Global Warming and the Coming Peaks in Oil, Gas and Coal Production

Carbon Mitigation Scenarios for the Next 100 Years

Bruce Hodge
June, 2006

Global Warming

Introduction

- It’s a fact that our world is warming.
- Scientific consensus:
  - Global warming is primarily induced by human activities, principally because of greenhouse gas emissions from combustion of fossil fuels.
  - Increased greenhouse gas emissions will result in increased average global temperatures.
- Atmospheric concentrations of greenhouse gases are the highest in at least 650,000 years (as measured by Antarctic ice core samples)*
- Our energy future choices and global warming are inextricably linked.
- What are our options?

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* Science 25 November 2005: Vol. 310. no. 5752, pp. 1317 - 1321 (recent press reports (2006-Sep) indicate this has been extended to 800,000 years)

Global Warming

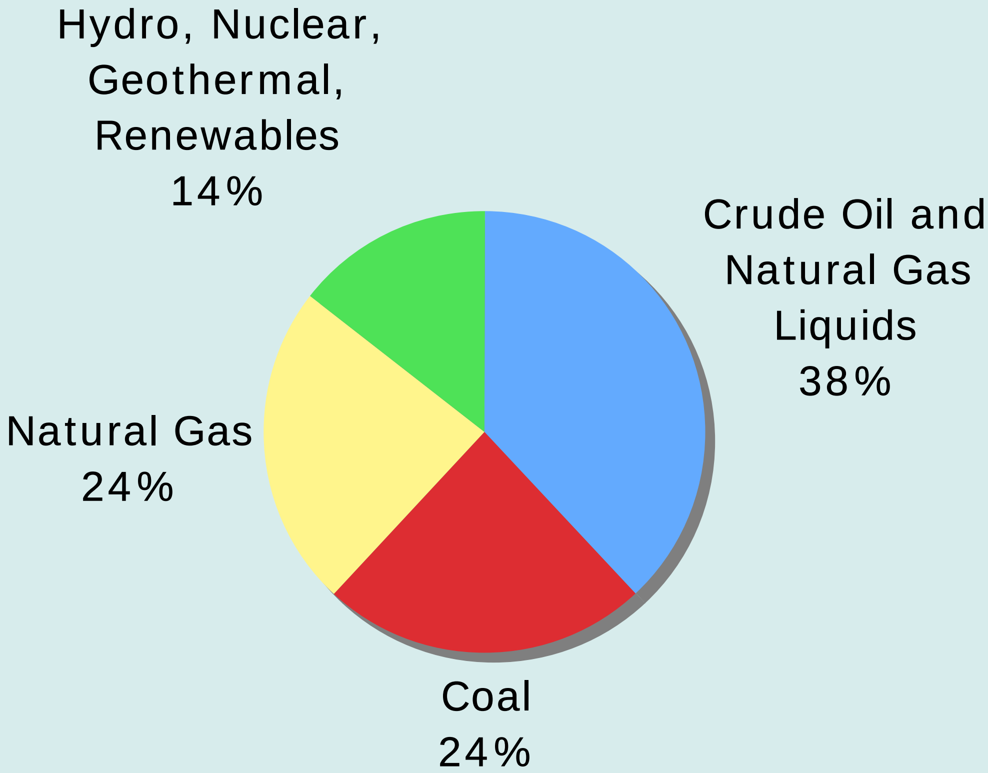
Presentation overview

- CO_2 emissions and global warming
- Mitigation of CO_2 emissions using stabilization wedges
- 100 year emissions / mitigation scenarios
  - Projected resource depletion curves for Oil, Gas, Coal
  - Projected CO_2 emissions
  - Projected atmospheric CO_2 concentrations
  - Wedge mitigation scenarios
  - Per capita impacts
- Conclusions

Global Warming

The world's energy is principally carbon-based

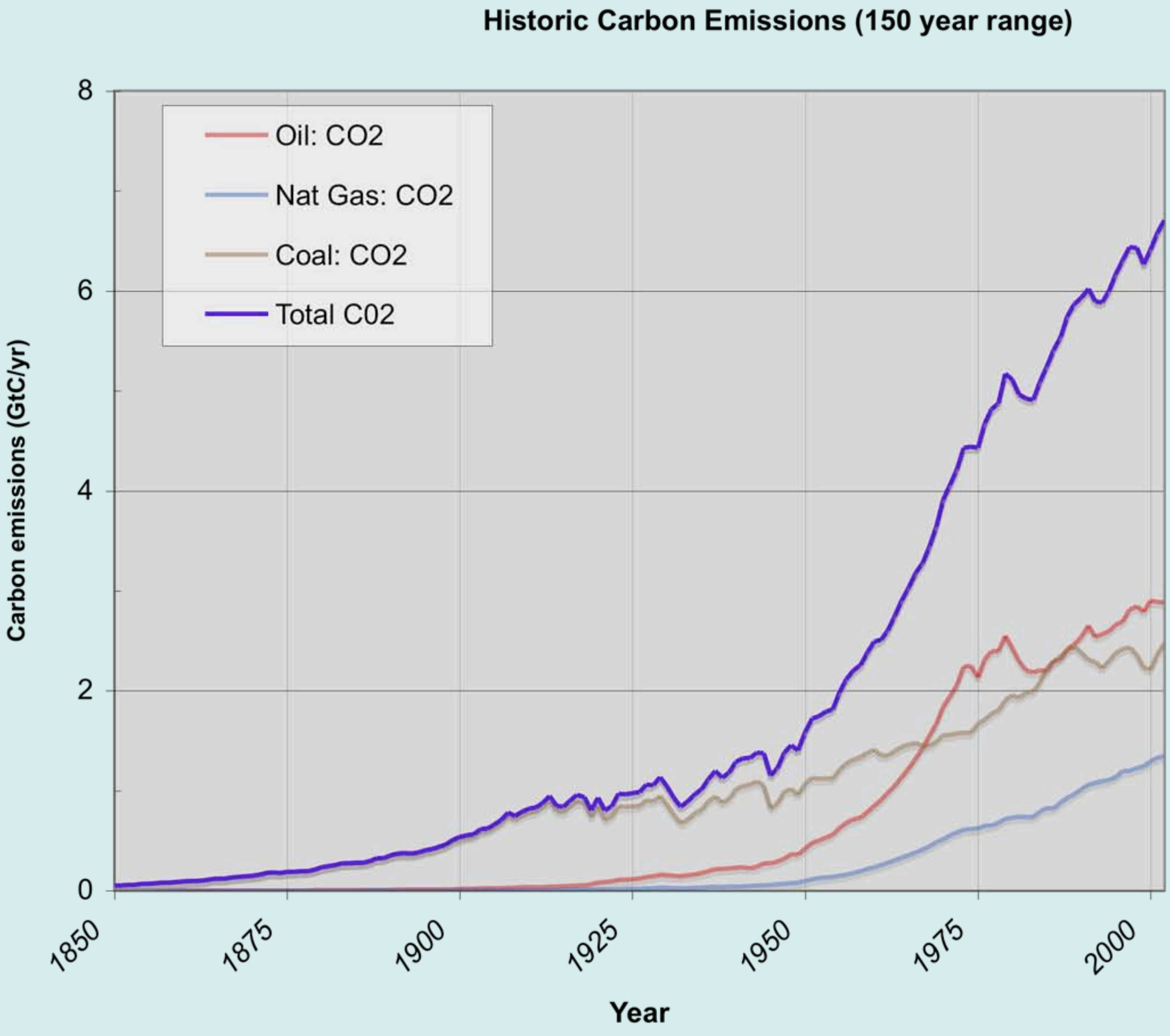
Over 85% of the world energy supply is carbon-based.



Source: EIA Annual Energy Review 2004 (2003 numbers)

Global Warming

Historic CO_2 Emissions for Oil, Gas & Coal



Total CO_2 emissions at about 7GtC / yr

Source: Global, Regional, and National Fossil Fuel CO_2 Emissions

G. Marland, T. A. Boden, and R. J. Andres

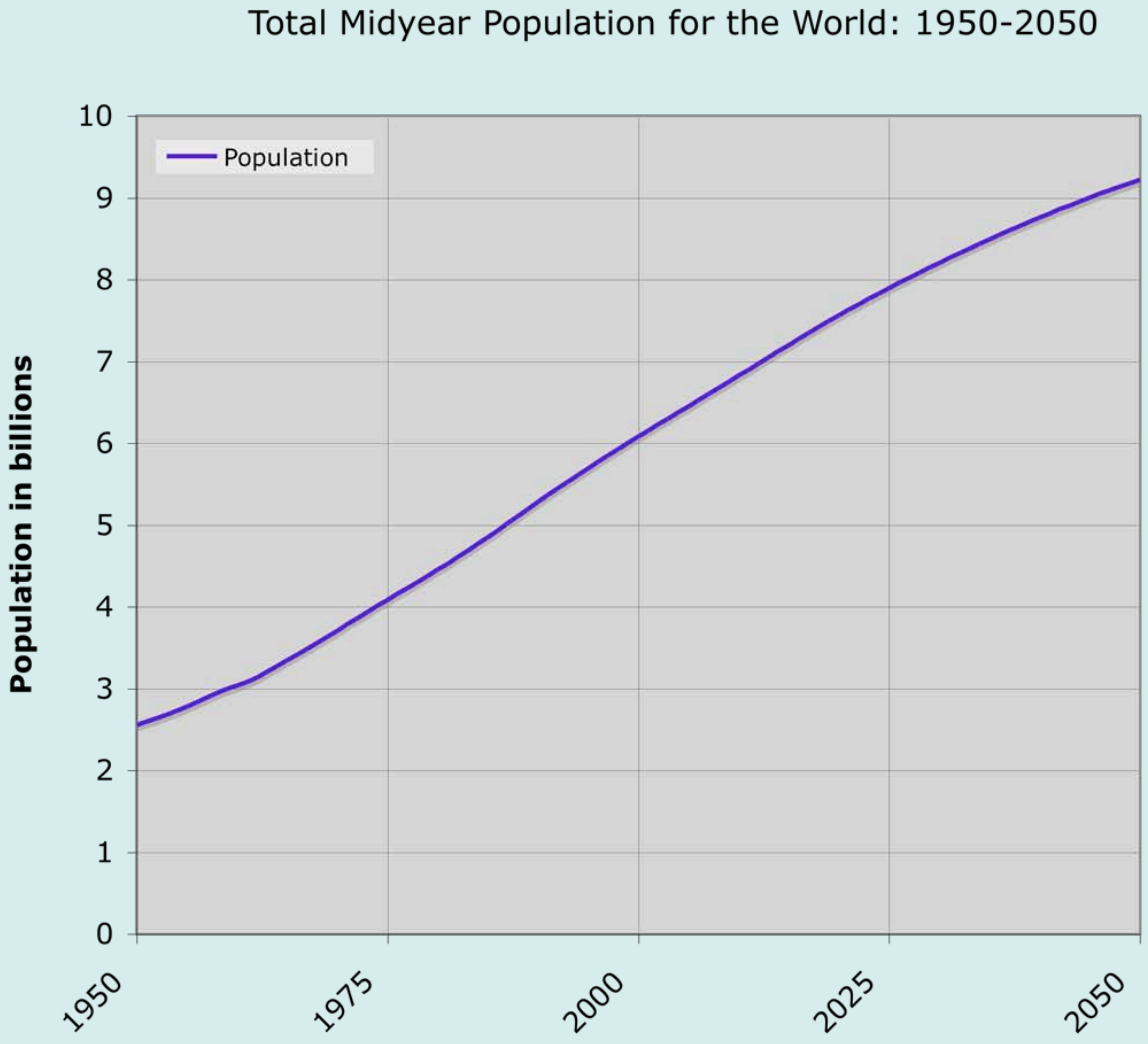
Carbon Dioxide Information Analysis Center

Oak Ridge National Laboratory

U.S. Dept. of Energy

Global Warming

Global population (historic & projected)



Global population will grow 50% by 2050.

Global Warming

Carbon Emissions, CO_2 Concentrations and Temperature

- Carbon emissions (measured in GtC / yr) add to the amount of CO_2 in the atmosphere (ppm), which then cause mean global temperature to rise. 1 GtC is a giga-tonne of carbon or a billion metric tons.
- An atmospheric concentration of 500 ppm of CO_2 leads to a projected 3ºC (± 1) increase in mean global temperature (temperature models are evolving).
- Scientists often relate CO_2 concentrations to pre-industrial emissions (280ppm) via a simple multiplier (e.g. 2x or 3x pre-industrial concentrations).

Global Warming

Carbon Sources & Sinks

- Sources emit CO_2; Sinks absorb CO_2
- Historically the sinks have been able to “balance” the sources.
- Principal anthropogenic sources are emissions from burning of **oil, gas and coal.**
- Natural sinks (ocean & land)
  - Currently remove about 35% of anthropogenic carbon emissions
  - Ocean: 2 GtC per year
  - Land: 0.5 GtC per year
  - Combined 2.5 GtC/yr
- Modeling future ocean & land sink rates is a research challenge and affects calculations concerning atmospheric CO_2 concentrations - uncertainty in these models is high.

Global Warming

What *IS* an acceptable CO_2 stabilization level?

- Current CO_2 concentration is 377 ppm* compared to 280 ppm at the beginning of the industrial age.
- Up to now, many scientists have accepted the idea that stabilizing the CO_2 concentration at around 500 ppm will avoid disastrous climate change.
- A new book by top UK scientists, *Avoiding Dangerous Climate Change***, suggests that a more aggressive target of 450 ppm is necessary… But is that enough?

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* Measured in 2004 at Mauna Loa

** *Stabilising climate to avoid dangerous climate change*, Hadley Centre for Climate Change

http://www.metoffice.com/research/hadleycentre/pubs/brochures/2005/CLIMATE_CHANGE_JOURNAL_150.pdf

Global Warming

What *IS* an acceptable CO_2 stabilization level?

- A report commissioned by the Pentagon* suggests that abrupt climatic change is very possible. One possible scenario involves the interruption of the Gulf Stream because of the effects of massive fresh water inputs from the melting Greenland ice sheet, plunging Europe into a much colder climate (i.e. the collapse of thermohaline circulation)
- What is an acceptable level? We don't know...
- However, we do know that the current levels of CO_2 are causing significant impacts upon the earth's climate, which suggests that we need a target below current levels.

** An Abrupt Climate Change Scenario and Its Implications for United States National Security* Oct 2003, By Peter Schwartz and Doug Randall

http://www.grist.org/pdf/AbruptClimateChange2003.pdf

Climate Mitigation

Introduction

- Climate change can be mitigated by various strategies that reduce carbon emissions.
- Let’s take a look at one methodology that allows us to quantify the effects of mitigation strategies: stabilization wedges.

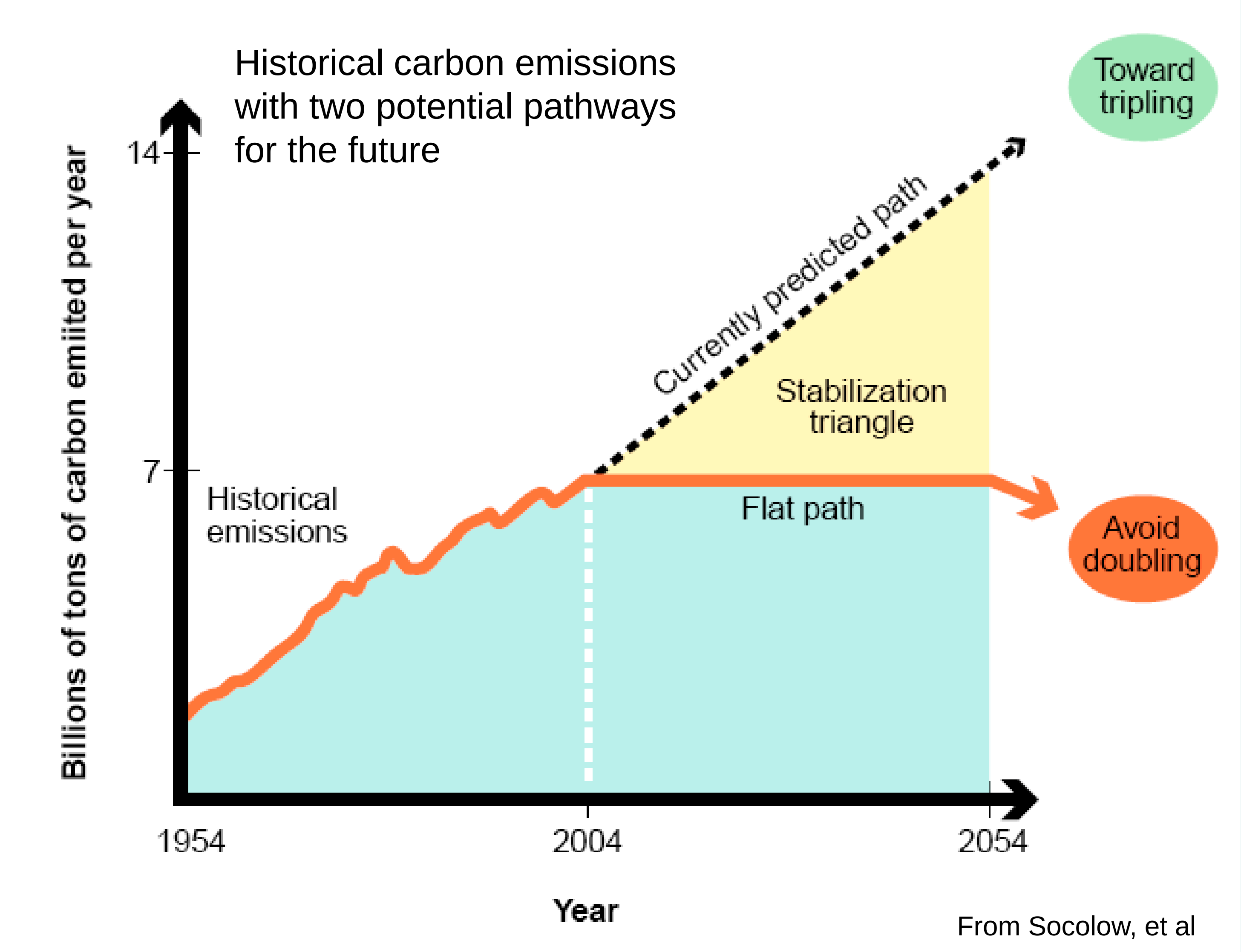
Climate Mitigation
Stabilization Wedges

- Research papers* by R. Socolow, S. Pacala, et al (Princeton) have introduced the concept of *stabilization wedges.*
- Each wedge represents a reduction of 25Gt of carbon emissions over a 50 year period.
- Socolow, et. al present 14 different wedges that are proven technologies that can be scaled and implemented over a 50 year period.
- Projects that the implementation of 7 wedges over the next 50 years, followed by even more significant reductions starting in 2050 will keep CO_2 concentrations from rising above 500ppm.

** Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies,* S. Pacal and R. Socolow, Aug 2004 *Science*

Solving the Climate Problem, R. Socolow, R. Hotinski, J.B. Greenblatt, S. Pacala, Dec. 2004 *Environment*

Climate Mitigation
Stabilization Triangle

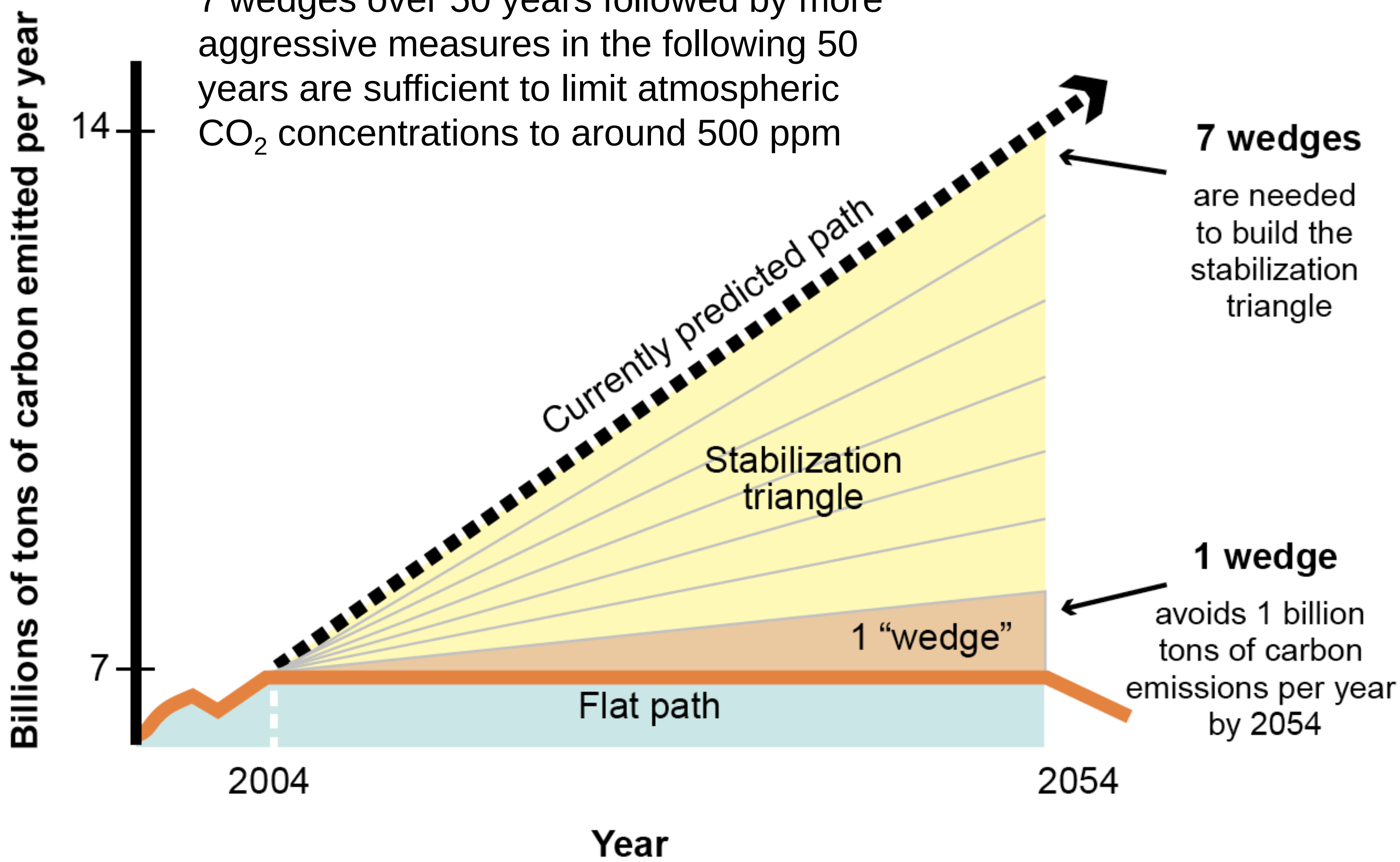


"Currently predicted path" is BAU, i.e. 1.5% growth/year

Tripling in the graph refers to a tripling of CO_2 concentrations compared to pre-industrial levels of 280, and doubling is similarly construed.

Climate Mitigation
Stabilization Wedges

7 wedges over 50 years followed by more aggressive measures in the following 50 years are sufficient to limit atmospheric CO_2 concentrations to around 500 ppm



Source: Socolow, et al

Climate Mitigation
Stabilization Wedge Types

- Conservation
  - I.e. using less or simply doing without
- Increased energy efficiency
  - Transportation
  - Buildings
  - Industry
- Non-carbon energy production
  - Renewables such as solar, wind and bio-fuels
  - Carbon sequestration - carbon is removed from carbon based fuels and injected into deep wells as CO_2
  - Nuclear power
- Natural sinks
  - Planting trees, reducing deforestation

Climate Mitigation
Examples of a 50 year wedge

- Wind electricity (1 wedge)
  - Deployment of 2000 GW by 2054
  - I.e. about 2 million 1MW windmills
  - 50 times today's installed base
  - Windmills cover an area about the size of Germany
- Photovoltaic (PV) electricity (1 wedge)
  - Deployment of 2000 GW by 2054
  - Only 3 GW is currently installed
  - 700 times today's installed base
  - Array's combined area roughly equal to New Jersey
- Biofuels (1 wedge)
  - Requires 1/6 of the world's cropland
  - Biofuel feedstock must be grown without fossil fuel inputs
- More efficient automobiles (1 wedge)
  - Increase fuel economy from 30 to 60 mpg for 2 billion cars by 2054
  - Today's installed base is about half a billion cars

Source: Socolow, et. al

Climate Mitigation
Stabilization Wedges

- Socolow's 7 wedge projection is based on the following critical assumption:
  - Business-as-usual (BAU) energy use is 1.5% growth/year (same as current) for the next 50 years.
- Note that:
  - BAU energy use results in a doubling of the rate of global energy use in 50 years in an era which will be characterized by tightening energy supplies.
  - This is an 80% increase of global per-capita energy use (assuming global population peaks in 2050 at around 9 billion people).

Climate Mitigation

Carbon emissions and their mitigation

- This study…
  - Models carbon emissions in more detail by breaking down projected carbon based emissions by energy source (oil, gas, coal) and uses plausible depletion scenarios.
  - Models their mitigation by the application of different numbers of 100 year wedges
  - Models the effect of delayed implementation of wedges and links each scenario to projected atmospheric CO_2 levels and per-capita energy services.
- Next…
  - A number of scenarios that model future carbon emissions and potential mitigation efforts over the next 100 years

Carbon-based Energy

A Tour of Carbon Based Energy Supplies

- What follows is a tour of each of the principal carbon-based energy supplies.
- Although energy analysts will typically break down supplies into finer detail, we simplify by examining the broad categories of oil, natural gas, and coal.
- Let’s start with oil, which will likely be the first to become depleted…

Carbon-based Energy
Oil Production

- Consumption to date: ~900 billion barrels
- Current consumption/production rate: ~80 million barrels/day or ~30 billion barrels/yr.
- Supplies are currently extremely tight: production essentially equals consumption.
- Total amount remaining (the remaining oil reserve) is a matter of dispute for reasons that go beyond purely technical ones.
- In effect, a giant global poker game; oil reserve numbers are manipulated for business and political reasons.

Carbon-based Energy
Peak Oil

- A growing chorus of oil geologists* and other analysts are making total recoverable oil estimates of around 1.2 trillion barrels, and estimate a peak in global oil production somewhere between 2005 and 2030.
- Future oil production is likely to follow a depletion profile where extraction peaks at certain point in time and declines after.
- After the peak, demand exceeds supply
  - Price increases and/or instability?
  - Uncharted territory

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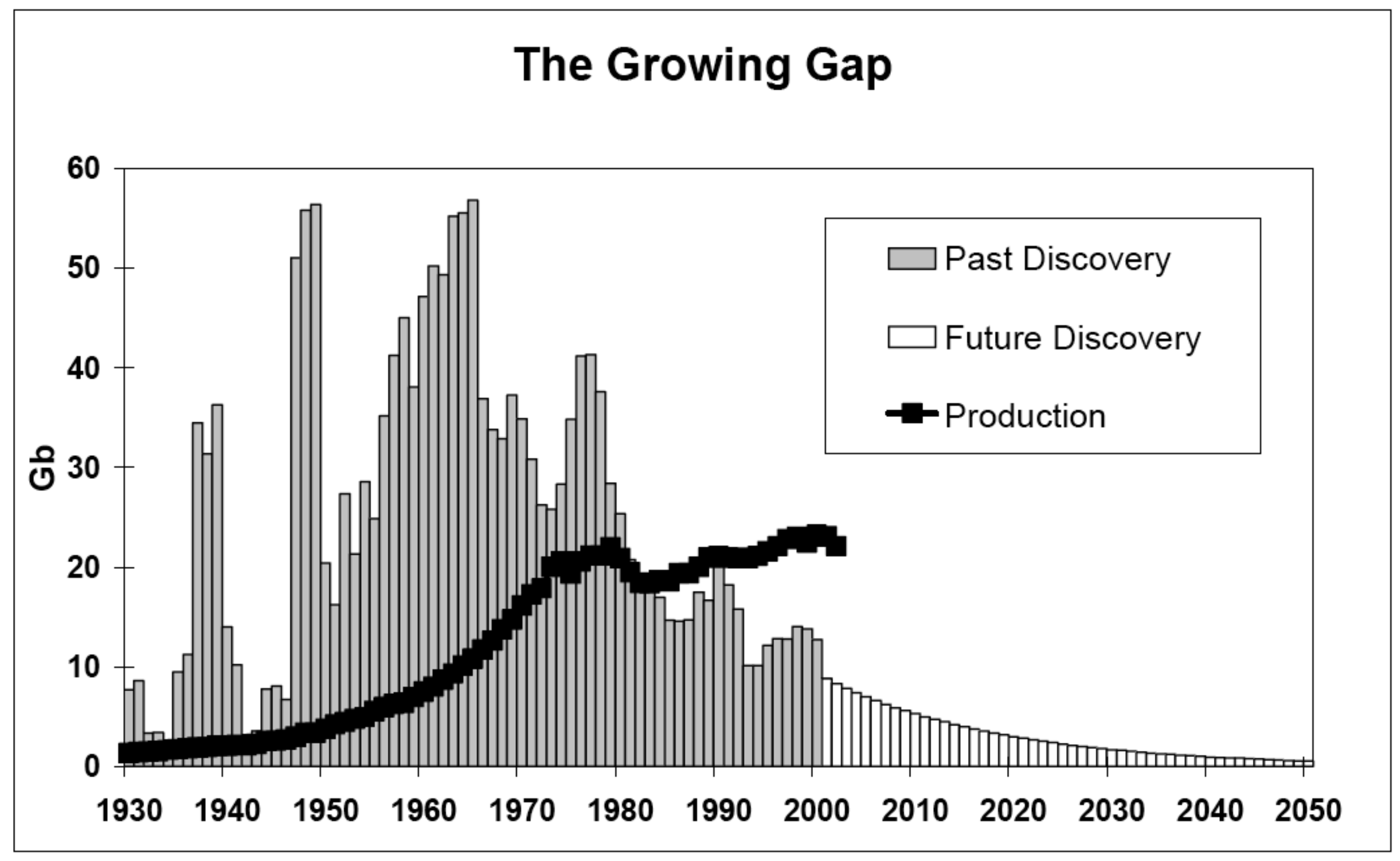
* Including but not limited to:

C.J. Campbell, Jean Laherrere - *The End of Cheap Oil*

Kenneth Deffeyes, *Hubbert's Peak, The Impending World Oil Shortage*

Carbon-based Energy
Peak Oil

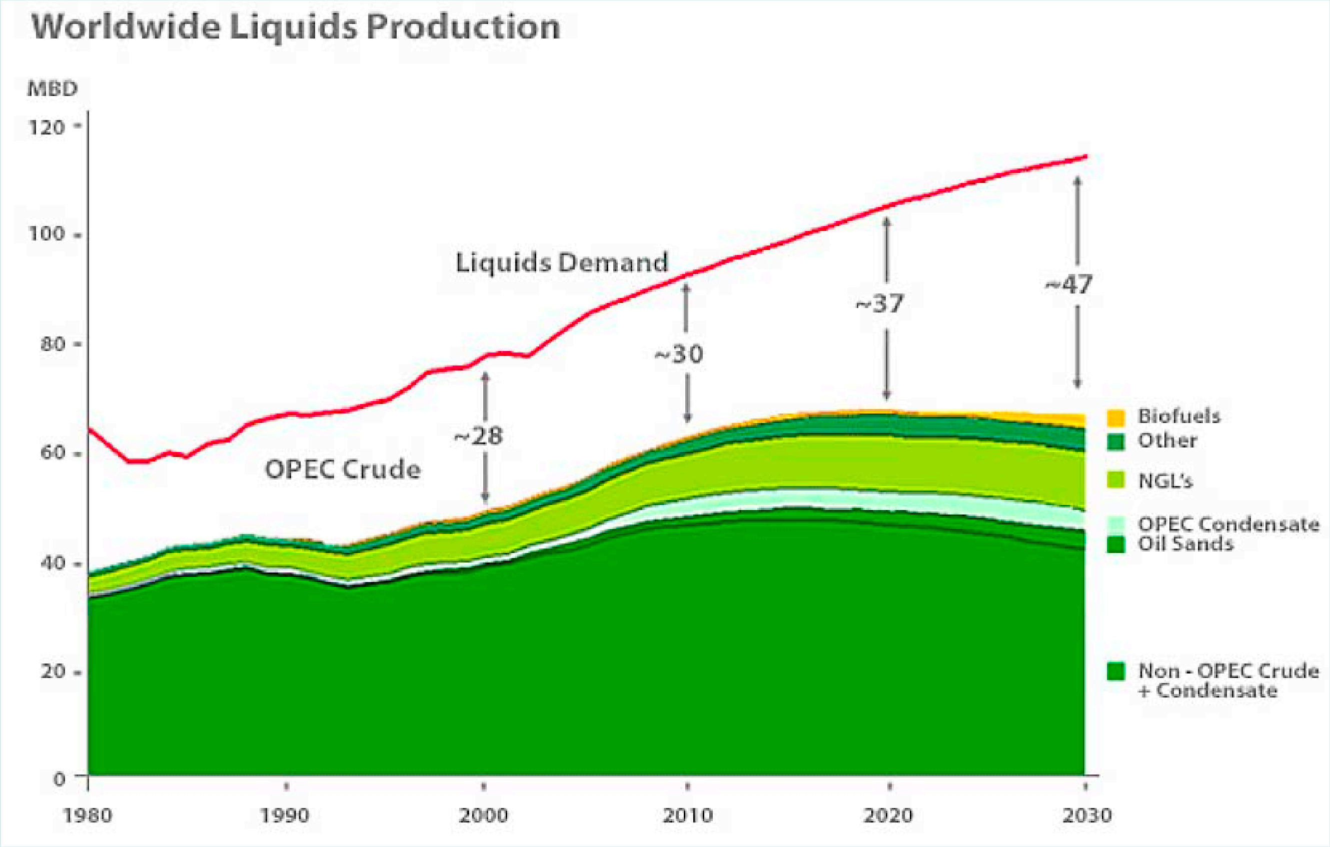


Production lags discovery

Source: C.J. Campbell - *Oil Depletion - The Heart of the Matter*

Carbon-based Energy
Peak Oil

Exxon Mobil estimates a peak on non-OPEC conventional oil in 5 years!



After the non-OPEC peak in 2010, production increases will have to come from OPEC.

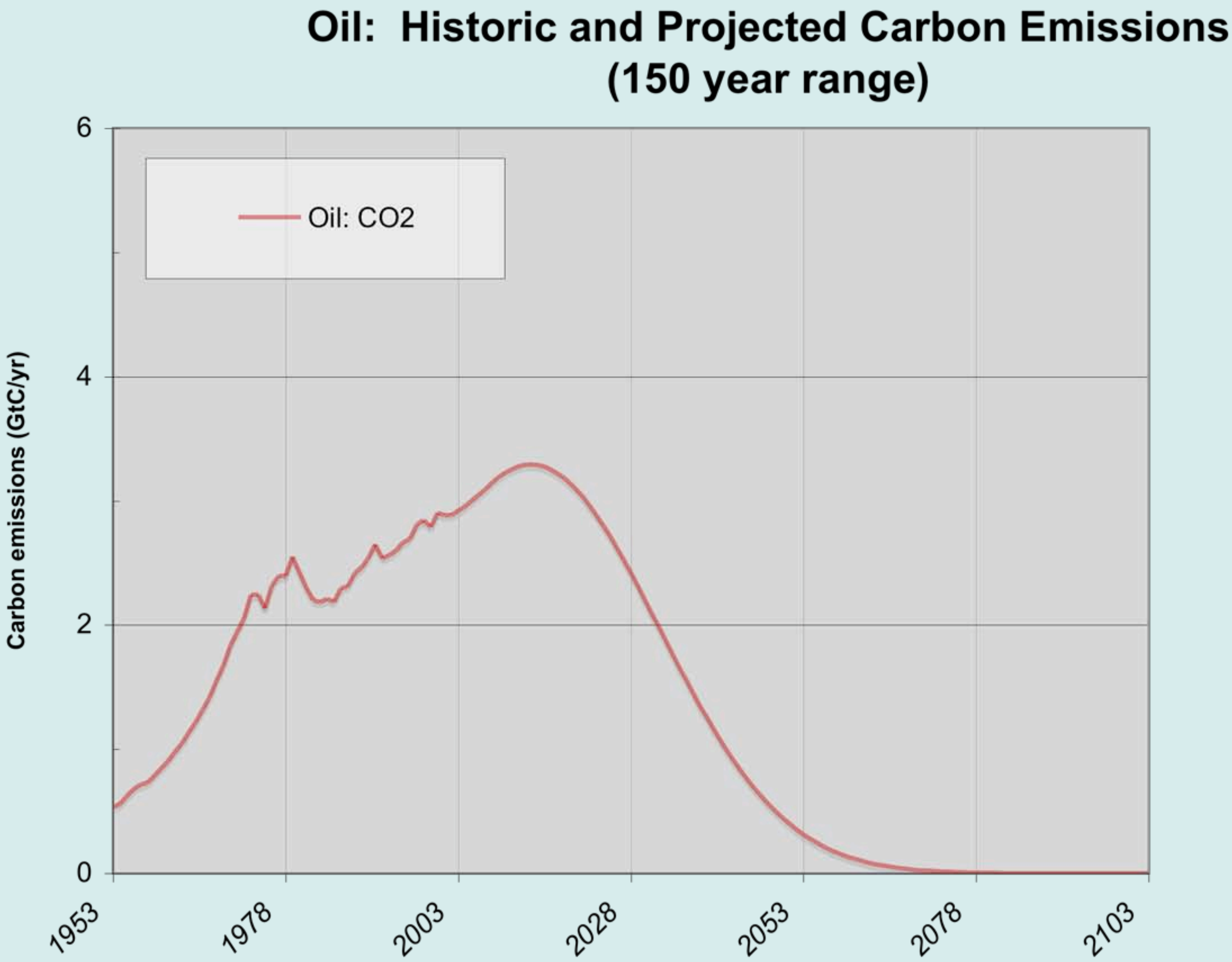
OPEC's future production capabilities are largely unknown.

Source: Exxon Mobil 2005 Energy Outlook

Carbon-based Energy
Peak Oil

- We can make a reasonable projection of oil depletion by picking a peak year and a subsequent depletion rate, knowing the total estimated reserves.
- In all of baseline projections (oil is just the first!) I've used exponential growth and decay curves (the same curves as compound interest).
- Although the actual shape of the curve for future years may differ from the projected shape, the impact upon CO_2 concentrations is largely the same.

Carbon-based Energy
Baseline Peak Oil Scenario



Oil is almost completely depleted in 50 years

Carbon-based Energy
Natural Gas

- Natural gas production is likely to peak roughly 20 years after oil peaks or somewhere between 2010 and 2025.
- Industry estimates:
  - Proved reserves - 6300 Tcf (trillion cubic feet) *
  - Resources (yet to be discovered) - 4200 Tcf **
- Independent estimates ***
  - Total recoverable (reserves+resources) of 12,500 Tcf
  - 185 GtC
- Natural gas will be under increasing production pressures as a substitute for oil, despite transport difficulties.

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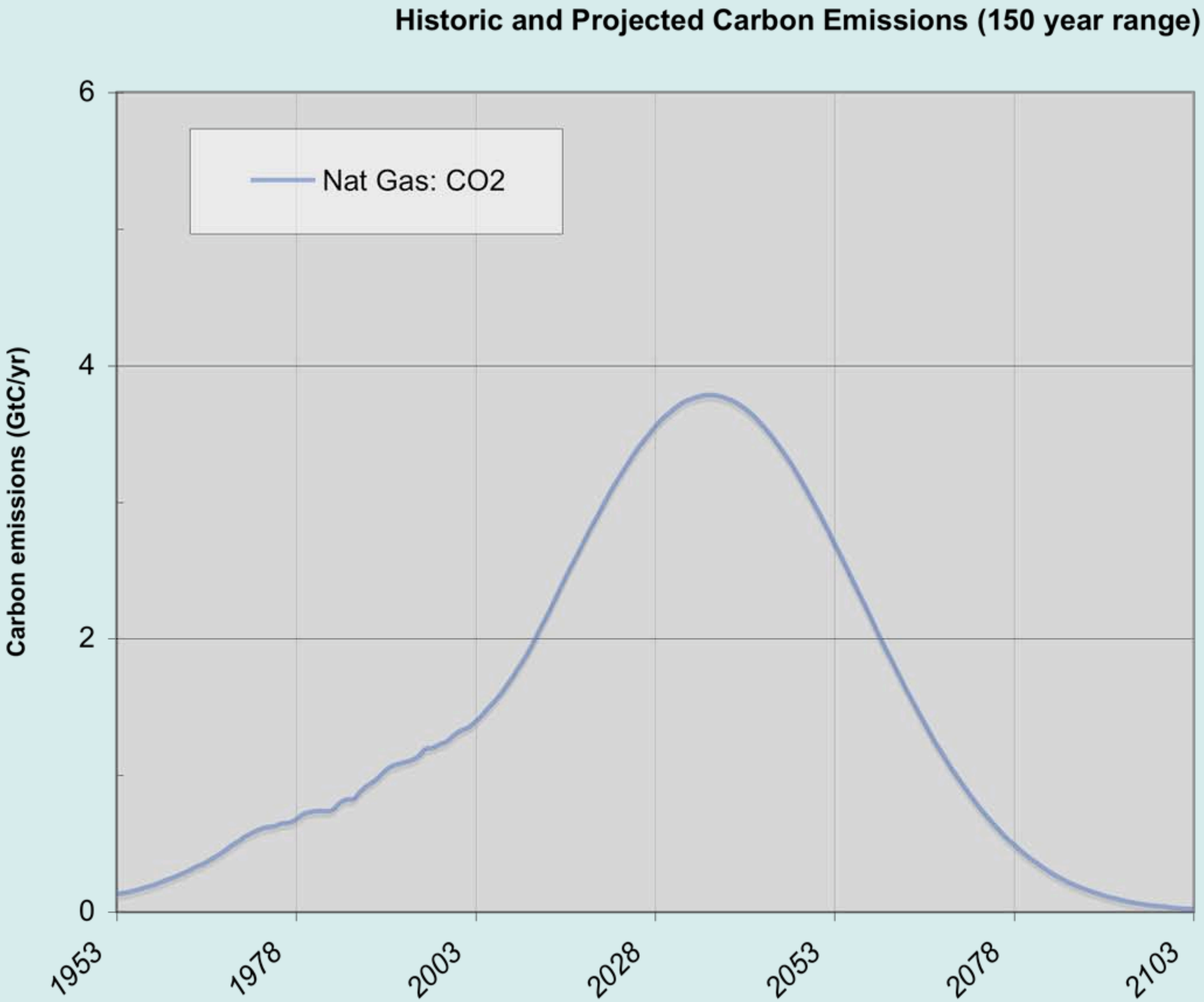
* BP Statistical Review of World Energy, June 2005

** Undiscovered (EIA, International Energy Outlook 2005)

*** *High Noon for Natural Gas: The New Energy Crisis*, by Julian Darley

Carbon-based Energy
Baseline Peak Gas Scenario



Gas is almost completely depleted by 2075

Carbon-based Energy
Coal

- Predicting future coal production is difficult because the reserves are still large in comparison with oil and gas.
- Estimated remaining coal resources: 1 trillion tons *
(~750 GtC emissions)
- Baseline scenario assumes current annual growth continues for next 50 years, then starts a gradual decline.
- This scenario triples coal production with a peak at around 2085.
- Factors that limit coal production:
  - increasing environmental costs
  - decreasing EROEI (energy returned on energy invested)
- The limits to coal production will be set by carbon emission restrictions and environmental concerns, not by the size of the remaining reserves.

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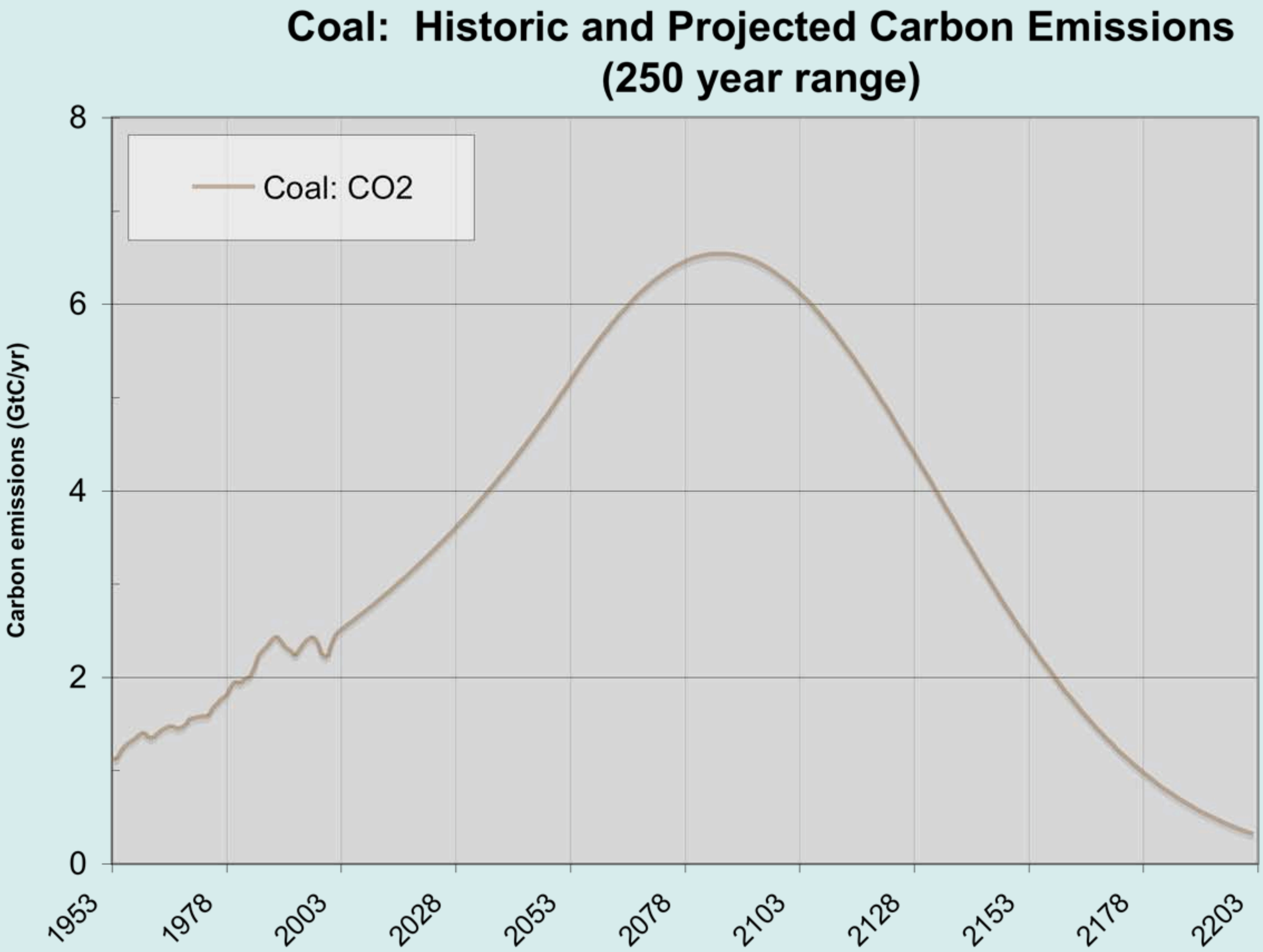
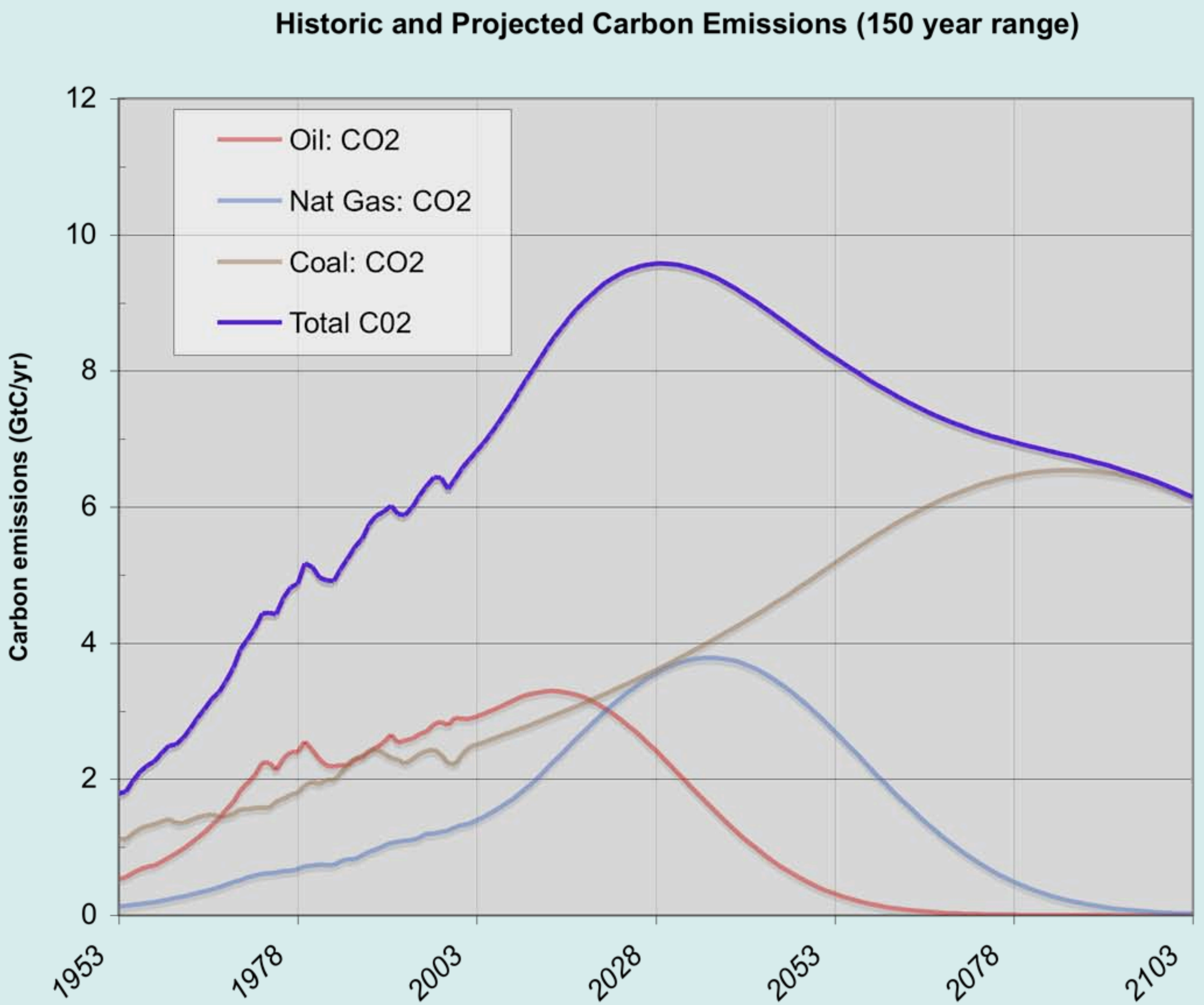
* Energy Information Administration (EIA), *International Energy Annual 2003*

Carbon-based Energy
Baseline Coal Scenario



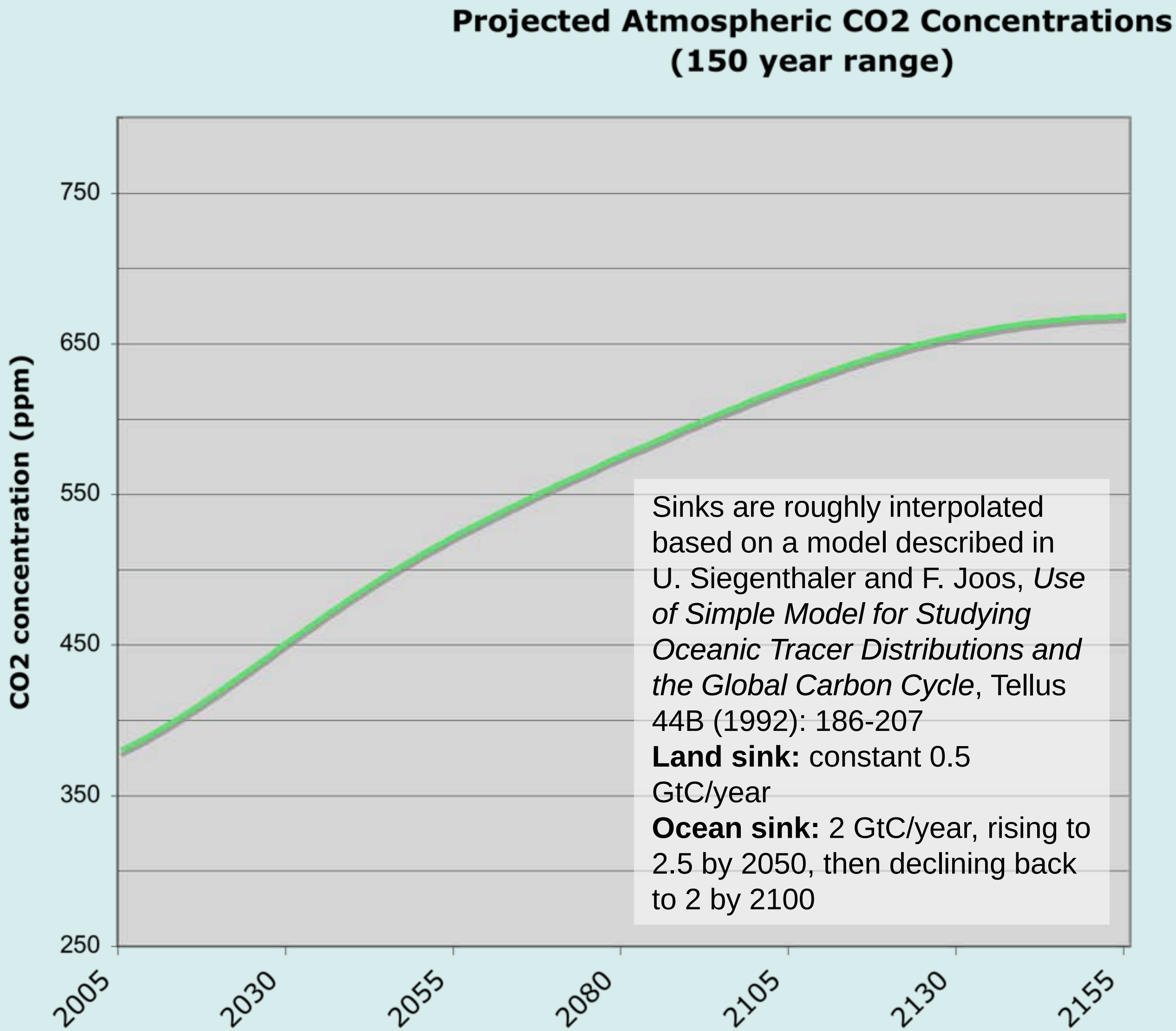
Coal is almost completely depleted by 2200 (I.e 200 years left)

Carbon-based Energy
Unmitigated Carbon Emissions



- Peak in overall energy production and CO_2 emissions at ~10 GtC in around 25 years (compared to Socolow BAU 14 GtC in 2050)
- By 2100, energy is obtained exclusively from coal as oil and gas supplies become exhausted
- Steep decline in total energy
- Serious challenges facing global energy supply

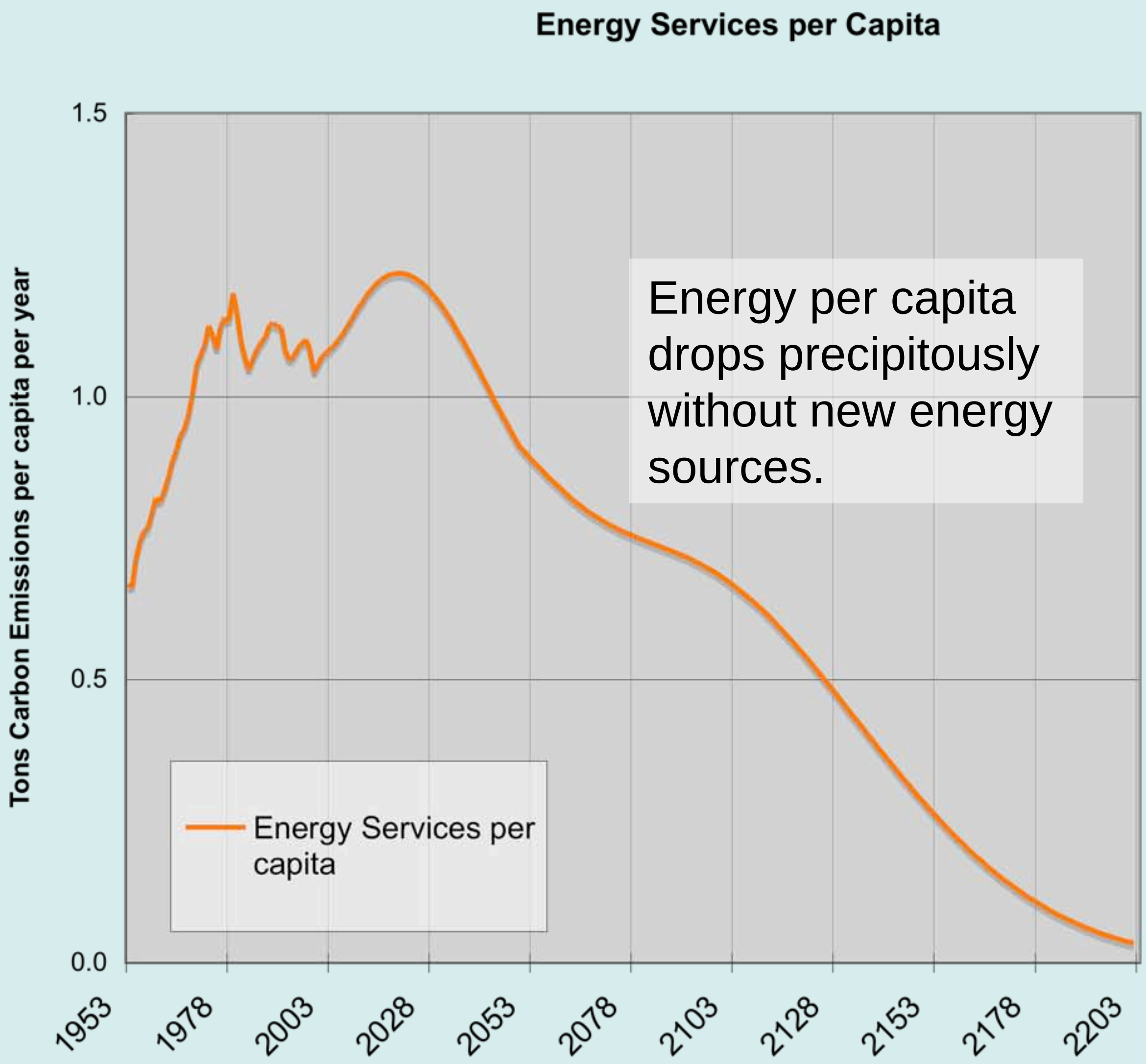
Carbon-based Energy
Unmitigated emissions - CO_2 concentrations



- Concentrations climb to 2.4x pre-industrial levels by 2150
- Climate worsens substantially or even becomes unstable

Carbon-based Energy

Unmitigated emissions - Per capita energy



Carbon-based Energy

Summary of carbon-based energy future

- The coming peaks in oil and gas will contribute to a combined peak in energy production in about 25 years.
- Coal will then become the principal driver of carbon-based energy sources
- Allowing unfettered production of carbon-based fuels will cause our CO_2 concentrations to peak at above 650 ppm after 150 years - causing an unacceptable level of warming
- The loss of oil & gas resources along with the gradual decline of coal will push the world towards a low-energy regime
- The likely peak of global population in 2050 of about 9 billion people will only exacerbate energy issues

Climate Mitigation

Mitigation Scenarios

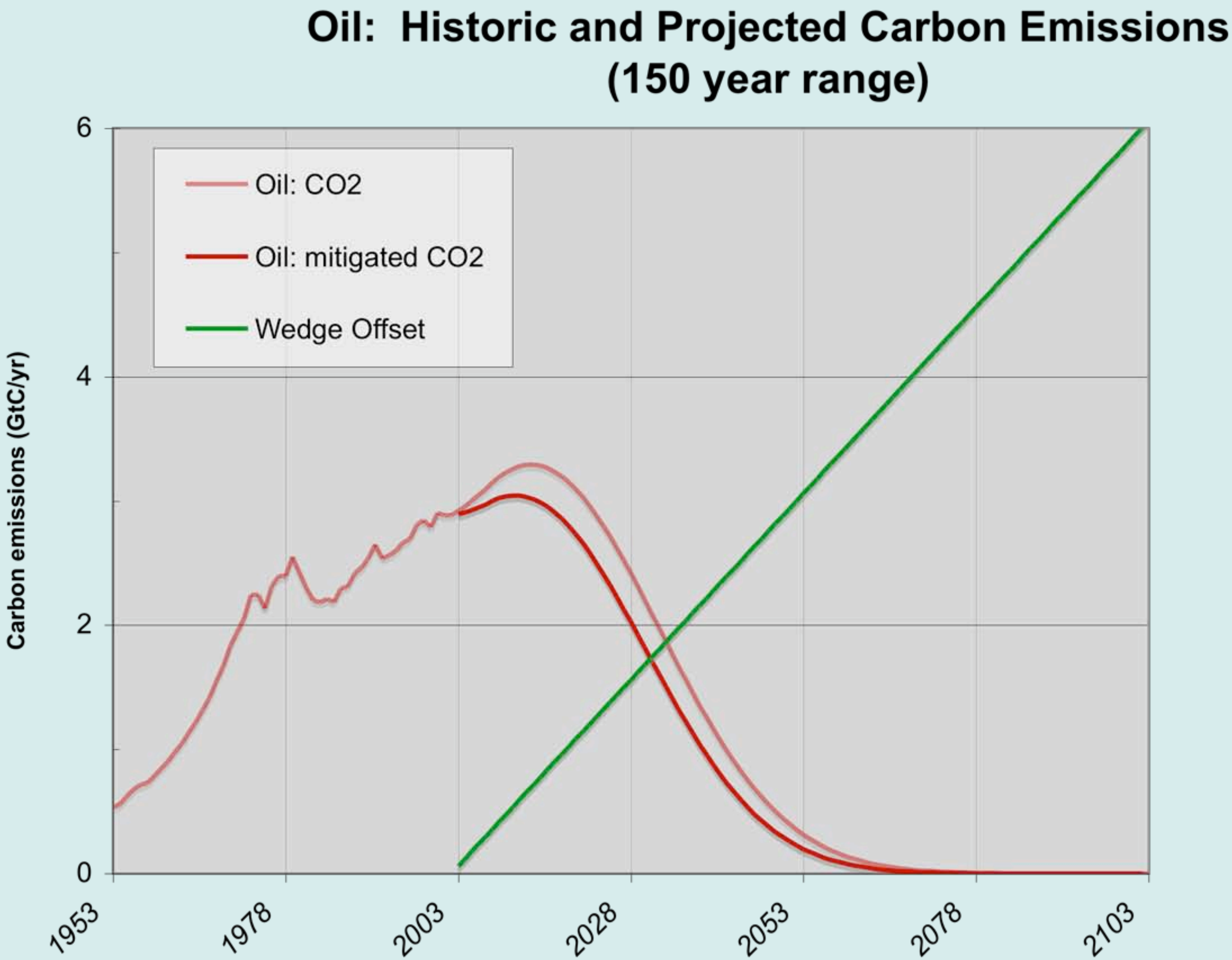
- Fortunately the implementation of wedges can both mitigate CO_2 emissions and replace our declining and polluting energy sources with renewable sources
- Let’s take a look at how different mitigation scenarios impact CO_2 emissions and the resulting atmospheric concentrations…

Climate Mitigation

Wedge model details

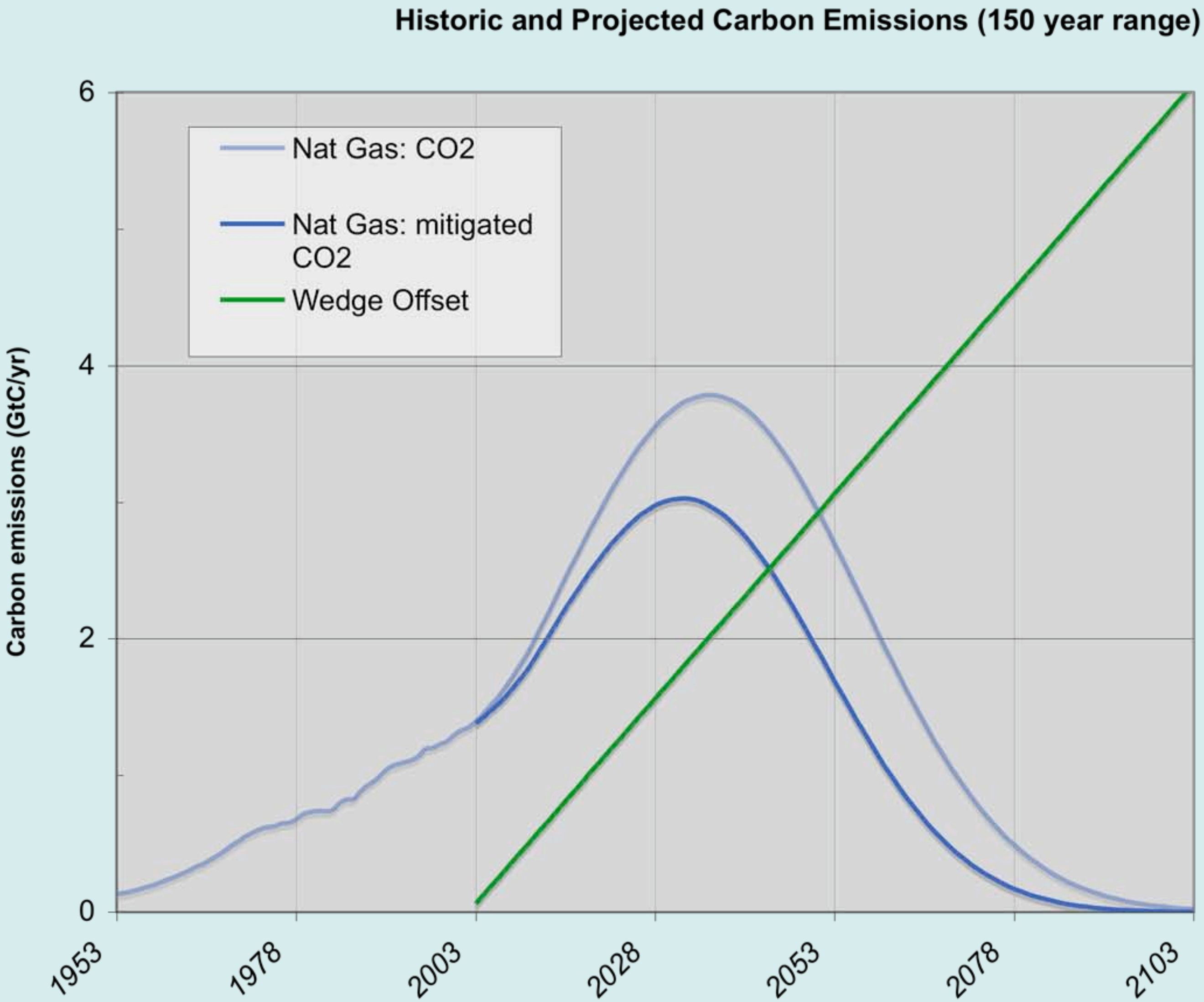
- Assumptions in allocating the CO_2 reductions from wedges:
  - 50% for new non-carbon energy sources, 50% for efficiency measures.
  - Conservation is imposed by decreasing yields in oil and gas and is not explicitly included in wedges.
  - Wedges offset each primary carbon based energy source based on the proportion consumed as predicted by the depletion scenarios
  - Wedges always displace (not augment) existing energy sources.
- Now let’s examine how the implementation of 3 wedges will affect CO_2 emissions of oil, gas, and coal…

Climate Mitigation
3 Wedges: Oil



Impact of wedges is moderate because the oil supply runs out early on, and wedge offsets must also be applied to gas and coal

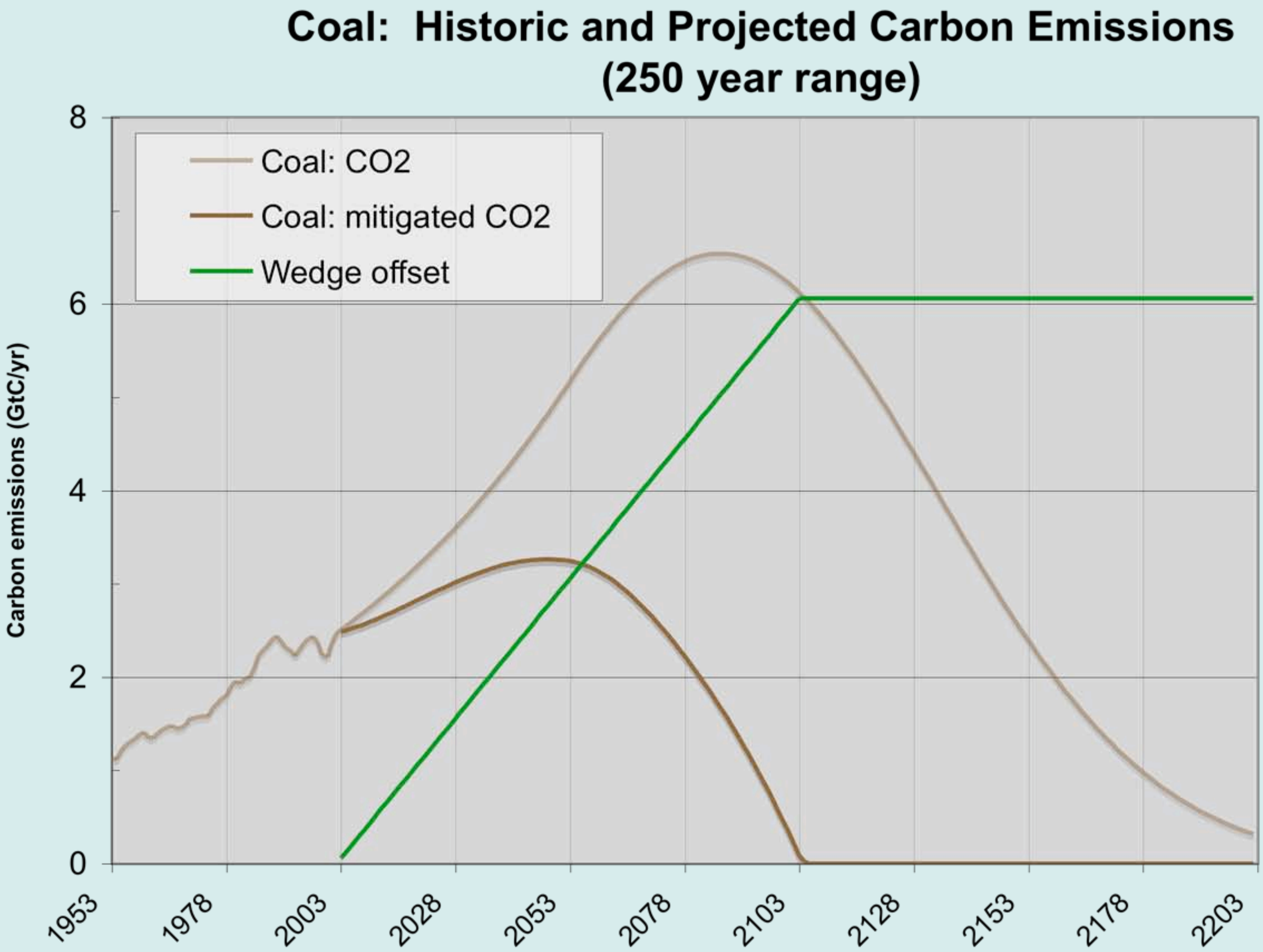
Climate Mitigation
3 Wedges: Natural Gas



Impact of wedges is more pronounced than oil because since the oil supply runs out early on, wedge offsets can now be applied to only gas and coal

With mitigation, gas emissions are near ZERO by ~2075.

Climate Mitigation
3 Wedges: Coal

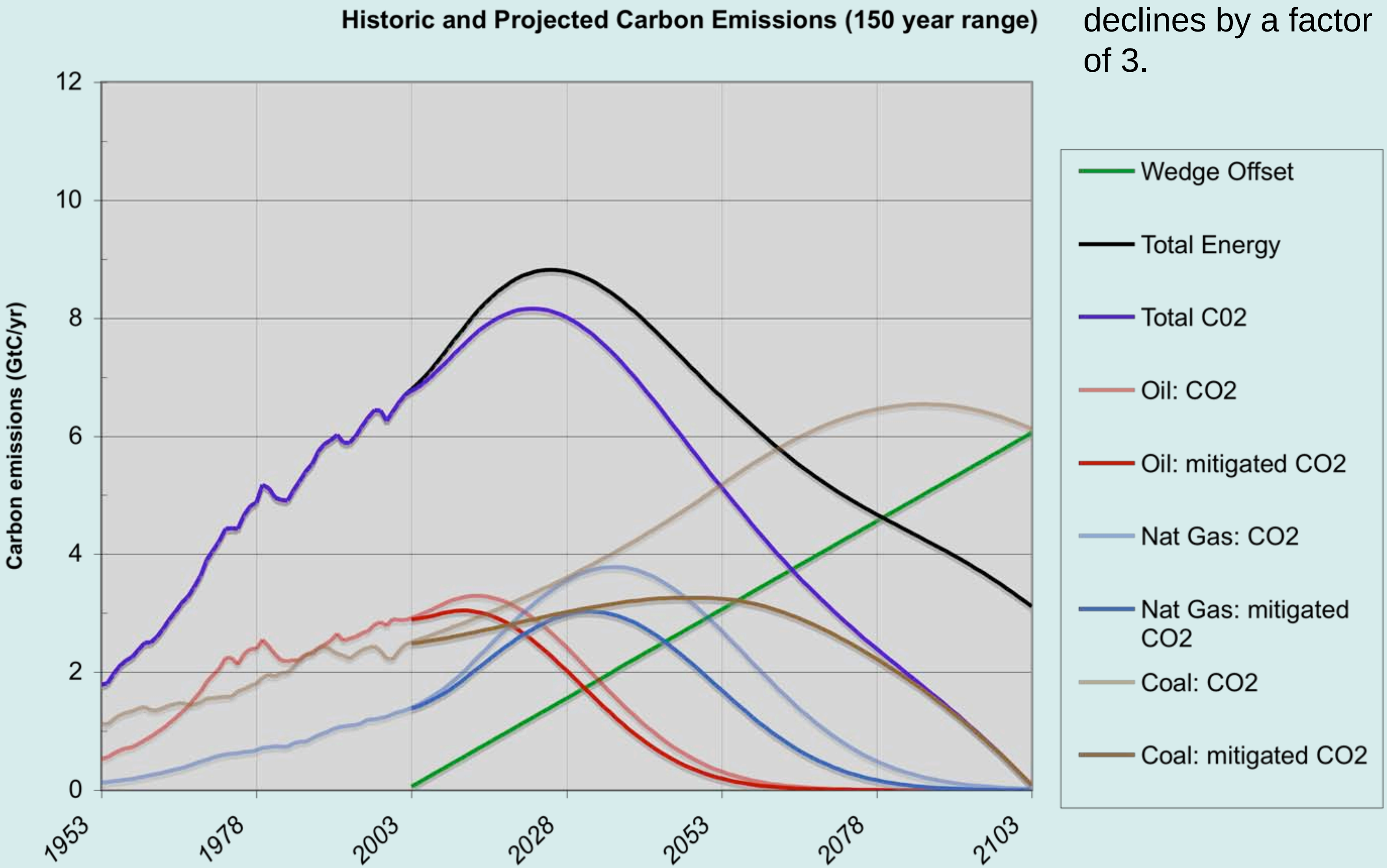


Coal emissions can be cut to ZERO by 2100 with 3 wedges

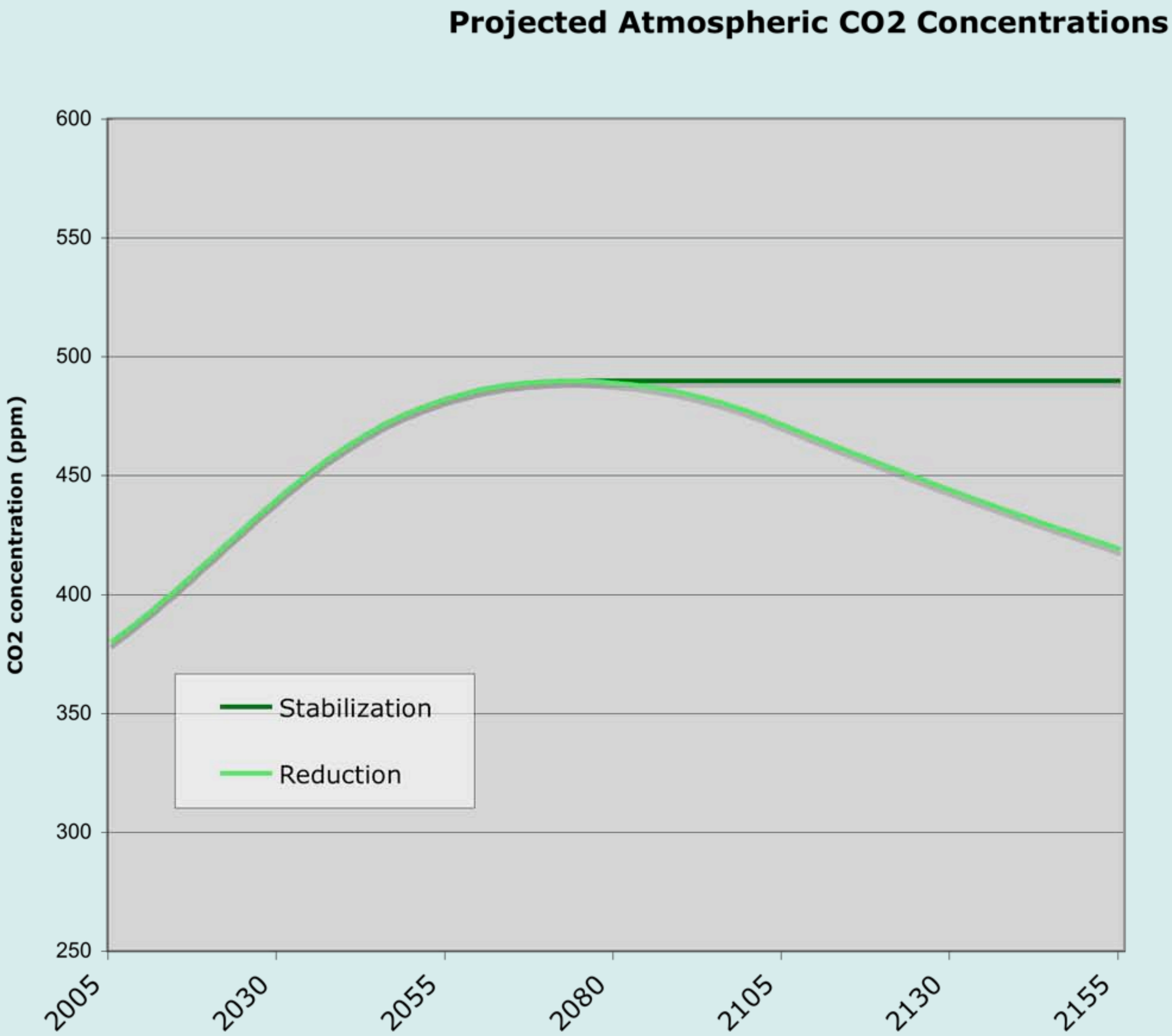
Note that the wedge contribution increases linearly (non-exponential growth), for the first 100 years and then is held constant afterwards

Climate Mitigation
3 Wedges: All

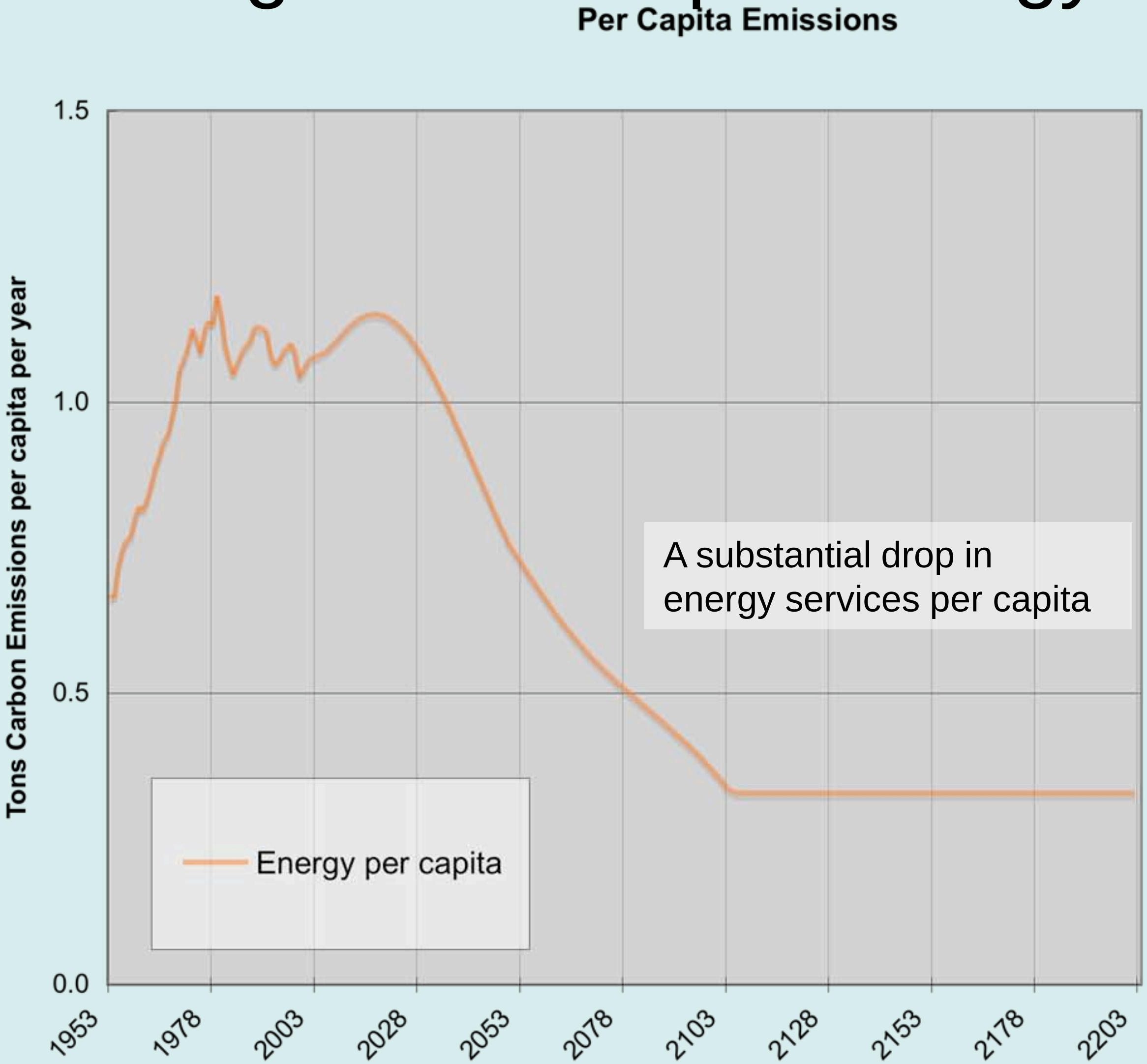
It's possible to bring total CO_2 emissions to ZERO by 2100, but total energy declines by a factor of 3.



Climate Mitigation
3 Wedges - CO_2 Concentration

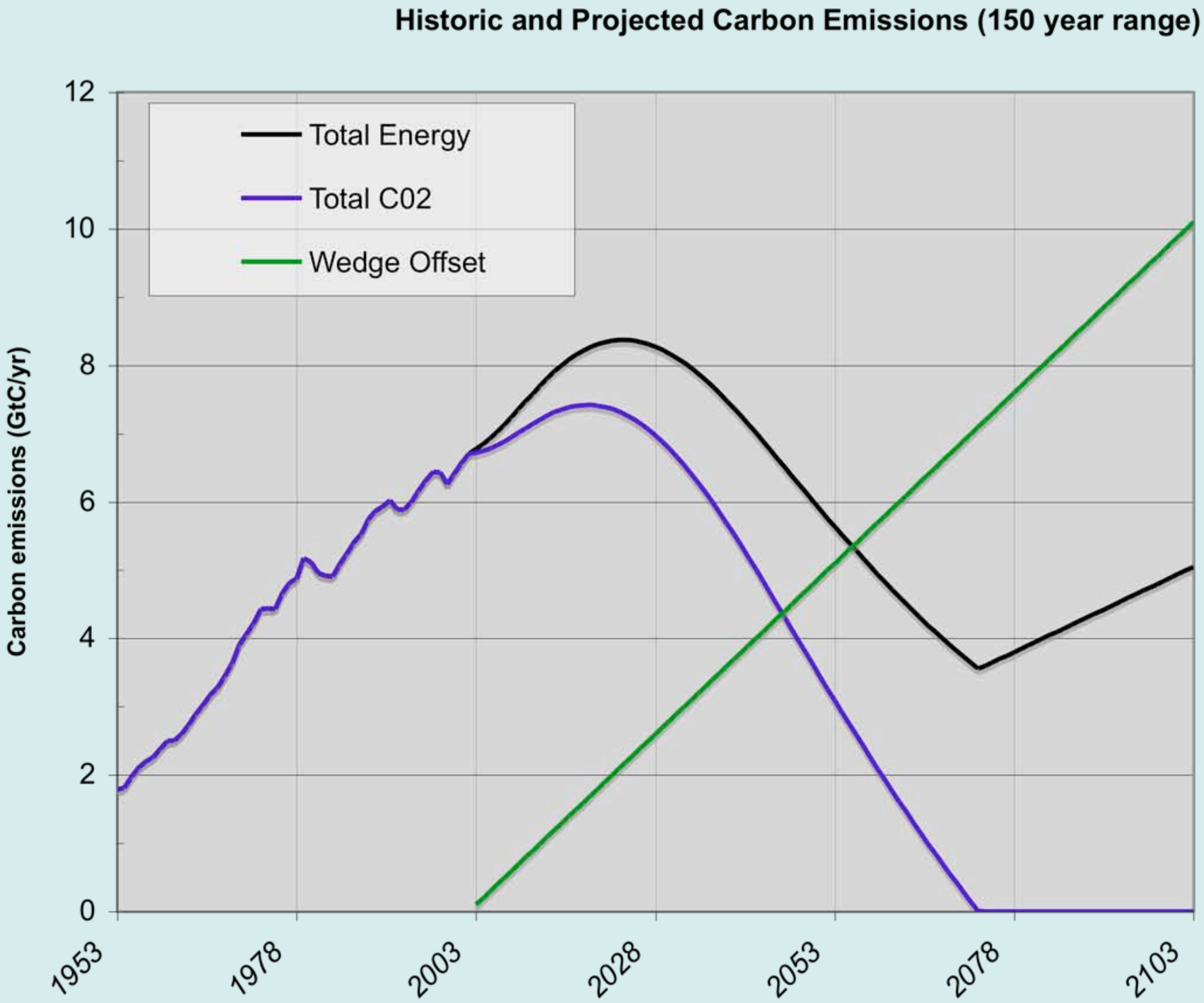


Climate Mitigation
3 Wedges - Per capita energy



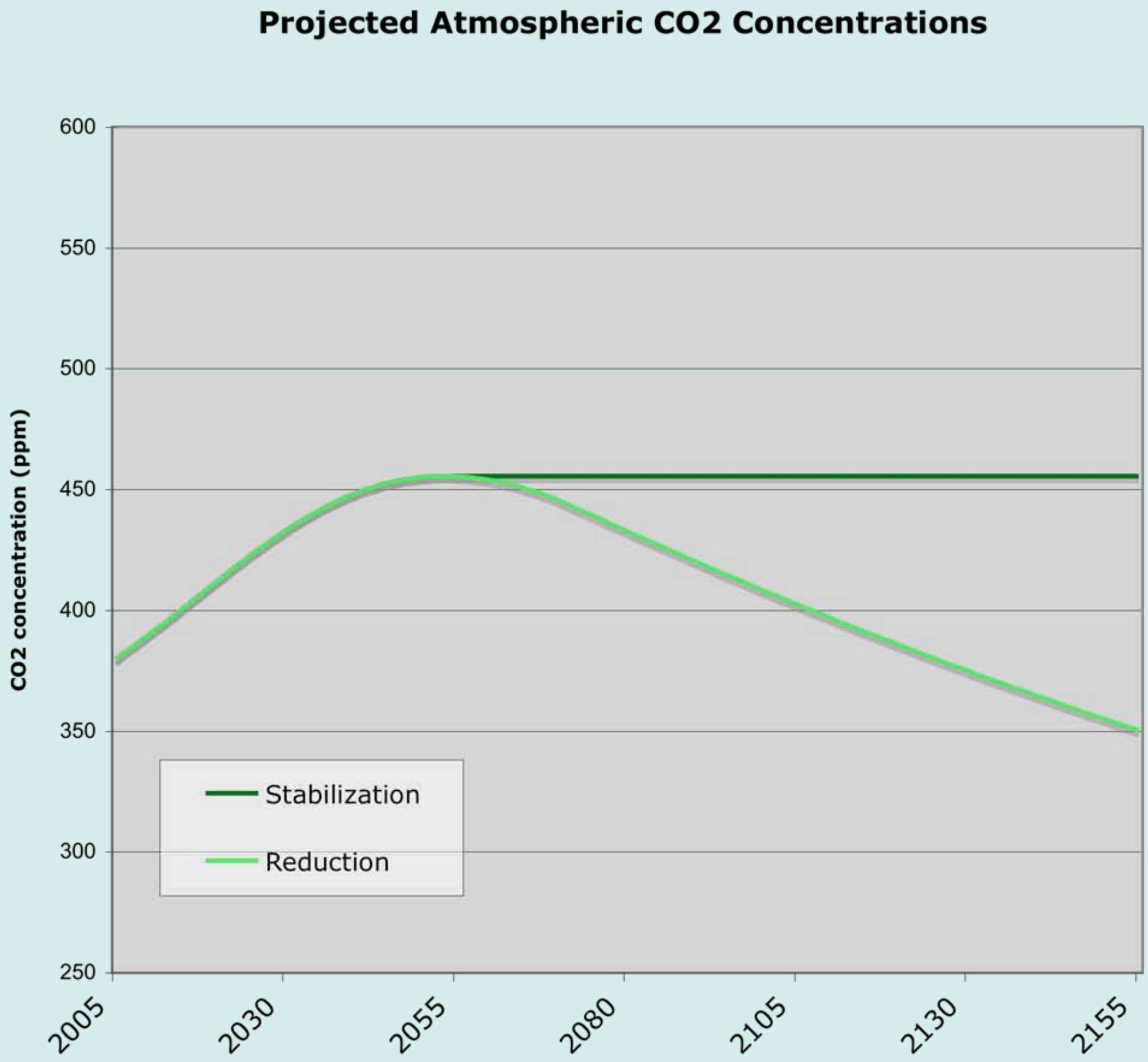
(Energy per capita calculated based on projections of 9 billion in 2050, then stable population at 9 billion)

Climate Mitigation
5 Wedges: All



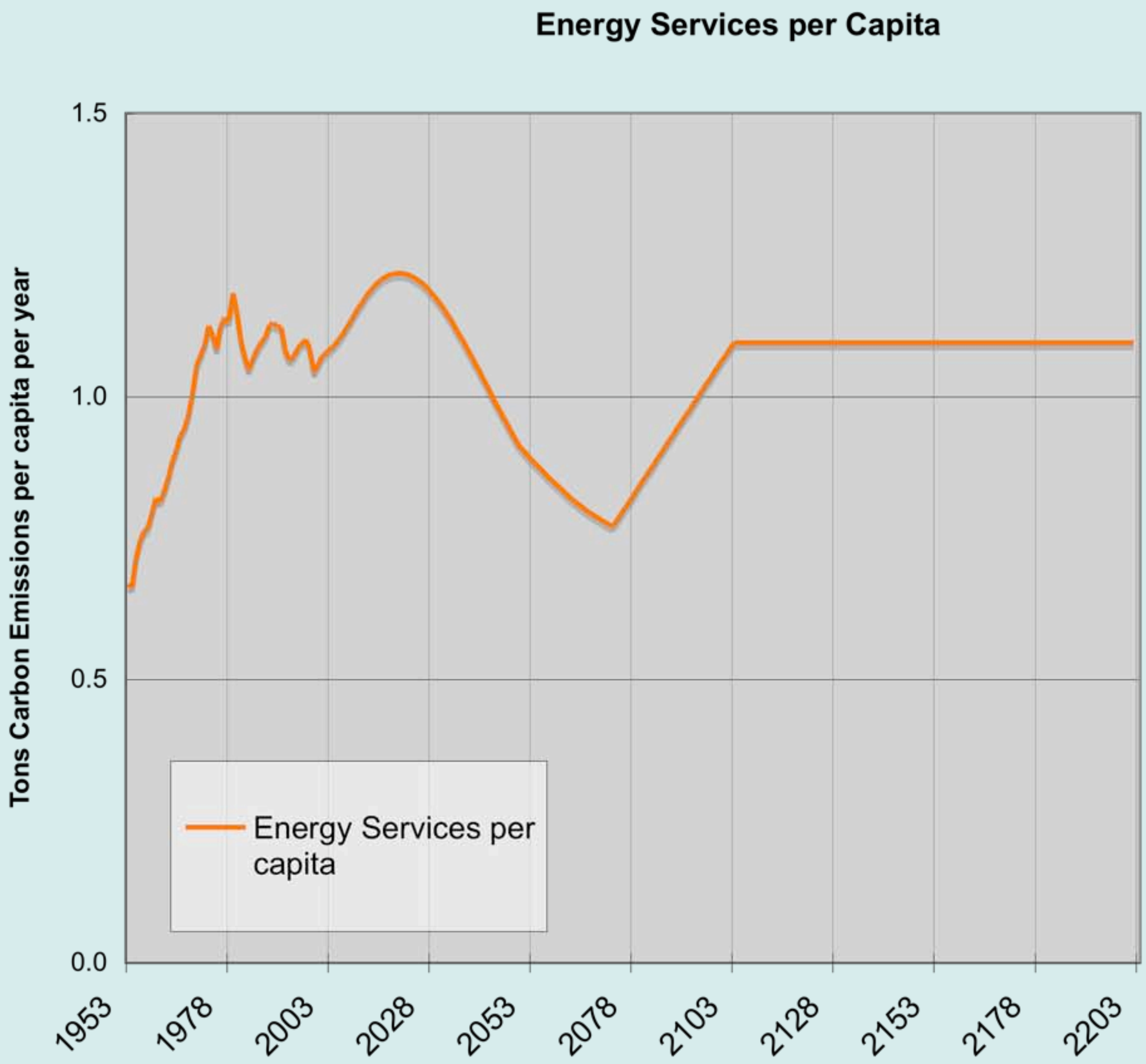
5 wedges can drive CO_2 emissions to ZERO in ~75 years

Climate Mitigation
5 Wedges - CO_2 Concentration



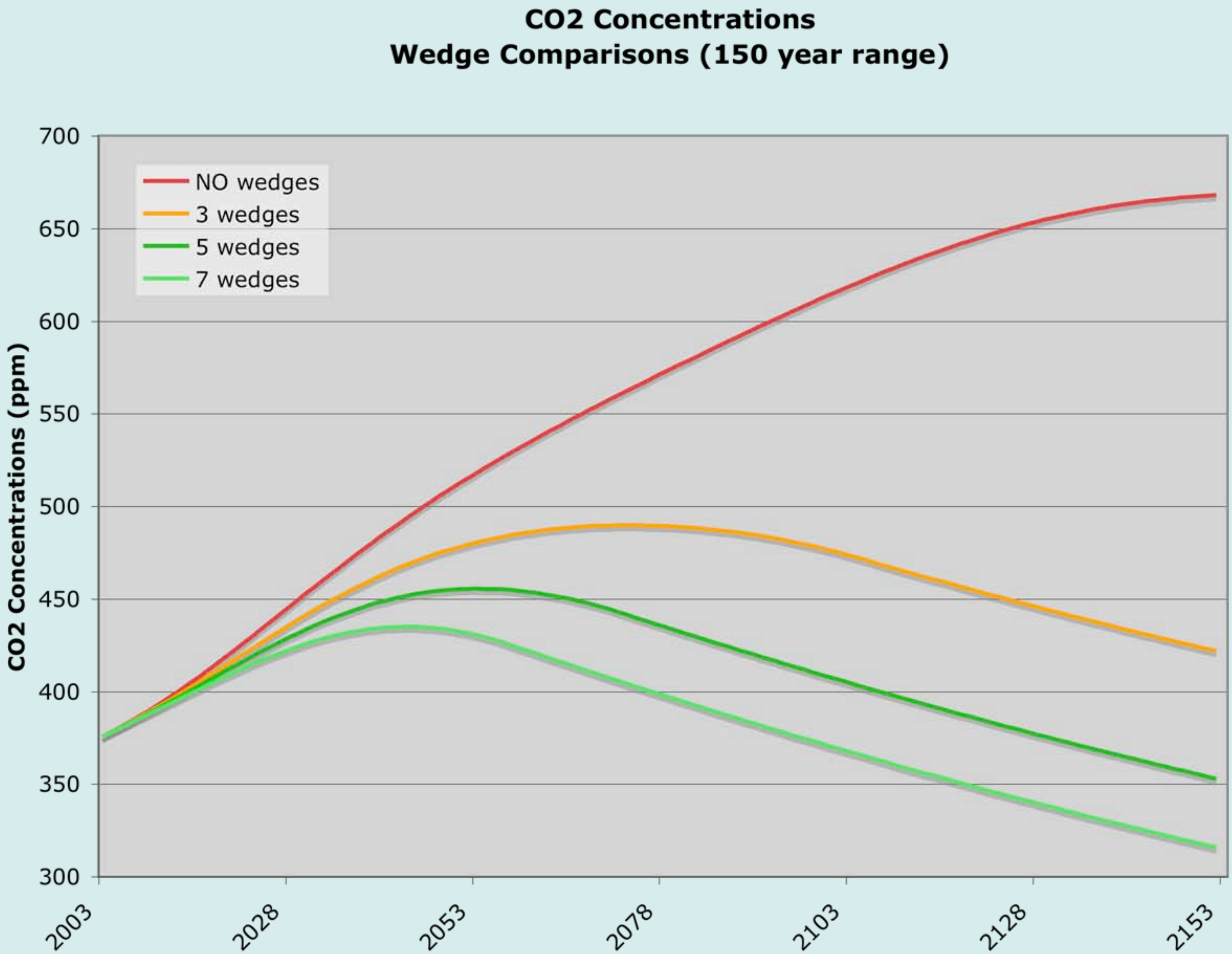
CO_2 concentrations can fall to below current levels in about 150 years.

Climate Mitigation
5 Wedges - Energy Services per Capita

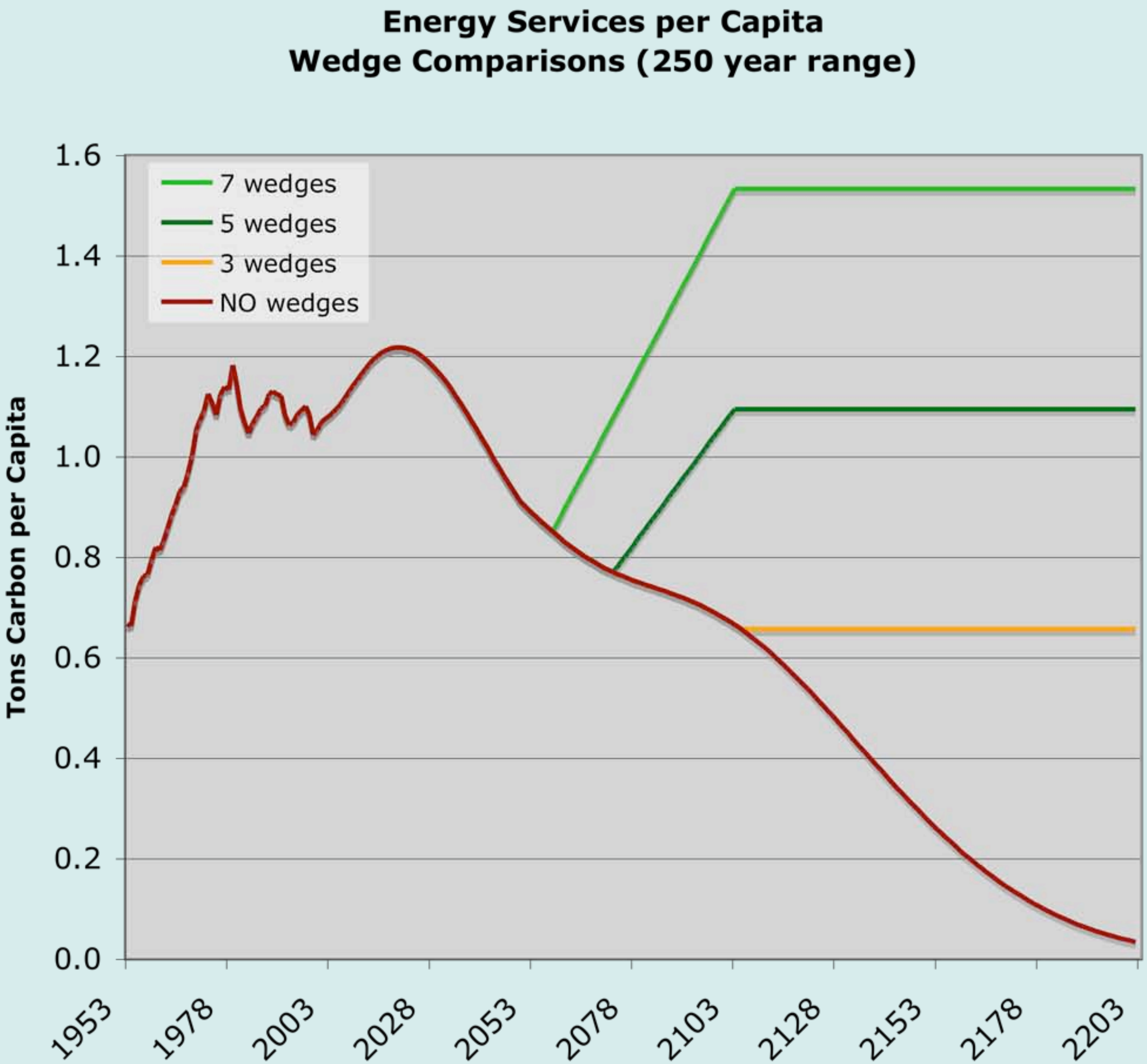


Energy services can come back to around current levels in 100 years, after weathering a very steep drop that begins in about 25 years.

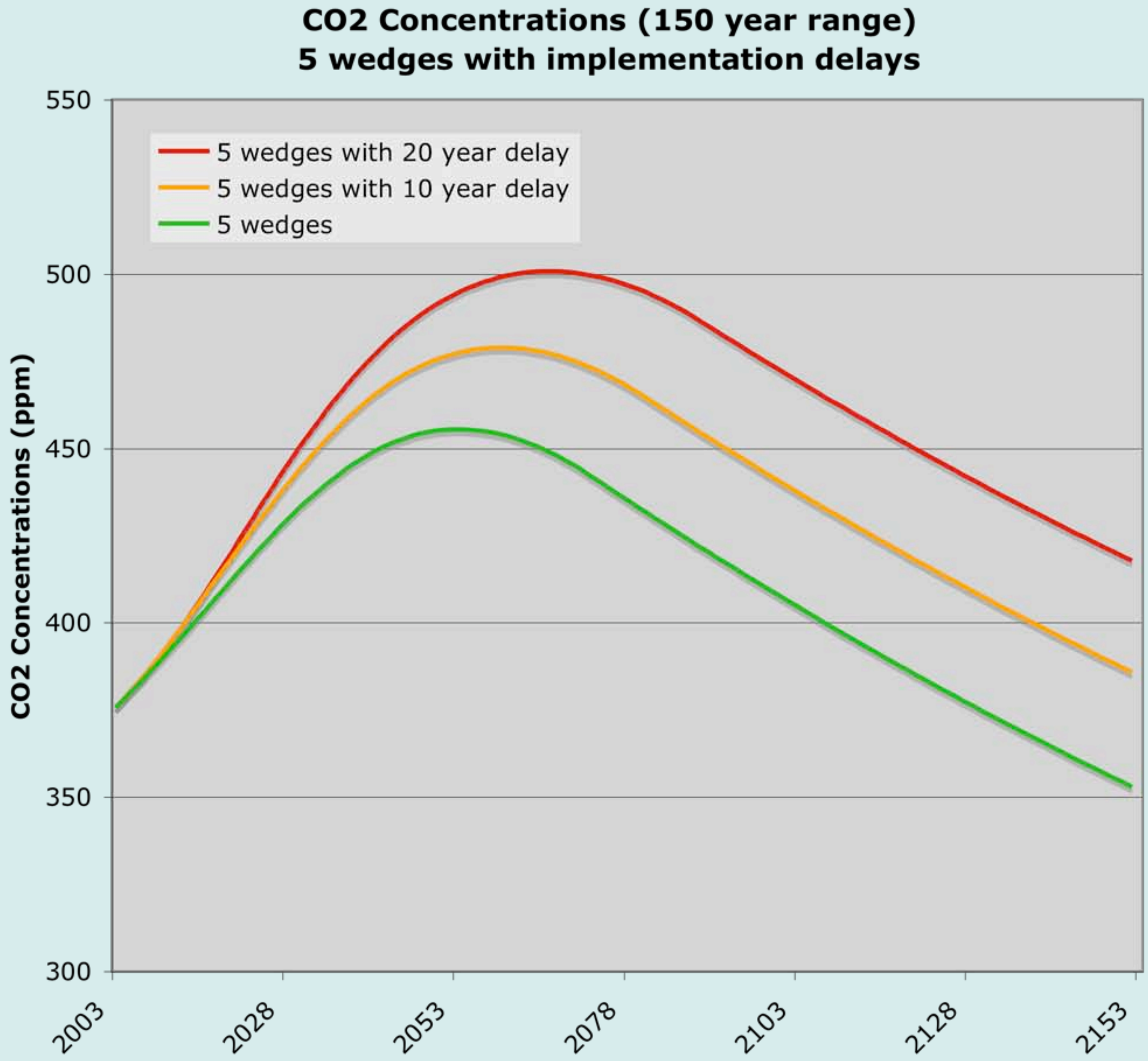
Climate Mitigation
Comparison of Wedge Scenarios



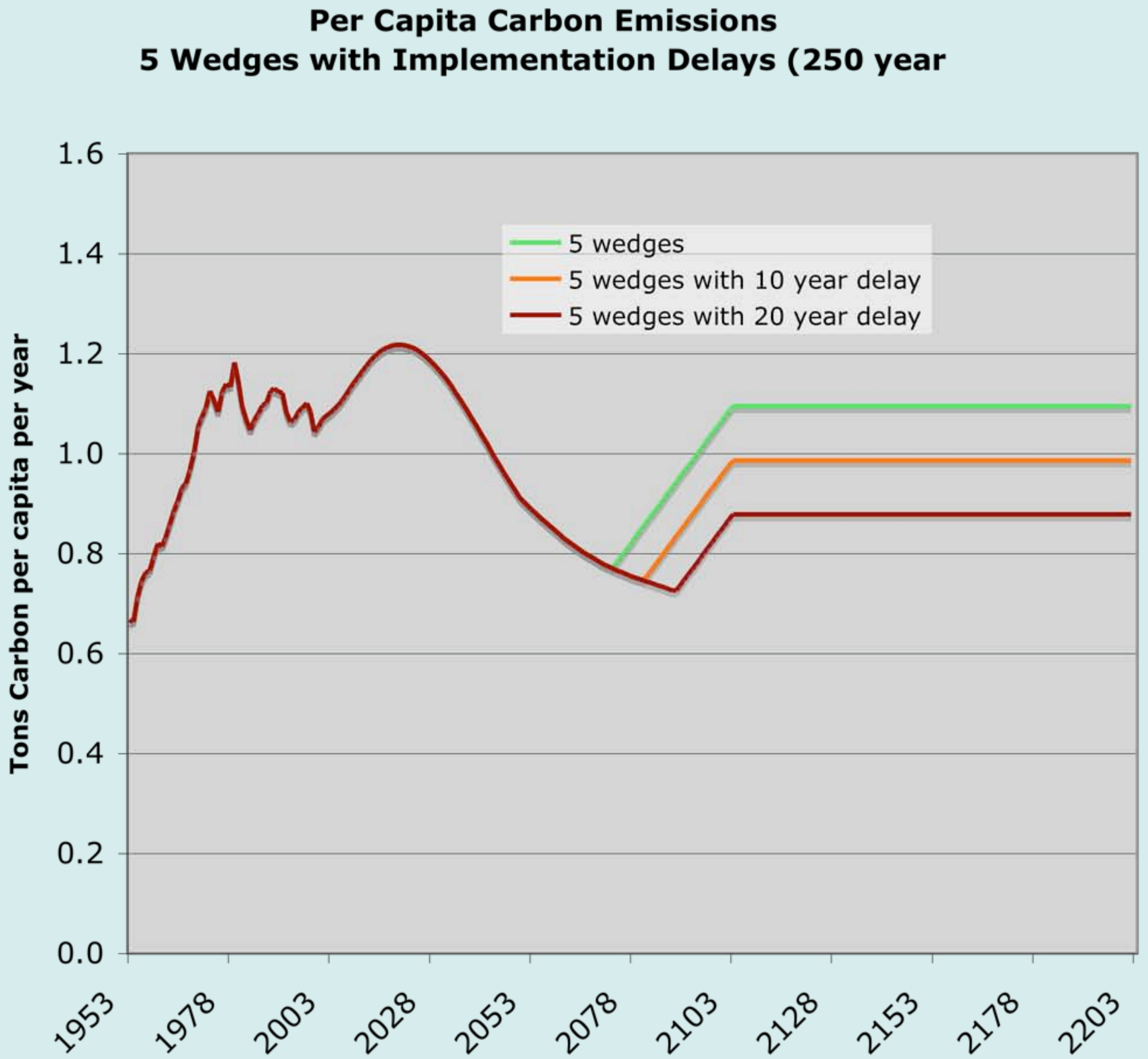
Climate Mitigation
Comparison of Wedge Scenarios



Climate Mitigation
Delayed implementation



Climate Mitigation
Delayed implementation



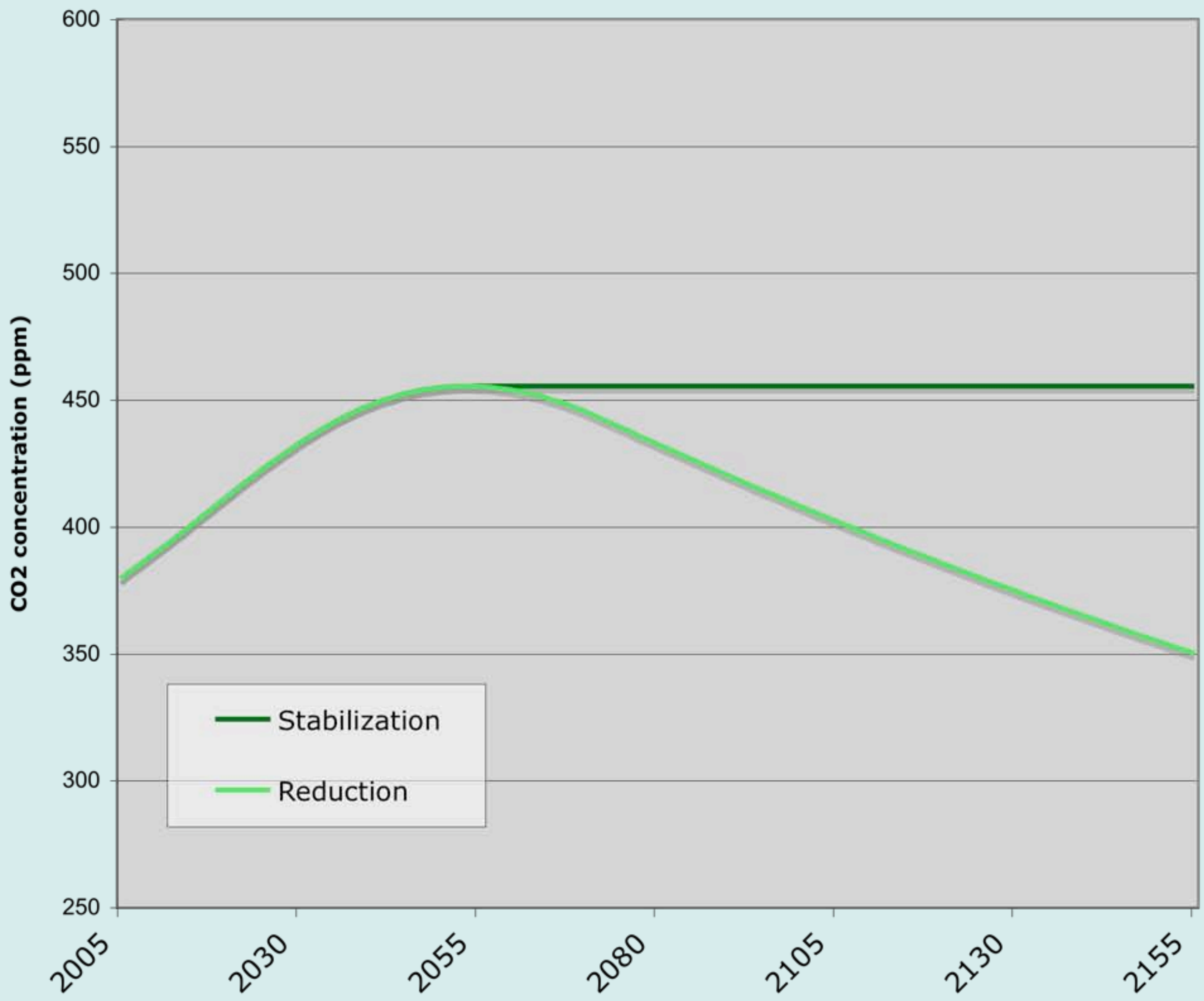
Conclusions

An uncertain future…

- Even with aggressive mitigation measures, **the world will be significantly warmer over the next 100-200 years**
- To mitigate climate change, **the world will have to cope with significantly less total available energy over the next 100 years**, with a peak in roughly 25 years followed by a sharp drop in available energy.
- Energy services per capita also faces a significant drop after the energy peak
- The coming peaks in oil and gas production will make it somewhat easier to mitigate climate change since there is less carbon to offset.
- Appropriate actions can both mitigate climate change and replace obsolete energy sources with new renewable sources.

Conclusions
Implementation of **5 Wedges** without delay

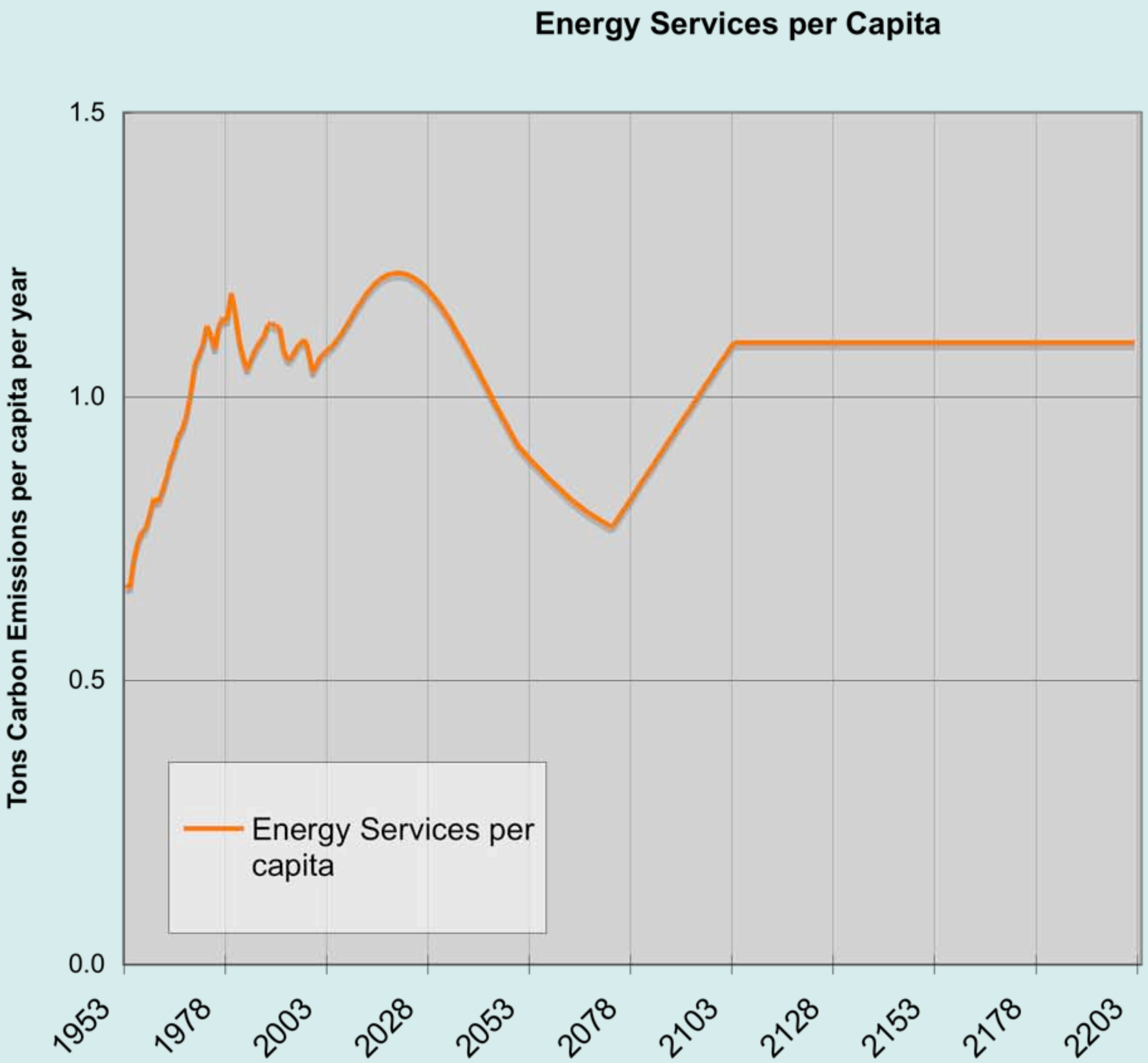
Projected Atmospheric CO2 Concentrations



Carbon concentrations peak at just over **450** ppm in about 50 years, then eventually **drop to below current levels (350 ppm)** by a **hundred** years after that (in 2155)

Peaking at ~450 ppm reduces the risk of severe climate disruption

Conclusions
Implementation of **5 Wedges** without delay



- Energy services per capita declines after total energy peak but recovers to near current level by 2100.
- Achieving steady state energy services per capita at or below the current level is a good long term goal for energy sustainability.

Conclusions
Wedge implementation

- Implementation of wedges can accomplish:
  - A replacement for fossil energy sources that will be mostly depleted within 100 year (oil and gas) and 200 year (coal) ranges.
  - Climate stabilization
  - A far more efficient energy infrastructure that can serve as the foundation for future innovations.
- Delays in wedge implementation cause a higher peak in atmospheric CO_2. The longer the delay, the worst the penalty.

Conclusions
Wedge implementation

- Wedge implementation requires that we think carefully about our future capital investments, both institutionally and individually.
- Ideally wedges should be stepping stones to viable long term solutions – not stop-gap measures.
- Although wedges can be implemented with non-renewable solutions such as carbon sequestration and nuclear power
  - Those solutions are only temporary…
  - Better to invest as much as possible in renewable energy sources.

Conclusions
Challenges ahead require immediate action

- We should act to set targets and implement wedge strategies without delay.
- Inaction or “business as usual” is not an option.
- We need to bring new energy sources online *AND* mitigate global warming.
- We need to devise globally effective economic strategies to facilitate the implementation of wedges.
- Global warming (and environmental degradation in general) needs appropriate economic price signals.

Conclusions
Uncertainties

- CO_2 concentrations may be higher than estimates if ocean/land sink rates change for the worse.
- CO_2 concentrations may also be driven higher if other unconventional carbon sources such as oil sands come into significant use. Hopefully, they will *NOT* enjoy large-scale adoption! Otherwise we need even more wedges!
- Sudden climate change is a distinct possibility, but the triggers are largely unknown.

Conclusions

What can *I* do?

- Educate others on the links between energy & climate.
- Think locally *AND* globally!
- Examine personal energy use and carbon emissions
    - Use less!
    - Envision strategies for switching to renewable energy.
    - Choose Green Power (such as PaloAltoGreen).
    - Drive a HEV or PHEV (pluggable hybrid electric vehicle)*.
    - Buy carbon offsets (available online).
    - Urge your municipality to devise a plan for becoming carbon neutral.

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* A typical HEV (hybrid electric vehicle) is a Toyota Prius or Honda Civic.

See www.calcars.org for more info on the promise of PHEVs.

Conclusions

What can *I* do?

- Lobby congress to:
    - set wedge implementation targets.
    - levy a carbon tax.
    - establish a carbon budget.
- Educate yourself and others on what's happening internationally in this arena
- Get creative! Let's kick-start the fixes for global warming together!

Thanks!

Send comments to:

Bruce Hodge

hodge@tenaya.com

See this presentation online at:

www.tenaya.com/globalwarming