Be the Solution: Climate Change Mitigation Strategies

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Presentation Outline

1. Theories of mitigation
   a. Socolow's Stabilization Wedges
   b. McKinsey Abatement Cost Curve

2. From theory to practice

3. Additional commentary - McKibben & Global Warming's New Math

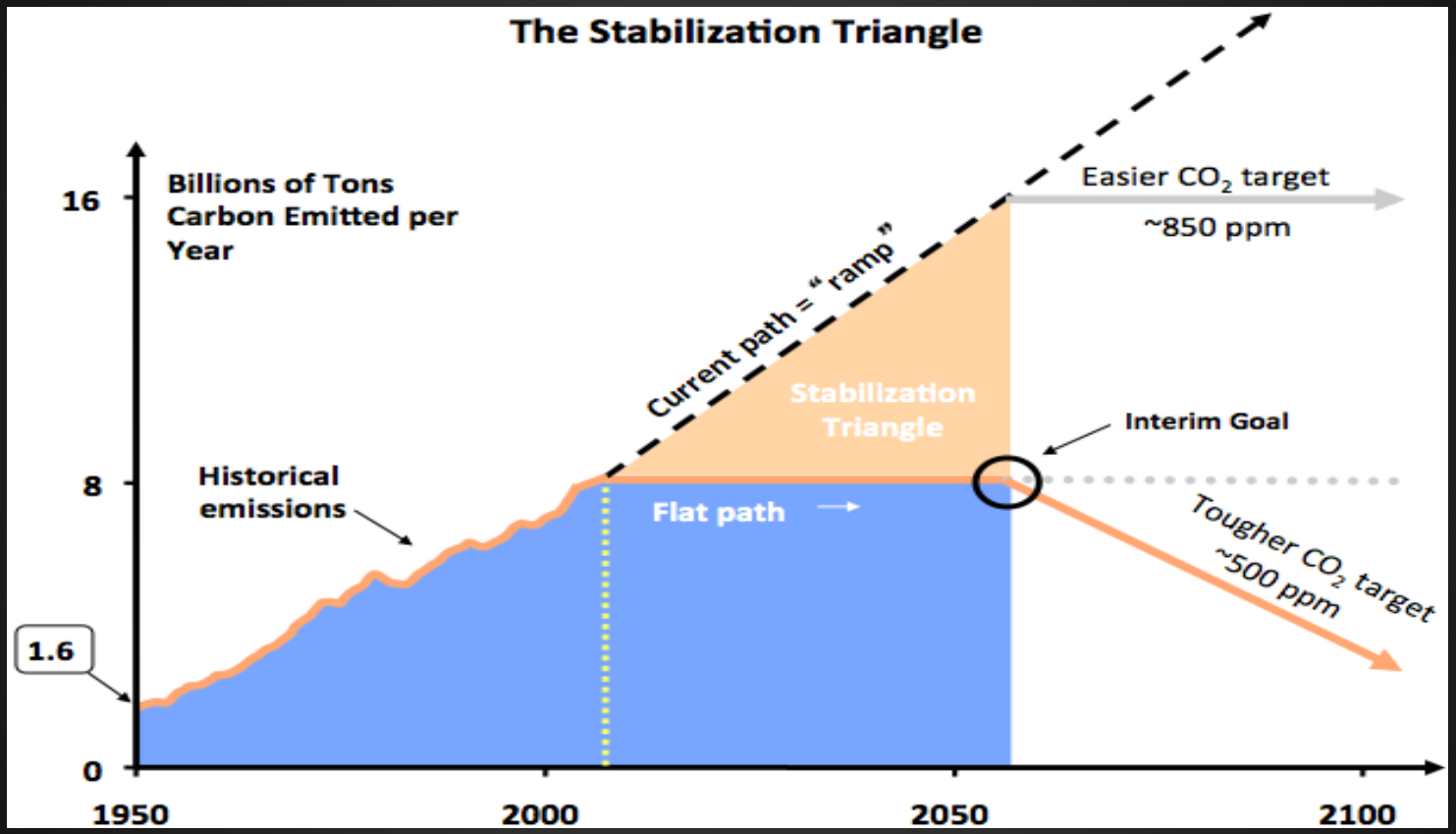
Socolow: "Stabilization Wedges"

- Visualizing climate change mitigation strategies
  - stabilization triangle
  - stabilization wedge

- 15 different strategies covering a portfolio of technology and science that have already been implemented and tested

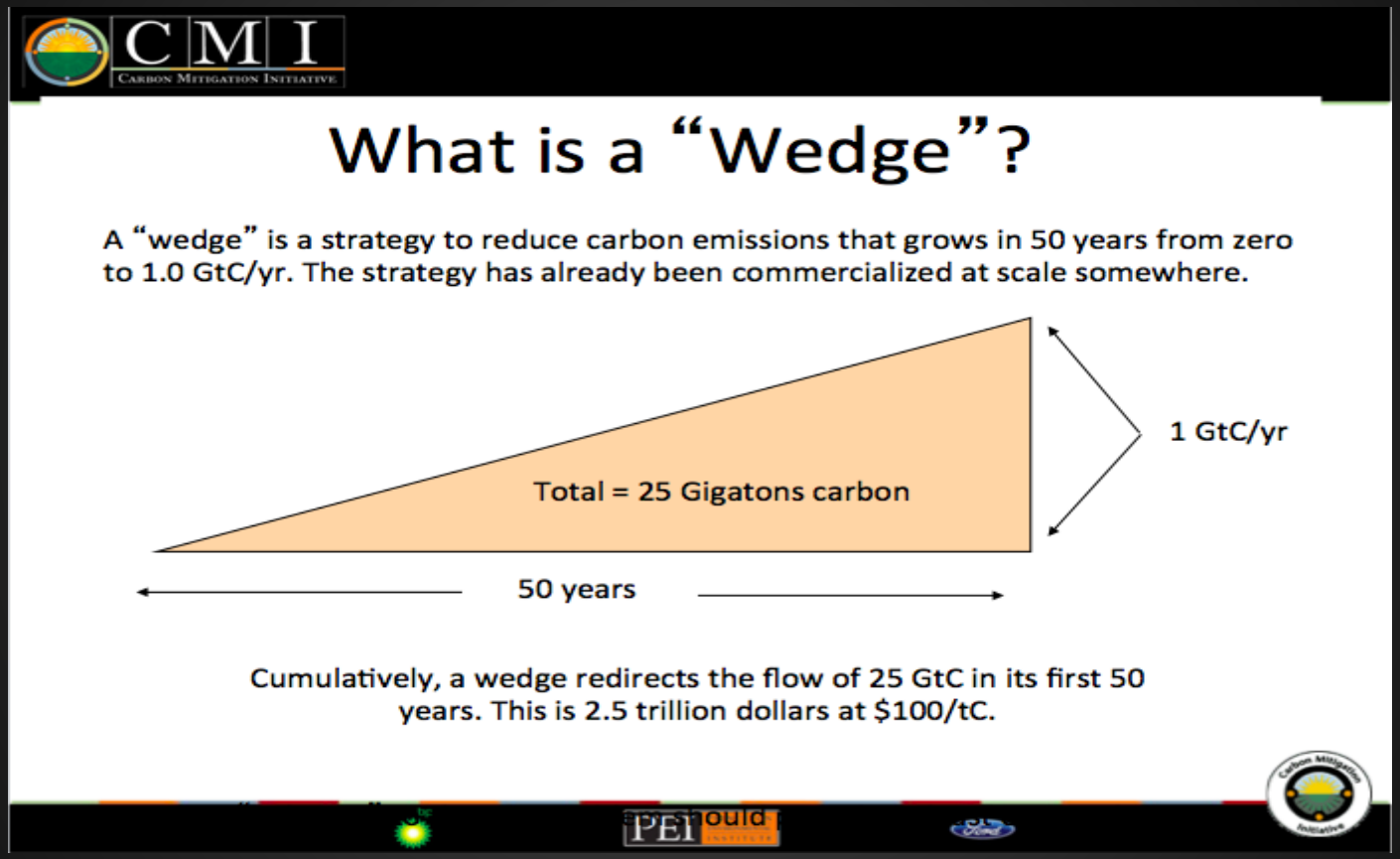
- Goal = keep atmospheric CO_2 (equilibrium concentration) at less than double pre-industrial CO_2 concentrations of 280 ppm

Stabilization Triangle



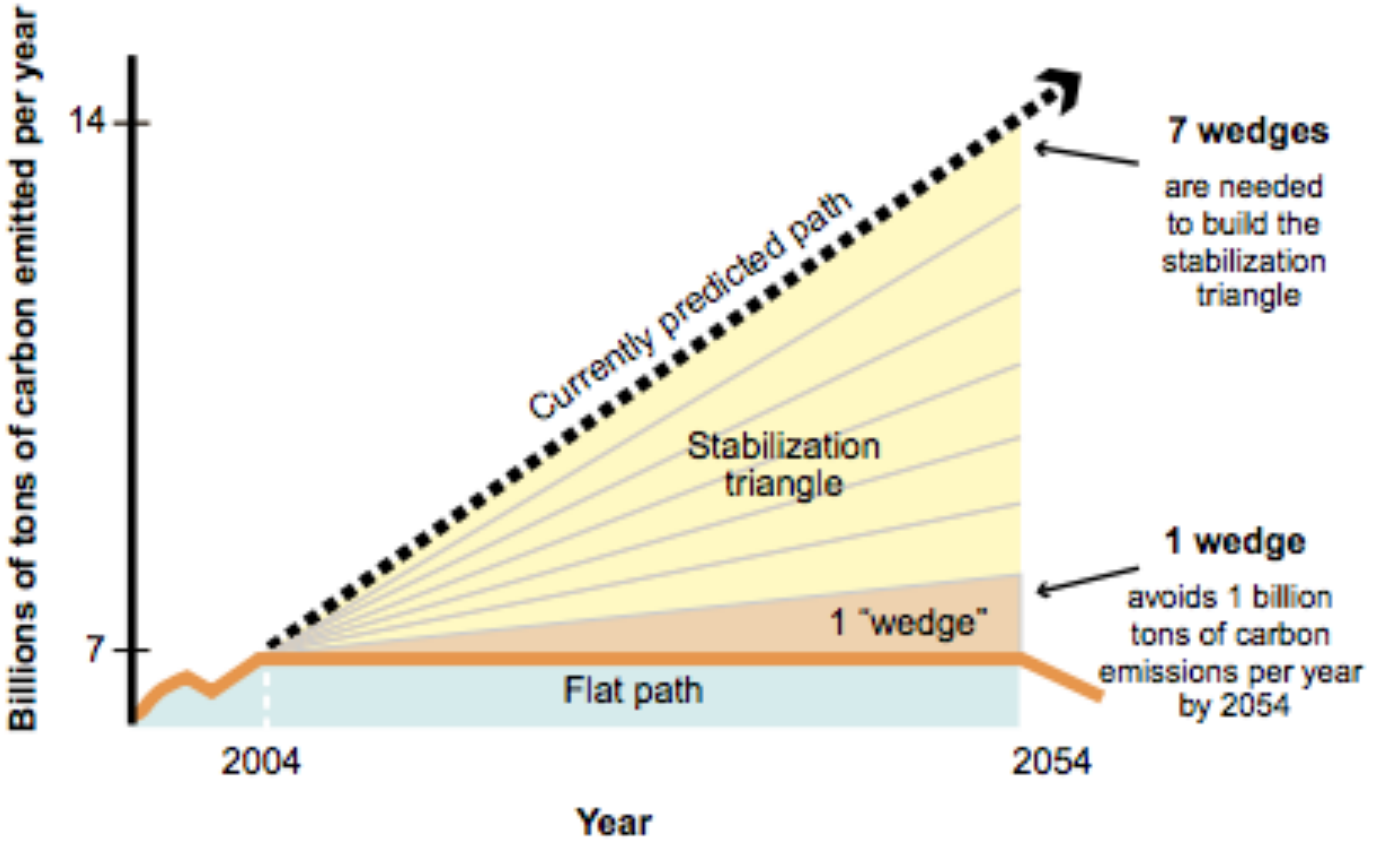
Total CO2 emissions avoided over 50 years if emission rate is stabilized (equilibrium concentration) compared to current projections toward doubling emission

Stabilization Wedge



1 "wedge" grows to reduce emissions by 1 Gt CO2 per year after 50 years. Over the intervening 50 years, 25 Gt CO2 will be avoided

Figure 1b. Stabilization wedges



NOTE: The stabilization triangle in Figure 1a can be divided into seven equal "wedges" that represent activities capable of reducing one billion tons of carbon per year by 2054.

SOURCE: R. Socolow, R. Hotinski, J. B. Greenblatt, and S. Pacala.

Stabilization Strategies & Categories

Five categories to achieve a flat trajectory for emissions, 15 specific strategies:

- **Energy Conservation**
  - Transport efficiency = 0.8 wedge
  - Reduced miles traveled
  - Building efficiency (direct residential/industrial use)
  - Efficiency of electricity production

- **Renewable Energy**
  - Electricity: Replacing coal with 50X wind, 700X solar, or 100X geothermal = 1 wedge
  - Biofuels: 50X production increase = 1 wedge

Stabilization Strategies & Categories

- **Enhanced Natural sinks**
  - Forest: Stop deforestation = 0.5 wedge, Reforest 300 million hectares = 0.5 wedge
  - Soil: Conservation tillage of all global agricultural land = 1 wedge
  - Ocean = Uncertainty

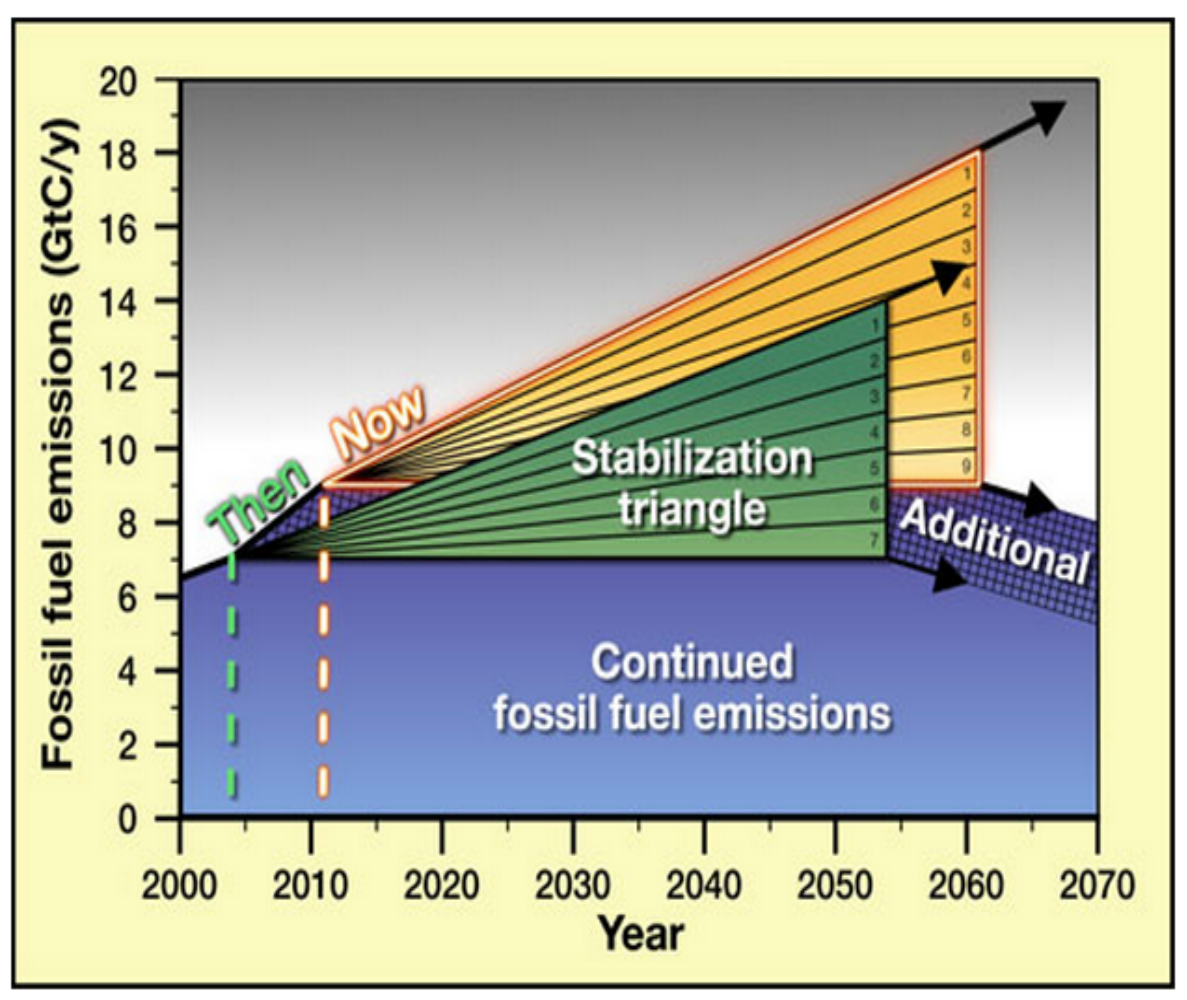
- **Nuclear energy**
  - 3X current nuclear power generation = 1 wedge
  - Update all nuclear facilities = 0.5 wedege

Stabilization Strategies & Categories

- **Fossil Carbon Management**
  - Fuel switching (coal to gas): Change the mix of fossil fuels in current global energy market
  - Fossil-based electricity with carbon capture and storage (CCS): Separate stream of CO2 from other products during combustion and prevent it from being released into the atmosphere
  - Coal synfuels with CCS
  - Fossil-based hydrogen fuel with CCS

http://cmi.princeton.edu/wedges/pdfs/climate_problem.pdf

Stabilization Wedges Reaffirmed



In 2011, Socolow reaffirmed belief that "existing technologies could affordably limit warming"

9 wedges instead of 7

Consequences from delay:

- 1/2º C increase in global surface temp.
- 50 ppm increase in equilibrium concentration.

http://thebulletin.org/web-edition/features/wedges-

McKinsey: "A cost curve for greenhouse gas reduction"

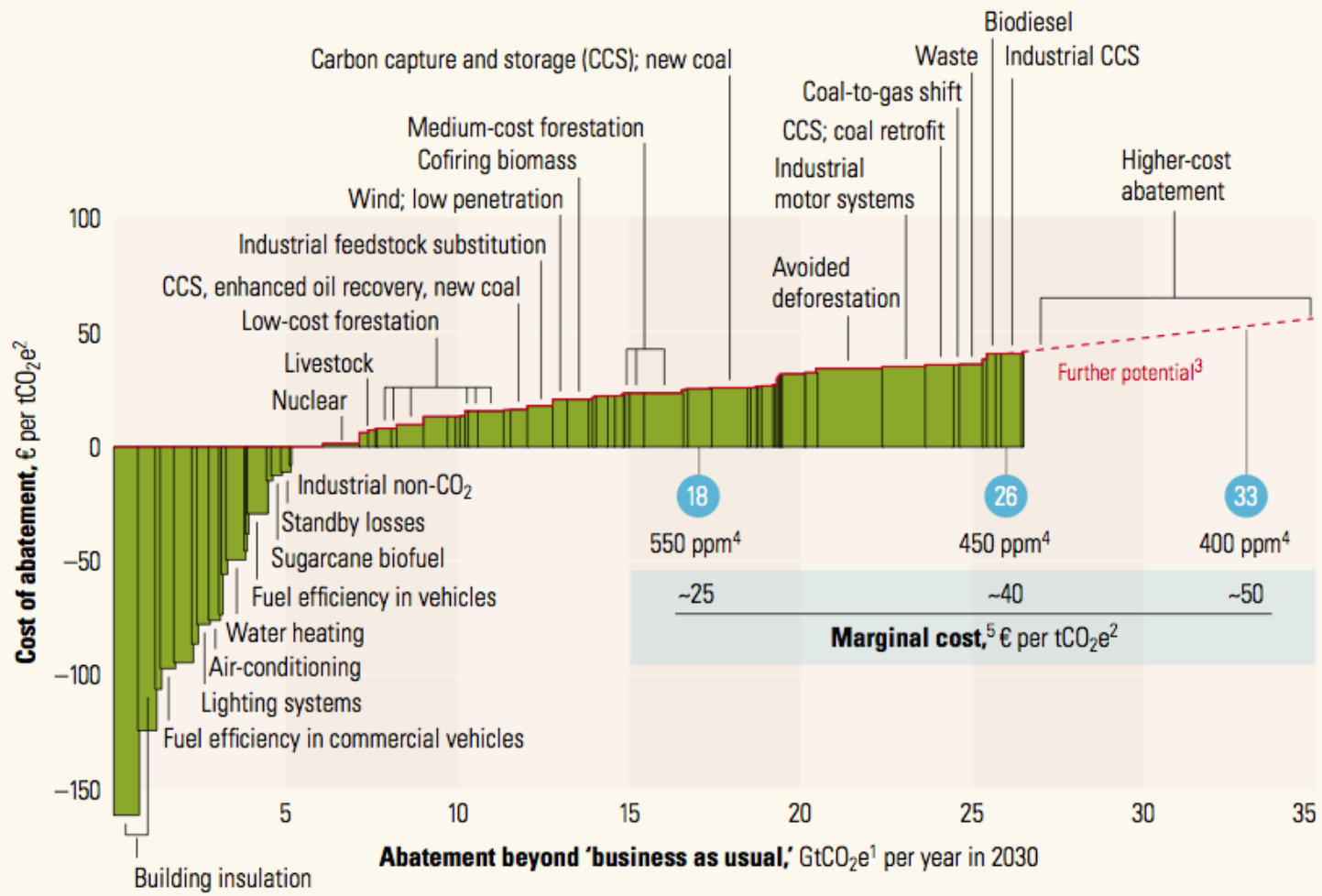
- Alternative strategy to visualize costs and potential abatement through various measures
  - Significance, cost, and relative importance of possible measures

- Calculates marginal cost of various abatement measures (Gt CO_2e/y by 2030 up to 40 euro/t)
  - Emissions relative to IEA/EPA business-as-usual projections

- Targets: keep atmospheric concentrations below 550, 450, or 400 ppm CO_2 by 2030
  - Reaching any of these would require 50%+ improvement in global greenhouse gas efficiency (emissions/GDP)

What might it cost?

Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in $GtCO_2e$[1]



[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2] tCO_2e = ton of carbon dioxide equivalent.
[3] Measures costing more than €40 a ton were not the focus of this study.
[4] Atmospheric concentration of all greenhouse gases recalculated into CO_2 equivalents; ppm = parts per million.
[5] Marginal cost of avoiding emissions of 1 ton of CO_2 equivalents in each abatement demand scenario.

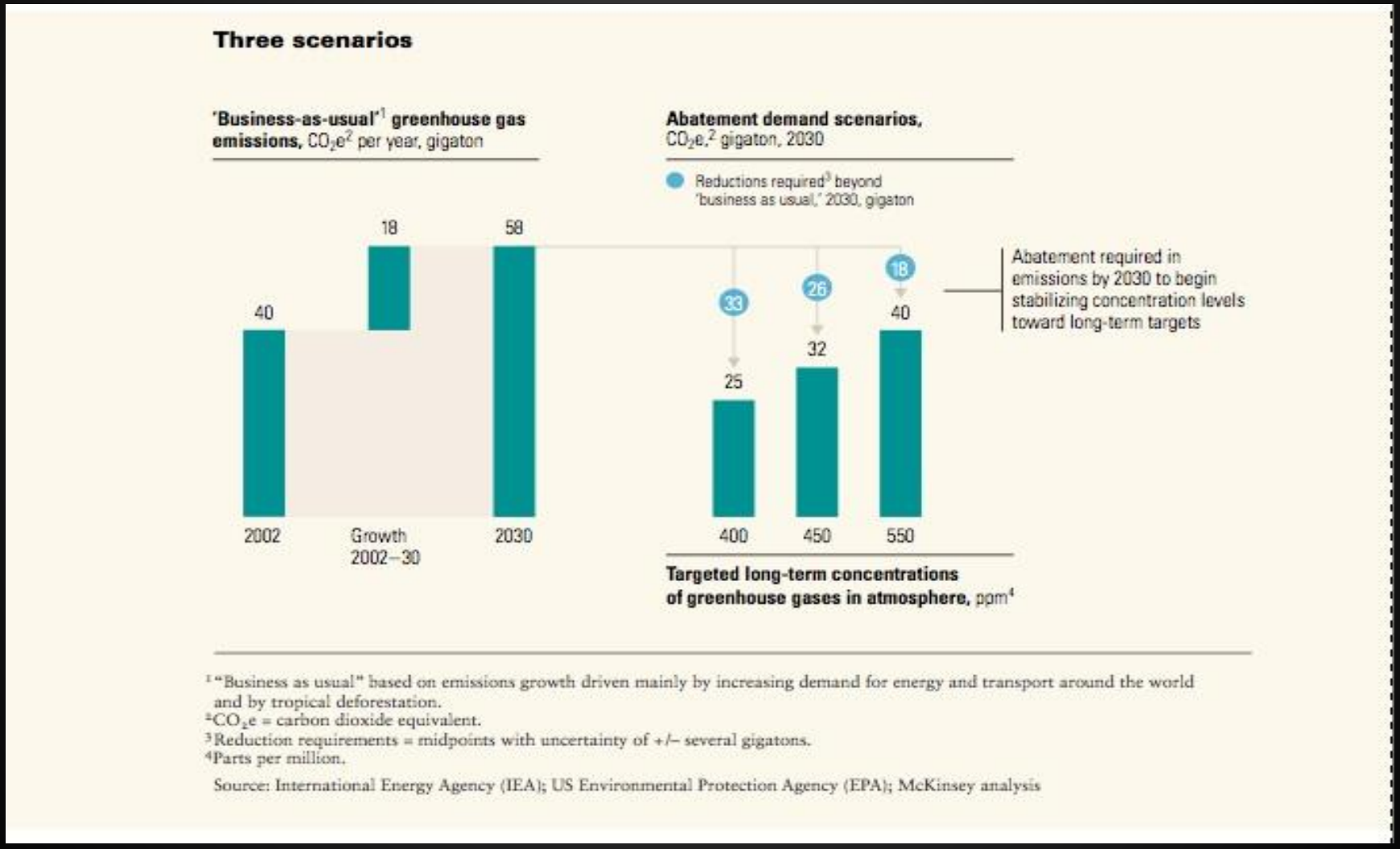
Cost Curve Explained...

- Prospective annual marginal cost of abatement per ton of CO2e (euro/t)
  - Only shows measures for which the cost is estimated to be <40 euro/t in 2030
  - e.g. wind power cost = additional cost over fossil fuels

- Abatement potential of each abatement measure (Gt CO2e)
  - Width of each column demonstrates the quantity of CO2e abated

- Why do some measures have a negative cost of abatement?
  - Increased efficiency brings savings - but transaction costs & status quo bias reduce the likelihood of implementation for these measures

Three scenarios addressed:



[1] "Business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[2] CO_2e = carbon dioxide equivalent.
[3] Reduction requirements = midpoints with uncertainty of +/– several gigatons.
[4] Parts per million.

Source: International Energy Agency (IEA); US Environmental Protection Agency (EPA); McKinsey analysis

Abatement Sectors:

- Power Generation - 5.9 Gt CO2e/y
- Manufacturing Industry - 6.0
- Residential/Commercial Buildings - 3.7
- Transportation - 2.9
- Forestry - 6.7
- Agriculture/waste disposal - 1.5

Abatement potential by sector

EXHIBIT 3

Abatement potential

Abatement potential for greenhouse gases by sector, $GtCO_2e$[1] per year by 2030 (costing up to €40 per ton)

100% = 26.7

		Possible abatement measures (examples)
Power, manufacturing		
Power	5.9	• Renewables (wind, solar, biomass) • Nuclear • Carbon capture and storage
Manufacturing	6.0	• Energy efficiency (eg, cogeneration, process shift) • Fuel switching (eg, biofuels) • Carbon capture and storage in industrial process
Buildings, transportation		
Buildings	3.7	• Improved building insulation, heating/cooling efficiency • Energy efficiency in lighting, appliances
Transportation	2.9	• Fuel-efficient vehicles • Biofuels
Forestry, agriculture		
Forestry	6.7	• Deforestation avoided • Afforestation/reforestation
Agriculture/waste	1.5	• Capture of methane from landfills • New agricultural methods without tillage[2]

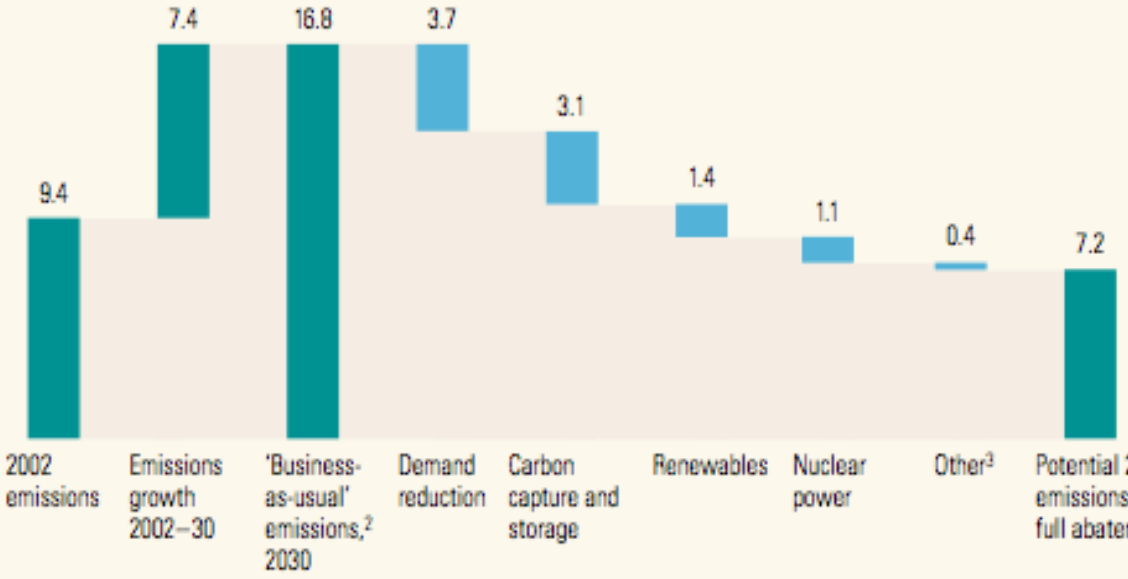
[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent.
[2] Reduces CO_2 emissions from soil.

Power sector abatement potential:

EXHIBIT 5

Abatement potential in the power sector

Emissions development and abatement potential in power sector, greenhouse gases measured in $GtCO_2e$ per year by 2030 (costing ≤ €40 per ton)[1]



[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent; figures do not sum to 100%, because of rounding.
[2] "Business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
[3] For example, coal-to-gas shift beyond "business as usual," improved efficiency in existing plants; these measures compete with other measures and could have higher impact on abatement in other abatement scenarios.

Cost Curve - Key Findings...

- Low cost measures focus on:
  - improving energy efficiency & lowering energy demand
- High cost measures focus on:
  - more GHG-efficient technologies in power generation/manufacturing & a shift to cleaner industrial processes - e.g. wind power, carbon capture and storage
- Over 25 years, power generation and manufacturing industry can provide less than half of potential reductions
- ~3/4 of potential abatement from technology independent measures or mature technologies

Cost Curve - Key Findings

- Almost 1/4 of potential reductions, according to McKinsey, would have no net life cycle costs
    - If they are free or net positive, why haven't we implemented them yet? Status quo bias, transaction costs (e.g. billions of small emitters in the energy efficiency measures)
- Substantial potential lies with developing economies
- Economic growth strongly correlated with implementation of low-cost measures - cheaper when building new than to retrofit
- Cost for 450 ppm target: 500 billion euro - 1,100 billion euro in 2030 (0.6%-1.4% of 2030 global GDP)

Role of developing economies:

EXHIBIT 4

Developing economies will play an important role

Abatement potential for greenhouse gases by region, $GtCO_2e$[1] per year by 2030 (costing up to €40 per ton)

100% = 26.7

		% of global emissions	
		'Business as usual,'[3] 2030	After abatement
Eastern Europe[2]	1.6	9	11
Western Europe[2]	2.5	8	7
North America	4.4	15	14
Other developed countries	2.5	11	13
China	4.6	18	18
Other developing countries	11.1	39	37

[1] $GtCO_2e$ = gigaton of carbon dioxide equivalent.
[2] Eastern Europe includes former Soviet Union and Balkans; Western Europe includes EU25 plus Iceland, Norway, Switzerland, Turkey, minus Baltic states.
[3] "Business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.

Cost Curve - Assumptions

- Certain actions have already begun to take place (e.g. wind power) and will continue to scale up
- Significant decrease in cost of certain technologies (e.g. carbon capture/storage dropping to 20-30 euro/t in 2030)
- Significant increase in implementation of key technologies in new factories (e.g. 85% of all new coal-fired power plants from 2020 onward will have CCS)
- Focus would be on all cheapest abatement measures
  - Highly fragmented across sectors & regions - collecting all the possible reductions is logistically and politically challenging

Cost Curve - Policy Implications

- Ensure strict energy efficiency standards (prescriptive regulation)
- Establish long-term incentives for adoption of GHG-efficient technologies
- Incentivize/support cost efficiency improvements for key technologies such as carbon capture & storage
- Address agriculture/forestry potential through development mechanisms in developing countries

Practical methods

- Supply v. demand side approaches
- Market-based measures v. prescriptive
- Energy solutions
- Sequestration
- Ecosystem-based methods
- Geoengineering: http://grist.org/basics/a-mad-scientists-guide-to-re-engineering-the-planet

Policies for Mitigation Measures

- Practically, mitigation comprises both supply and demand side solutions.
- Requires command and control, market incentives policies or a combination of both
- Such policies should address emission source rather than peripheral aspects e.g. carbon tax vs SUV tax.

Efficiency and conservation

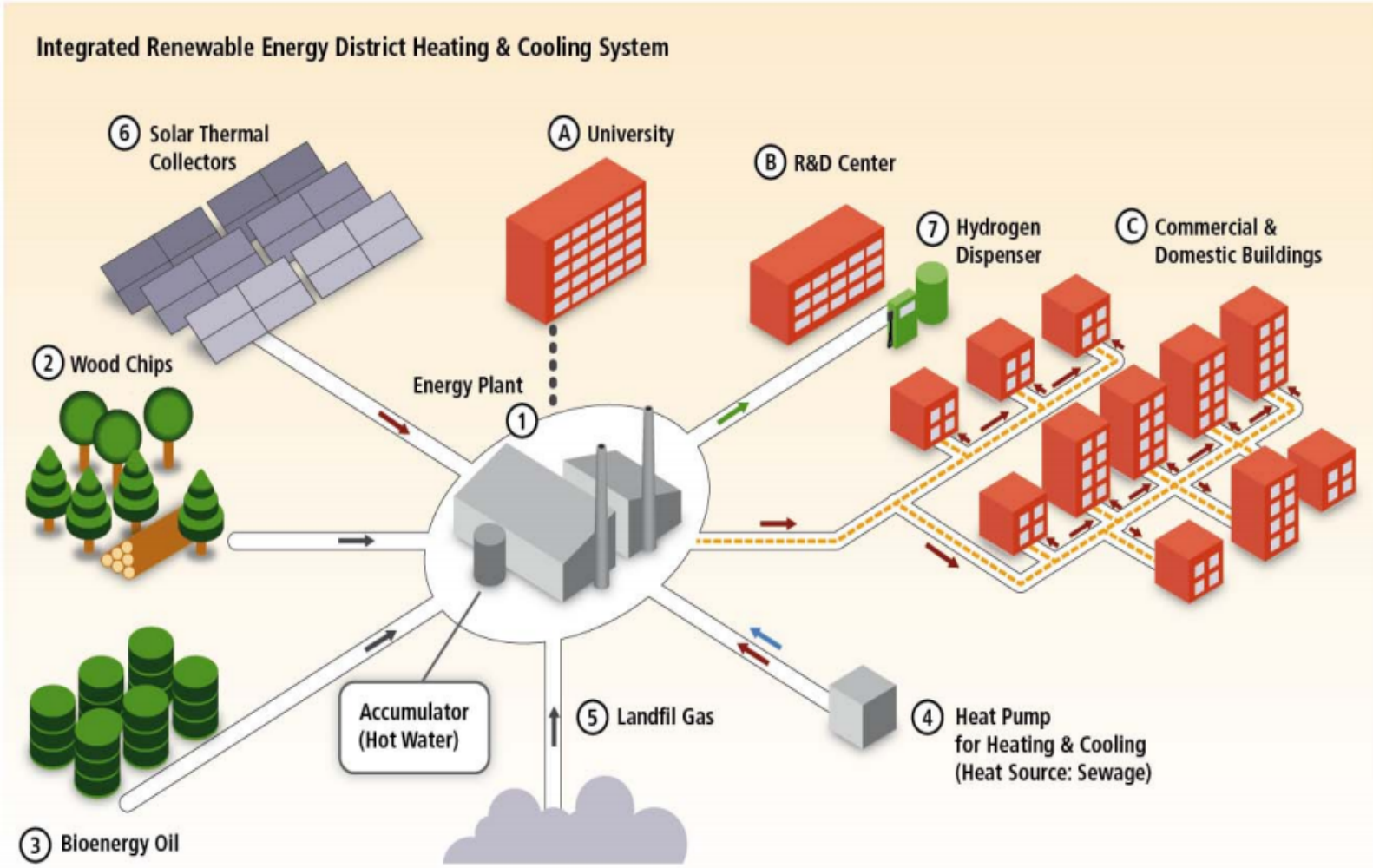
- Policies such as carbon trading or carbon tax can help reduce miles travelled
- Increased building and transport efficiency through command and control policies or special incentives.
- Incentives for buying more energy efficient appliances to reduce consumption and certification systems
- Proper pricing of of energy to influence behaviour

Fossil fuels

- Carbon trading policies to allow major energy users to consider use of cleaner energy
- Use of legal tools to mandate carbon capture and storage for fossil fuel refineries and power plants.
- Use of coal synfuels must be accompanied by CCS technology
- Some major CCS projects in the world include Sleipner(Norway) and Salash (Algeria)

www.cpmi.princeton.edu/wedges

An integrated RE-based energy plant in Lillestrøm, Norway, supplying commercial and domestic buildings



Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change

Biostorage

- Enhancing natural sinks is a key strategy to address carbon emission
- Initiatives like REDD and REDD+ will play a key role in reducing deforestation
- Oceans capacity to absorb CO2 are affected by rising temperature and change in pH.
- Implement national and multilateral environmental agreements and initiatives to enhance marine and land conservation
- Agroforestry, organic and no-tilling agriculture will reduce carbon emission and disruption of important biogeochemical cycles such (C, N, S).

Other important measures

- Nuclear energy will be important in the near future as a source of cleaner energy. Efforts to seek safer ways for nuclear energy development must continue.

- Geoengineering could provide viable option for carbon mitigation in the future. However, this option is currently riddled with controversies. (*http://grist.org/basics/a-mad-scientists-guide-to-re-engineering-the-planet/*)

- A global shift to a vegetable based diet will afford the world significant reductions in carbon emission

McKibben: New Math

- **2 Degrees C** (3.6 F) - thus far, we have raised global average surface temperature by 0.8 C

- **565 Gt CO2** - "budget" amount of CO2 we can add to the atmosphere to have 80% chance of staying below 2 C rise (2011 emissions = 31.6 Gt)

- **2,795 Gt CO2** - amount of CO2 stored in proven fossil fuel reserves of fossil fuel companies - 5 times our "budget" and economically "above ground" and figured in share prices, budgets, borrowed money

- Russia's Lukoil and America's ExxonMobil (top two) - reserves worth 40 Gt CO2 each; top six firms hold >25% of remaining carbon budget

Exam Questions:

- Socolow:
  - What is the "stabilization triangle"?
  - What is a "stabilization wedge"?
  - How has this approach changed over time?
- McKinsey:
  - How does the McKinsey Cost Curve approach climate change mitigation?
  - What are some critiques of the McKinsey Cost Curve?
- Theory to Practice:
  - What sorts of mitigation measures might require prescriptive/command and control regulation? Market-based regulation?
- McKibben:
  - What are the three types of numbers we should be concerned about for mitigating climate change?

References & links

http://www.centerforsustainability.org
http://www.c2es.org/
http://www.climatestrategies.us

Stabilization Wedges, 2004
Alternative Wedges
Socolow on Wedges, 2011
McKinsey Report (source for all McKinsey graphs)
McKibben: New Math
IPCC Report