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Technology and Stabilization

Workshop on GHG Stabilization Scenarios

Jae Edmonds

22 January 2004

National Institutes for Environmental Studies

Tsukuba, Japan

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Dedicated to the Memory of Tsuneyuki Morita

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Key Question for Today

- What are the energy technology implications of stabilizing climate—not just CO_2 concentrations?
  - Interactions with uncertainty in biogeochemical parameterization;
  - Interactions with uncertainty in technology developments.

- Inspired by the work of Richels, Manne and Wigley.

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APPROACH

- Background—MiniCAM
- A Reference Case—MiniCAM B2
- Stabilize mean global temperature change to 2°C (relative to pre-industrial) at minimum cost.
- Sensitivities
  - Physical science uncertainties
    - Climate sensitivity
    - Ocean diffusivity
    - Terrestrial carbon uptake
  - Energy technology uncertainties
    - CO_2 capture and storage
    - H_2 systems
    - Biotechnology

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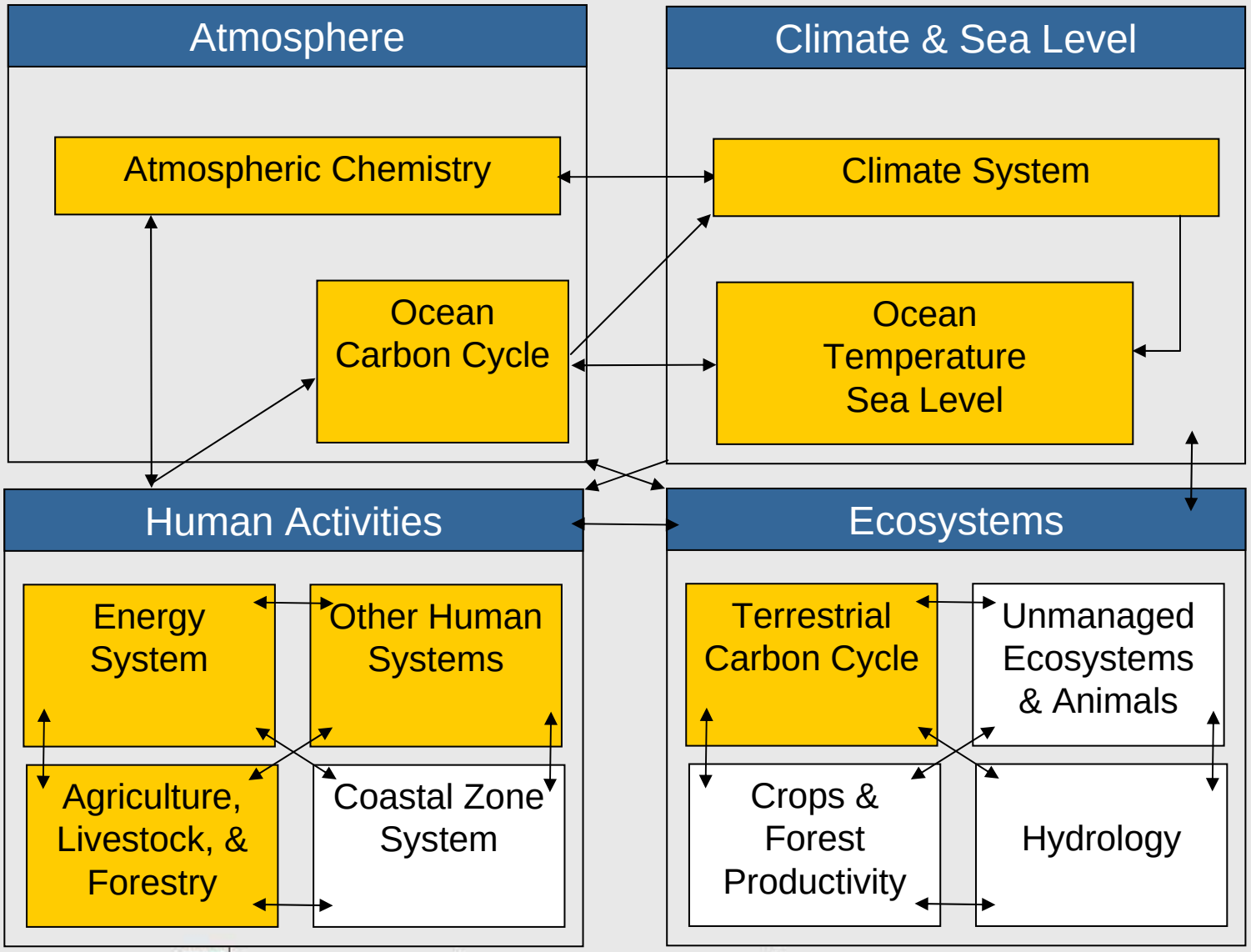
MiniCAM



The MiniCAM

KEY CHARACTERISTICS

- Energy-Agriculture-Economy Market Equilibrium
- 17 Global Regions
- 15-year time steps
- Multiple Greenhouse Gases
- Internally Generated Demographics
- Land Resource Constraints
- **69 Energy Technology Options**

The MiniCAM KEY CHARACTERISTICS

15 Greenhouse Related Gases Tracked

- **Carbon Dioxide**
- **Methane**
  - 15 Source Sectors
  - Energy, Human Wastes, Agriculture, Land-Use
- **Nitrous Oxide**
  - 12 Source Sectors
  - Energy, Human, Industrial, Agriculture, Land-Use
- **Halocarbons, etc.**
  - 15 Source Sectors (7 gases)
- **Reactive Gases**
  - NOx, VOC, CO
- **Sulfur Dioxide**
- **Carbonaceous Aerosols**
  - Black Carbon & Organic Carbon
  - 19 Source Sectors each (Energy & Land-Use Combustion)

GHG concentrations and radiative forcing calculated using MAGICC (Wigley *et al.*)

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MiniCAM B2

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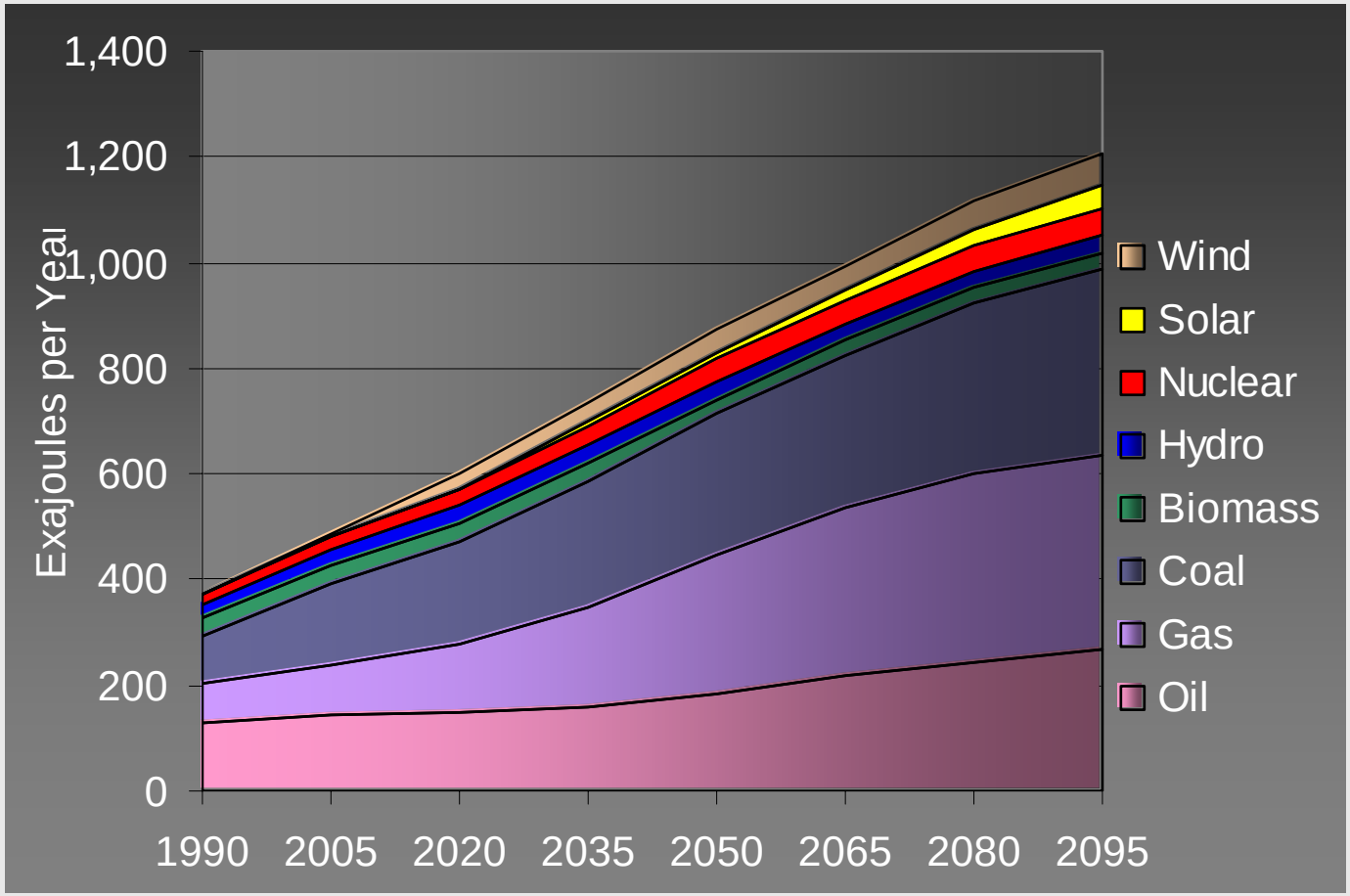
The Reference Primary Energy System
SRES MiniCAM B-2



B2 Greenhouse Gas Emissions, Concentrations, Temperature Rise &

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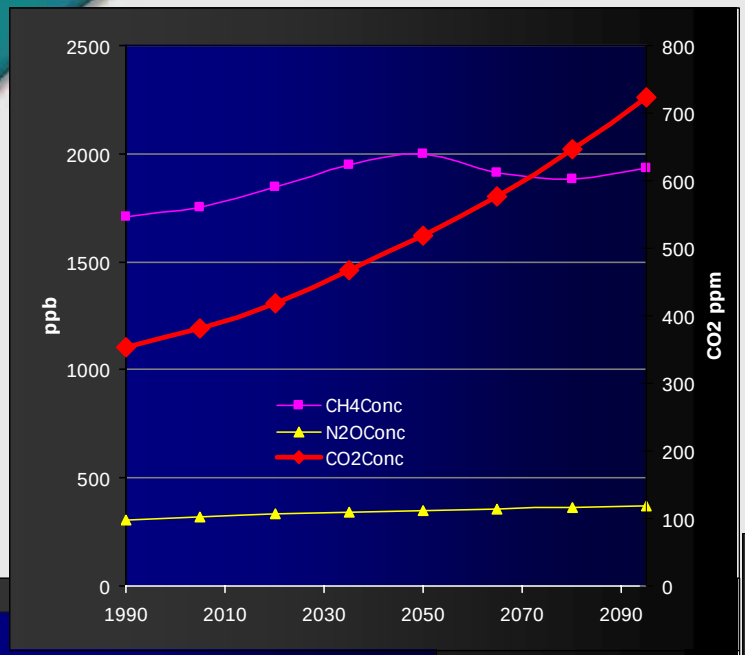
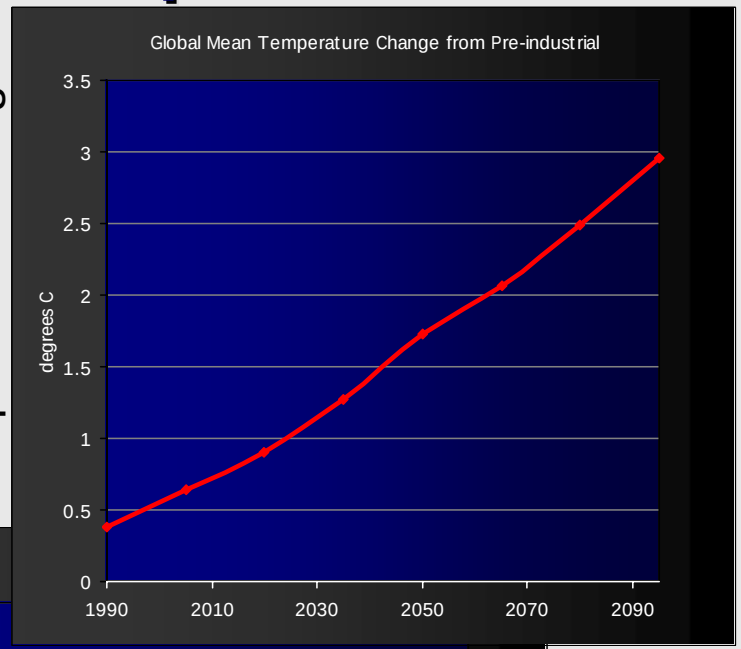
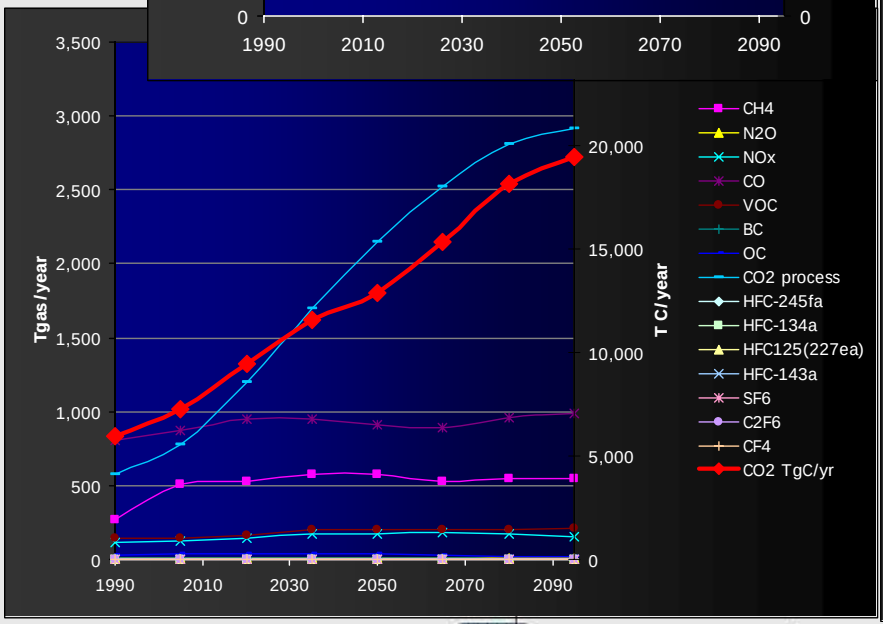
Concentrations



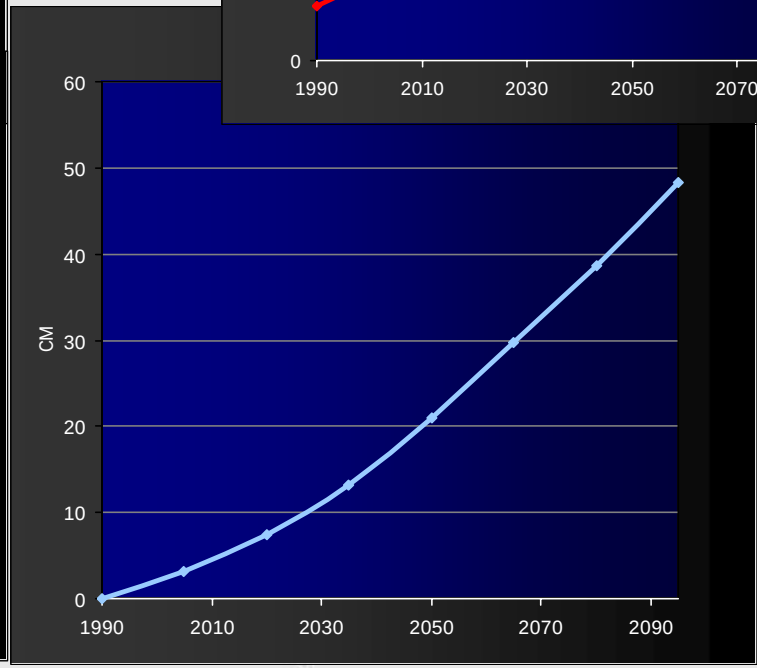
Global Mean Temperature Change



Emissions



Sea Level Rise



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Climate Stabilization

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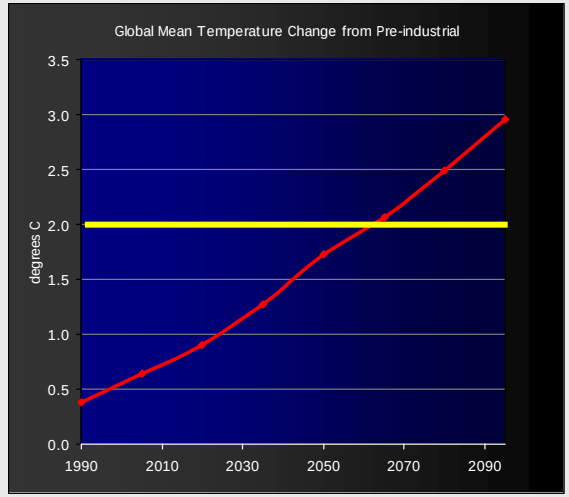
The Analysis

- Global Mean Temperature Change not to exceed 2°C.



- **This limit does NOT reflect a determination as to a change that avoids dangerous anthropogenic interference with the climate system.**
  - **Other values could equally well have been chosen.**
  - **Future work will explore other values.**

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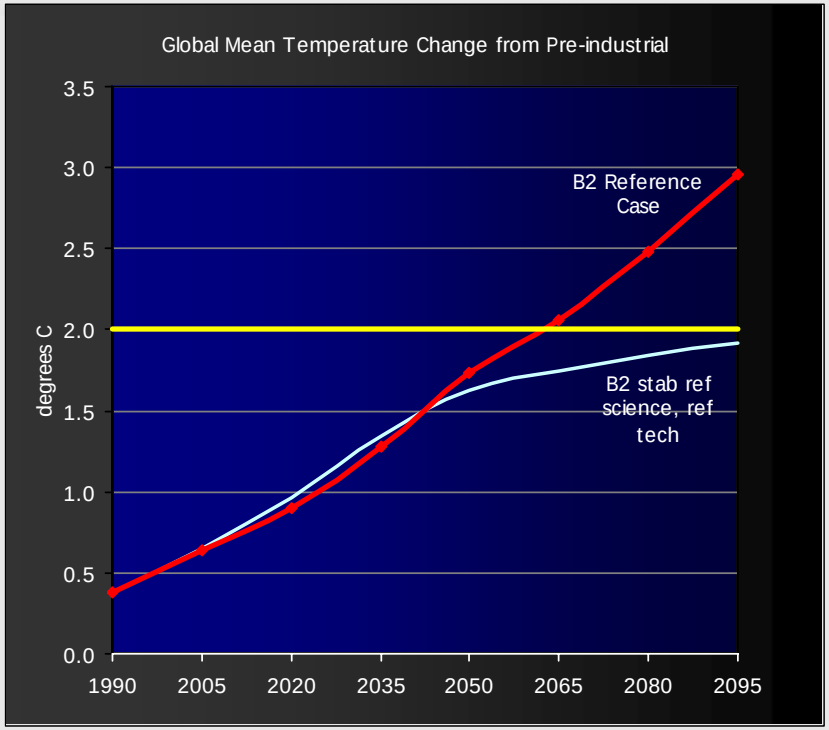
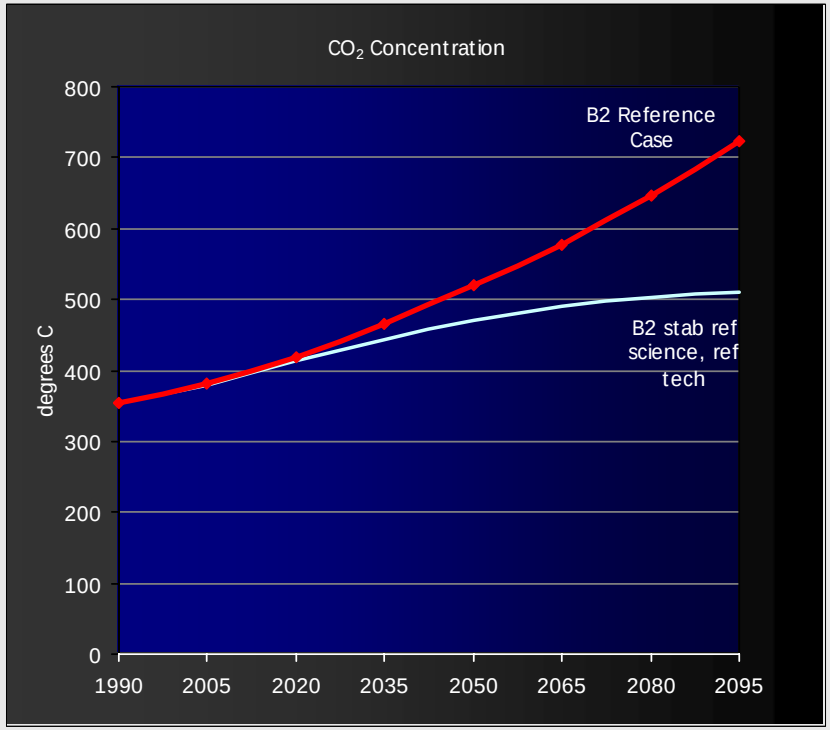
Approach

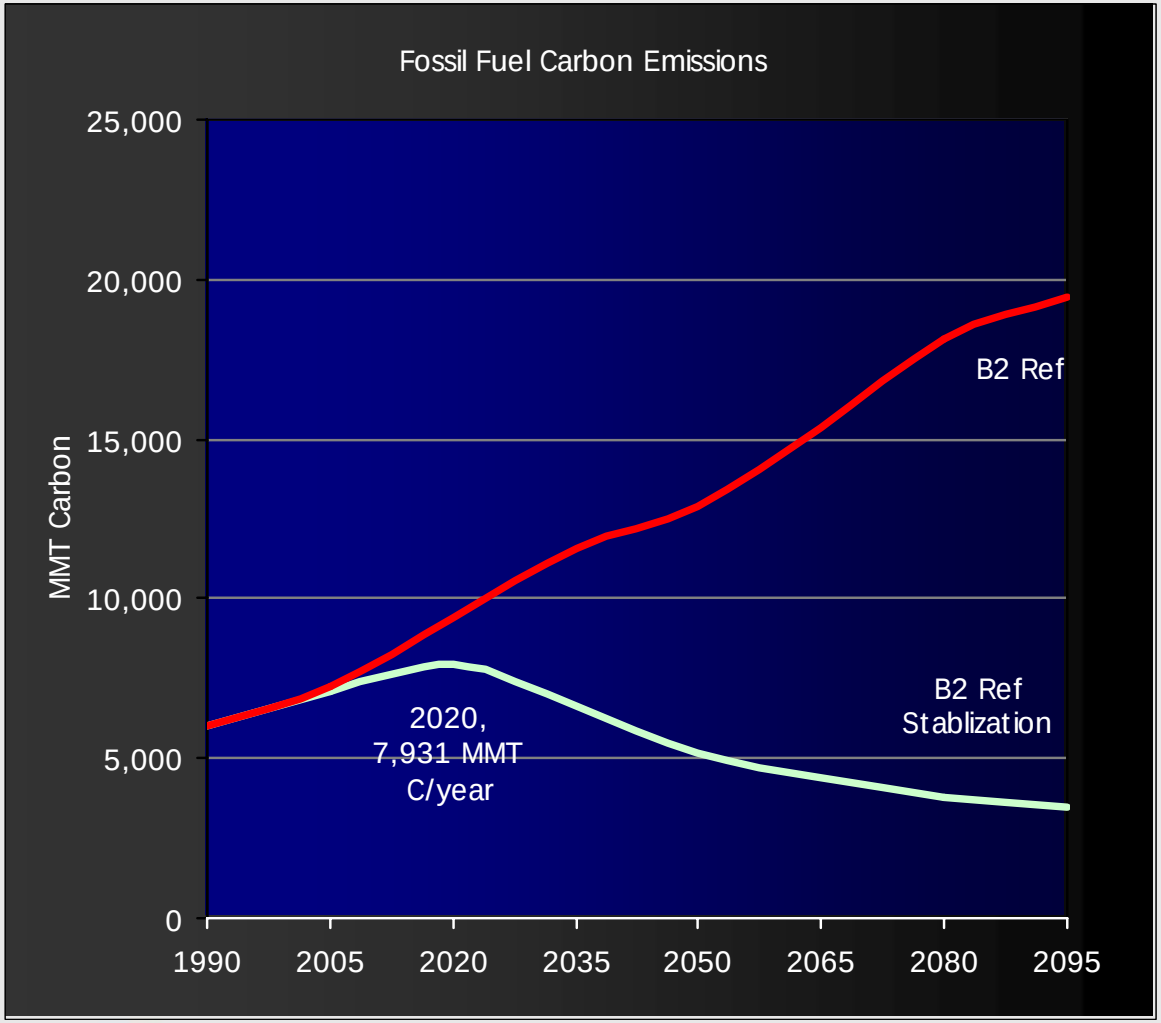
Minimize the cost of stabilizing climate change

Reference B2 and Stabilization with Reference Technology and Physical Parameters

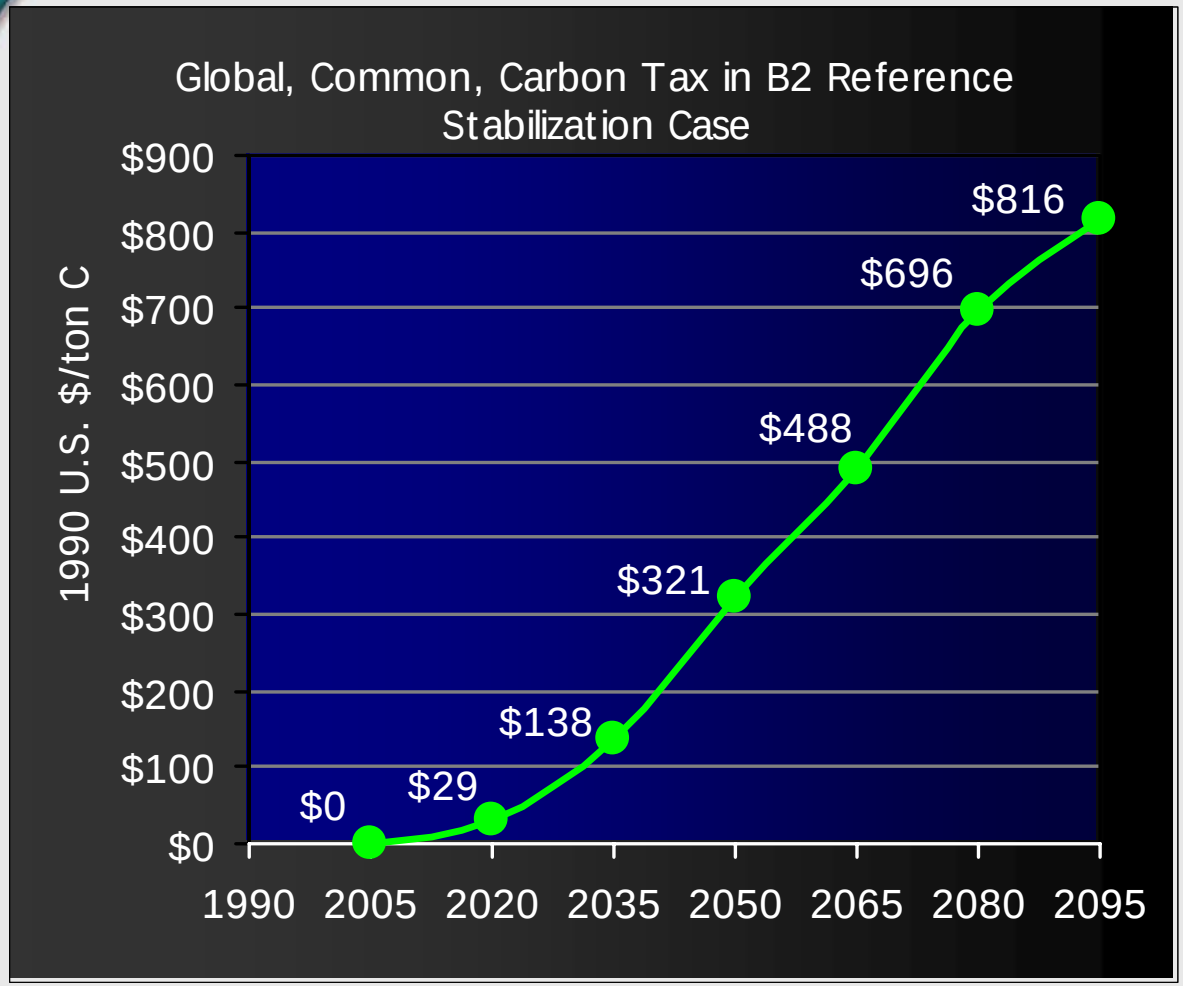




CO_2 Emissions



Carbon Tax and Total Cost
B2 Ref and B2 Ref with Stabilization



Present Discounted Cost

$4.625 trillion

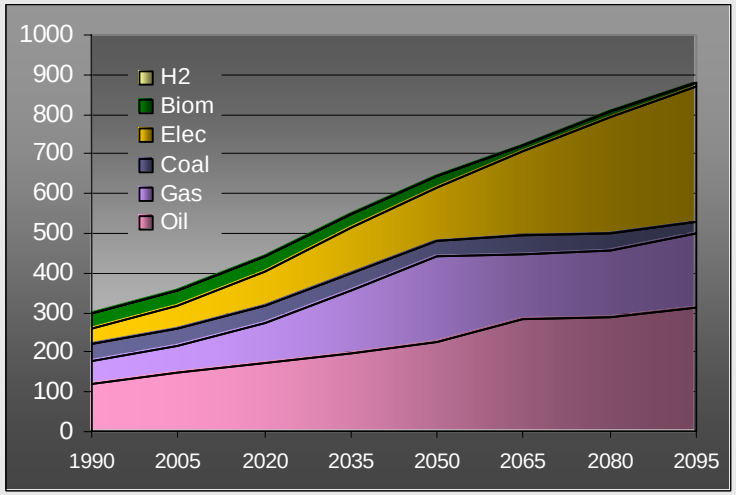
1990 U.S. dollars, discounted @ 5%/year, 1990 to 2095

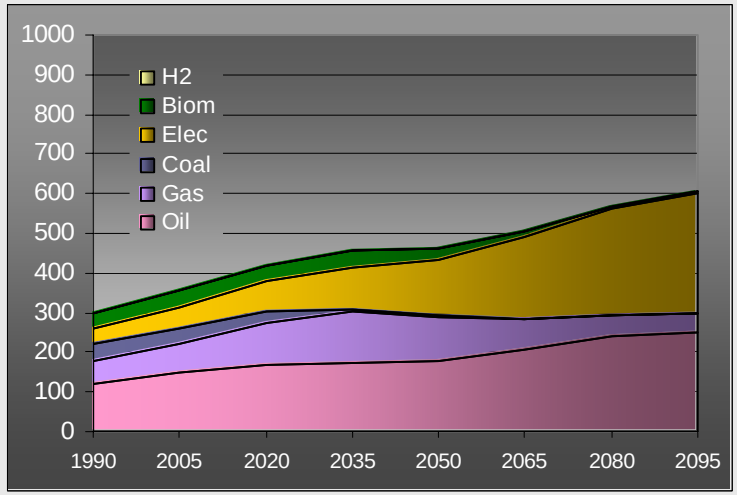
Energy and Stabilization

B2 Reference

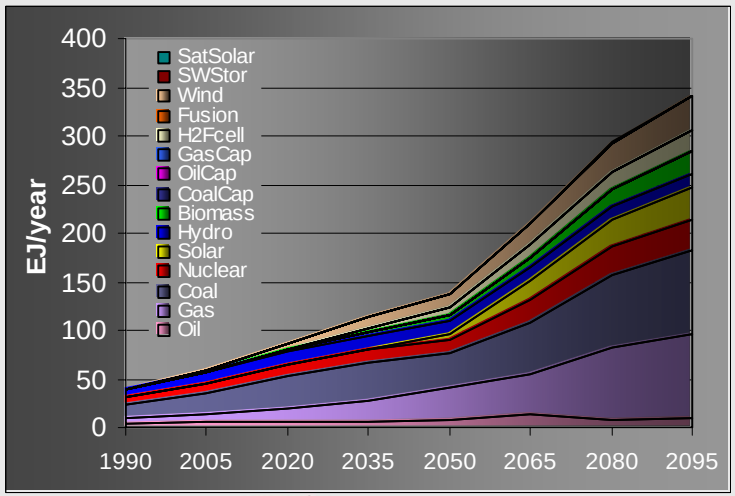
B2 Reference with Climate Stabilization

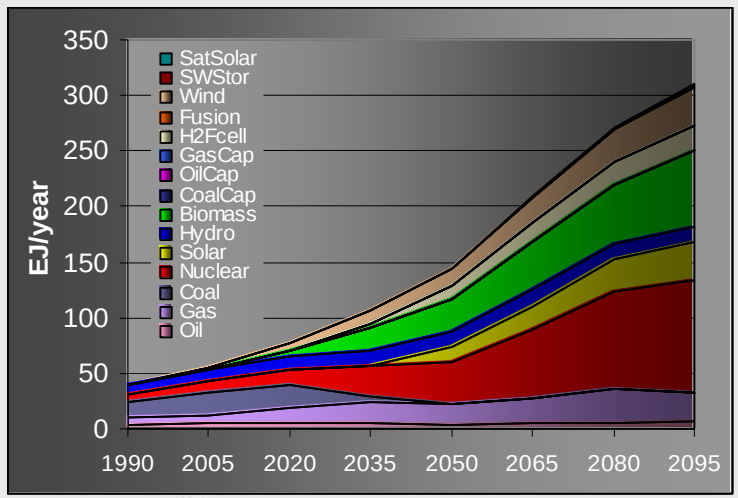
Final Energy



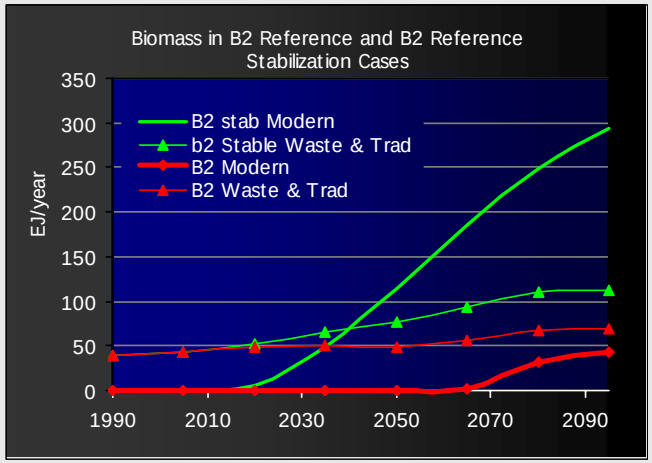


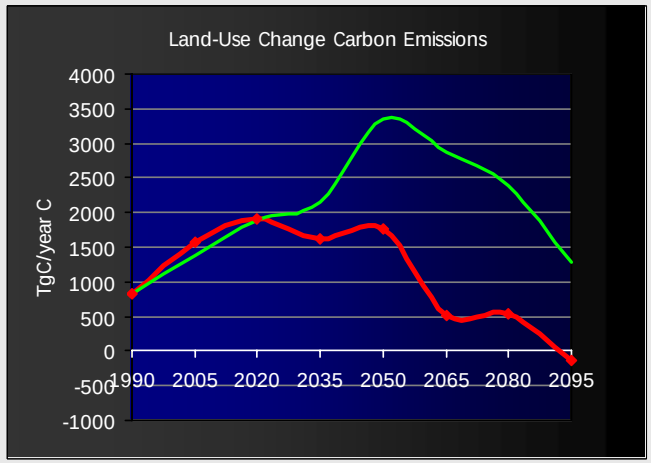
Electric Power

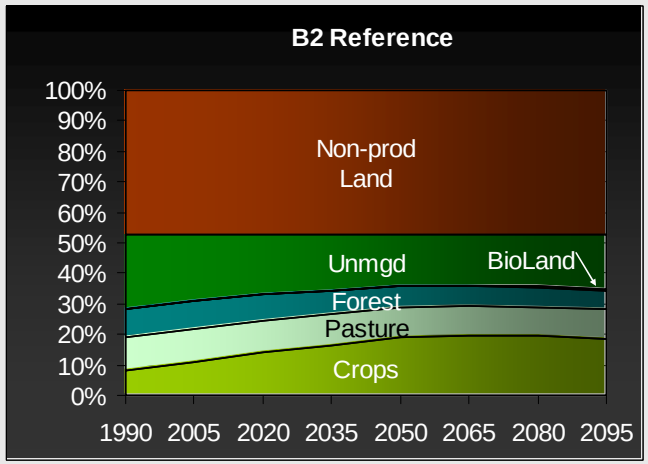


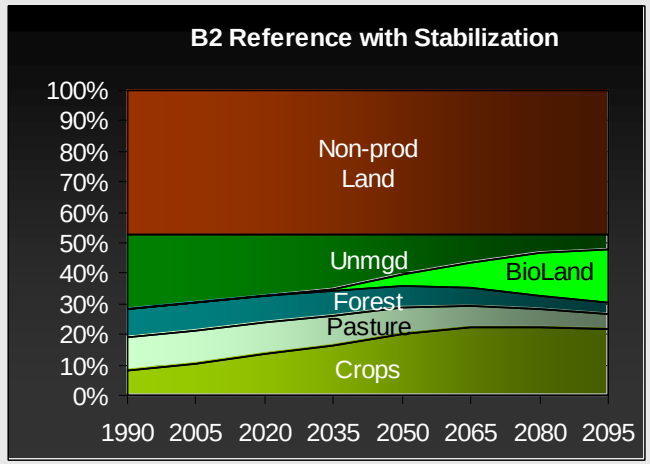


Biomass and Land-Use Change Emission









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Physical Parameter Uncertainty & Climate Stabilization

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Alternative Biogeophysical Parameterizations

SEVEN CASES
Reference
High Climate Sensitivity
High Ocean Diffusivity
High Carbon Uptake
Low Climate Sensitivity
Low Ocean Diffusivity
Low Carbon Uptake

High Climate Sensitivity	Low Value	Reference Value	High Value	Units
Climate Sensitivity	1.5	2.5	4.5	degrees C per CO_2 doubling
Ocean Diffusivity	1.0	2.3	3.3	cm^2/s
Carbon Uptake	low	mid	high	various

High Ocean Diffusivity	Low Value	Reference Value	High Value	Units
Climate Sensitivity	1.5	2.5	4.5	degrees C per CO_2 doubling
Ocean Diffusivity	1.0	2.3	3.3	cm^2/s
Carbon Uptake	low	mid	high	various

High Carbon Uptake	Low Value	Reference Value	High Value	Units
Climate Sensitivity	1.5	2.5	4.5	degrees C per CO_2 doubling
Ocean Diffusivity	1.0	2.3	3.3	cm^2/s
Carbon Uptake	low	mid	high	various

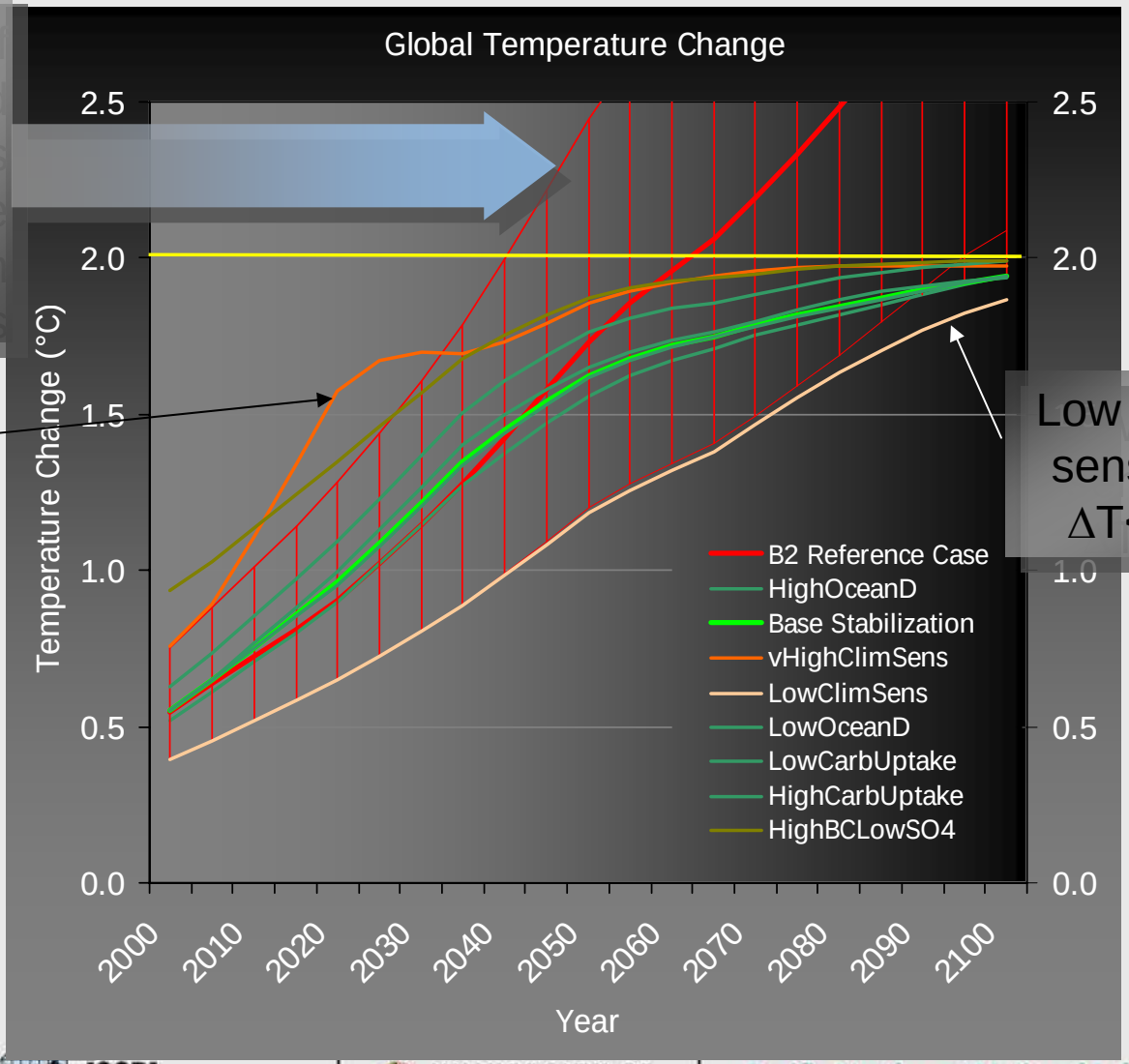
Each case uses the extreme value for one physical parameter and reference values for the others

Temperature, Stabilization, & Uncertainty in Biogeochemical Physical Parameters

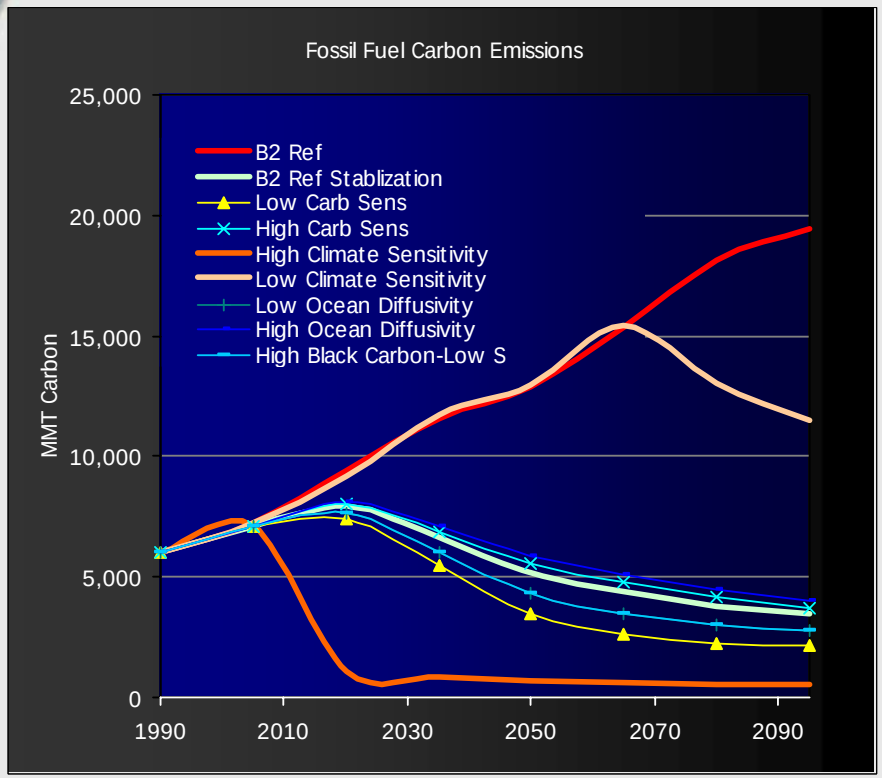
Range of unconstrained reference cases under alternative physical system parameterizations

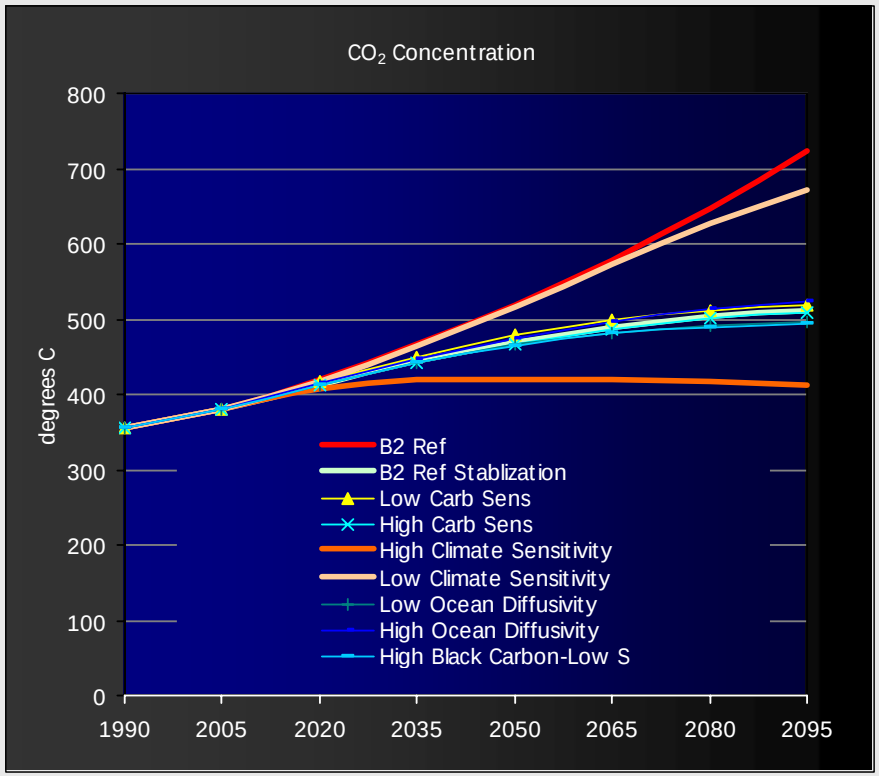
High climate sensitivity, ΔT< 2°C

Low climate sensitivity, ΔT< 2oC

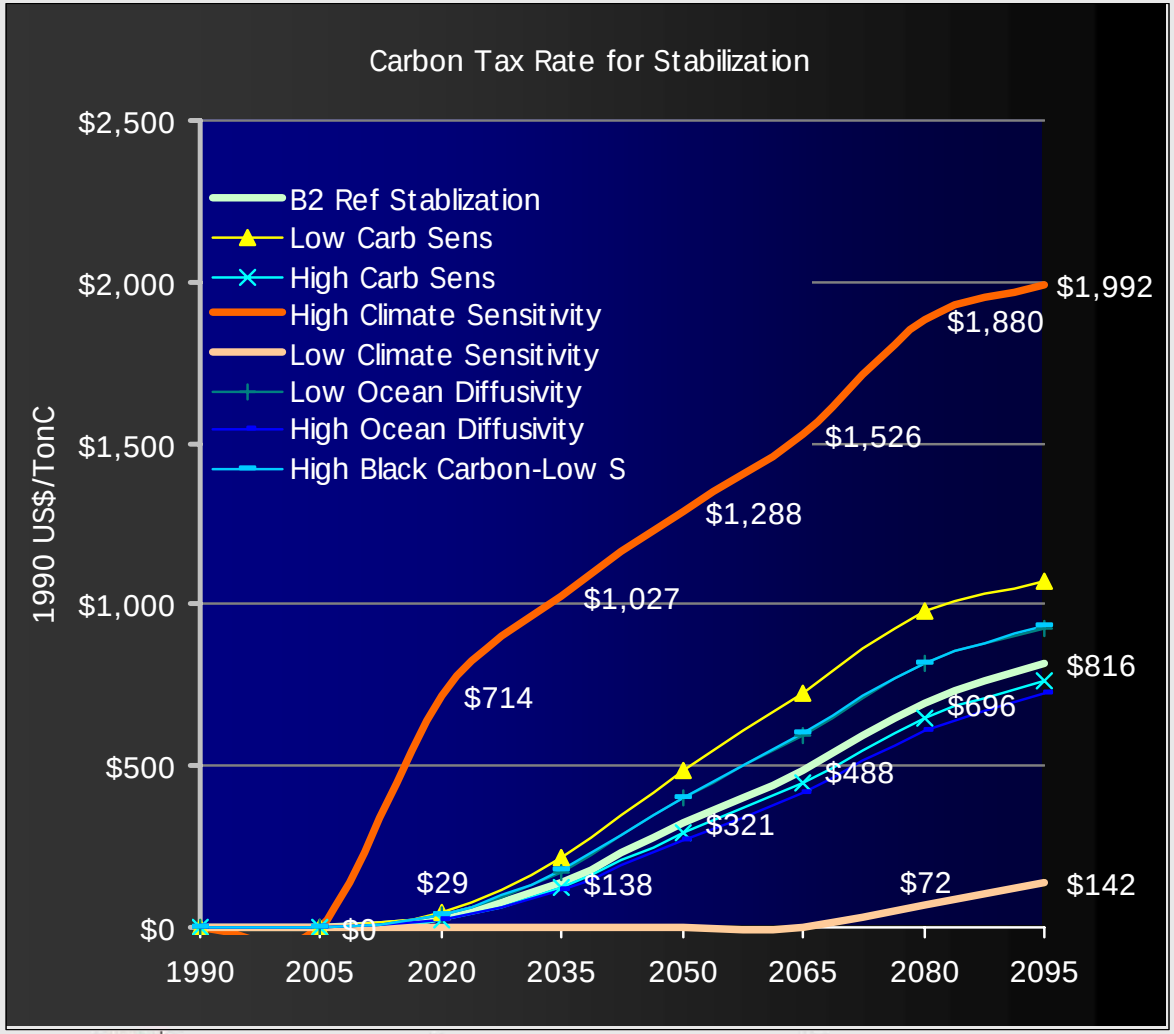


Carbon and GMT Change Stabilization

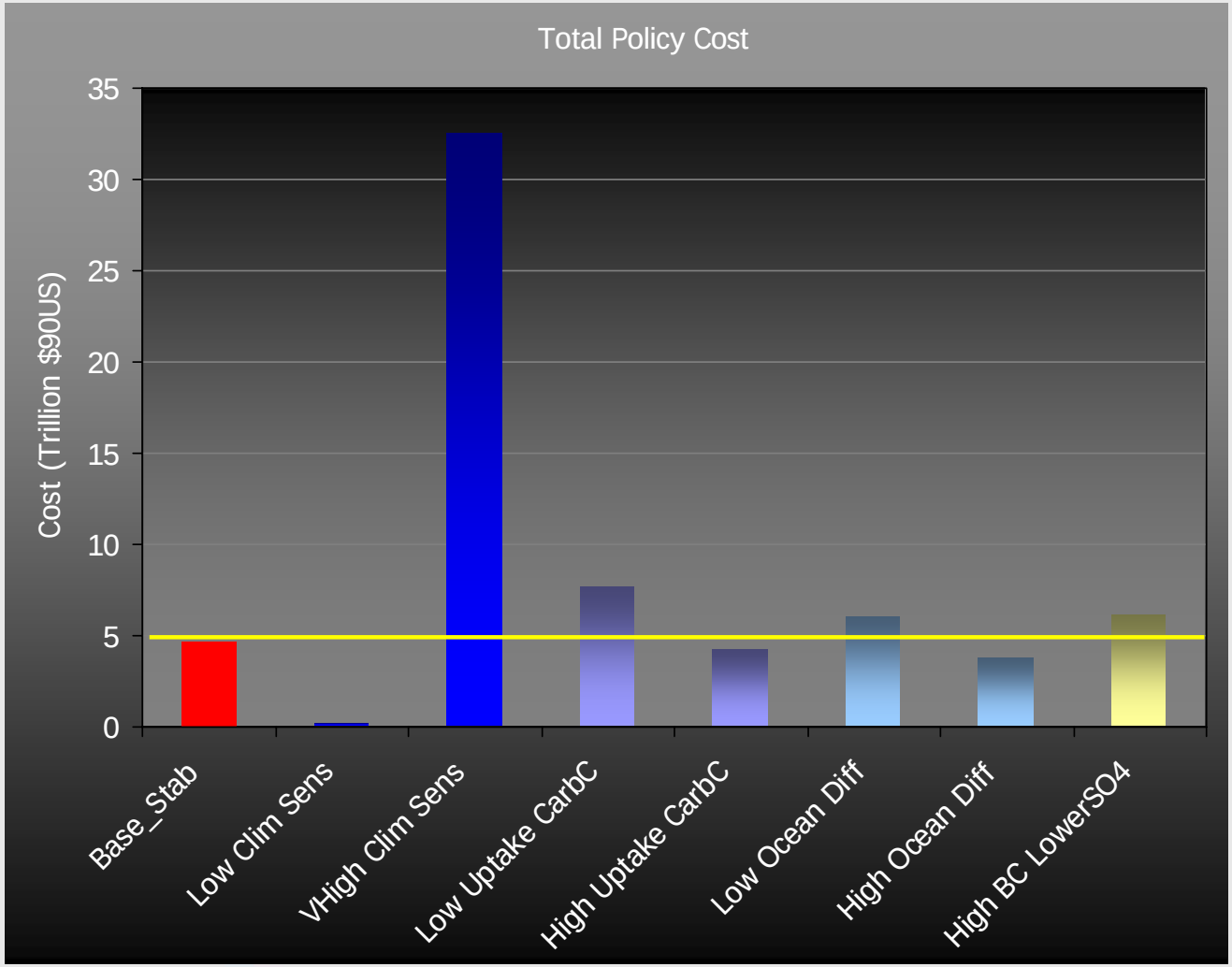




Biogeochemical Parameter Uncertainty and Cost



B2 Reference with Stabilization Alternative Biogeophysical Parameters



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Technology Availability & Climate Stabilization

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Technology Performance

	Units	1990	Ref 2095	Adv 2095
PRIMARY ENERGY SUPPLY				
Oil	1990 US$/gJ	$1.13	$7.55	$3.27
Gas	1990 US$/gJ	$1.40	$5.03	$3.40
Coal	1990 US$/gJ	$0.76	$1.42	$1.08
Biomass	1990 US$/gJ	$1.63	$1.95	$1.89
ELECTRIC POWER GENERATION	**(fuel + non-fuel cost)**			
Nuclear	1990 US cents/kWh	5.8	5.8	5.8
Solar	1990 US cents/kWh	61.0	6.0	6.0
Wind	1990 US cents/kWh	8.0	4.0	4.0
Gas	1990 US cents/kWh	3.5	4.4	4.4
Coal	1990 US cents/kWh	3.8	3.8	3.8
CARBON CAPTURE & STORAGE				
Power penalty, coal	% derating	25	not available	15
Capital cost, coal	% of non-capture K	88	not available	63
Power penalty, gas	% derating	13	not available	10
Capital cost, gas	% of non-capture K	89	not available	72
Storage	1990 US$/tC	37	not available	37
Capture efficiency	%	90	not available	90
TRANSPORTATION				
US Automobile Performance	mpg	18	60	100
Fuel Cell	mpg (equivalent)	43	60	100
Agriculture & Biomass				
Crop & Biomass Productivity	Annual Ave		0.70%	1.10%
	(added .25% in early years, and 0.5% in latter years)			
Hydrogen Production				
Natural Gas	1990 US$/gJ	$6.50	$9.00	$15.00
Coal	1990 US$/gJ	$9.00	$7.40	$29.00
Advanced H2	1990 US$/gJ	NA	NA	$5.50

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WARNING!!!

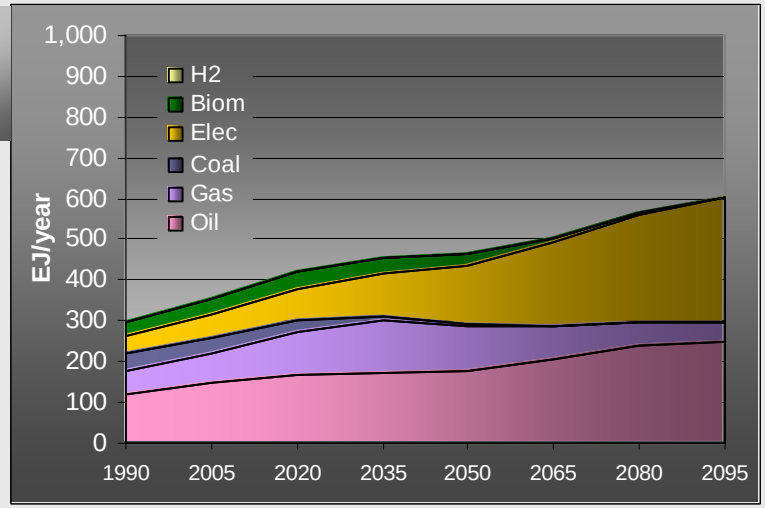
The Advanced Technology Case Is Just One of Many Possible Outcomes for Investments in a Diversified Portfolio of Energy Technology R&D

Includes information from three "deep dives" undertaken under the GTSP

- **Carbon Capture and Storage**
- **Bio-technology**
- **Hydrogen and Advanced Transportation Systems**

Technology & Stabilization

B2 Ref with Stabilization



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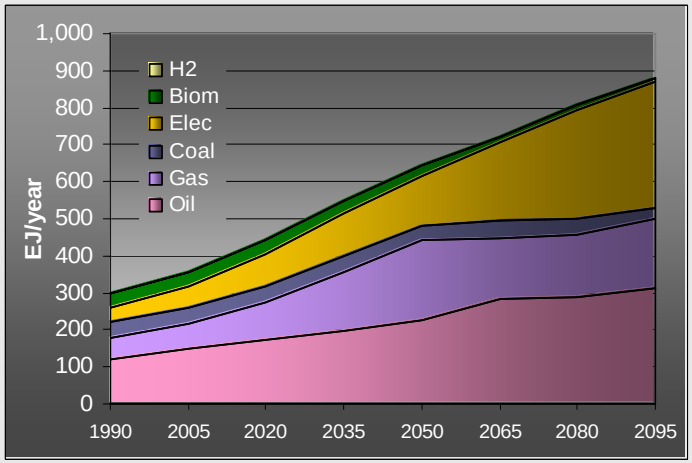
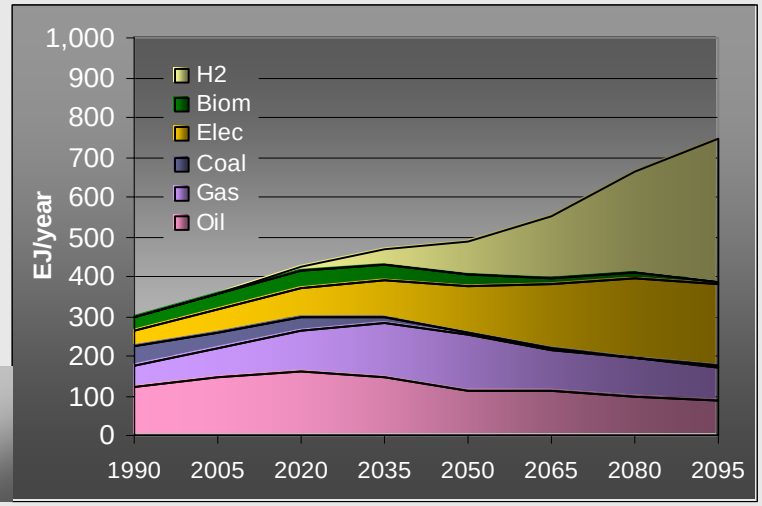
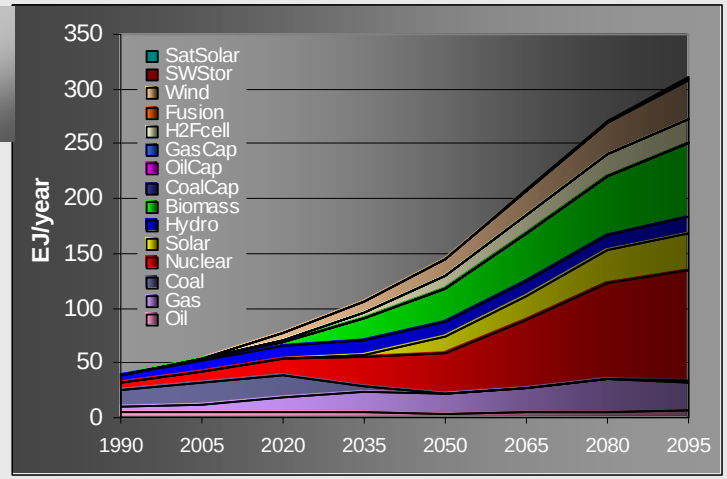


B2 AT with Stabilization



Power Generation and Stabilization—Electrification

B2 Ref with Stabilization



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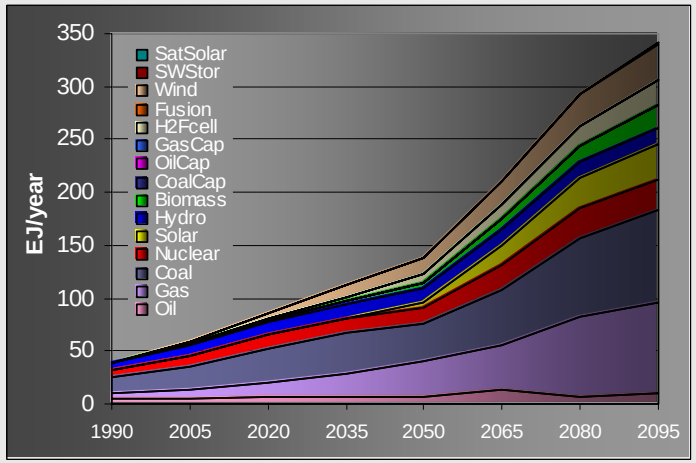

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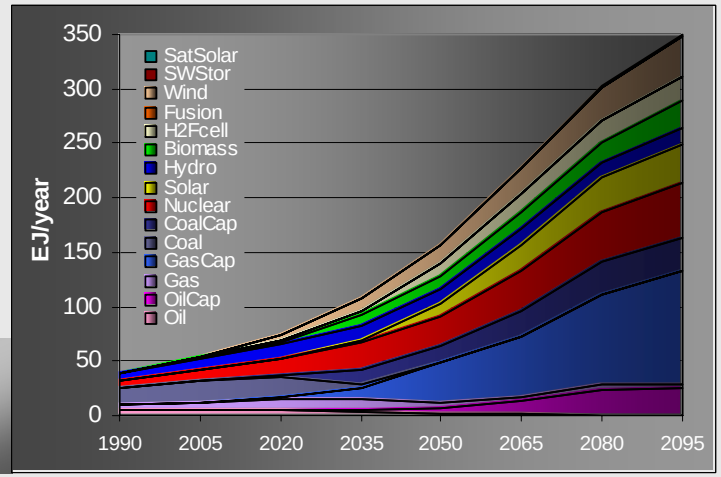
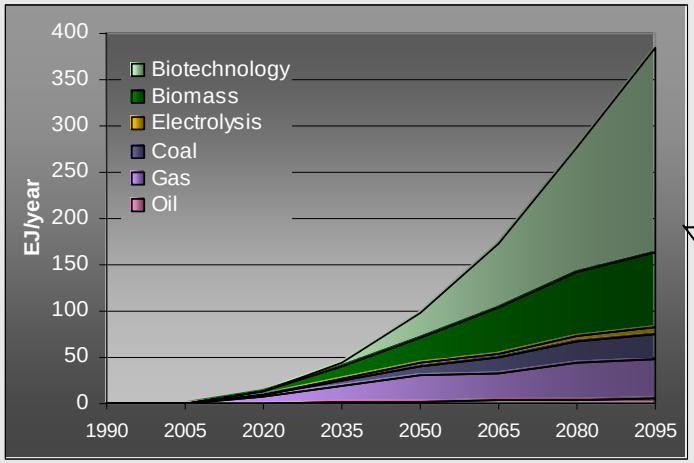
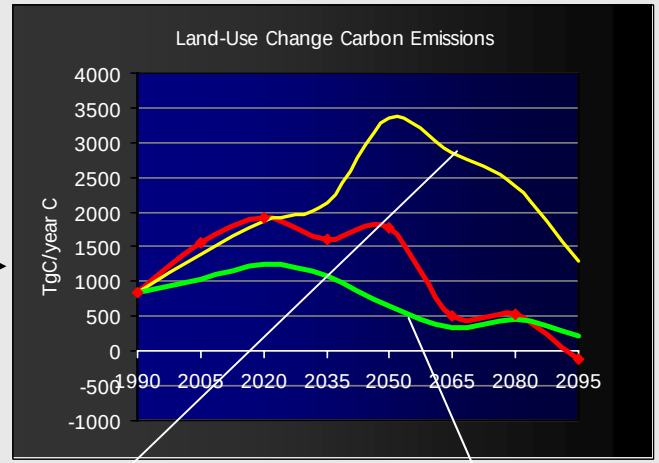


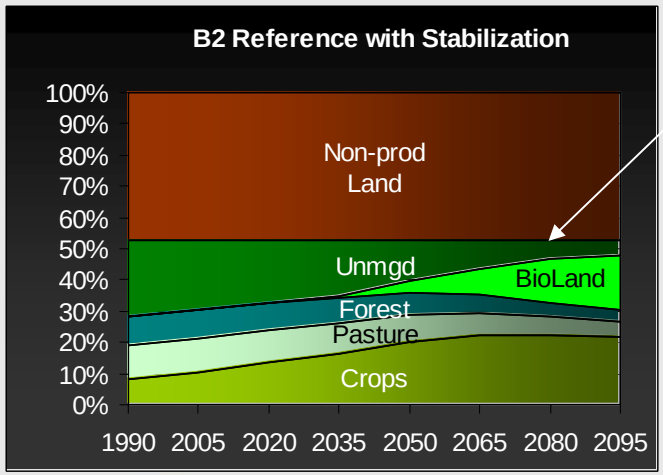
H2 and Biotech
B2 AT with Stabilization

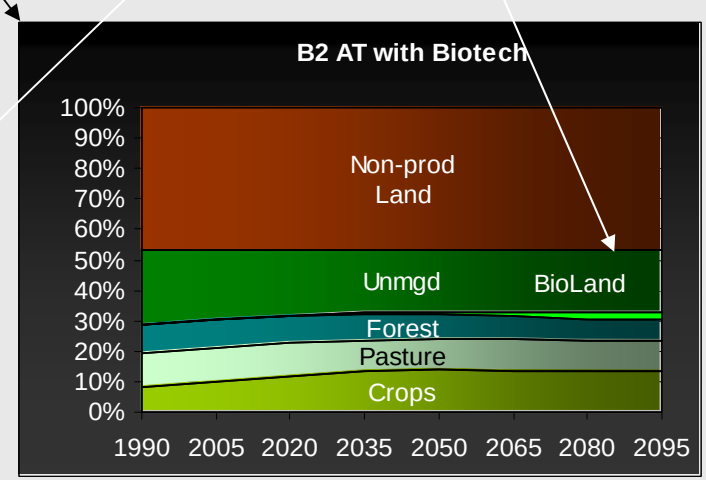
What if agricultural and biomass crop productivities could be maintained and a biological source of H2 that is cost-competitive with CH4?



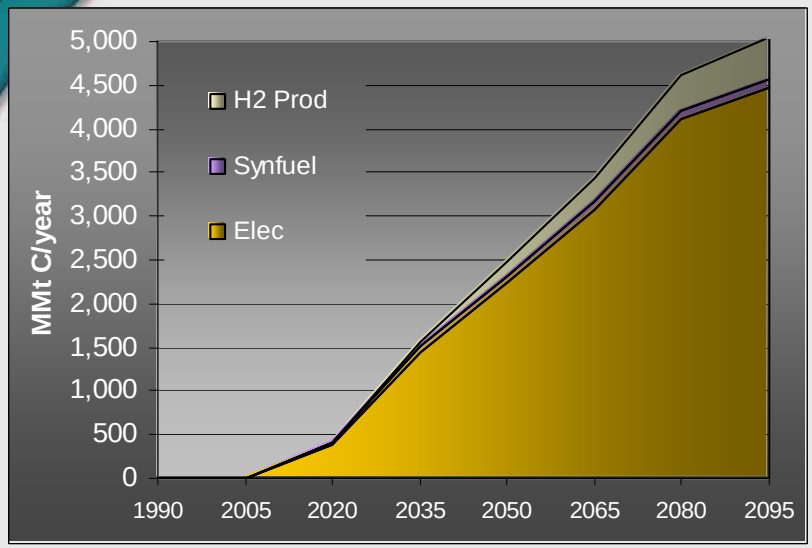
Biotechnology& Land Use

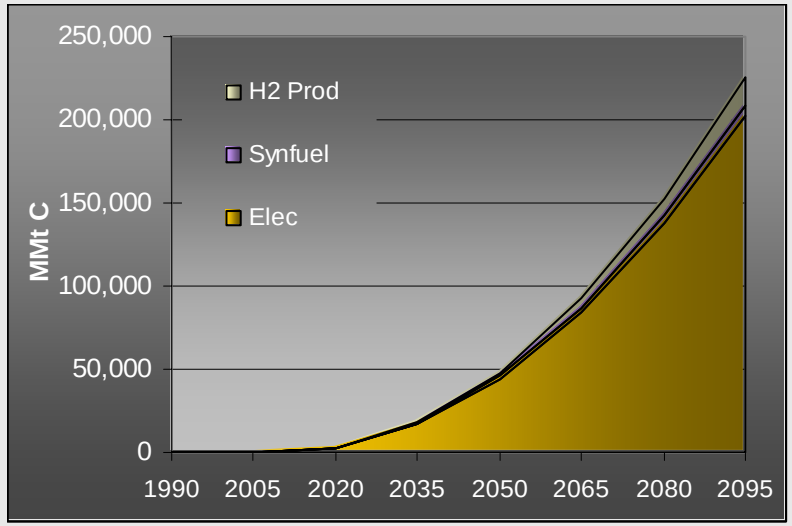






CO_2 Capture and Storage B2 AT with Stabilization

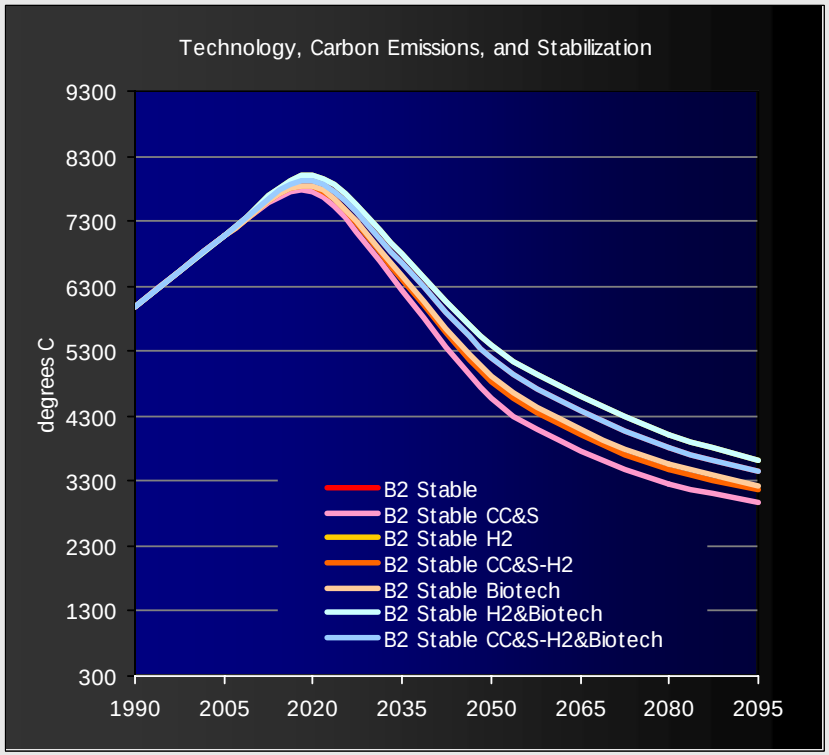


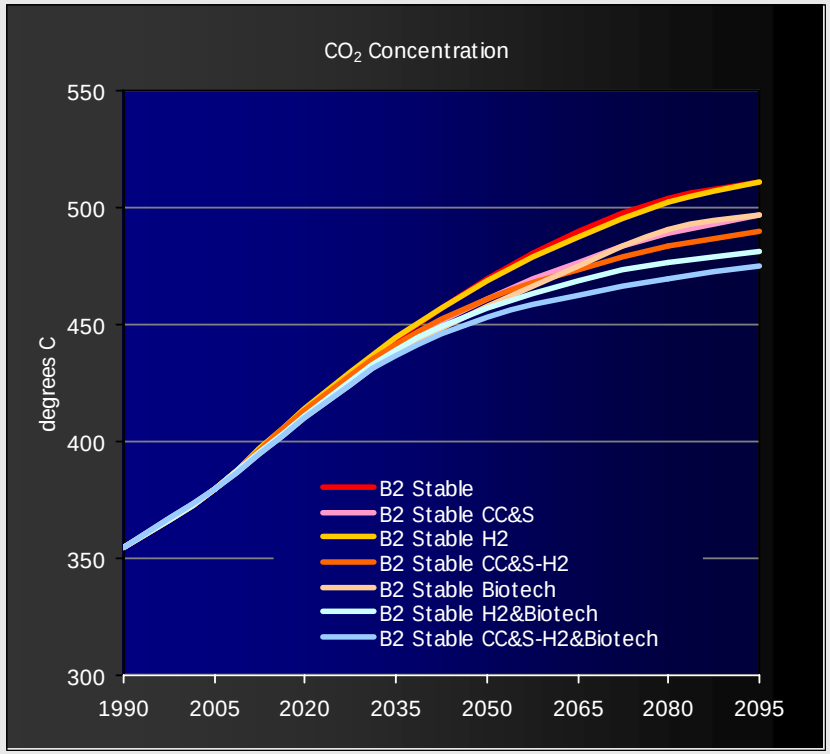


Carbon Storage Reservoir	Range (PgC)
Deep Saline Reservoirs	*87 to 2,727*
Depleted Gas Reservoirs	*136 to 300*
Depleted Oil Reservoirs	*41 to 191*
Unminable Coal	*>20*
Basalt Formations	*>1,000*
Deep Ocean	*1,400 to 27,000*

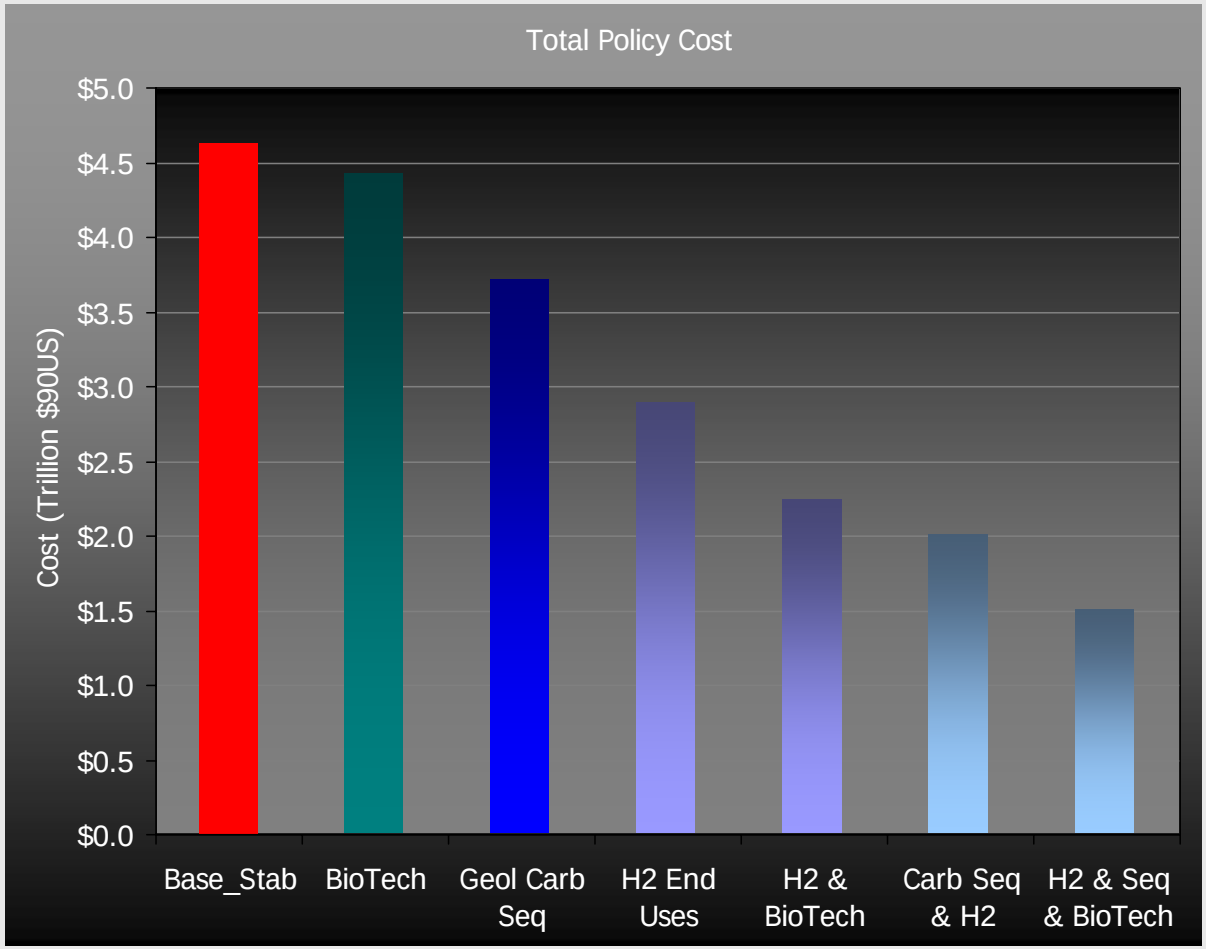
Source: Herzog et al. (1997), Freund and Ormerod (1997), PNNL (2001).

Technology, Carbon Emissions, & CO_2 Concentration





Technology and Cost



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Some Major Points

- The inclusion of non-CO_2 greenhouse gases in an analysis of greenhouse gas stabilization has important implications.
- Limiting the change in radiative forcing to 2°C implies stabilizing CO_2 concentrations at 500 ppm.
  - Emissions peak in 2020 and decline to 3.4 PgC/year by 2095.
- An improved technology portfolio could reduce the cost substantially—from $4.5 trillion to $1.5 trillion.
- Uncertainty in climate sensitivity has huge implications for a 2°C limit on GMT change:
  - Low climate sensitivity means no mitigation until the second half of the century
  - High climate sensitivity means immediate, radical emissions mitigation.

The GTSP Web Site

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END

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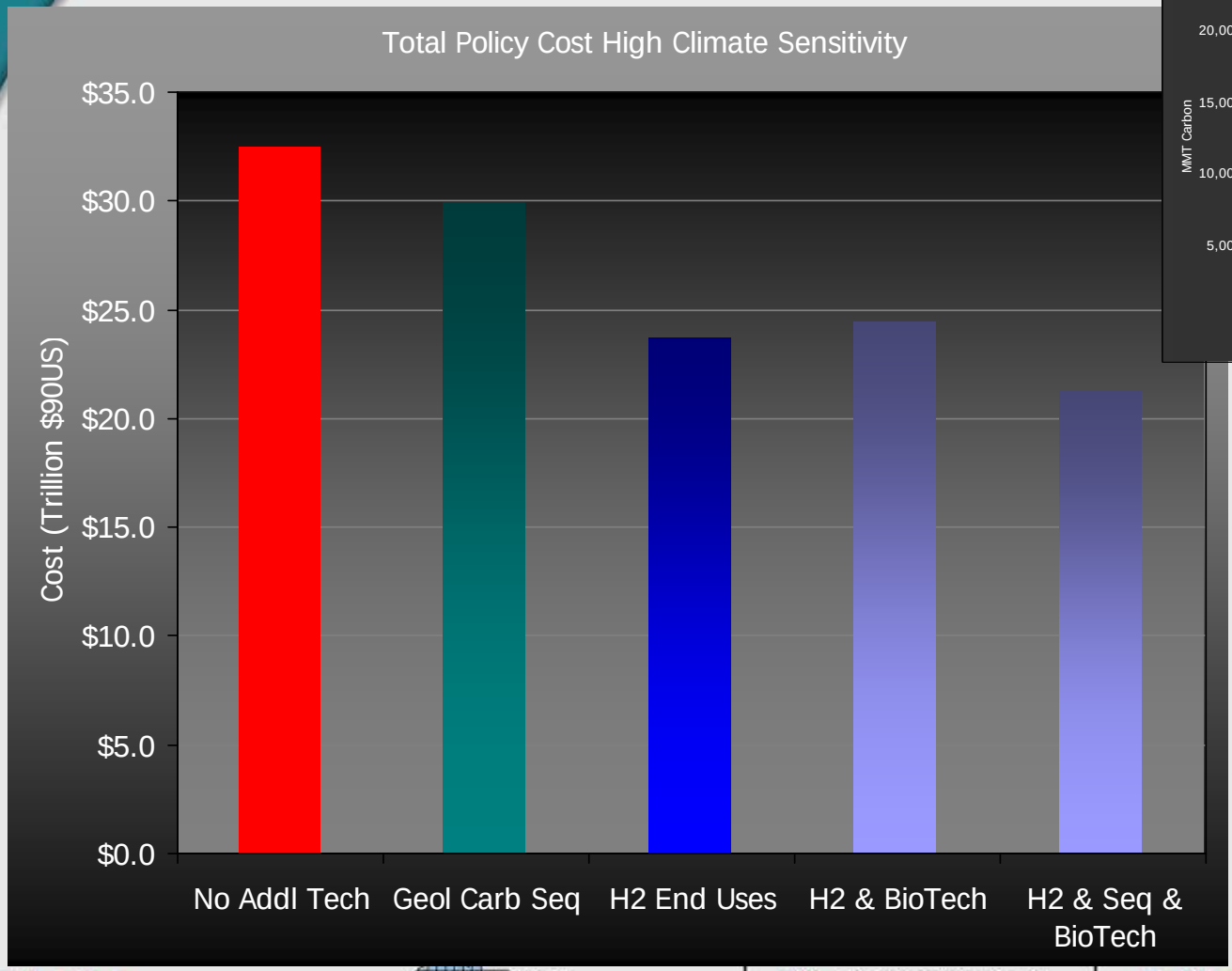
GTSP "Deep Dives"

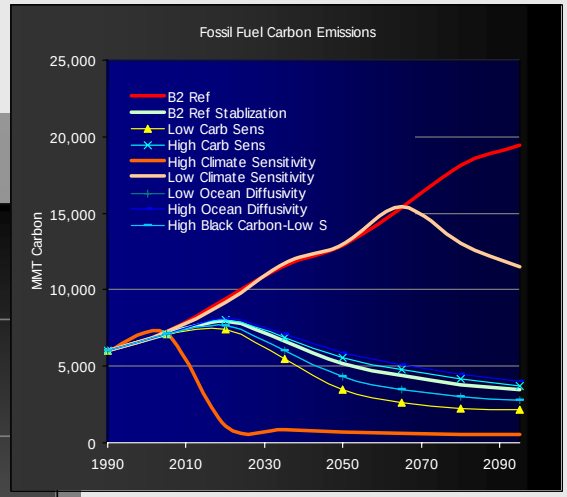
- Carbon Capture and Storage
- Bio-technology
- Hydrogen and Advanced Transportation Systems
- **Nuclear (fission/fusion)**
- **Wind, Solar and Other Renewables (including SSP)**
- **Energy Intensity**

Cross-Cutting Themes

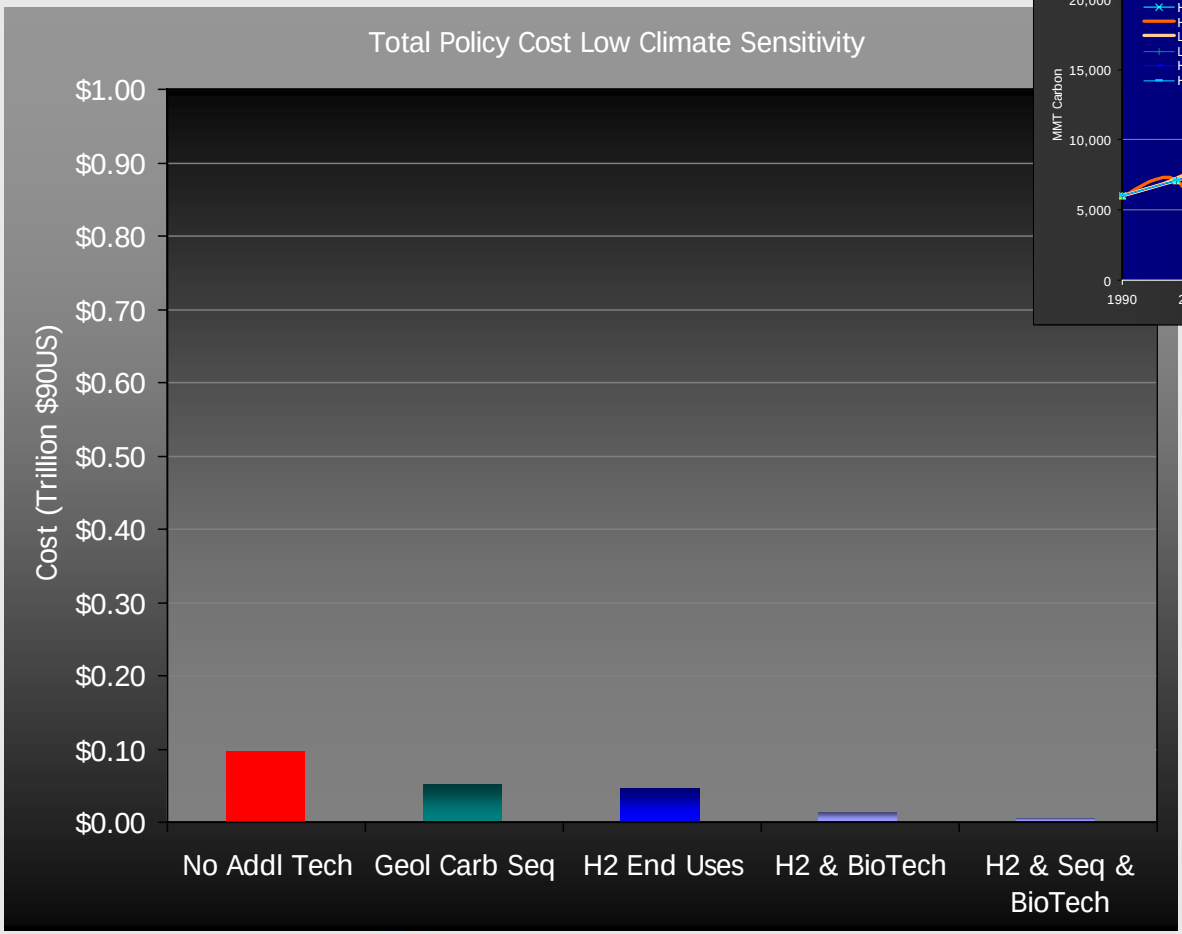
- **Modeling**
- **Non-CO_2 Greenhouse Gases**
- **Scenarios**
- **Institutions and Implementation**

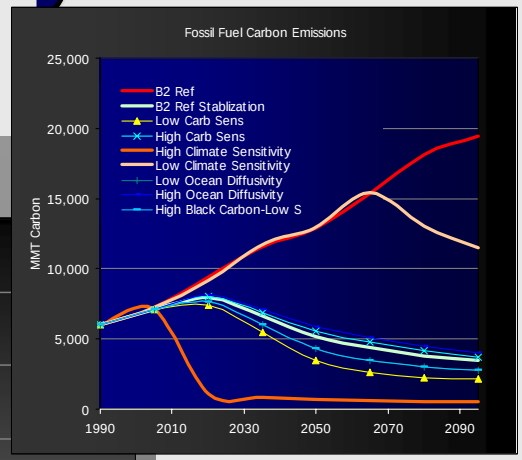
Technology & High Climate Sensitivity





Technology & Low Climate Sensitivity





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