Climate Change Mitigation under Strong Carbon Constraints

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50th Anniversary of the Global CO_2 Record
Symposium and Celebration, Nov. 28-30, 2007, Kona, Hawaii

From Dave Keeling's autobiography

A safe approach is just to remain an interested observer of the unfolding scientific evidence of man-made global climate change and its possible significance to human welfare. Without risk one can comment dispassionately…I believe, however, that a more prudent attitude would be to heed the rise in atmospheric CO_2 concentration as serious unless proven to be benign. (p. 76)

"Rewards and penalties of monitoring the earth," *Annual Review of Energy and the Environment*, 1998, Vol. 23, pp. 25-82.

The mitigation thread through this symposium (1 of 2)

1. The previous session and this talk

2. Thursday, 4:30 p.m.

   "Ozone Depletion: The Story of a Successful International Agreement and Its Relevance For Climate Change" (Susan Solomon)

3. Friday

   A. Canonical mitigation

      i. Renewable energy (Charles Kutscher)

      ii. CO_2 capture and storage (Julio Friedmann)

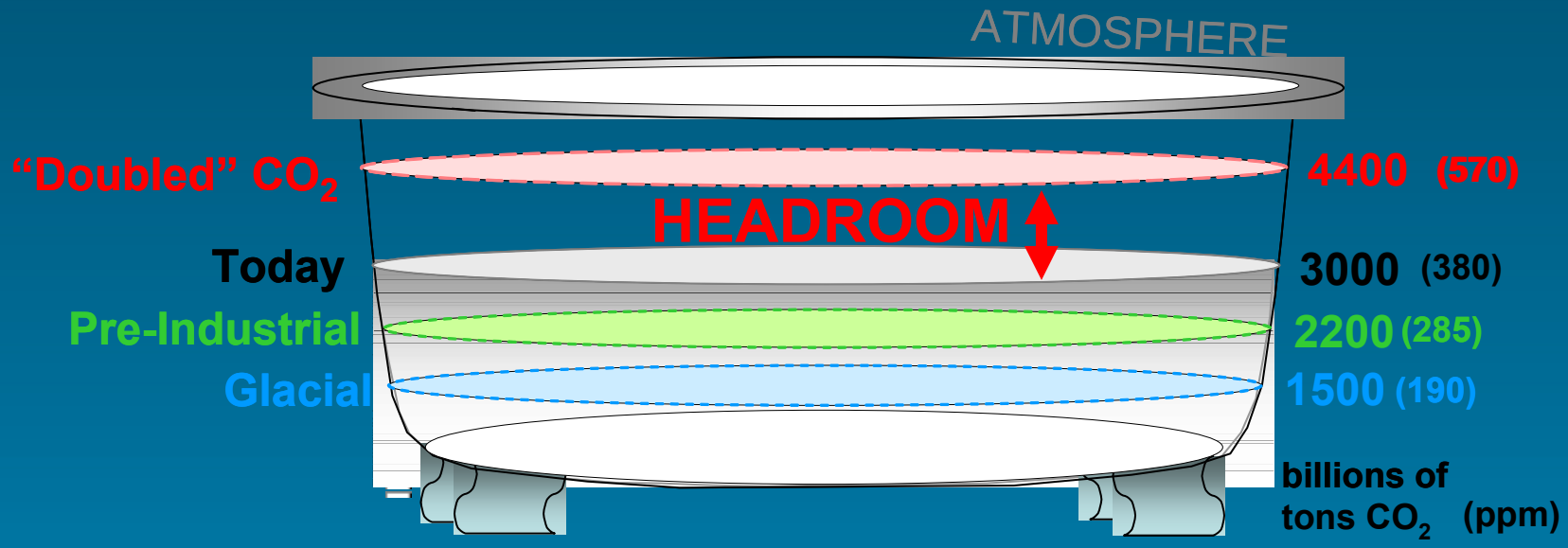
The mitigation thread through this symposium (2 of 2)

3. Friday (continued)
    B. Geoengineering
        i. Albedo modification (David Keith)
        ii. Modification of the ocean sink (David Karl)
    C. Regional efforts
        i. California's A.B. 32 (Fran Pavley)
        ii. Regional Greenhouse Gas Initiative (Joanne Morin)
        iii. Western Governors' Association (David Van't Hof)
    D. Economic tools & financial incentives (Mike Walsh)

Outline of Talk

1. Bridging the gap between stabilization targets and mitigation activity with the “wedge” model.
2. Wedges of efficiency and wedges of substitution for conventional coal.
3. A new role for environmental scientists: Assessors of the environmental consequences of “solutions.”
4. Parting thoughts for Bali: Equitable mitigation.

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

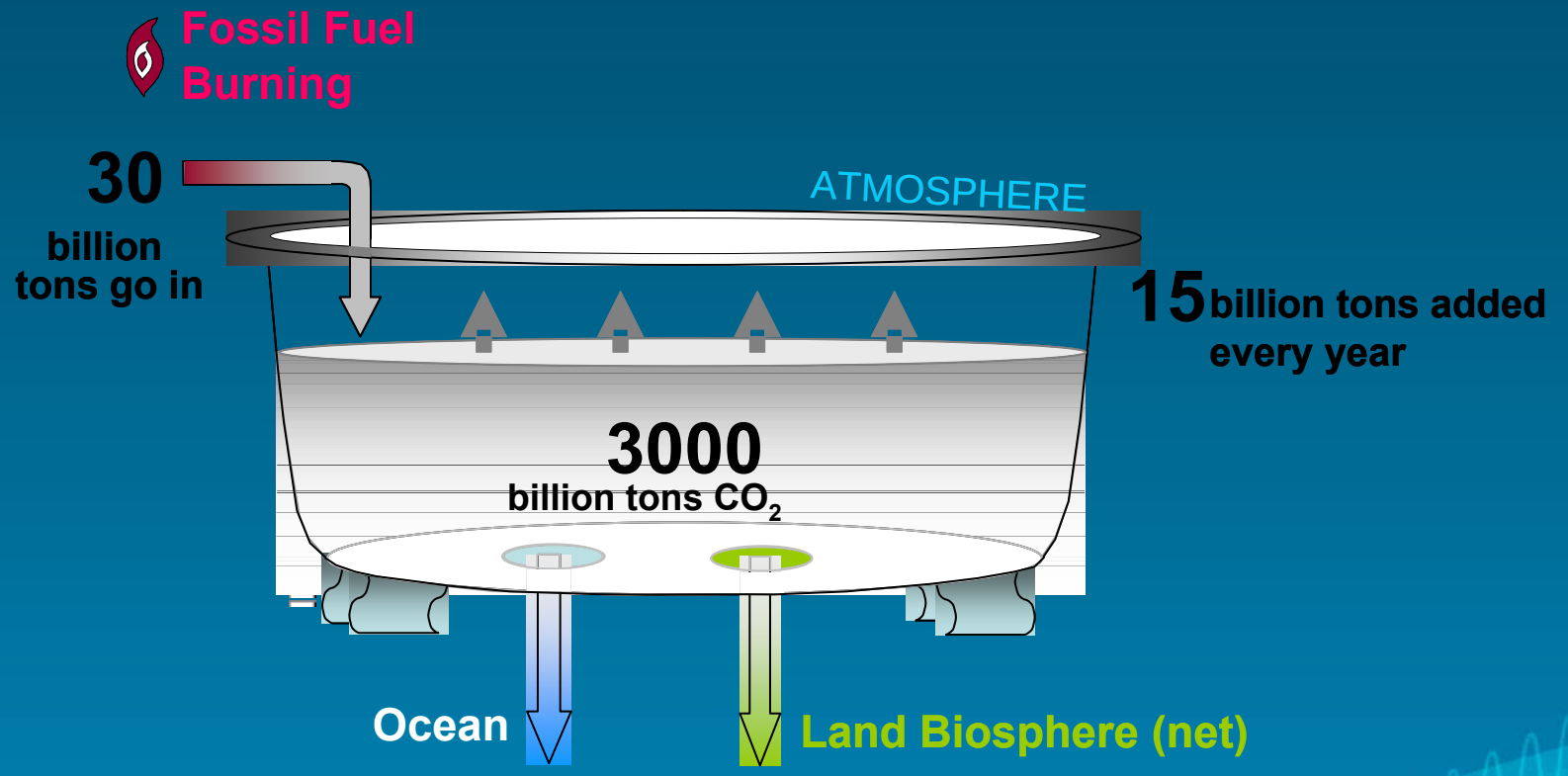


Rosetta Stone: To raise the concentration of CO_2 in the atmosphere by **one part per million:**

add **7.7 billion tons of CO_2,**

in which are **2.1 billon tons of carbon.**

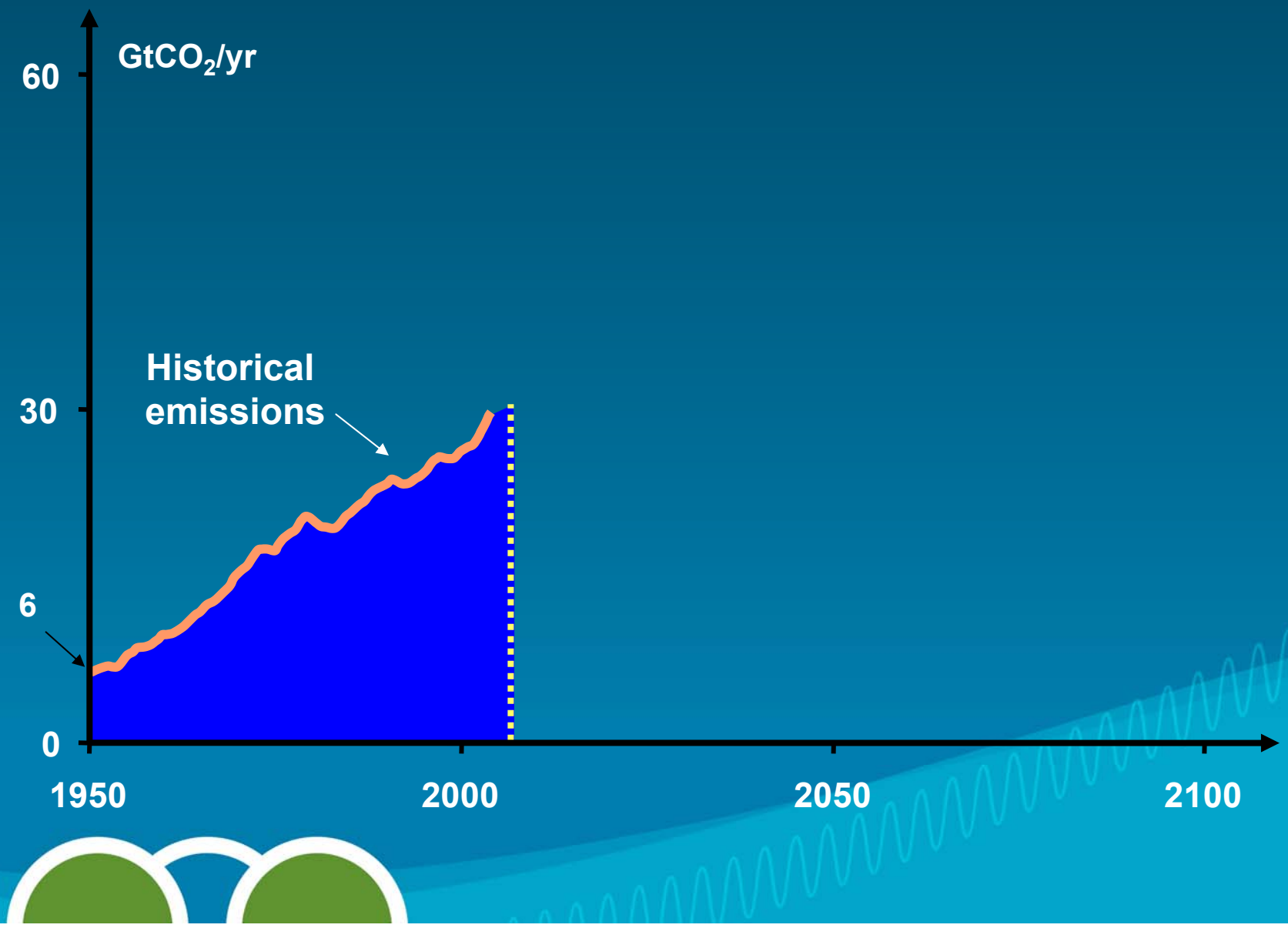
About half of the carbon we burn stays in the atmosphere for centuries



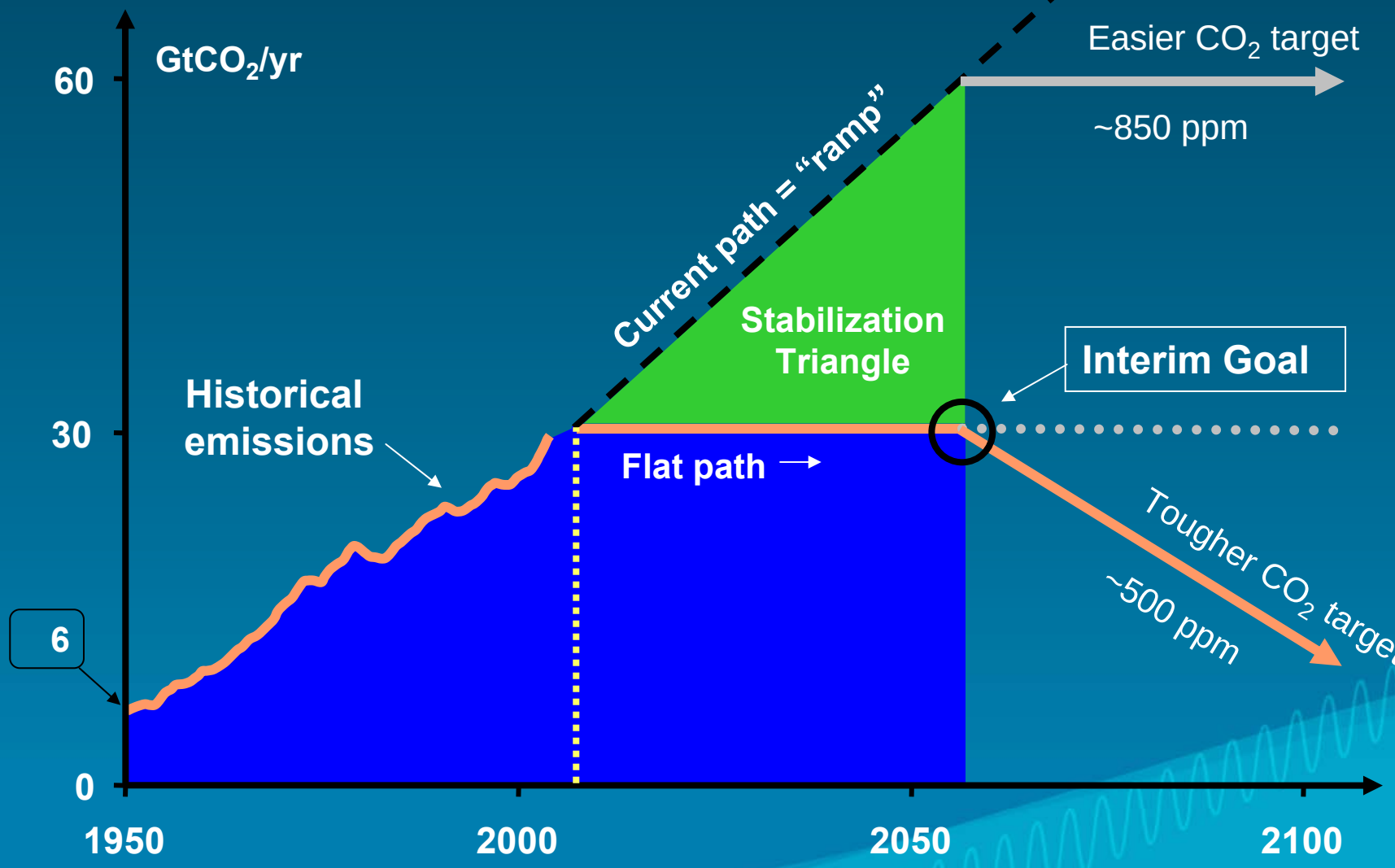
On the heels of Mauna Loa measurements of the CO_2 concentration…

…came CO_2 emissions inventories!

Historical Emissions

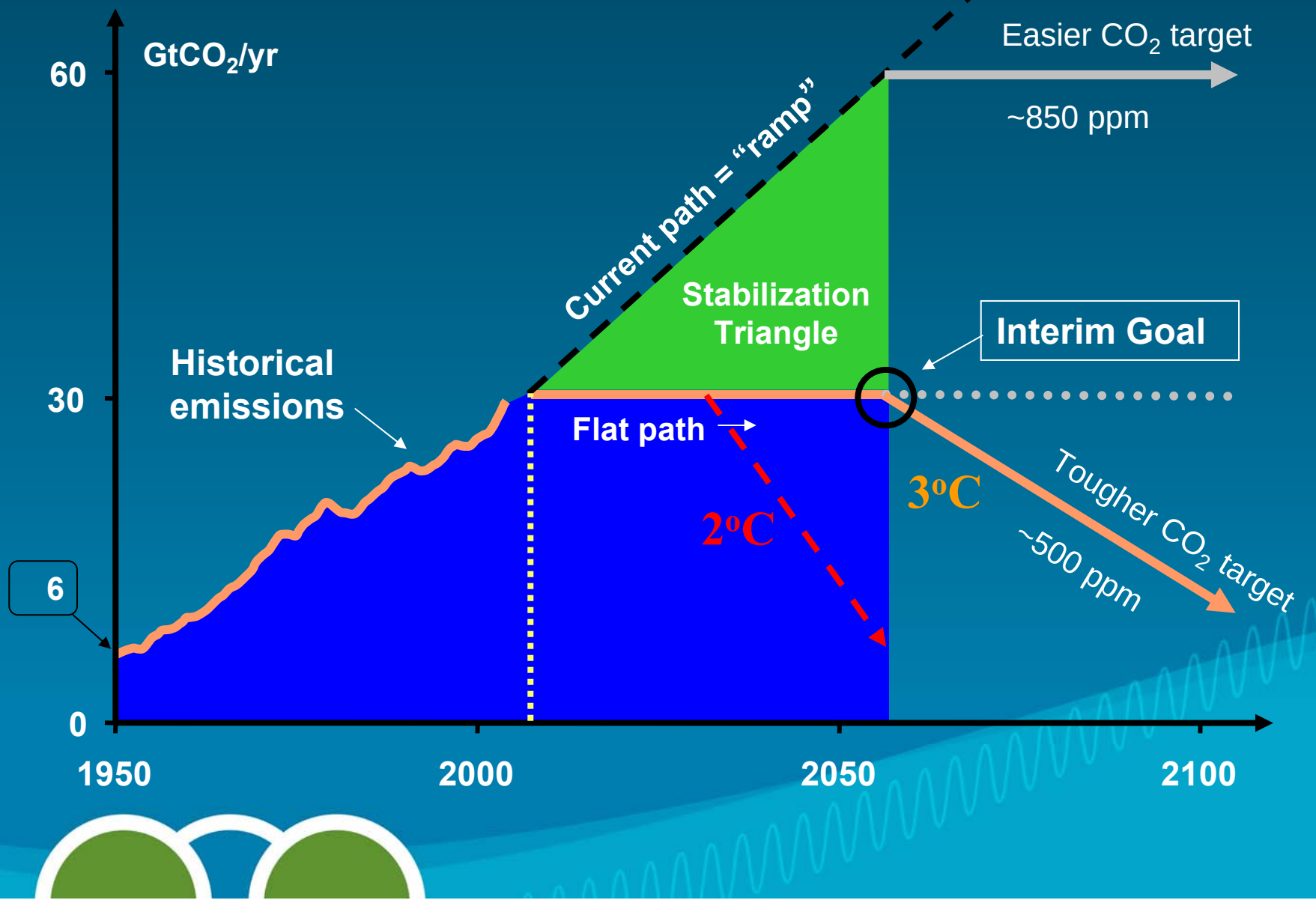


The Stabilization Triangle



Today and for the interim goal, global per-capita emissions are ≈ 4 tCO_2/yr.

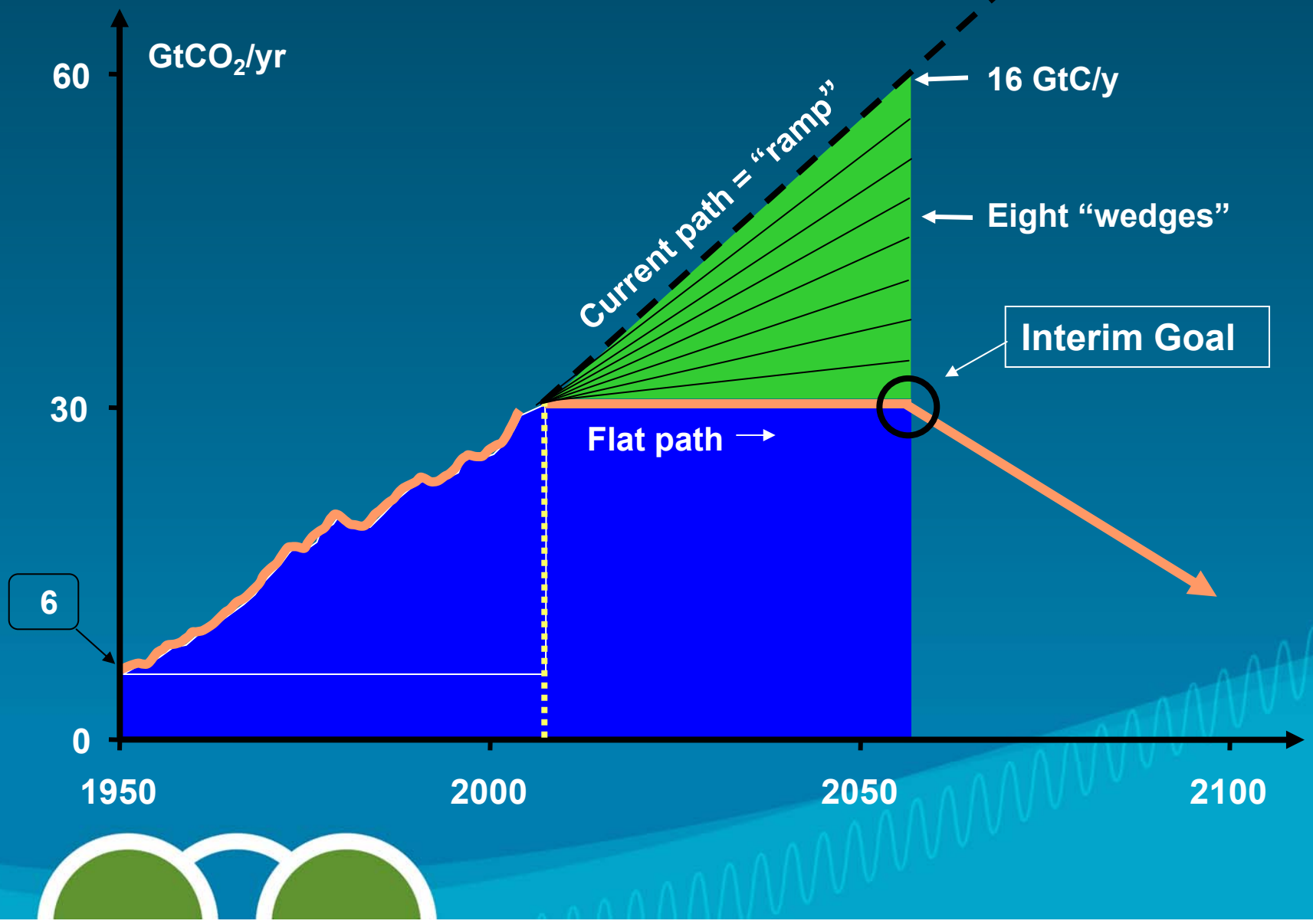
The 2°C Variant is still tougher



Four ways to emit 4 tonCO_2/yr

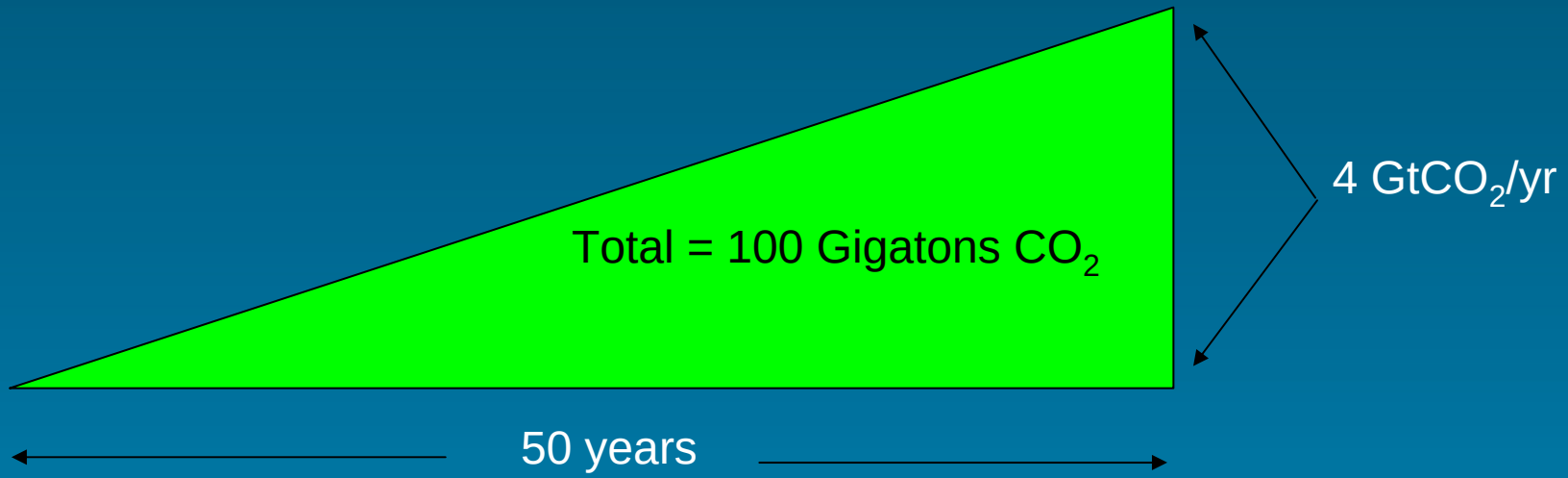
Activity	**Amount producing 4tCO_2/yr (1tC/yr) emissions**
a) Drive	10,000 miles/yr, 30 miles per gallon
b) Fly	10,000 miles/yr
c) Heat home	Natural gas, average house, average climate
d) Use lights and appliances	300 kWh/month when all coal-power (600 kWh/month, natural-gas-power)

Stabilization Wedges



What is a “Wedge”?

A “wedge” is a strategy to reduce carbon emissions that grows in 50 years from zero to 4 $GtCO_2$/yr. The strategy has already been commercialized at scale somewhere.

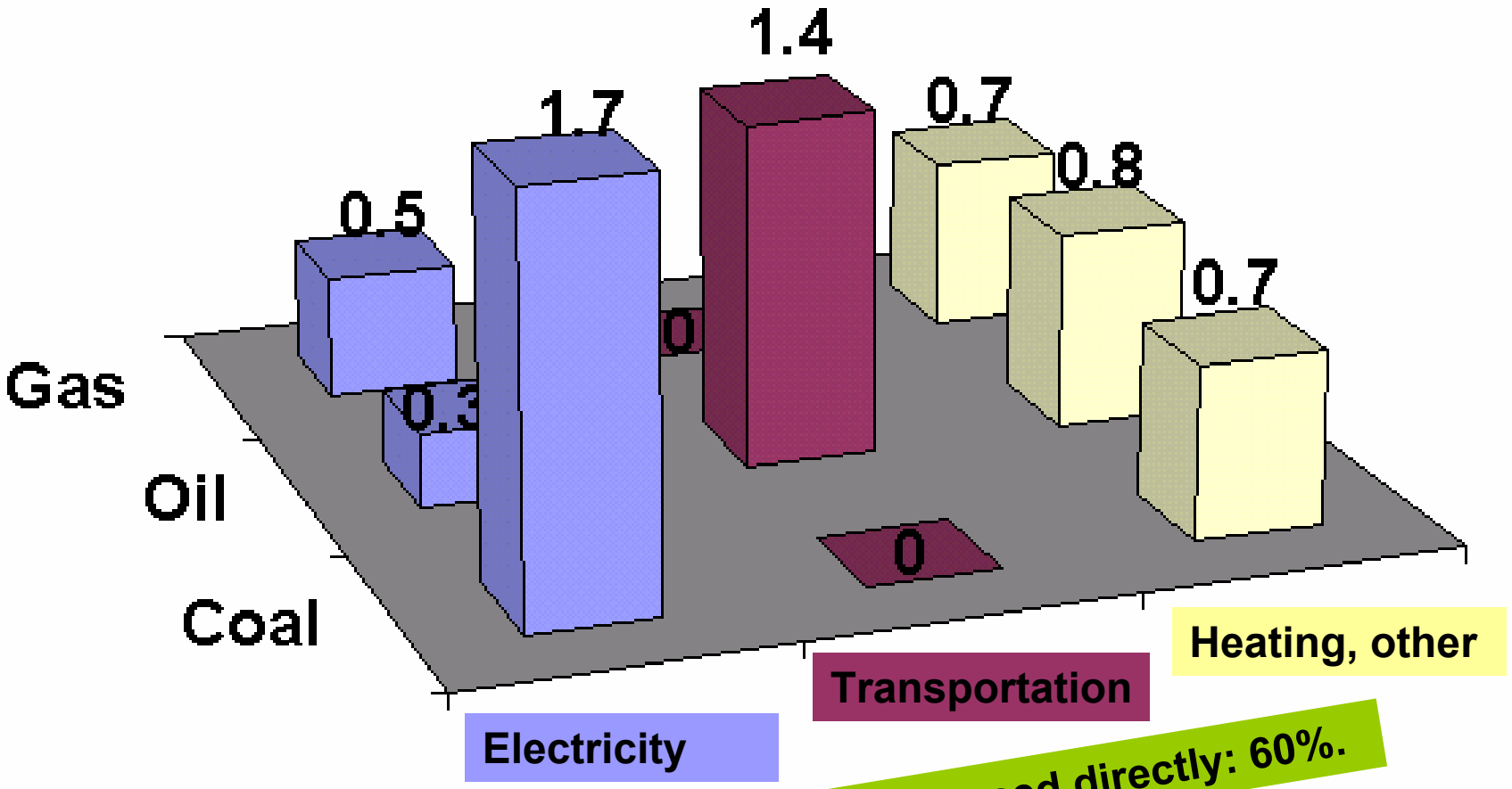


Cumulatively, a wedge redirects the flow of 100 $GtCO_2$ in its first 50 years. This is three trillion dollars at \$30/tCO_2.

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

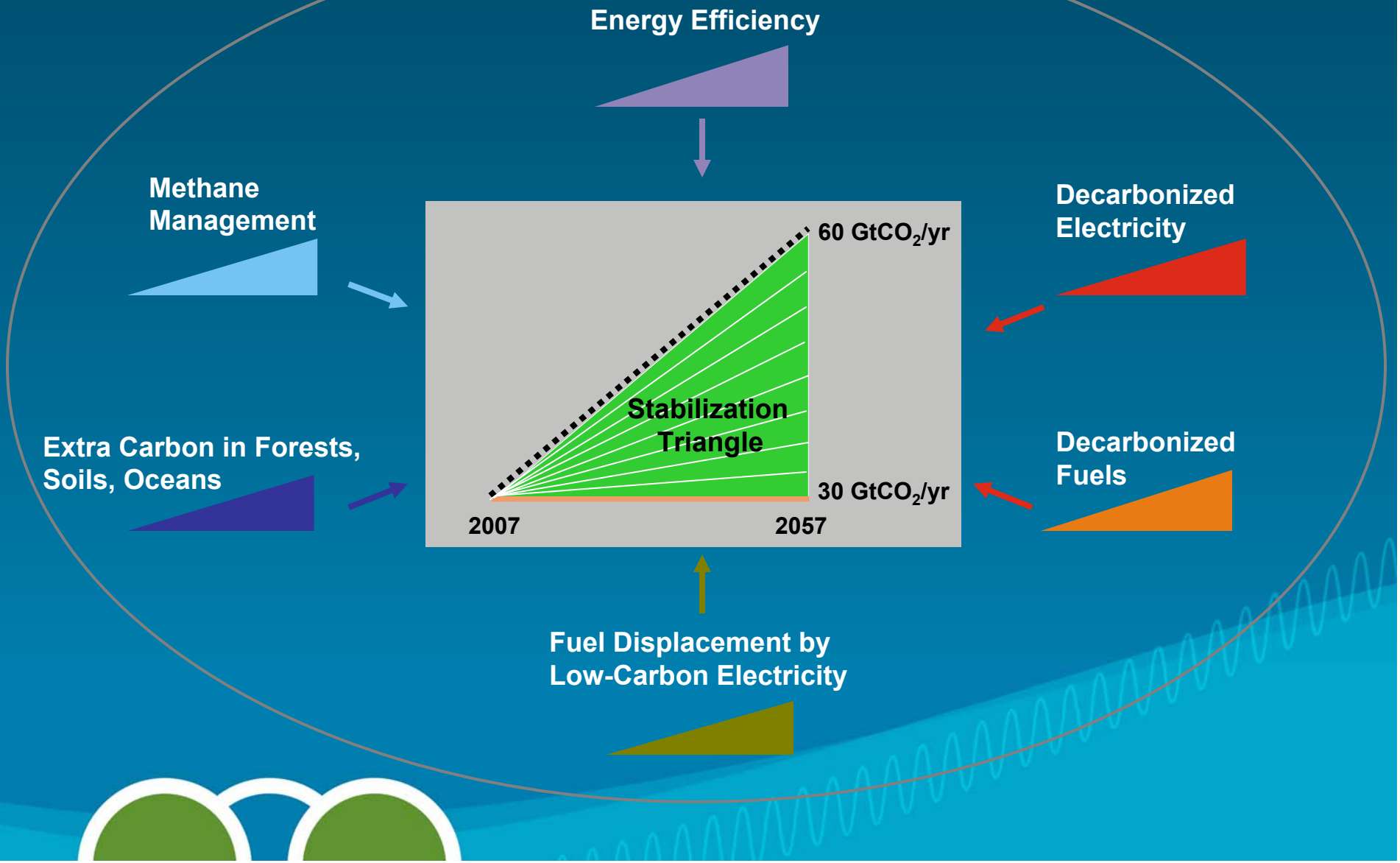
Global CO_2 Emissions by Sector and Fuel

Allocation of 6.2 GtC/yr (22.7 $GtCO_2$/yr) emitted in 2000



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

Fill the Stabilization Triangle with Eight Wedges in six broad categories

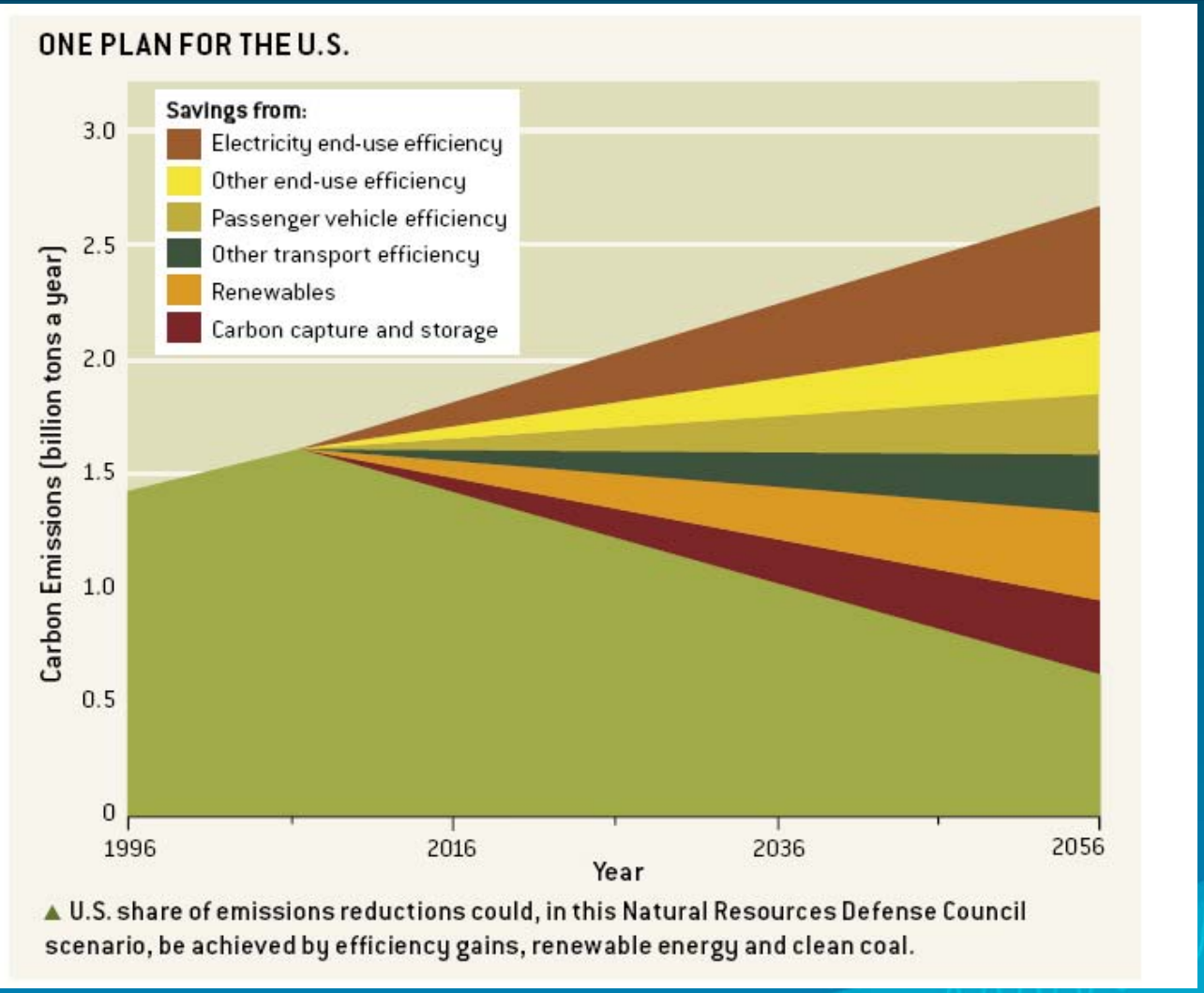


“The Wedge Model is the iPod of climate change: You fill it with your favorite things.”

David Hawkins, NRDC, 2007.

Therefore, prepare to negotiate with others, who have different favorite things.

U.S. Wedges



Source: Lashof and Hawkins, NRDC, *in* Socolow and Pacala, *Scientific American*, September 2006, p. 5700

Now we go on a hunt for wedges!

Priorities:

- **Efficiency wedges**
- **Wedges displacing conventional coal power**

Efficient Use of Fuel

Effort needed by 2055 for 1 wedge:

Note: 1 car driven 10,000 miles at 30 mpg emits 4 tons of CO_2.

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

Efficient Use of Electricity

motors

lighting

cogeneration

Effort needed by 2055 for 1 wedge:

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

Target: Commercial and multifamily buildings.

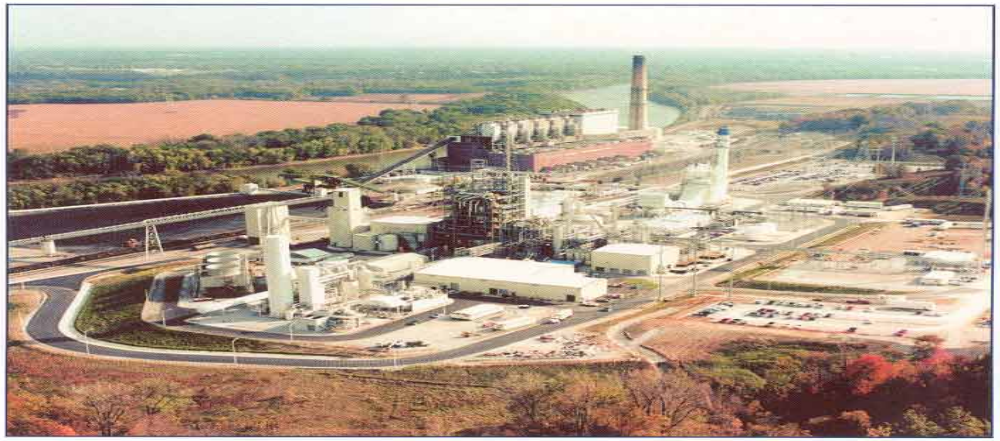
Coal-electricity Wedges

700 modern 1-GW coal plants, with CO_2 vented, will emit 4 $GtCO_2$ each year (6 $MtCO_2$/yr per plant).*

Electricity-carbon wedges result from not building such plants.

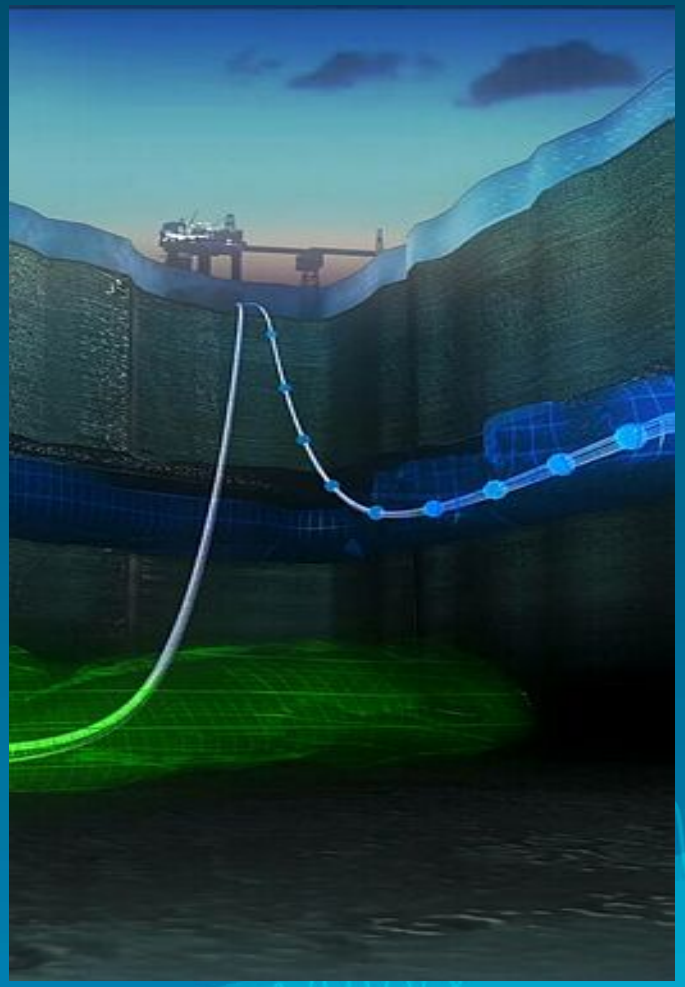
*For example, 90% capacity factor, 50% efficient.

Coal with Carbon Capture and Storage



The Wabash River
Coal Gasification Repowering Project

Graphics courtesy of DOE Office of Fossil Energy



Graphic courtesy of Statoil ASA

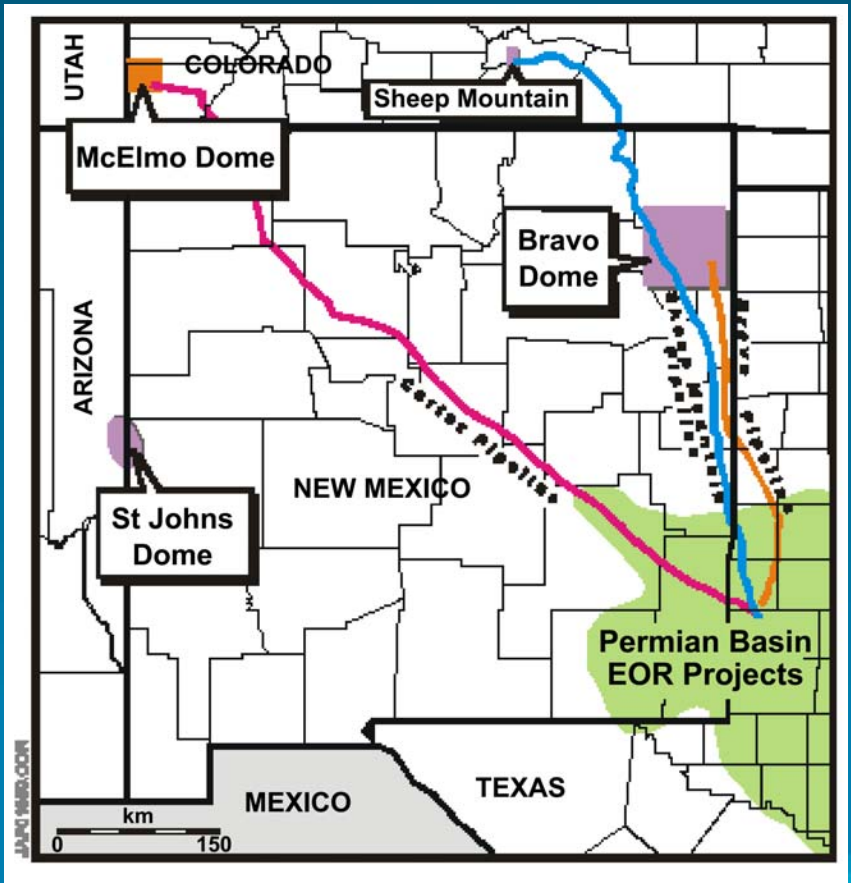
Effort needed by 2055 for 1 wedge:

Carbon capture and storage (CCS) at 800 GW coal power plants.

CCS at “coal-to-liquids” plants producing 30 million barrels per day.

Natural CO_2 fields in southwest U.S.

- McElmo Dome, Colorado: 1500 $MtCO_2$ in place
- 800 km pipeline from McElmo Dome to Permian Basin, west Texas, built in the 1980s for enhanced oil recovery



Two conclusions:

1. CO_2 in the right place is valuable.

2. CO_2 from McElmo was a better bet than CO_2 from any nearby site of fossil fuel burning.

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

Wind Electricity

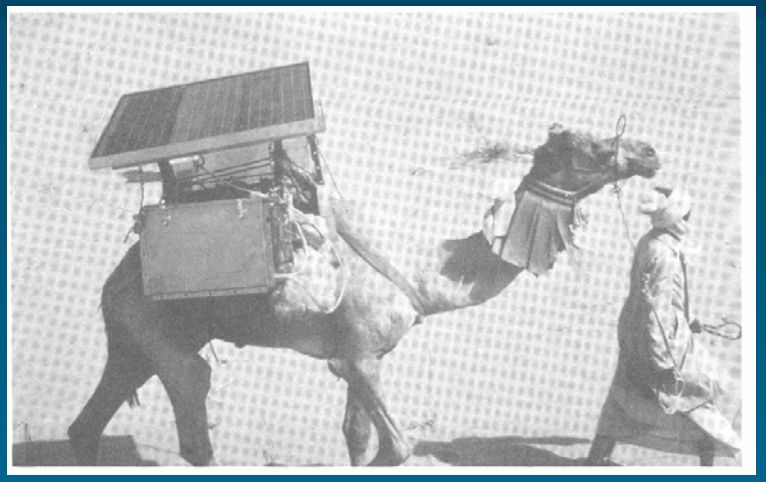
Prototype of 80 m tall Nordex 2,5 MW wind turbine located in Grevenbroich, Germany (Danish Wind Industry Association)

Effort needed by 2055 for 1 wedge:

One million 2-MW windmills displacing coal power.

2006: 75,000 MW (4%)

Photovoltaic Power



Effort Needed by 2055 for one wedge:

2000 GW_{peak} (400 x current capacity)

2 million hectares (80 x 100 miles)

Graphics courtesy of DOE Photovoltaics Program

Concentrating Solar Power (CSP)

Effort Needed by 2055 for one wedge:

2000 GW_{peak}

2 million hectares*
(80 x 100 miles)

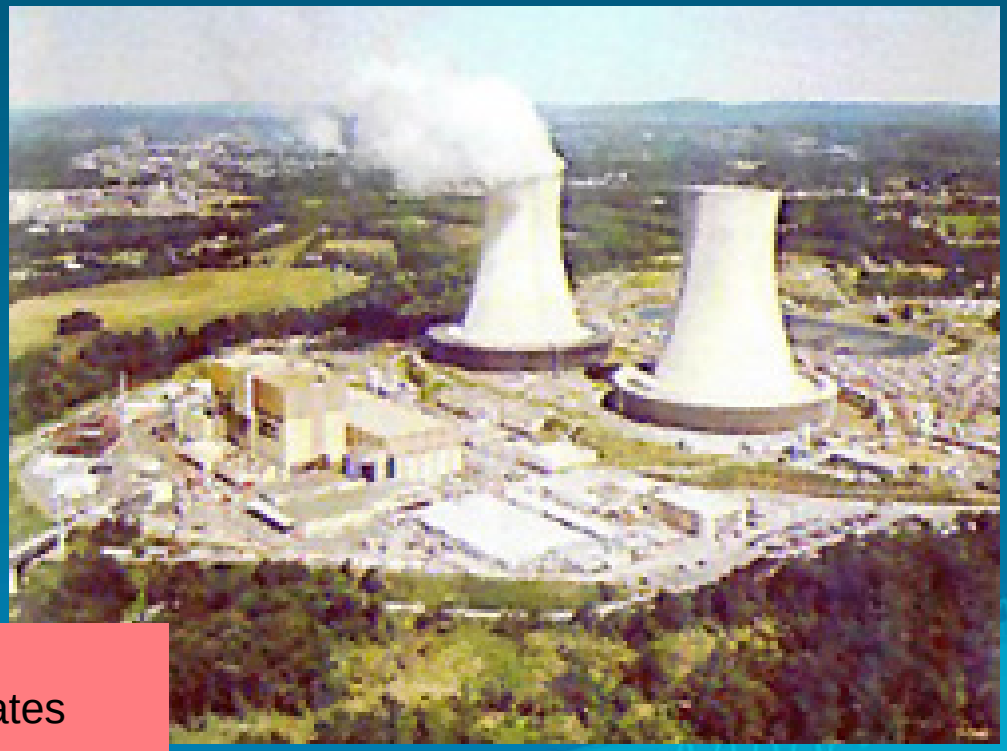
*assumes same 10% site-conversion efficiency as PV

Source: Noah Kaye, SEIA, April 2007

Nuclear Electricity

Effort needed by 2055 for 1 wedge:

700 GW (twice current capacity) displacing coal power.



Graphic courtesy of NRC

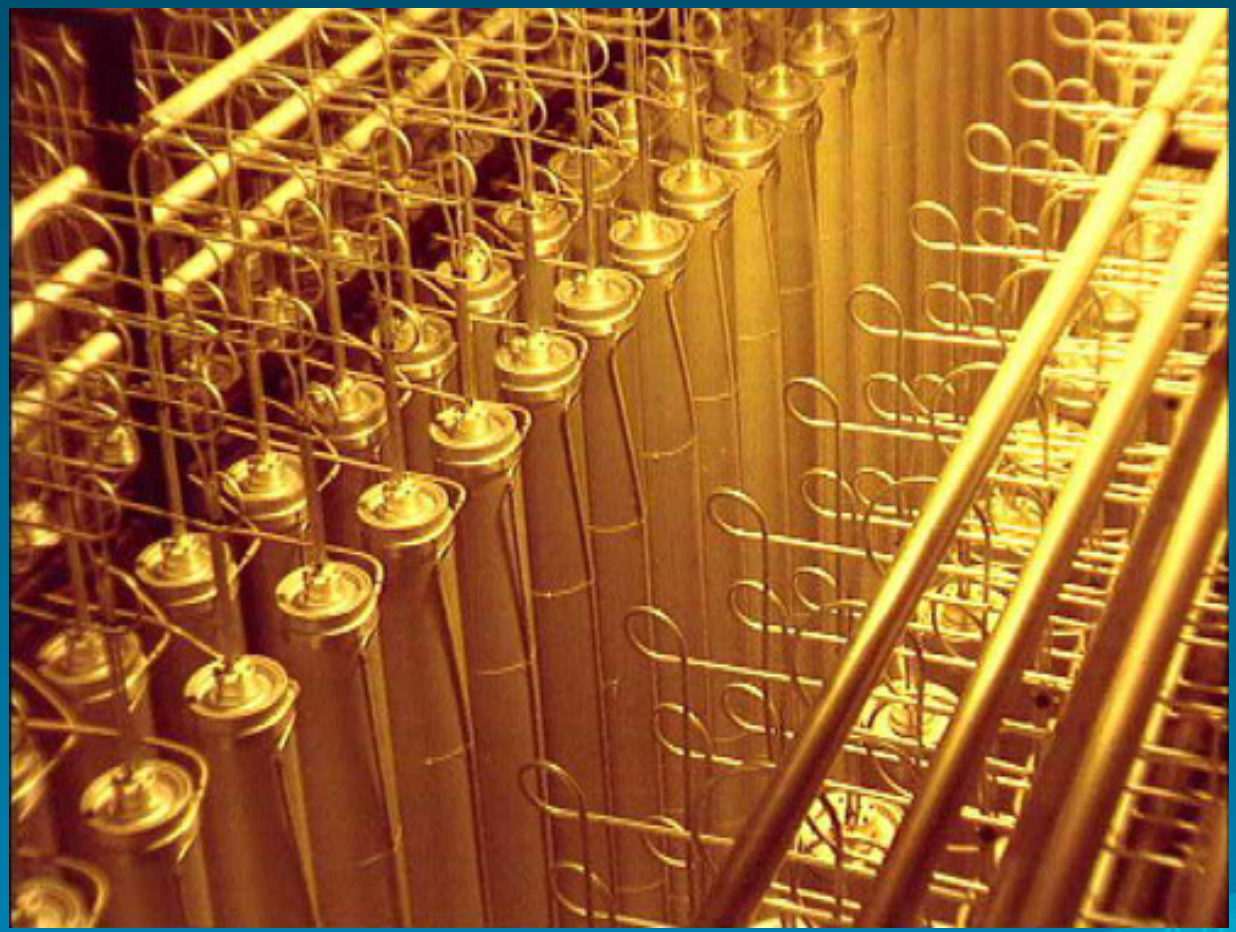
Phase out of nuclear power creates the need for another half wedge.

Retrievable Storage

The nuclear industry may soon seek to renegotiate its social contract regarding nuclear waste, asking for a change of goal: *retrievable storage* instead of irretrievable storage.

Site: Surry station, James River, VA; 1625 MW since 1972-73,. *Credit*: Dominion.

Needed: A New International Regime



Pictured: A cascade of centrifuges for uranium enrichment.

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

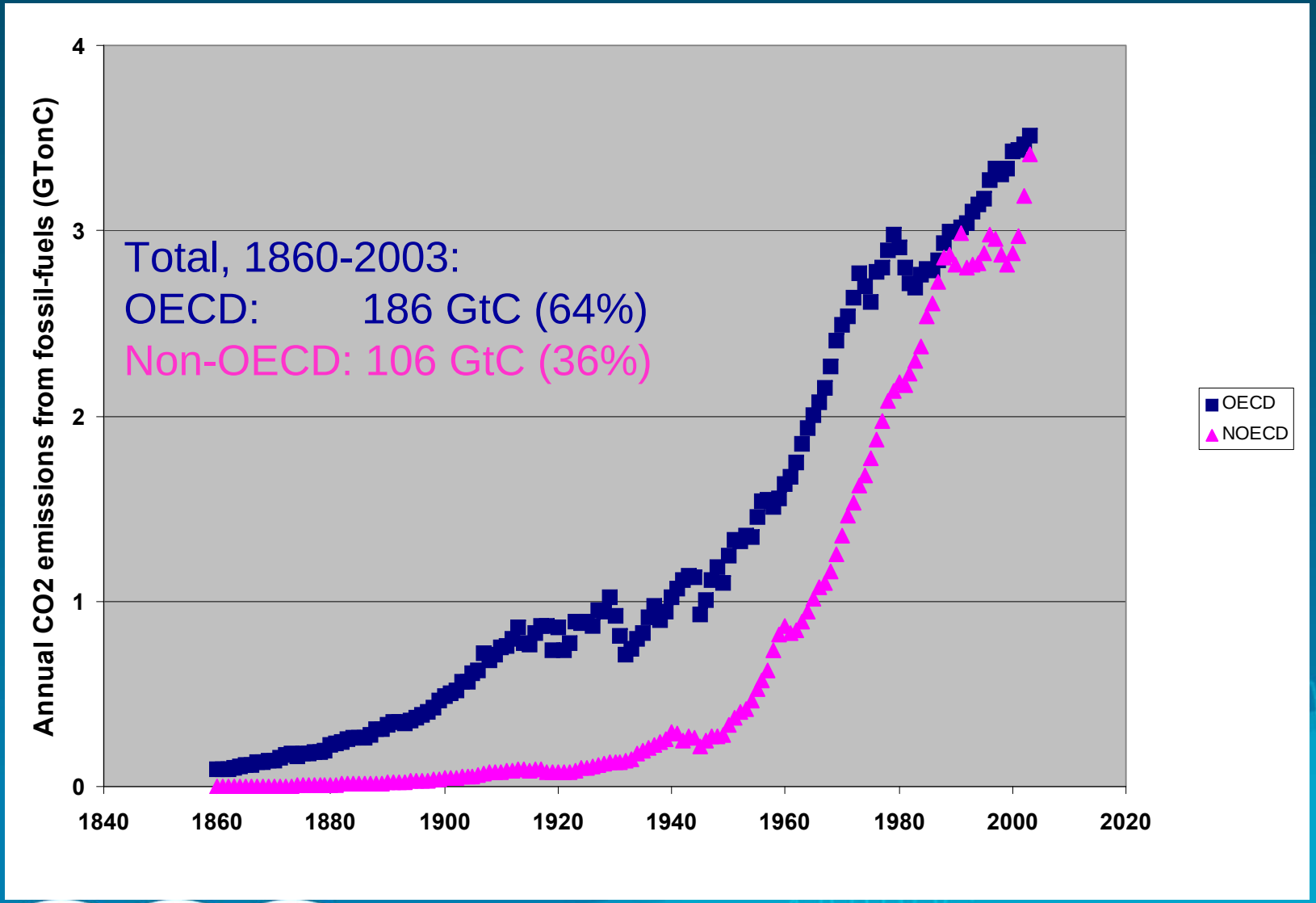
“Solution science” is emerging: the study of the environmental and social costs and benefits of stabilization strategies.

A new role for environmental scientists: Assessors of the environmental consequences of “solutions”

- Ocean fertilization
- Injection of particles into the stratosphere
- Modification of the boundary layer by large-scale deployment of wind farms
- Modification of the boundary layer and the hydrocycle by large-scale deforestation and reforestation

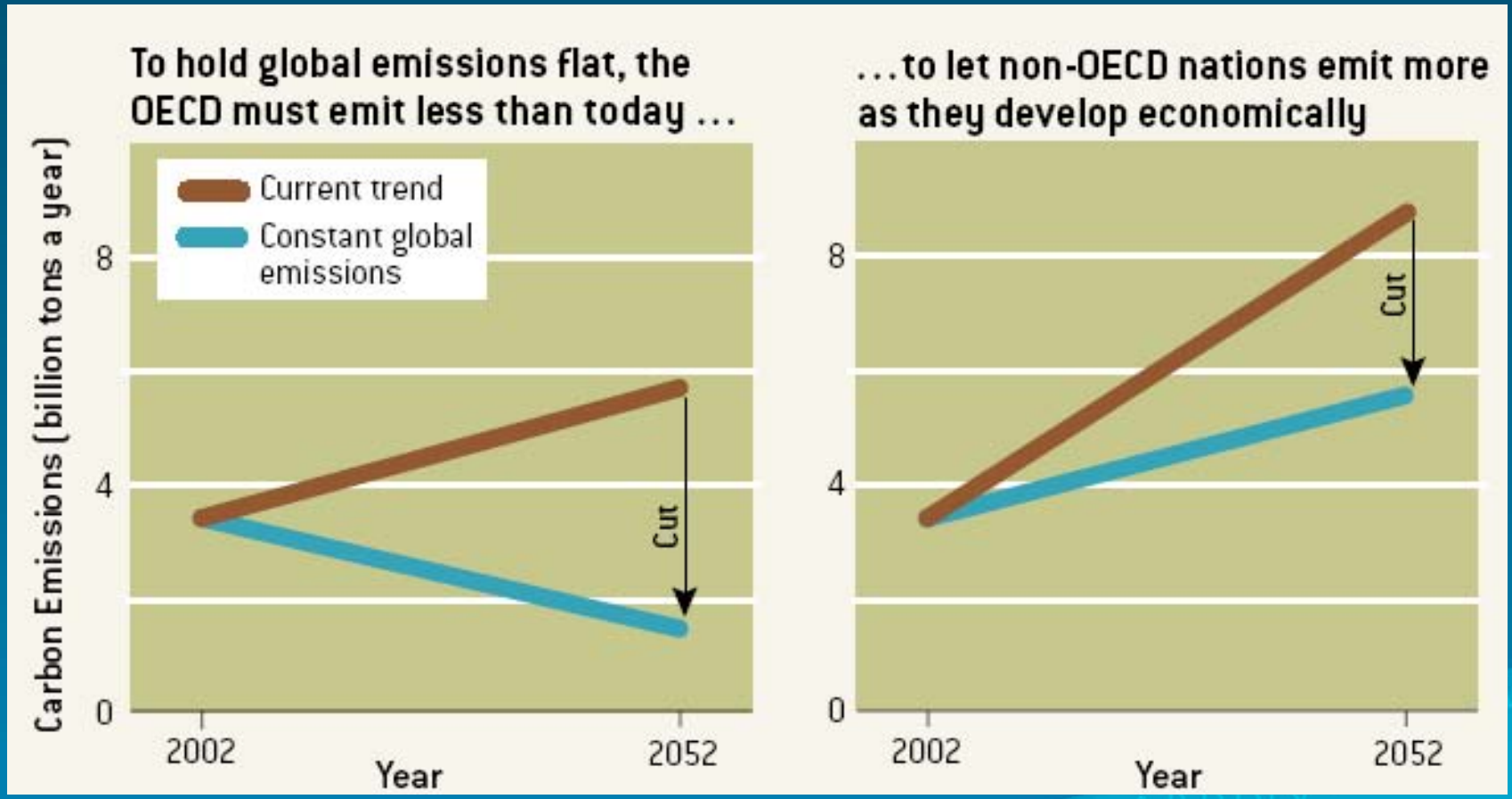
Parting thoughts for Bali:
A new look at equitable mitigation

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



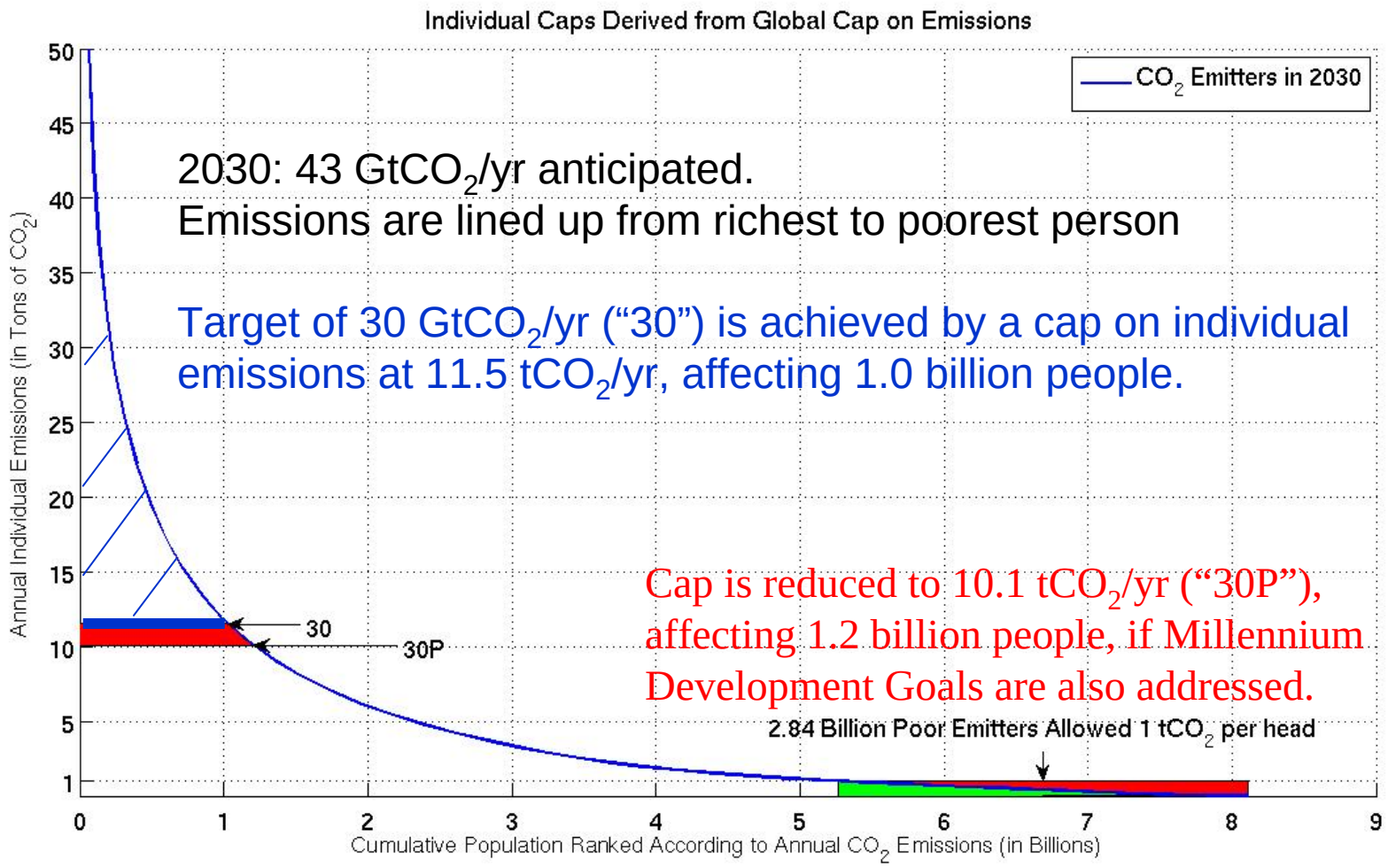
Source: Adrian Ross

OECD and non-OECD shares

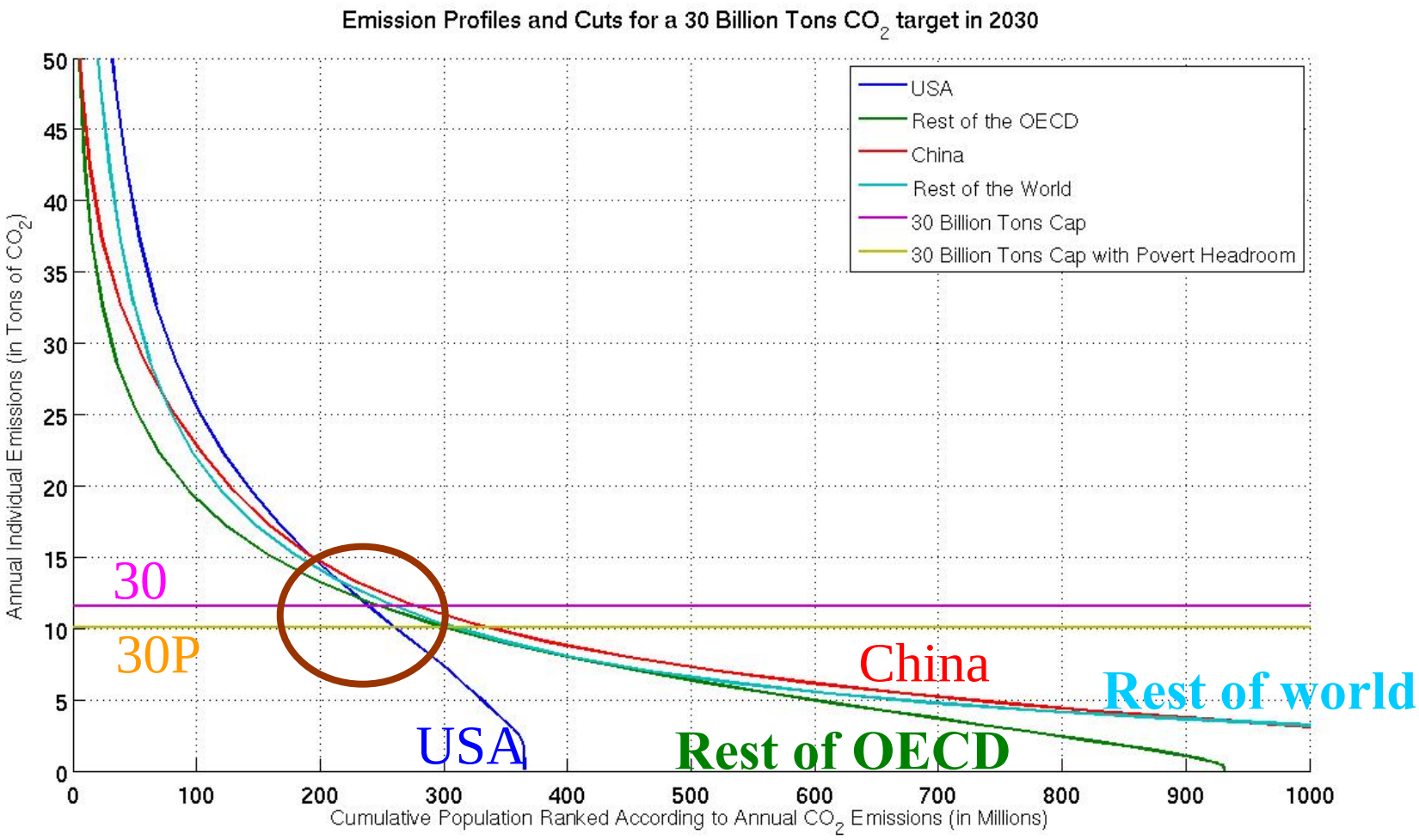


*Source*l Socolow and Pacala, *Scientific American*, September 2006, p.56

CO_2 emissions in 2030 by the world's individuals



Four comparable assignments!



A world transformed by deliberate attention to carbon

A world with the same total CO_2 emissions in 2057 as in 2007 will also have:

1. Institutions for carbon management that reliably communicate the price of carbon.
2. If wedges of *nuclear power* are achieved, strong international enforcement mechanisms to control nuclear proliferation.
3. If wedges of *CO_2 capture and storage* are achieved, widespread permitting of geological storage.
4. If wedges of *renewable energy* and *enhanced storage in forests and soils* are achieved, extensive land reclamation and rural development.
5. **A planetary consciousness**.

Not an unhappy prospect!

Never in history has the work of so few led to so much being asked of so many!

The warnings about global climate change from the climate scientists have launched a deep reexamination of the energy system and other resource-intensive aspects of ordinary living.

It is crucial that these scientists convey, as carefully as possible, what they know and how well or poorly they know it.

You have been doing this very well. Now, the stakes are rising.

From Dave Keeling's autobiography

Perhaps my success in sustaining time-series measurements will eventually raise the general scientific regard for making repetitive but important environmental measurements. Also, I hope that there will always be opportunity for individual scientists to pursue scientific leads not anticipated by committees or agencies. (p. 79)

"Rewards and penalties of monitoring the earth," *Annual Review of Energy and the Environment*, 1998, Vol. 23, pp. 25-82.

Extra Slides

From Dave Keeling's autobiography

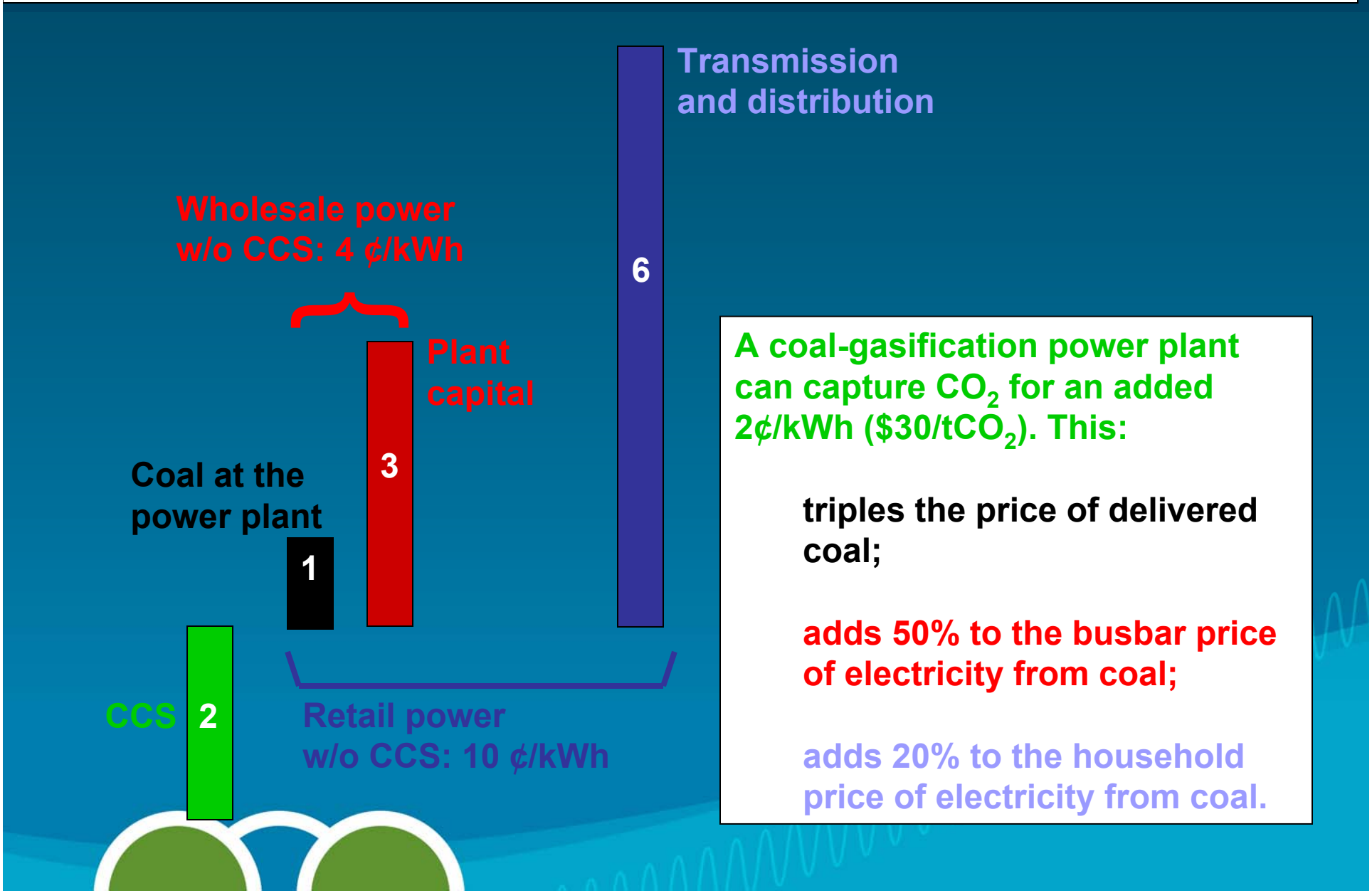
[In 1956] Wexler invited me to Washington. There I showed him my data suggesting that the amount of CO_2 in the open atmosphere might be far less variable than was generally believed… (p. 36)

[In March 1958] to our great surprise on the first day of operation [the air sampler] delivered within 1 ppm the CO_2 concentration that I had told [Ben] Harlan to expect… (p. 39)

[In November 1958] I was allowed to visit Mauna Loa and restart the analyzer. As new data emerged without further interruption, the concentration rose steadily. Then, in May, it started to decline. A regular seasonal pattern began to emerge… (p. 40)

"Rewards and penalties of monitoring the earth," *Annual Review of Energy and the Environment*, 1998, Vol. 23, pp. 25-82.

$30/tCO$_2$ ≈ 2¢/kWh induces CCS. Three views.



A coal-gasification power plant can capture CO_2 for an added 2¢/kWh ($30/tCO$_2$). 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.

Benchmark: $30/tCO$_2$

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.

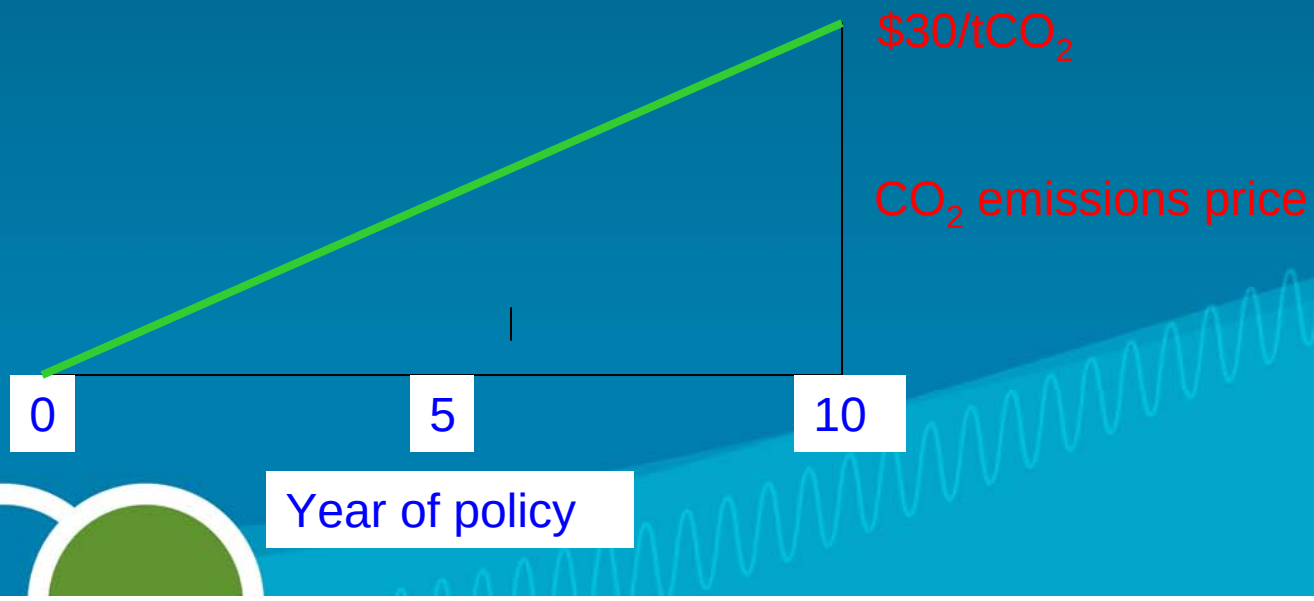
Form of Energy	**Equivalent to $30/tCO$_2$ (≈ $100/tC)**
Gasoline	25¢/gallon (ethanol subsidy: 50¢/gallon)
Electricity from coal	2.4¢/kWh (wind and nuclear subsidies: 1.8 ¢/kWh)
Electricity from natural gas	1.1¢/kWh

$30/tCO$_2$ is the current European Trading System price for 2008 emissions.
At this price, current global emissions (30 GtCO$_2$/yr) cost $900 billion/yr, 2% of GWP.

Avoid Mitigation Lite

Mitigation Lite: The right words but the wrong numbers. Companies' investments are unchanged: the emissions price is a cost of business. Individuals change few practices.

For specificity, consider a price ramp that is *not* "lite," one rising from zero to \$30/tCO_2 over 10 years.



Some carbon policy principles

- Establish a CO_2 price schedule forceful enough to drive investment decisions.
- Make the price salient as far upstream as possible (best, when C comes out of the ground or across a border).
- Supplement the price with sectoral policies (RPS, CCS, CAFE, appliance mandates).
- Stimulate international coordination.
- Allow a teething period.

An equity-based CO_2 strategy

1. ***Meet Basic Human Needs without considering carbon.***

   Don't discourage diesel engines for village-scale power or LPG for cooking.

   Expect a poor family to respond to a better insulated home by raising the indoor temperature ("takeback").

2. ***Attain all savings from the largest emitters***

3. ***Mitigate uniformly for the same income level across all countries.***

   Coordinated development and deployment of efficient appliances, urban mass transit, videoconferencing, CO_2 capture and storage, renewables, and nuclear power.