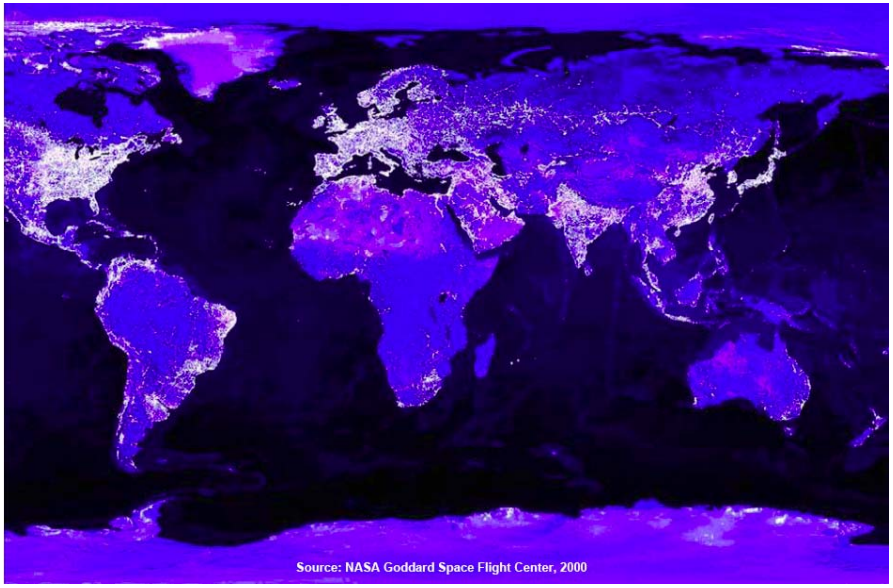
CCS: "Carbon Capture and Sequestration Approaches, Including Oxy Fuel Technology



Professor Steve Son

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Clean (or cleaner) coal?

- 80-90% of Indiana's power is from coal
- >50% of US electrical energy is from coal
- Why?

- What if we decided today to eliminate coal power, how long would it take?
  - What's the lifetime of a power plant?

Cleaner coal?

- Coal accounts for 37% of the worlds energy
- In Australia coal power generation accounts for 85% of its power production.
- In the United States 91% of its coal consumption is via power generation

Cleaner coal?

- Fossil fuels are needed to sustain economic progress now and for the foreseeable future
- Factors:
  - Current economy, abundance (THERE IS A LOT!!!), availability, proven technology, multi-trillion dollar production, transport (relatively easy – even from Wyoming!?!?), infrastructure
  - These factors can not be ignored

Do you "believe"?

- Each person on earth is producing an average of 3.7 tons/year of CO2!

- Overall public perception:
  - Climate change / global warming is real
    - is happening now (geological time too abstract)
    - caused by greenhouse gas (GHG) emissions
    - fossil fuel industry is main contributor
    - "something" can be / must be done
  - Lawmakers are responsive to public sentiments (carbon tax)
    - Industry positioning for carbon constrained world

What do "experts" say?

- Every authoritative report that has appeared in the past two years has concluded that
  - 1) Warming of climate system due to GHG increase is now unequivocal
  - 2) deployment of carbon capture and storage (CCS) is a viable mitigation option
  - 3) after renewable options CCS is a favorite option of climate "alarmists"
    - Other "engineered" options are typically viewed as only a last resort
      - Why?

Cost of Coal

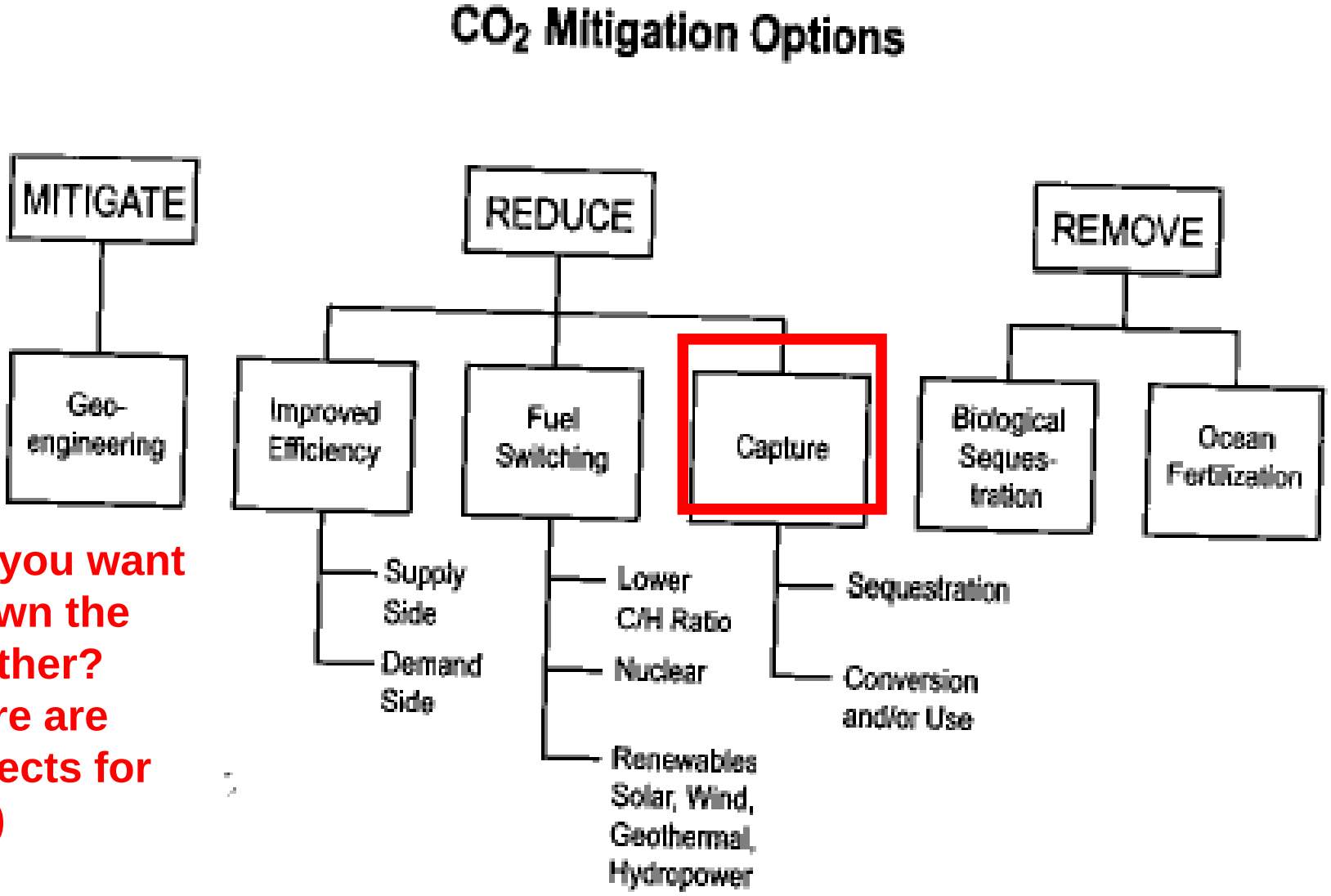
- Cost?
  - How does this compare to alternatives?

Table 7.6. Cost of Electricity Generated in the US from Coal and Natural Gas[d]

Technology	Fuel Cost $/million Btu	Contributions to Cost of Electricity COE $/MWh: Fuel	O&M	Capital	Total COE $/MWh
Pulverized coal with Supercritical Steam Boiler[a]	1.00	8.50	3.50	19.62	31.62
	1.25	10.62	3.50	19.62	33.74
	1.50	12.75	3.50	19.62	35.87
Pulverized Coal with Subcritical Steam Boiler[b]	1.00	9.22	3.50	18.40	31.12
	1.25	11.52	3.50	18.40	33.42
	1.50	13.83	3.50	18.40	35.73
Natural Gas Combined Cycle[c]	2.00[e]	16.60	2.00	10.72	29.32
	3.40[e]	25.66	2.00	10.72	38.38
	4.60[e]	37.71	2.00	10.72	47.43

Source: Beér, 2001.

Possible CO_2 Mitigation Options

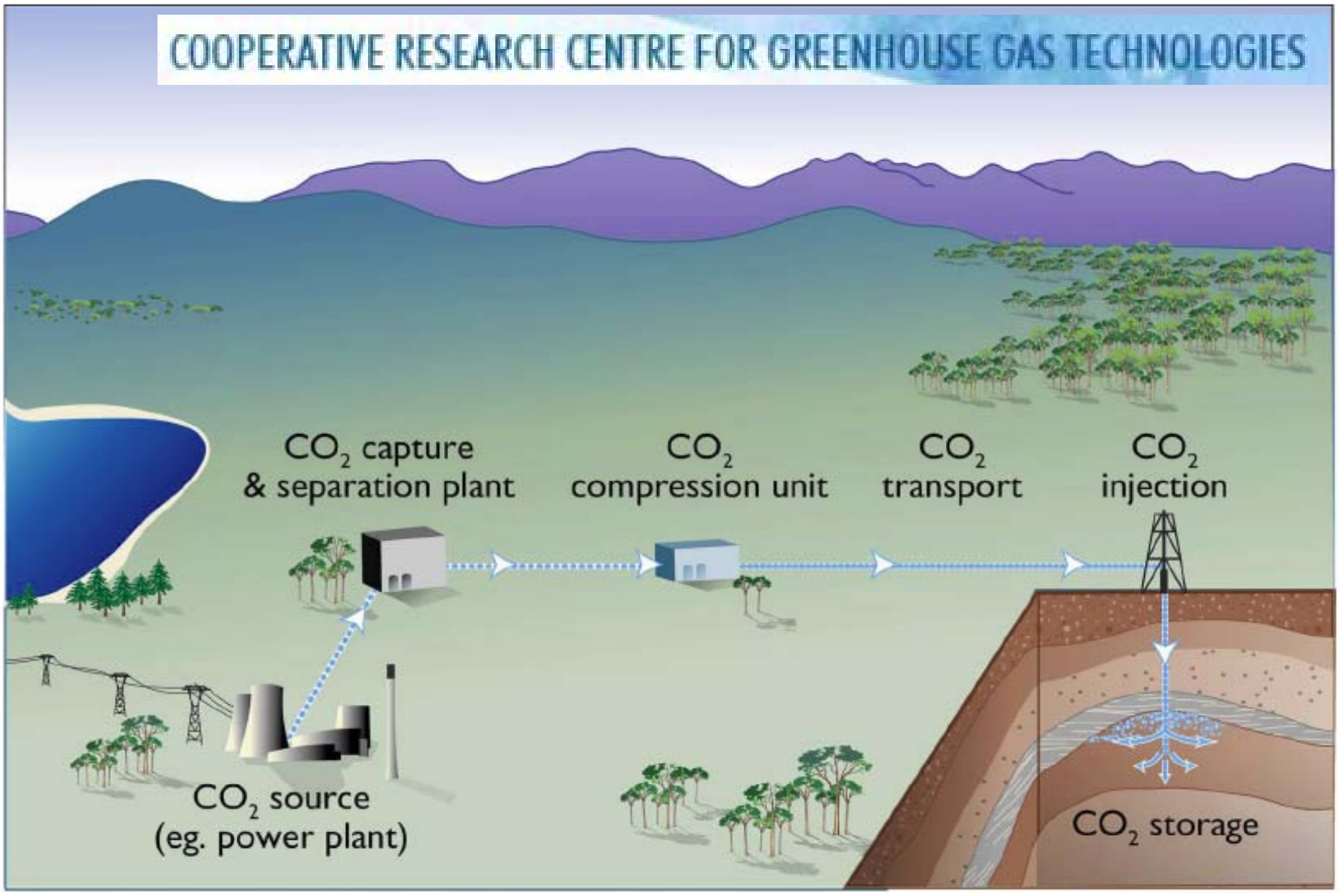


(Do you want to own the weather? There are projects for this)

Figure 7.16. Options for mitigation of the release of fossil fuel-derived carbon dioxide to the earth's atmosphere. Source: Herzog et al., 2000.

What is CCS?

- "carbon capture and sequestration"

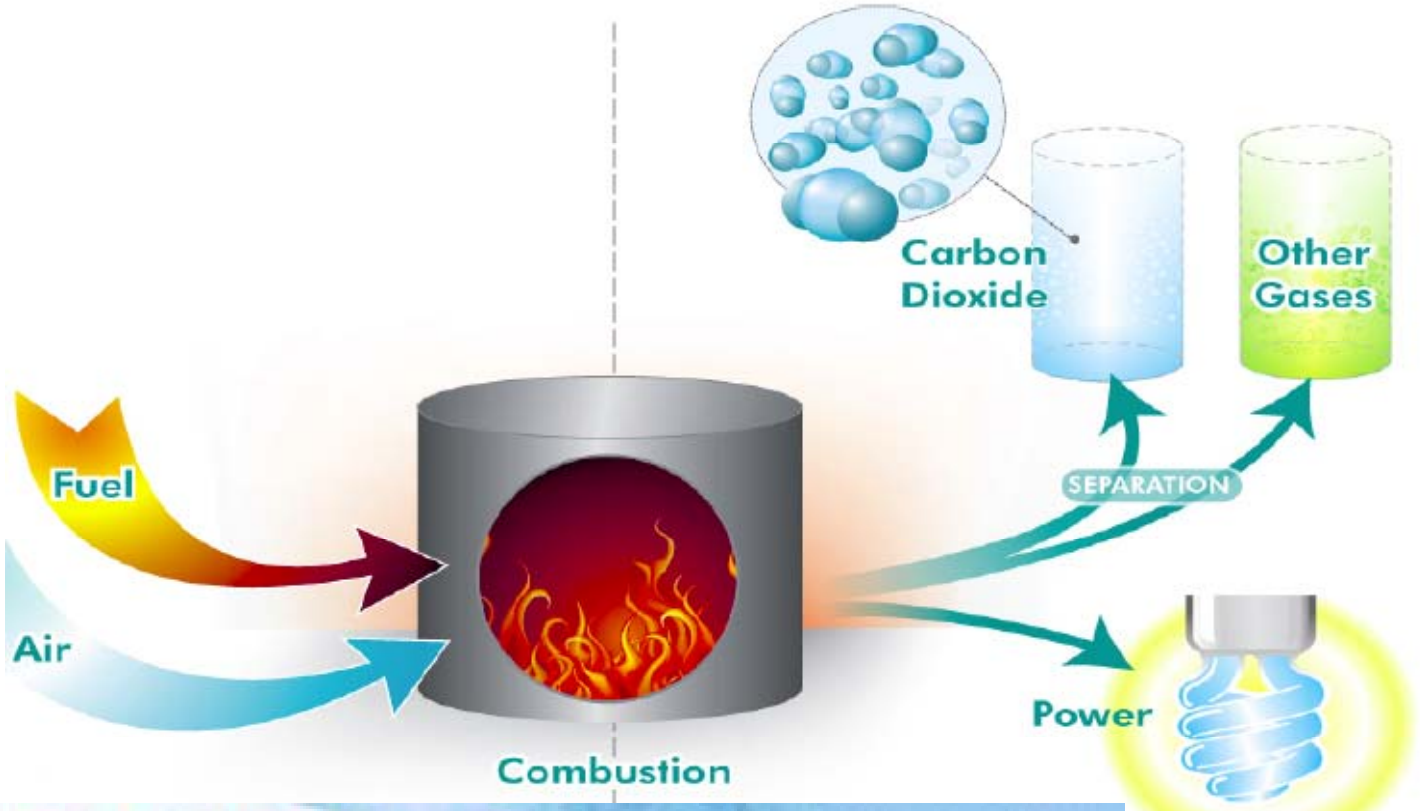


CCS Options

- Pre-combustion Carbon Capture
  - Take carbon out of the equation before furnace
    - IGCC
- Post Combustion Carbon Capture
  - Take CO_2 out of product stream
    - Amine Scrubbing
      - Other chemical absorption
    - Oxy-Fuel

Capture: Post Combustion Capture

- Post-combustion refers to capturing CO2 from a flue gas after a fuel has been combusted in air

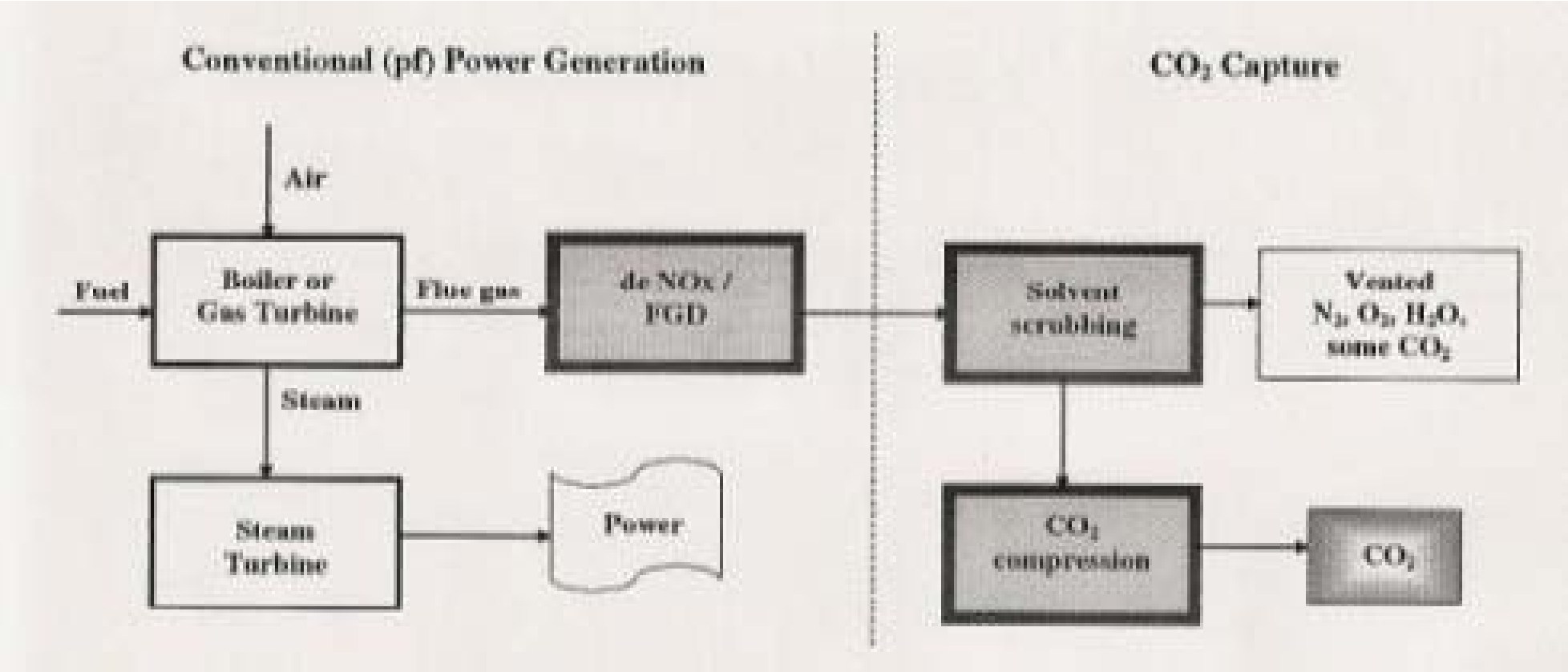


Capture: Amine (Current Approach)

- Both conventional and modern types of coal-fired power plants can be adapted for CCS

- Conventional coal-fired power plant:
  - Burn coal in air (like the old days)
  - Exhaust gas is ~15 % CO_2 (rest is mostly nitrogen and water vapor)
  - Exhaust gas flows over chemicals that selectively absorb CO_2 (amines)
  - The amines are heated to ~150 ºC to give up the CO_2 and produce a (nearly) pure CO_2 gas that can be sequestered.

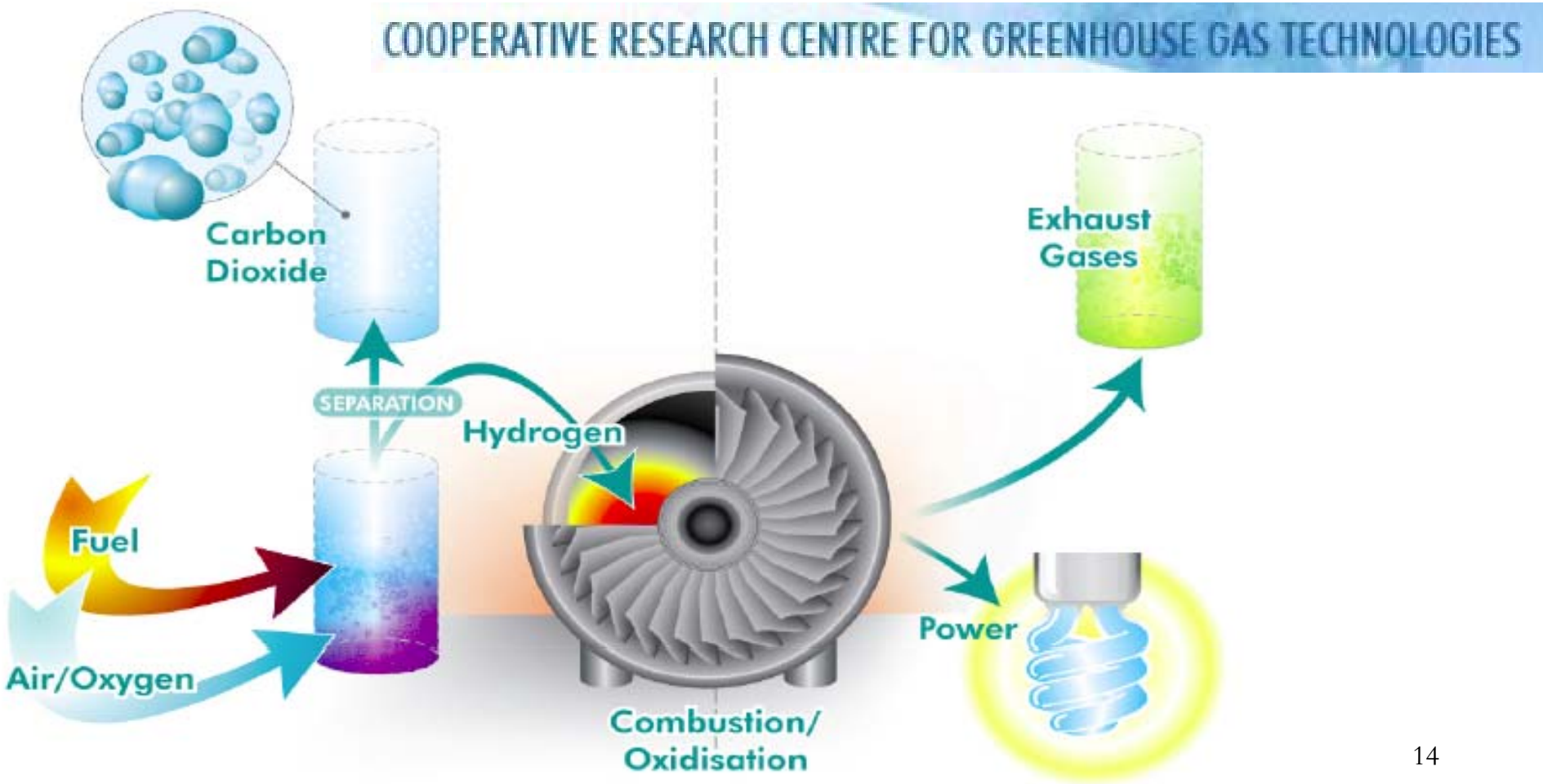
Capture: Amine (Current Approach)



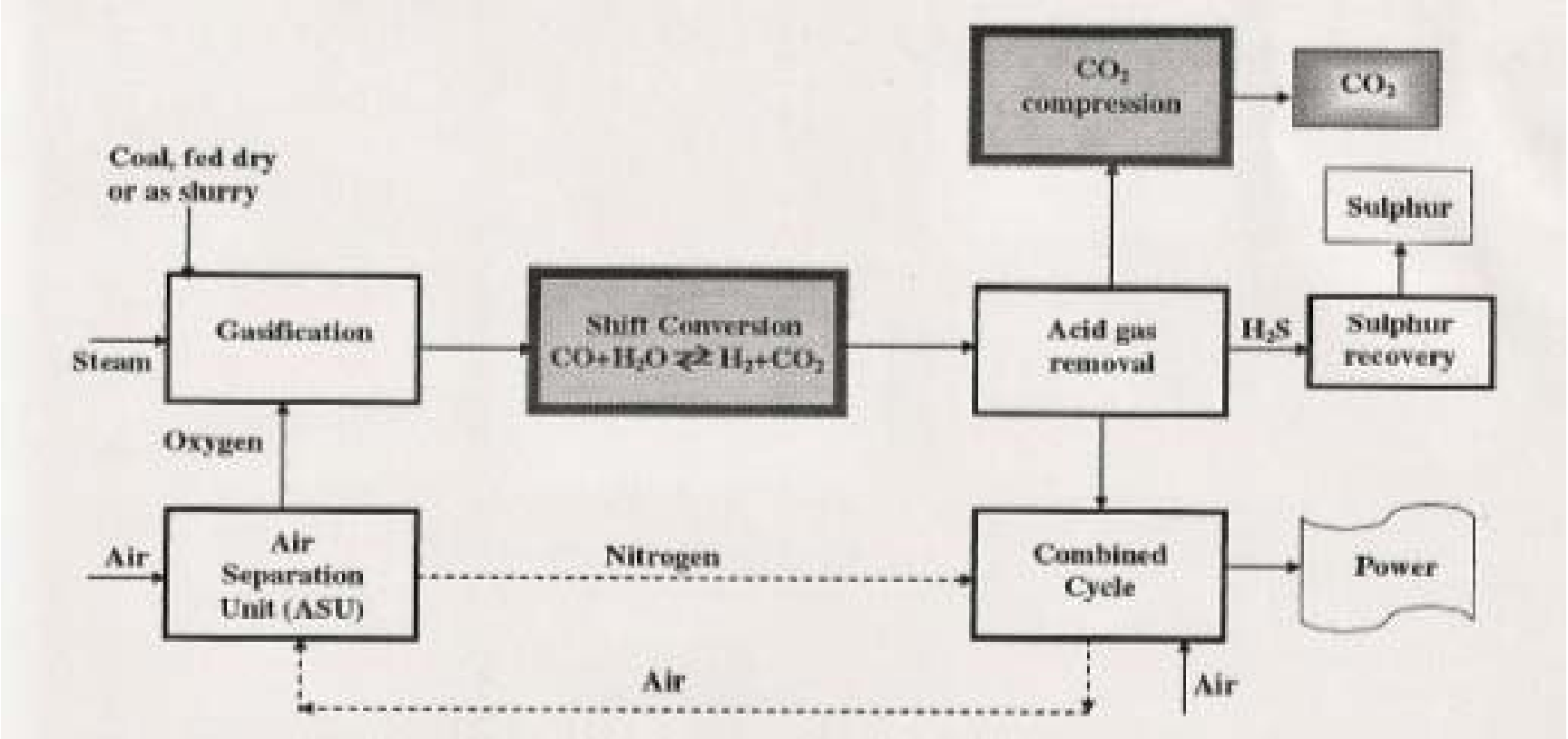
- **Can be applied slip stream (adjust to carbon tax)**
- **Other options require "all in commitment"**
- **CCS for an existing power plant can increase costs 20-30% in the consumers overall cost for electric**

Capture: Pre-Combustion Capture

- Pre-combustion refers to a process where a hydrocarbon fuel is gasified and water-gas shifted to form a mixture of hydrogen a CO_2 The CO_2 is captured from the synthetic gas and the H_2 is combusted. Often called IGCC (Integrated Gasification Combined Cycle)



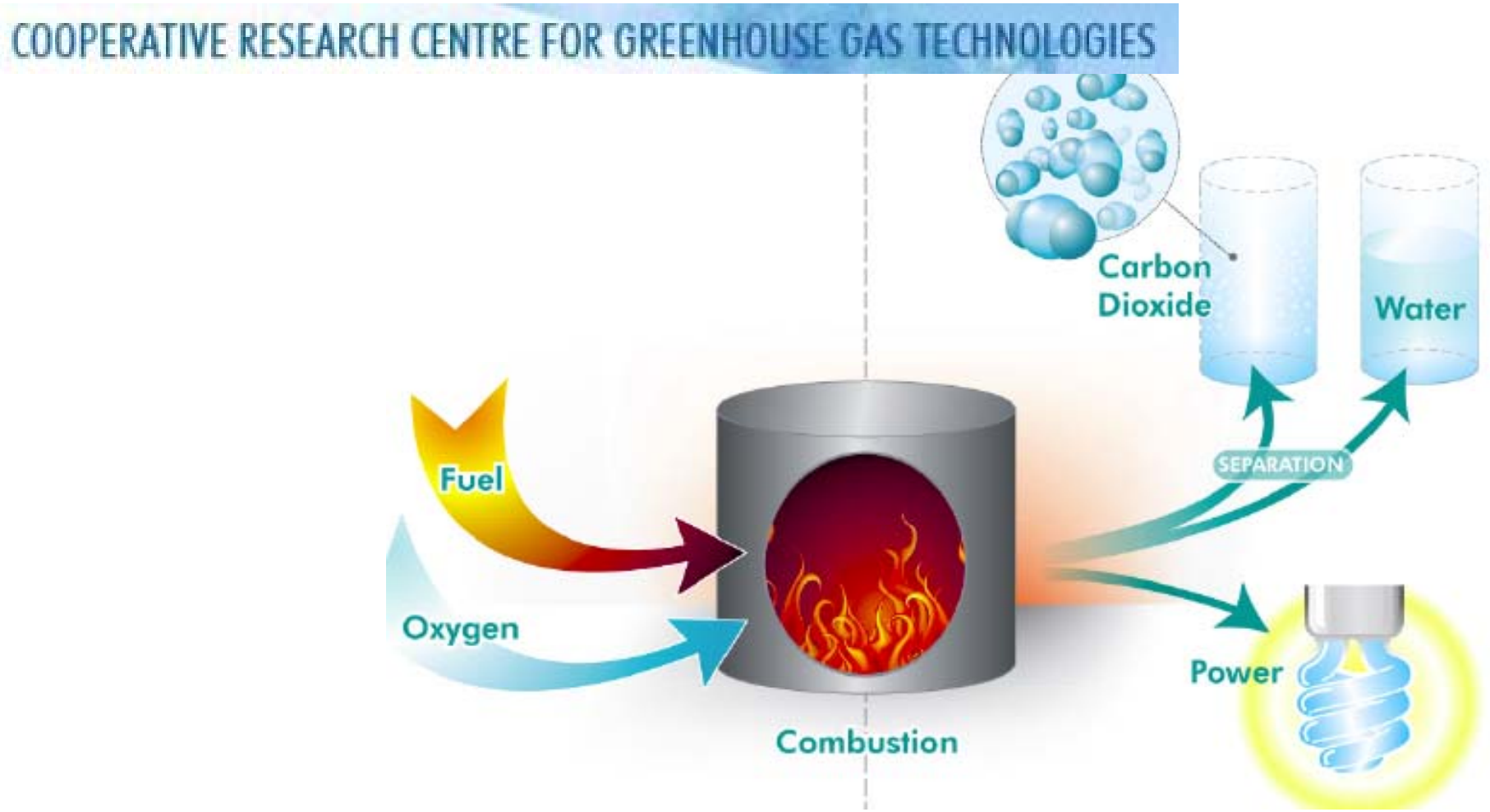
IGCC (Integrated Gasification Combined Cycle)



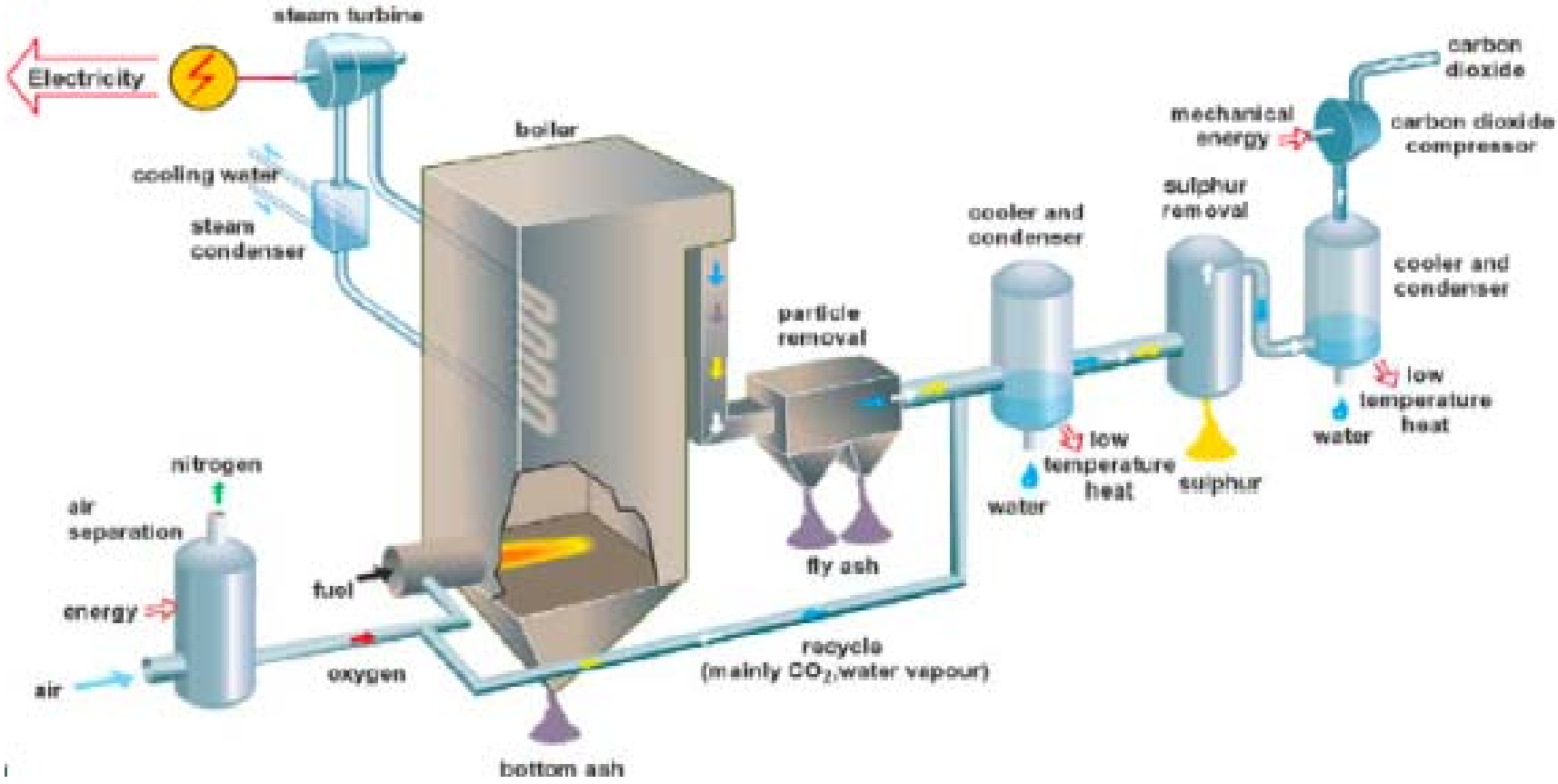
Coal is made of Porous Carbon and Volatile material (mostly CH_4)

Capture: Oxyfuel

- Conventional (or new designs) power station boilers burn pulverised coal in oxygen to fuel a steam generator, creating an exhaust mixture of highly concentrated CO_2 and water vapor. The concentrated CO_2 is easier & cheaper to capture.



Capture: Oxyfuel



- Large cryogenic oxygen production can be expensive…
- No-slip stream option (all or nothing)

Oxyfuel Capture: 1st Plant

Vattenfall Schwarze Pumpe Facility, Germany

- 30 megawatt (MW) wall-fired boiler oxyfuel pilot plant.
- CO_2 capture pilot unit operational since late 2008.
- Storage not yet in place, so venting CO_2

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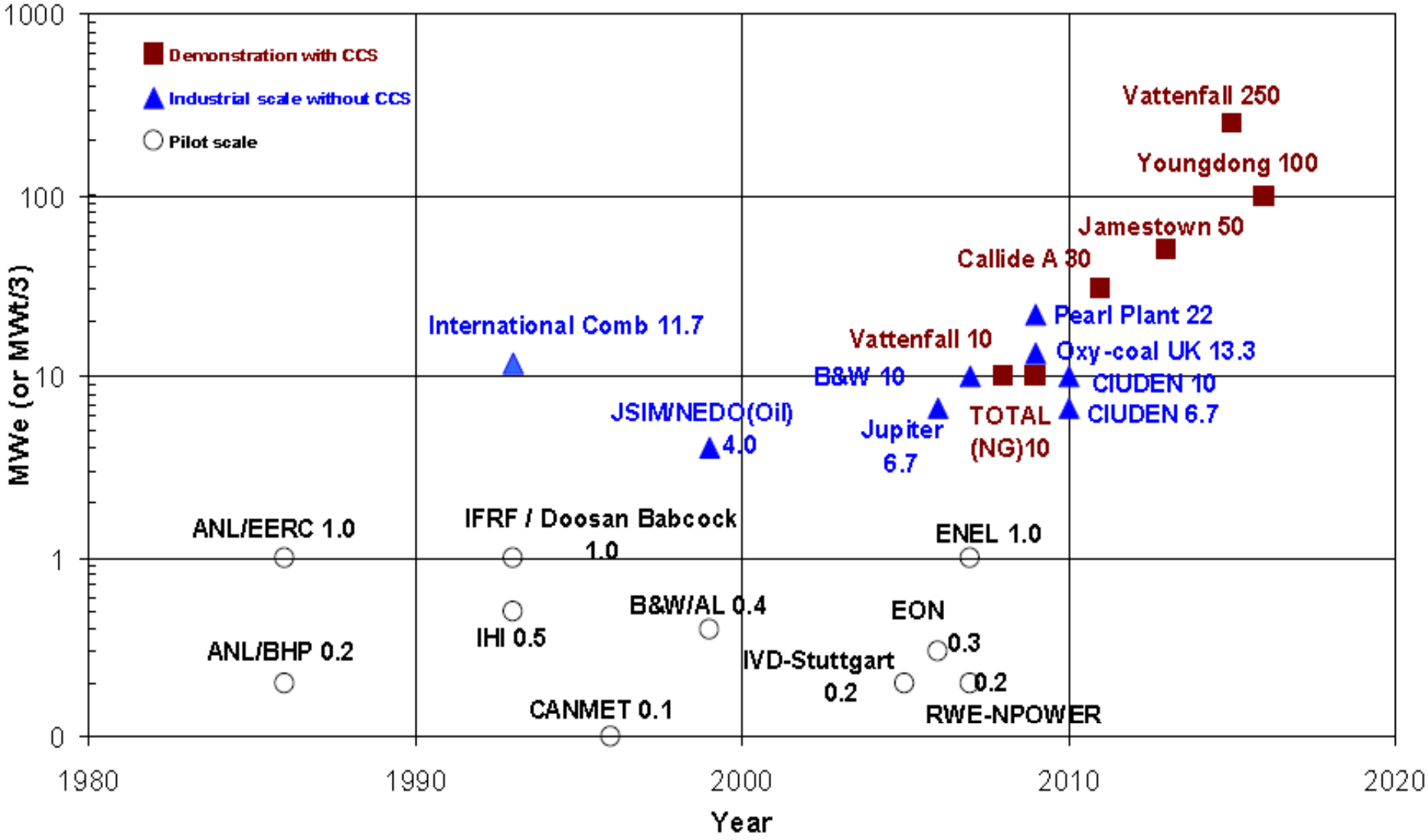
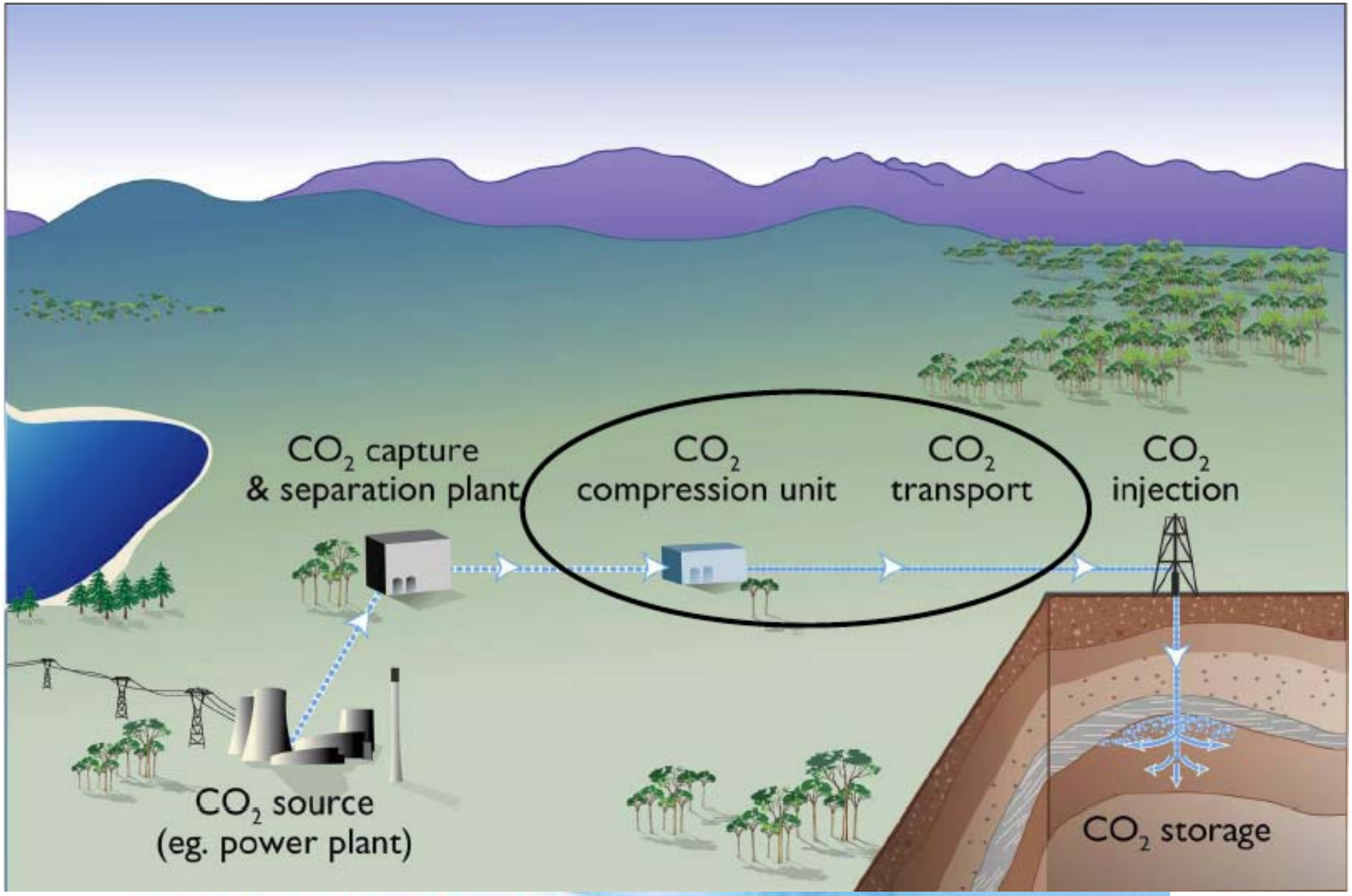
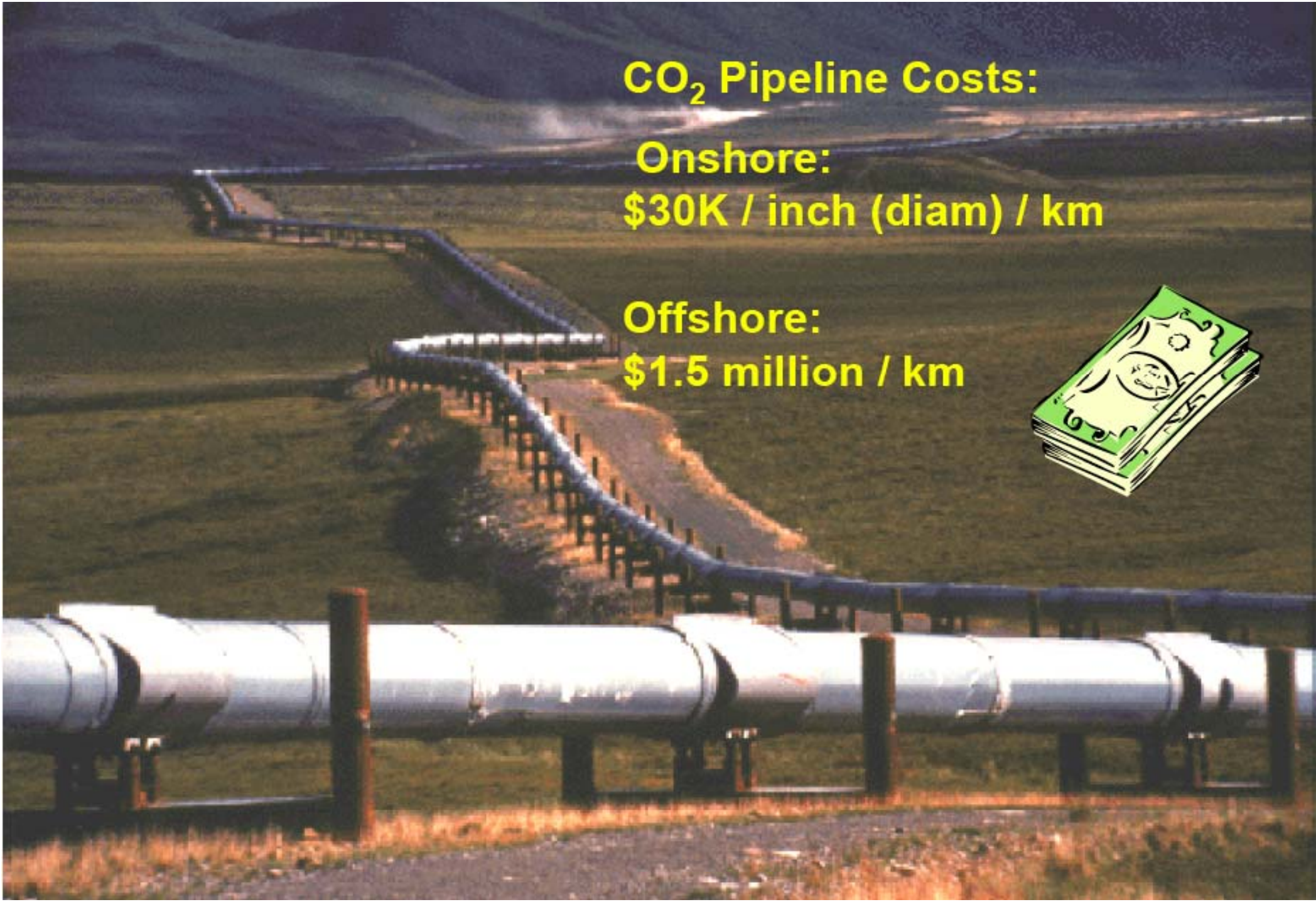
Progression in Oxy-fuel Plant Capacity



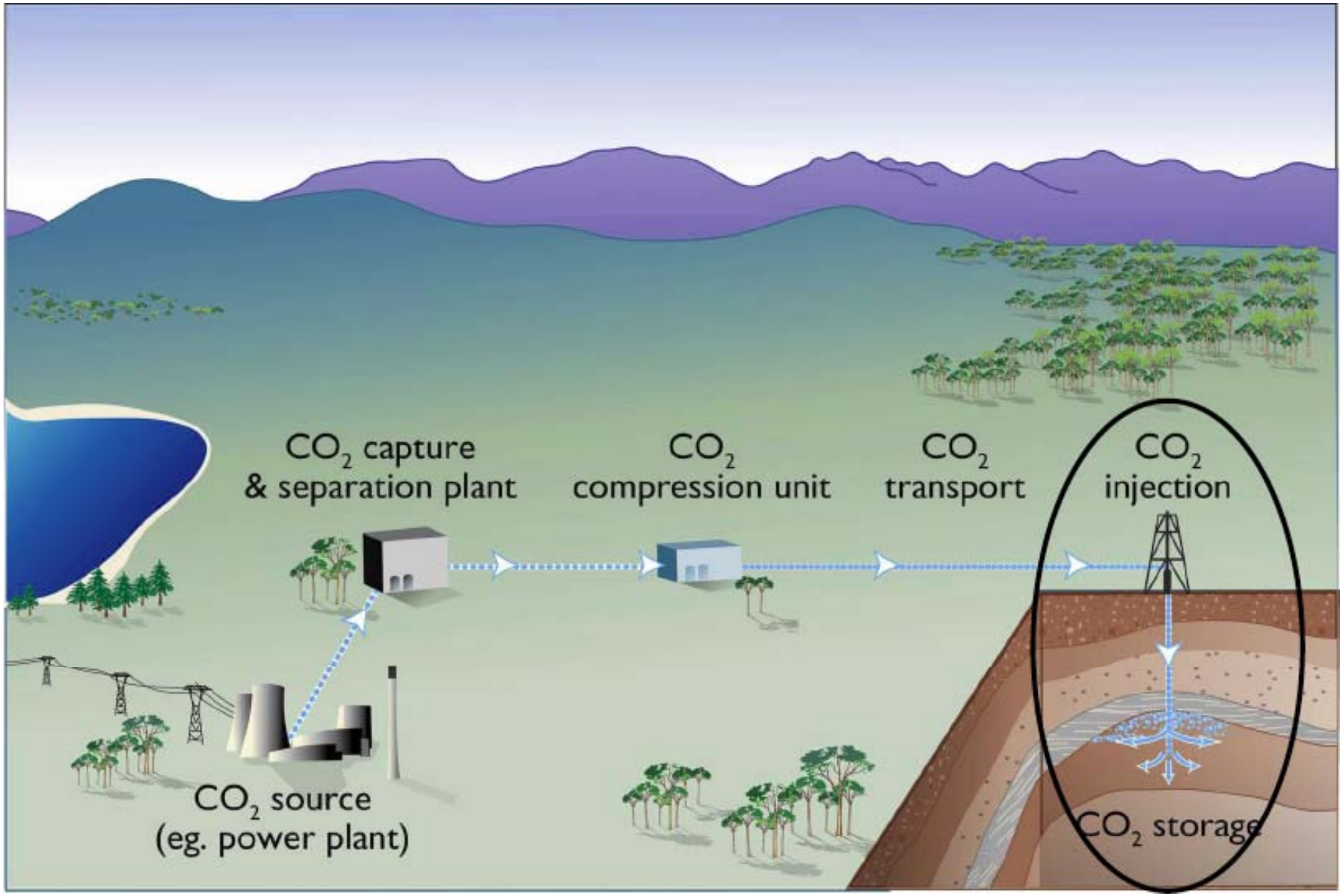
Compressing & Transporting the Carbon Dioxide




CO_2 Pipeline Costs:
Onshore:
$30K / inch (diam) / km
Offshore:
$1.5 million / km

Over 5000 km of supercritical CO2 pipelines in US already!

Geological Storage



Sequestration Capacity

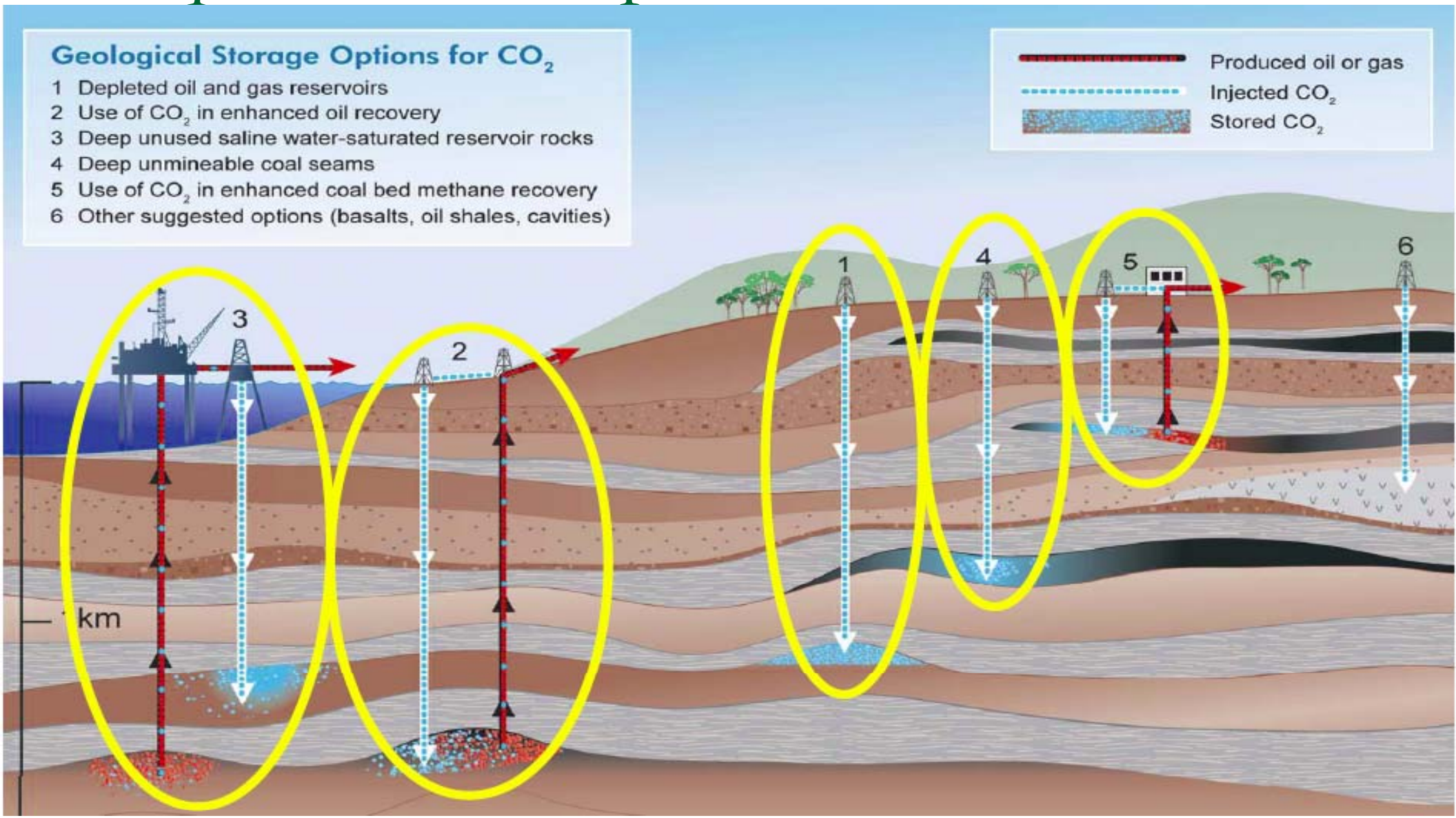
- Global CO_2 release is 22 Gt/year
- What if only a fraction of capacity feasible
  - Might need oceans then…

Table 7.5. Estimates of the CO_2 Capacity of Various Sequestration Options

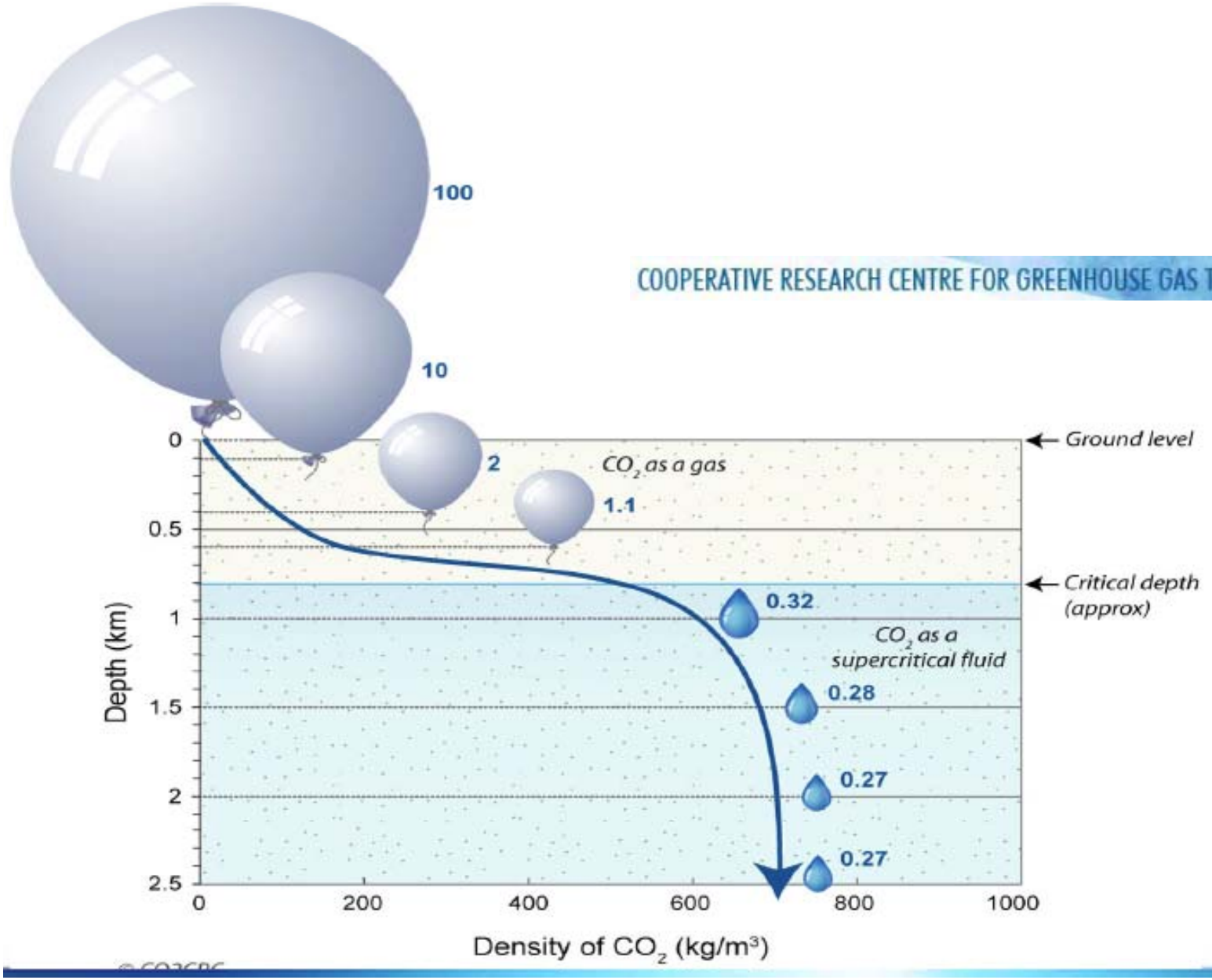
Sequestration Option	Worldwide Capacity (Order of Magnitude)
Ocean	100,000 Gt
Aquifers	10,000 Gt
Depleted Oil and Gas	1,000 Gt
Active Oil	1 Gt/yr
Utilization	0.1 Gt/yr
Coal Seams	?

Notes:
Total CO_2 emissions worldwide = 22 Gt/yr
CO_2 emissions from US power plants = 1.7 Gt/yr
Source: Herzog (2000).

Sequestration Options



Bury it deep!


CO2 storage effectiveness increases with depth
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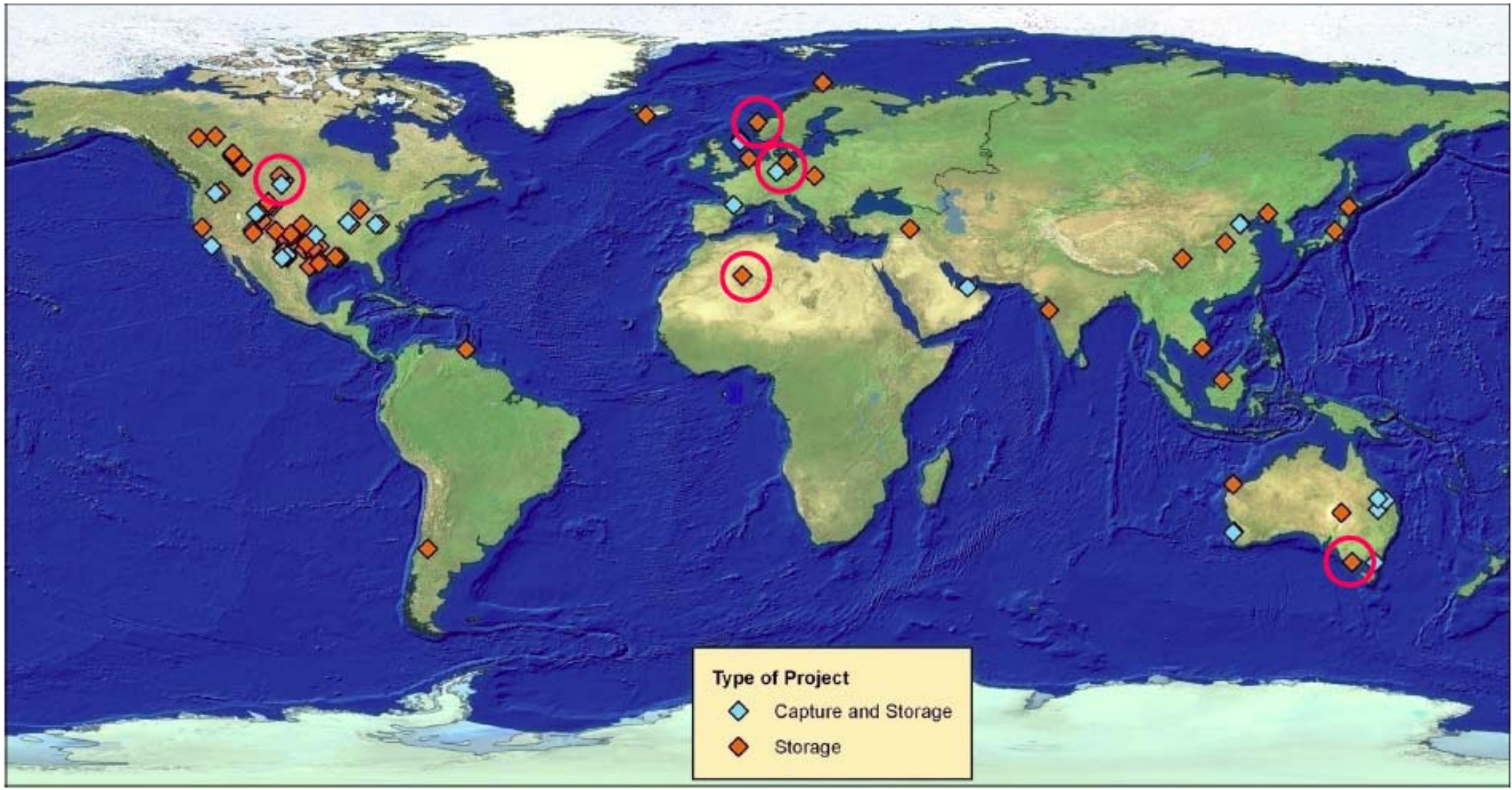
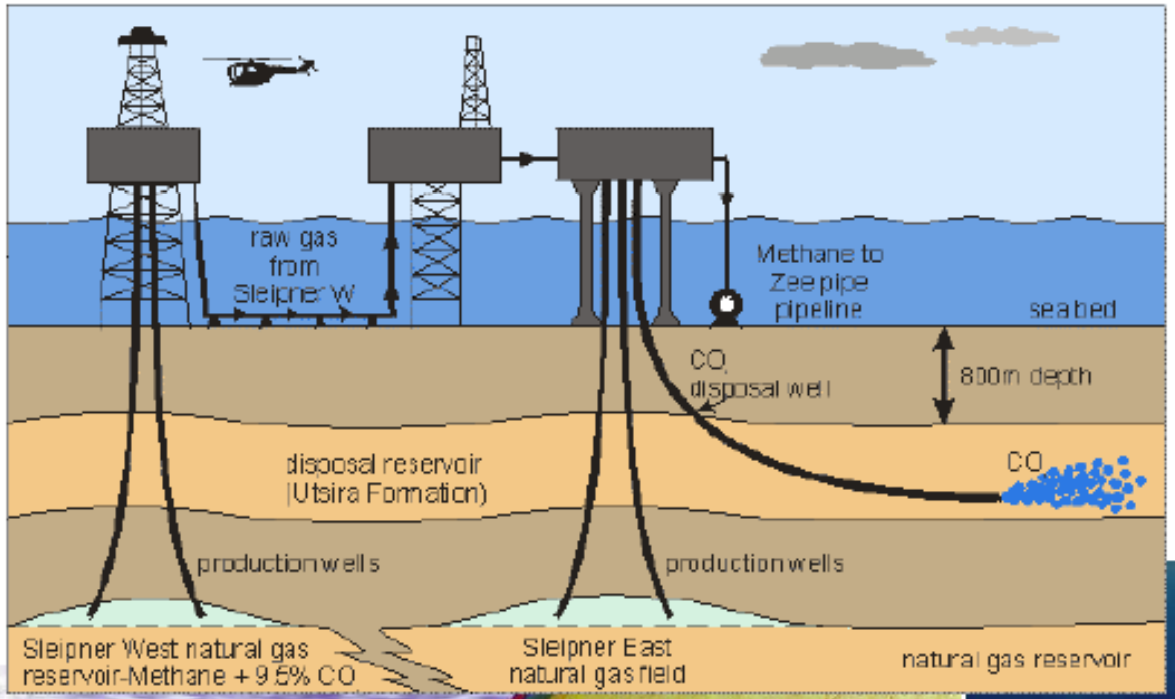
100
10
2
1.1
0.32
0.28
0.27
0.27
CO2 as a gas
CO2 as a supercritical fluid
Ground level
Critical depth (approx)
Depth (km)
0
0.5
1
1.5
2
2.5
0
200
400
600
800
1000
Density of CO2 (kg/m3)

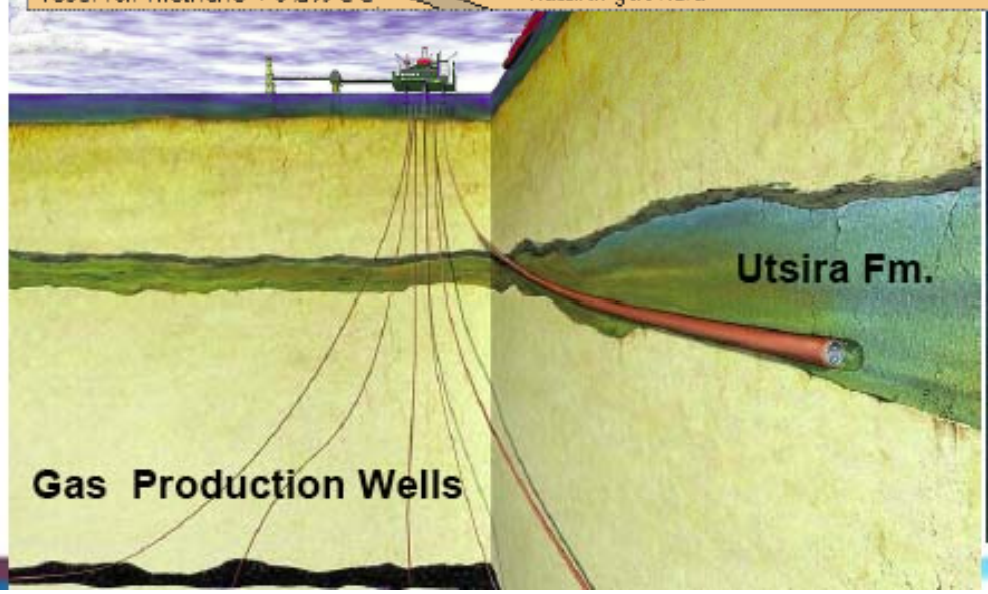
Current and proposed storage and capture projects



Sleipner (STATOIL)



- **Offshore Gas Production Facility**
- **250 kilometres west of Norway in the North Sea**
- **Injection into Utsira Formation, a sandstone reservoir rock.**
- **1 million tons CO_2 per year since 1996**



September 22, 2009 | 12 comments

Burying Climate Change: Efforts Begin to Sequester Carbon Dioxide from Power Plants

West Virginia hosts the world's first power plant to inject some of its CO_2 emissions underground for permanent storage

By David Biello

Doing it!

CARBON CAPTURE UNIT: The Mountaineer power plant near New Haven, W.Va., uses chilled ammonia technology to grab carbon dioxide from the coal-fired power plant's flue gas for subsequent storage underground.
COURTESY OF AMERICAN ELECTRIC POWER

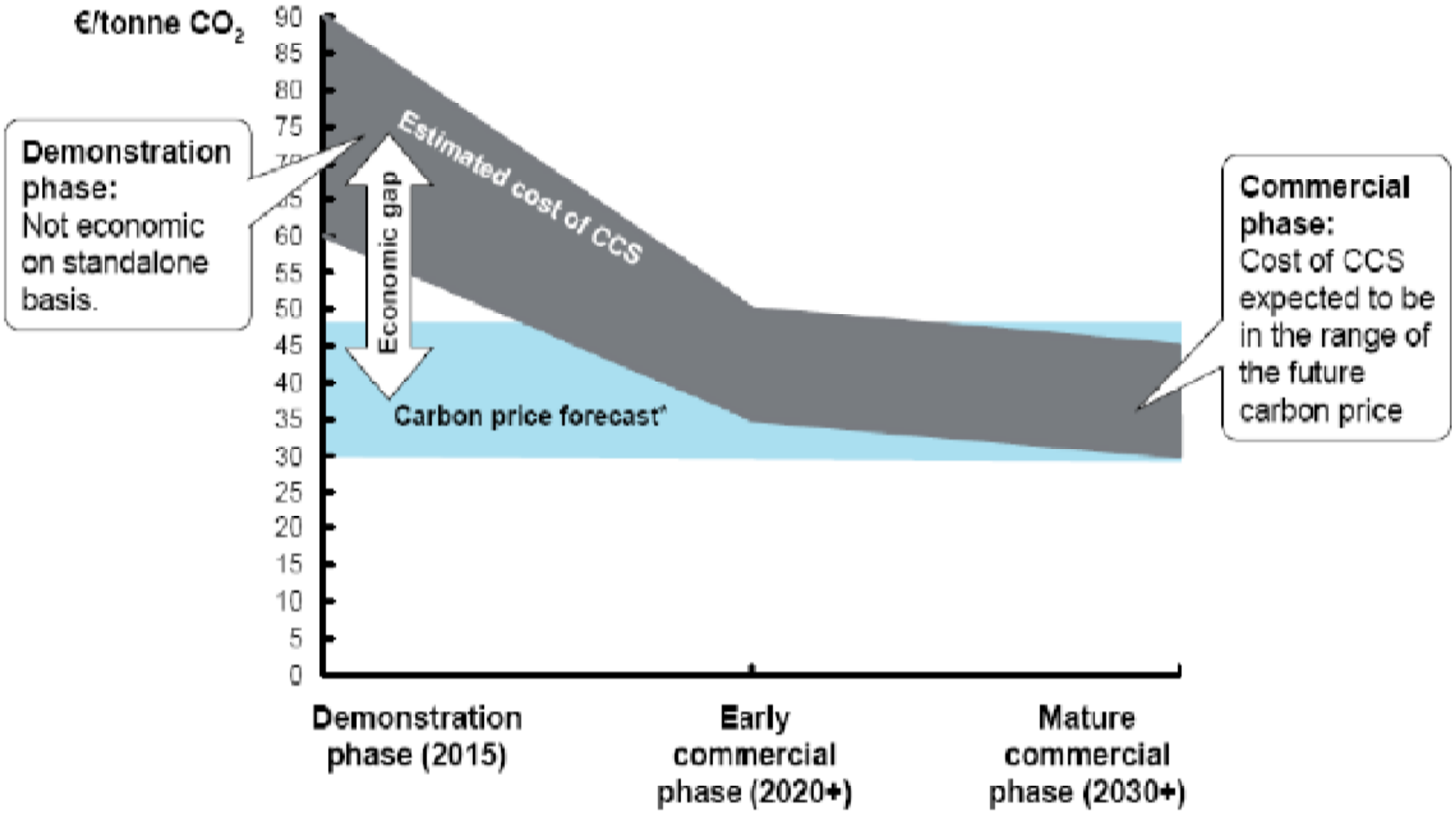
Over the next five years at least half a million tons of carbon dioxide will be injected into rock deep underneath the Mountaineer power plant near New Haven, W.Va. Although that is less than 0.00001 percent of global emissions of the greenhouse gas and less than 2 percent of the plant's own CO_2 output, the sequestration, which begins this week, marks the first commercial demonstration of the only available technological fix for the carbon problem of coal-fired power plants, one that many coal facilities around the world hope to emulate.

Coal accounts for roughly 50 percent of the electricity generated in the U.S. and as much as 75 percent of the electricity generated by American Electric Power, says Nick Akins, executive vice president of

Costs

- Costs of carbon capture and sequestration is a Complex process
  - NETL comprehensive study (http://www.netl.doe.gov/energy-analyses/baseline_studies.html)
  - Included detailed breakdown of likely cost of carbon capture and sequestration
  - Retrofitting CO_2 capture to today's power plants using existing technology could expensive
  - For pulverized coal plants, the cost of CO_2 capture, transport, and storage in an underground formation using today's technologies could add 70-100 percent to the cost of electricity

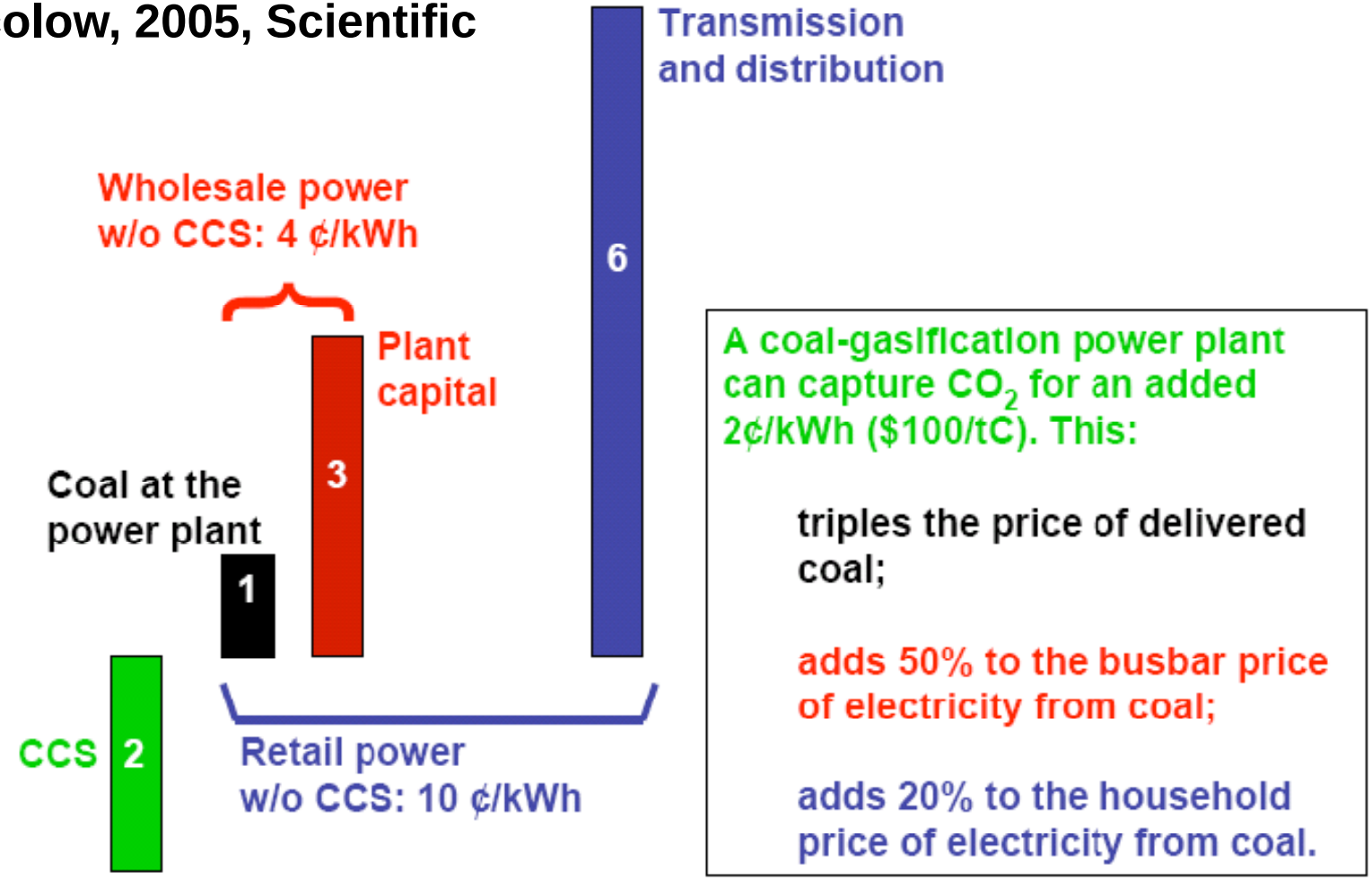
CCS: economics



- CCS could become cost-effective with future carbon legislation

CCS: economics

Source: Socolow, 2005, Scientific American



- CCS could become cost-effective with future carbon legislation

Other "Engineering" Options

- Global engineering (changing the earth's albedo)
  - Cloud seeding, droplets/particulates in atmosphere, reflectors or absorbers in space
- Direct capture from air by chemical methods
  - NaOH or other regenerable sorbents
- Direct capture from air by biological options
  - Fertilizing oceans for algae
  - Foresting desert areas
  - Algae for fuel production
- Not very popular

Politics

- CCS is quickly approaching commercial readiness
- Whether this technology is the long term solution to finding a clean abundant energy source will only be known in time
- This technology will surely hold some role in the near future (20 years)

Thank you - Questions

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