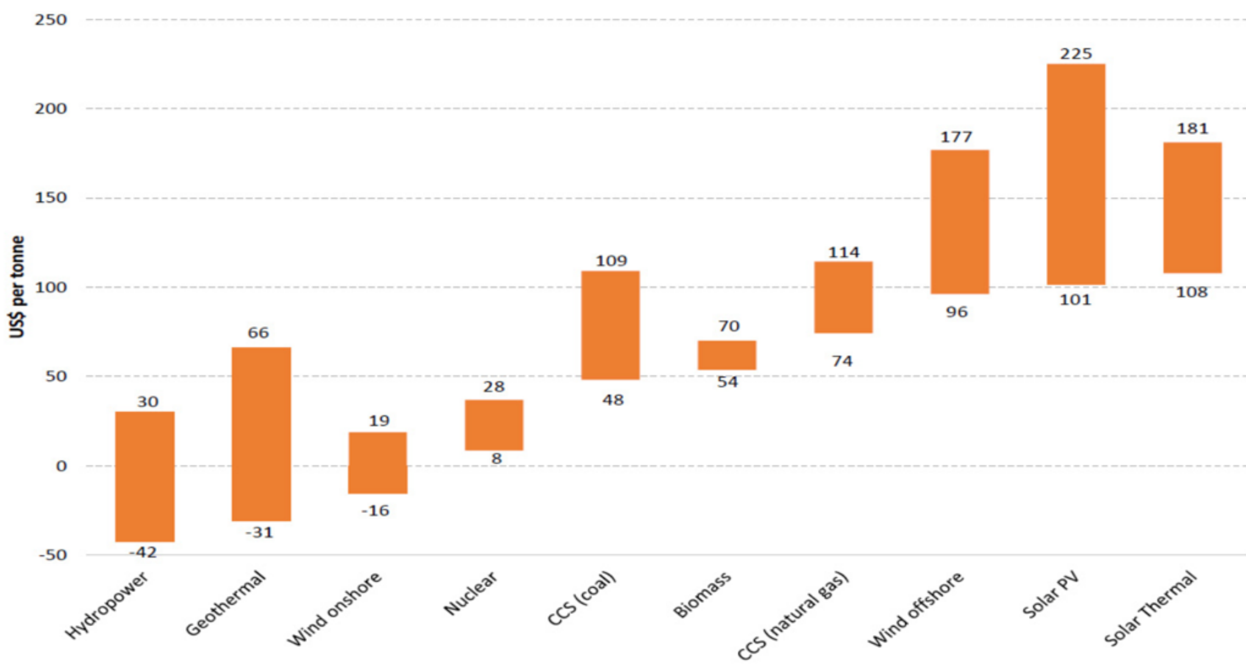
CO_2 Avoided Costs for Industrial and Power Plants ($/tonne)



Sources: CATF adaptations *Technology Roadmap- Carbon Capture and Storage*, 2013 Edition (Paris: OCED/IEA, 2013), page 51 and *The Costs of CCS and Other Low-Carbon Technologies in the United States -2015 update,* Global CCS Institute. CATF assumed $15 per tonne cost for saline injection and transport and -$20/tonne for EOR storage and transport.

The figure below compares the avoided cost of carbon dioxide for various technologies within the electric sector, including CCS with saline storage. As the figure shows, CCS compares quite favorably to other CO_2 abatement options.

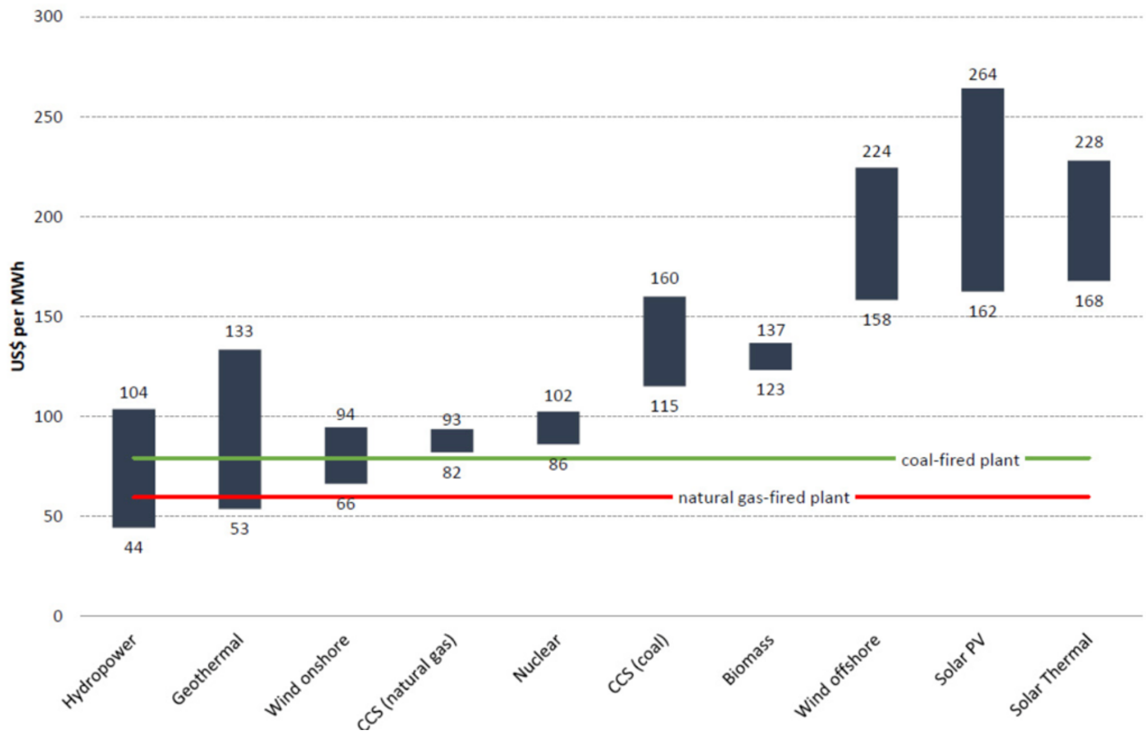
Avoided cost of CO2 for plant in the U.S. ($/tonne)



Source: Global CCS Institute, *The Costs of CCS and Other Low-Carbon Technologies in The United States 2015 Updated July 2015* Page 10.

Cost of electricity is also a frequently used measure of carbon abatement within the electric sector. The figure below shows the levelized cost of electricity (LCOE) for various technologies, including plants equipped for CCS with saline storage.

Levelized Cost of Electricity for Plants in the U.S. ($/tonne)



Source: Global CCS Institute, *The Costs of CCS and Other Low-Carbon Technologies in The United States 2015 Updated July 2015* Page 9.

As the figure above shows, CCS-equipped plants compare favorably with other low-carbon electricity options. One issue with LCOE as a measure of cost is that it does not effectively account for differences between intermittent resources like wind and solar and dispatchable generation such as coal, gas or nuclear. LCOE measures of wind and solar ignore costs incurred when these sources are unavailable. These costs include additional balancing, additional transmission and shadow generating capacity.

Accounting for the availability limitations of solar and wind can change the ranking of CCS relative to wind and solar. Van den Broek, et. al, compared costs of NGCC-CCS with intermittent offshore wind, solar and photovoltaic resources on the same baseload playing field, correcting for additional balancing, transmission and back-up needed by intermittent sources.[xi] They examined potential future cost reductions and a variety of back-up technology options. They then developed four stylized low-carbon systems and examined them in 2020, 2030 and 2040. The authors concluded that the system with the lowest LCOE and the lowest avoided cost of carbon was NGCC-CCUS.

Conclusions

Carbon capture and storage is essential for addressing climate change. Projections by the International Energy Agency show CCS will need to account for 6,000 million tonnes of CO_2 reduction worldwide by 2050. That's more CO_2 than emitted today in the entire U.S.

CCS is the only practical large-scale option to address industrial emissions, which account for almost 25% of global CO_2 emissions. CCS also works on other large stationary sources such as electric power plants. Over half of the CO_2 emissions in the United States come from the electric power and industrial sectors.

CCS is a cost-effective way to abate CO_2 emissions. While costs vary by industry and application, the avoided cost of capture is comparable to other low carbon options, especially when emissions are stored using EOR.

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[i] IPCC, 2014 Synthesis Report Summary for Policymakers, page 20 (2015) *available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf*

[ii] IPCC, page 28.

[iii] International Energy Agency, Energy Technology Perspectives 2010, page 107, (2010), *available at*: https://www.iea.org/publications/freepublications/publication/etp2010.pdf

[iv] International Energy Agency. World Energy Outlook, 2016

[v] International Energy Agency, Energy Technology Perspectives 2015, pages 207, (2015), *available at*: https://www.iea.org/etp/etp2015/

[vi] PBL Netherlands Environmental Assessment Agency and European Commission Joint Research Center, Trends in Global CO2 Emissions 2015 Report, page 38 (2015) available at: http://edgar.jrc.ec.europa.eu/news_docs/jrc-2015-trends-in-global-co2-emissions-2015-report-98184.pdf Note that 4.1% of CO_2 emissions comes from clinker production and the remainder from fuel consumption.

[vii] Celeste LeCompte, Science, *Fertilizer Plants Spring Up to Take Advantage of U.S.'s Cheap Natural Gas*, (April 25, 2013) *available at:* https://www.scientificamerican.com/article/fertilizer-plants-grow-thanks-to-cheap-natural-gas/

[viii] David L. Chandler, MIT News, *One order of steel; hold the greenhouse gases,* (May 8, 2013) *available at:* http://news.mit.edu/2013/steel-without-greenhouse-gas-emissions-0508

[ix] International Energy Agency, Energy Technology Perspectives 2010, page 161, (2010), *available at*: https://www.iea.org/publications/freepublications/publication/etp2010.pdf

[x] Global CCS Institute, "4.5 Cost of CO2 avoided", *available at:* https://hub.globalccsinstitute.com/publications/strategic-analysis-global-status-carbon-capture-storage-report-5/45-cost-co2-avoided

[xi] Machteld van den Broek *, et al., The Potential of Renewables Versus Natural Gas with CO_2 Capture and Storage for Power Generation under CO_2 Constraints*, 49 Renewable and Sustainable Energy Reviews 1296- 1322, (2015), *available at:* http://www.sciencedirect.com/science/article/pii/S1364032115003597