# Two-Degrees of Climate Change

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Global Energy Technology Strategy Program

*a presentation to*

## *Avoiding Dangerous Climate Change*

## A Scientific Symposium on Stabilisation of Greenhouse Gases

**Jae Edmonds**

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Met Office
Exeter, United Kingdom

Battelle
Office of Science, U.S. Department of Energy
JGCRI Joint Global Change Research Institute
University of Maryland
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# Acknowledgements

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- David Warrilow for the invitation
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## Colleagues

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## Sponsors

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# Key Question for Today

What are the energy technology implications of stabilizing climate change at 2°C relative to preindustrial—not just $CO_2$ concentrations

**This limit does NOT reflect a determination as to a change that avoids dangerous anthropogenic interference with the climate system.**

- Interactions with uncertainty in technology developments.
- Interactions with uncertainty in biogeochemical parameterization;

# The MiniCAM

## Integrated Assessment Model

- *Anthropogenic emissions*
  - *Energy-agriculture-economy market equilibrium*
    - *15 gaseous emissions—linked to associated human activities*
    - *14 global regions*
    - *2095 time horizon*
    - *Demographics module*
    - *Land resource constraints*
    - *Energy technology detail*
- *Natural system model (MAGICC)*
    - *Carbon cycle,*
    - *Air chemistry &*
    - *Climate*

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# MiniCAM B2

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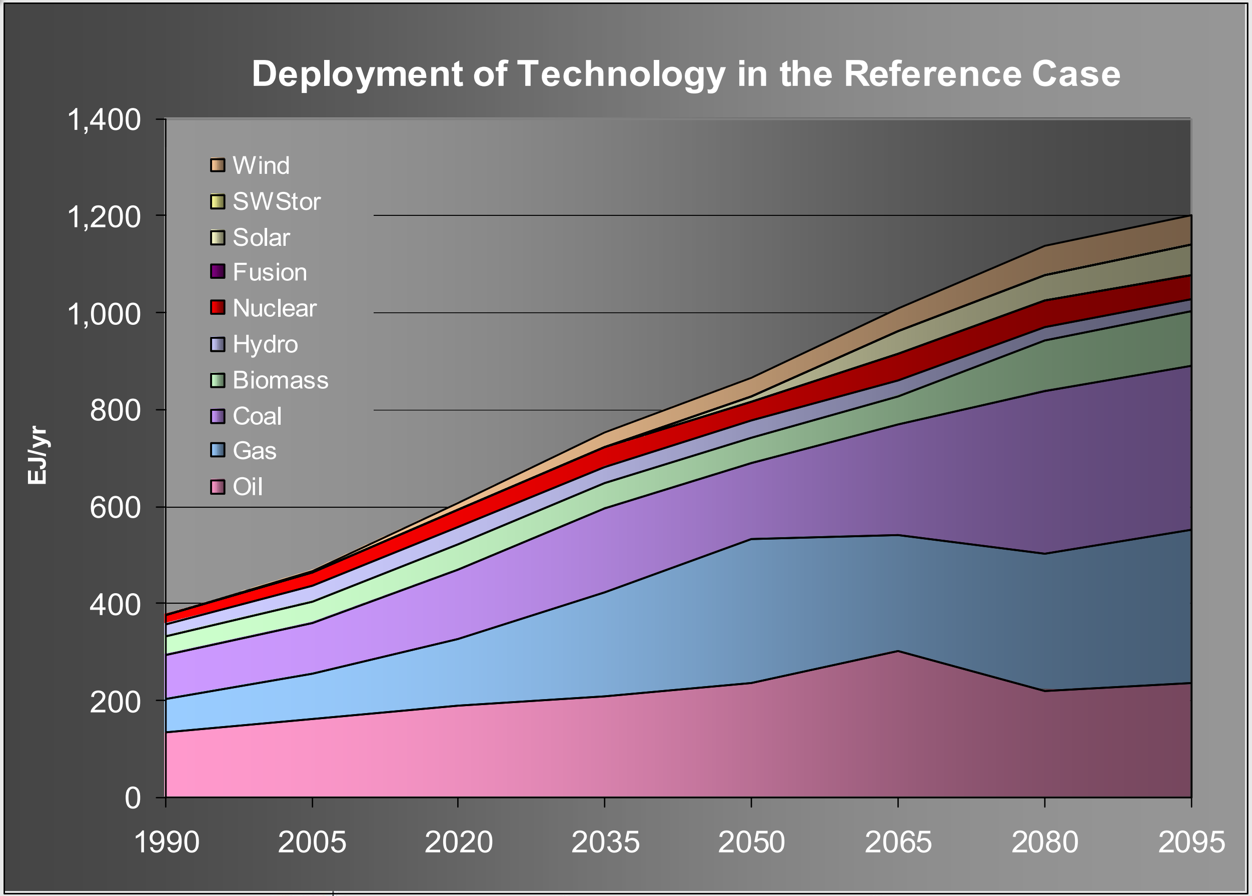
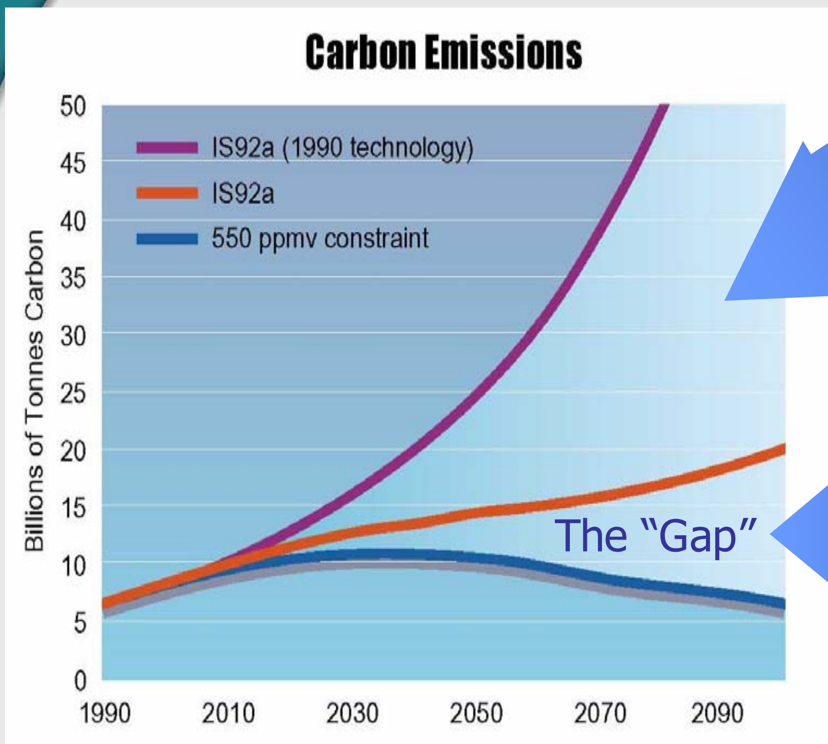
# The Reference Primary Energy System
# SRES MiniCAM B-2



# The Reference Case Technology




**Assumed Advances In**
- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

**Gap technologies**
- Improved performance of ref tech.
- Carbon capture & disposal
  - Adv. fossil
- H2 and Adv. Transportation
- Biotechnologies
  - Soils, Bioenergy, adv. Biological energy

# Greenhouse Gas Emissions, Concentrations, Temperature Rise & Sea Level Rise

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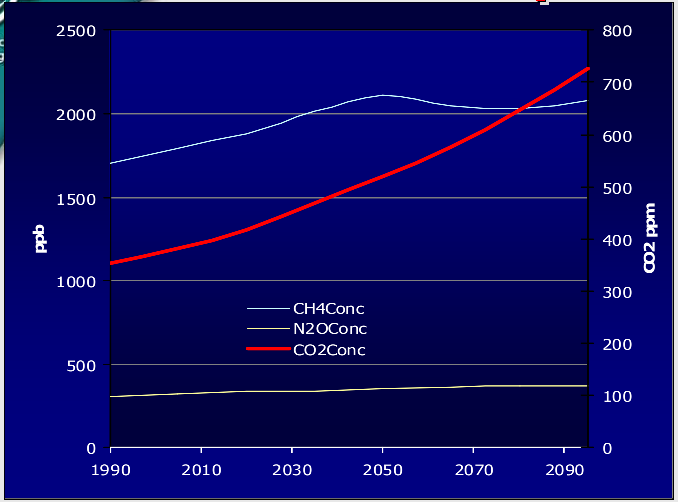
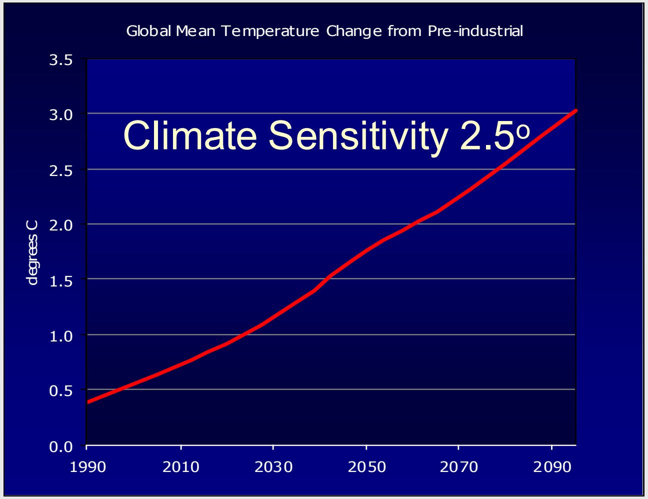
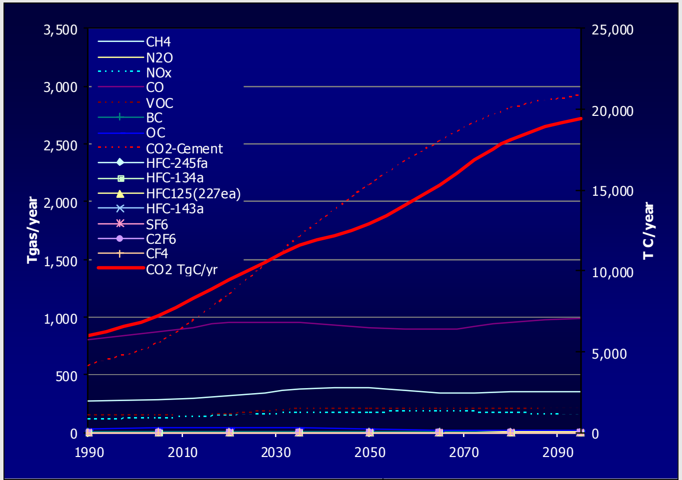
Concentrations



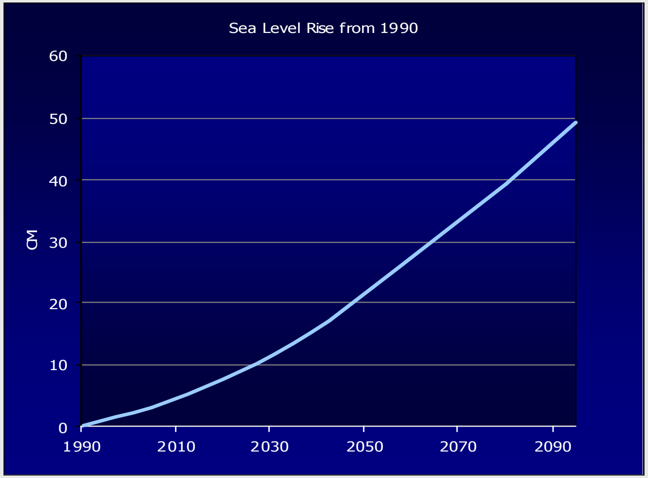

Global Mean Temperature Change




Emissions




Sea Level Rise



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# Climate Stabilization

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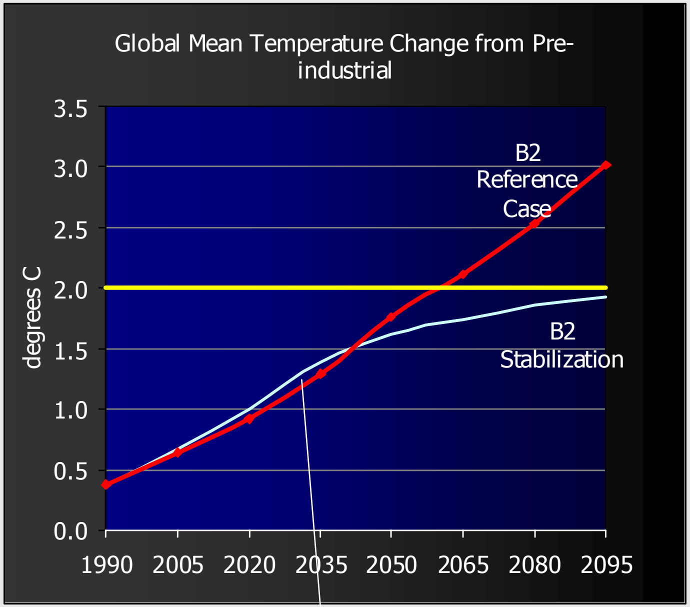
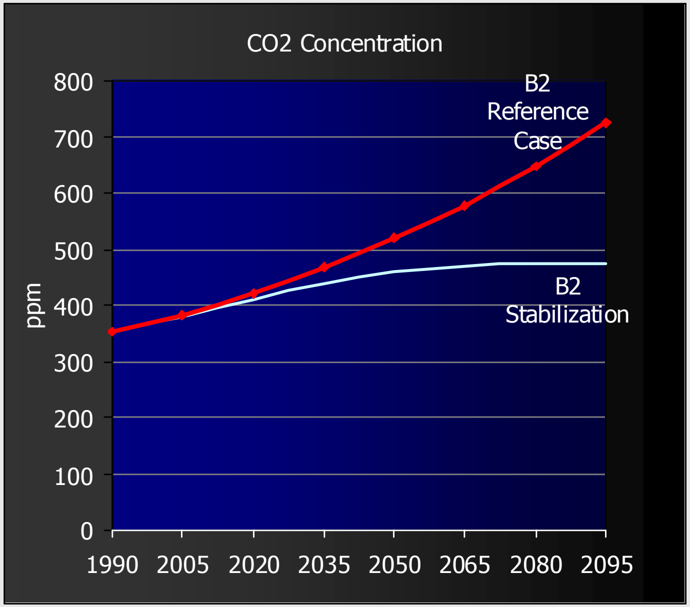
# Approach

Minimize the cost of stabilizing climate change

# Reference B2 and Stabilization with Reference Technology and Physical Parameters




The aerosol effect

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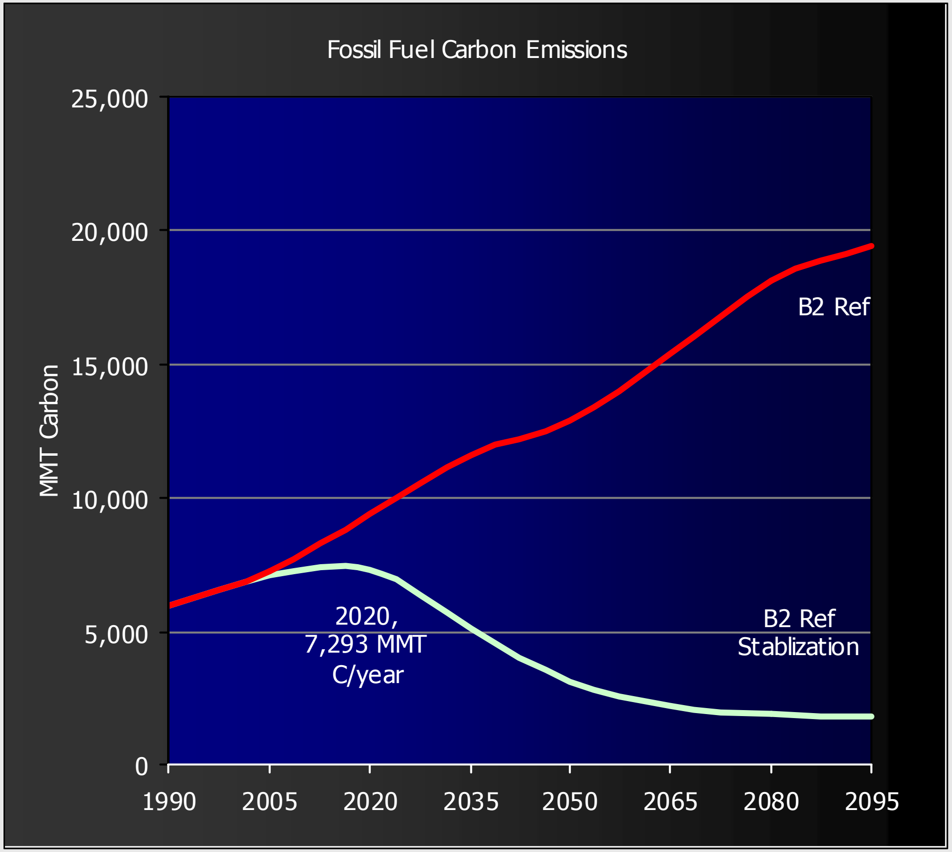
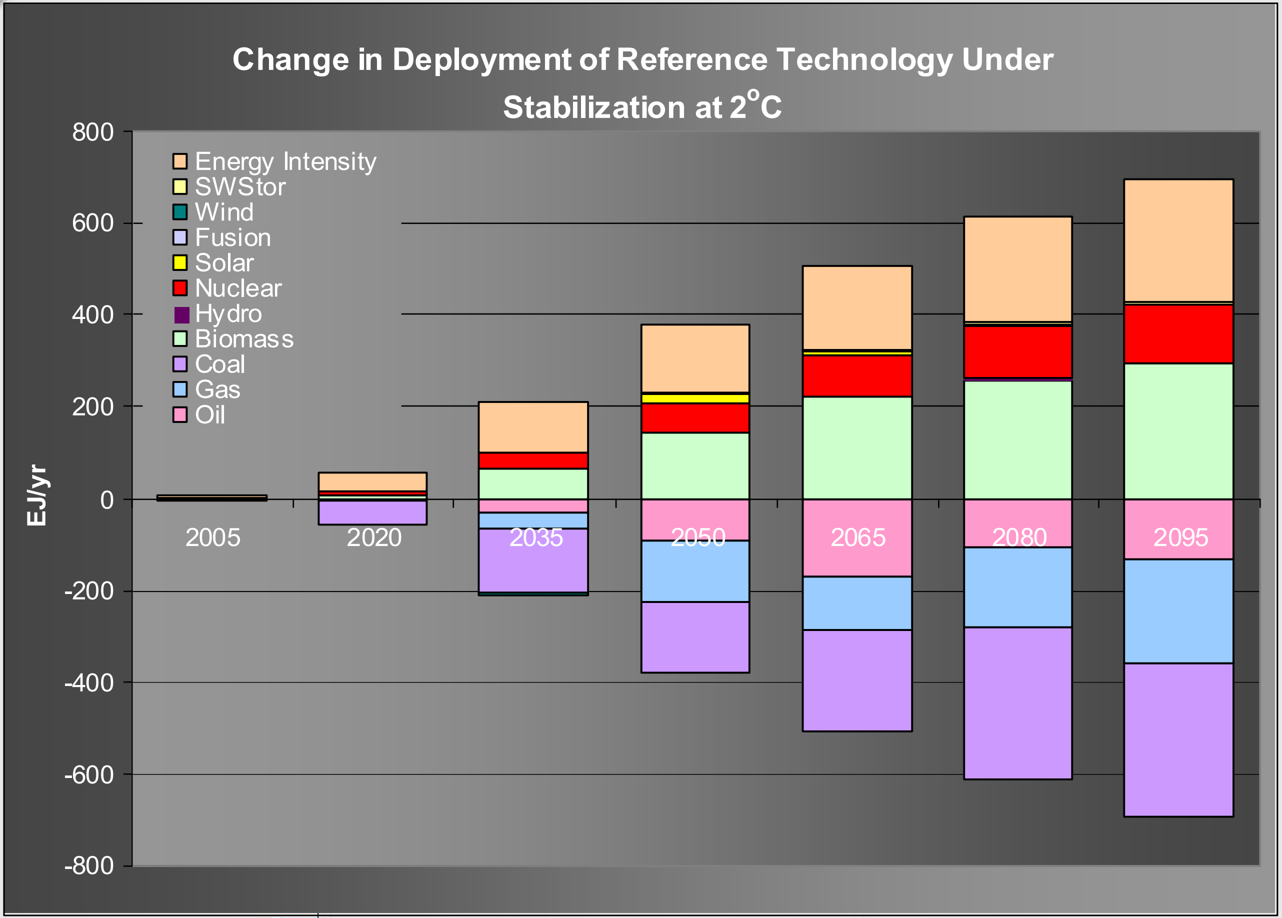
# $CO_2$ Emissions



# Energy and Stabilization

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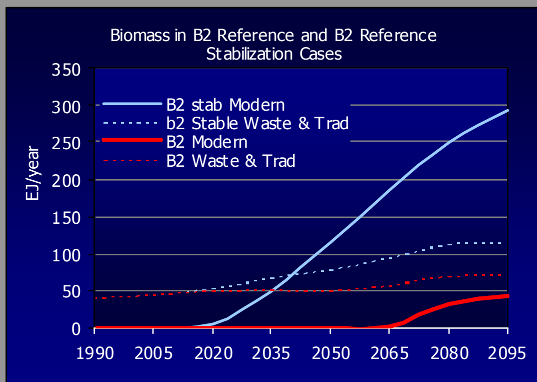
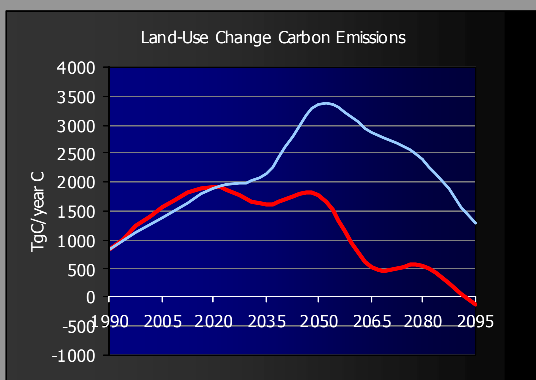
# Biomass and Land-Use Change Emission

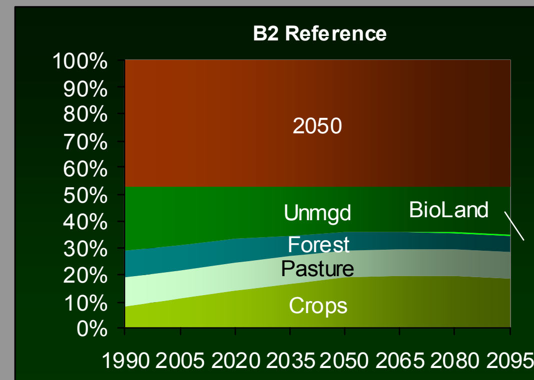
Energy



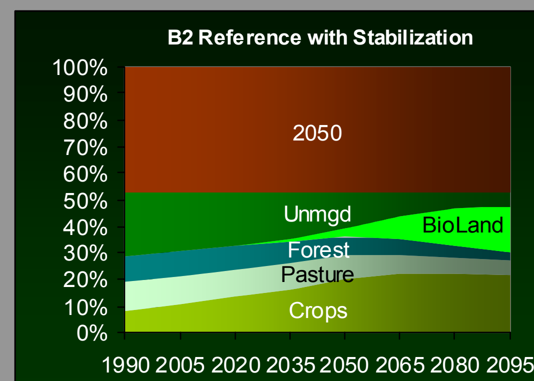

Land-use Emissions




B2 Reference




B2 Reference with Climate Stabilization



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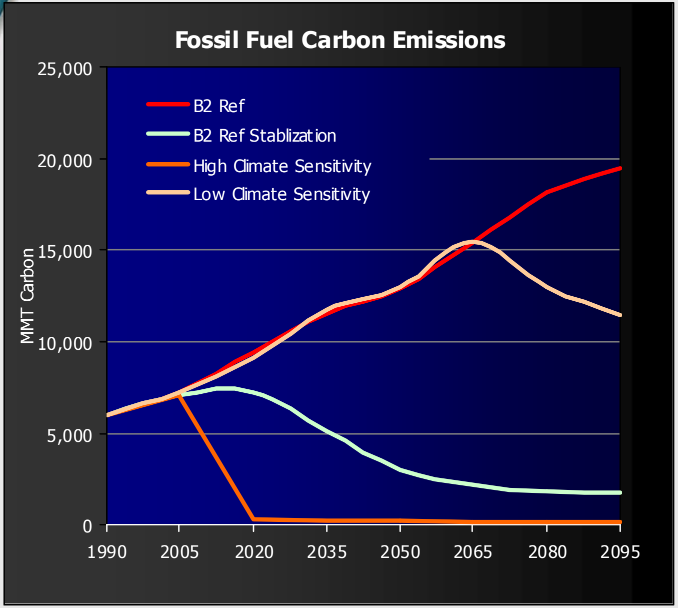
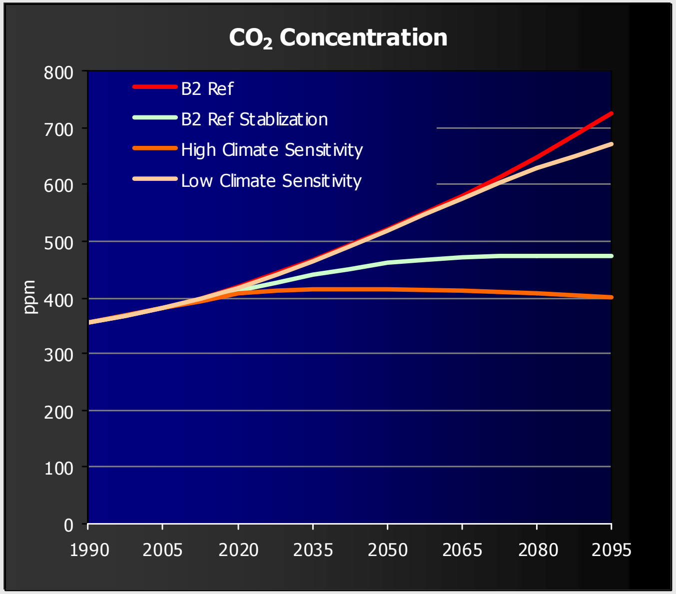
# Physical Parameter Uncertainty & Climate Stabilization

# Carbon and GMST Change Stabilization at ΔT<2°C



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# Technology Availability & Climate Stabilization

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# Technology Performance

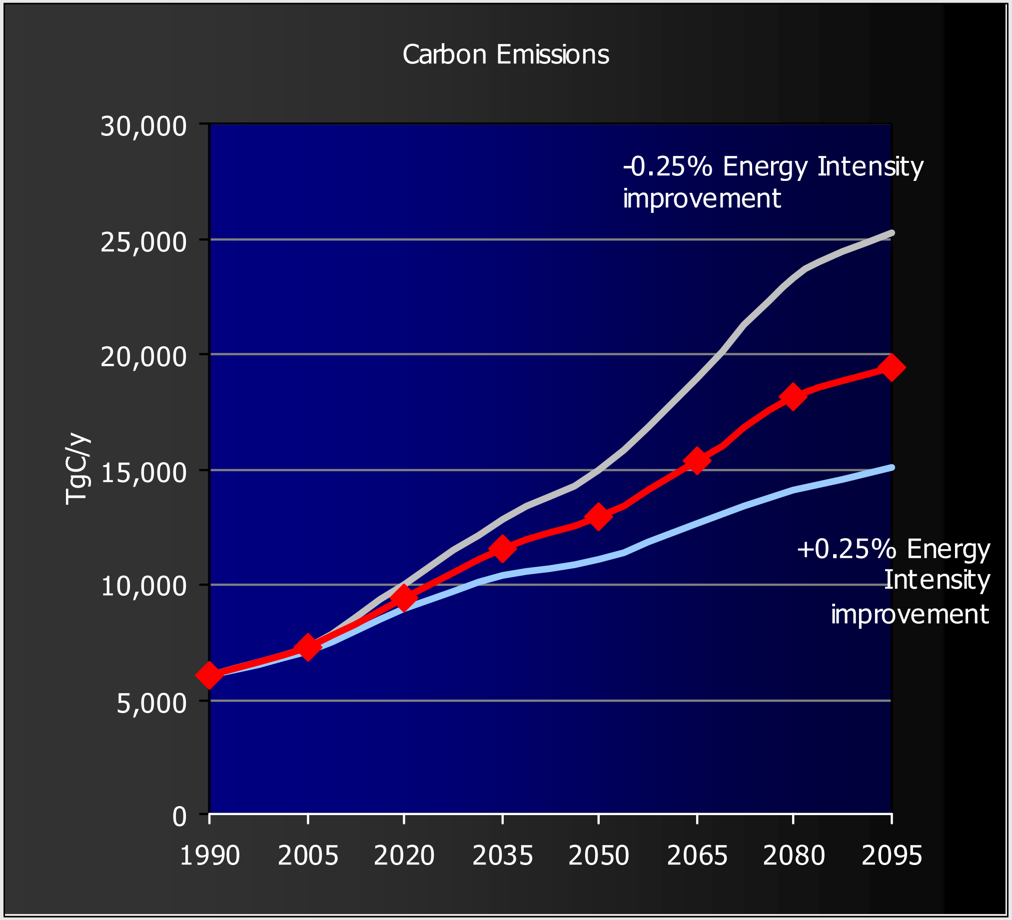
## Reference technological change case

## Accelerated improvements

- ►Wind & solar
- ►Biotechnology
- ►$CO_2$ capture & storage
- ►Energy efficiency
- ►Hydrogen systems

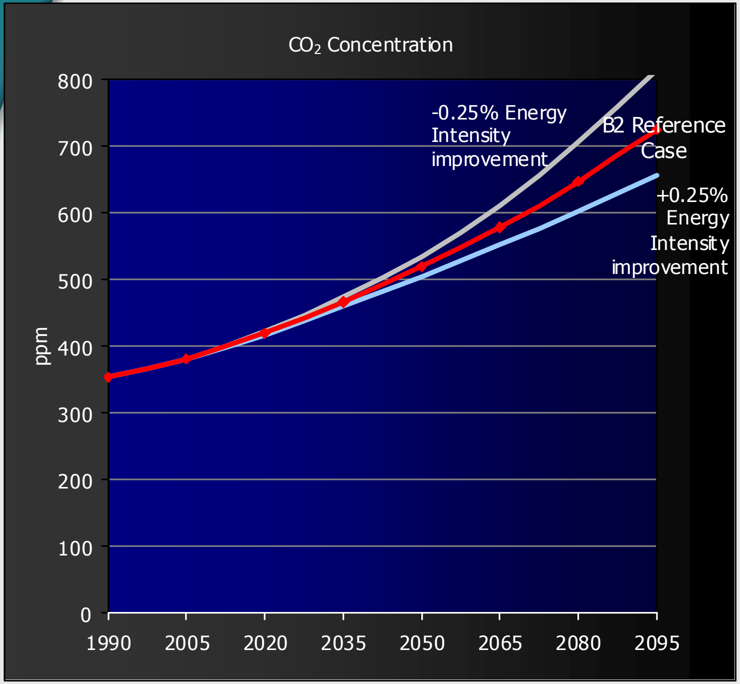
| | Units | 1990 | Ref 2095 | Adv 2095 |
|---|---|---|---|---|
| **PRIMARY ENERGY SUPPLY** | | | | |
| Oil | 1990 US$/gJ | $1.13 | $7.55 | $3.27 |
| Gas | 1990 US$/gJ | $1.40 | $5.03 | $3.40 |
| Coal | 1990 US$/gJ | $0.76 | $1.42 | $1.08 |
| Biomass | 1990 US$/gJ | $1.63 | $1.95 | $1.89 |
| **ELECTRIC POWER GENERATION** | (fuel + non-fuel cost) | | | |
| Nuclear | 1990 US cents/kWh | 5.8 | 5.8 | 5.8 |
| Solar | 1990 US cents/kWh | 61.0 | 6.0 | 4.0 |
| Wind | 1990 US cents/kWh | 8.0 | 4.0 | 4.0 |
| Gas | 1990 US cents/kWh | 3.5 | 4.4 | 4.4 |
| Coal | 1990 US cents/kWh | 3.8 | 3.8 | 3.8 |
| **CARBON CAPTURE & STORAGE** | | | | |
| Power penalty, coal | % derating | 25 | not available | 15 |
| Capital cost, coal | % of non-capture K | 88 | not available | 63 |
| Power penalty, gas | % derating | 13 | not available | 10 |
| Capital cost, gas | % of non-capture K | 89 | not available | 72 |
| Storage | 1990 US$/tC | 37 | not available | 37 |
| Capture efficiency | % | 90 | not available | 90 |
| **TRANSPORTATION** | | | | |
| US Automobile Performance | mpg | 18 | 60 | 100 |
| Fuel Cell | mpg (equivalent) | 43 | NA | 100 |
| **AGRICULTURE & BIOMASS** | | | | |
| Crop & Biomass Productivity | Annual Ave | | 0.70% | 1.10% |
| **HYDROGEN PRODUCTION** | | 2005 | Ref 2095 | Adv 2095 |
| Gas to H2 | % efficient | 70% | NA | 80% |
| Gas with C Capture, to H2 | % efficient | 58% | NA | 71% |
| Coal to H2 | % efficient | 62% | NA | 66% |
| Coal with C Capture, to H2 | % efficient | 52% | NA | 58% |
| Electrolysis | % efficient | 87% | NA | 94% |
| Biomass | % efficient | 60% | NA | 80% |
| Gas Non-fuel Costs | 1990 US$/gJ | $2.43 | NA | $1.55 |
| Gas with C Capture, Non-fuel Costs | 1990 US$/gJ | $3.16 | NA | $1.86 |
| Coal Non-fuel Costs | 1990 US$/gJ | $6.86 | NA | $6.86 |
| Coal with C Capture, Non-fuel Costs | 1990 US$/gJ | $8.91 | NA | $5.22 |
| Electrolysis Non-fuel Costs | 1990 US$/gJ | $5.58 | NA | $3.56 |
| Biomass Non-fuel Costs | 1990 US$/gJ | $5.53 | NA | $3.53 |

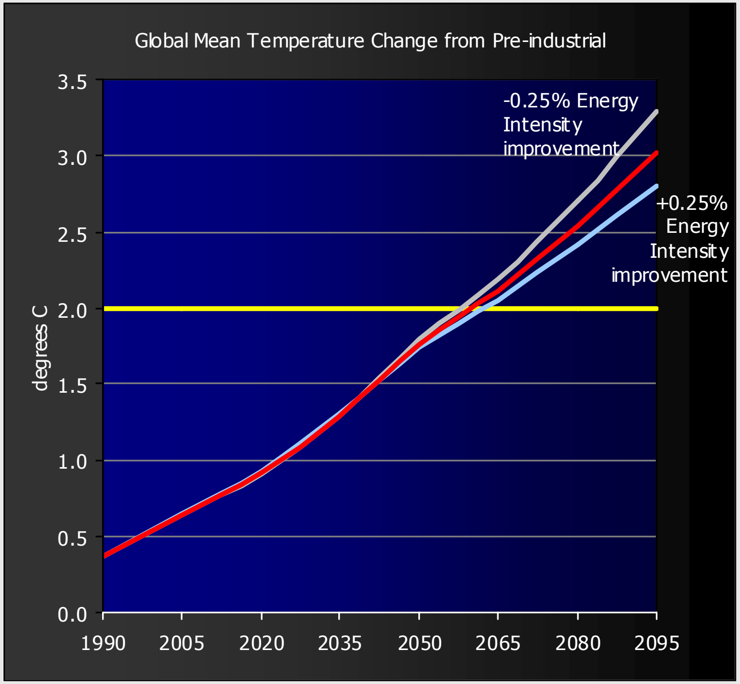
# Energy Intensity



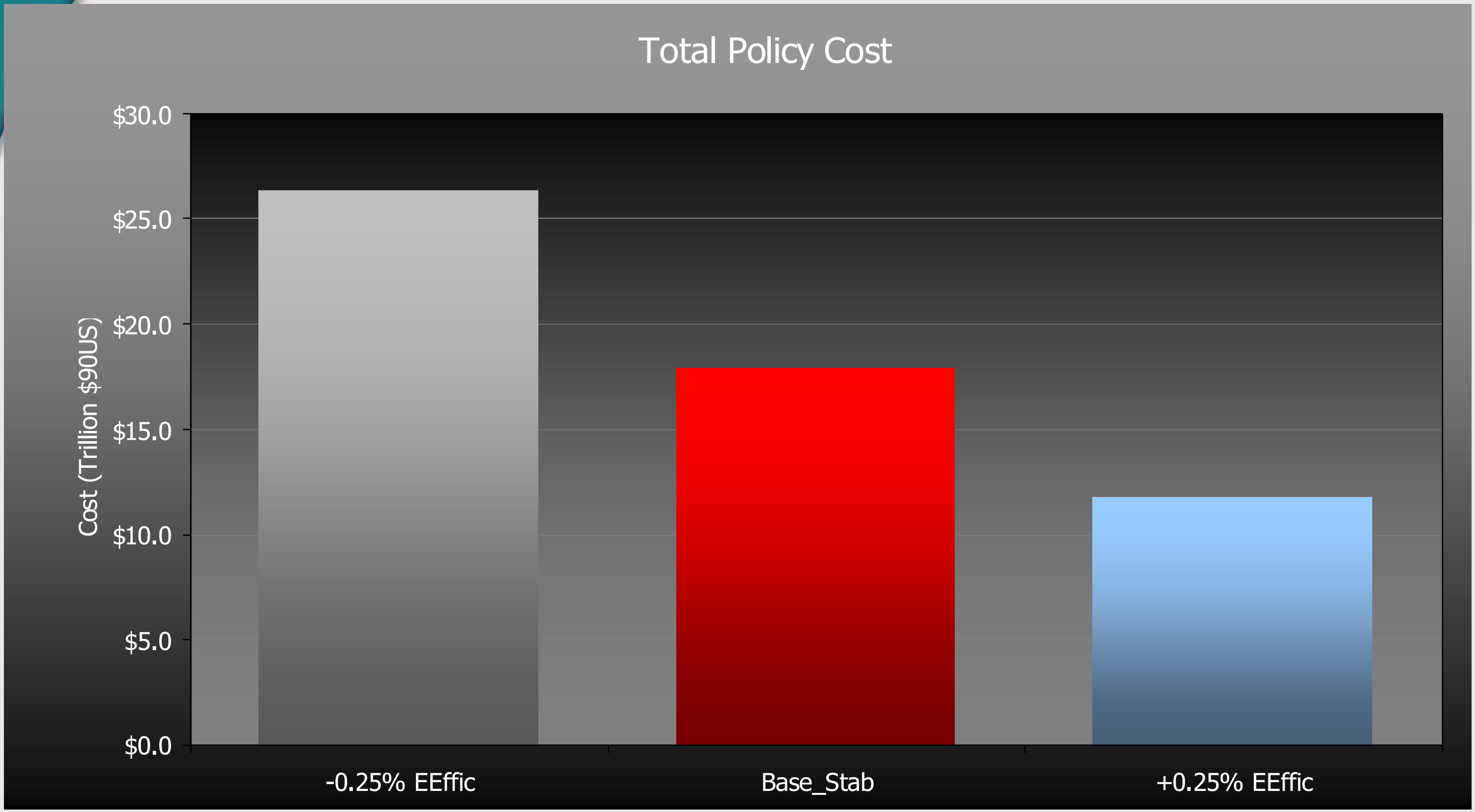
# Energy Intensity

## Technology Alone Doesn't Stabilize Climate



# Energy Intensity and Climate Stabilization

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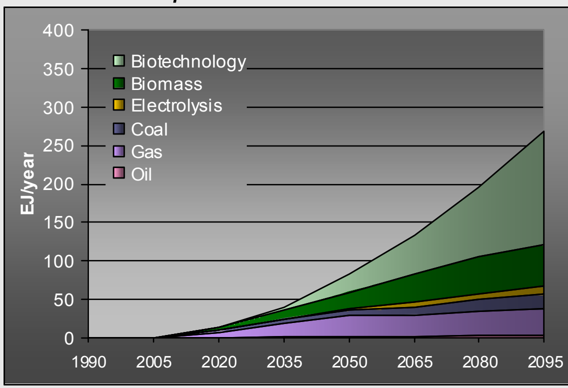
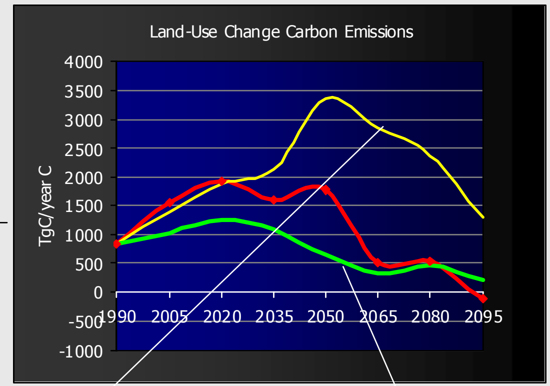
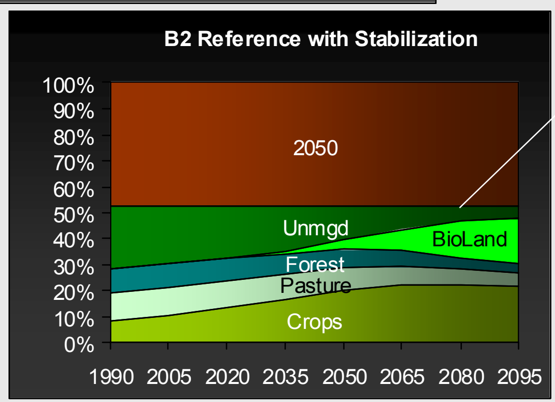
# H2 and Biotech
# B2 AT with Stabilization

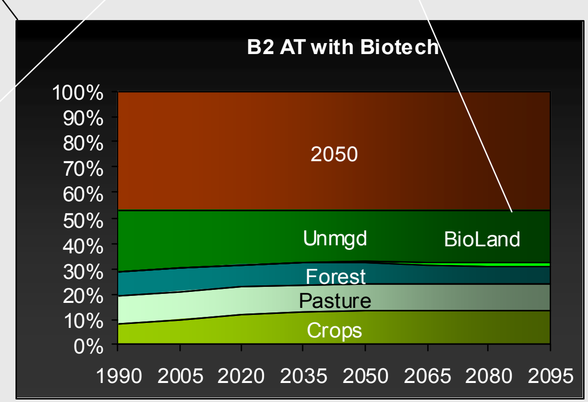
*What if agricultural and biomass crop productivities could be maintained and a biological source of H2 that is cost-competitive with CH4?*



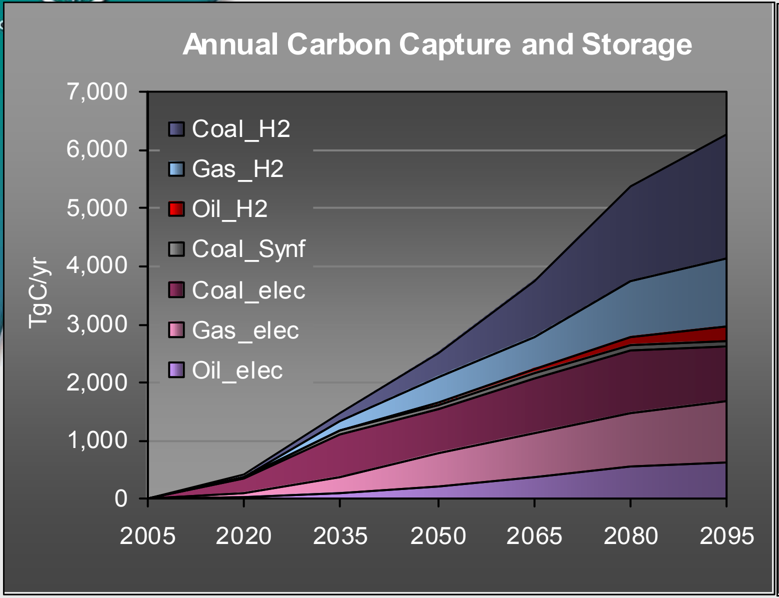

## Biotechnology& Land Use

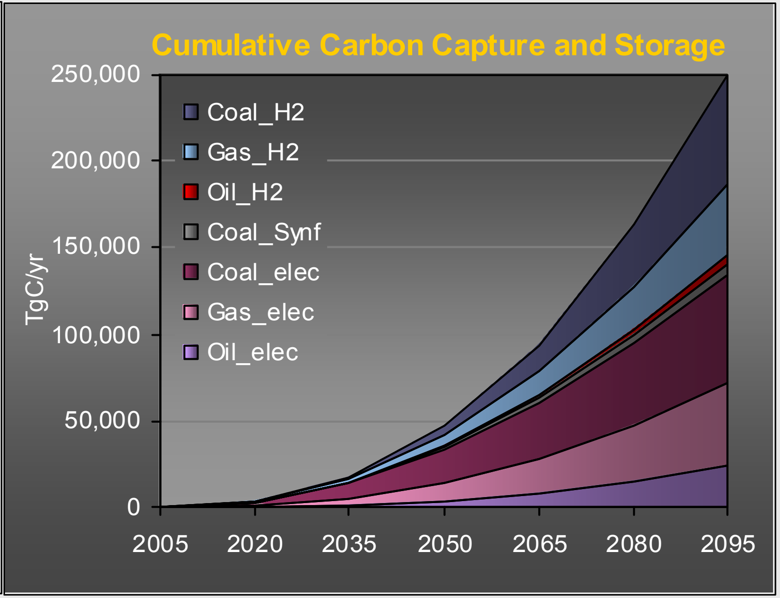


# $CO_2$ Capture and Storage B2 with Stabilization



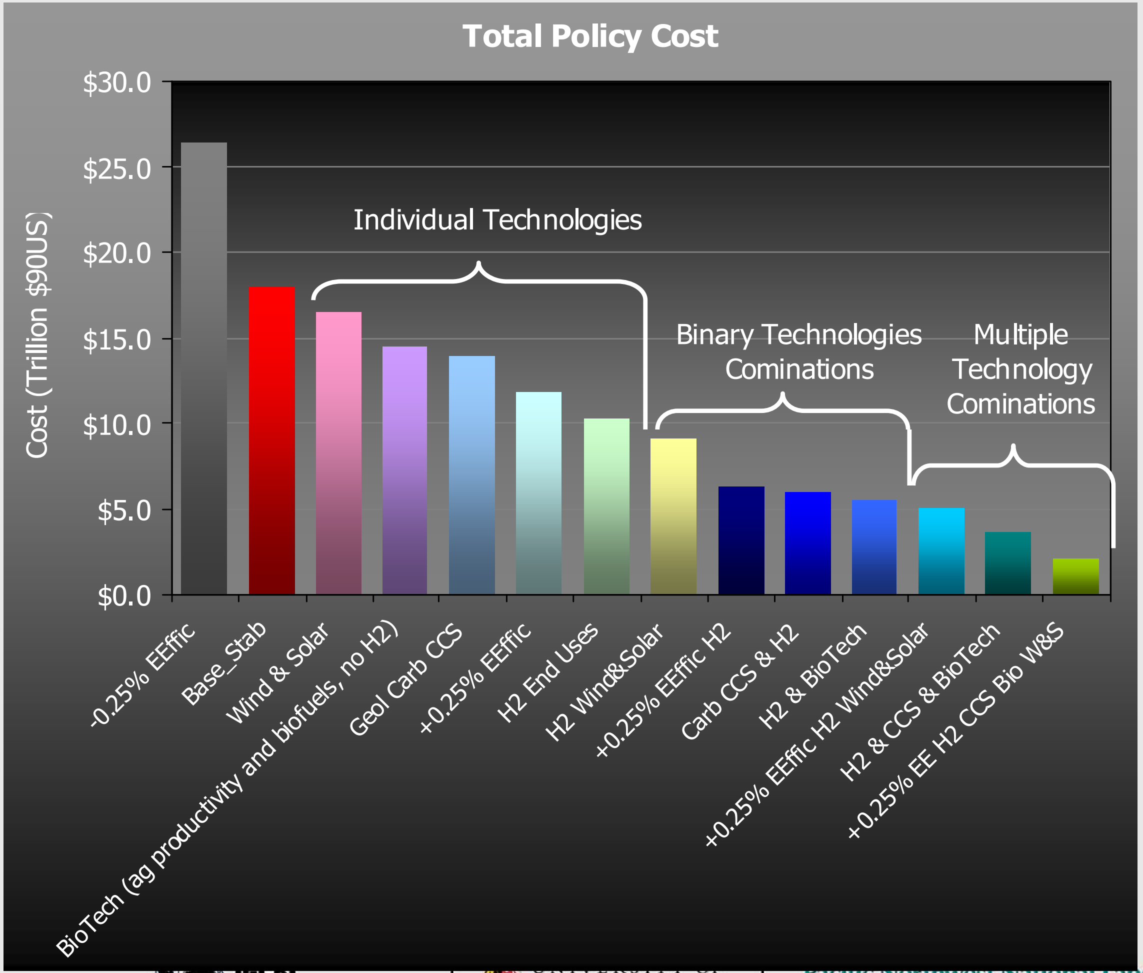




**Geologic Storage Capacity Estimates, All Grades (PgC)**

| Coal Basins | Depleted Oil Plays | Gas Basins | Deep Saline Formation On-shore | Deep Saline Formation Off-shore | TOTAL |
|---|---|---|---|---|---|
| 48 | 31 | 190 | 1,608 | 1,374 | 3,252 |

Source: Dooley, et al. 2004

# Technology and Cost



# Some Points

- Limiting climate change to $2^oC$ implies stabilizing all GHG's
  - $CO_2$ concentrations at <500 ppm if climate sensitivity is $2.5^oC$.
  - Emissions peak in 2020 and decline to 3.1 PgC/year by 2095.
  - Aerosol effects are present.
  - Non-$CO_2$ GHG's provide important mitigation options.
- An improved technology portfolio could reduce the cost substantially—from $17 trillion to very low levels.
- Uncertainty in climate sensitivity has huge implications for a $2^oC$ 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

## www.pnl.gov/gtsp

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