

# *The Economics of CCS*

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# Presentation plan

What is CCS?

Methods for capturing CO<sub>2</sub>

Why CCS is important?

Economic drivers of CCS - a basic approach

# What is CCS?

- ▶ CCS is a technology that comprises the separation of CO<sub>2</sub> from industrial- and energy-related activities and the transportation to storage locations such as saline aquifers and depleted oil and gas reservoirs
- ▶ Its main goal in this regard is to prevent CO<sub>2</sub> emissions from entering the atmosphere.

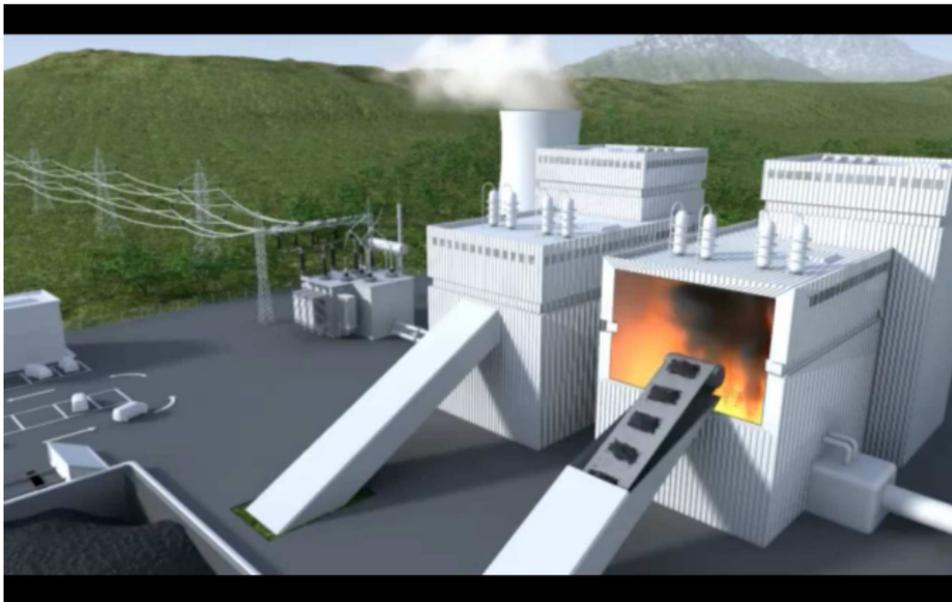
- ▶ CCS can be used by large stationary point sources such as fossil fuel-fired power plants and emission-intensive industrial facilities.
- ▶ The rates of carbon captured can be as high as 85–95%.
- ▶ There are three methods for capturing CO<sub>2</sub>.
  1. *Post-combustion* carbon capture
  2. *Pre-combustion* carbon capture
  3. *Oxy-fuel combustion process*

# Methods for capturing CO<sub>2</sub>

- ▶ *Post-combustion* carbon capture removes carbon from coal fired power generation or natural gas combined cycles after combustion. Here, CO<sub>2</sub> is separated from the flue gases using a liquid solvent.

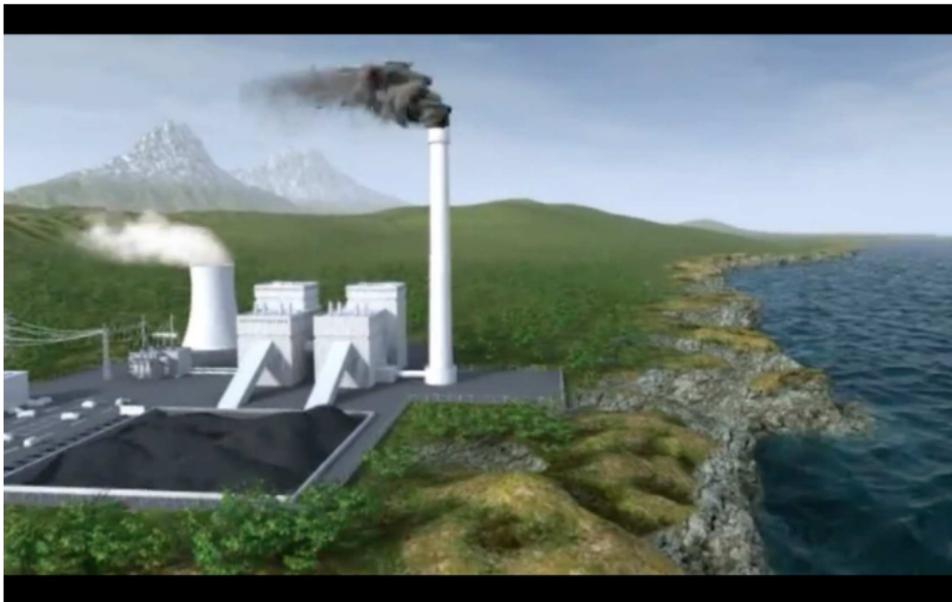
# *Post-combustion* carbon capture

Burning of coal



# *Post-combustion* carbon capture

CO<sub>2</sub> emissions upon combustion



# *Post-combustion* carbon capture

Emissions can be eliminated by implementing CCS



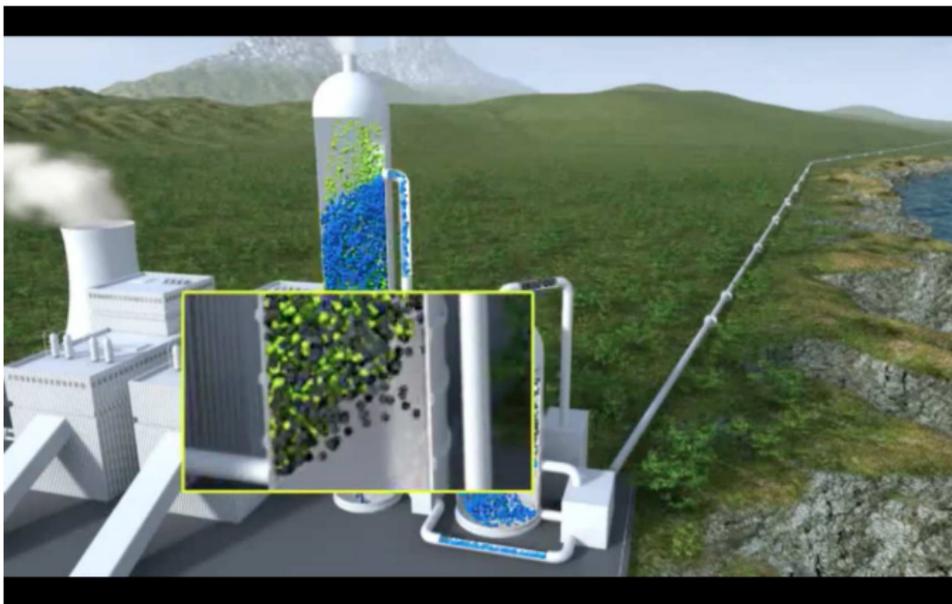
## *Post-combustion* carbon capture

The cleaning system: the flue gas enters the first tank of the CO<sub>2</sub> capture plant.



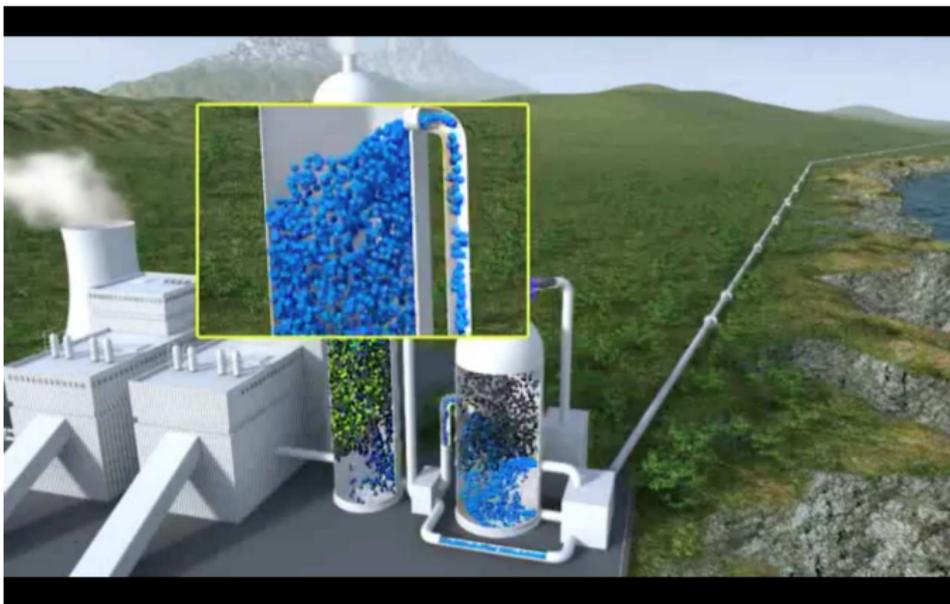
# *Post-combustion* carbon capture

It mainly consists of CO<sub>2</sub> (black particles), nitrogen and water vapor (green particles).



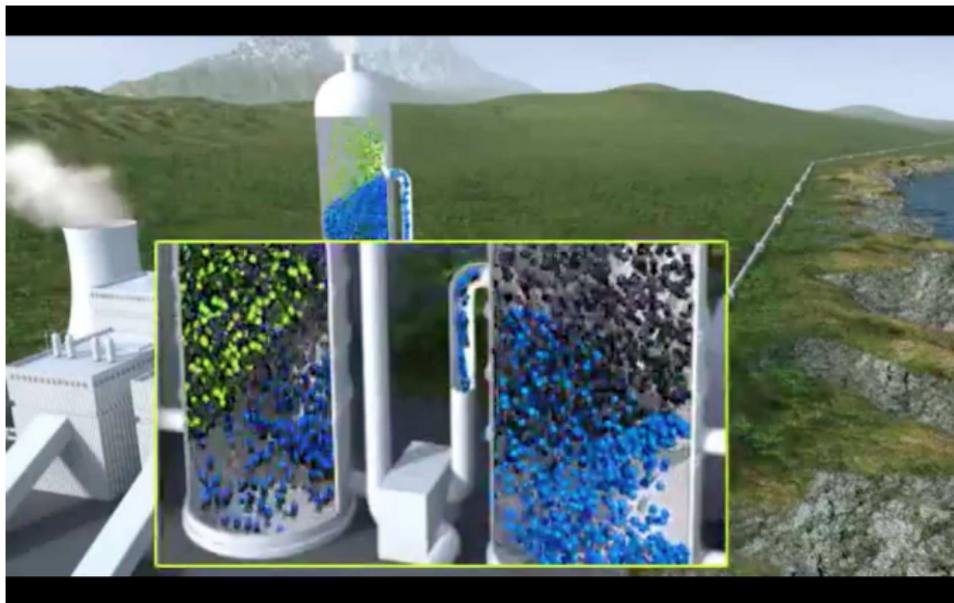
## *Post-combustion* carbon capture

Blue particles entering the top of the capture plant are a chemical –also called solvent– that can react with  $\text{CO}_2$



## *Post-combustion* carbon capture

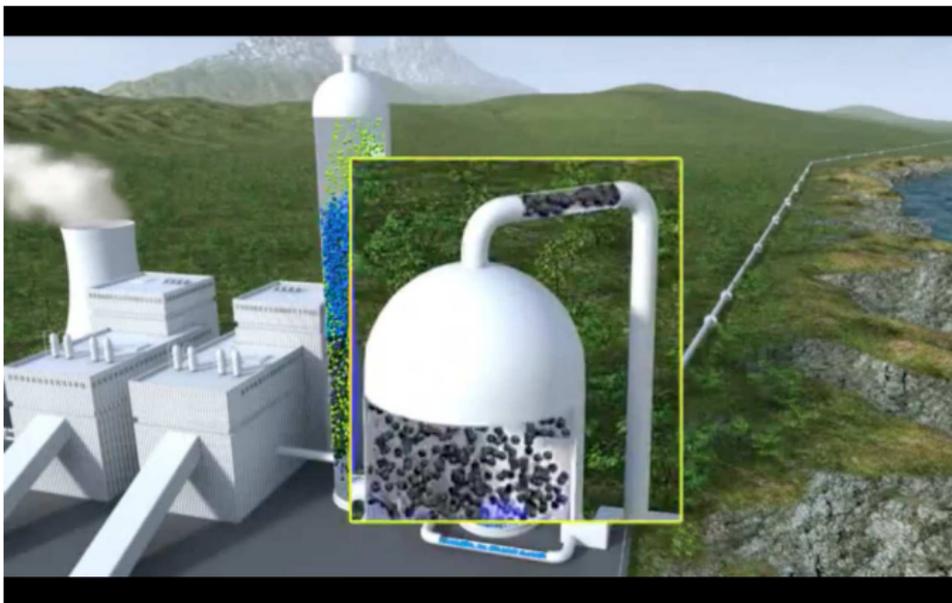
Once the solvent is reacted with  $\text{CO}_2$ , it leaves the first tank and is pumped in to the second tank



# Post-combustion carbon capture

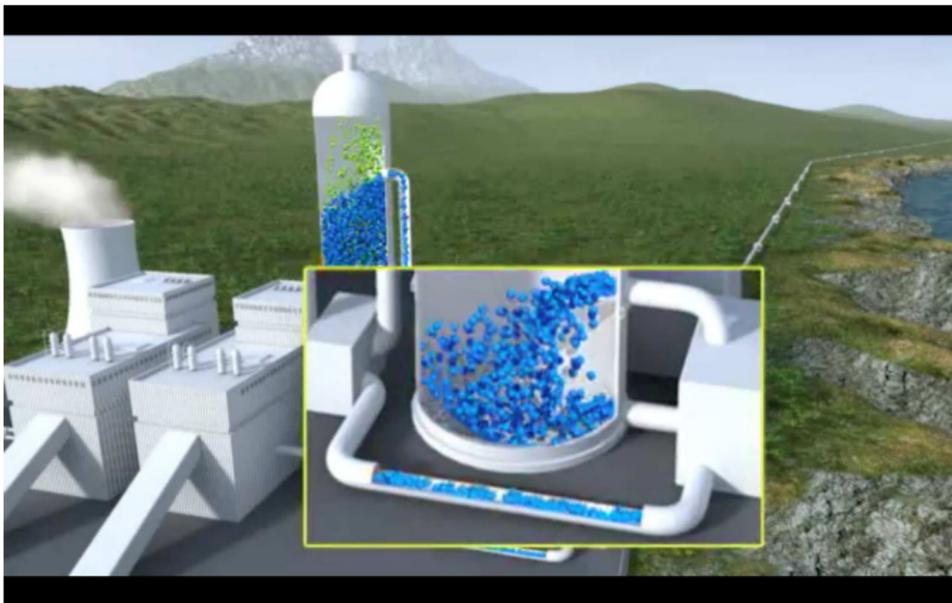
To separate CO<sub>2</sub> from the solvent, the solvent is heated  
(*requires a lot of energy*).

This process produces a gas stream of CO<sub>2</sub> and...



# Post-combustion carbon capture

...a liquid stream of pure solvent



# *Post-combustion* carbon capture

Pure CO<sub>2</sub> leaves the top of the tank...



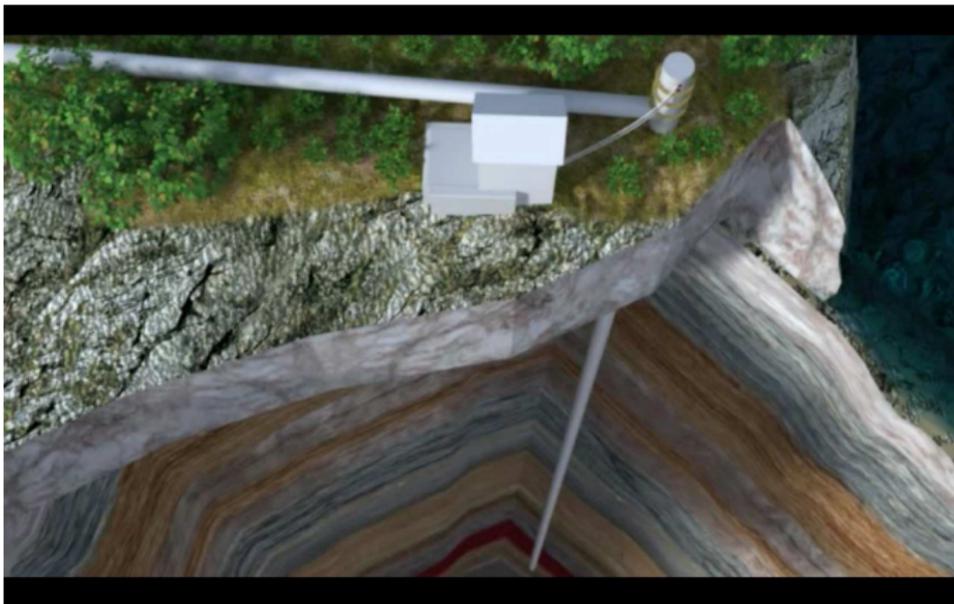
# *Post-combustion* carbon capture

...is compressed and transported, ...



## *Post-combustion* carbon capture

...and injected to convenient storage locations such as porous rock formations.



# Methods for capturing CO<sub>2</sub>

- ▶ In *pre-combustion* carbon capture, fuel is pretreated and converted into a mix of CO<sub>2</sub> and hydrogen. The hydrogen is then separated from the carbon before being burned to produce electricity.
- ▶ In the *oxy-fuel combustion process*, the fuel is burned using oxygen rather than air. The result is a flue stream of CO<sub>2</sub> and water vapour. Because no nitrogen is present, CO<sub>2</sub> can be easily removed

## Cost estimates for CO<sub>2</sub> avoided:

- ▶ Post-combustion CO<sub>2</sub> capture from coal-fired power generation using amines (58 USD<sub>2010</sub>/tCO<sub>2</sub> - 63% mark-up)
- ▶ Pre-combustion CO<sub>2</sub> capture from integrated gasification combined cycles (43 USD<sub>2010</sub>/tCO<sub>2</sub>)
- ▶ Oxy-combustion CO<sub>2</sub> capture from pulverized coal power generation (52 USD<sub>2010</sub>/tCO<sub>2</sub>)
- ▶ Post-combustion CO<sub>2</sub> capture from natural gas combined cycles (80 USD<sub>2010</sub>/tCO<sub>2</sub>)

Some more up-to-date figures:

**Tablo 1:** Farklı karbon yakalama teknolojilerinin maliyet tahminleri.

	SPK		DKC		EGKC		OKSI-SPK	
	A	B	A	B	A	B	A	B
<b><u>Kaçınılan</u> (avoided)</b>								
<b><u>CO2 maliyeti</u></b>	63	59	87	80	46	43	62	52
<b>(\$ / tCO2)</b>								

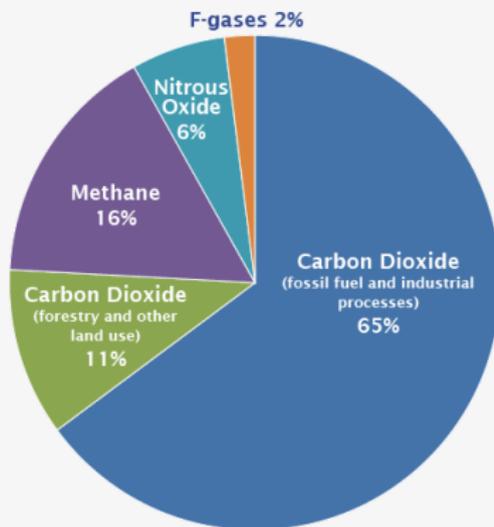
**Not:** Farklı karbon yakalama teknolojilerinin maliyet tahminleri. SPK: Süperkritik pulverize kömür; DKC: Doğalgaz kombine çevrim; EGKC: Entegre gazlaştırma kombine çevrim; OKSI-SPK: SPK santralinde oksi-yakıt yakma. A ve B sütunlarındaki rakamlar, sırasıyla, Rubin ve ark. (2015) ve Finkenrath (2011) makalelerinden alınmıştır. Rakamlara nakliye ve depolama maliyetleri ve olası EOR etkileri dahil değildir.

# Why CCS is important?

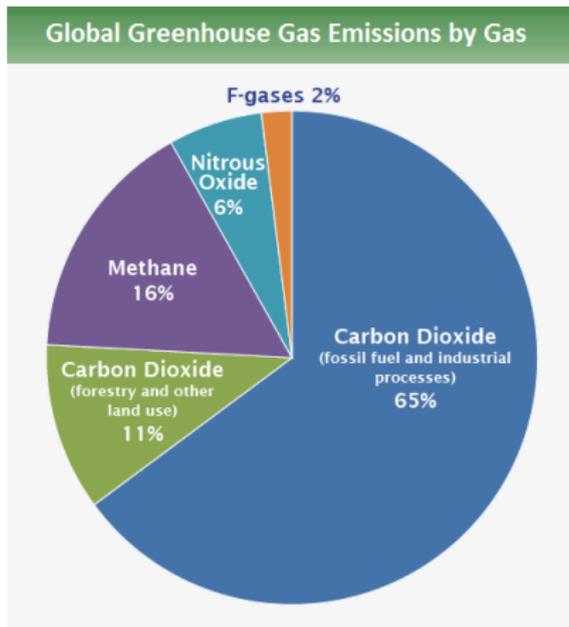
## Greenhouse effect (GE)

- ▶ Earth's surface would be below the freezing point of water if it was not for the GE
  - ▶ GE is a process by which the solar energy that reaches the Earth's surface is radiated back and partially absorbed by the atmosphere, making the atmosphere and hence the earth's surface warmer (IPCC, 2007; Freund, 2013).
- ▶ GE originate from greenhouse gases (GHGs).
  - ▶ CO<sub>2</sub> is the primary GHG emitted through human activities
  - ▶ It has hundreds of years of atmospheric lifetime.
  - ▶ Thus, adding more of CO<sub>2</sub> to the atmosphere intensifies the GE and warms the Earth's climate.

## Global Greenhouse Gas Emissions by Gas



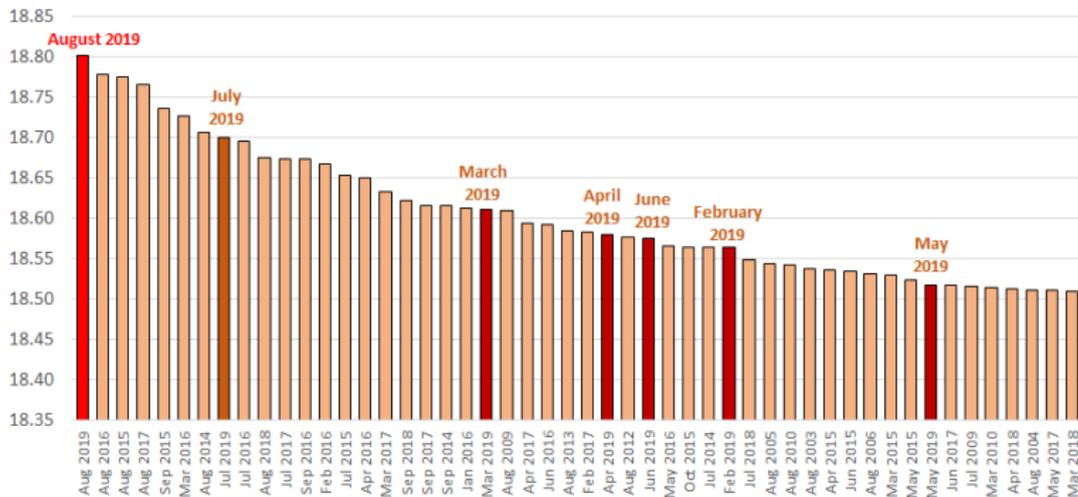
# Sektörel bazda küresel CO2 emisyonlar?



- ▶ More than half of the observed increase in global average surface temperature caused by the anthropogenic increase in GHG concentrations (IPCC).
- ▶ Rising global temperatures, which change the Earth's climate, has already started to take its toll
  - ▶ retreat of glaciers
  - ▶ increased surface melting of the Greenland ice sheet
  - ▶ global mean sea level rise
  - ▶ extreme weather events such as higher incidences of heat waves / destructive storms / changes to rainfall patterns.
- ▶ Unless GHG emissions decrease substantially, there will be further warming, long-lasting changes in all components of the climate system, and severe, pervasive and irreversible impacts for people and ecosystems (IPCC, 2014).

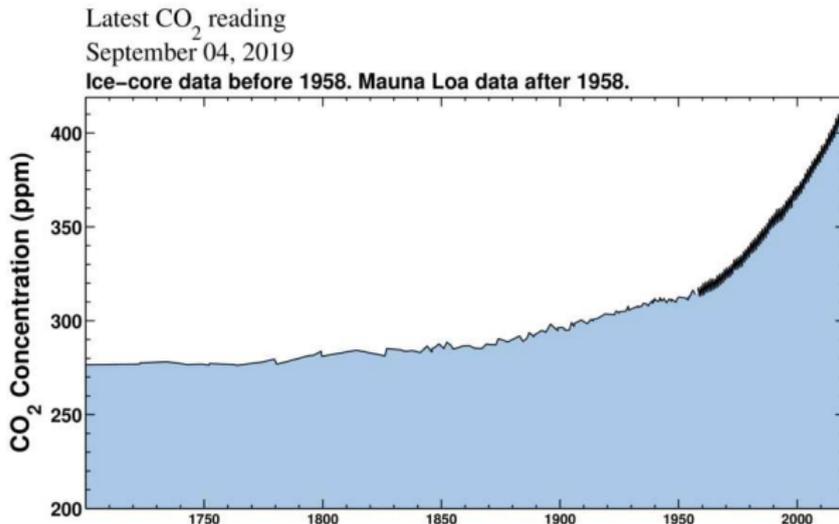
# Hottest 50 months since 1854

Global Sea Surface Temperatures: Top 50 Warmest Months Since 1854



Source: National Oceanic and Atmospheric Administration (NOAA) - Extended Reconstructed Sea Surface Temperature

- ▶ Yet, the share of fossil fuels within the world energy supply is relatively unchanged over the past 40 years.
- ▶ These fuels still supply over 80% of all primary energy needs and will remain the dominant source of energy for the decades to come (IEA, 2013).
- ▶ Current trend in atmospheric CO<sub>2</sub> concentration Source: Mauna Loa Observatory, Hawaii



- ▶ Current trend of the CO<sub>2</sub> emissions and the dominant role that fossil fuels maintain can prove disastrous for future generations unless.
- ▶ Given that fossil fuels will continue to supply a major share of energy needs, CCS appears to be the only technology that can substantially reduce CO<sub>2</sub> emissions (Amigues et al., 2016).

# Important role envisioned for CCS

- ▶ Several international and intergovernmental agencies, including IEA, IPCC, EIA, envision an important role for CCS and recommend its use in order to achieve the environmental goals.
- ▶ To bring down GHG emissions to 50% of their 2005 level by 2050, IEA (2008) shows that about 20% of the reductions should come from CCS activities.

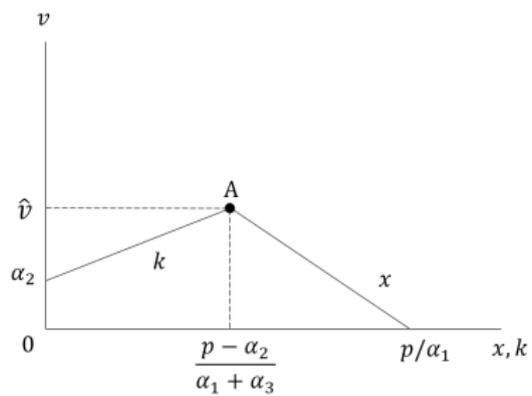
- ▶ IEA Energy Technology Perspectives (2012)
  - ▶ Under the 2DS, CCS contributes one-sixth of CO<sub>2</sub> emission reductions required in 2050, and 14% of the cumulative emissions reductions between 2015 and 2050 (compared to 6DS)

- ▶ Yet, the progress in CCS is slow and far below than what is required to limit the global temperature rise to 2°C (IEA, 2013).
- ▶ The technology still absent in a number of key industrial sectors (iron, steel, cement...)
- ▶ Even though CCS is a key (carbon intensive) technology,
  - ▶ what can be the reason for these technologies not to have had an international breakthrough?

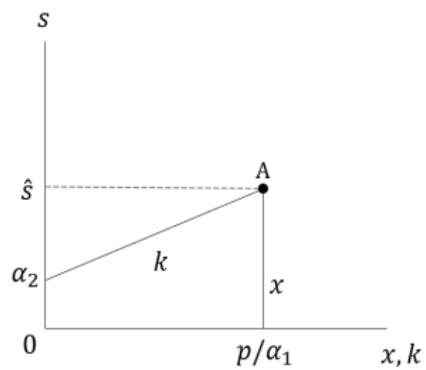
# Economic drivers of CCS - a basic approach



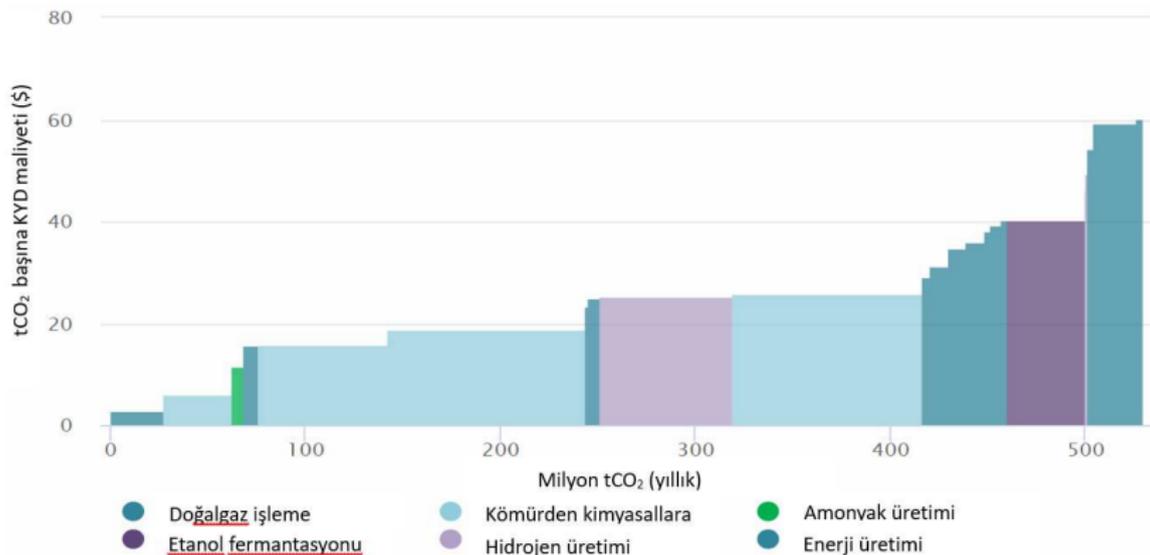
# Carbon tax



# Subsidies



# Breakeven investment costs of several CCS projects



Kaynak: Carbon capture, utilisation and storage: A critical tool in the climate energy toolbox, IEA.

<https://www.iea.org/topics/carbon-capture-and-storage/policiesandinvestment/>

## Bibliography

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