Battelle
The Business of Innovation

Post-Kyoto Strategies: *Stabilizing Radiative Forcing in New Economic-demographic Future Scenarios*

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Joint Global Change Research Institute

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Office of Science
U.S. DEPARTMENT OF ENERGY
JGCRI Joint Global Change Research Institute
UNIVERSITY OF MARYLAND
GTSP Global Energy Technology Strategy Program

Today's discussion

1. A NEW reference scenario using PNNL MiniCAM.
2. The challenge of climate change—stabilizing radiative forcing.
3. Economic implications.
4. The technology response.

Development along a reference path

New Scenarios

The Modeling Teams

Research Team	MIT	Stanford-EPRI	PNNL
Integrated Assessment Model	IGSM (EPPA)	MERGE	MiniCAM

New Scenarios

- Revisiting ALL components of our analysis
  - **Demographic & economic foundations**
  - **Addressed the PPP versus MER issues**
  - **Non-CO_2 GHG emissions**
  - **Carbon cycle**
  - **Agriculture-land-use**
- Scenarios will be used in future GTSP analysis.

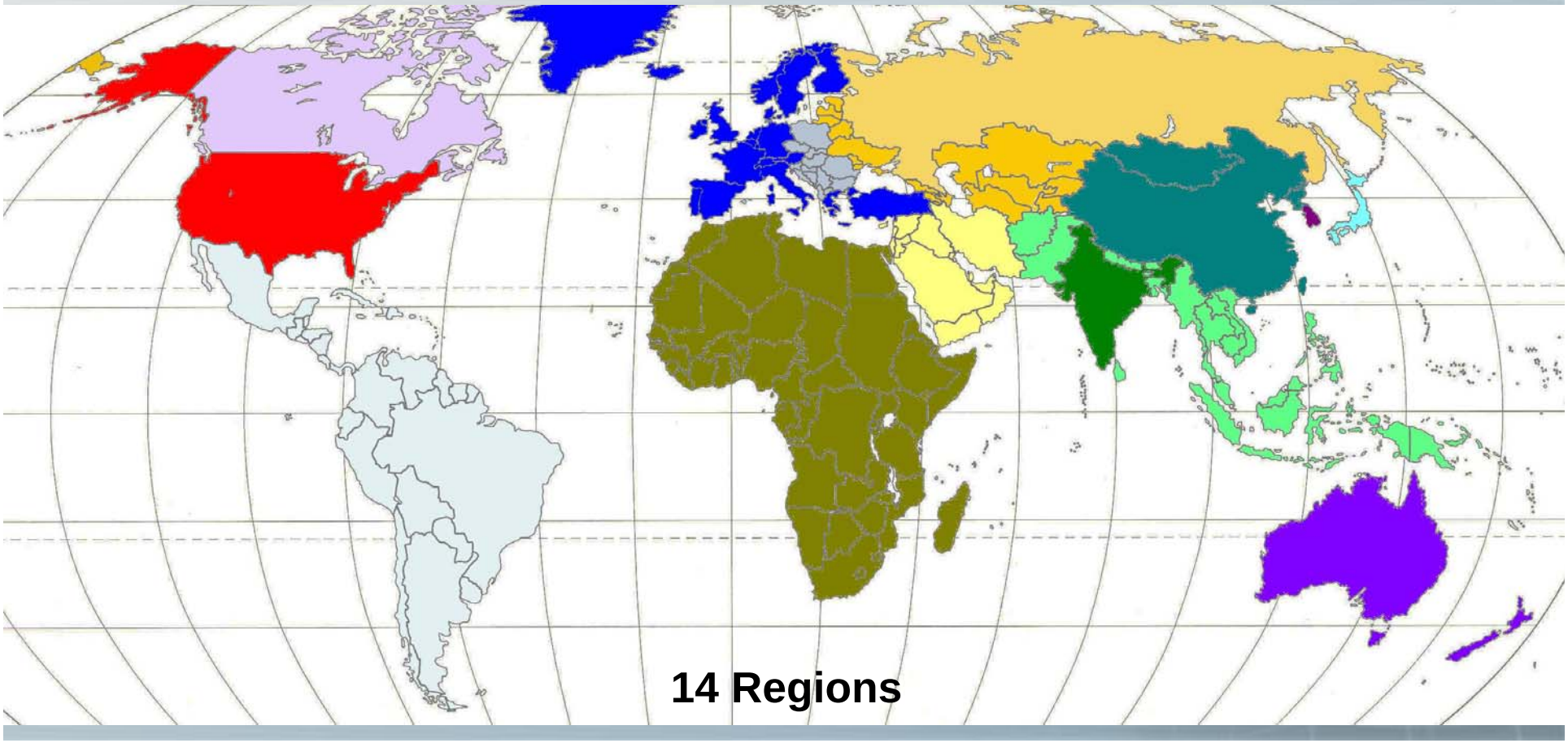
MiniCAM—An Integrated Assessment Model

Emissions, Atmosphere, Climate

Emissions: Energy-economy-agriculture-land-use model

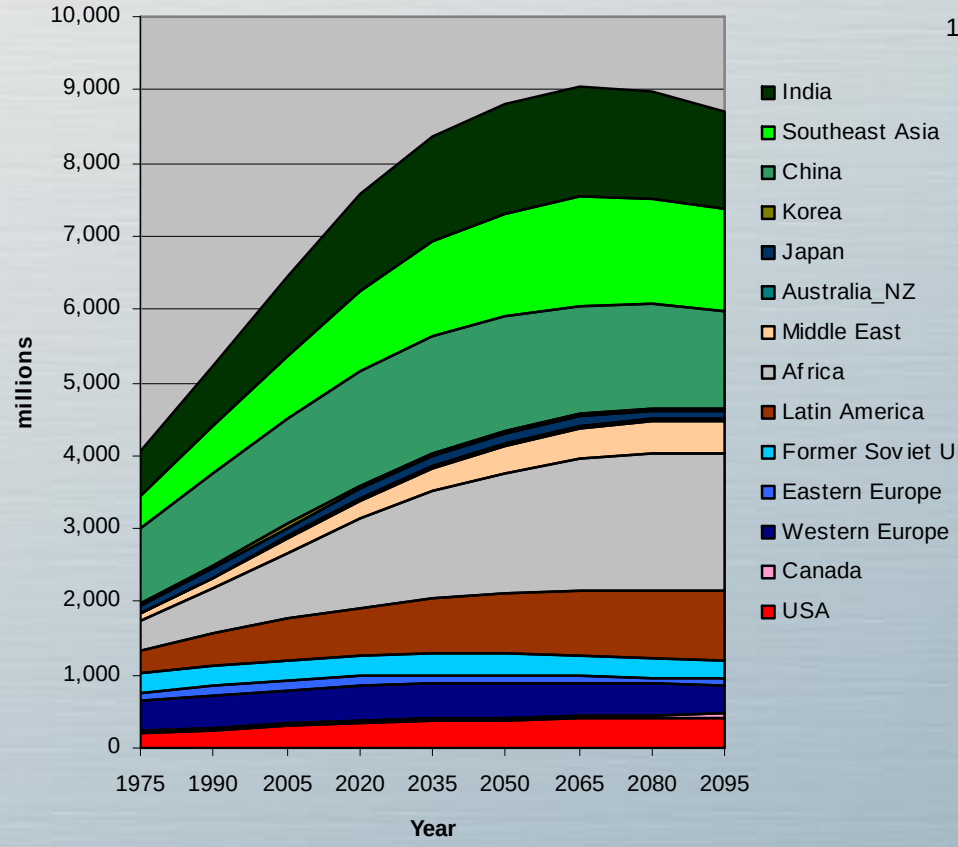
15 gaseous emissions—linked to associated human activities

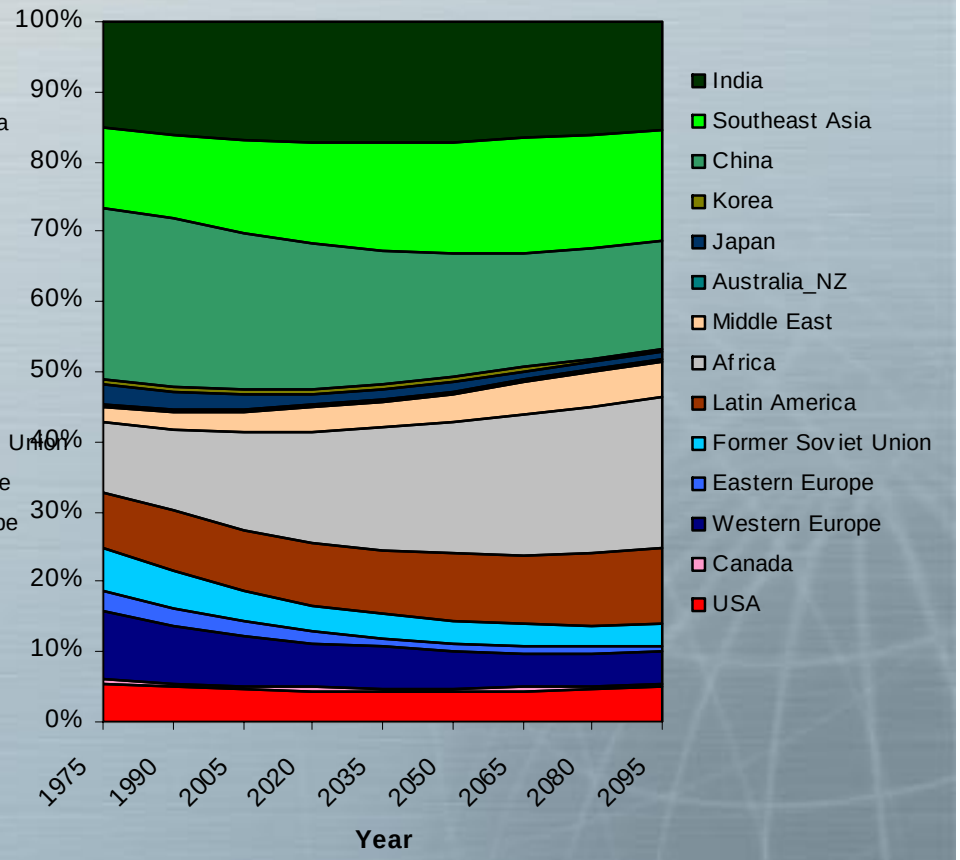
2095 time horizon



Demographics

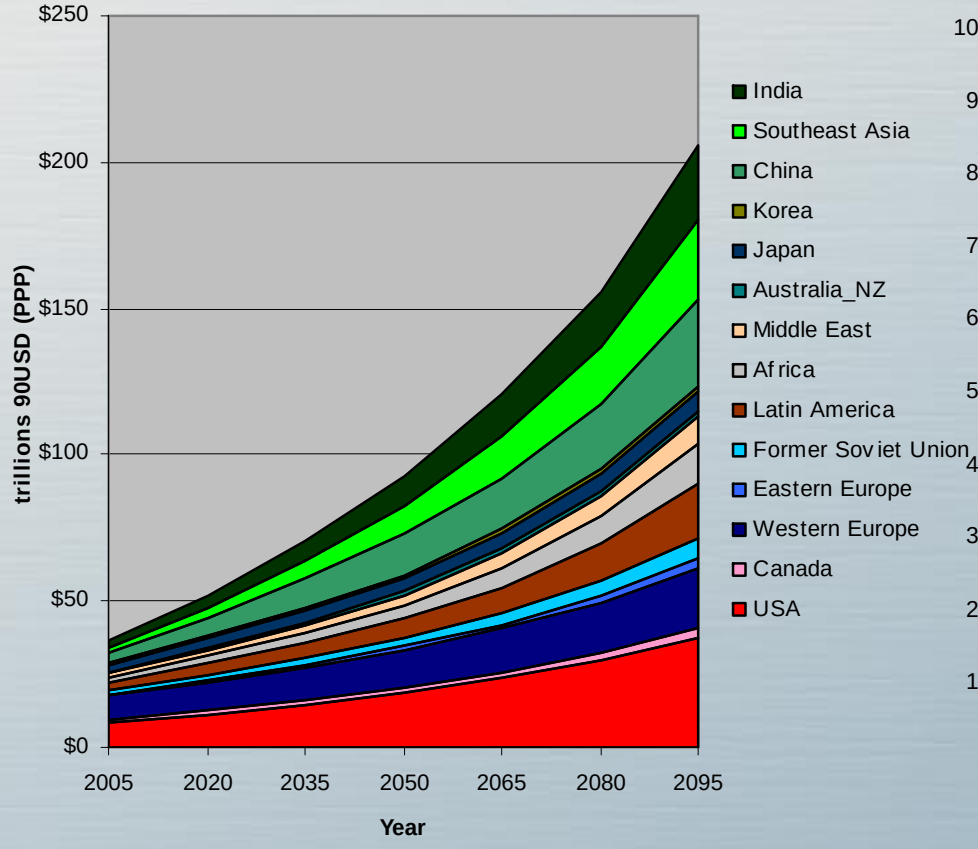
A world of 8.5 billion people & demographic transitions

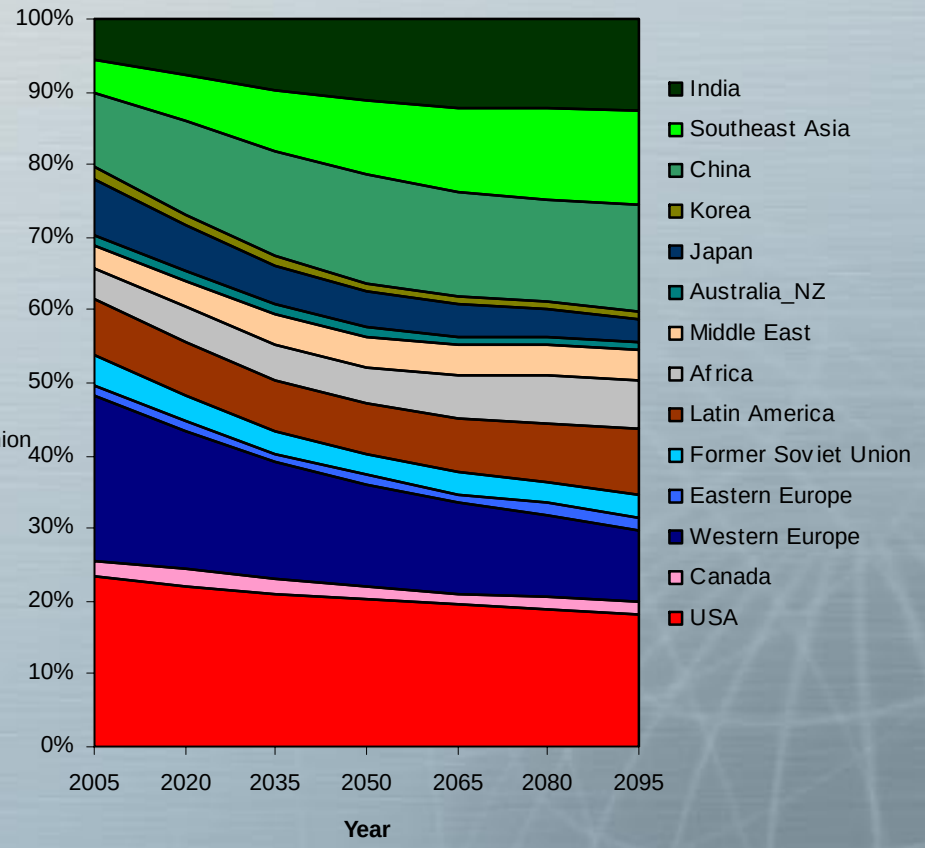




Economics

A $200 trillion world with a changing economic balance

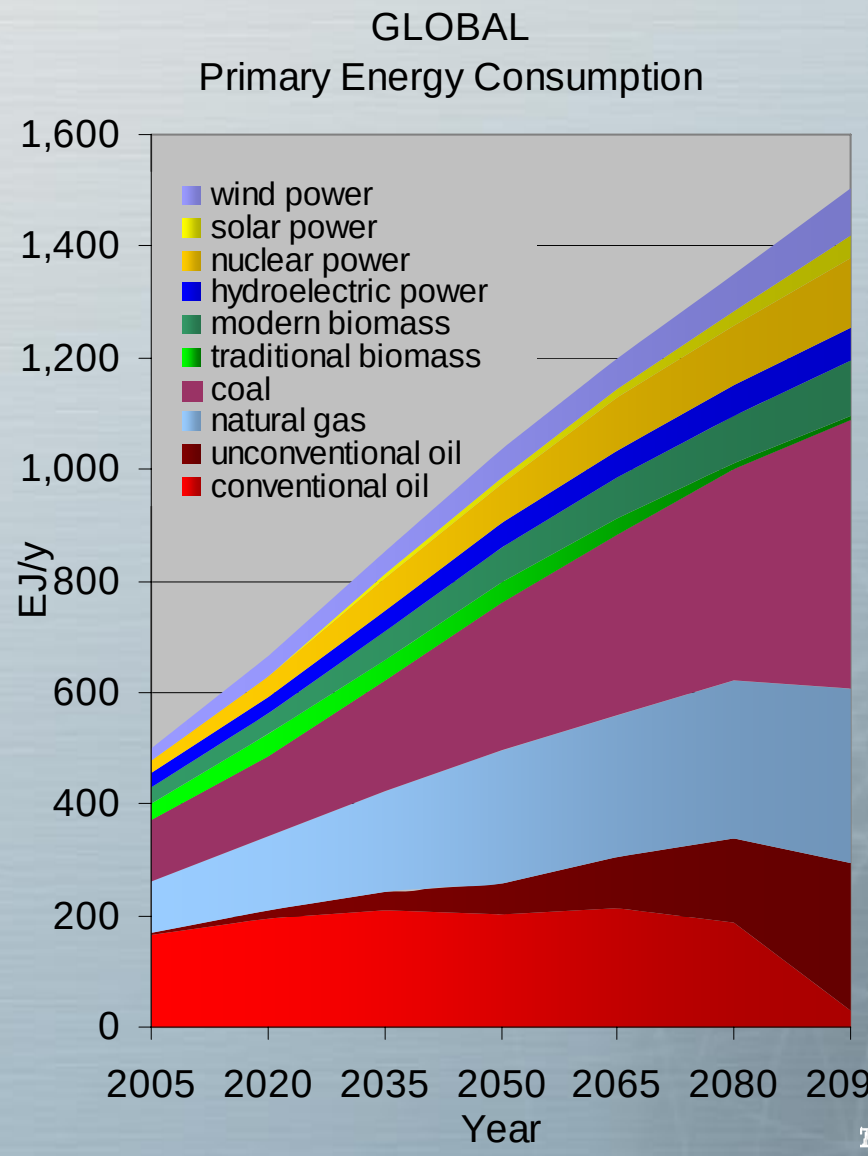




2005=37 trillion 90USD
2050=93 trillion 90USD

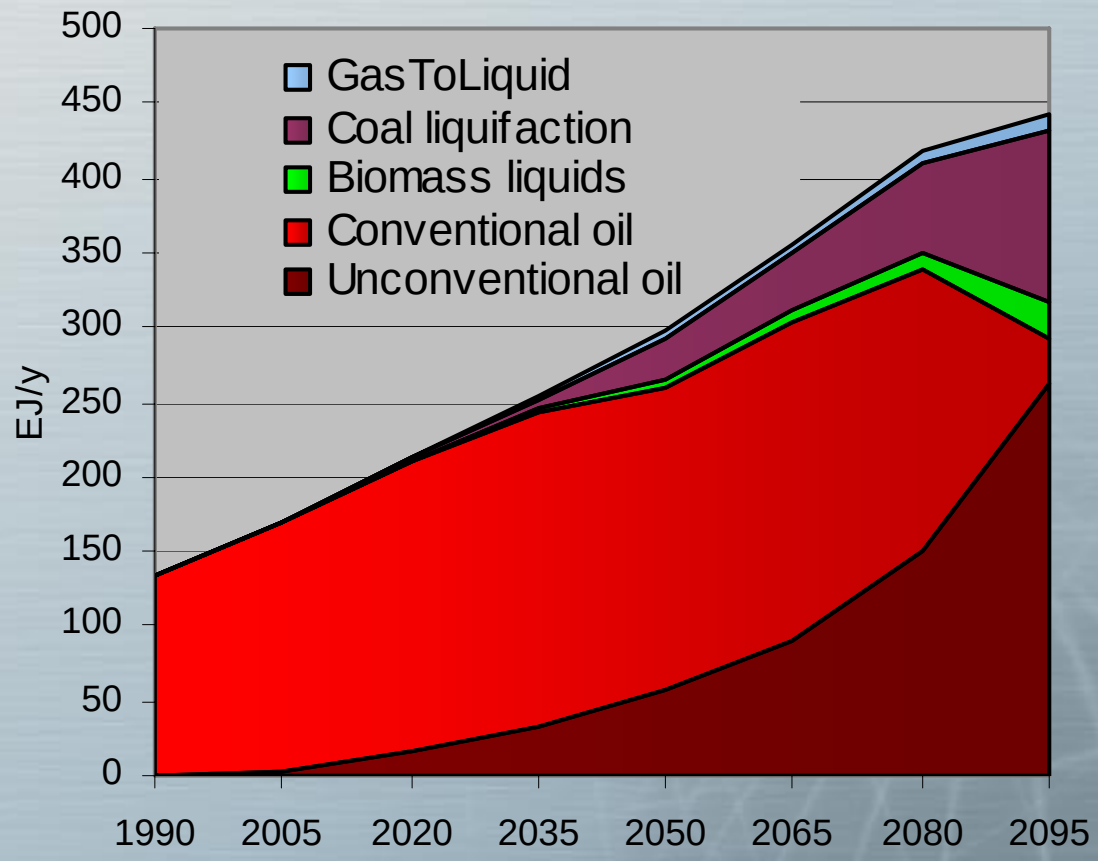
Primary Energy

A 1,500 EJ/y world, dominated by fossil fuels, but with increasingly disperse sources



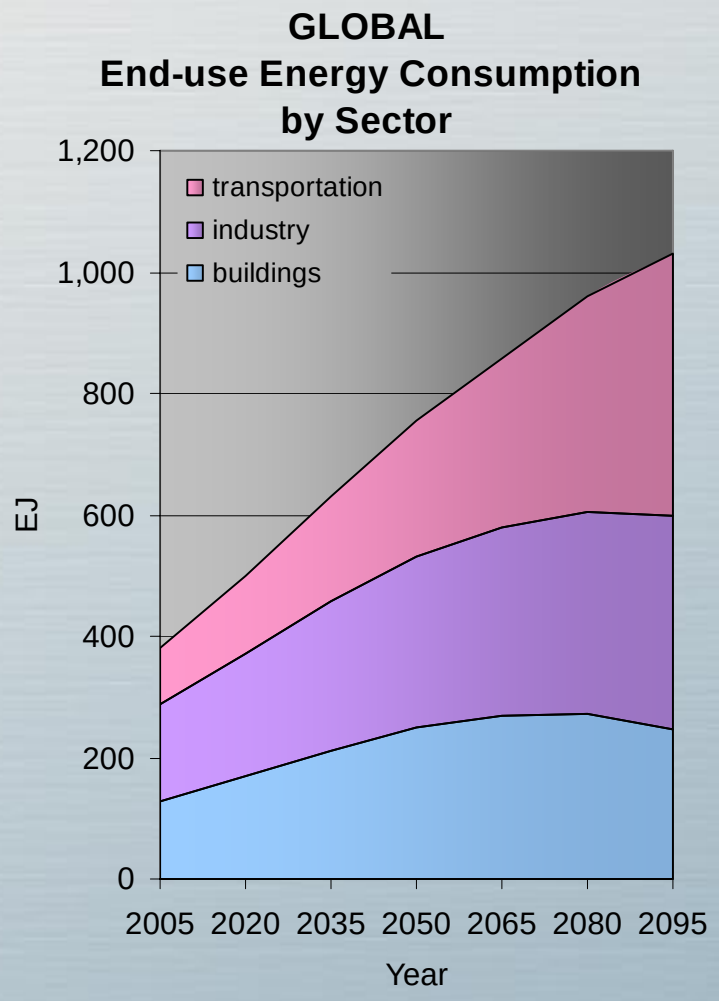
The Oil Market—global

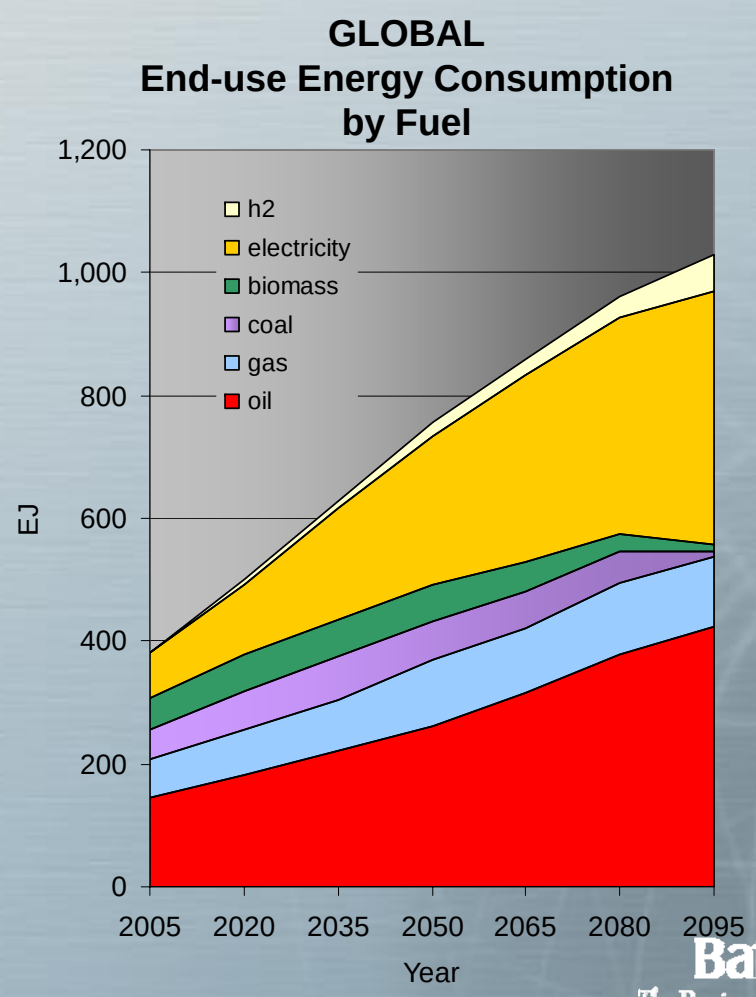
- Conventional oil production is limited.
- Shale oil and synfuels become the dominant forms of liquid fuels in the second half of the century.
- Implication—higher CO_2 emissions.



End-use Energy

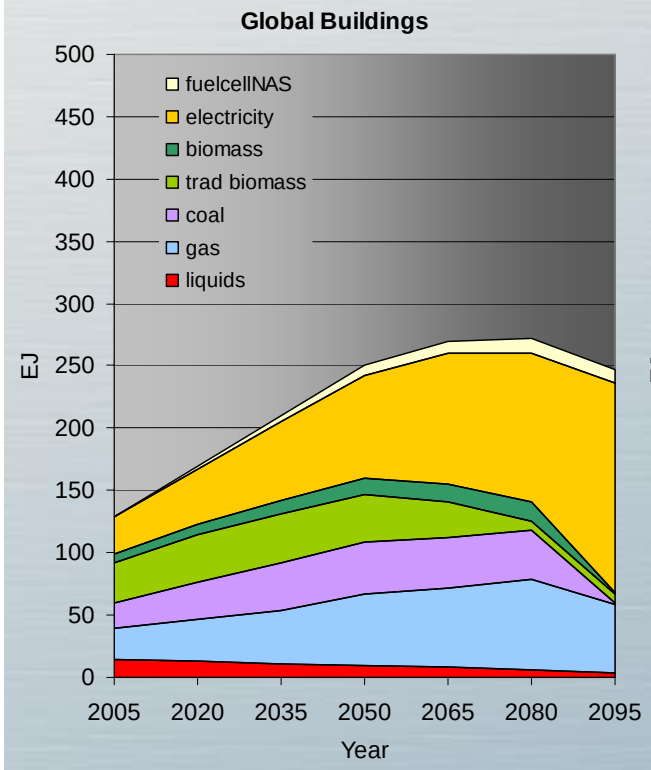
A 1,000 EJ world with rapidly growing transport demand

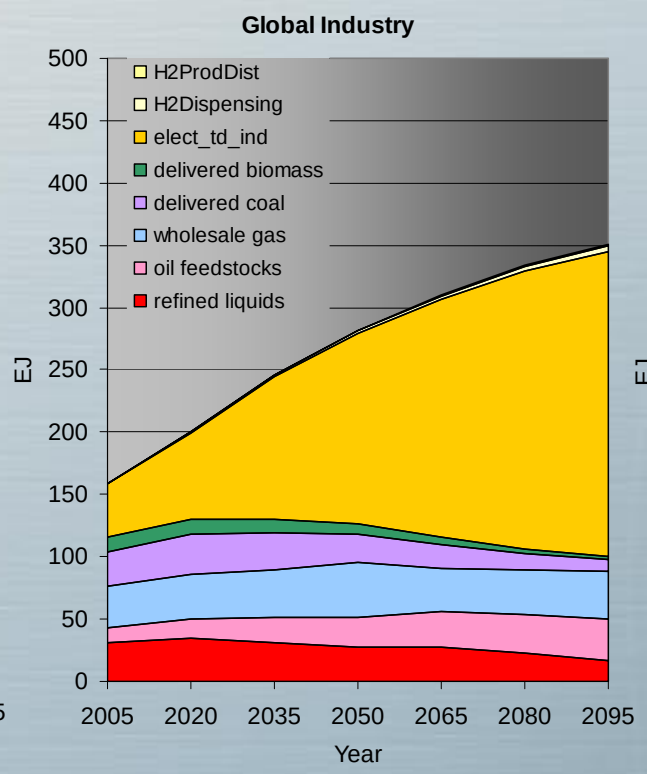


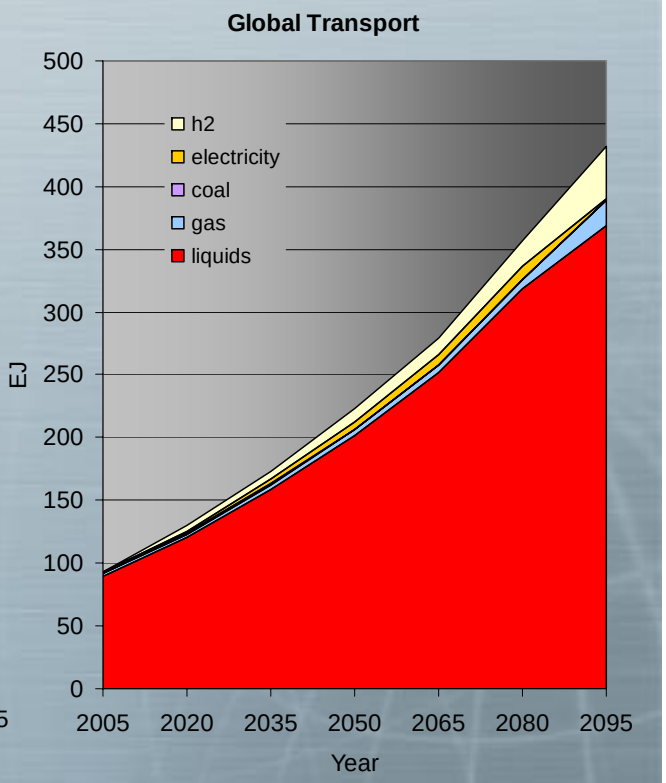


End-use energy by sector—Global

A 1,000 EJ world with rapidly growing transport demand

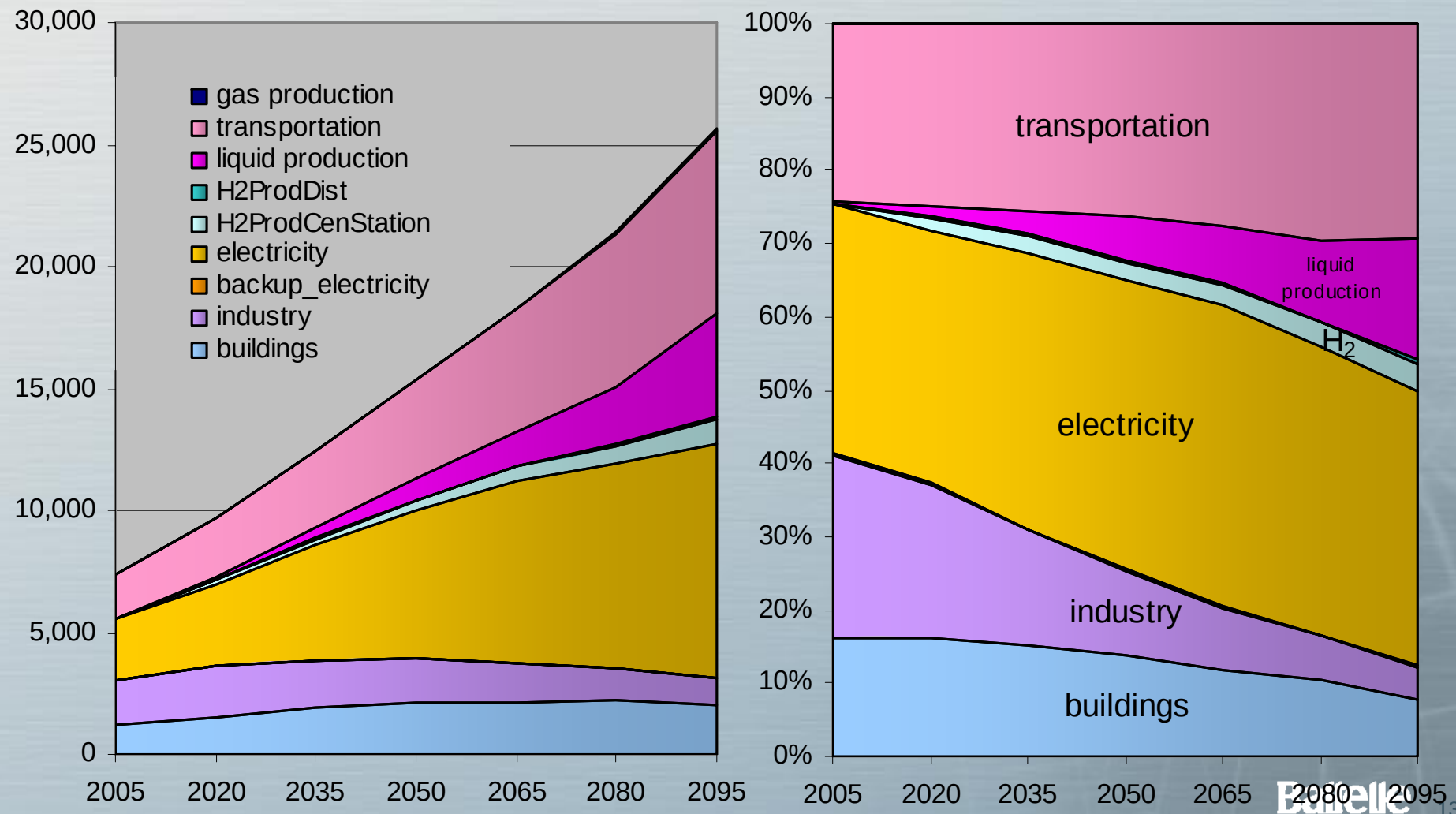




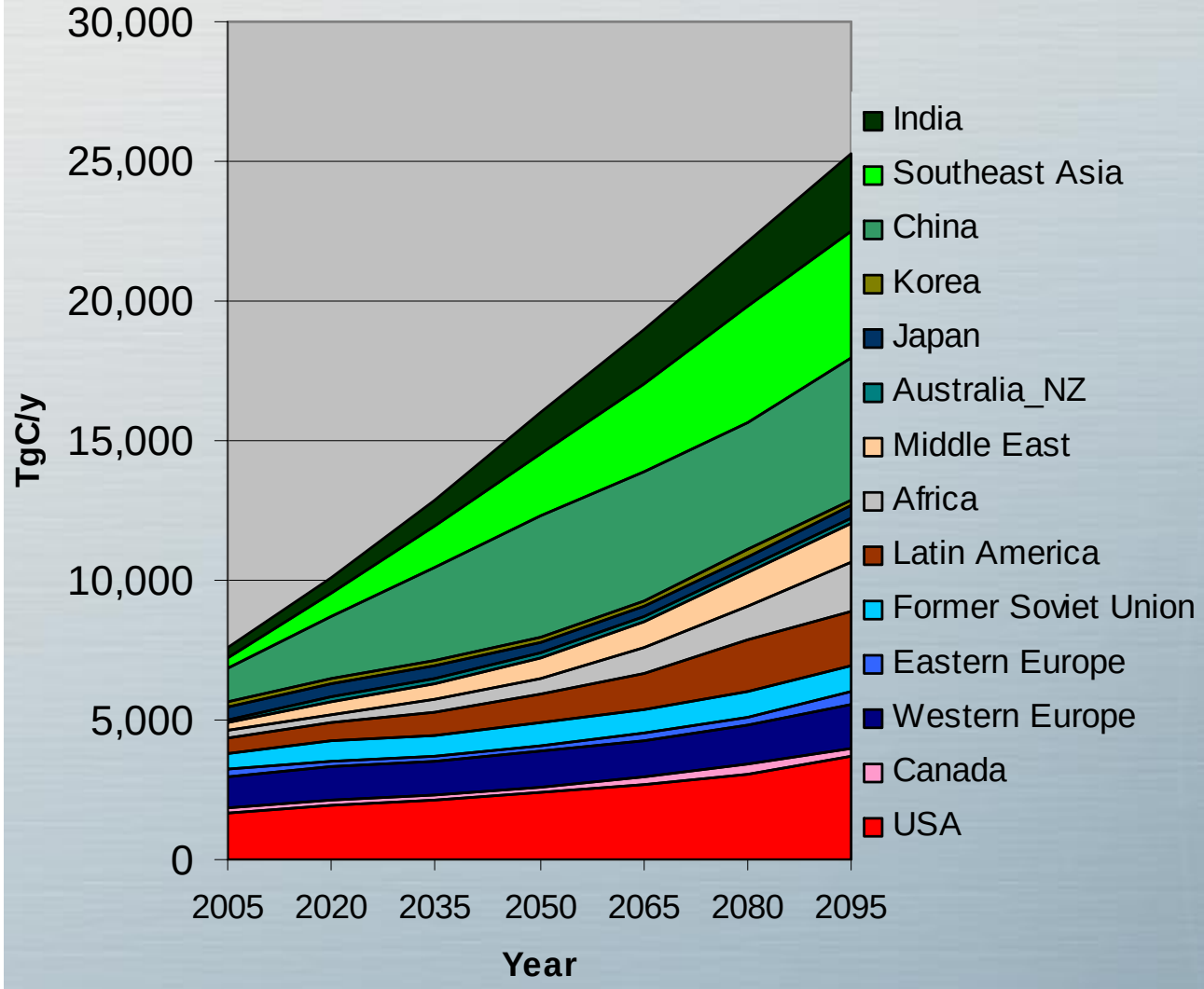


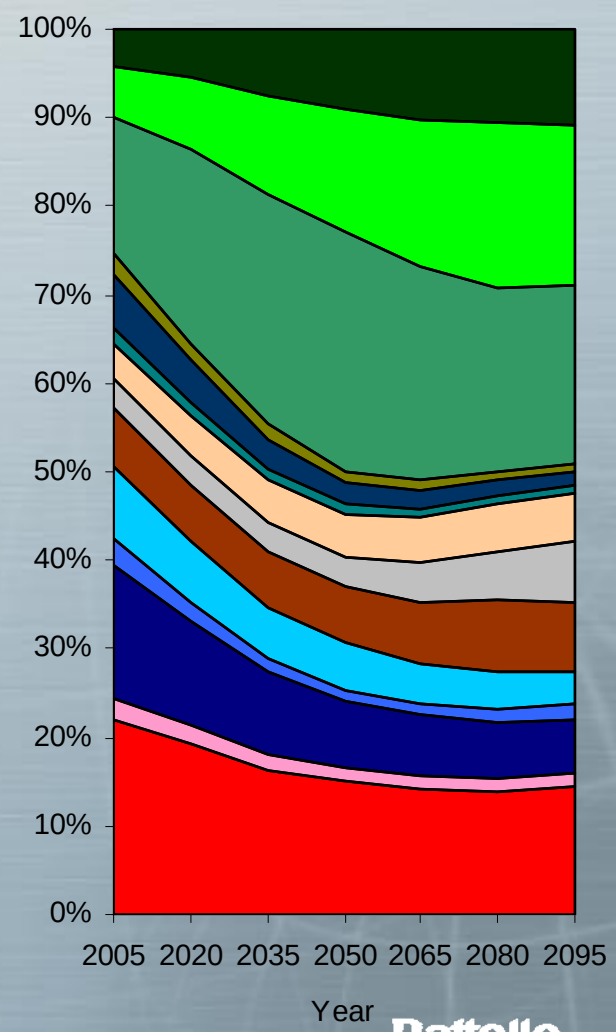
Fossil Fuel CO_2 by Sector of Origin

Global



Fossil fuel CO_2 emissions by region



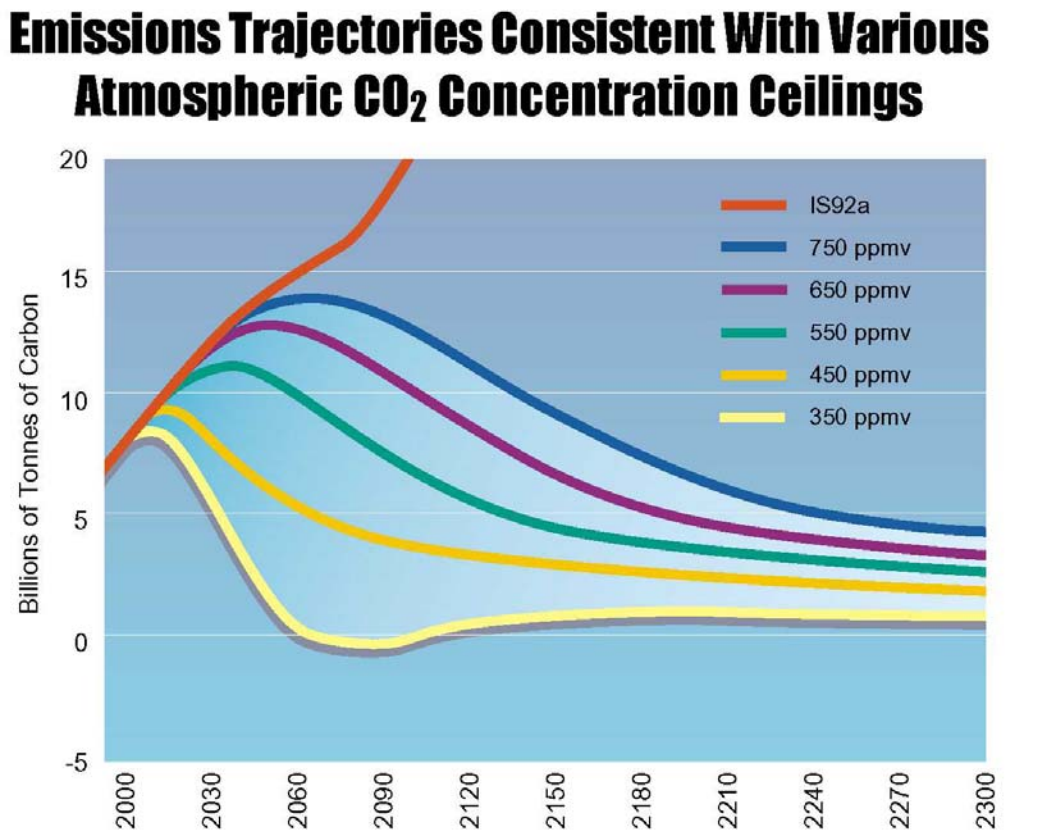


The challenge of climate change

Stabilizing CO_2 Concentrations

- Stabilization of greenhouse gas **concentrations** is the goal of the Framework Convention on Climate Change.

- Stabilization means that **GLOBAL** emissions must peak in the decades ahead and then decline indefinitely thereafter.



- Climate change is a **long-term**, century to millennial problem—**with implications for today**. It will not be solved with a single treaty, single technology, by a single country, or by a quick fix.

Scenario Architecture

Level	Radiative Forcing From Preindustrial (Wm^{-2})	Approximate 2100 CO_2 Level (ppmv)
Level 1	3.4	450
Level 2	4.7	550
Level 3	5.8	650
Level 4	6.7	750

The Gases

CO_2, CH_4, N_2O, HFCs, PFCs, SF_6

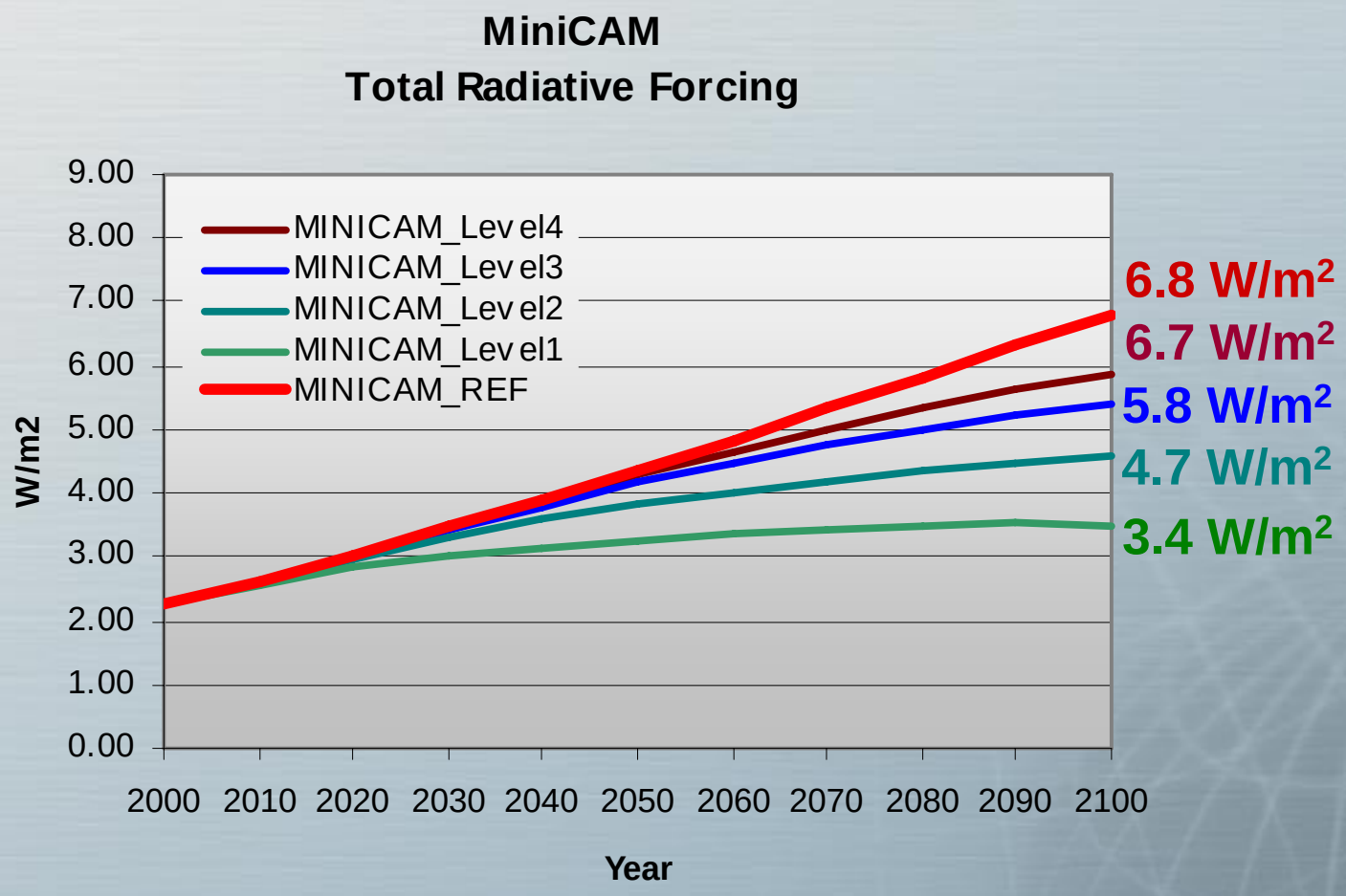
WARNING: We have not considered chemically active gases such as CO, NOx, or VOCs, nor the aerosols and dark particles.

Implementing Stabilization

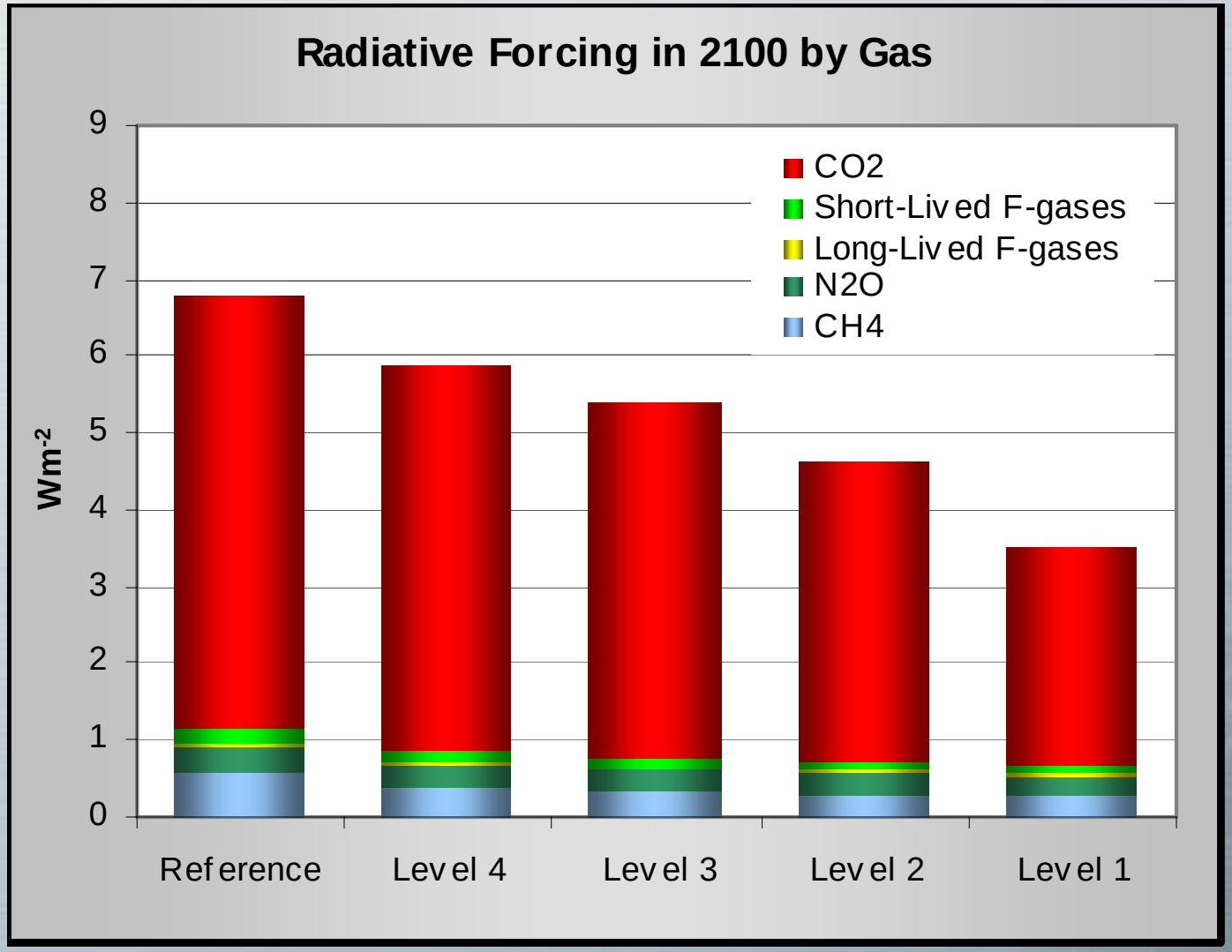
- Assume current policies are effective
  - U.S. 18% reduction in GHG/GDP by 2012
  - Kyoto Protocol
- Assume all nations participate in supplementary programs to achieve stabilization of radiative forcing
  - Perfect "Where Flexibility";
  - Use WRE methodology to limit fossil fuel CO_2 emissions;
  - Use GWPs to compute prices for non-CO_2 GHGs.

Radiative Forcing

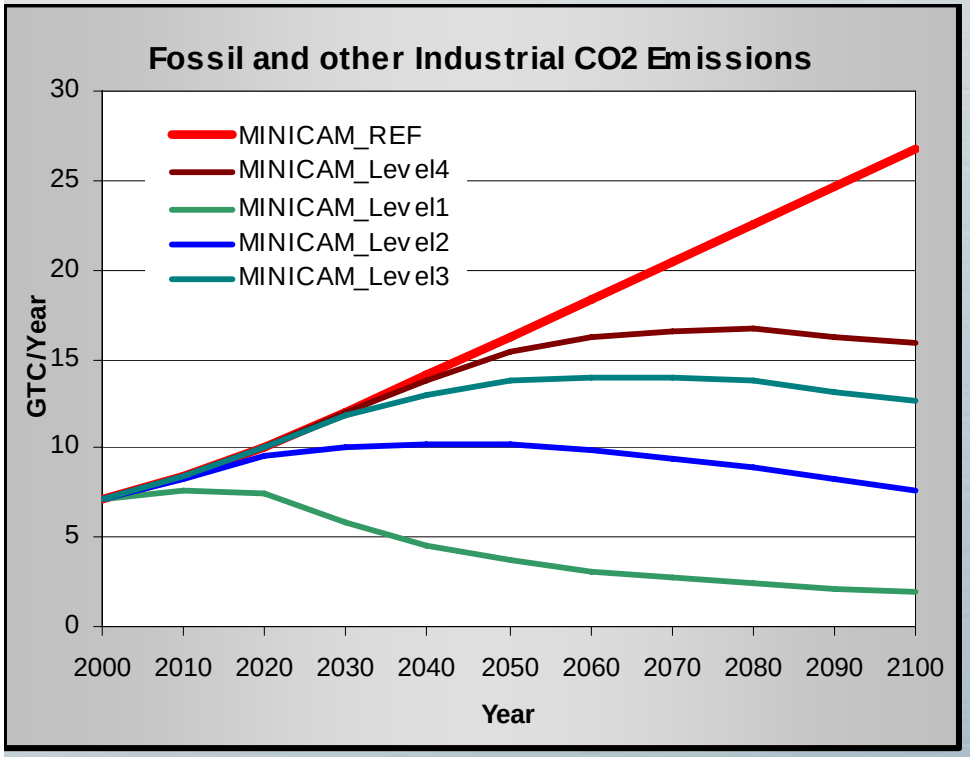
Note that the time scale of the climate change problem is sufficiently long that some stabilization cases will not reach their limits until the 22nd century.

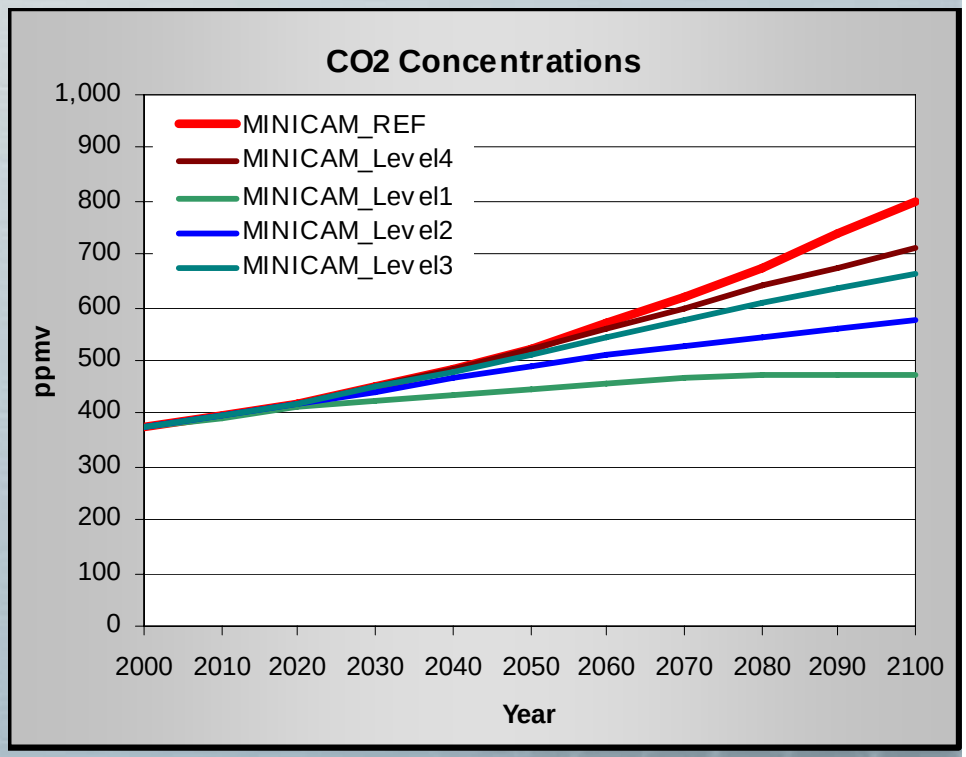


Composition of Radiative Forcing



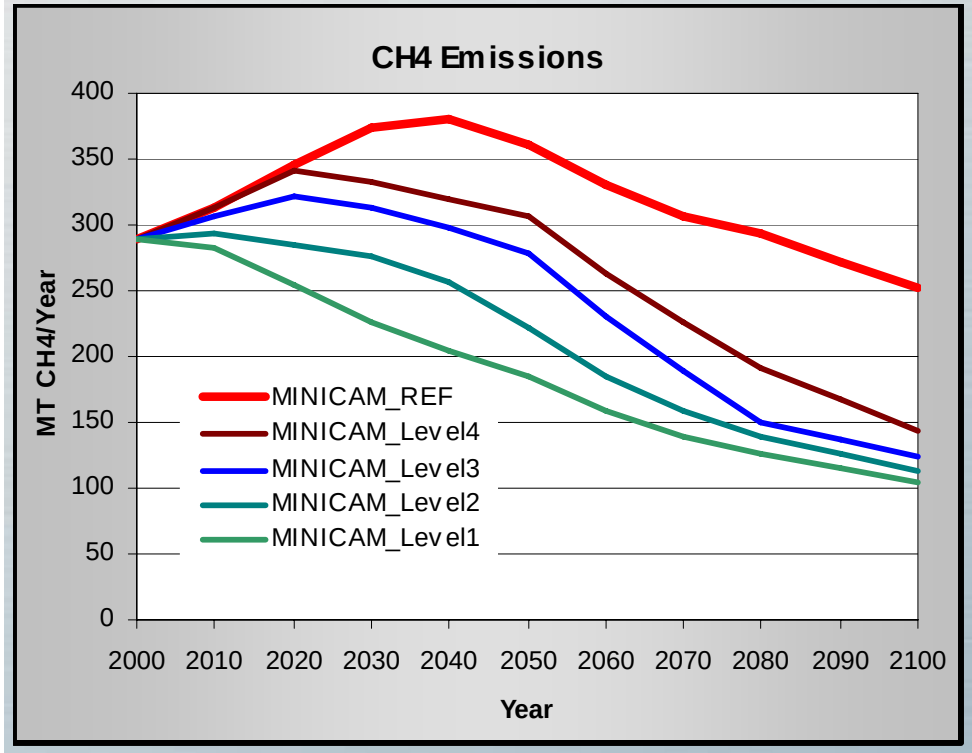
Greenhouse Gases—CO_2

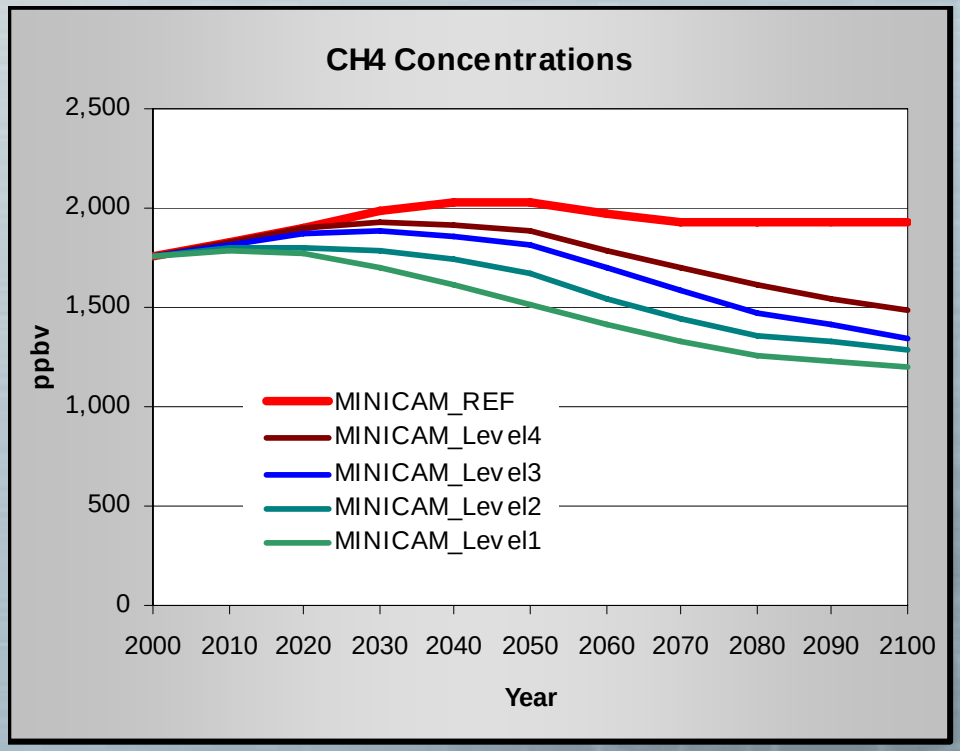




Greenhouse Gases—CH_4

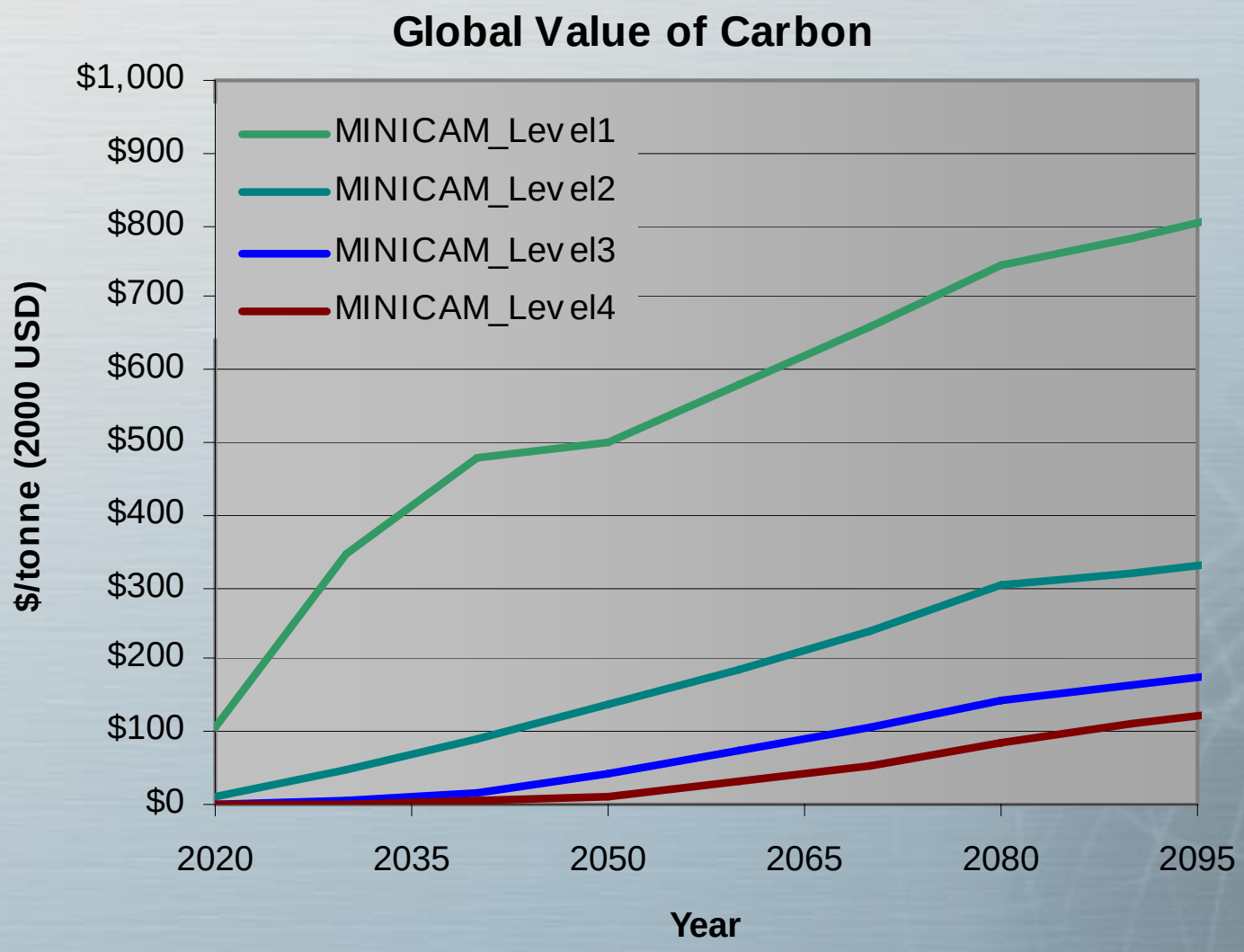
Non-CO_2 greenhouse gas technology can be an important component of an overall strategy to address climate change.





Implications for energy and technology

The Carbon Price



Inter-temporal economic efficiency

- Minimizing the cost of stabilizing the rate of climate change is a classic stock pollutant problem.
  - Efficient prices are not constant.
  - They rise steadily until they either hit a backstop or a steady-state concentration.

GHG price in year t = GHG price in the previous year X (1 + rate of interest + removal rate from the atmosphere)

e.g. For CO_2 the price would rise at the interest rate, say 4%/y + the average removal rate from the atmosphere, approximately 1%/y or 5%/y

- i.e. the price should double every 15 years.

Inter-temporal economic efficiency

- CO_2
  - Interest rate = ~4%/y
  - Removal rate = ~1%/y
  - Rate of price escalation = 5%/y
  - Price doubles every 15 years.
- CH_4
  - Interest rate = ~4%/y
  - Removal rate = ~11%/y
  - Rate of price escalation = 15%/y
  - Price doubles every 5 years.

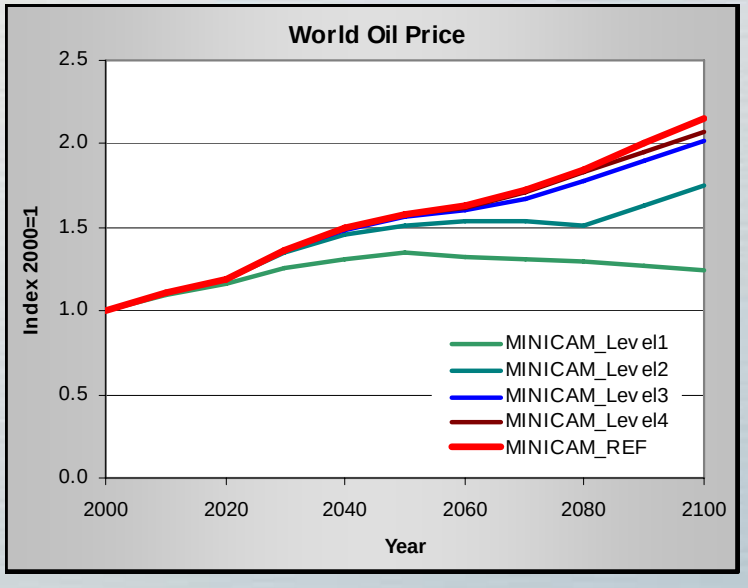
This is very different from using GWPs!

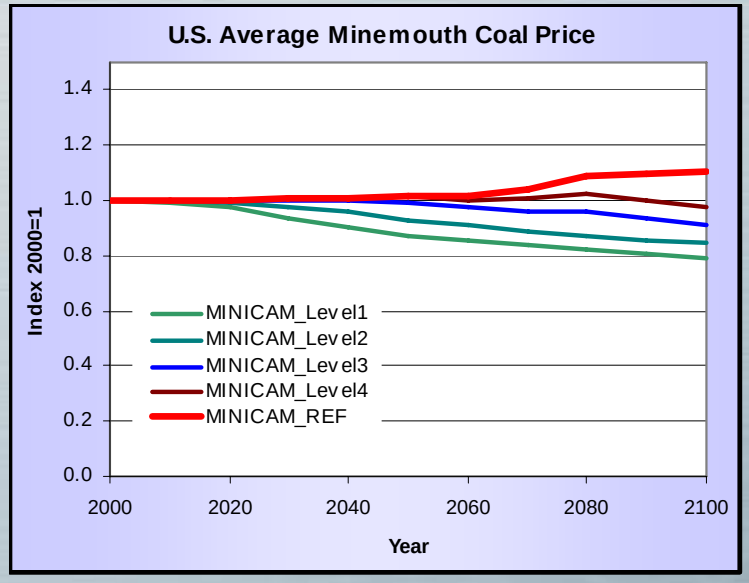
Inter-temporal economic efficiency

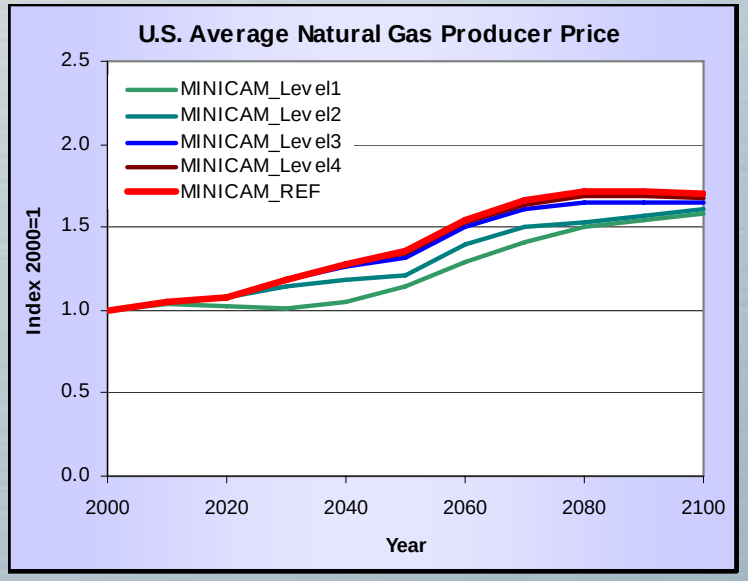
- When the GHG concentrations reach their steady-state concentrations, then GHG prices are determined by the removal rate from the atmosphere.
  - The atmospheric removal rate determines allowable emissions from that point forward.

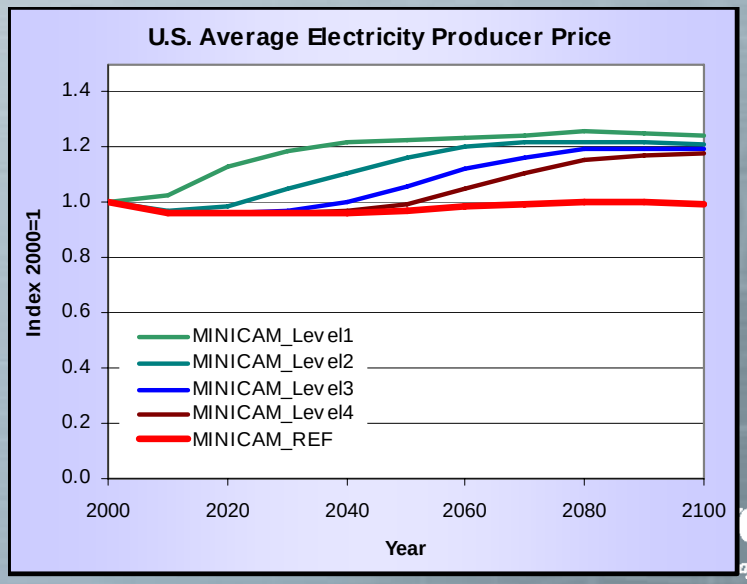
- If the rate of change matters then the rates of rise and initial values can be changed dramatically.

Effect of carbon price on producer prices







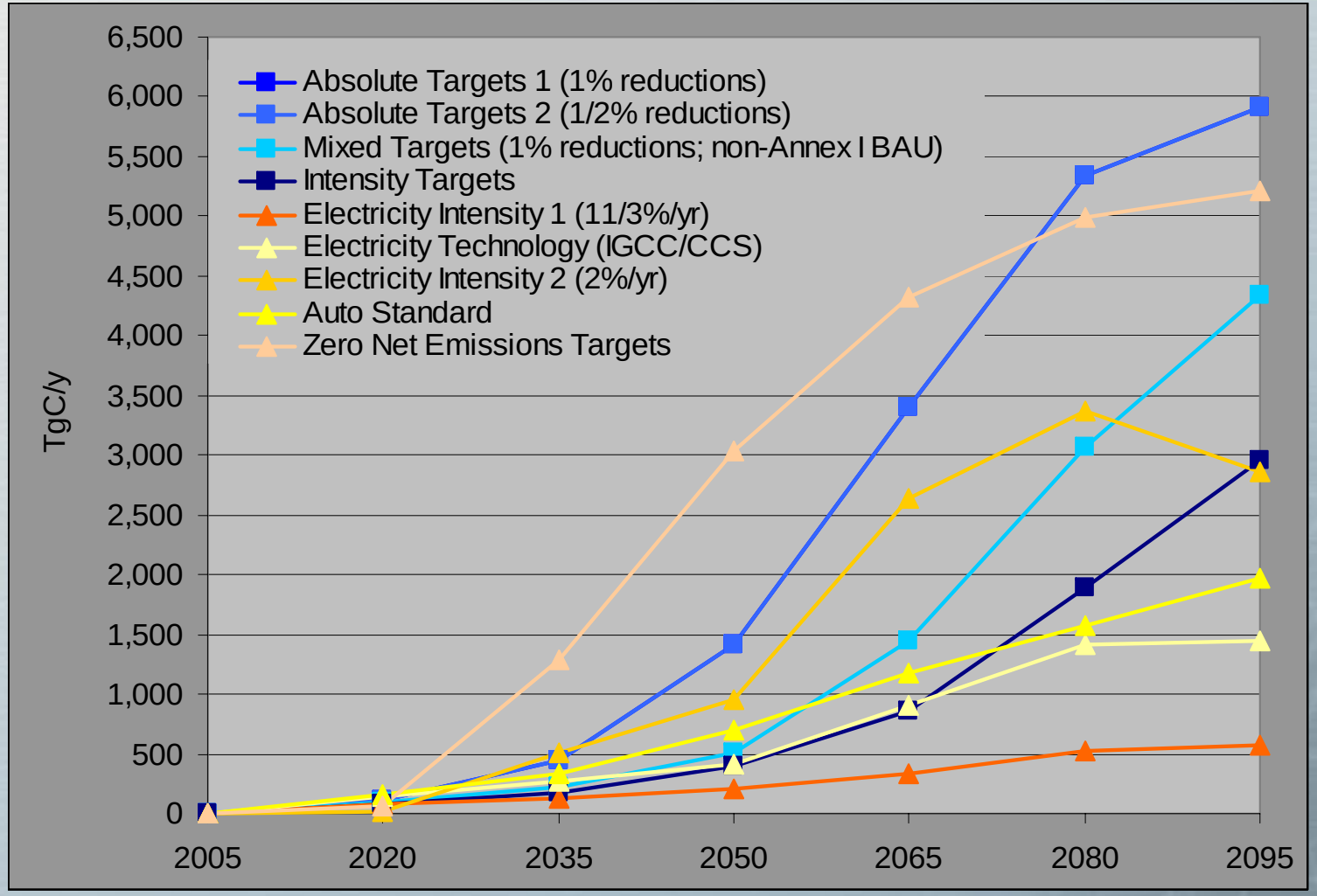


Effect on consumers

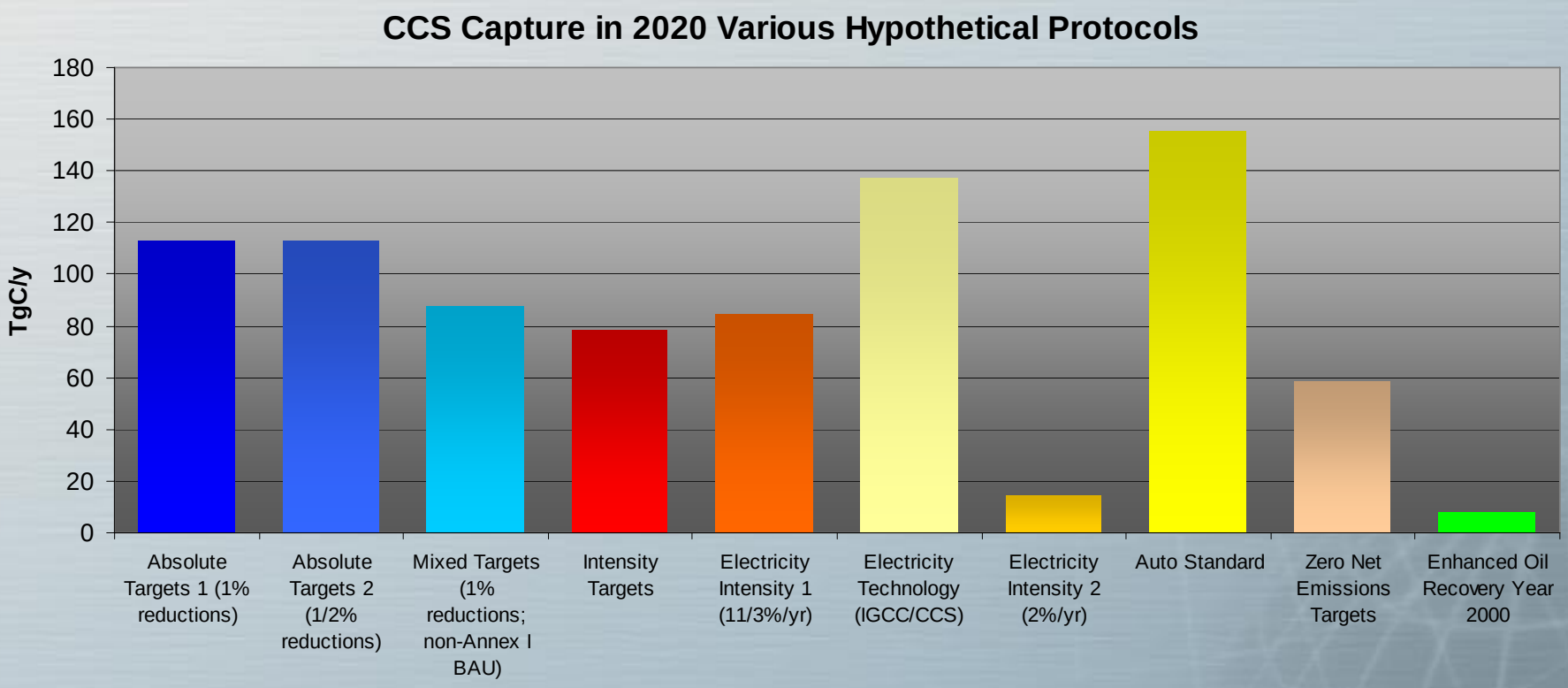
Impact of $100/tonne C on fuel prices

Fuel	Added Cost ($)
Crude Oil ($/bbl)	**$12.19**
Gasoline ($/gal)	**$0.26**
Heating Oil ($/gal)	**$0.29**
Wellhead Natural Gas ($/tcf)	**$1.49**
Residential Natural Gas ($/tcf)	**$1.50**
Minemouth Coal ($/short ton)	**$55.33**
Utility Coal ($/short ton)	**$55.33**
Electricity (c/kWh)	**1.76**

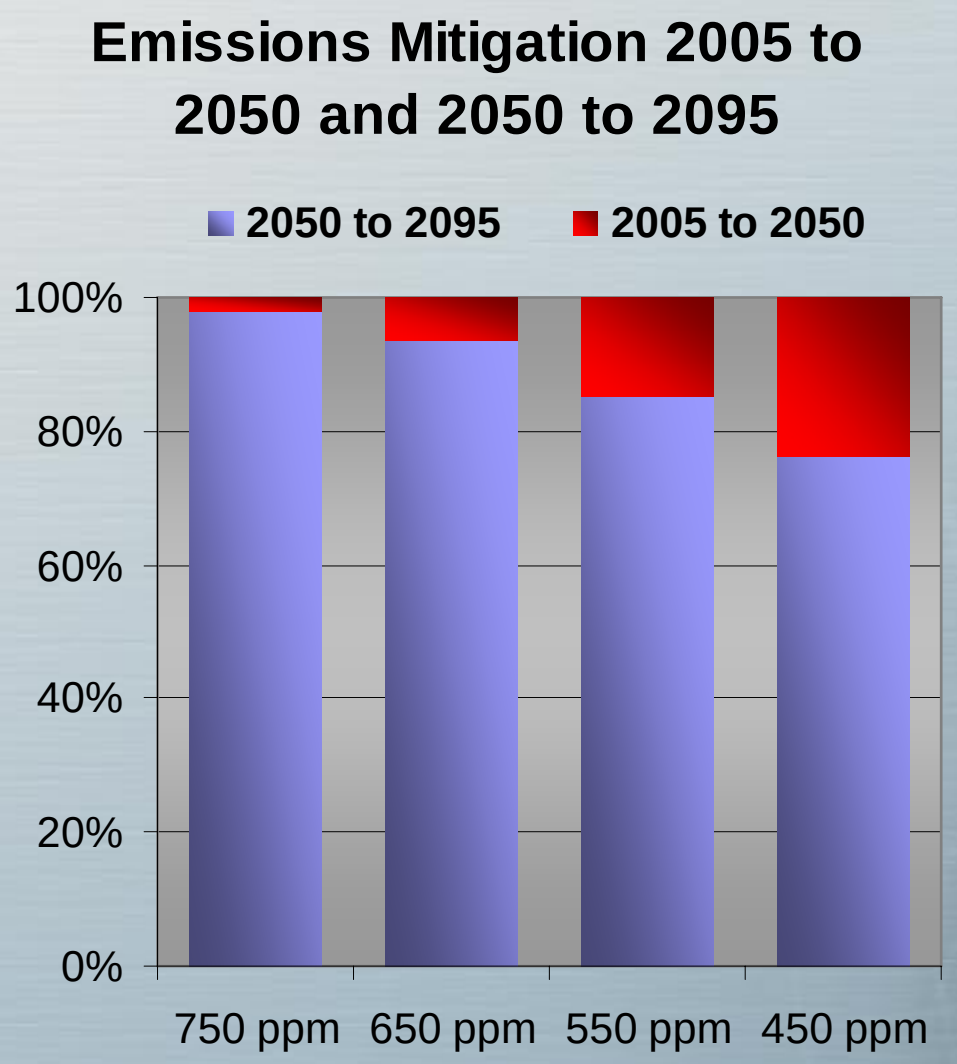
Pocantico Process



Pocantico CCS Capture in 2020



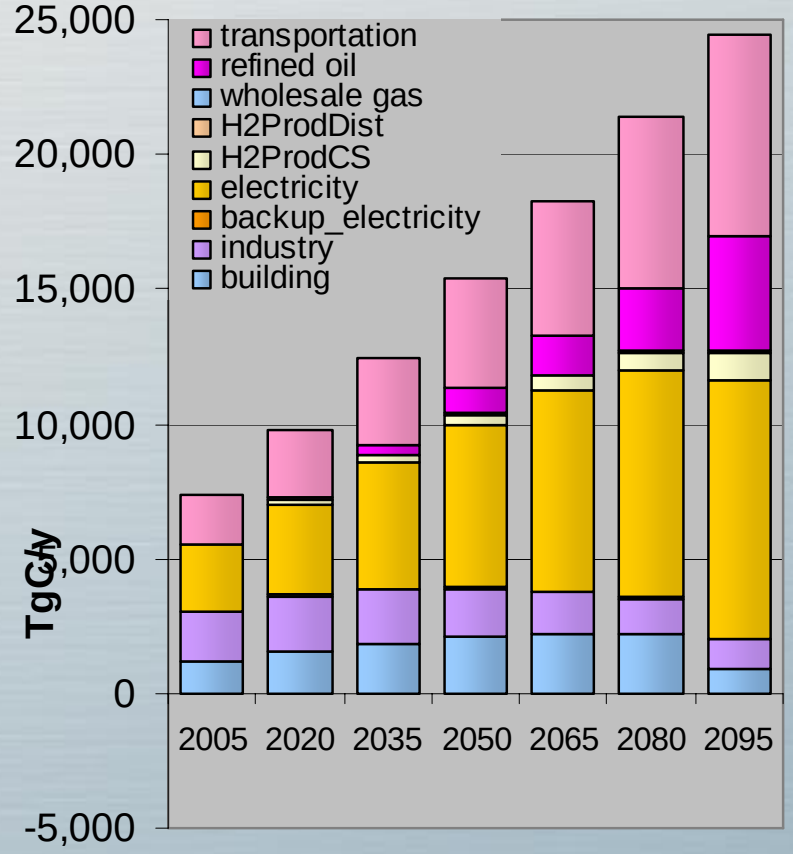
CO_2 emissions mitigation during 2005 to 2050 is just the start



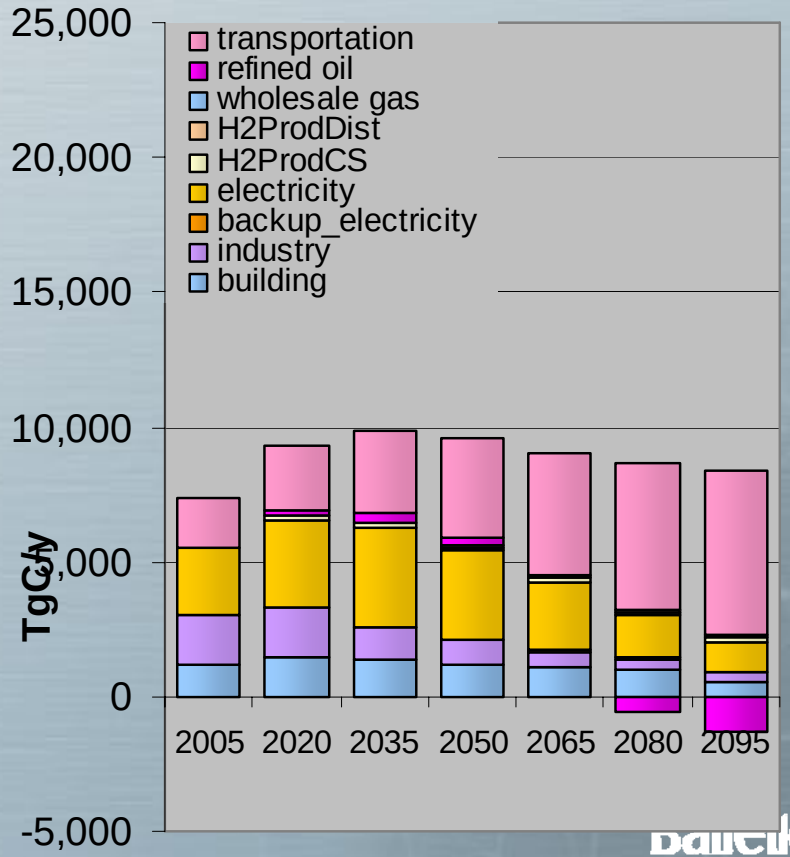
CO_2 Emissions—Global

Stabilization changes the sources of CO_2 emissions. Utility emissions drop to virtually zero. Transportation emissions dominate. CCS technologies enable net refining emissions to go negative.

Reference



4.7 W/m2 (~550 ppm CO_2)



The energy system—Global
4.7 W/m^2 (~550 ppm CO_2)

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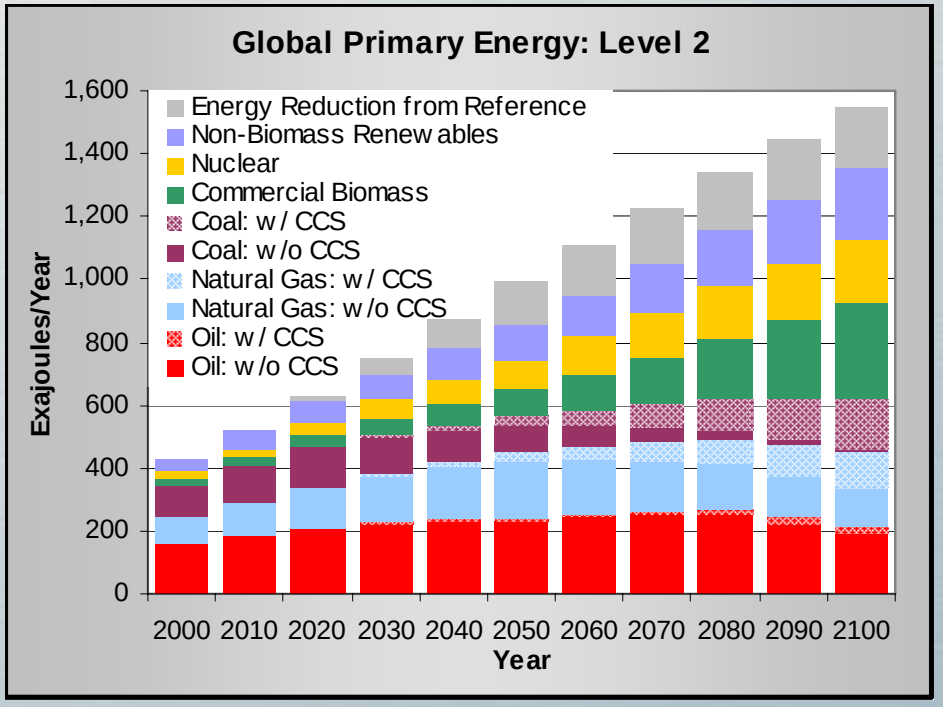
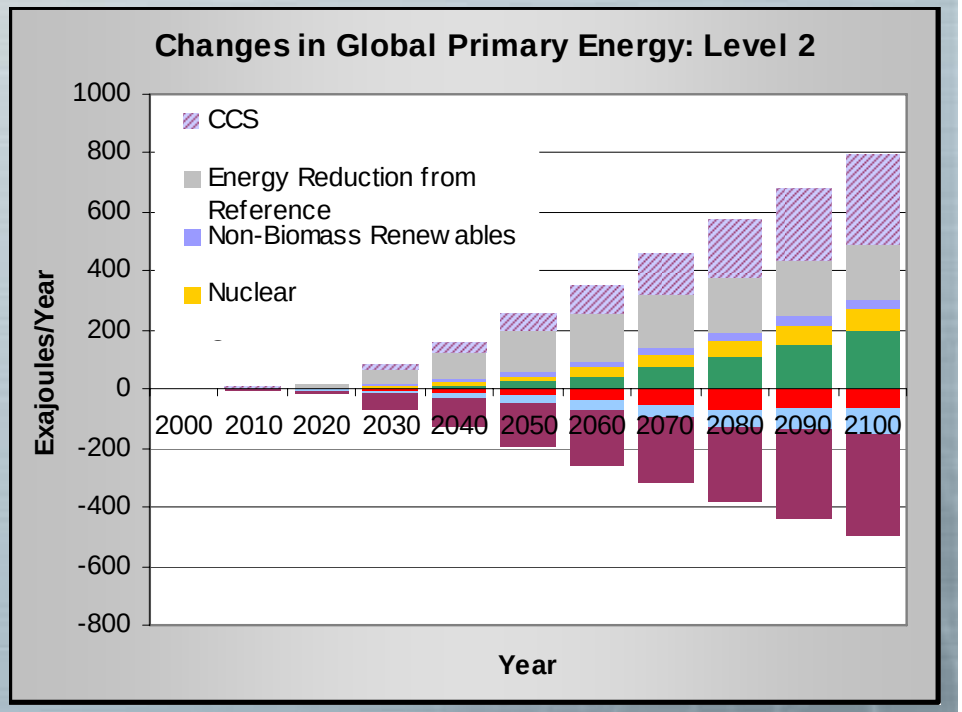
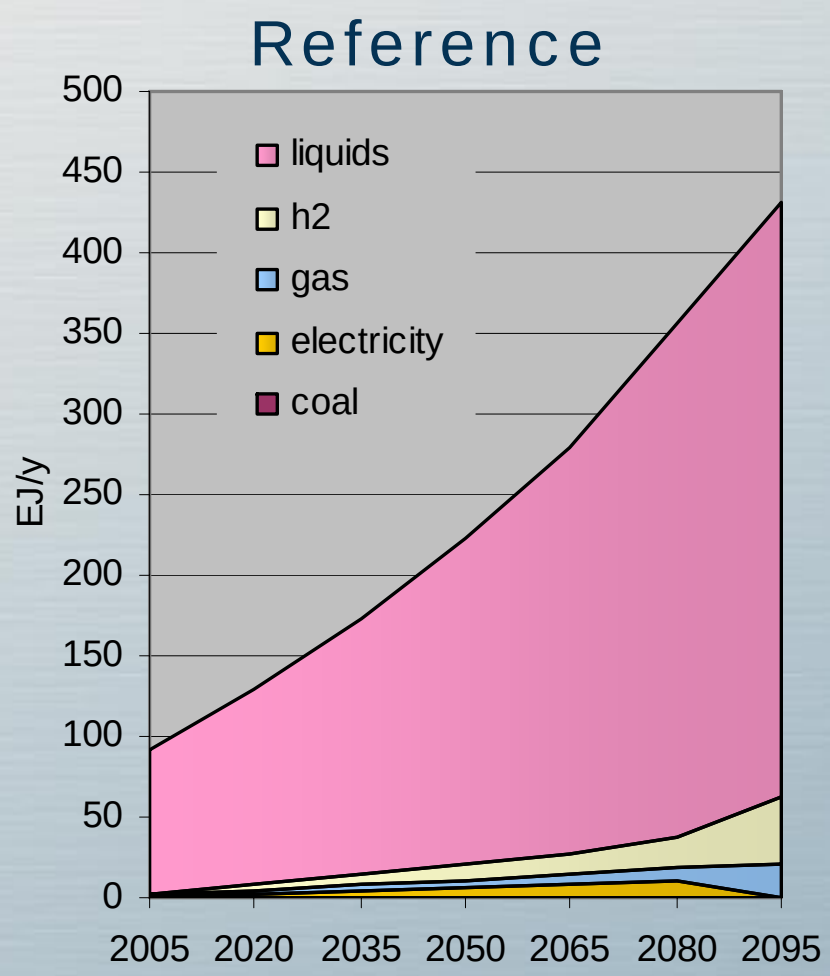


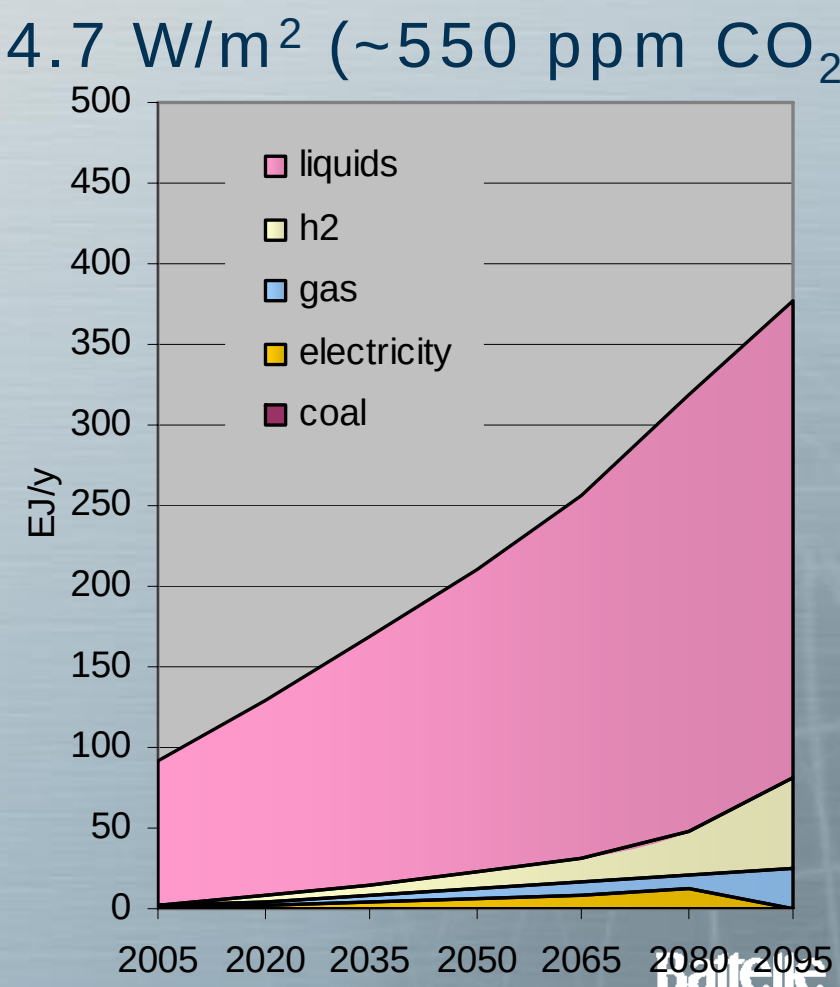
Change relative to reference



Transport Energy Use—Global

Remains dominated by liquid fuels, but ...

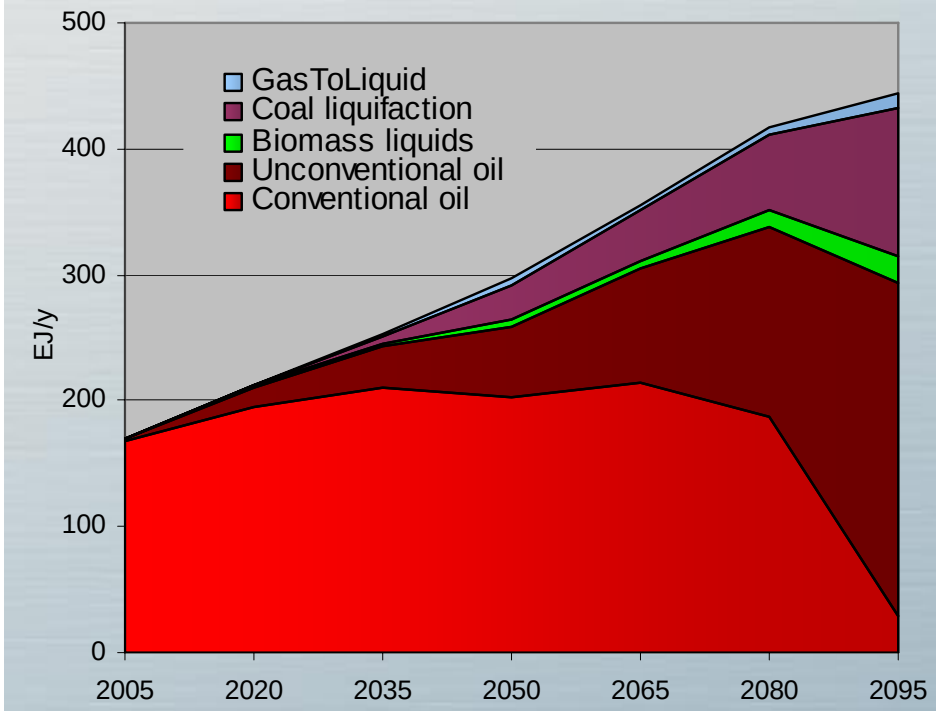




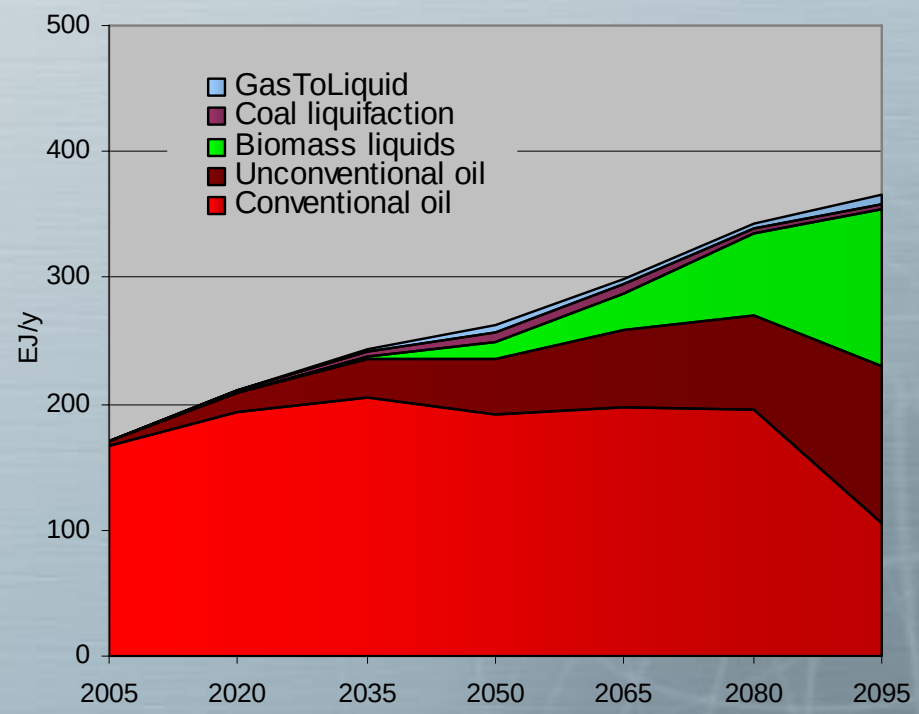
Oil Supply—Global

Stabilization extends the life of conventional oil, reduces shale oil production, eliminates coal liquefaction and promotes bioenergy.

Reference

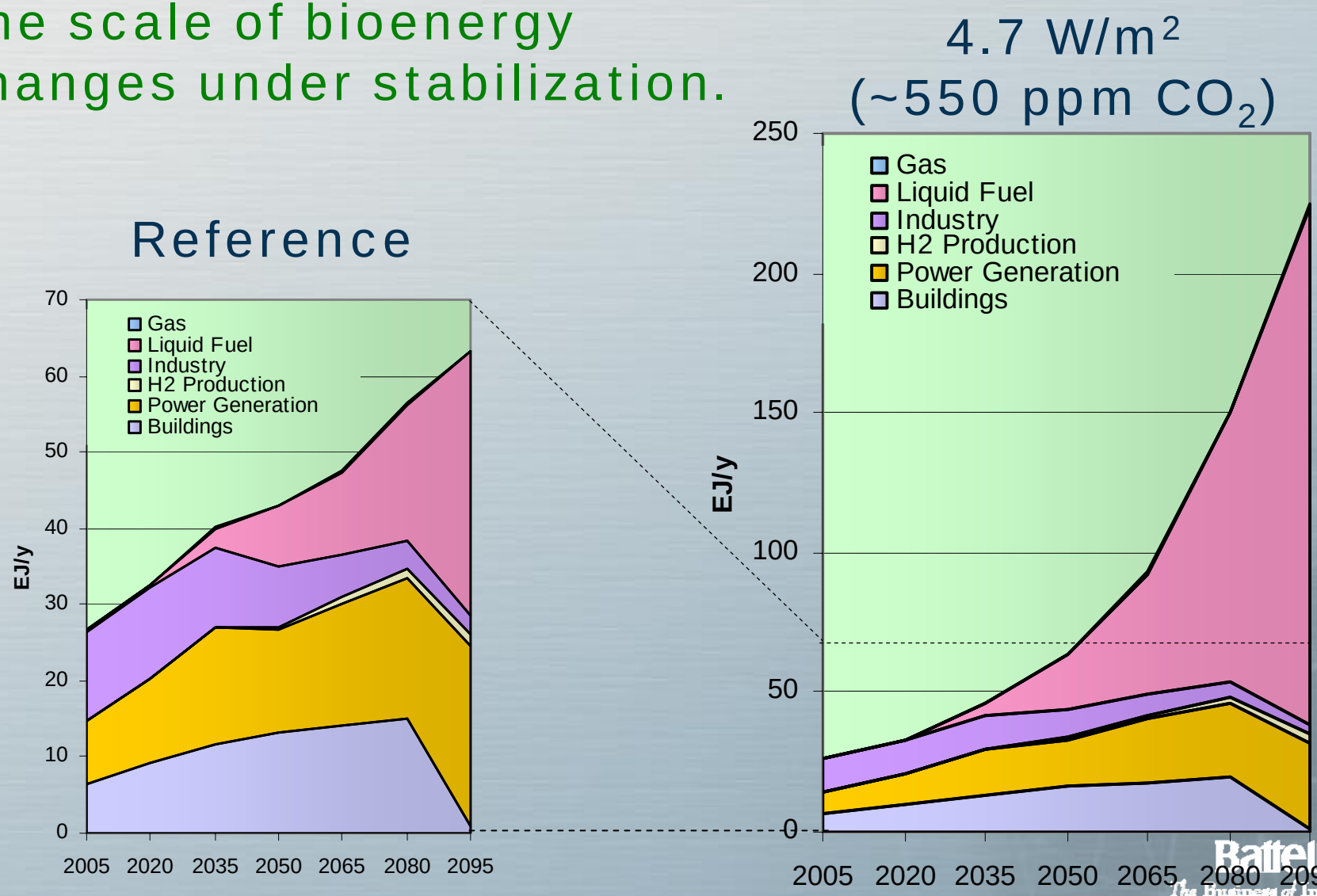


4.7 W/m^2 (~550 ppm CO_2)

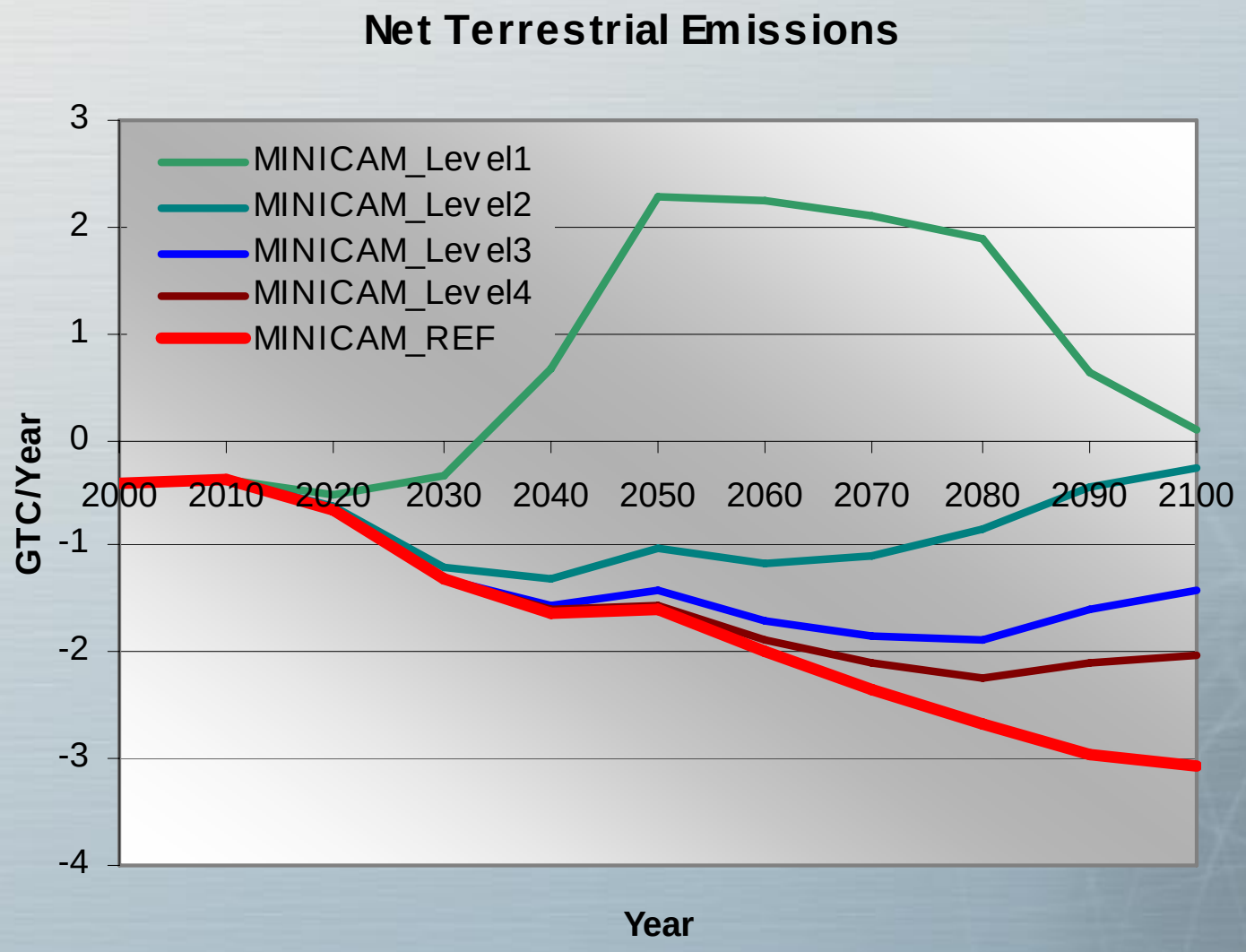


Bioenergy Consumption—Global

The scale of bioenergy changes under stabilization.



Implications for agriculture & land use

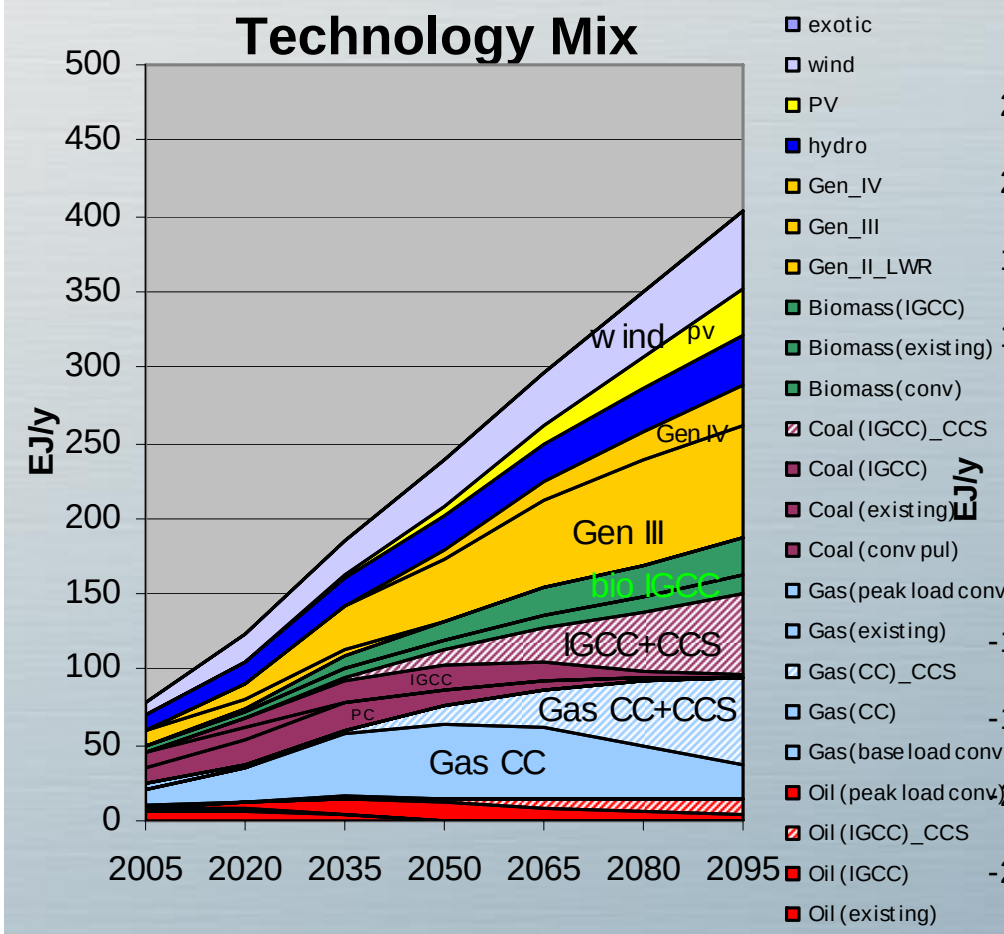


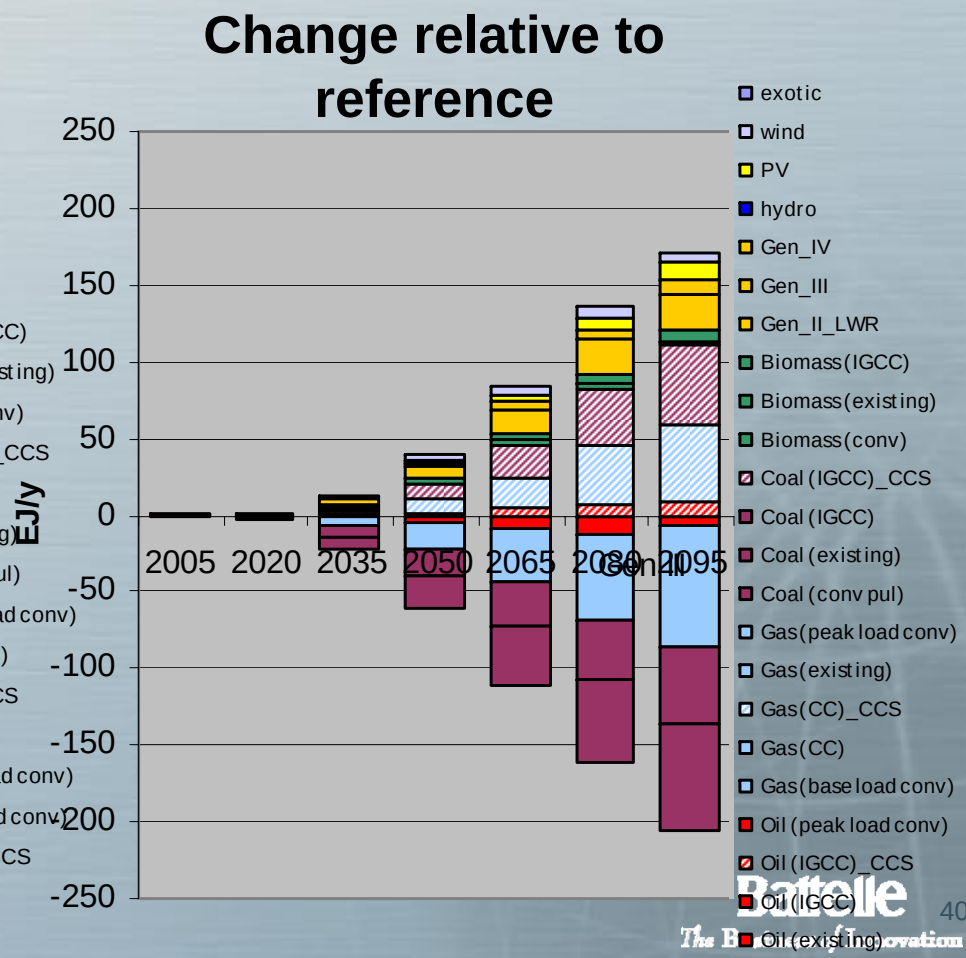
Implications for policy

- Land-use change emissions are accelerated by the imposition of a limit on fossil fuel CO_2.
- **The reason is that terrestrial carbon is not valued!**
- The implication for policy is that terrestrial carbon needs to be valued just as much as fossil fuel carbon.

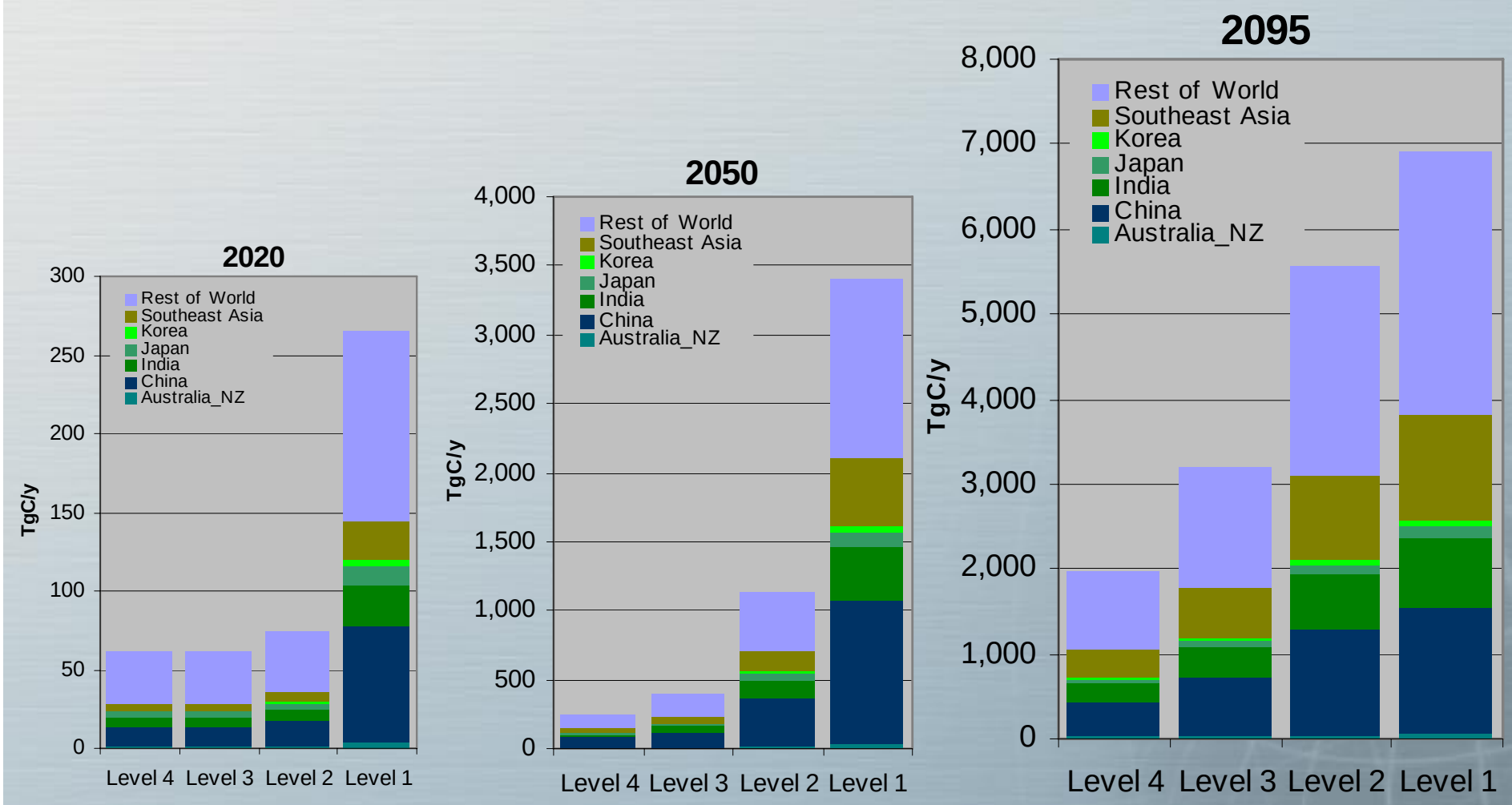
Electric power—Level 2 Global 4.7 W/m^2 (~550 ppm CO_2)

Non-emitting technologies expand market share and fossil generation deploys CCS.

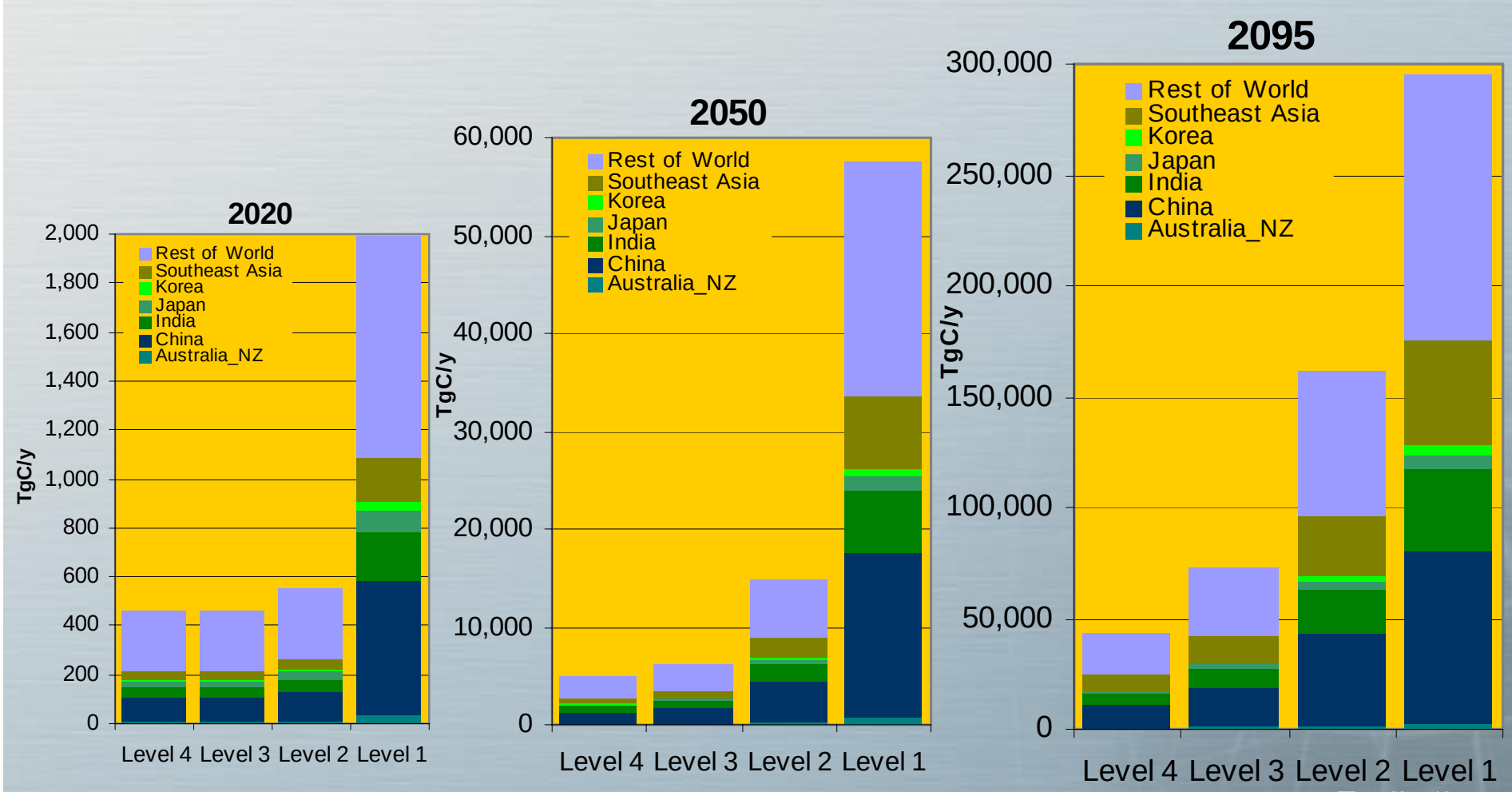




Annual CO_2 Capture and Storage

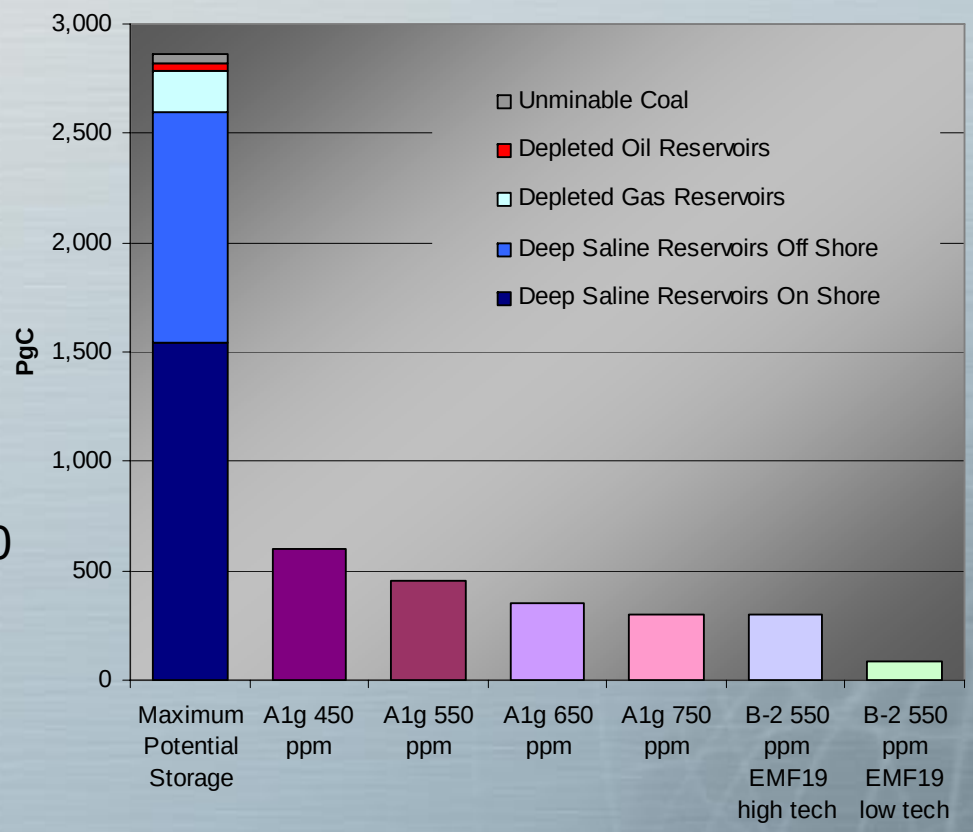


Cumulative CO_2 Capture and Storage



Projection of CO_2 Storage Demand *Global 2000-2100*

- For stabilization scenarios from 450-750ppmv, most integrated assessment models show a demand for no more than 600 GtC (2,220 $GtCO_2$) storage over the course of this century.
- Published estimates of potential storage capacity place the potential global geologic CO_2 storage capacity at approximately 3,000 GtC (11,000 $GtCO_2$).
- A broad portfolio of carbon management technologies will be needed to fulfill the UNFCCC stabilization goal.



Summary

- New scenarios of energy, economy, and greenhouse gas emissions have been developed using the PNNL MiniCAM.
  - Higher transportation demands
  - Higher fossil fuel demands
  - Higher CO_2 emissions (2095 ~27 PgC/y)
  - Lower CH_4 emissions (2095 ~250 Tg/y)
- New stabilization scenarios based on radiative forcing
- Implications for energy technology and the economy
  - Dramatic changes are ultimately required in all sectors of the economy
  - Changes need to begin in the near term to meet any stabilization goals, and are more dramatic for stringent scenarios.

GTSP
Global Energy Technology Strategy Program

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