The stabilization of CO_2 emissions in the coming 50 years

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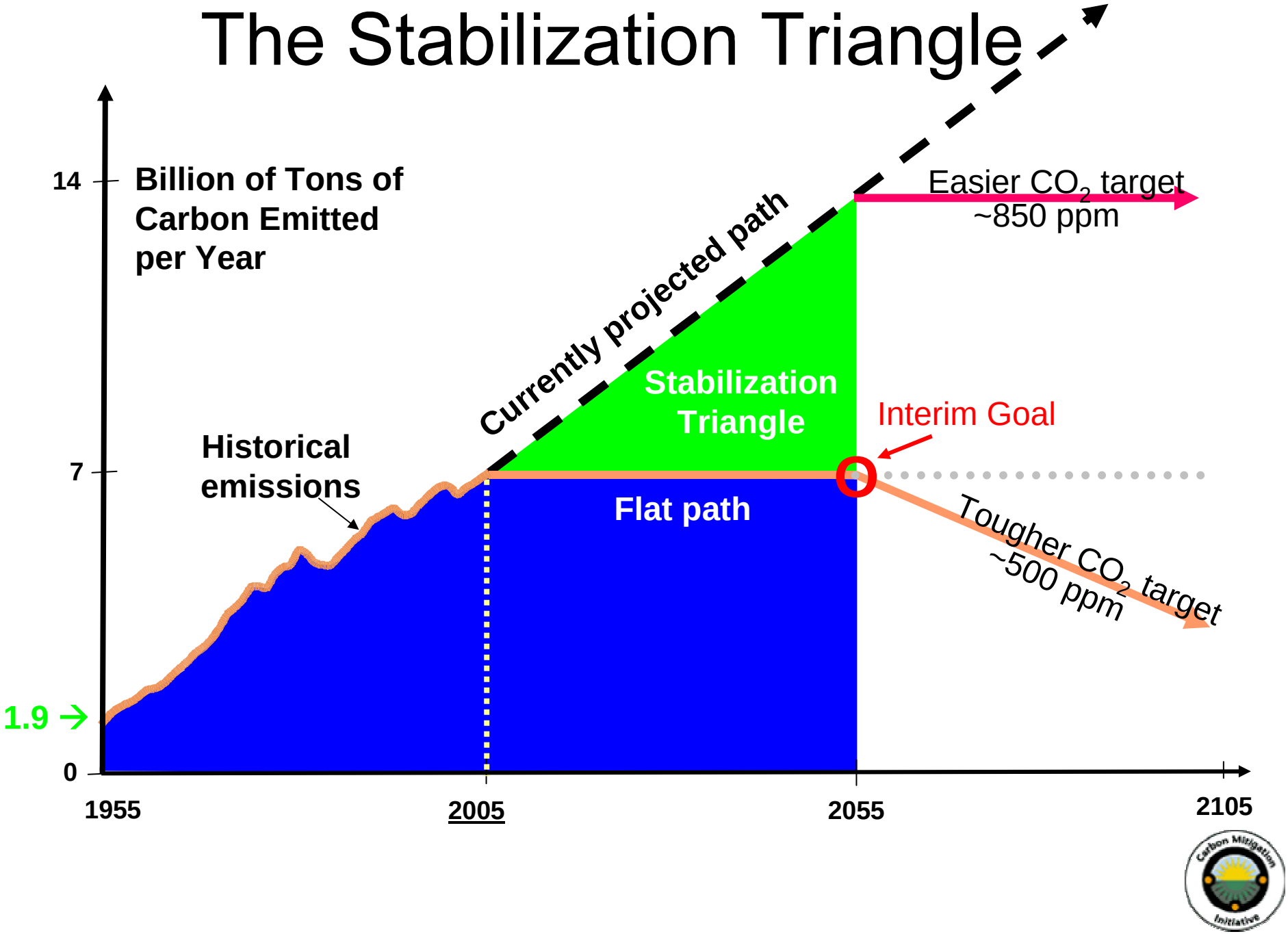
What if the fossil fuel future is robust, but the Greenhouse problem is severe?

		Will the fossil fuel system wither away?	
		YES	NO
Will the case for Greenhouse damage wither away?	YES	A nuclear or renewables world unmotivated by climate.	Most people in the fuel industries and most of the public are here
	NO	Environmentalists, nuclear advocates are often here.	OUR WORKING ASSUMPTIONS

Outline of Talk

- “Wedges”: Quantification of mitigation to achieve climate stabilization
- Wedges from CO_2 capture and storage
- Parting thoughts

The Stabilization Triangle



The Flat Path is an Idealization of Stabilization below Doubling

Stabilization below doubling (450-550 ppm) is the century-scale carbon management goal recommended by many environmental scientists.

This century-scale goal is broadly consistent with the *Interim (50-year) goal:*

7 GtC/y in 2055, as in 2005

Uncertainty of ± 3 GtC/y in land plus ocean sink.

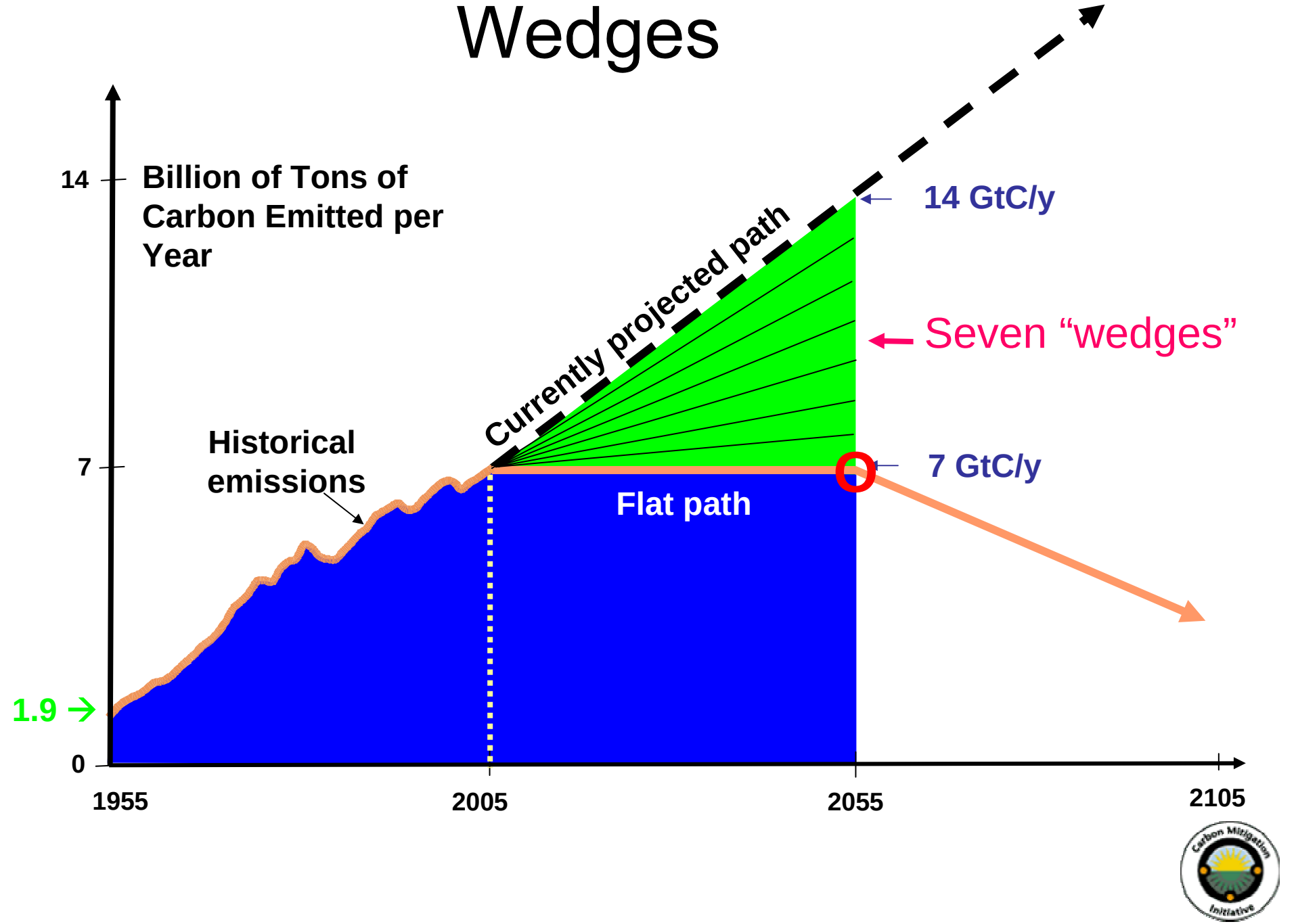
Further emissions cuts are required after 2055.

The Currently Projected Path is an Idealization of Business As Usual

The “currently projected path,” is a ramp that rises linearly from 7 GtC/y and intersects 14 GtC/y in 2055.

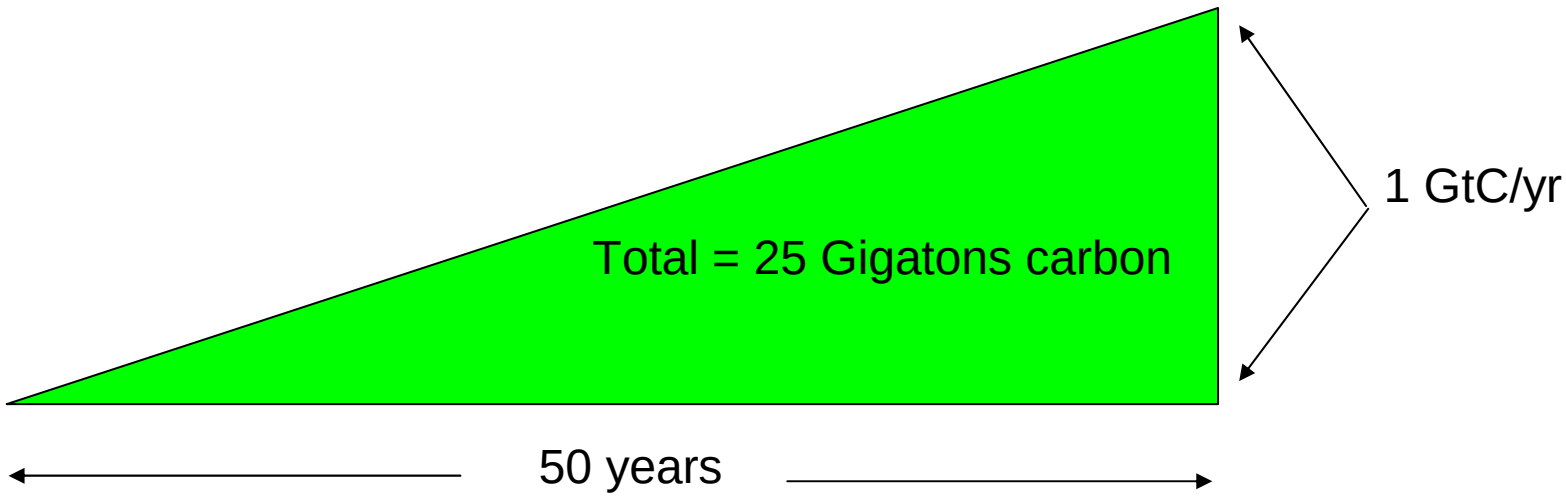
It is near the center of the cloud of estimates of Business As Usual (BAU) – a world *oblivious* to global carbon management.

Wedges


14
Billion of Tons of Carbon Emitted per Year
7
0
1.9
Historical emissions
Currently projected path
14 GtC/y
Seven "wedges"
7 GtC/y
Flat path
1955
2005
2055
2105

What is a “Wedge”?

A “wedge” is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr. The strategy has already been commercialized at scale somewhere.



Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

A “solution” to the CO_2 problem should provide at least one wedge.

Humanity Already Has The Tools

- READINESS: All wedge technologies are already deployed somewhere at commercial scale.
- PORTFOLIO: No single wedge technology can do the whole job, or even half the job.
- CHOICE: Not every wedge technology is needed.

Efficiency and Conservation

transport

buildings

industry

Effort needed by 2055 for 1 wedge:

2 billion cars at 60 mpg instead of 30 mpg.

power

lifestyle

Wind Electricity

Effort needed by 2055 for 1 wedge:

Two million 1-MW windmills displacing coal power.

Today: 40,000 MW (2%)

Prototype of 80 m tall Nordex 2,5 MW wind turbine located in Grevenbroich, Germany (Danish Wind Industry Association)

Nuclear Electricity

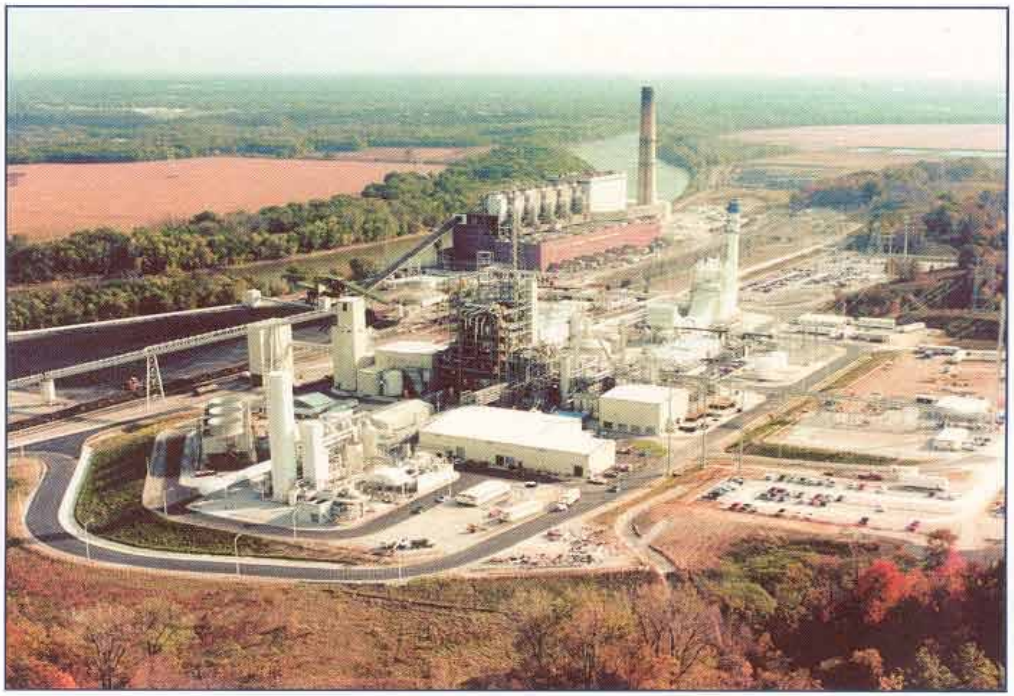
Effort needed by 2055 for 1 wedge:

700 GW (twice current capacity) displacing coal power.

Graphic courtesy of NRC

Phase out of nuclear power creates the need for another half wedge.

Power with Carbon Capture and Storage



The Wabash River
Coal Gasification Repowering Project

Effort needed by 2055 for 1 wedge:

Carbon capture and storage at 800 GW coal power plants.

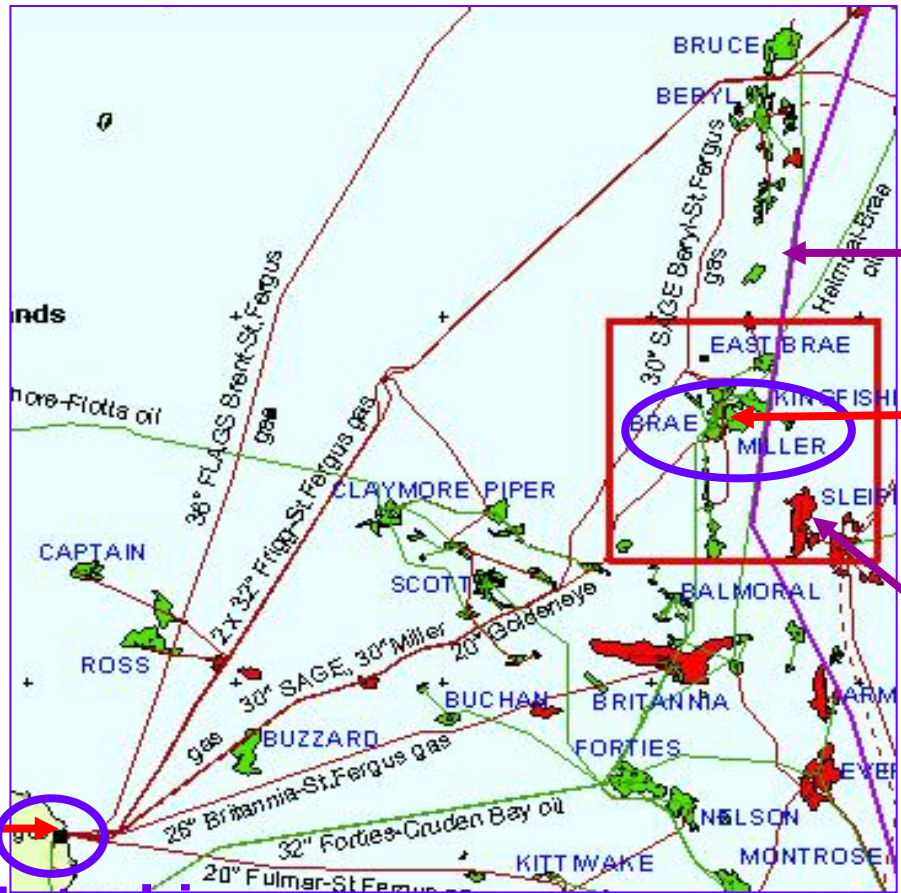
Graphics courtesy of DOE Office of Fossil Energy

Already, in the middle of the Sahara!

At In Salah, Algeria, natural gas purification by CO_2 removal plus CO_2 pressurization for nearby injection

Separation at amine contactor towers

Soon, BP's DF-1: natural gas power with CCS



UK-Norway border

Miller field
1.3 $MtCO_2$/yr

Sleipner

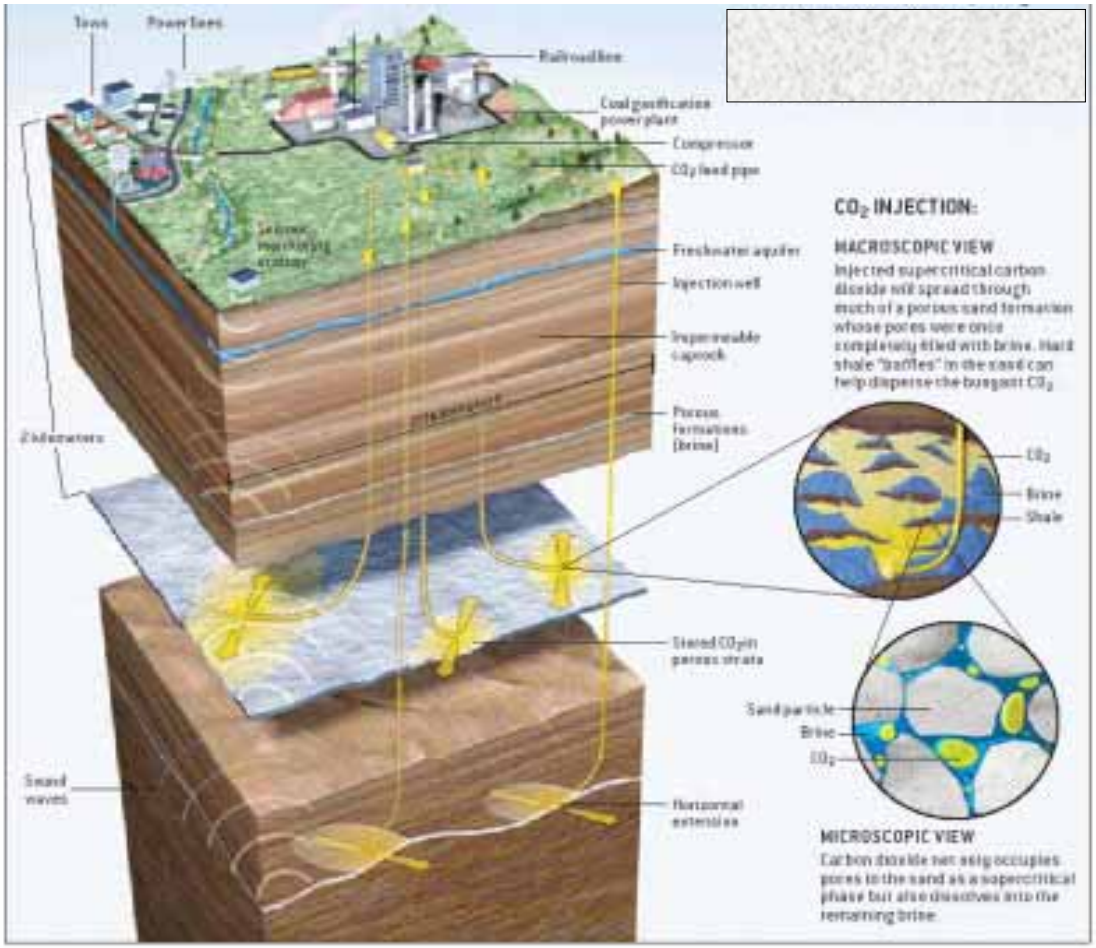
Peterhead
350 MW via H_2 turbines

Aberdeen, 30 miles south

A sequence of CCS opportunities

	CAPTURE	STORAGE
Near-term (0-5 years)	Concentrated CO_2 streams: 1) natural gas separation; 2) hydrogen for refineries, chemicals (NH_3, urea)	Enhanced oil recovery (EOR)
Mid-term (5-15 years)	Coal, petcoke, and natural gas power plants Biomass power plants? Coal-to-synfuels plants?	Aquifer storage
Long-term (15-25 years)	Coal-to-H_2 for distributed H_2 Direct capture from the air?	Mineral storage?

The Future Fossil Fuel Power Plant



Shown here: After 10 years of operation of a 1000 MW coal plant, 60 Mt (90 Mm^3) of CO_2 have been injected, filling a horizontal area of 40 km^2 in each of two formations.

Assumptions:
- 10% porosity
- 1/3 of pore space accessed
- 60 m total vertical height for the two formations.

- *Note:* Plant is still young.

A 1000 MW coal plant with CCS requires lifetime storage of 3×10^9 barrels of CO_2

CO_2 emissions rate: **6 $MtCO_2$/yr = 150,000 bbl/day.**

Assume: 1) 9 barrels CO_2/t, and 2) extra coal for CCS balances less than 100% CO_2 capture.

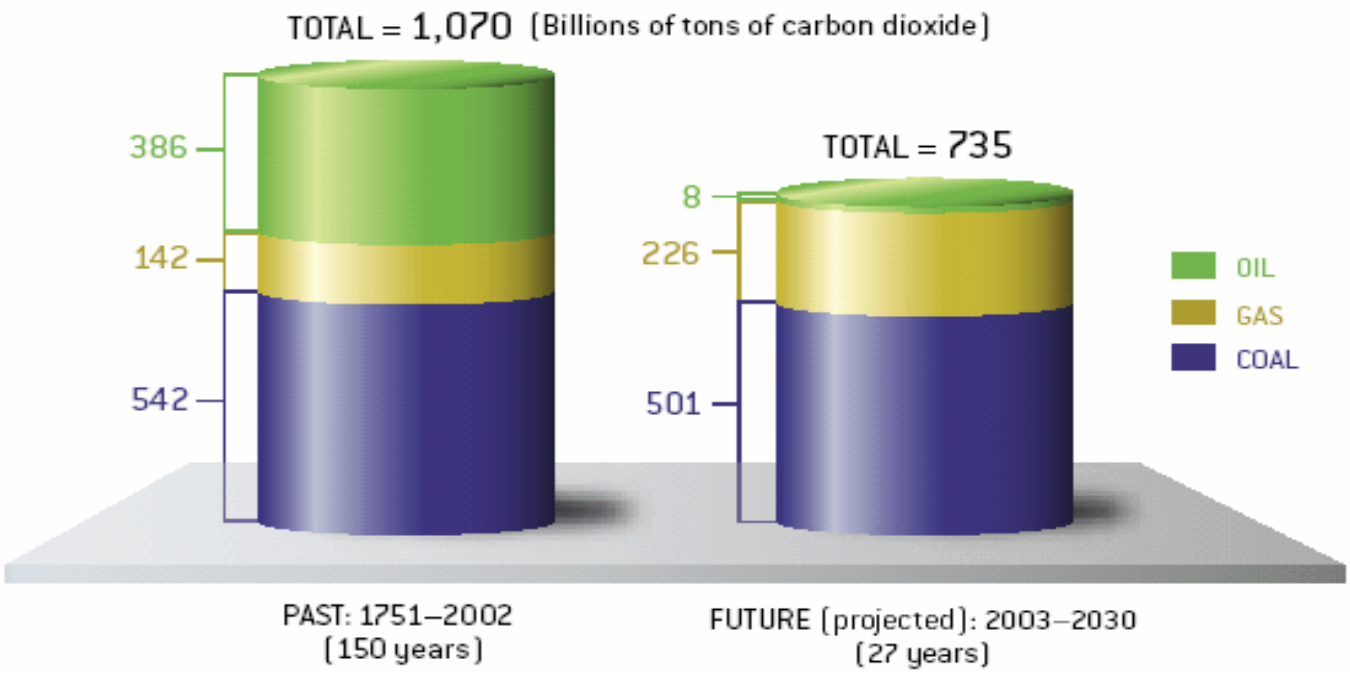
For 60-year plant lifetime***:*** **3 billion barrels.**

World's oil fields larger than 3 billion barrels: **80.**

Percent of total production from these 80 fields: **40%.**

This is familiar territory!

The Demography of Capital



Historic emissions, all uses

2003-2030 power-plant lifetime CO_2 commitments
WEO-2004 Reference Scenario.
Lifetime in years: coal 60, gas 40, oil 20.

Policy priority: Deter investments in new long-lived high-carbon stock: not only new power plants, but also new buildings.

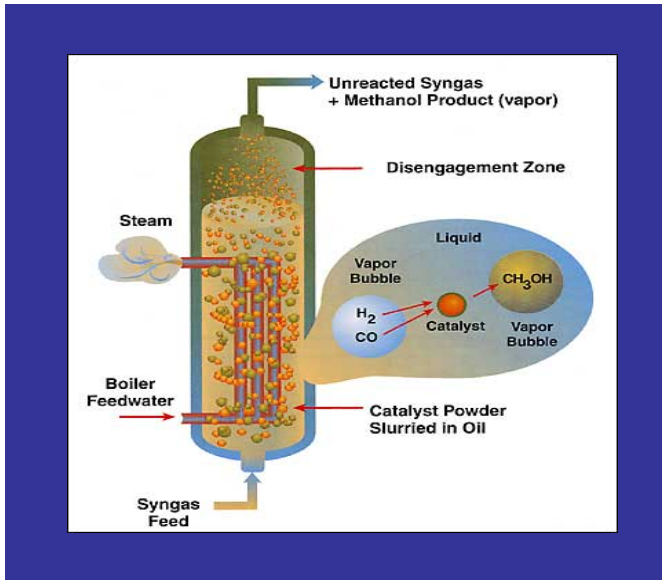
Credit for comparison: David Hawkins, NRDC

*Coal-based Synfuels with CCS**

Carbon capture and storage

Effort needed by 2055 for 1 wedge Capture and storage of the CO_2 byproduct at plants producing 34 million barrels per day of coal-based synfuels

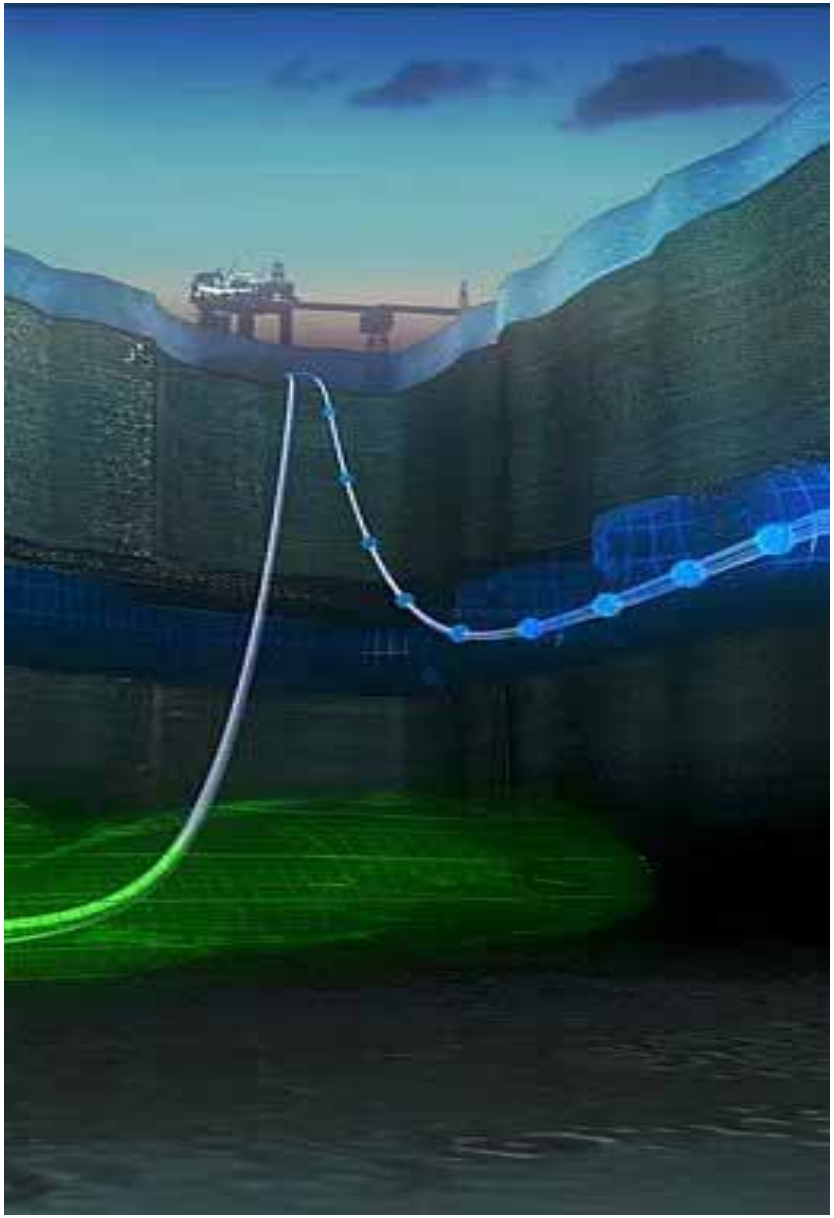
Assumption: half of C originally in the coal is captured, half goes into synfuels.



Graphics courtesy of DOE Office of Fossil Energy

Result: Coal-based synfuels have no worse CO_2 emissions than petroleum fuels, instead of doubled emissions.

Carbon Storage



Sleipner project, offshore Norway

Graphic courtesy of Statoil ASA

Effort needed by 2055 for 1 wedge:

3500 Sleipners @1 $MtCO_2$/yr

100 x U.S. CO_2 injection rate for EOR

A flow of CO_2 into the Earth equal to the flow of oil out of the Earth today

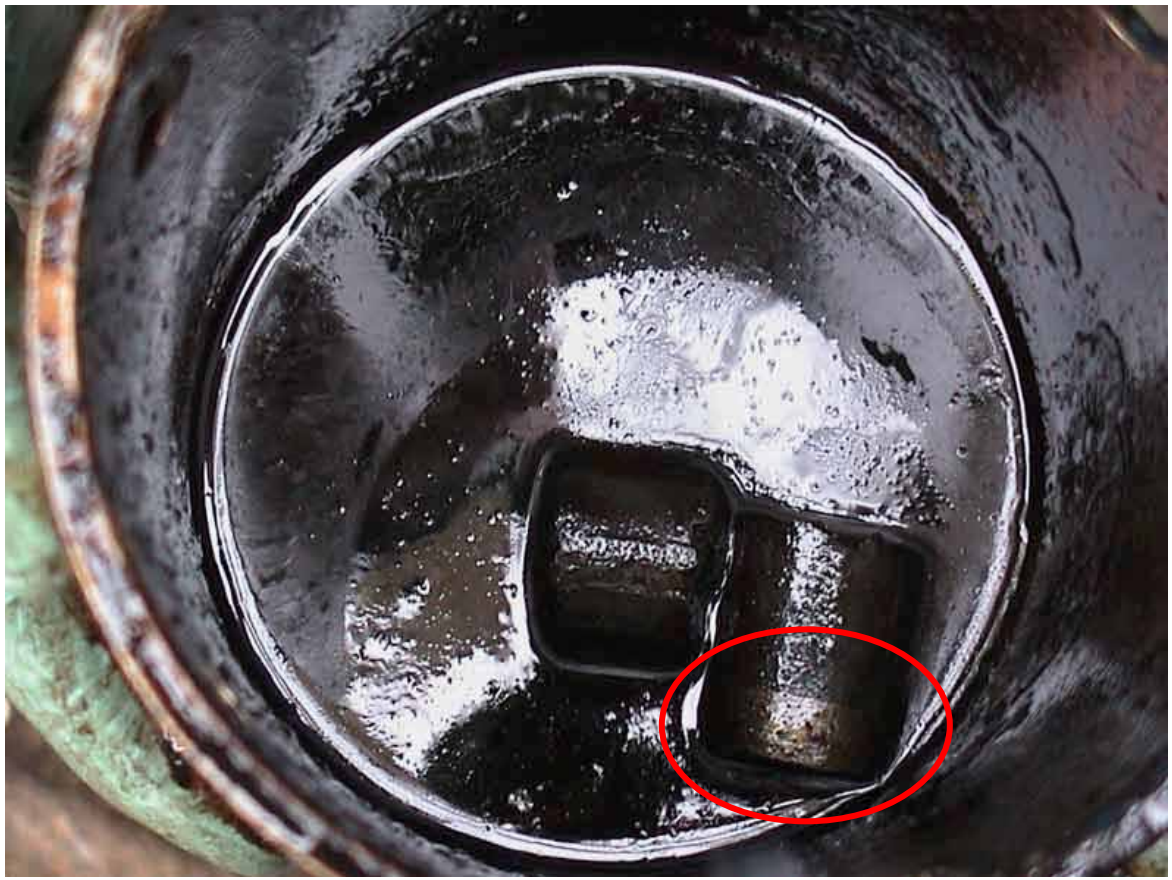
Graphic courtesy of David Hawkins

Leakage through old cement?

To establish a baseline with no exposure to CO_2, Prof. George Scherer (Princeton), used a Schlumberger tool to recover 19-year-old cement from between the casing and the well in Teapot Dome, Wyoming.

Other researchers are obtaining samples from the Permian Basin, West Texas, where cement has been exposed to CO_2 in brine for 30 years.

Our best sample



Cement adhered to outside casing was recovered at 933.3 m at a band of dense limestone. Scanning electron microscopy comparisons with original cement materials reveal that calcium leaching has occurred since injection 19 years ago.

Start Now to Gain Experience with the Permitting of Storage Sites

- *Public approval* – Openness, fairness, vigilance, responsiveness
- *Goals* – What constitutes victory? Retention time of 500 years?
- *Storage integrity: sudden vs slow escape*
  - Sudden escape could be catastrophic.
  - Slow escape from a few sites is inconsequential.
    - How can permitting assure no sudden escape yet promote early experience with a variety of sites?
- *Co-sequestration* – Can co-capture and co-storage allow avoidance of some pollution control (S, N, Cl, Hg)?

Uncertainties of permitting could dominate total sequestration costs.

The Interim Goal is Within Reach

Reasons for optimism that global emissions in 2055 need not exceed today's emissions:

- The world today has a terribly inefficient energy system.
- Carbon emissions have zero economic cost.
- Most of the 2055 physical plant is not yet built

Consensus Building via Wedges?

Advocates of particular wedges agree:

1. It is already time to act.
2. It is too soon to pick “winners.”
3. Subsidy of early stages is often desirable.
4. At later stages, markets help to choose the best wedges.
5. The best wedges for one country may not be the best for another.
6. The environmental and social costs of scale-up need attention.

Can a consensus for early action be built on stabilization wedges?

Leapfrogging and Wedges

"To leapfrog": To introduce advanced technology in developing countries *first*, industrialized countries *later*.

Some developing countries can leapfrog to advanced coal technology with CO_2 capture and storage.

The world learns faster, reducing everyone's costs.

The world compensates those who move first.

Leapfrogging is a path to globally coordinated mitigation.

Can We Do It?

People are becoming increasingly anxious about our limited understanding of the experiments we are performing on the only Earth we have…

…and are learning that there are ways to live more cautiously.

We should anticipate a discontinuity:

What has seemed too hard becomes what simply must be done.

Precedents include abolishing child labor, addressing the needs of the disabled, and mitigating air pollution.