The Critical Role of Energy Efficiency in Mitigating Global Warming

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Proceeding on Motion of the Commission
regarding an Energy Efficiency Portfolio Standard

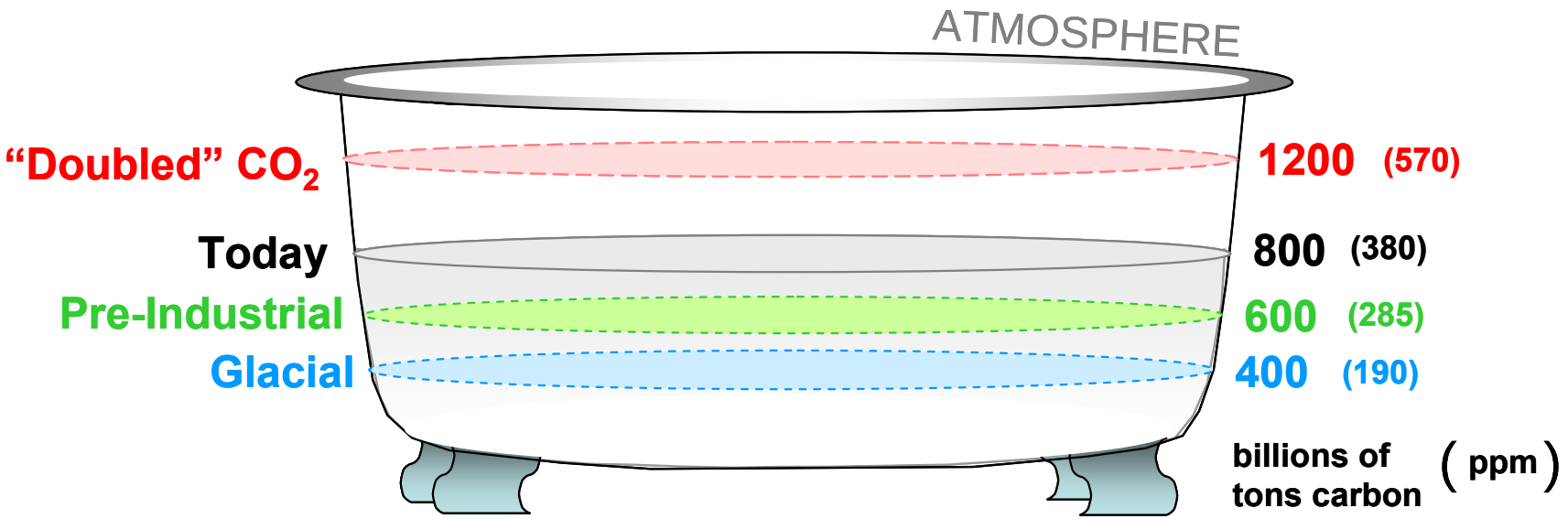
Albany Law School, Albany, New York
July 19, 2007

For further reading, see two papers by Steve Pacala and Rob Socolow:

1) "Stabilization Wedges: Solving the climate problem for the next 50 years with current technologies," *Science*, **305** (5686), August 13, 2004, 968-972 (and its Supporting Online Material).

2) "A plan to keep carbon in check," *Scientific American*, September 2006, 50-57.

Past, present, and potential future levels of carbon in the atmosphere

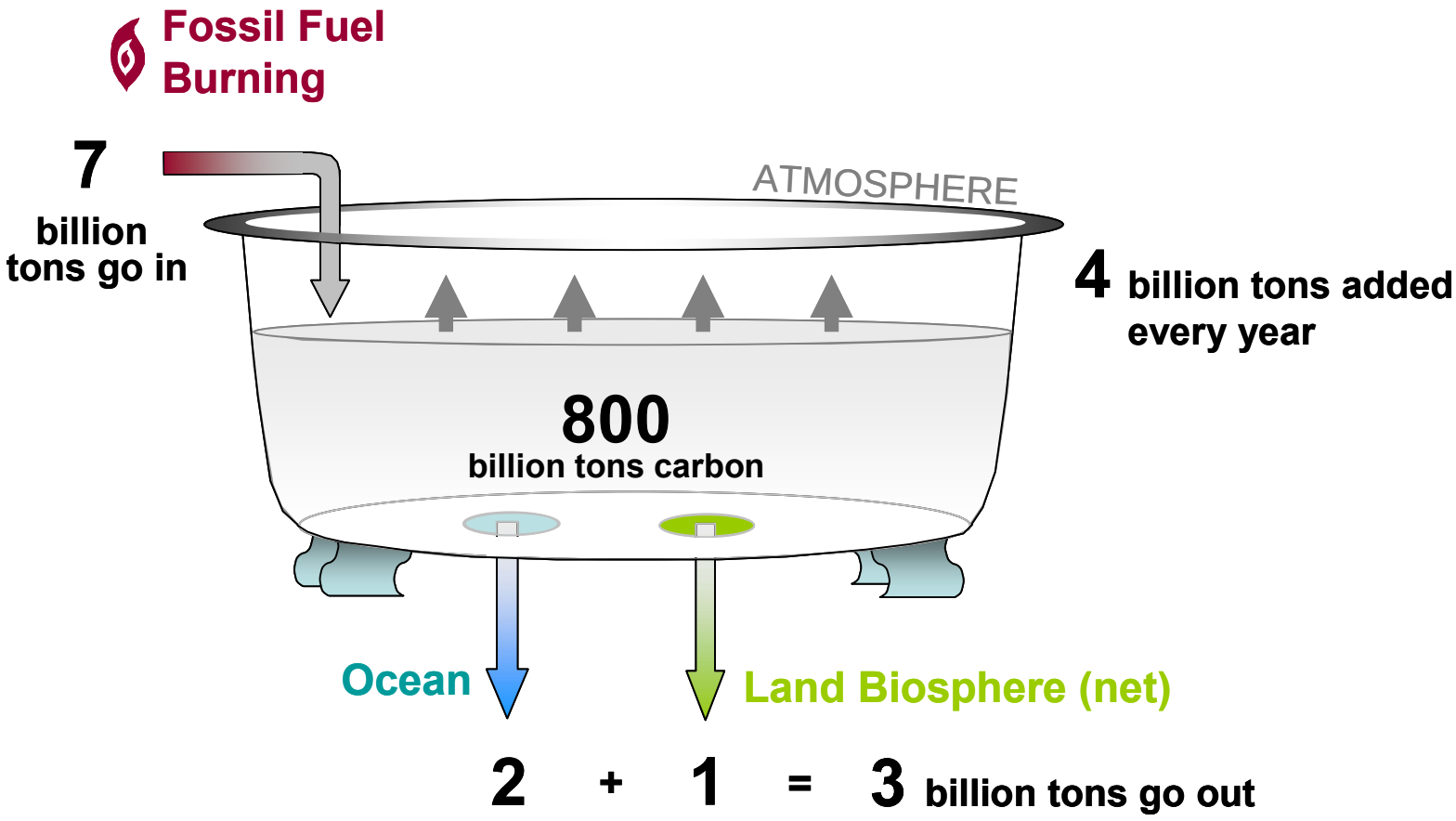


Rosetta Stone: Adding 2.1 billion metric tons of carbon (7.7 billion metric tons of CO_2) to the atmosphere as CO_2 raises its CO_2 concentration by one part per million.

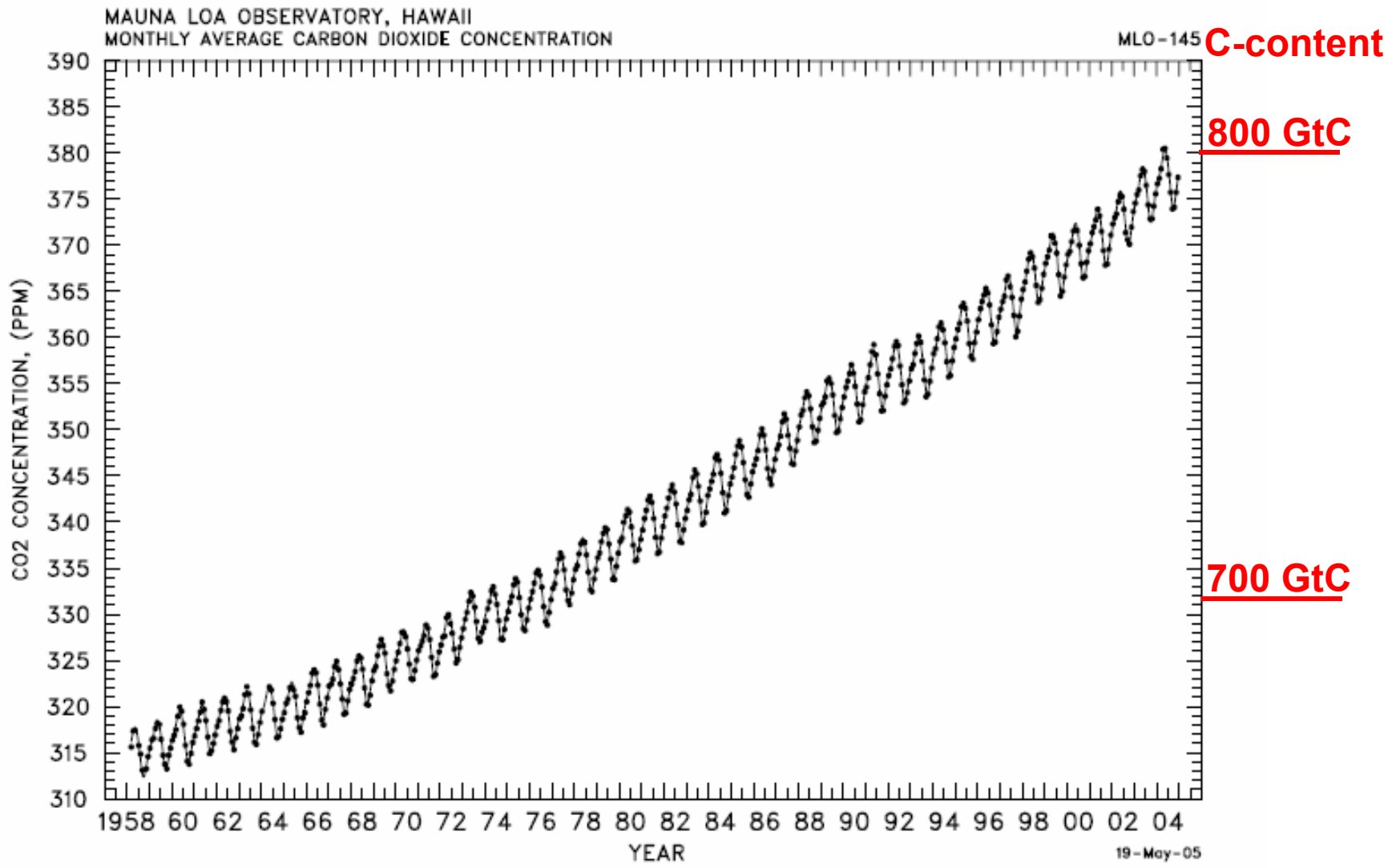
Antarctic Ice Core

*Source***:** Gabrielle Walker, **“**Frozen time,” *Nature;* Jun 10, 2004; 429, 6992; Research Library Core, pg. 596

About half of the carbon we burn stays in the atmosphere for centuries

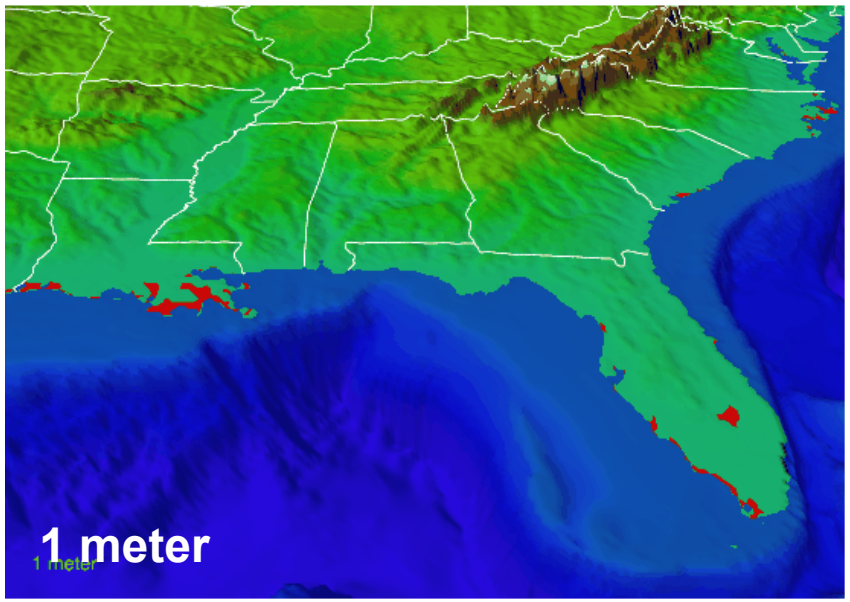


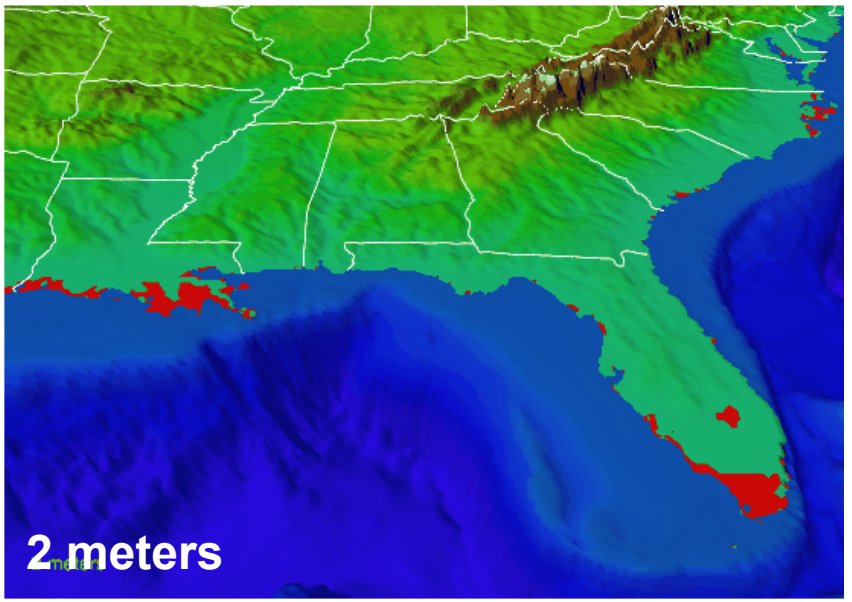
Mauna Loa CO_2 data. 1958-2004

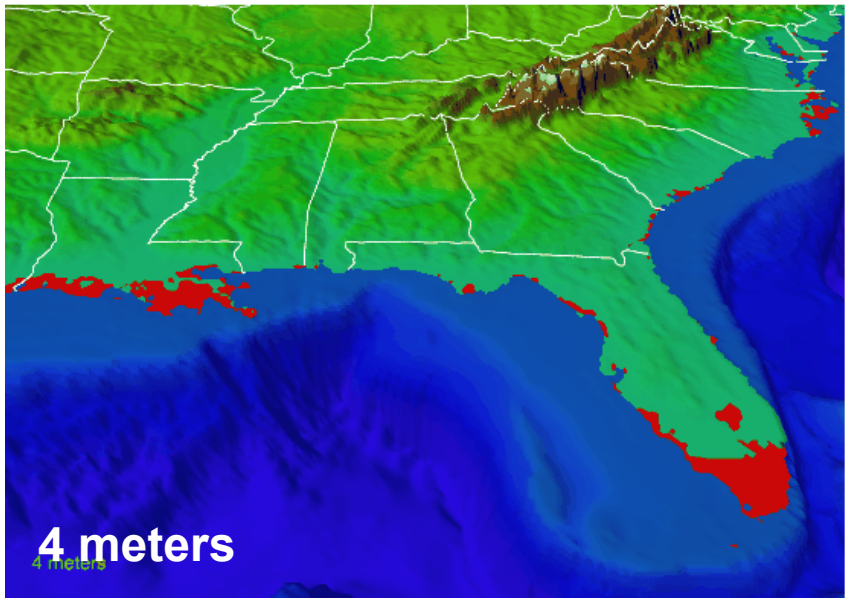


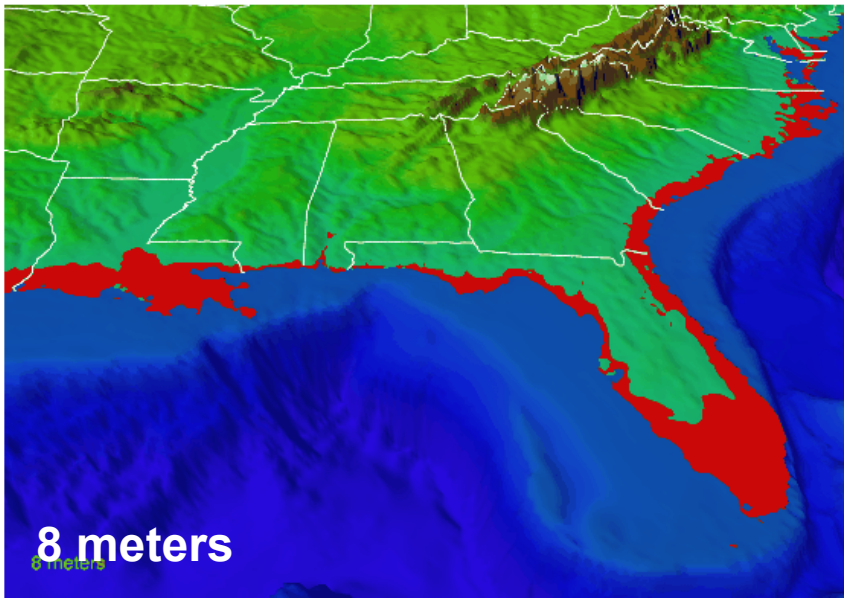
Source: Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center
http://cdiac.ornl.gov/trends/co2/graphics/mlo145e_thrudc04.pdf

Sea Level Rise



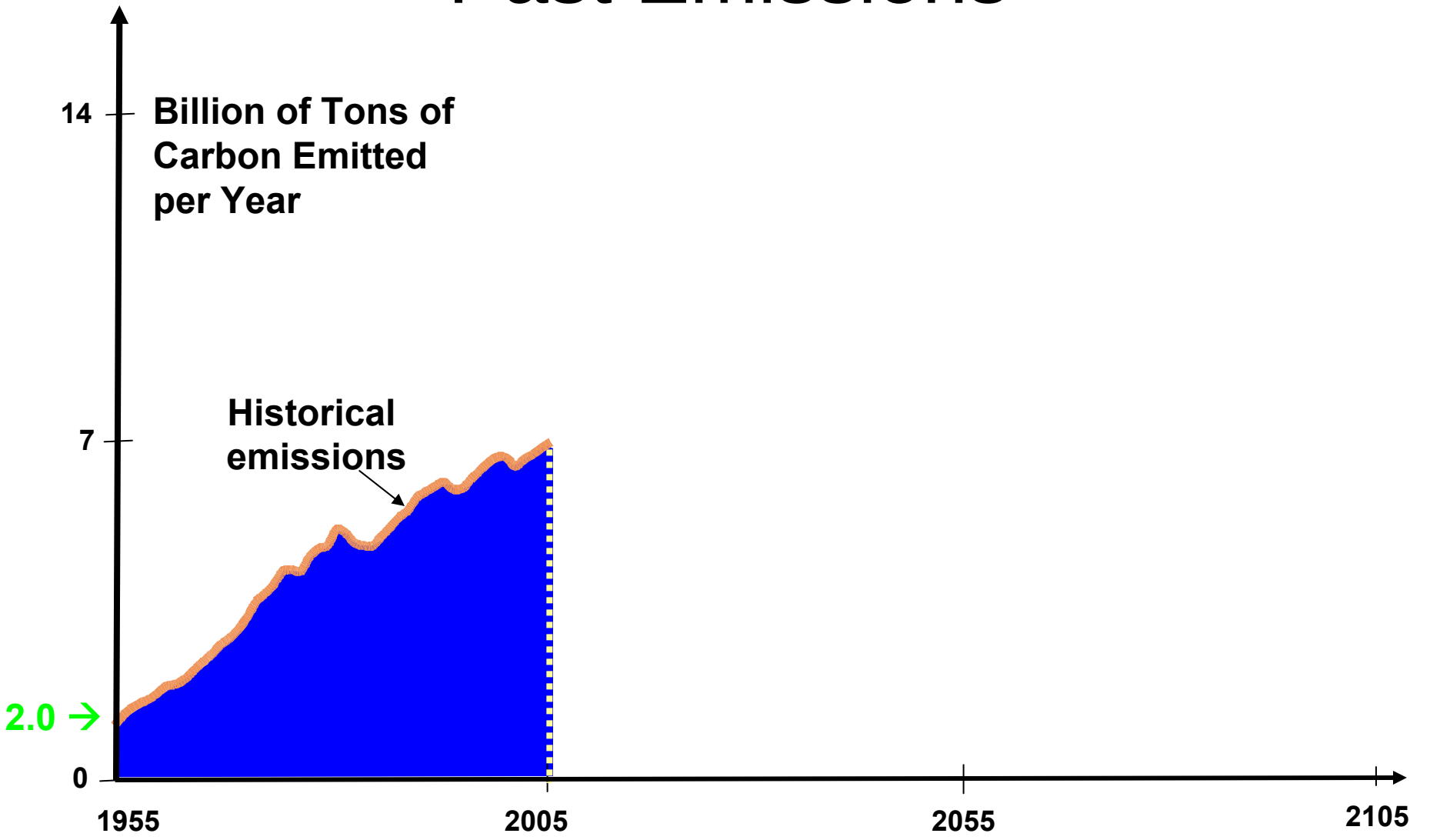




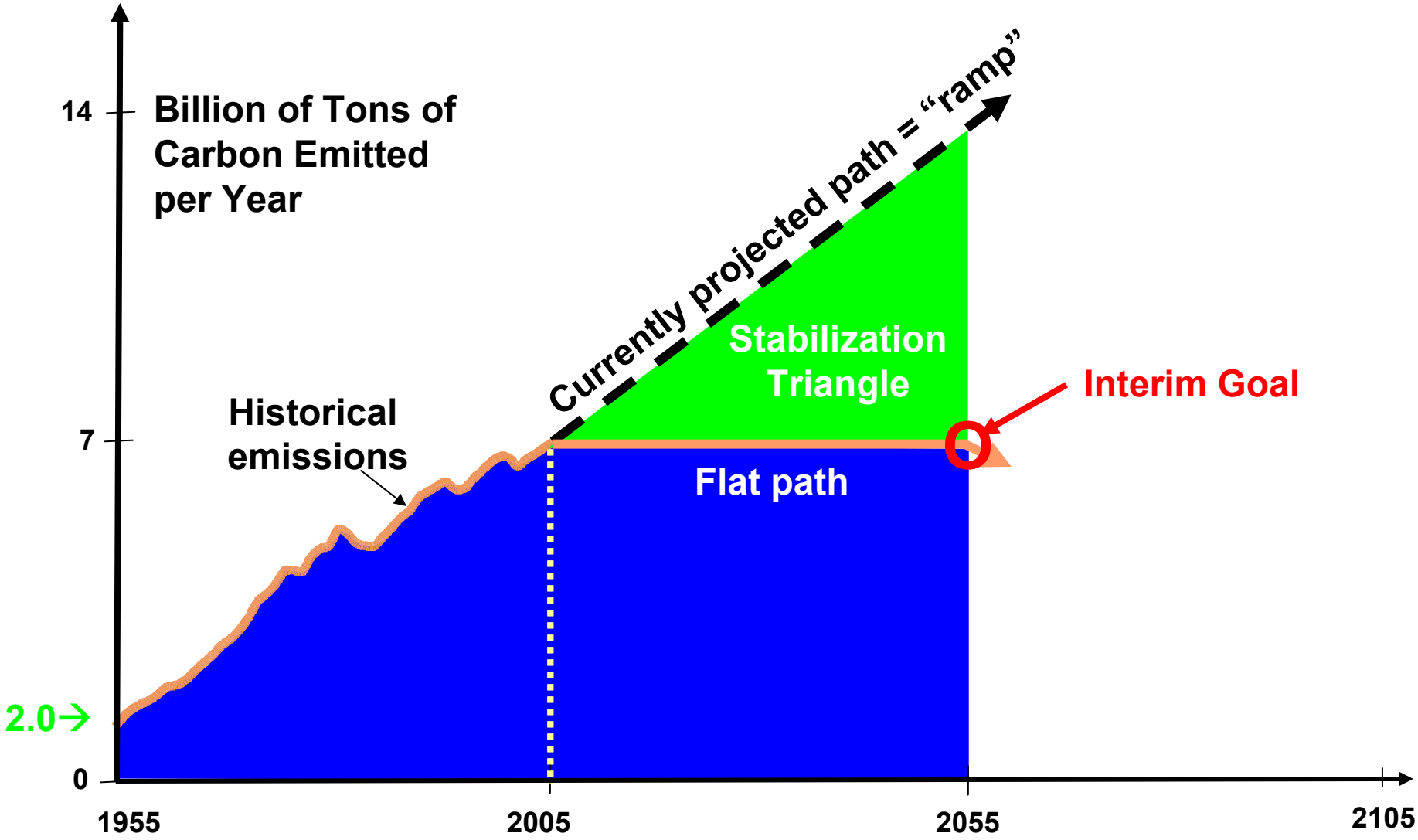


The Wedges Model

Past Emissions

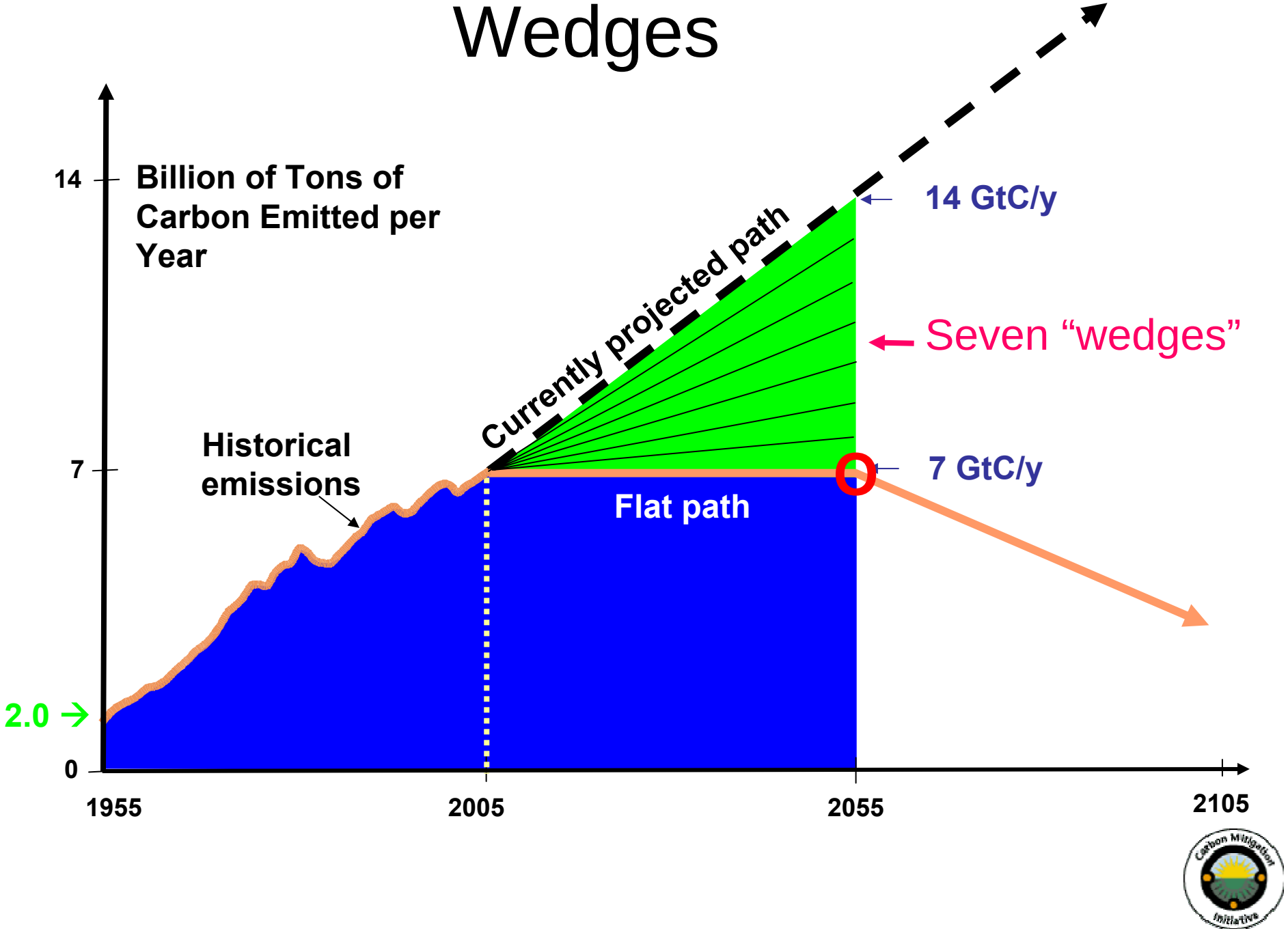


The Stabilization Triangle



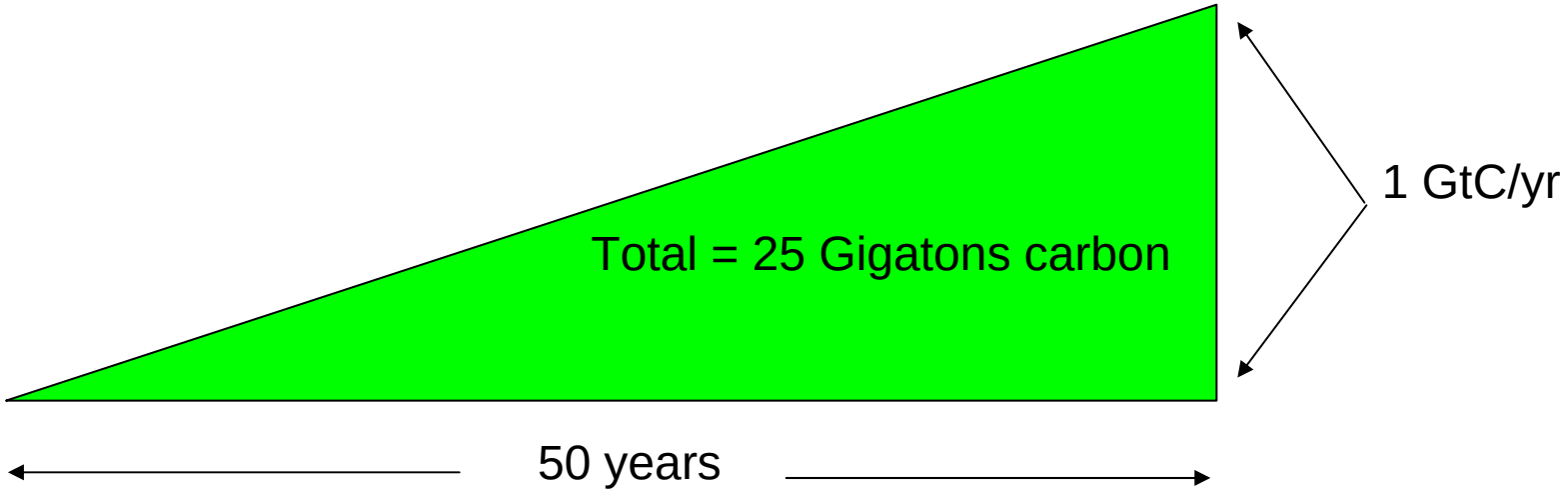
Today and for the interim goal, global per-capita emissions are ≈ 1 tC/yr.

Wedges


14
Billion of Tons of Carbon Emitted per Year
7
2.0
0
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.



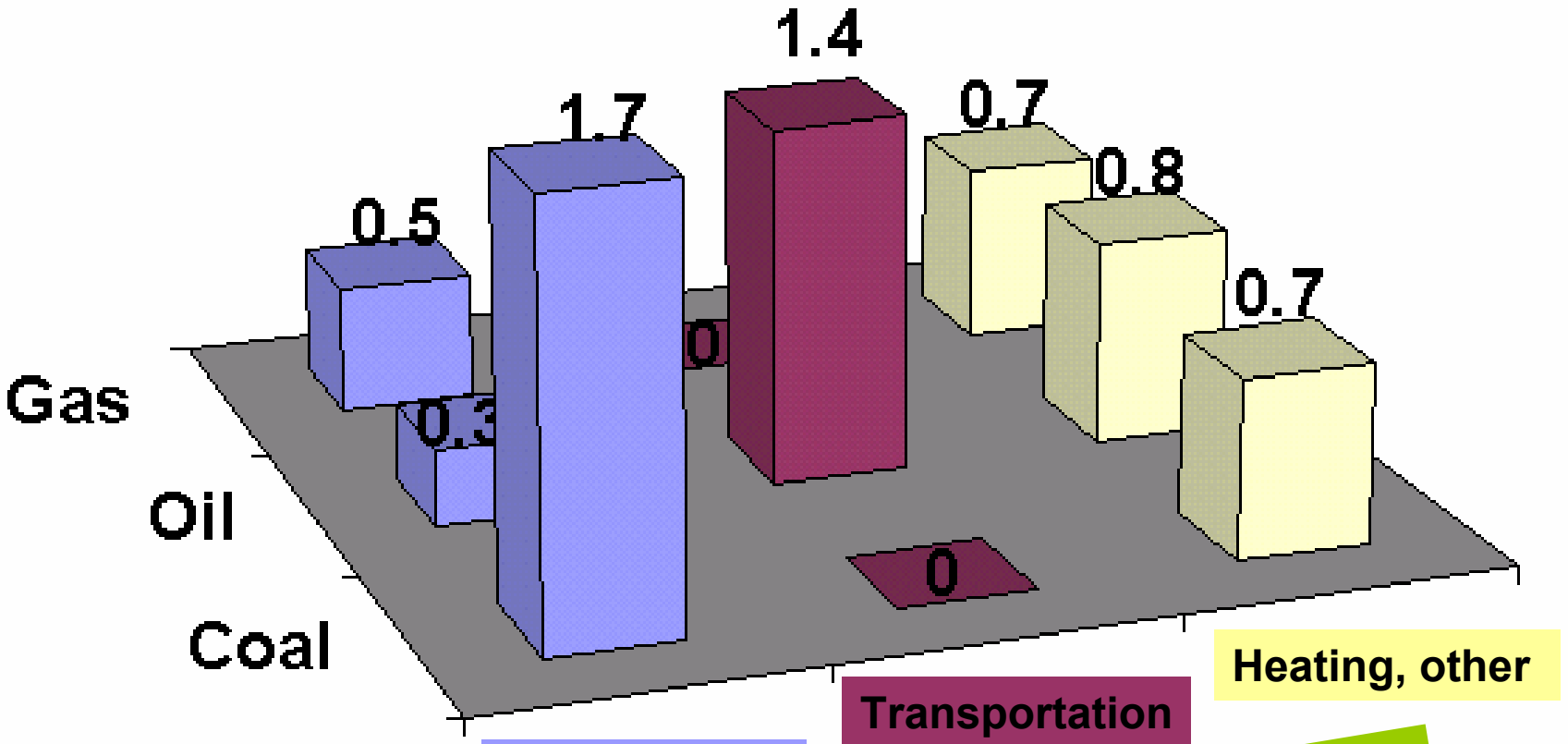
Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

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

Now we go on a hunt for wedges

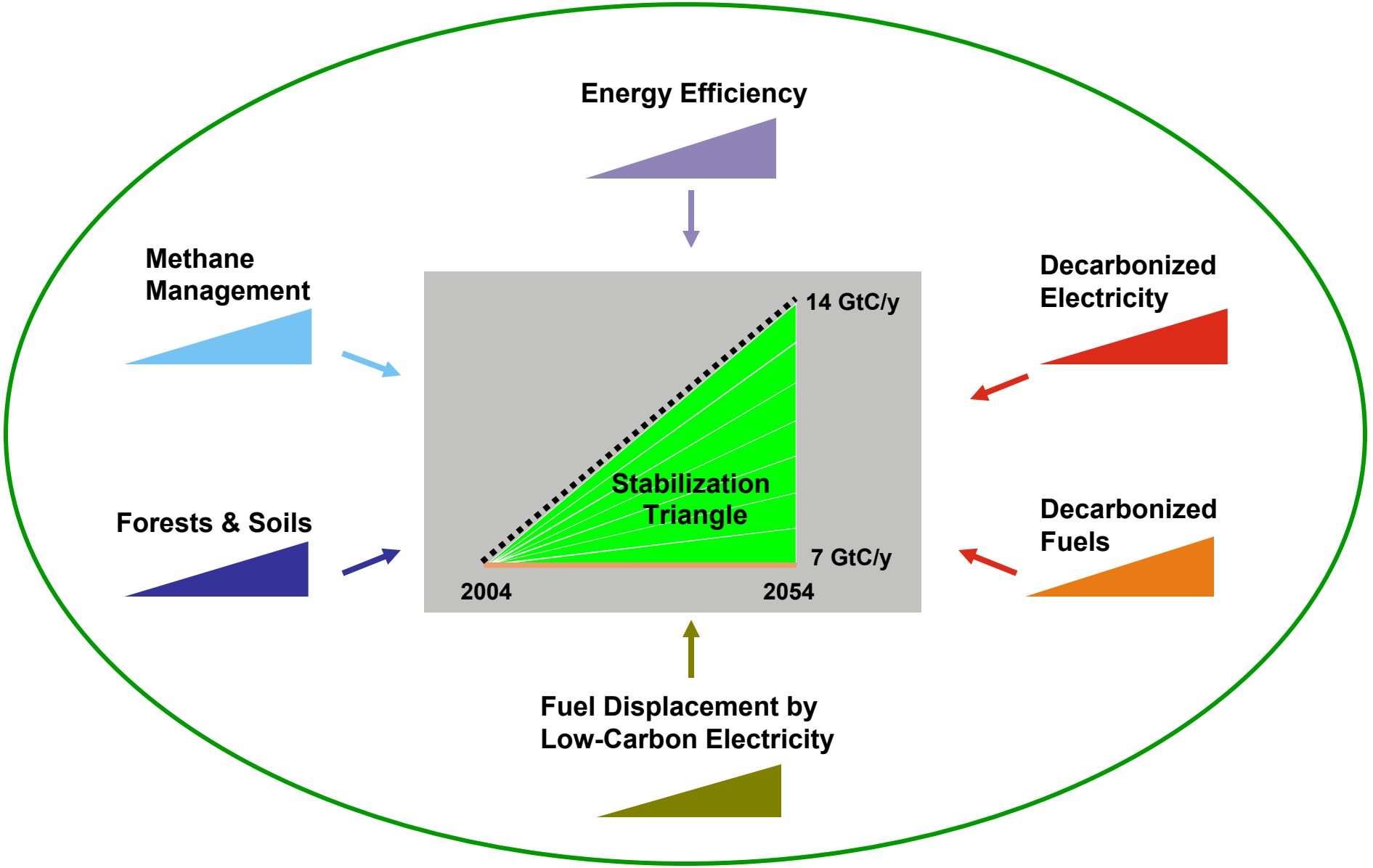
CO_2 Emissions by Sector and Fuel

Allocation of 6.2 GtC/yr 2000 global CO_2 emissions

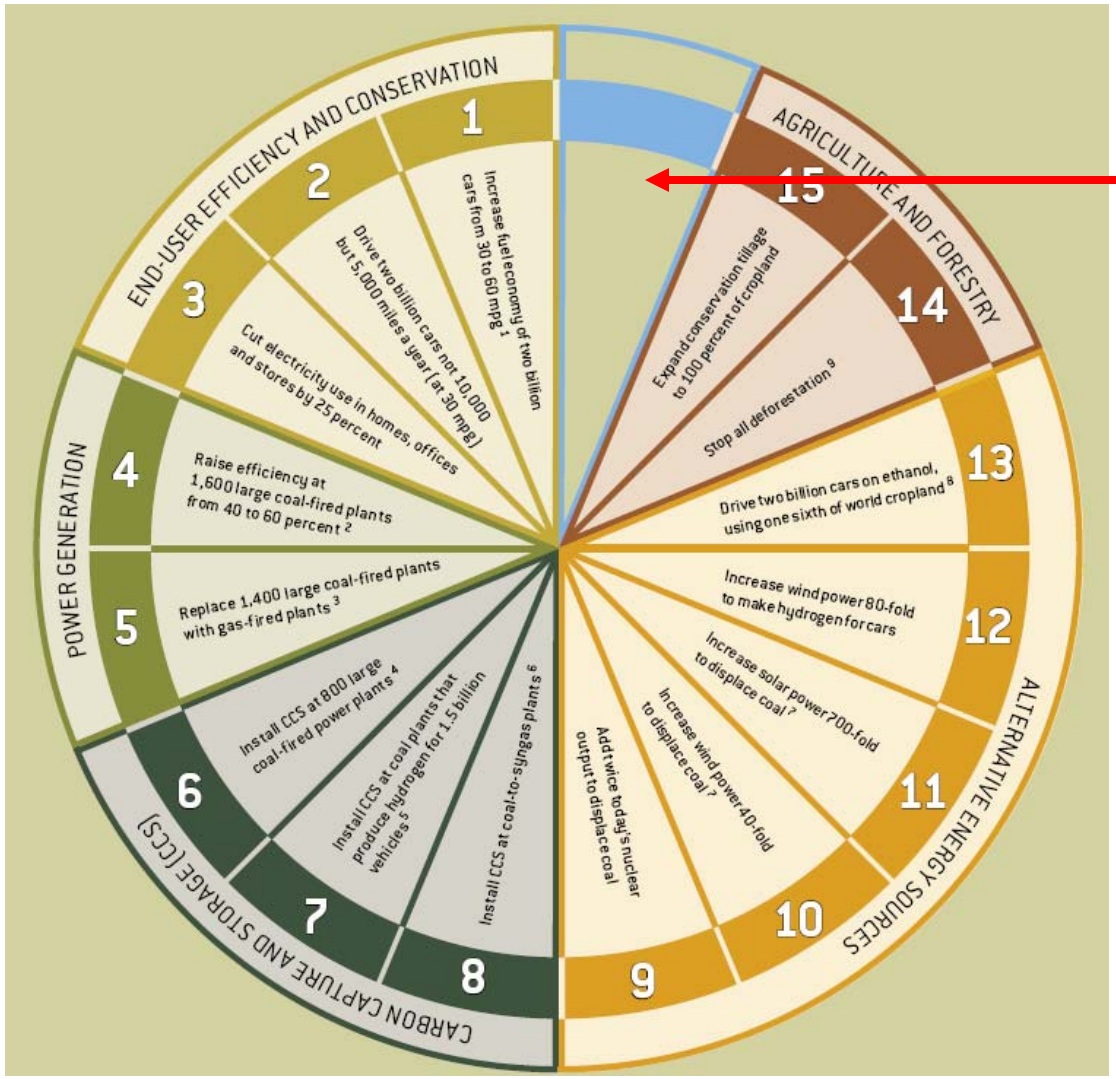


Electricity: 40%; fuels used directly: 60%.

Fill the Stabilization Triangle with Seven Wedges



15 Ways to Make a Wedge



Industrial energy efficiency
"Upstream" investment
Concentrated solar power
Methane mitigation
Population

Not commercial, so not included:

Fusion

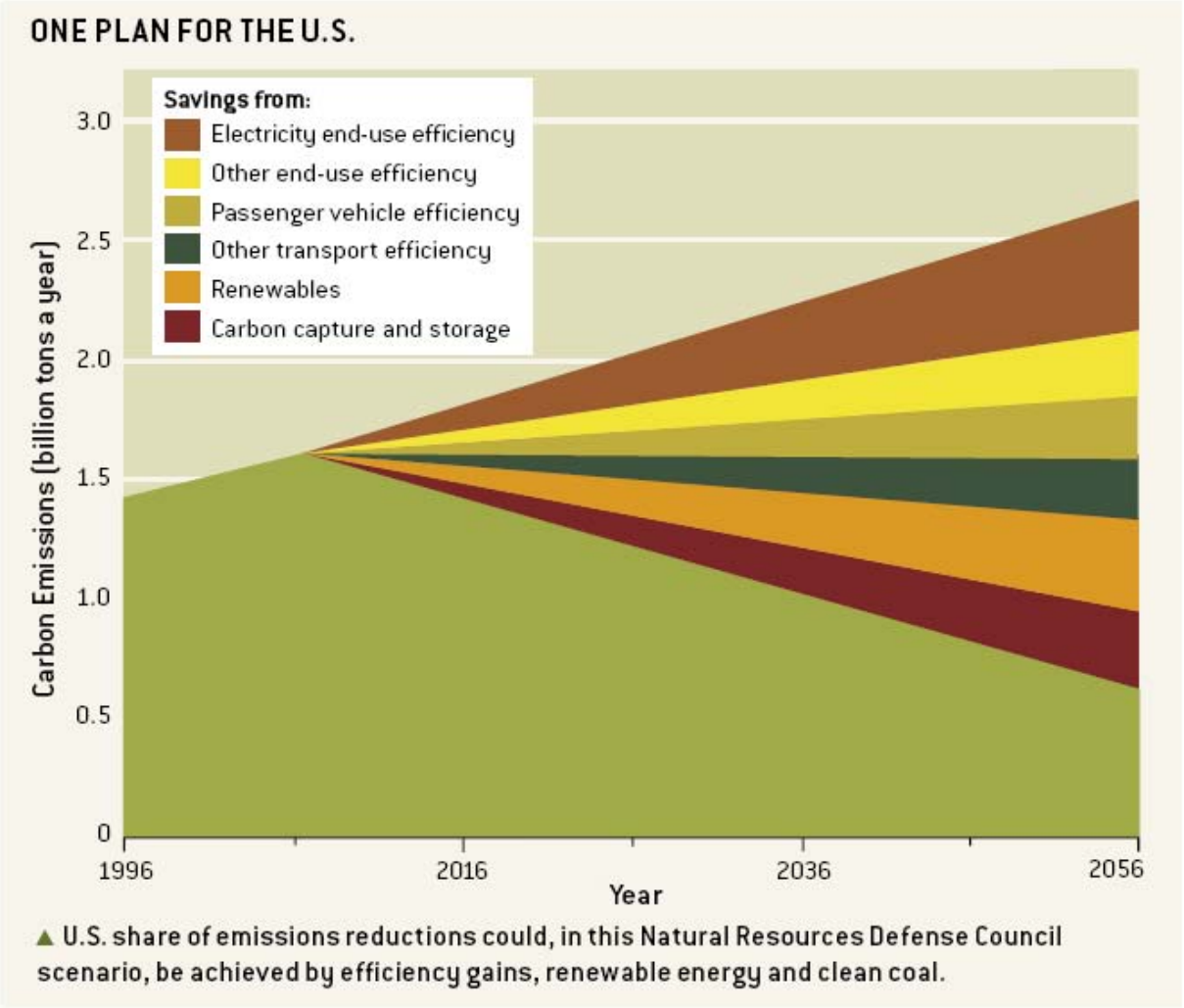
Capture of CO_2 from air

Source; Socolow and Pacala, *Scientific American*, September 2006, p.54

“The Wedge Model is the IPOD of climate change: You fill it with your favorite things.”

David Hawkins, NRDC, 2007.

U.S. Wedges



Source: Lashof and Hawkins, NRDC, *in* Socolow and Pacala, *Scientific American*, September 2006, p. 57

Every wedge strategy can be implemented well or poorly

Every wedge has a dark side, generating opposition that thwarts implementation.

Conservation	Regimentation
Renewables	Competing uses of land
Nuclear power	Nuclear war
“Clean coal”	Mining: worker and land impacts

“Solution science” is emerging: the study of the environmental and social costs and benefits of stabilization strategies.

Priority #1: Invent a smart-carbon post-industrial society

The post-industrialized age features unprecedented private consumption. In industrialized countries more than 60% of oil is used in vehicles, more than 60% of electricity in buildings.

The CO2 mitigation challenge is a challenge to both energy supply systems and the energy end-use systems.

Efficient Use of Fuel

Effort needed by 2055 for 1 wedge:

Note: 1 car driven 10,000 miles at 30 mpg emits 1 ton of carbon.

2 billion cars driven 10,000 miles per year at 60 mpg instead of 30 mpg.

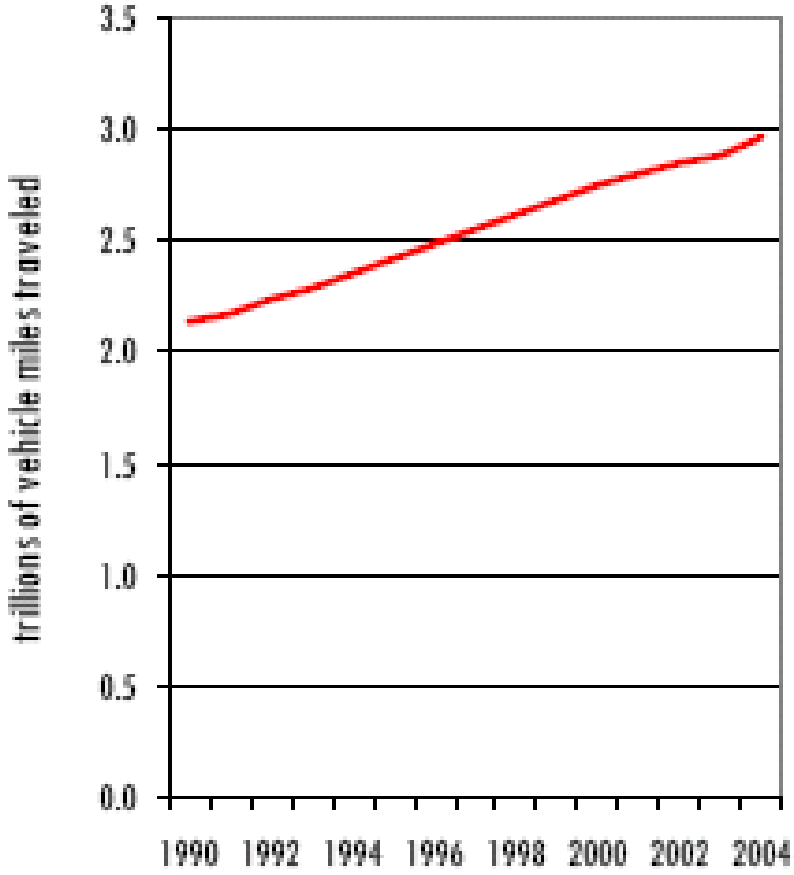
2 billion cars driven, at 30 mpg, 5,000 instead of 10,000 miles per year.

Property-tax systems that reinvigorate cities and discourage sprawl

Video-conferencing

U.S. vehicle-miles traveled,1990-2004

Figure P. Trends in Vehicle Miles Traveled, 1990-2004[62]



Source: U.S. PIRG Education Fund, 2007. *The Carbon Boom: State and National Trends in Carbon Dioxide Emissions Since 1990, April 2007* (44 pp.), p. 27.

Efficient Use of Electricity

motors

lighting

cogeneration

Effort needed by 2055 for 1 wedge:

25% reduction in expected 2055 electricity use in commercial and residential buildings.

Assumes: 40% of global CO2 continues to be emitted at power plants and 70% of electricity is used in buildings.

Target: Commercial and multifamily buildings, worldwide.

Five ways to cut 1 tonC/yr by half

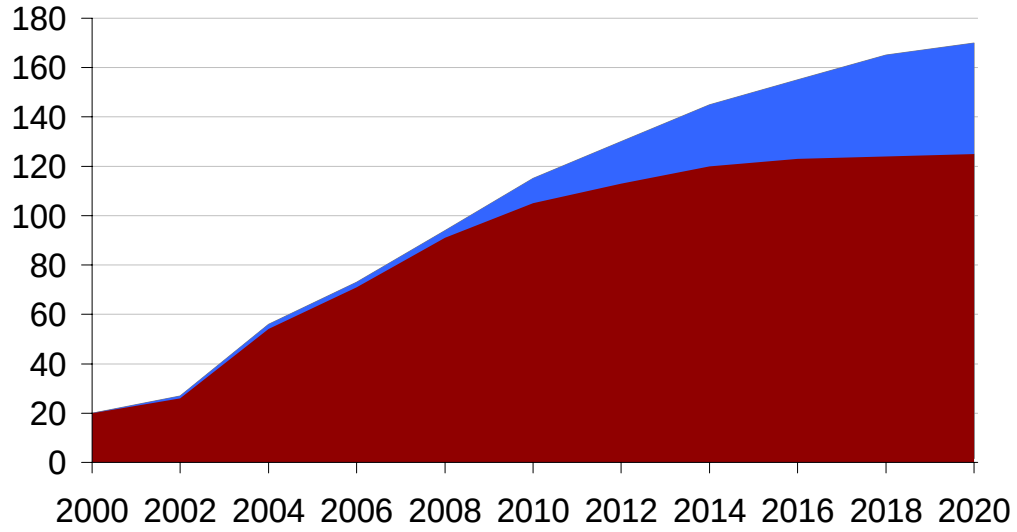
	1 ton carbon/yr	Cut in half	How?
a) Drive	10,000 mi, 30 mpg	60 mpg	Lighter, less power(?)
b) Drive	10,000 mi, 30 mpg	5,000 miles	Live closer to work
c) Fly	10,000 miles	5,000 miles	Video-conference
d) Heat home	Nat. gas, av. house, av. climate	Insulate, double-pane windows, fewer leaks, condensing furnace,	
e) Lights	300 kWh/month when all-coal power (600 kWh/month, NJ)	All-coal power: add CCS* at 60% of the plants, or permanently replace twenty 60W incandescent bulbs, lit 6 hrs/day, with compact fluorescents.	

*CCS = CO_2 capture and sequestration

China Appliance Standards

Business as Usual: CO_2 emissions from air conditioners in 2020 are 9x those in 2000.

New Air Conditioner Standard: Down 25% (45 $MtCO_2$/yr) in 2020.



50 million new, efficient air conditioners per year in 2020

To achieve efficiency

Measure, measure, measure (institutionalize skepticism: trust, but verify)

For existing buildings, go building by building

For new buildings, anticipate the undoing of good intentions (e.g., interior design and the aesthetics of daytime mood lighting)

Use policy:

- Performance standards (appliance efficiency, interior temperature, light levels)
- Bounty for old stuff (cars, appliances)
- Time-of-day pricing and congestion charges(!)
- Lifeline rates

Utility economics: decouple revenue from sales

Anticipate increases in kWh consumption via shifts from fuel to power (hybrid vehicle, heat pump)

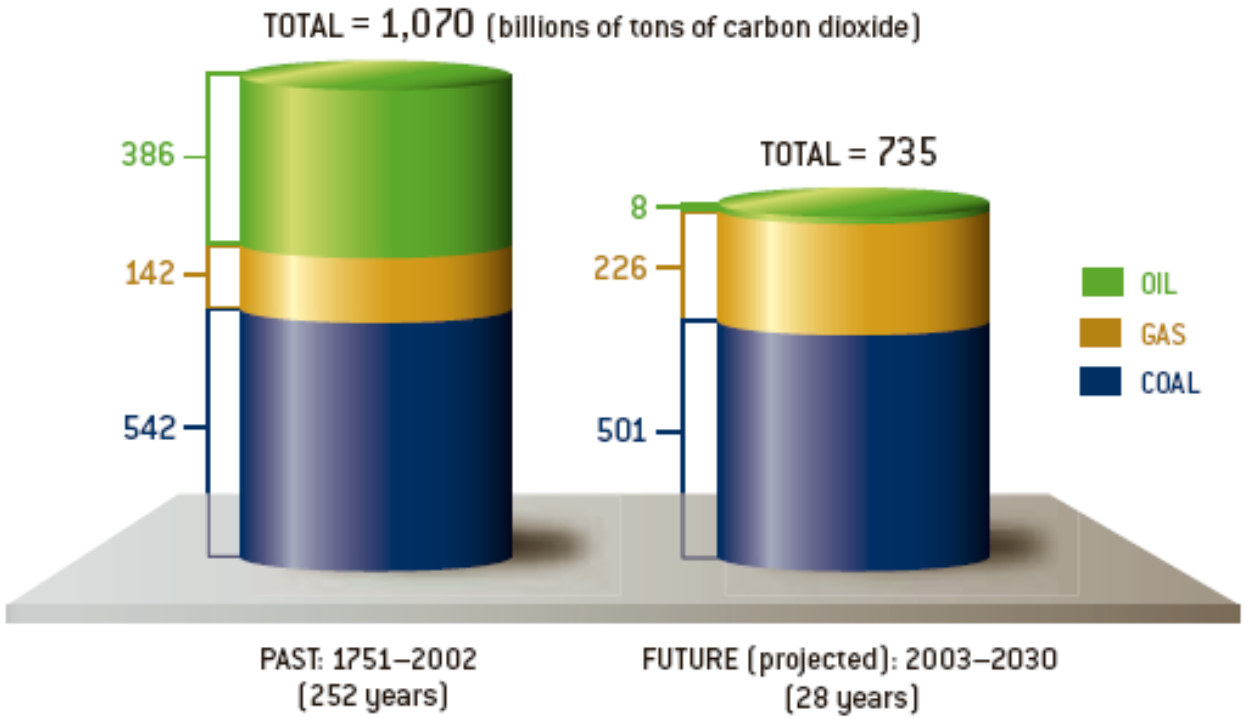
Priority #2: Redirect the Rush to Coal

700 GW, with CO_2 vented, will emit a billion tons of carbon as CO_2 each year. So, one wedge results from not building these plants.

The IEA Reference Scenario projects the construction of 1800 large coal plans (1 GW) world-wide by 2030.

More coal will be dug out of the ground to feed these plants over their lifetimes than has been dug out for all purposes until now.

Emission Commitments from Capital Investments



Historic emissions, all uses

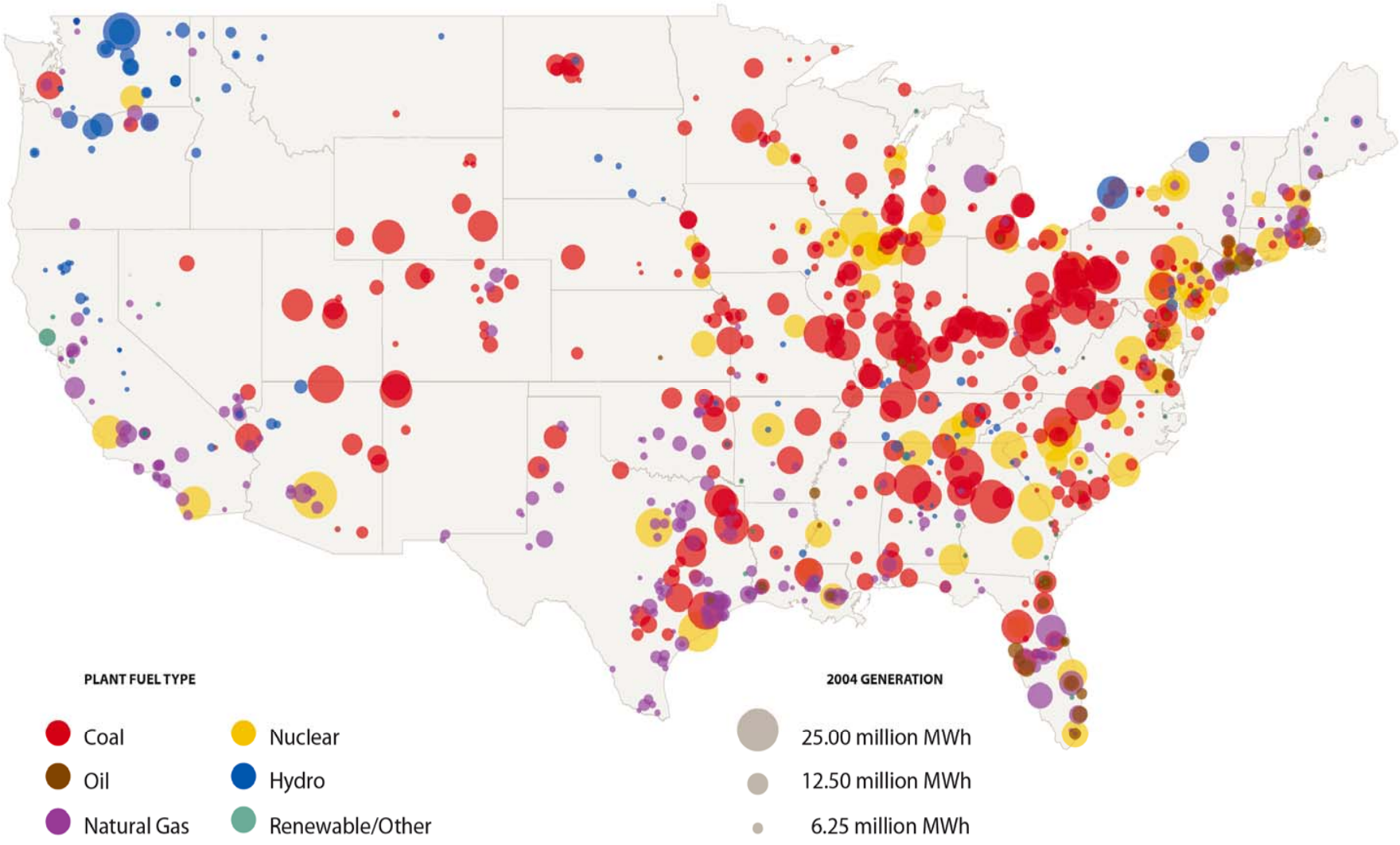
2003-2030 power-plant lifetime CO_2 commitments
WEO-2004 Reference Scenario.
Lifetime in years: coal 60, gas 40, oil 20.

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

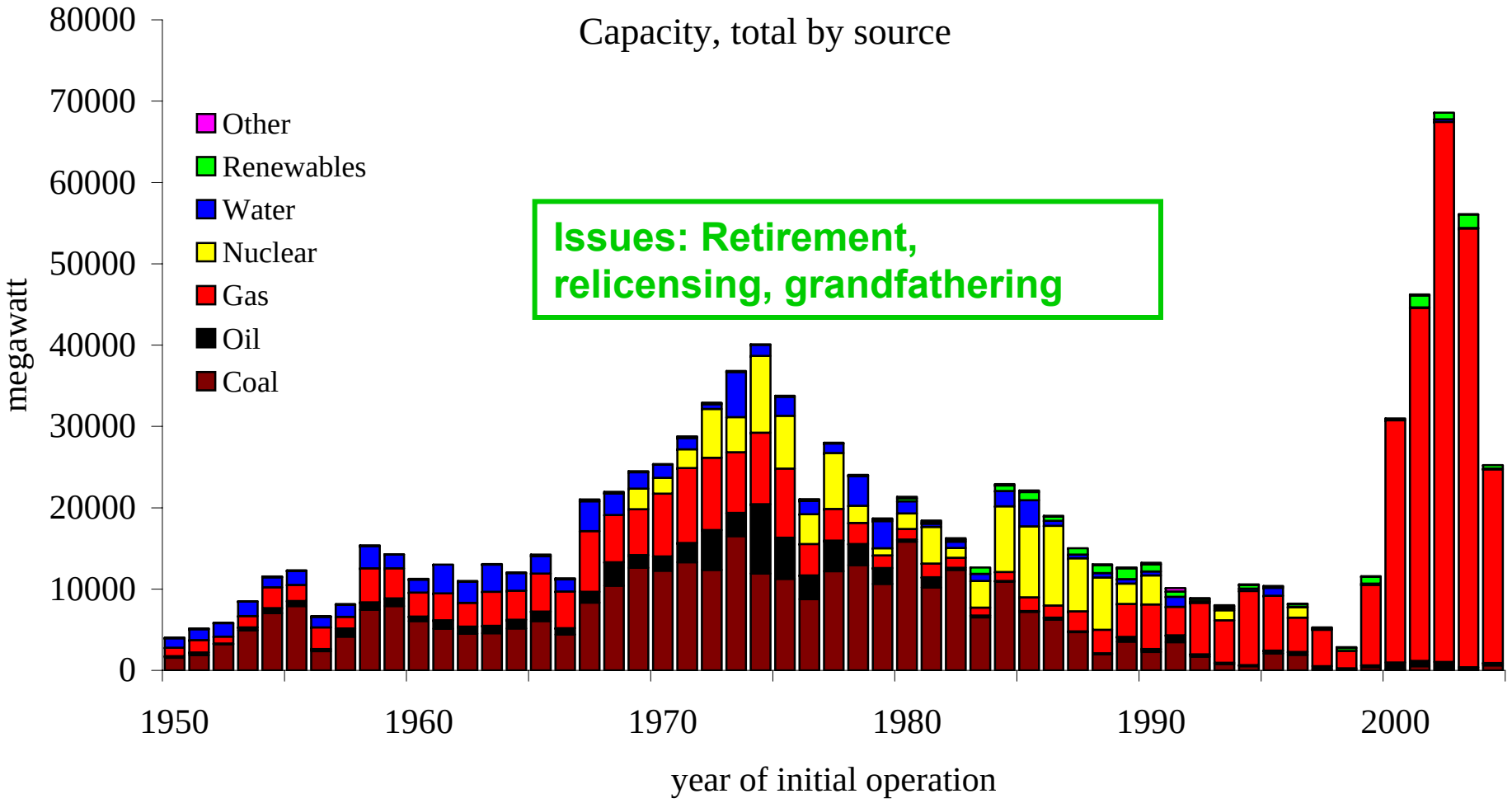
***Needed*: "Commitment accounting."**

Credit for comparison: David Hawkins, NRDC

U.S. Power Plants by Fuel Type



U.S. Power Plant Capacity, by Vintage



Source: EIA

Wind Electricity

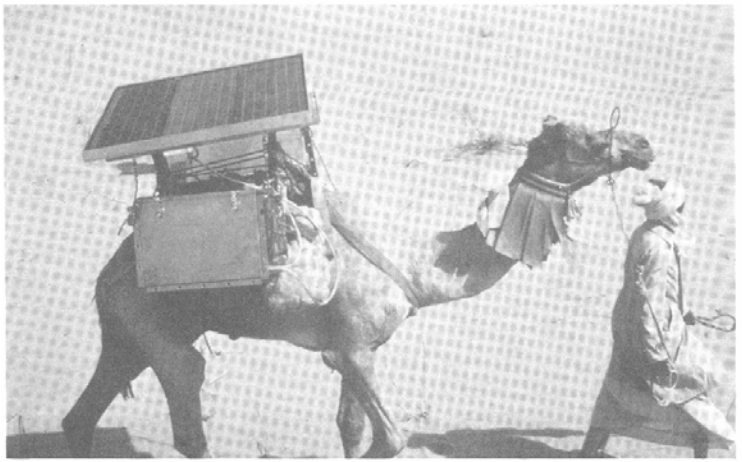
Effort needed by 2055 for 1 wedge:

One million 2-MW windmills displacing coal power.

2006: 75,000 MW (4%)

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

Photovoltaic Power



Effort Needed by 2055 for one wedge:

2000 GW_{peak} (400 times current capacity)

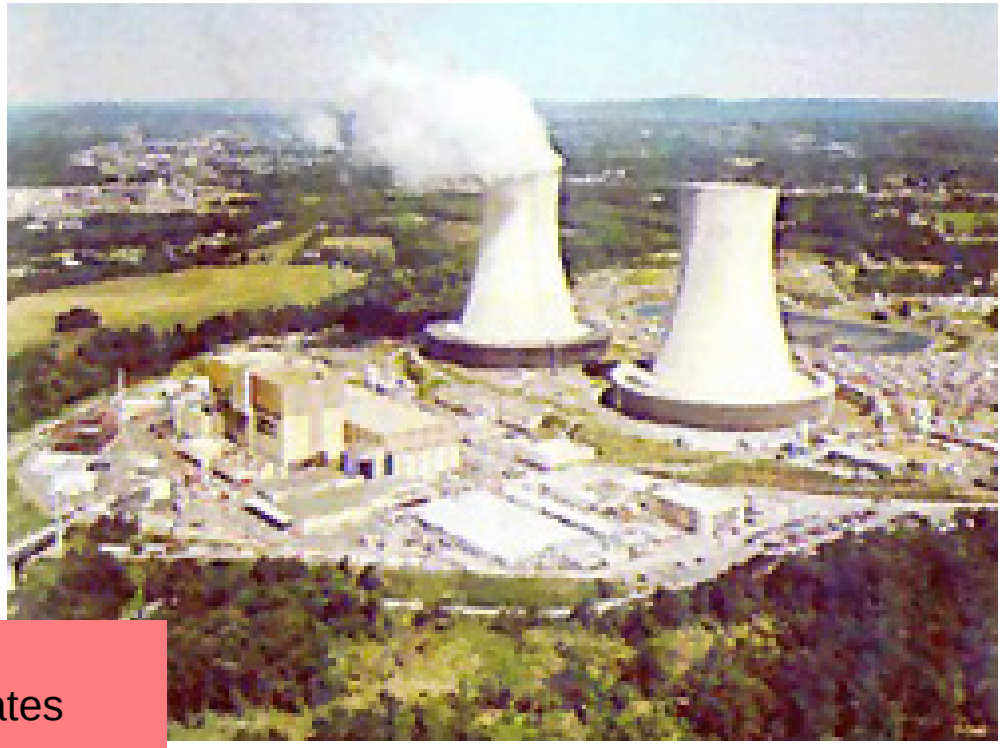
2 million hectares

Graphics courtesy of DOE Photovoltaics Program

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.

The Future Fossil Fuel Power Plant

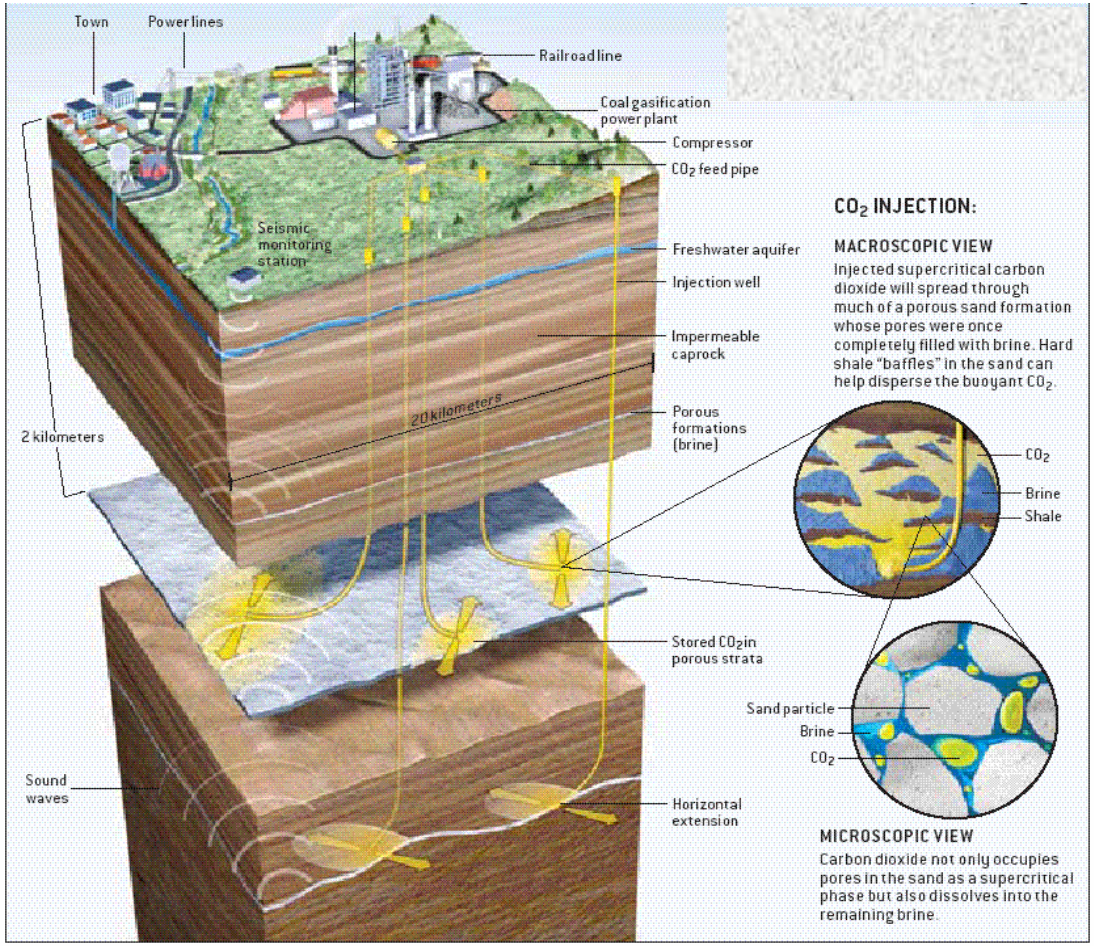


ILLUSTRATION BY DAVID FIERSTEIN; CONCEPT BY JULIO FRIEDMANN Lawrence Livermore National Laboratories

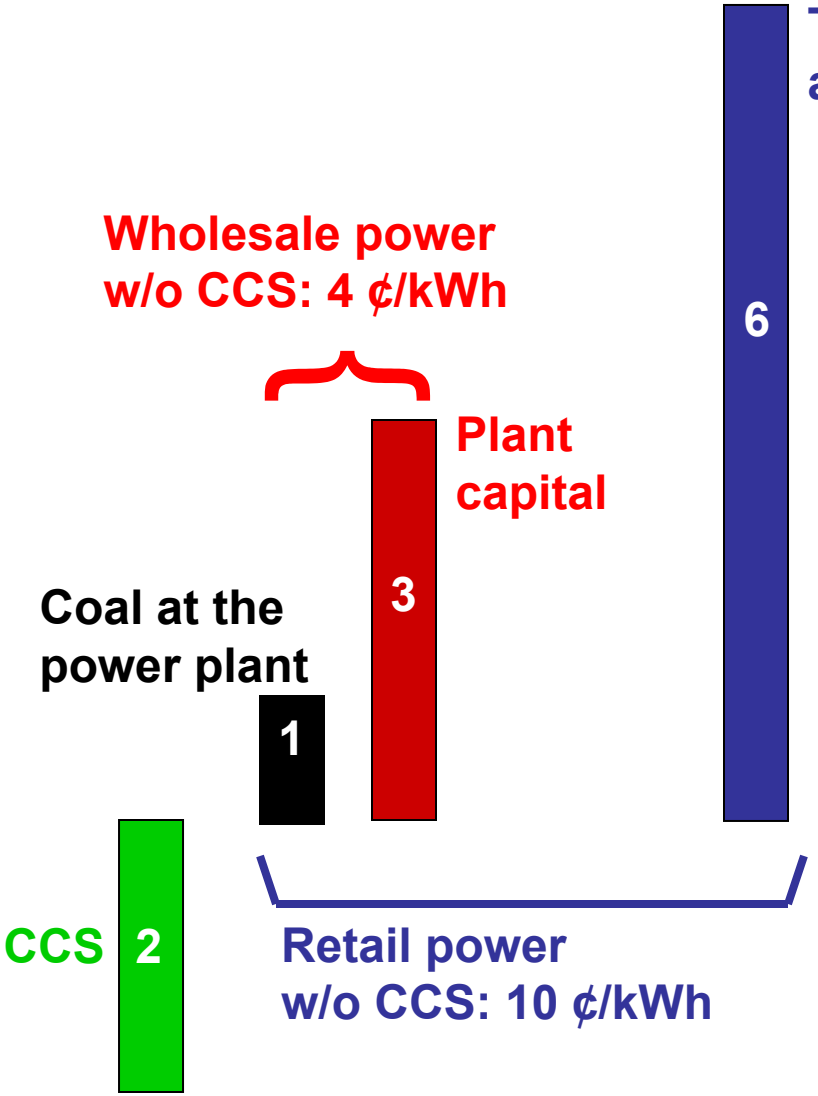
Shown here: After 10 years of operation of a 1000 MW coal plant, 60 Mt (90 Mm^3) of CO_2 have been injected, filling a horizontal area of 40 km^2 in each of two formations.

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

- *Note:* Plant is still young.

Note: Injection rate is 150,000 bbl(CO_2)/day, 3 billion barrels over 60 years.

$100/tC ≈ 2¢/kWh induces CCS. Three views.



A coal-gasification power plant can capture CO_2 for an added 2¢/kWh ($100/tC). This:

triples the price of delivered coal;

adds 50% to the busbar price of electricity from coal;

adds 20% to the household price of electricity from coal.

Avoid Mitigation Lite

Carbon emission charges in the neighborhood of $30/tCO$_2$ can enable scale-up of most of the wedges, if supplemented with sectoral policy to facilitate transition.

Form of Energy	**Equivalent to $100/tC or $30/tCO$_2$**
Natural gas	$1.50/1000 scf
Crude oil	$12/barrel
Coal	$65/U.S. ton
Gasoline	25¢/gallon (ethanol subsidy: 50¢/gallon)
Electricity from coal	2.2¢/kWh (wind and nuclear subsidies: 1.8 ¢/kWh)
Electricity from natural gas	1.0¢/kWh

$100/tC was the approximate EU trading price for a year ending April 2006, when it fell sharply.

Can We Do It?

People (we!) are becoming increasingly determined to lower the risk that we and our children will experience major social dislocation and environmental havoc as a result of rising CO_2 in the atmosphere

…and we are learning that there are many ways of changing how we live, what we buy, and how we spend our time, that will make a difference.

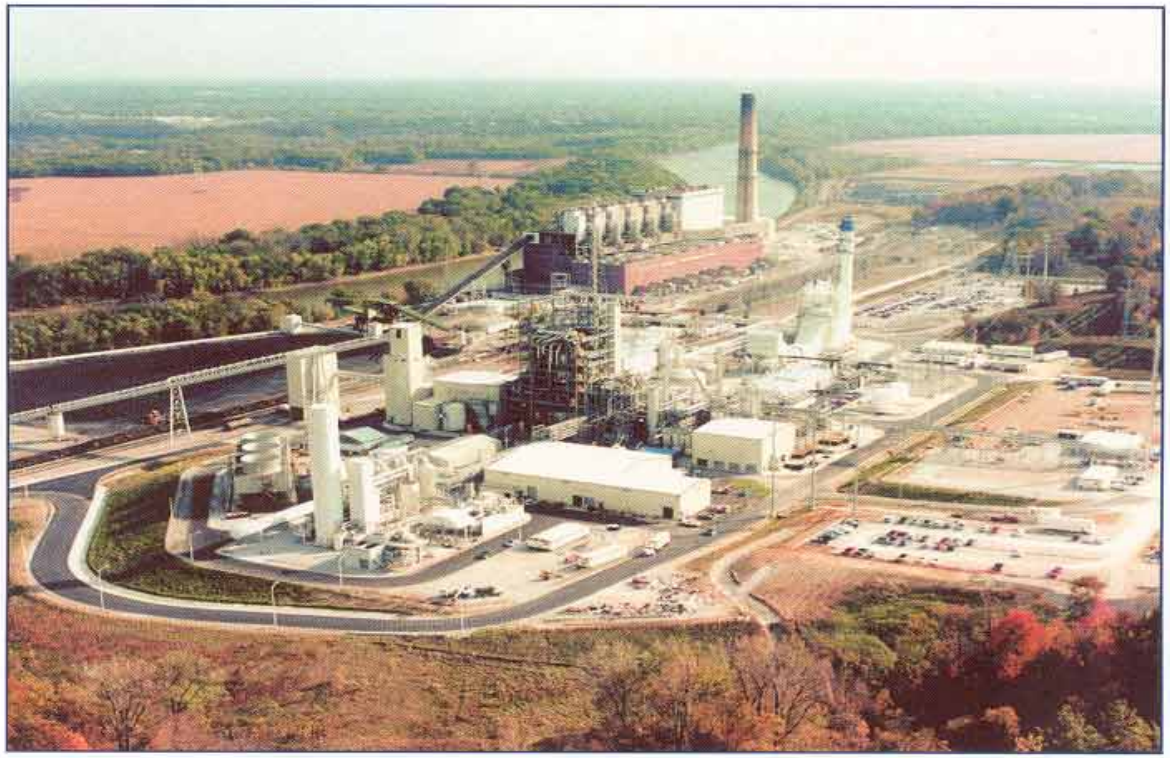
We are in the midst of a discontinuity:

What once seemed too hard has become what simply must be done.

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

Extra Slides

Power with Carbon Capture and Storage



The Wabash River
Coal Gasification Repowering Project

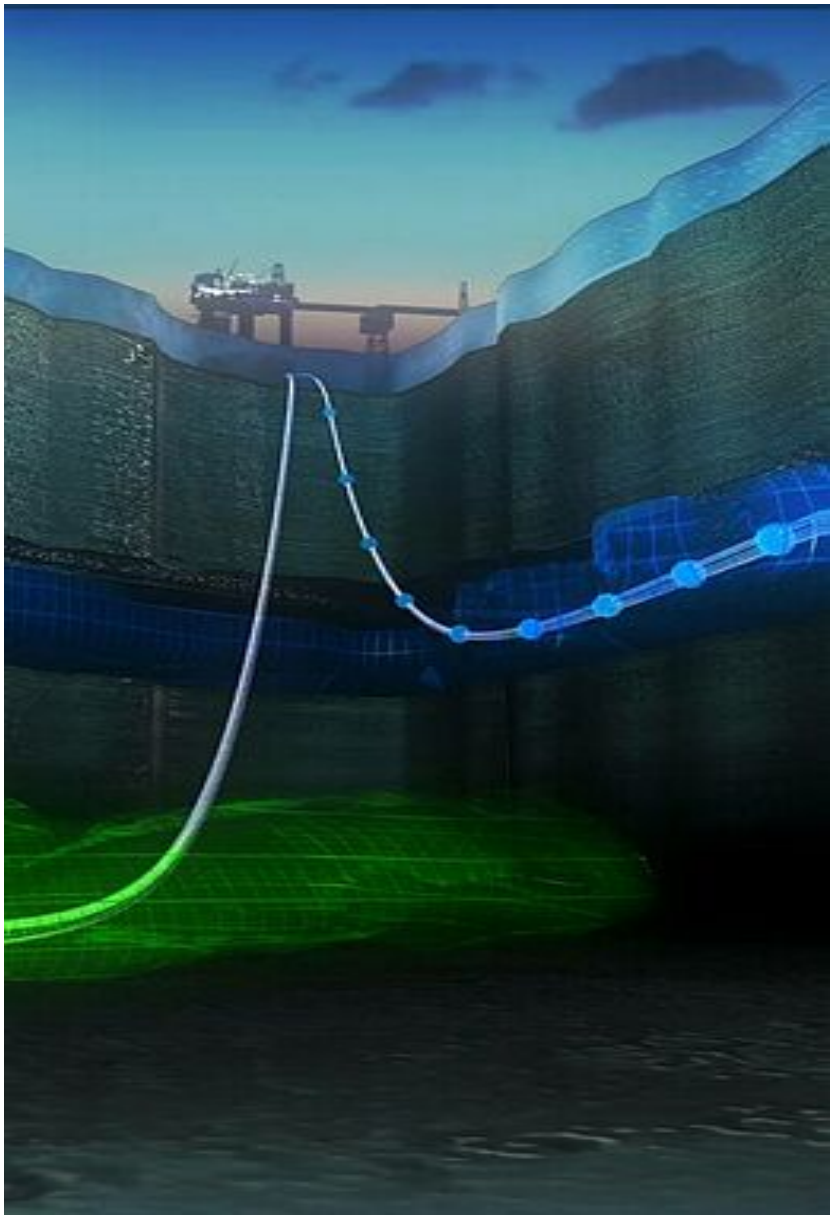
Effort needed by 2055 for 1 wedge:

Carbon capture and storage at 800 GW coal power plants.

Output of Wabash gasifier: CO + H_2. Gases go directly to turbine.

Add for CCS power: CO + H_2O → CO_2 + H_2; then CO_2 - H_2 separation; then H_2 to turbine, and CO_2 handoff from coal industry to oil and gas industry.

Graphics courtesy of DOE Office of Fossil Energy



Sleipner project, offshore Norway

Graphic courtesy of Statoil ASA

Carbon Storage

Effort needed by 2055 for 1 wedge:

900 Carson refinery projects @ 4 $MtCO_2$/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

Efficient Use of Fuel

Effort needed to reduce demand 1 mbd (U.S. light-duty vehicles):

a) **2.5 mpg improvement, or**

b) **1000 miles/yr less driving per vehicle.**

Priority #3: Address the global oil constraint without making the climate problem worse

Synfuels from coal and tar sands make the climate problem worse – unless accompanied by CO_2 capture and storage.

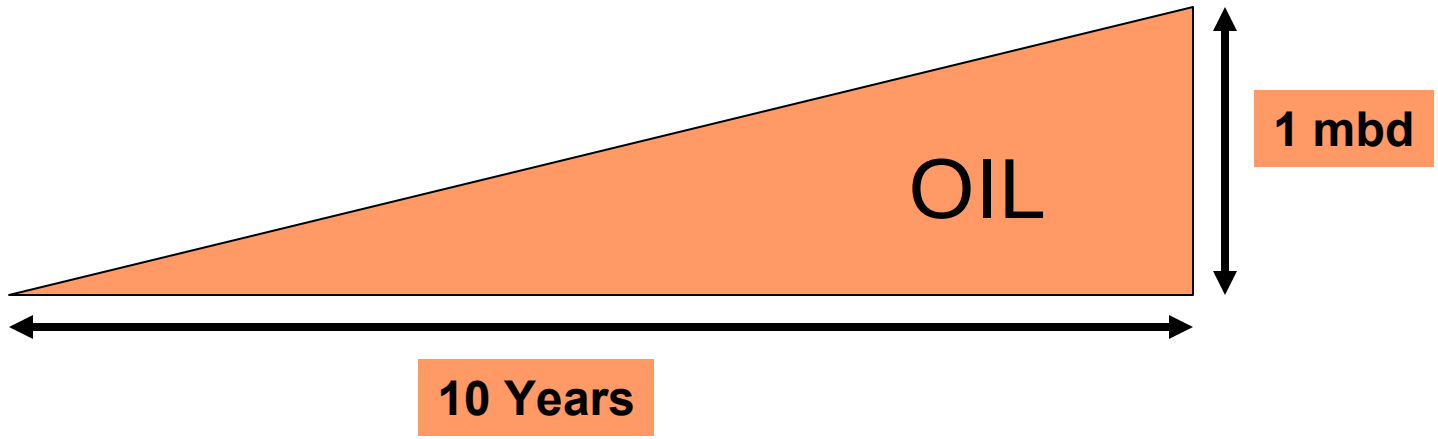
The impact on climate of the electrification of transport depends on the carbon intensity of the grid.

Biofuels are a double-win, but land constraints are severe.

Efficient vehicles are the clearest win-win option.

The Analogous Oil Wedge

1 oil wedge is a strategy or campaign that results in the reduction of pressure on oil markets (by either supply augmentation or demand reduction) by 1 million barrels per day after 10 years.



This is a much smaller wedge than the carbon stabilization wedge:

Vertical dimension: **24 mbd = 1 GtC/yr**.

Slope: **4.8 mbd/10 yr = (1 GtC/yr)/50 yr**

At $55/bbl, area of oil wedge is $100 billion (25 times smaller).

Inventor of the oil wedge: Robert Hirsch

Biofuels

Usina Santa Elisa mill in Sertaozinho, Brazil (http://www.nrel.gov/data/pix/searchpix.cgi?getrec=5691971&display_type=verbose&search_reverse=1_

Effort needed for 1 mbd:

12 million hectares (15t/ha).

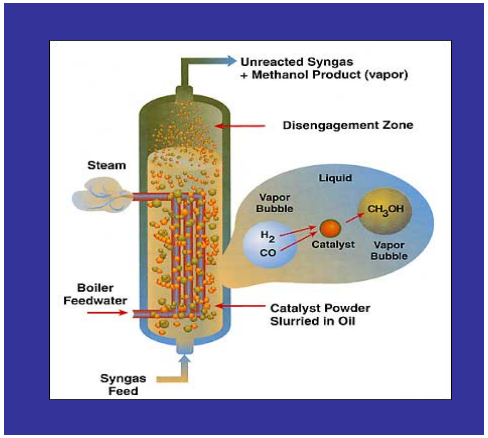
2002 production:

Brazil	220,000 b/d
U.S.	140,000 b/d

Challenge: To find ecologically responsible ways to grow biomass for power and fuel on hundreds of millions of hectares.

*Coal-based Synfuels with CCS**

***Carbon capture and storage**



Graphics courtesy of DOE Office of Fossil Energy

Effort needed for 1 mbd: 120 Mt/yr coal to synfuels.

World coal consumption, 2002: 4800 Mt/yr

China: 1300 Mt/yr.

U.S and Canada: 1100 Mt/yr.

Sasol's synfuels plants in South Africa produce 165,000 b/d.

Why "synfuels with CCS"? Twice as much CO_2 is emitted per kilometer when driving the same car with a coal-based synfuel as with a petroleum fuel.

The "second CO_2" can be captured at the synfuels plant and stored below ground, making synfuels no less bad for climate than petroleum fuels.

Priority #4: Engage the whole world

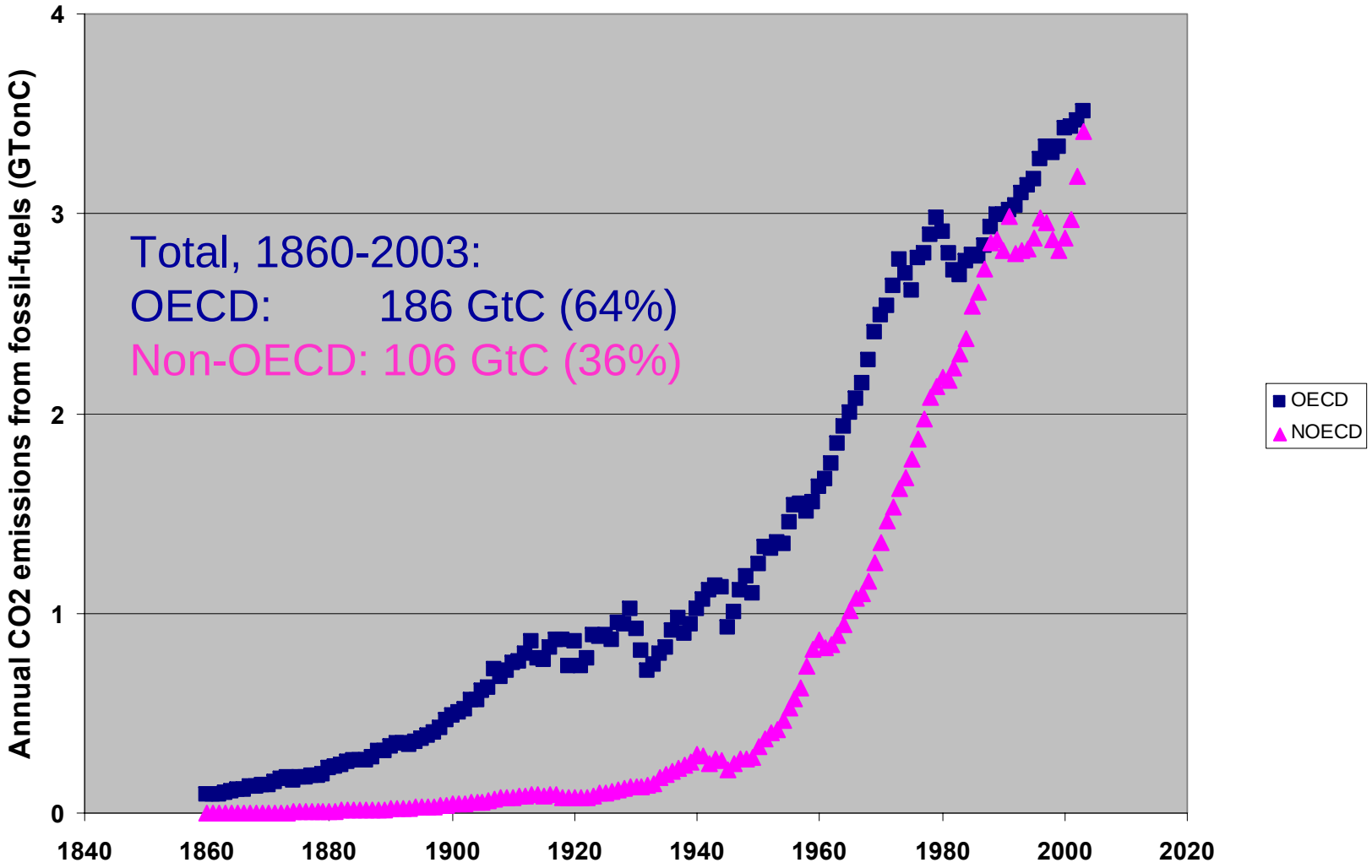
Persuade fast-growing countries to price their own CO_2 emissions, thereby controlling their own destiny, stimulating their own industries, and accelerating domestic carbon-wise capital investment.

Urge a uniform mitigation effort for the same income level across all countries.

Expand investments in poverty alleviation, with minimal regard for CO_2.

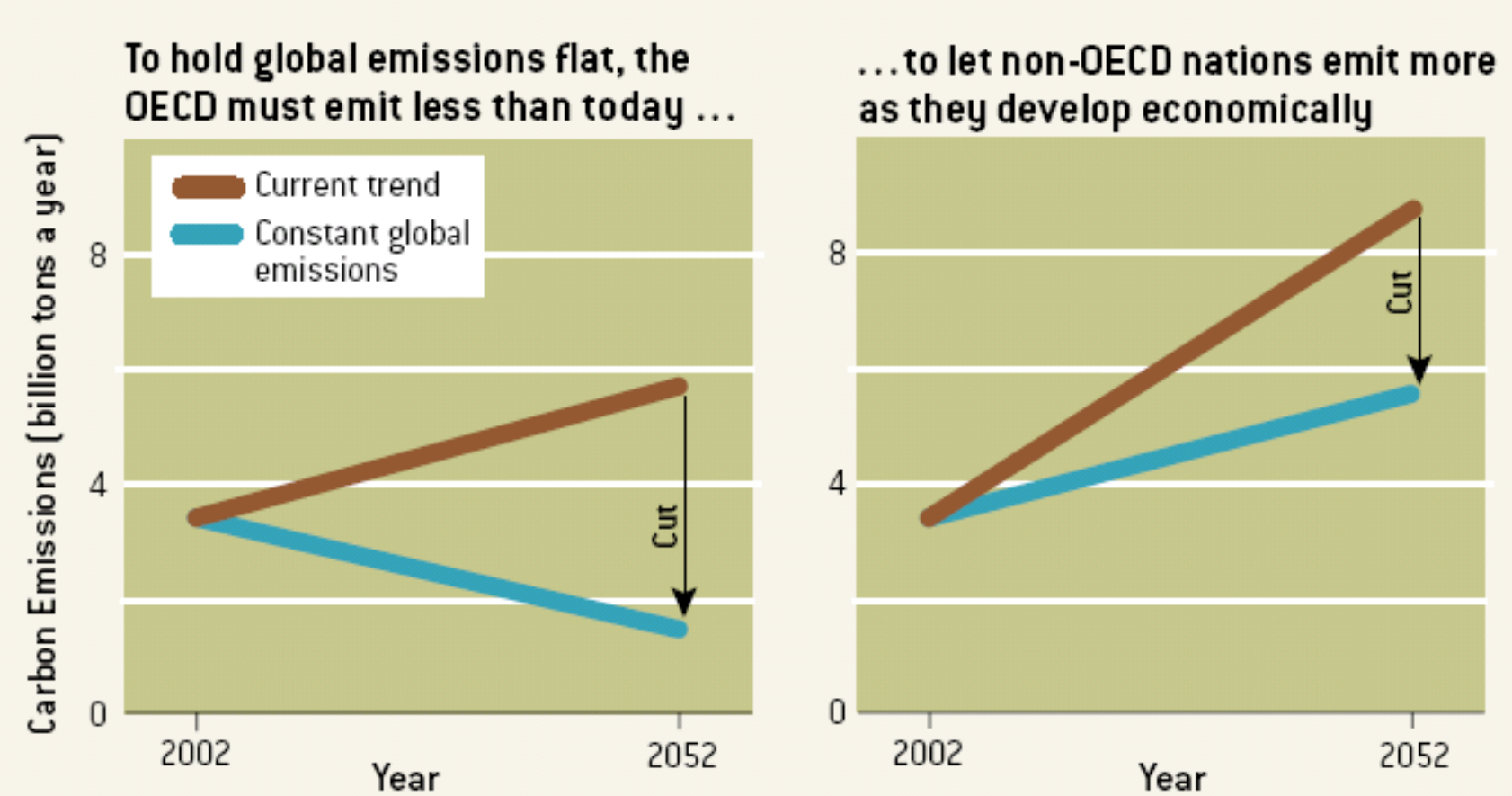
Expand investments in adaptation.

CO_2 emissions, OECD and non-OECD, 1860-2003



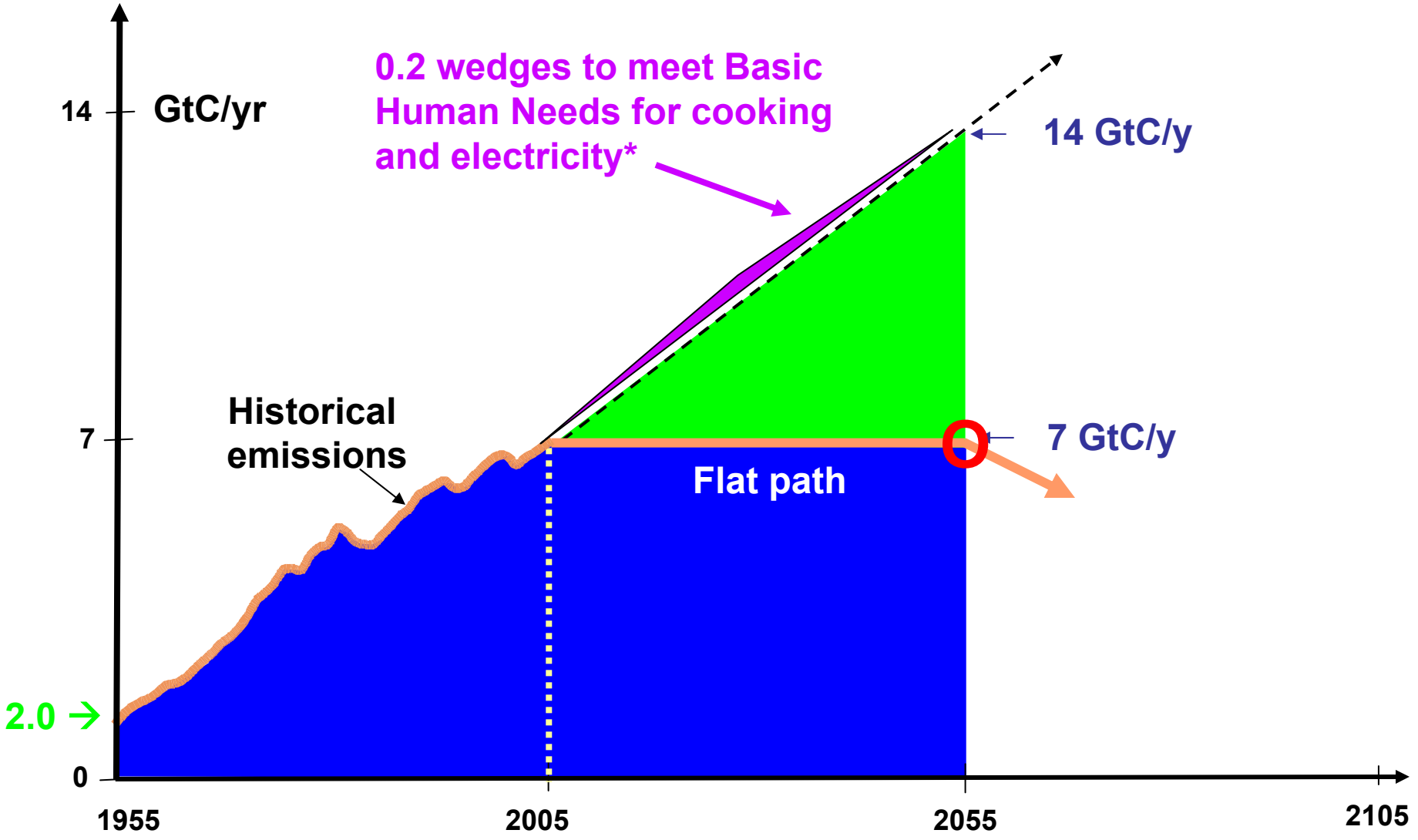
Source: Adrian Ross

OECD and non-OECD shares



*Source*I Socolow and Pacala, *Scientific American*, September 2006, p.56

Add 0.2 wedges for Basic Human Needs



- 1.6 billion @ 50 kWh/month + 2.6 billion @ 3 kg propane/month.
- Meet these needs in the next 25 years instead of 25 years later.

Summary

1. Invent a smart-carbon post-industrial society.

2. Redirect the Rush to Coal.

3. Address the global oil constraint without making the climate problem worse.

4. Engage the whole world.