

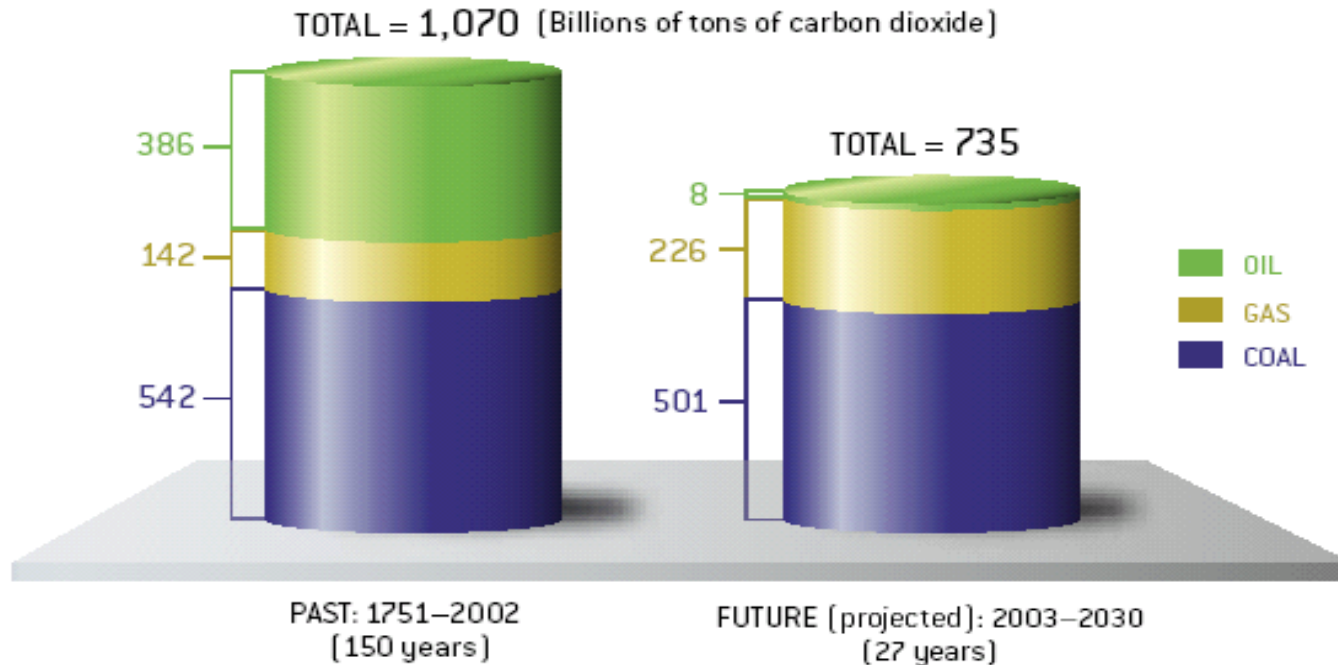
Stabilization Wedges and the Urgency of Scale-Up

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keynote talk

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The Demography of Capital



PAST: 1751–2002
[150 years]

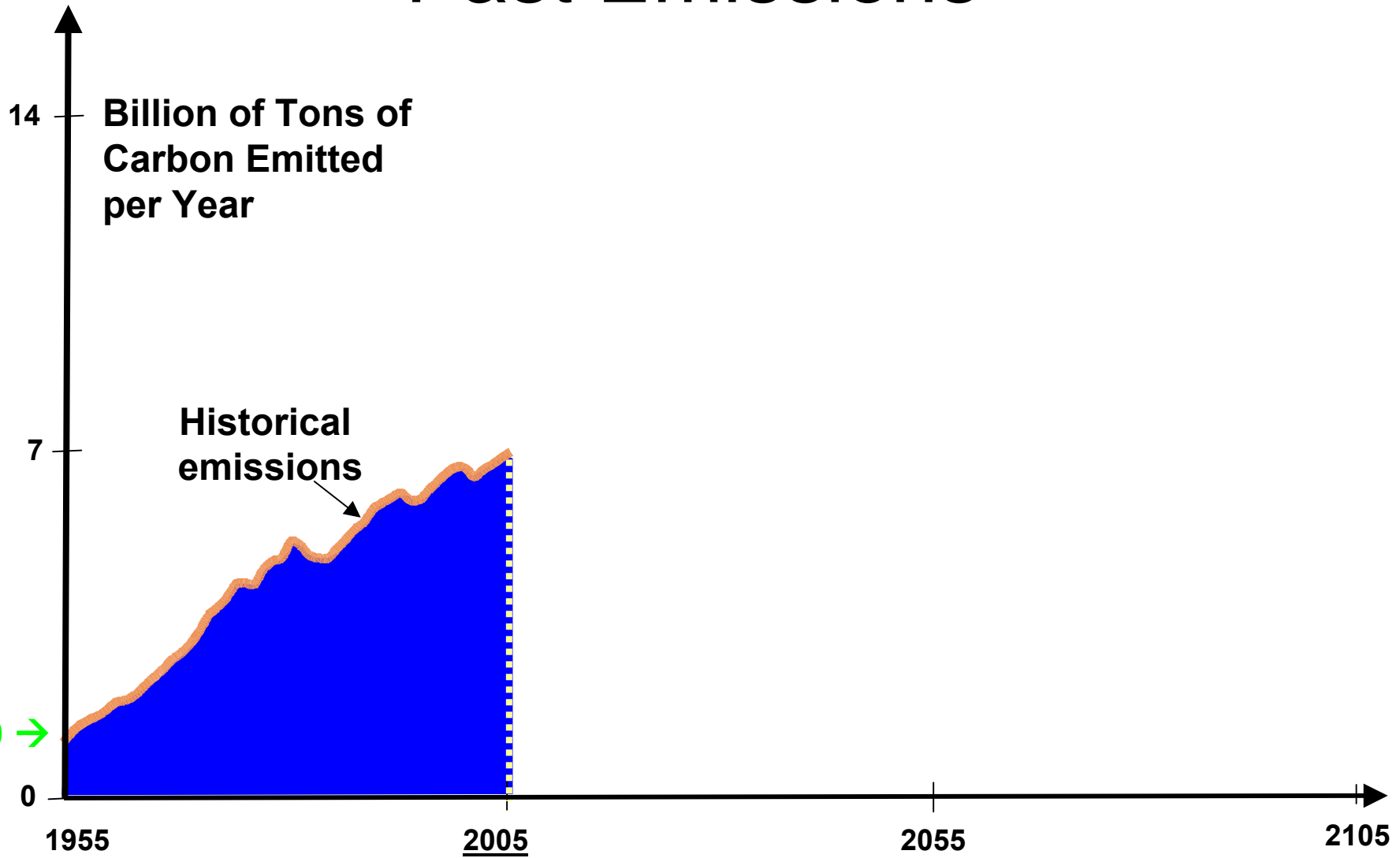
**Historic
emissions,
all uses**

FUTURE (projected): 2003–2030
[27 years]

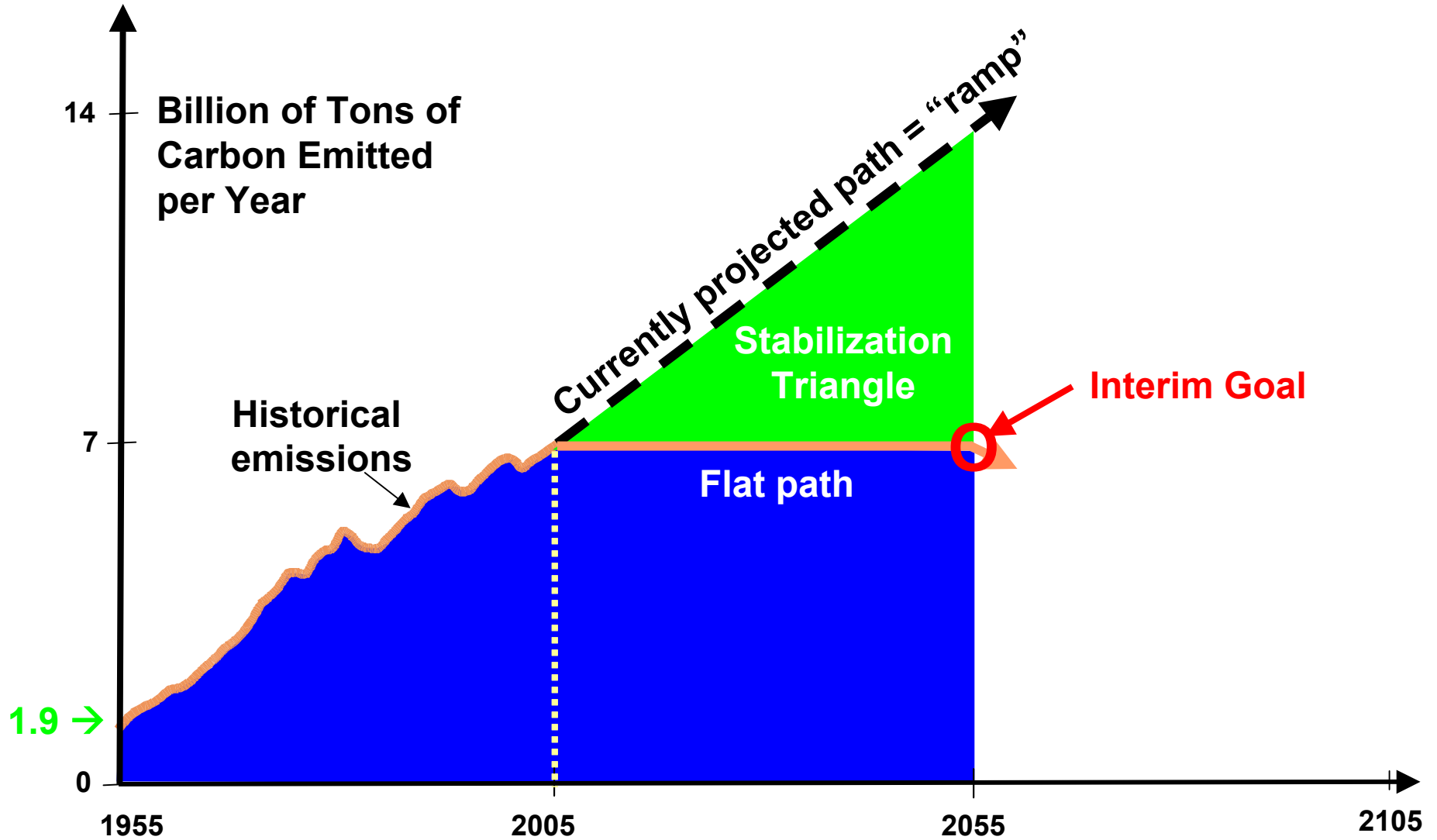
2003-2030 power-plant lifetime CO₂ commitments
WEO-2004 Reference Scenario.
Lifetime in years: coal 60, gas 40, oil 20.

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

Past Emissions



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.

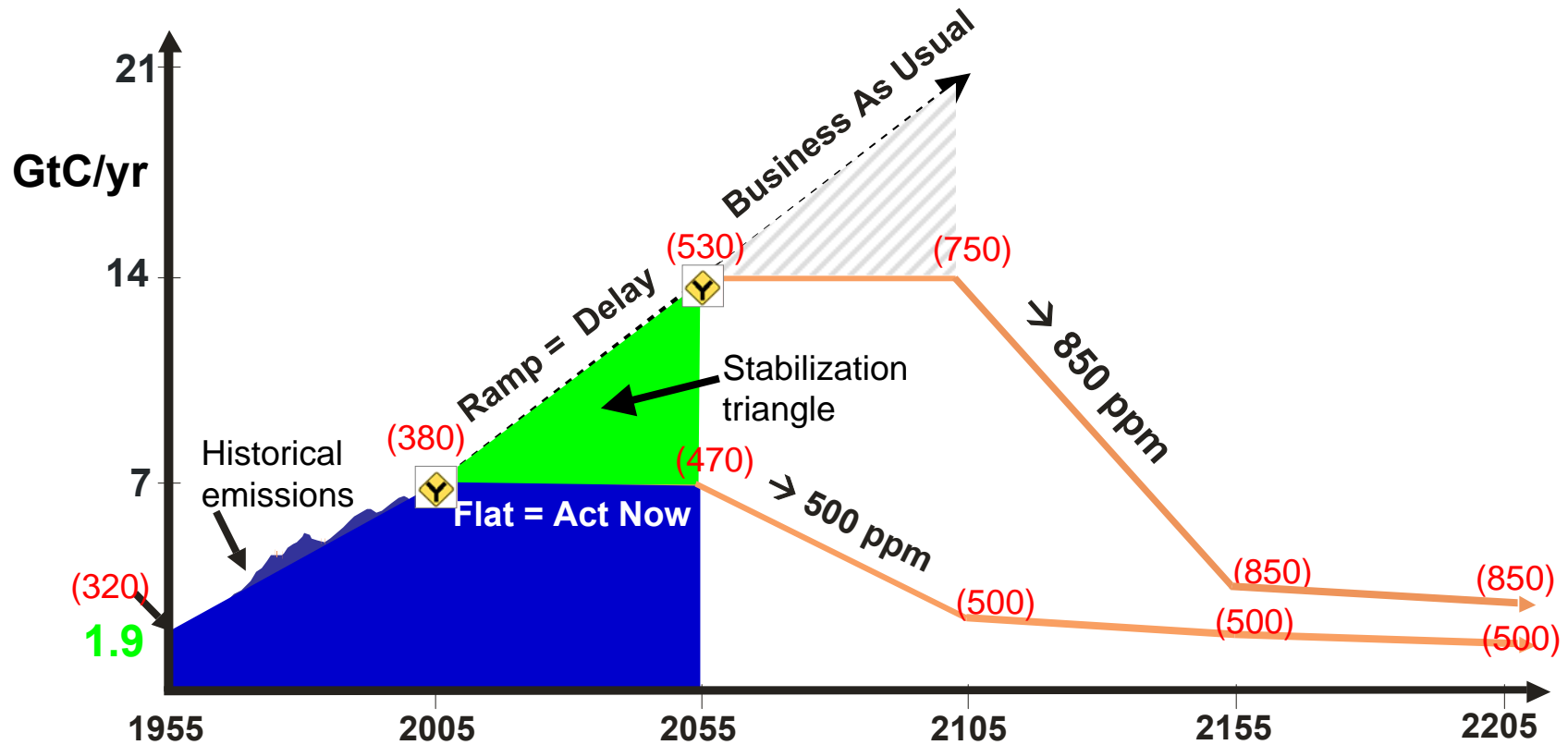
This century-scale goal is broadly consistent with the *Interim (50-year) goal*:

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 Stabilization Triangle: Beat doubling or accept tripling (details)



Values in parentheses are ppm. Note the identity (a fact about the size of the Earth's atmosphere): 1 ppm = 2.1 GtC.

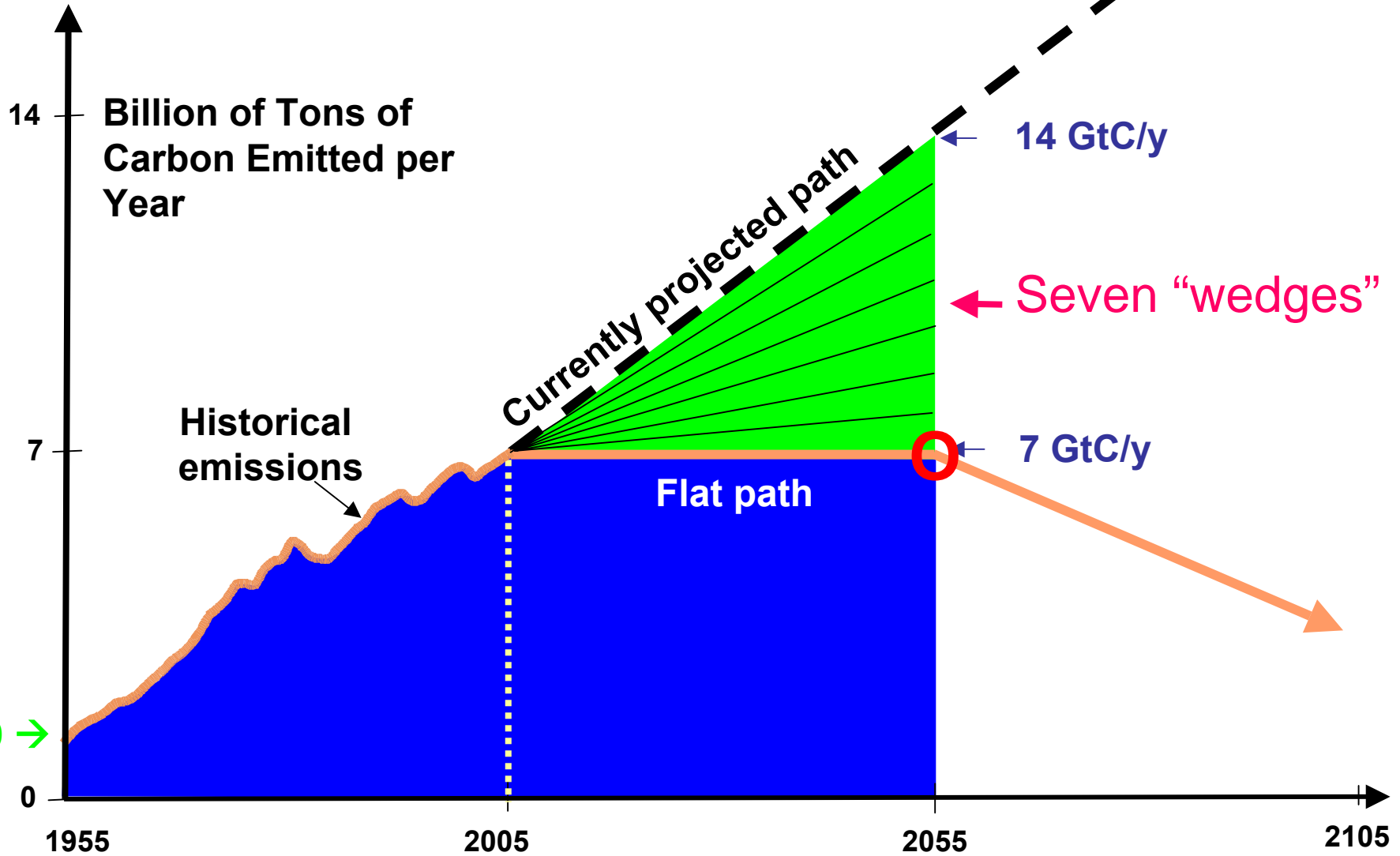
The Interim Goal is Within Reach

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 just begun to be priced.
- Most of the 2055 physical plant is not yet built

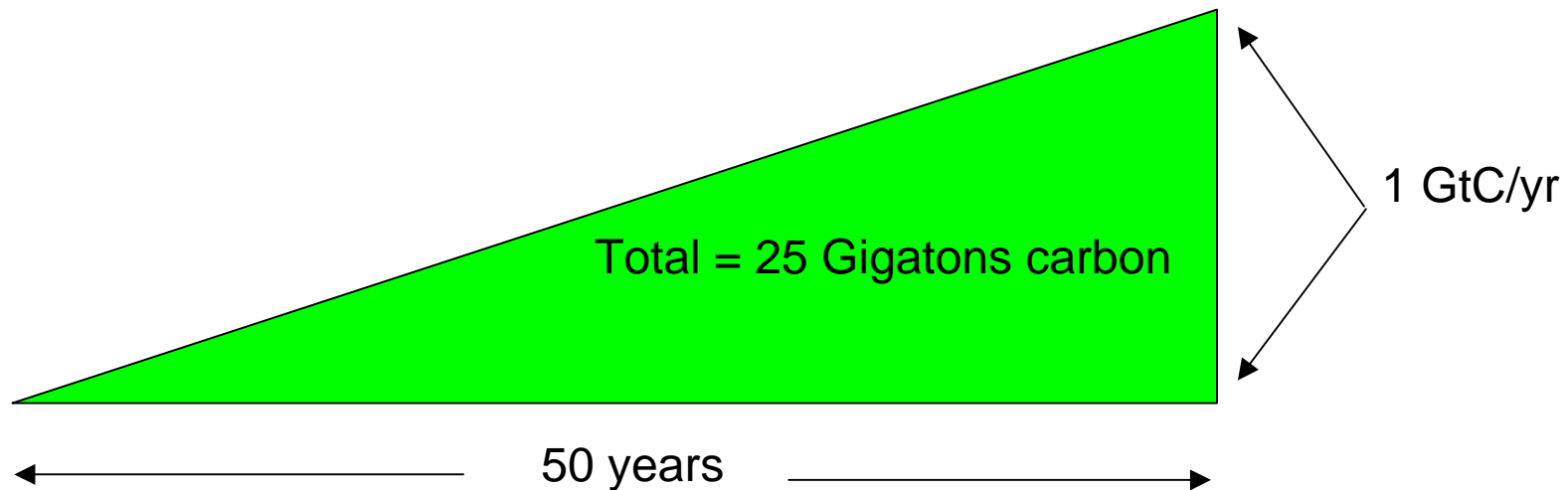


Wedges



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 CO₂ problem should provide at least one wedge.



Wedges

EFFICIENCY

- Buildings, appliances, transport, *industrial processing*, *lighting*, *electric power plants*, *upstream extraction*.

DECARBONIZED ELECTRICITY

- Natural gas for coal
- Power from coal or gas with carbon capture and storage
- Nuclear power
- Power from renewables: wind, photovoltaics, *solar concentrators (troughs and dishes)*, *hydropower*, *geothermal*.

DECARBONIZED FUELS

- Synthetic fuel from coal, natural gas, and biomass, with carbon capture and storage
- **Biofuels**
- Hydrogen
 - from coal and natural gas, with carbon capture and storage
 - from nuclear energy
 - from renewable energy (hydro, wind, PV, etc.)

FUEL DISPLACEMENT BY LOW-CARBON ELECTRICITY

- *Grid-charged batteries (“plug-in hybrids”) for transport*
- *Heat pumps for furnaces and boilers*

NATURAL SINKS

- Forestry (reduced deforestation, afforestation, new plantations)
- Agricultural soils

METHANE MANAGEMENT

- *landfill gas, cattle, rice, natural gas*

Italics: Not on list in *Science*

Efficiency and Conservation

transport



buildings



industry



Effort needed by 2055 for 1 wedge:

2 billion cars at 60 mpg instead of 30 mpg.

Twice today's coal power utilized at 60% instead of 40% efficiency (combined heat and power, power plant technology)

power



lifestyle



Baseload carbon-free electricity (geothermal, nuclear, hydro...)

Effort needed by 2055 for 1 wedge: 700 GW displacing coal power.

Geothermal power

TABLE I. World-wide geothermal installed capacity in the year 2000 in MWe.

United States	2,228	Kenya	57
The Philippines	1,909	Guatemala	33
Mexico	855	China	29
Italy	785	Russia	23
Indonesia	589	Turkey	20
Japan	547	Portugal (Azores)	16
New Zealand	437	Ethiopia	9
Iceland	170	France (Guadalupe)	4
El Salvador	161	Thailand	0.3
Costa Rica	142	Australia	0.17
Nicaragua	70	Total	8154

8 GW are installed, 1% of a wedge.

Nuclear power



Graphic courtesy of NRC

350 GW are installed. Phase out is minus a half wedge.

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)*



Biofuels



Effort needed by 2055 for 1 wedge:

Two billion 60 mpg cars running on biofuels

250 million hectares of high-yield crops (one sixth of world cropland)

Usina Santa Elisa mill in Sertãozinho, Brazil

(http://www.nrel.gov/data/pix/searchpix.cgi?getrec=5691971&display_type=verbose&search_reverse=1_



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.



Summary: What's appealing stabilization wedges?

The stabilization triangle:

Does not concede doubling is inevitable.

Shortens the time frame to within business horizons.

The wedge:

Decomposes a heroic challenge (the Stabilization Triangle) into a limited set of monumental tasks.

Establishes a unit of action that permits quantitative discussion of cost, pace, risk.

Establishes a unit of action that facilitates quantitative comparisons and trade-offs.

National subsidies have elicited wedge technologies at large scale

Wedges Technology	Subsidy
CO ₂ transport	EOR (U.S.)
CO ₂ geological storage	EOR (U.S.), Sleipner (Norway)
Wind	Wind electricity (Germany, Denmark, U.K.)
Nuclear power	Nuclear power (U.S., Russia, France)
Coal-to-H ₂	Fertilizer (China)
Biofuels	Sugarcane ethanol (Brazil)
<i>Coal-to-liquids (negative wedges)</i>	<i>Synfuels (South Africa)</i>

All of the wedge technologies have already been commercialized at scale, but generally in only a few countries. Most subsidies have been motivated by energy security, not climate. The whole world has learned from these national experiences.

\$100/tC

Carbon emission charges in the neighborhood of \$100/tC can enable scale-up of most of the wedges. (PV is an exception.)

Form of Energy	Equivalent to \$100/tC
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
Today's global energy system	\$700 billion/year (2% of GWP)

\$100/tC is approximately the October 2005 EU trading price.

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?

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.

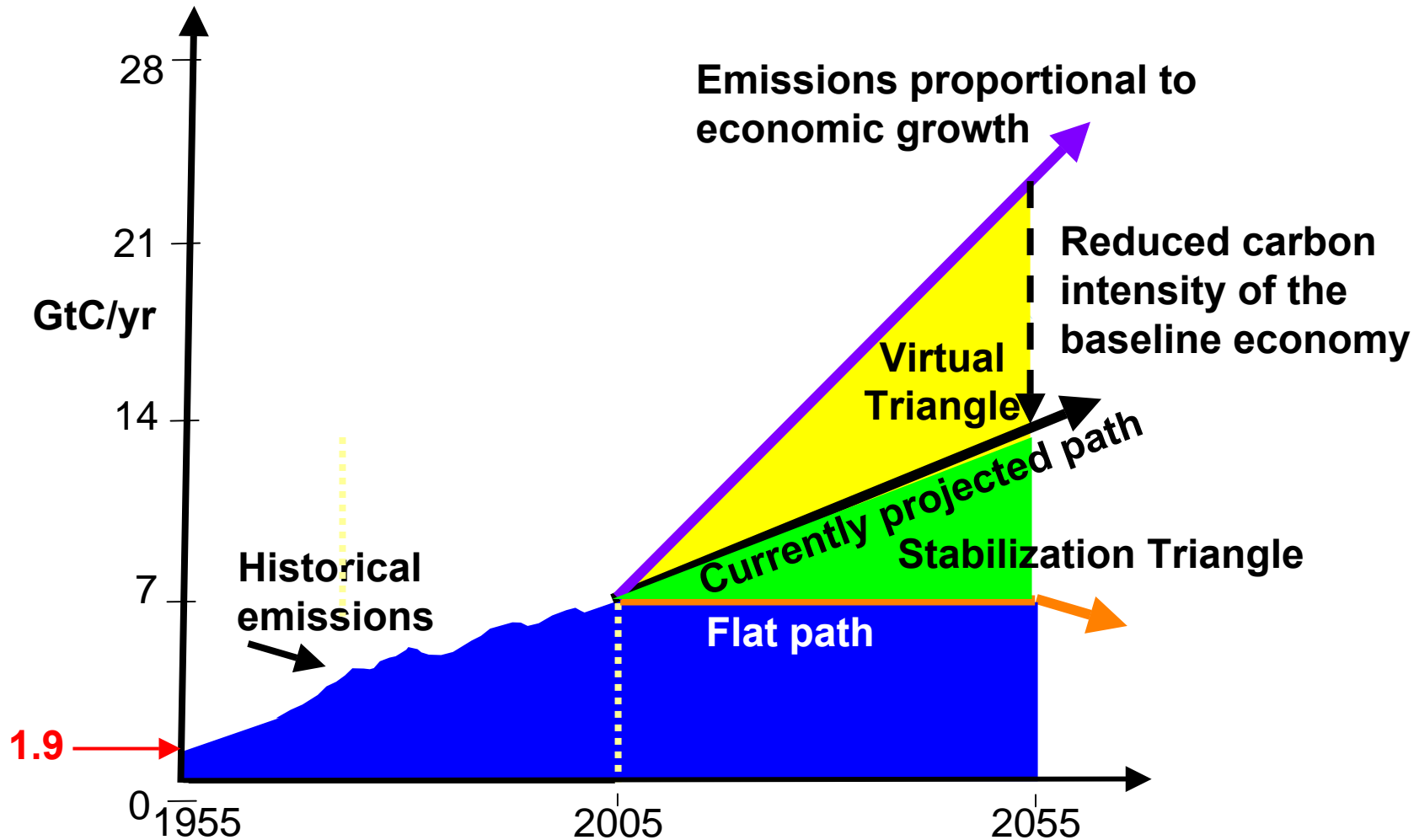
We should anticipate a discontinuity:

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

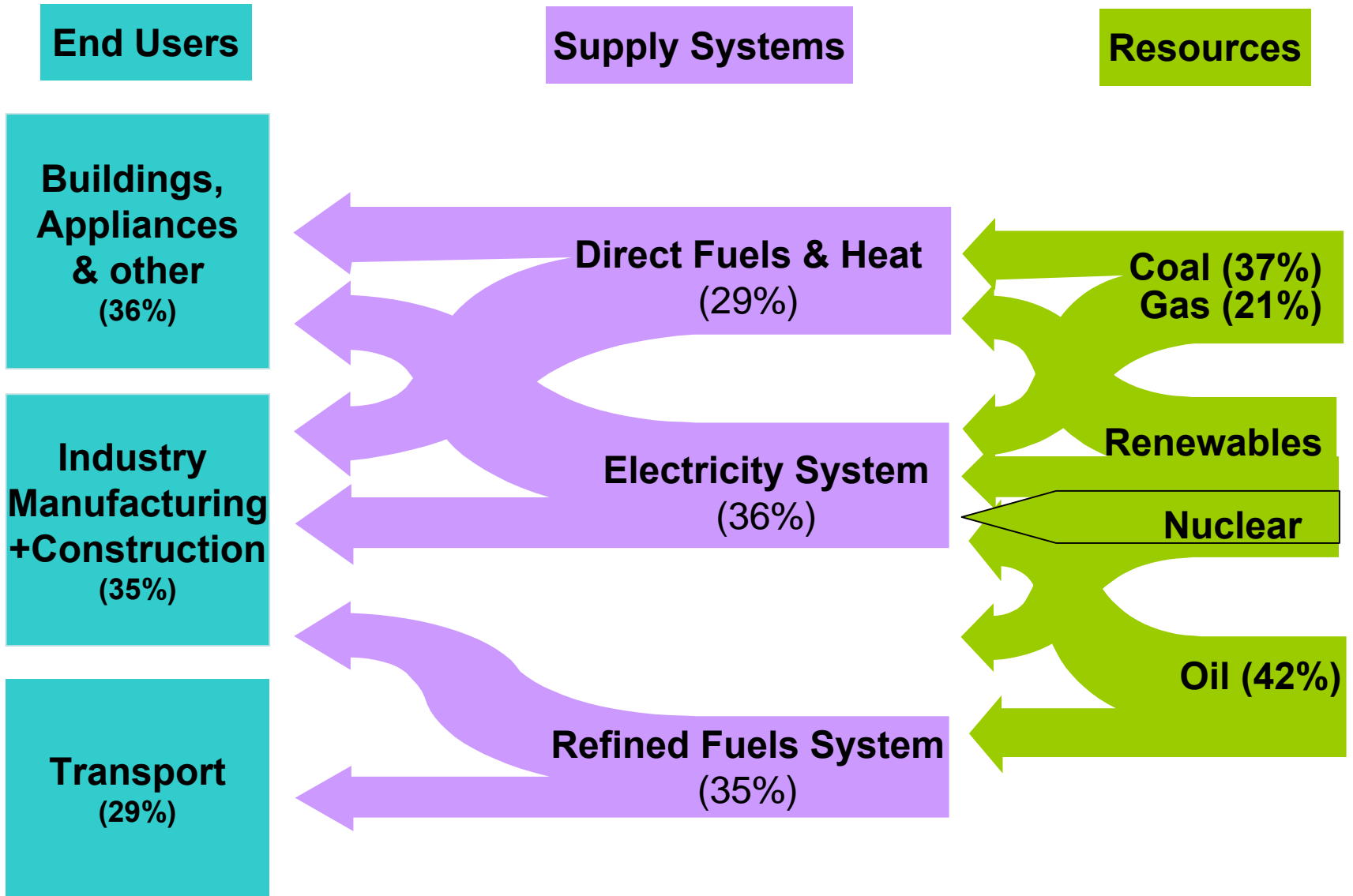
Precedents include abolishing child labor, addressing the needs of the disabled, and mitigating air pollution.

EXTRA SLIDES

The Virtual Triangle: Large Carbon Savings Are Already in the Baseline



Carbon Flows in the Energy System



Percents of global energy-related CO2 emissions, including emissions embodied in fuels and electricity. Source: Michael Grubb. Slide modified by DEFRA, UK.

The Demography of Capital

Long-lived capital stock (lifetime >50 years) is the source of a significant fraction of global CO₂ emissions.

Examples: power plants, residential and commercial buildings, fuels infrastructure

Retrofitting after construction is usually very costly.

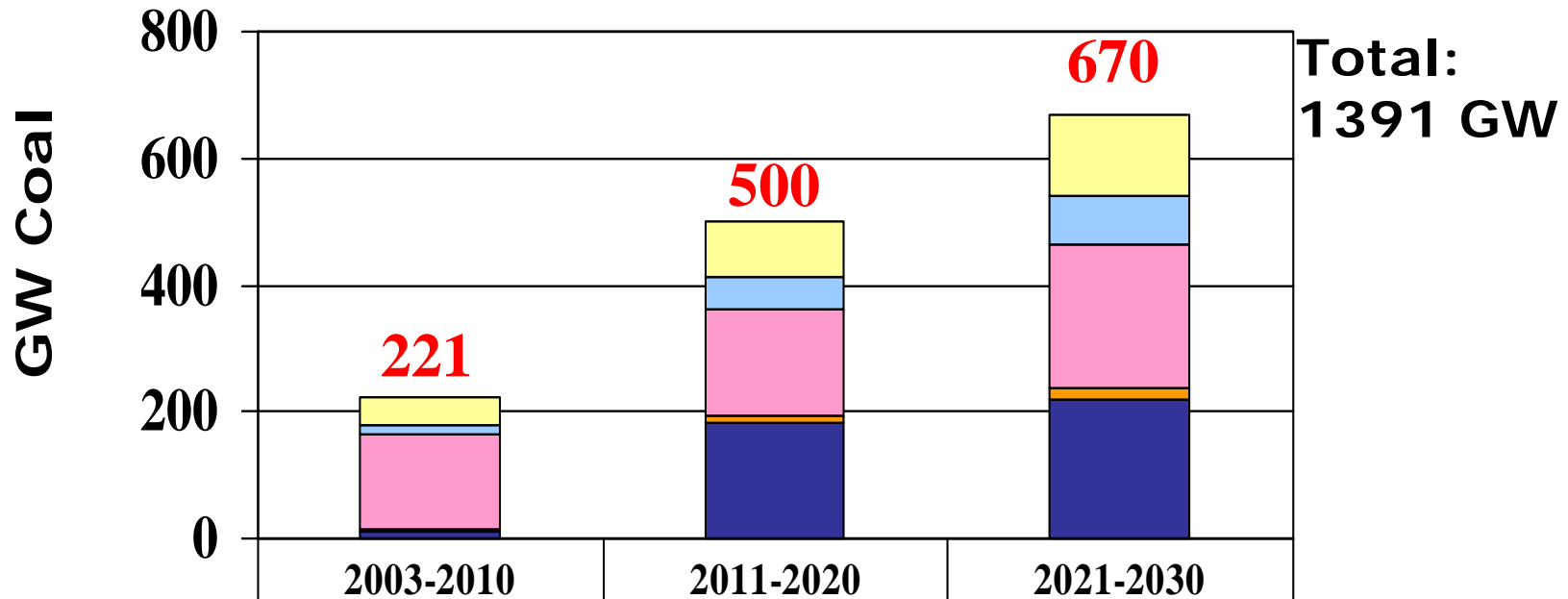
Two messages:

Avoid premature retirement: DELAY

Avoid new high-carbon stock: ACT NOW

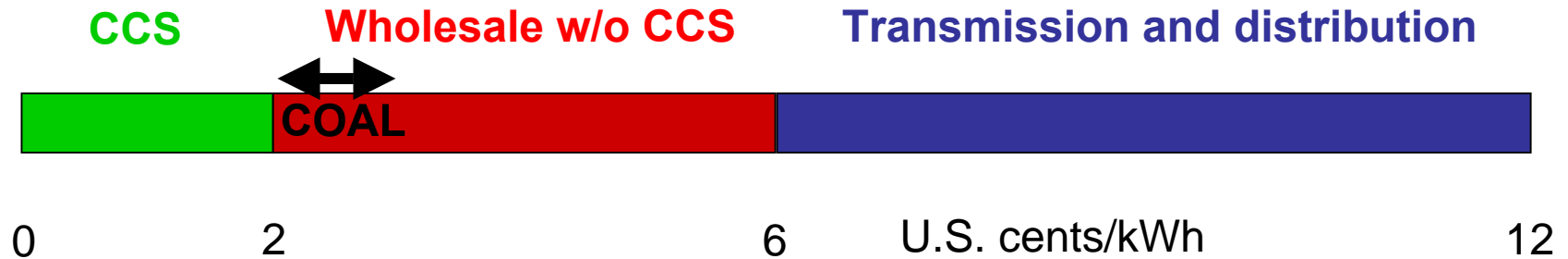
One must heed both messages.

New Coal Build by Decade



	2003-2010	2011-2020	2021-2030
Other Developing	43	90	128
India	16	48	79
China	150	168	226
Transition	1	11	19
OECD	12	184	218

\$100/tC \approx 2¢/kWh will induce CCS. Is it added to the cost of coal, busbar power, or household power?



A coal-gasification power plant can capture CO₂ for an added 2¢/kWh. It will do so if the cost of carbon emissions exceeds about \$100/tC (\$27/tCO₂).

Can policy guarantee pass-through of CCS costs without overheads? If so, that's a retail surcharge of 20%. If not, then maybe 50%.

The coal mine owner sees a surcharge of 200%!

A world transformed by deliberate attention to carbon (1 of 2)

A world with the same total CO₂ emissions in 2055 as in 2005 will also have:

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

The list continues...

A world transformed by deliberate attention to carbon (2 of 2)

The list continues...

A world with the same total CO₂ emissions in 2055 as in 2005 will also have:

5. If *hydrogen* is widely used, broad acceptance of its safety.
6. If transportation has become energy-efficient, solutions to congestion.
7. A planetary consciousness.

Not an unhappy prospect!