CCSP Product 2.1A: An Application of Integrated Assessment Modeling

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Joint Global Change Research Institute

Integrated Assessment Modeling

Integrated Assessment: A Comprehensive Paradigm

Atmosphere – Ocean System

Atmospheric Chemistry ↔ Climate

Oceans, Carbon Cycle, Sea Level, Temperature

Links may be formal or informal depending on the application

Human Systems

- Energy System
- Agriculture, Livestock, Forestry
- Other Human Systems
- Anthropogenic Coastal Zone

Ecosystems

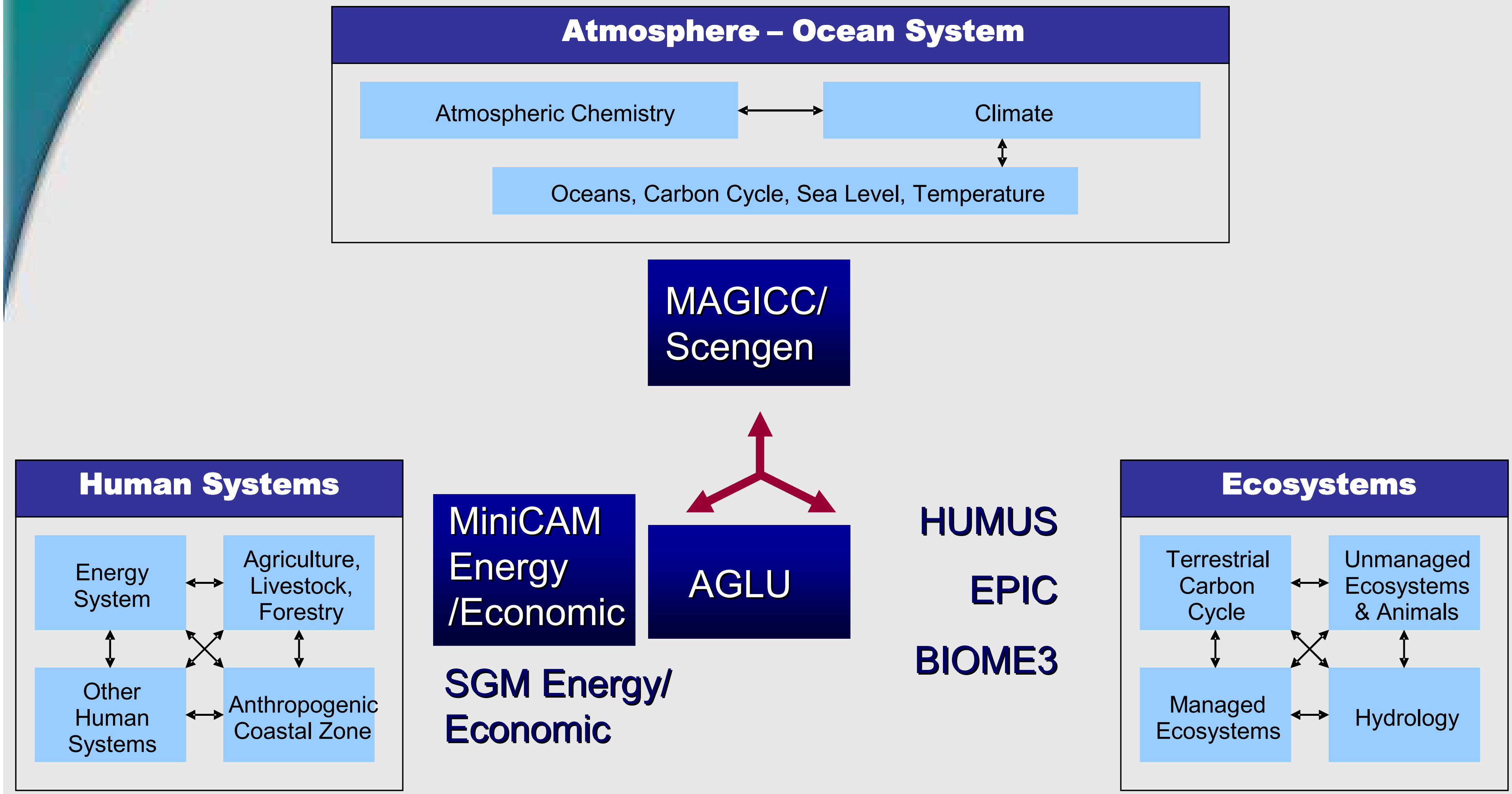
- Terrestrial Carbon Cycle
- Unmanaged Ecosystems & Animals
- Managed Ecosystems
- Hydrology

IA models are comprehensive.

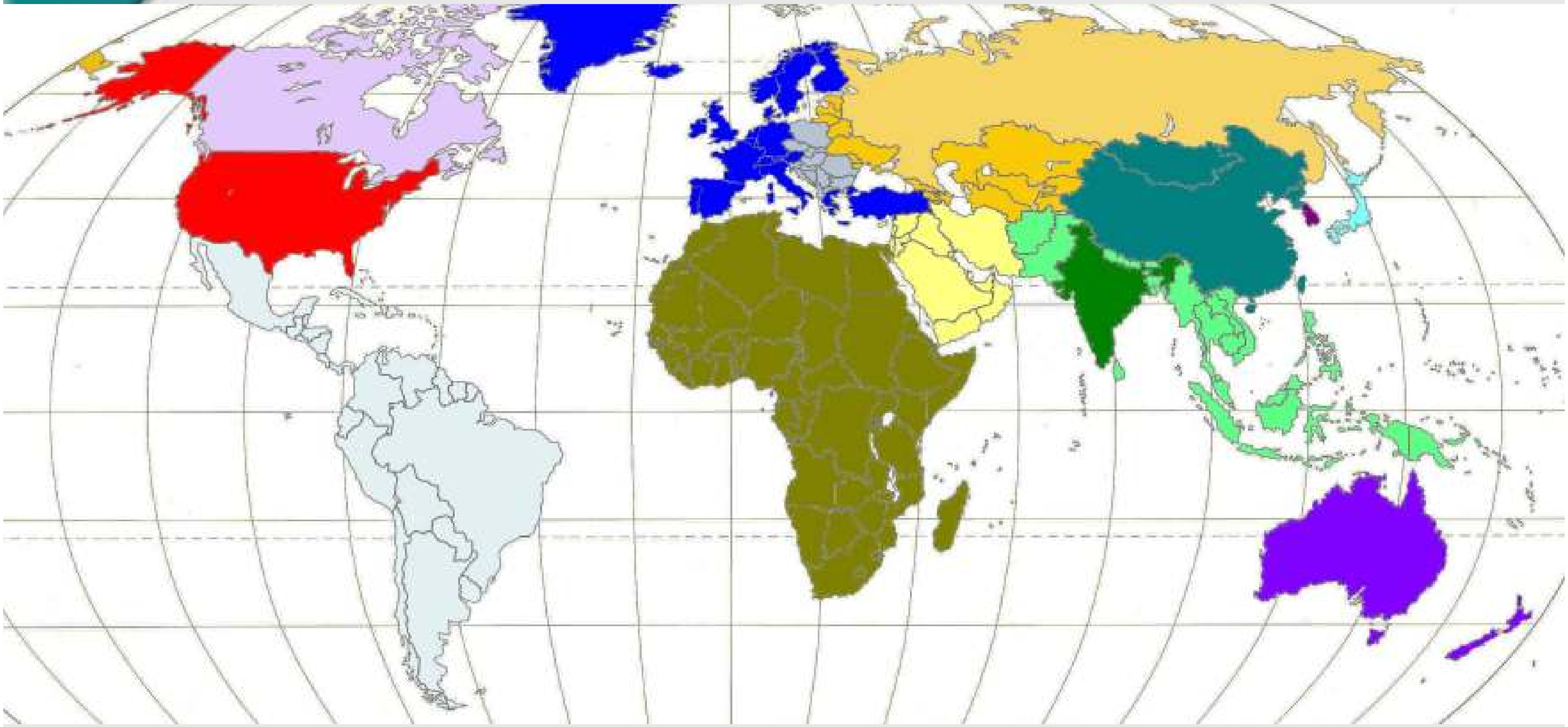
IA models are used to inform climate decision-making.

IA models have their roots in energy-economic modeling.

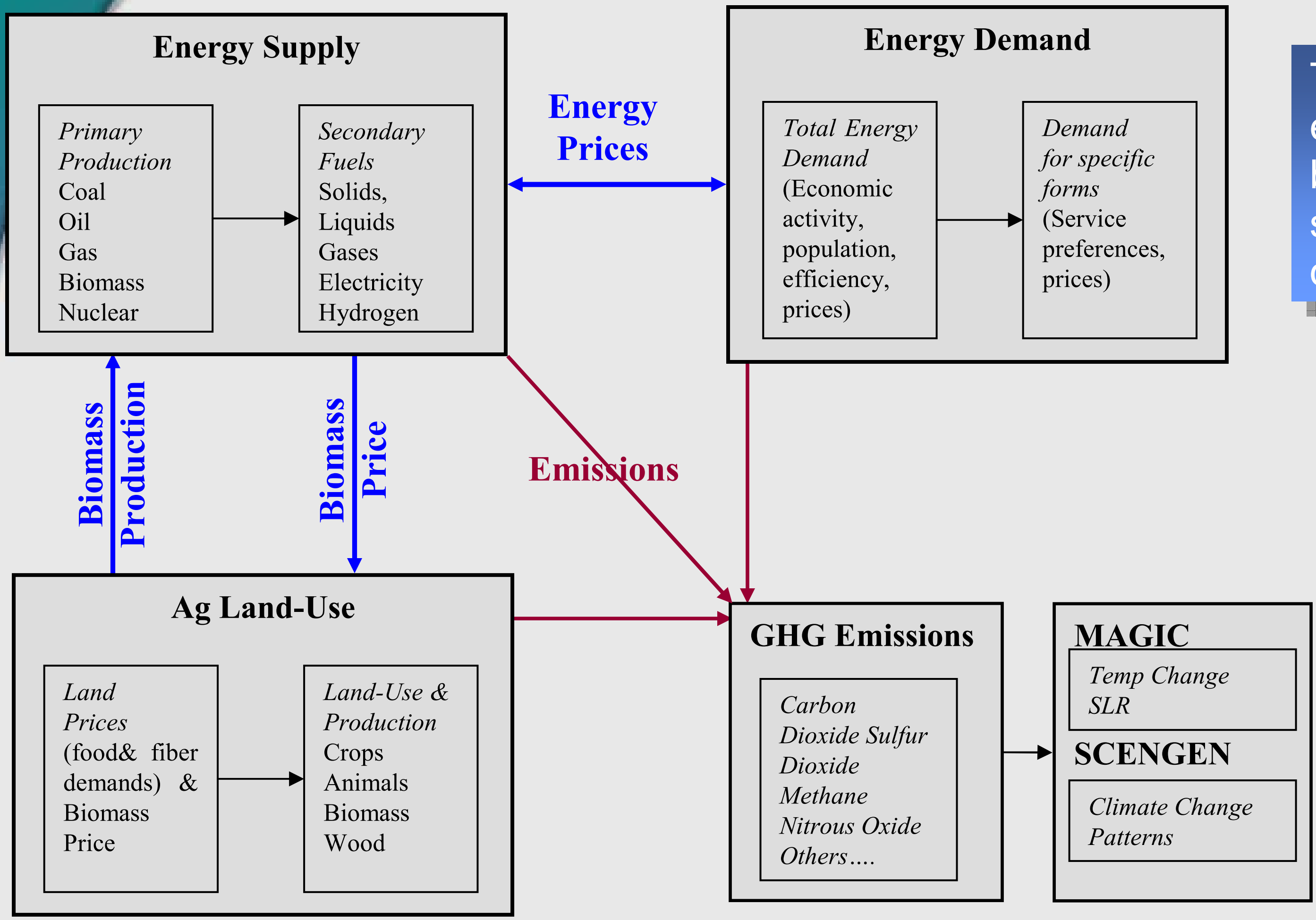
Integrated Assessment Modeling: IA Research and IA Models at JGCRI



14 MiniCAM Regions

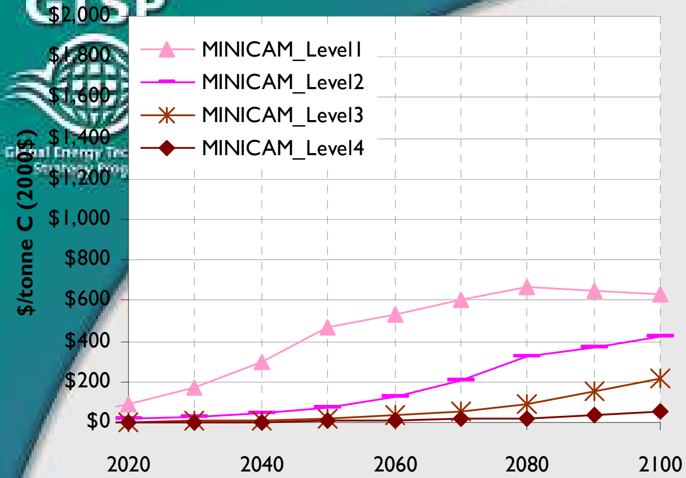


Schematic of MiniCAM

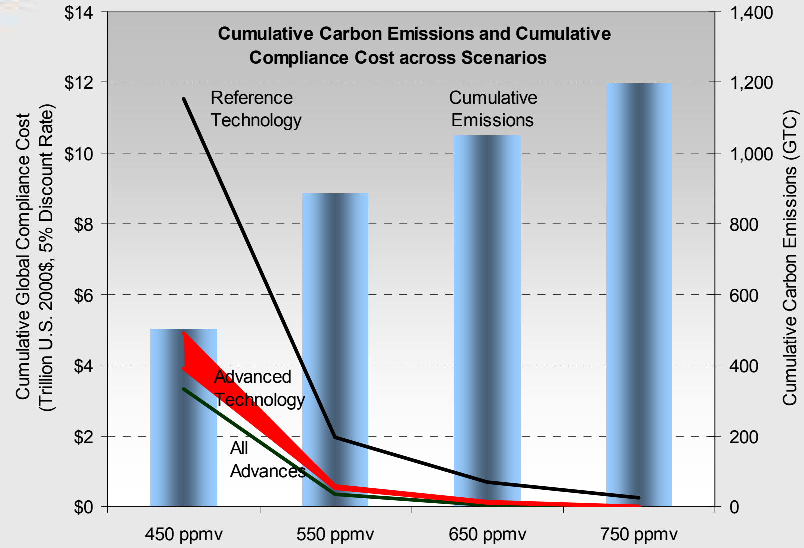


The final equilibrium is based on equating supplies and demands.

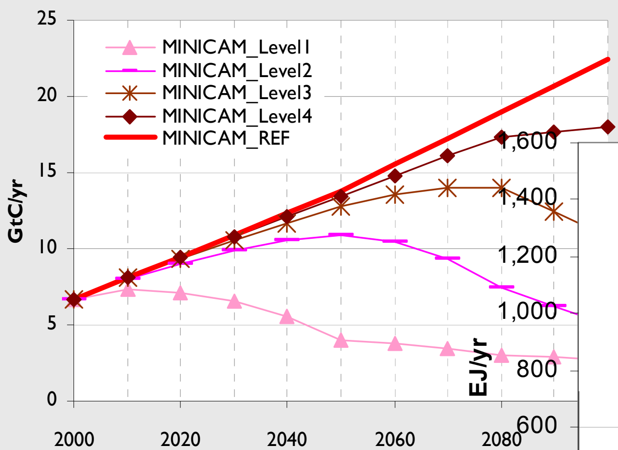
Climate and carbon cycle inform the paths/approaches to stabilization.



The value of carbon

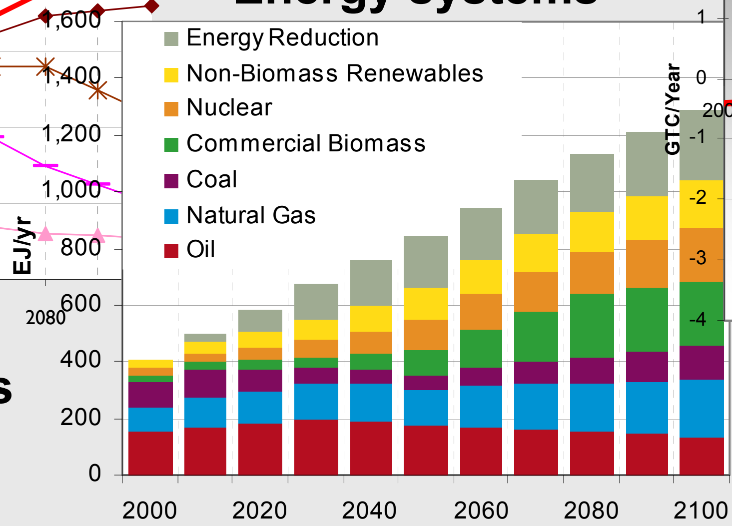


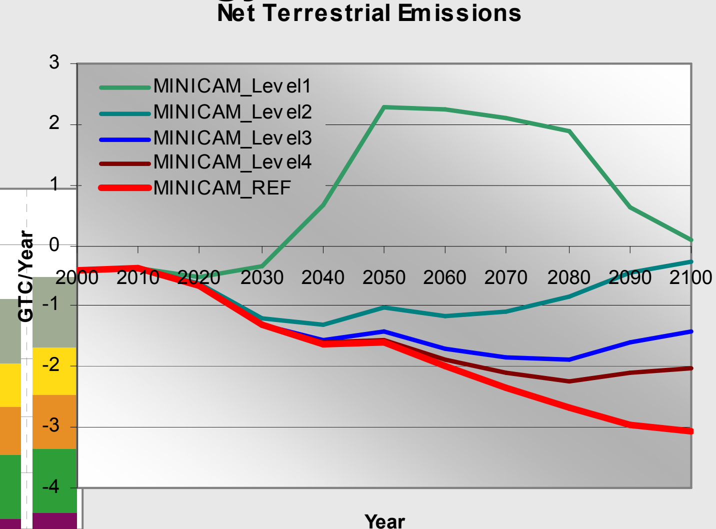
The value of technology



Emissions Pathways

Energy systems





Feedbacks/Dynamics

The CCSP Scenarios

GTSP

Global Energy Technology Strategy Program

The CCSP Strategic Plan called for 21 synthesis and assessment products

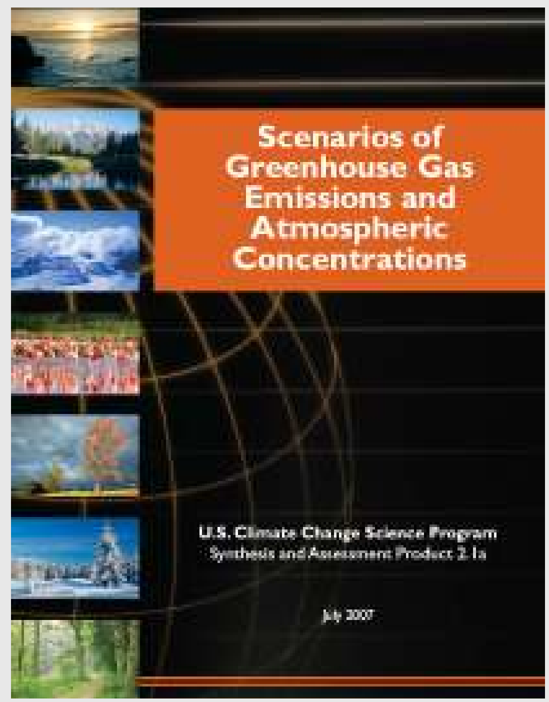
Goal 1: Extend knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed changes

Goal 2: Improve understanding of the forces bringing about changes in the Earth's climate and related systems

Goal 3: Reduce uncertainty in projections of how the Earth's climate and environmental systems may change in the future

Goal 4: Understand the sensitivity and adaptability of different natural and managed systems to climate and associated global changes

Product 2.1: Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with the CCTP. Review of integrated scenario development and application.



Study Design

- Three modeling teams
  - MIT (IGSM) – Henry Jacoby, John Reilly
  - PNNL (MiniCAM) – Jae Edmonds, Hugh Pitcher
  - EPRI (MERGE) – Rich Richels
  - Coordinator – Leon Clarke
- From each team:
  - One reference scenario
  - Four stabilization scenarios
- Explore the emissions, energy, and economic implications of stabilization

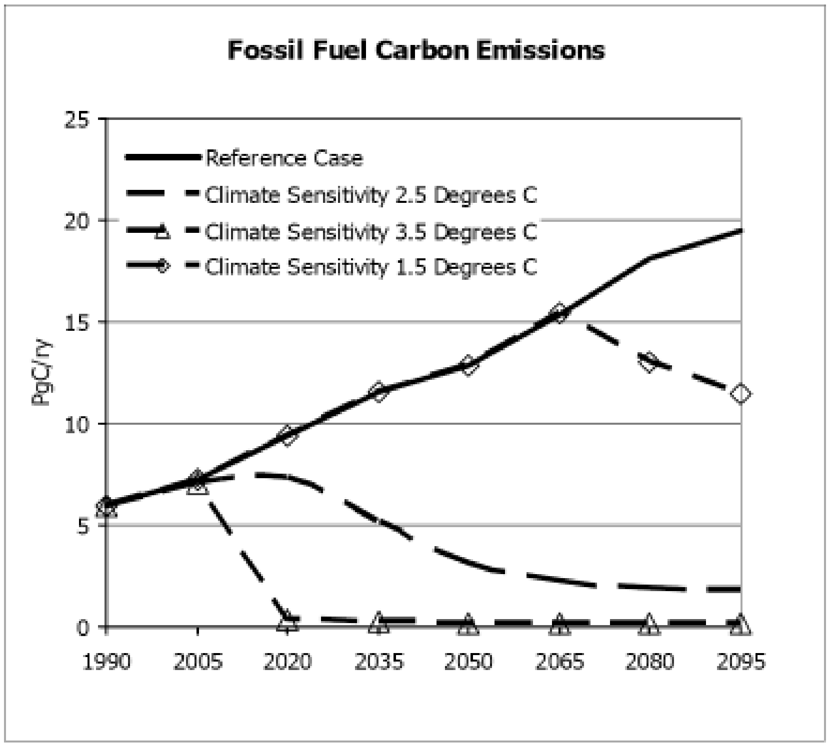
Study Design

- Stabilize greenhouse gases, not just CO_2
  - Stabilize total radiative forcing from CO_2, N_2O, CH_4, HFCs, PFCs, and SF_6
  - Other radiatively-important substances (e.g., aerosols) not included
- Long-term (many century) stabilization; study period through 2100.
- Four stabilization scenarios roughly consistent with 450 ppmv through 750 ppmv CO_2, along with one reference scenario.

	Total Radiative Forcing from GHGs (Wm^{-2})	Approximate Contribution to Radiative Forcing from non-CO_2 GHGs (Wm^{-2})	Approximate Contribution to Radiative Forcing from CO_2 (Wm^{-2})	Corresponding CO_2 Concentration (ppmv)
Level 1	3.4	0.8	2.6	450
Level 2	4.7	1.0	3.7	550
Level 3	5.8	1.3	4.5	650
Level 4	6.7	1.4	5.3	750
Year 1998	2.1	0.65	1.46	365

CCSP Product 2.1A stopped at radiative forcing

Figure 4: Carbon Emissions Pathways for Three Alternative Climate Sensitivity Values



Uncertainty in climate sensitivity has important ramifications for carbon emission pathways to stabilization.

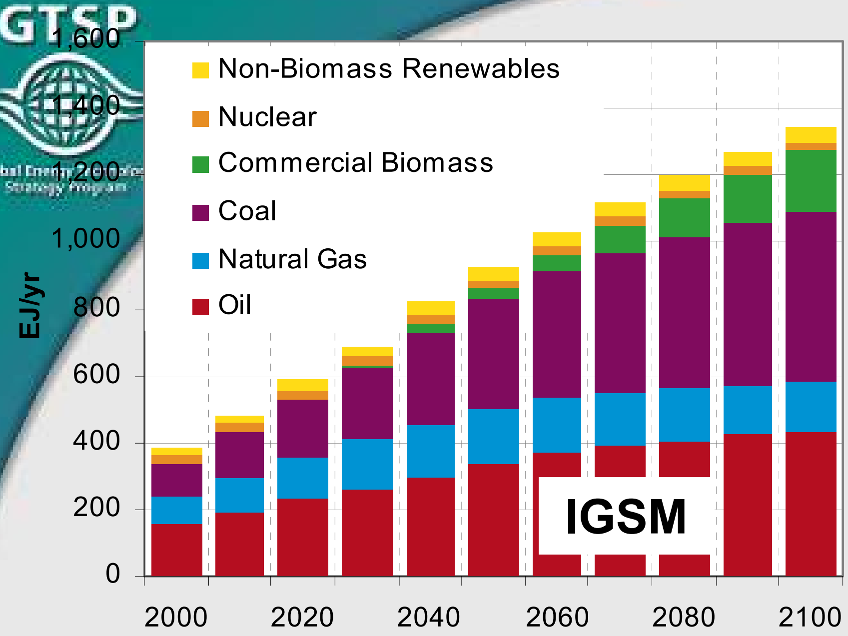
From Edmonds, J. and S. Smith (2006), The technology of two degrees, Chapter 41 in *Avoiding Dangerous Climate Change*, Shellnhuber, H., Cramer, W., Nakicenovic, N., Wigley, T., and Yohe, G., eds., Cambridge University Press.

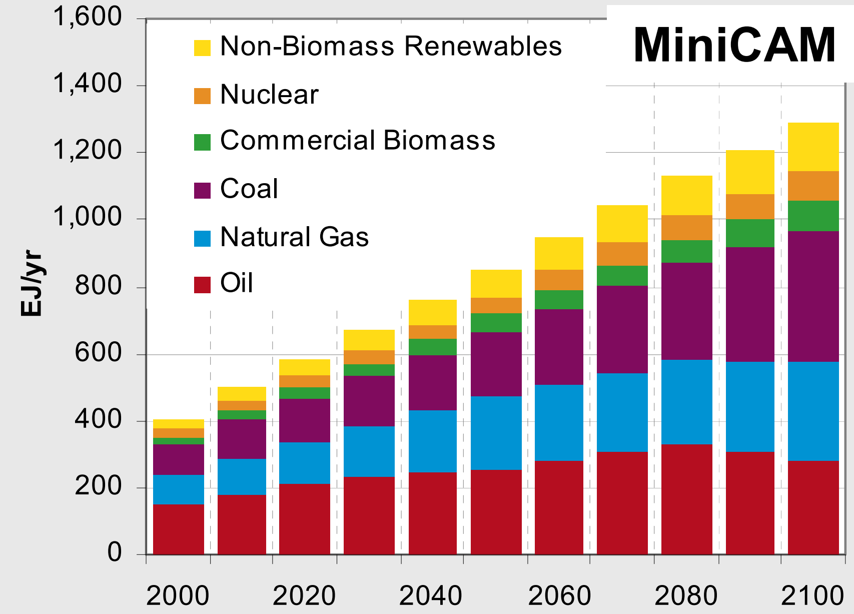
Study Design

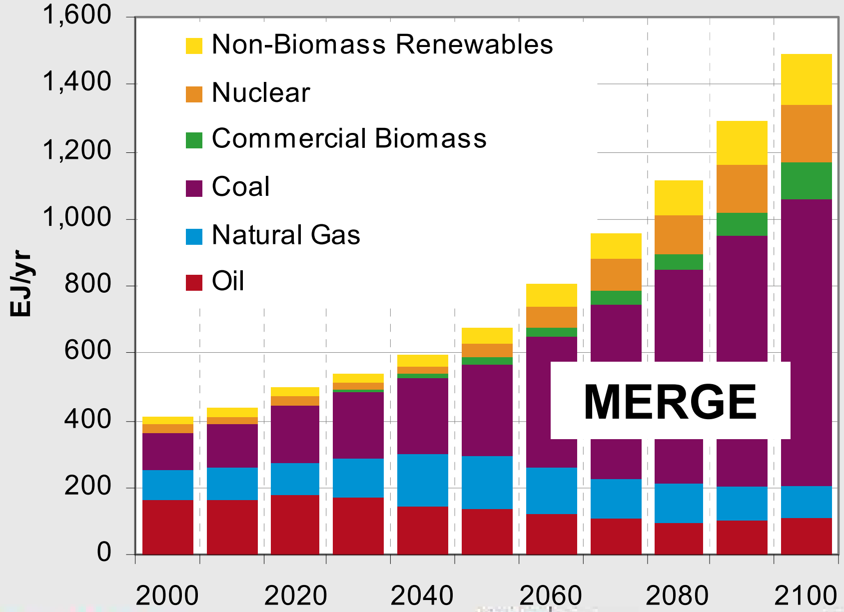
- All modeling groups assume existing climate programs (Kyoto, U.S. intensity target) but then assume perfect where, when, and what flexibility going forward.
- Assumptions (e.g., population, economic growth, technological change) developed individually by the modeling groups.
- No likelihoods assigned to any scenarios or parameters.
  - Teams directed to develop assumptions they consider “plausible” and “meaningful”.
  - These are not the only sets of assumptions that these three modeling teams could have developed.

THIS IS NOT A COST-BENEFIT ANALYSIS

The Reference Scenarios

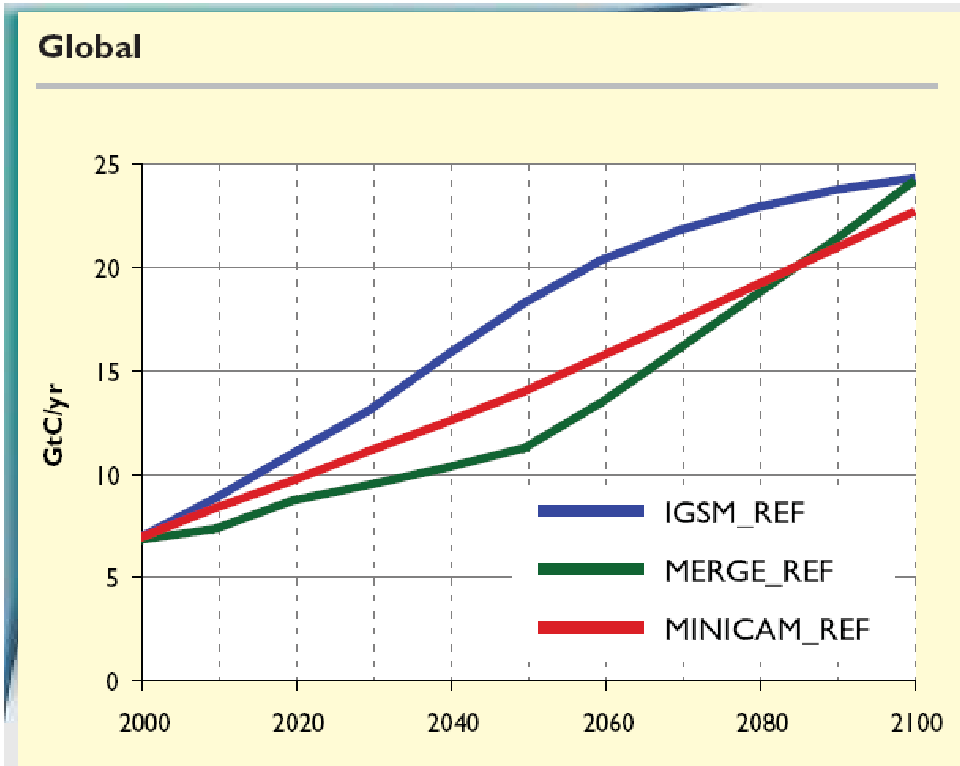


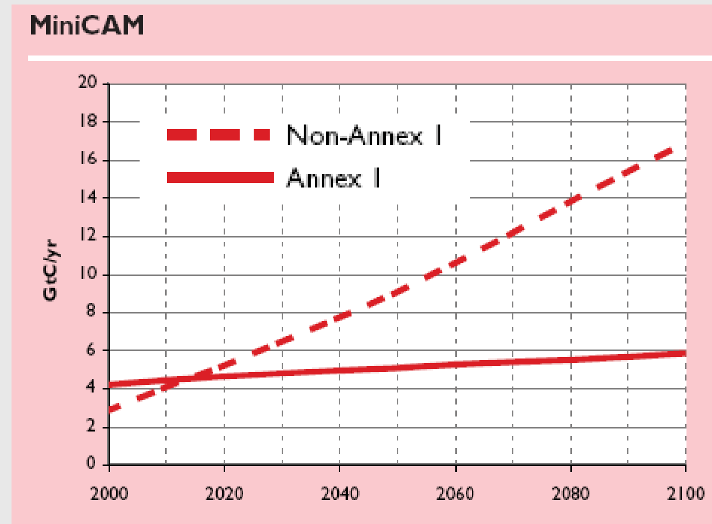


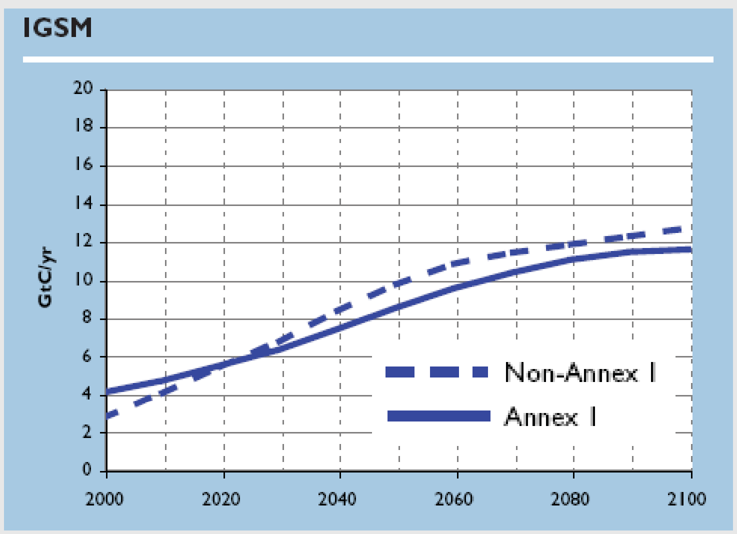


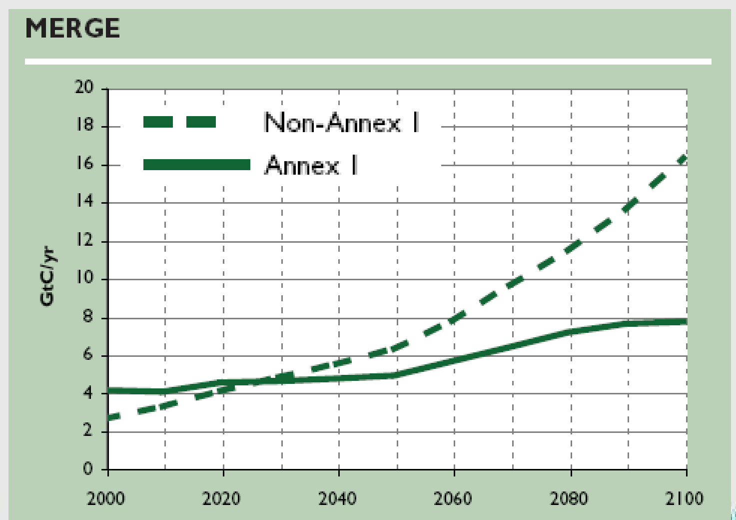
- **Primary energy** grows to between three and four times today's levels by the end of the century.
- All models envision penetration of fossil alternatives for conventional oil
- Substantial growth in sources that don't emit carbon
- But fossil fuels remain the dominant energy source.

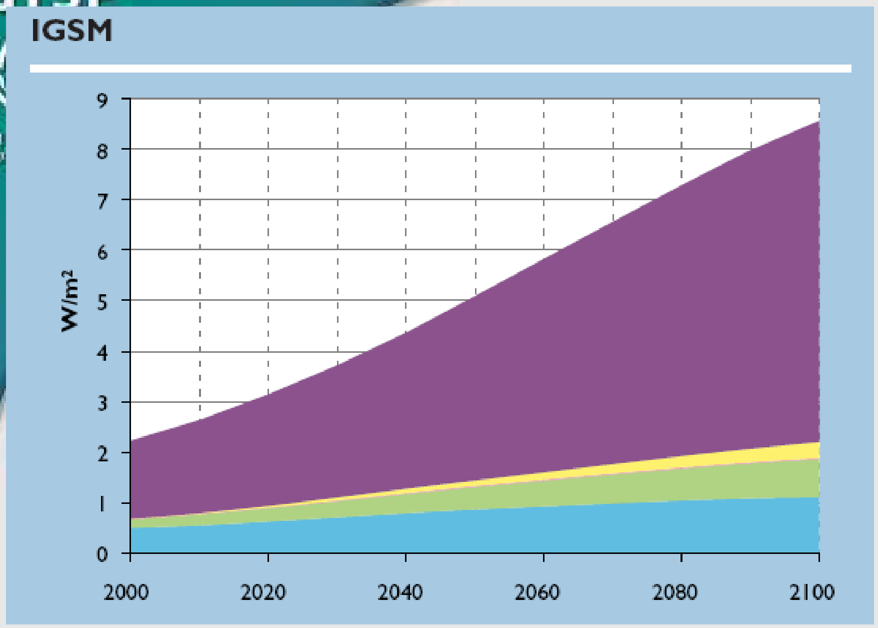
Continually increasing CO_2 emissions over the coming century with important transitions in emitting countries.

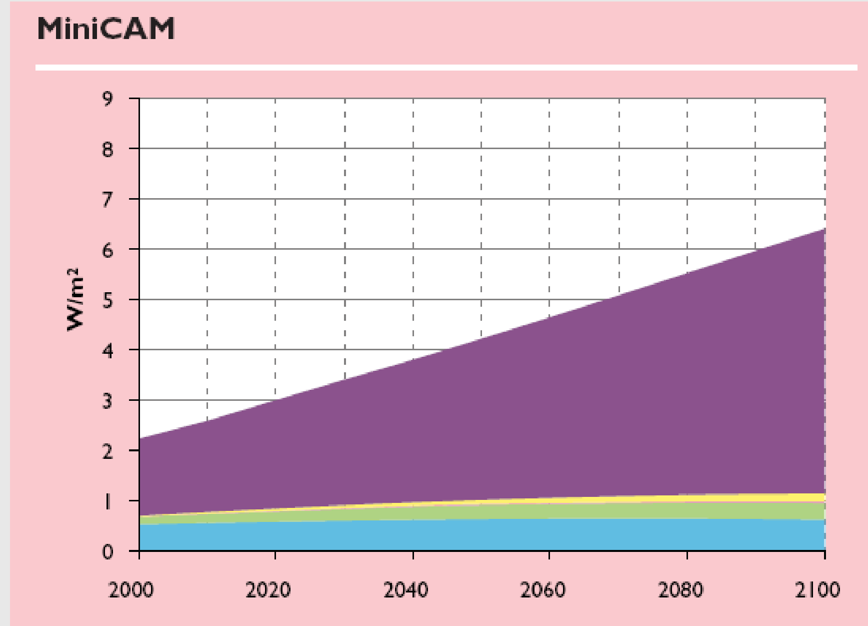


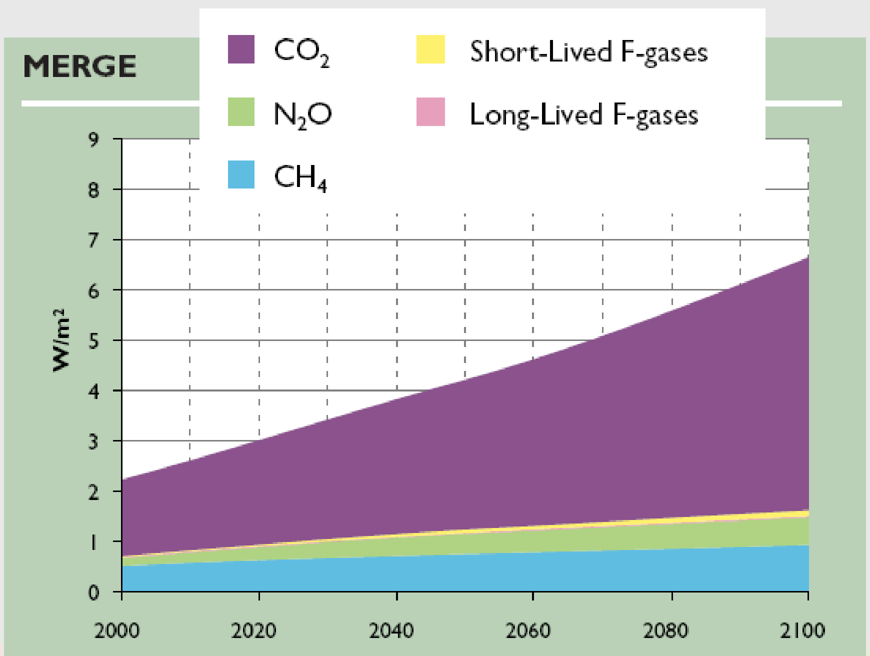






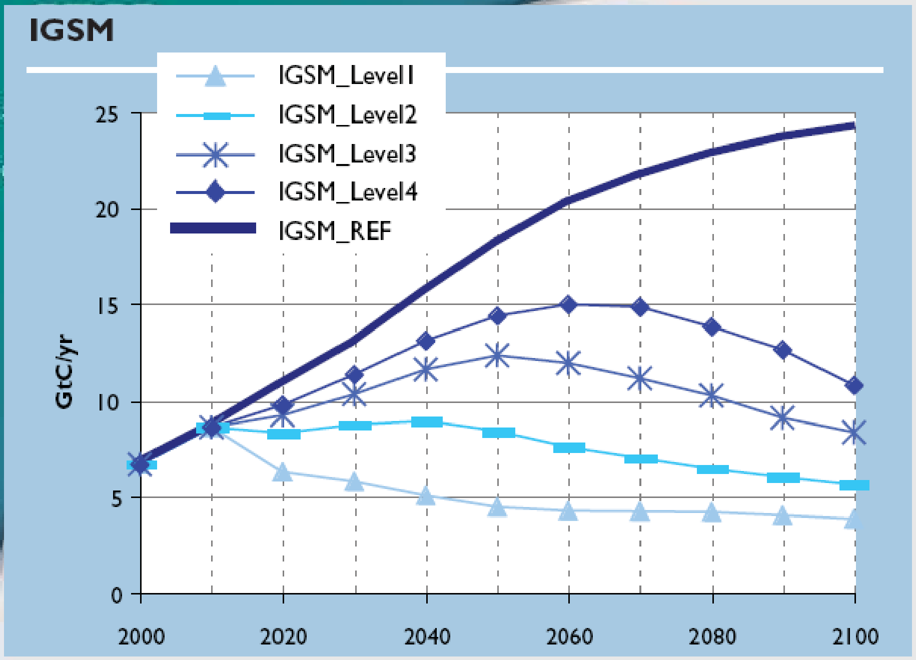


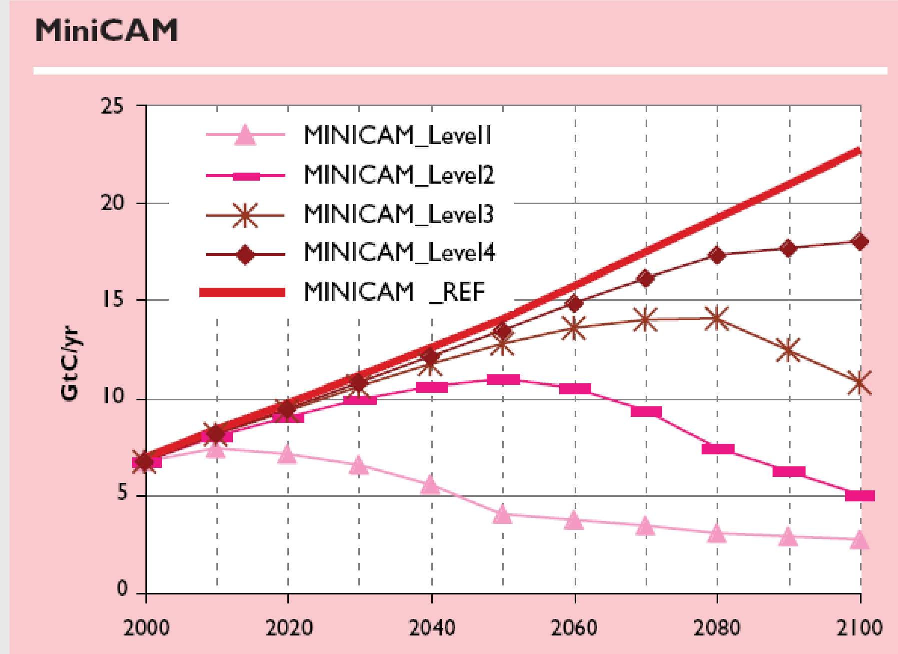


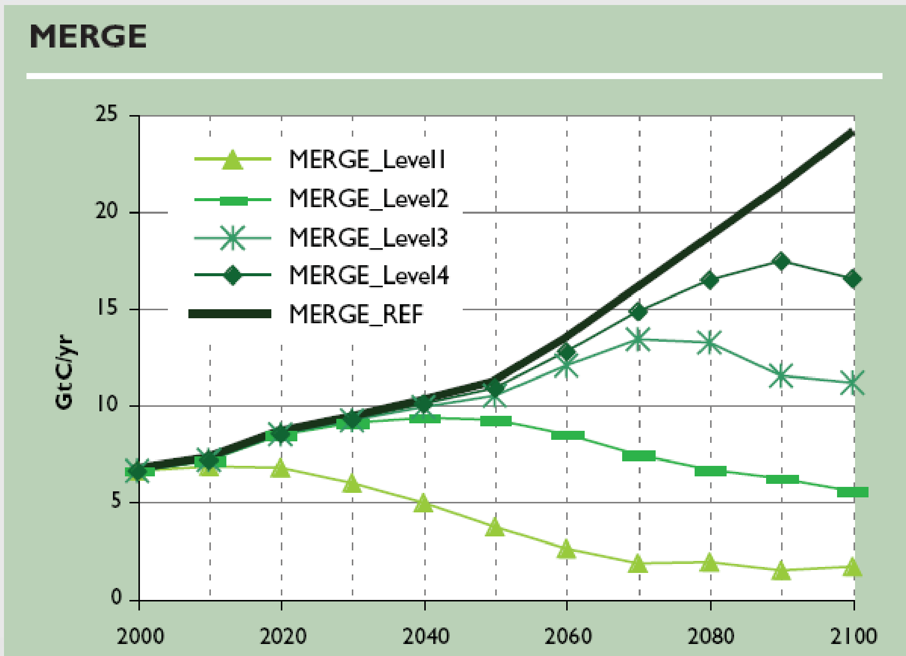


- **Radiative forcing** trajectories are not consistent with stabilization at any of the four levels considered in the exercise
- CO_2 takes on an increasingly large share of radiative forcing in all three scenarios
- Contributions of non-CO_2 GHGs vary among the models

Stabilization Scenarios

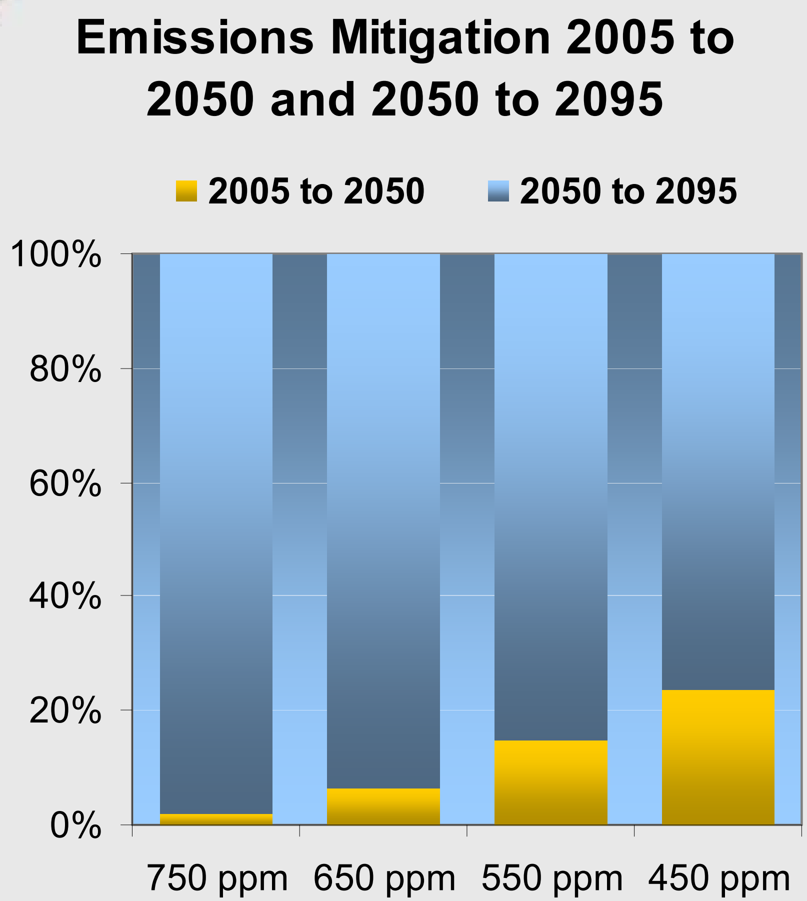






- **Fossil and Other Industrial Emissions** ultimately decline toward the rate at which emissions are balanced by removal processes.
- Stabilization at 450 ppmv is has fundamentally different implications than stabilization at 550 ppmv and above.
- Emissions pathways are not identical across models.

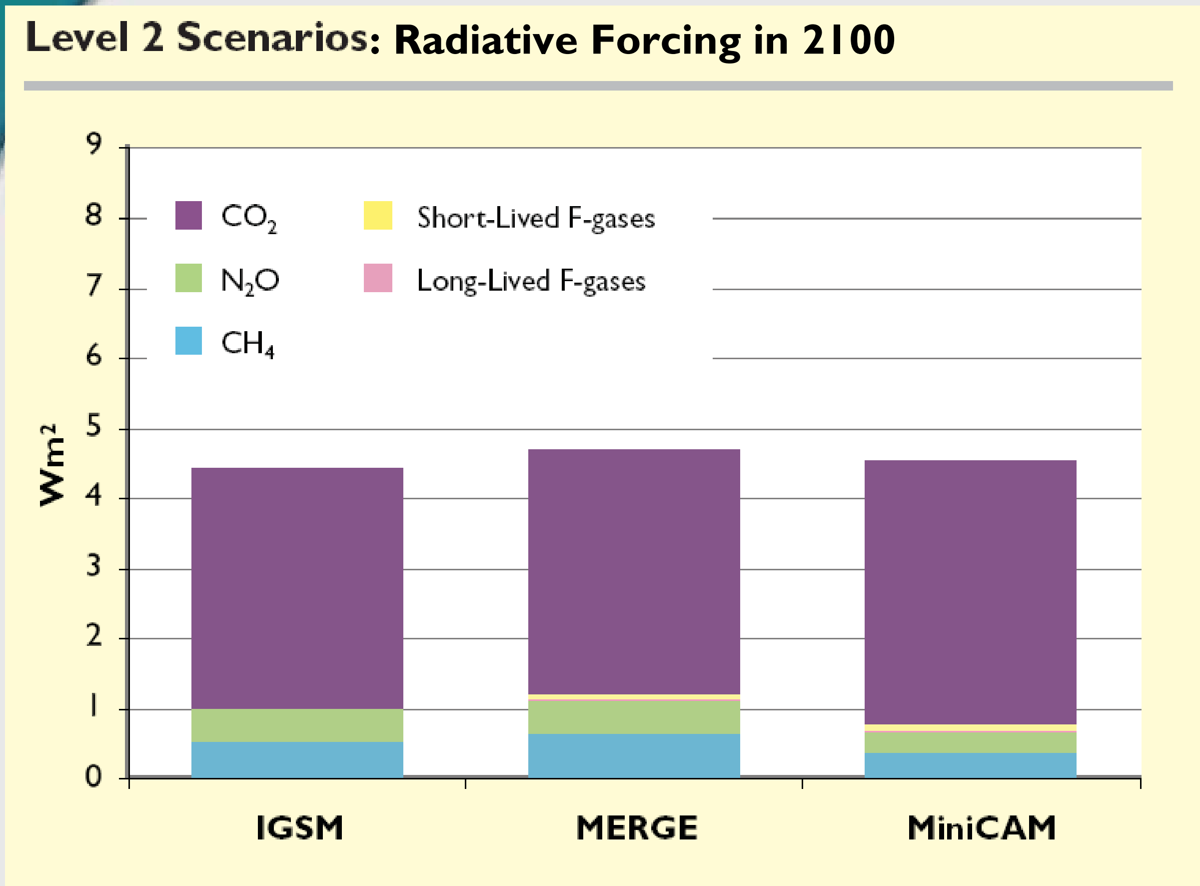
CO_2 emissions mitigation during 2005 to 2050 is just the start



- The time scale of emissions mitigation is a century or more.
- Energy technology will be needed to help control emissions in the NEAR-, MID-, and Long-term to address climate change.

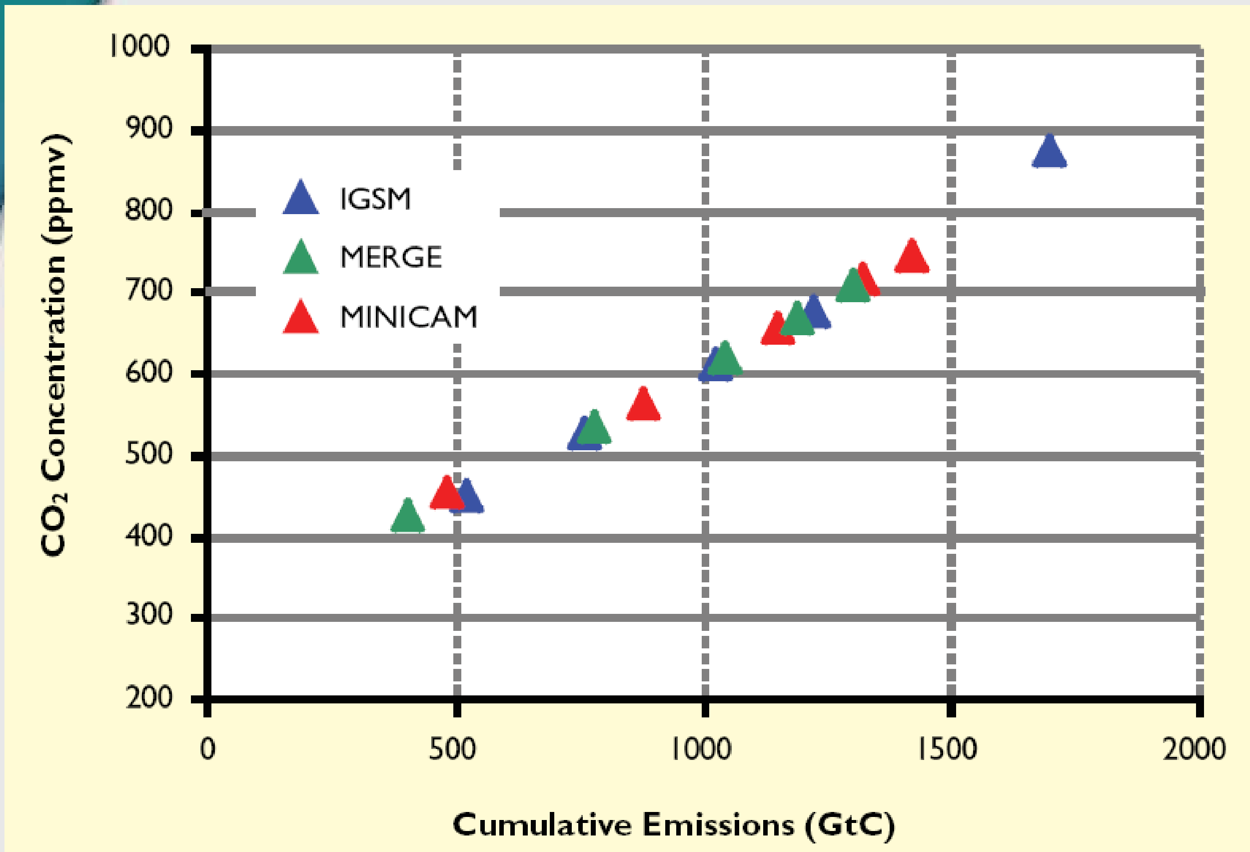
From Edmonds, J., Wise, M., Dooley, J., Kim, S., Smith, S., Runci, P., Clarke, L., Malone, E., and Stokes, G., 2007, *Global Energy Technology Strategy, Addressing Climate Change: Phase 2 Findings from an International Public-Private Sponsored Research Program*, Battelle Memorial Institute.

CO_2 emissions pathways vary across models



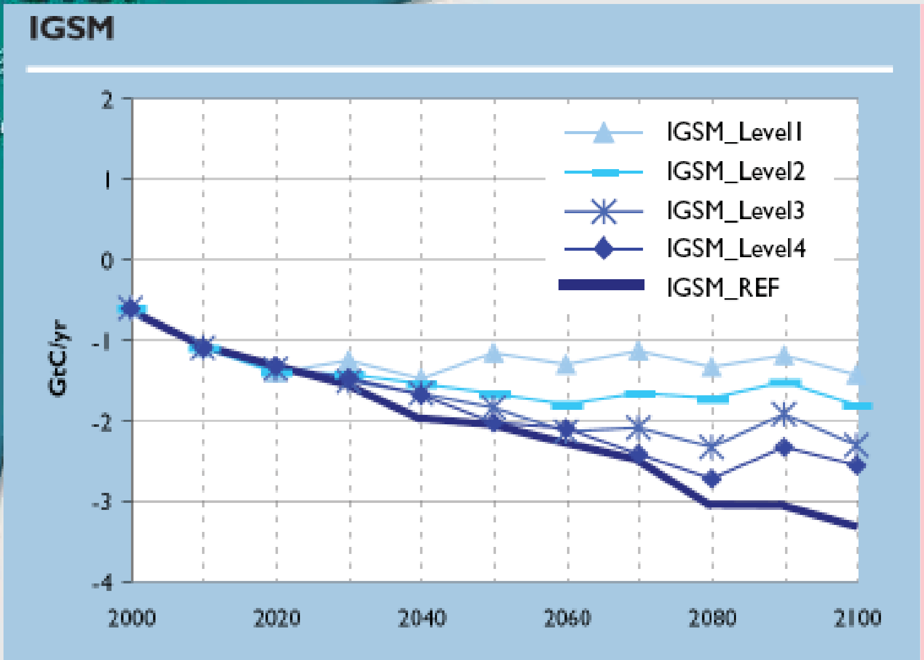
Differing contributions from non-CO_2 greenhouse gases

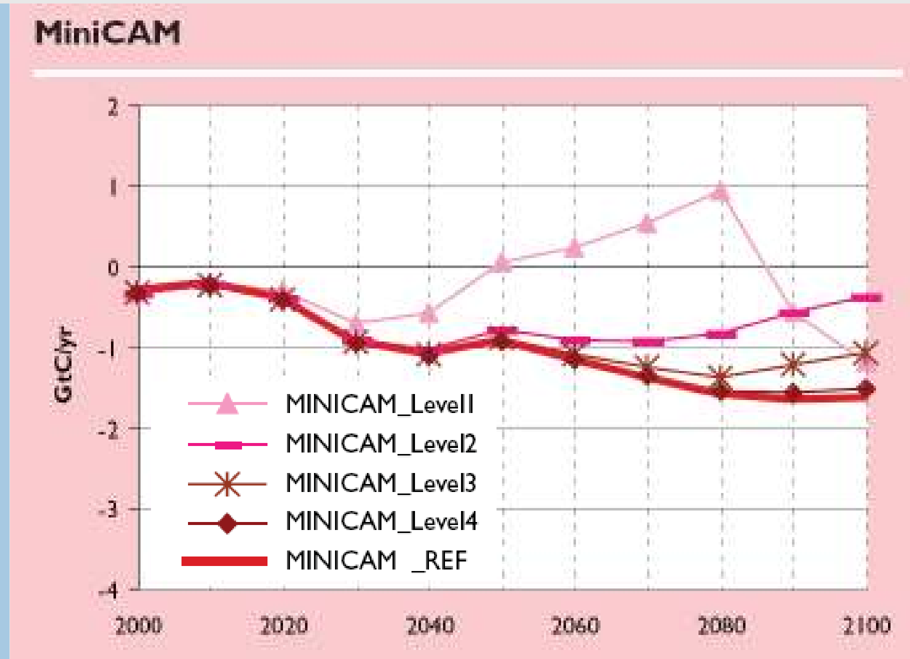
CO_2 emissions pathways vary across models

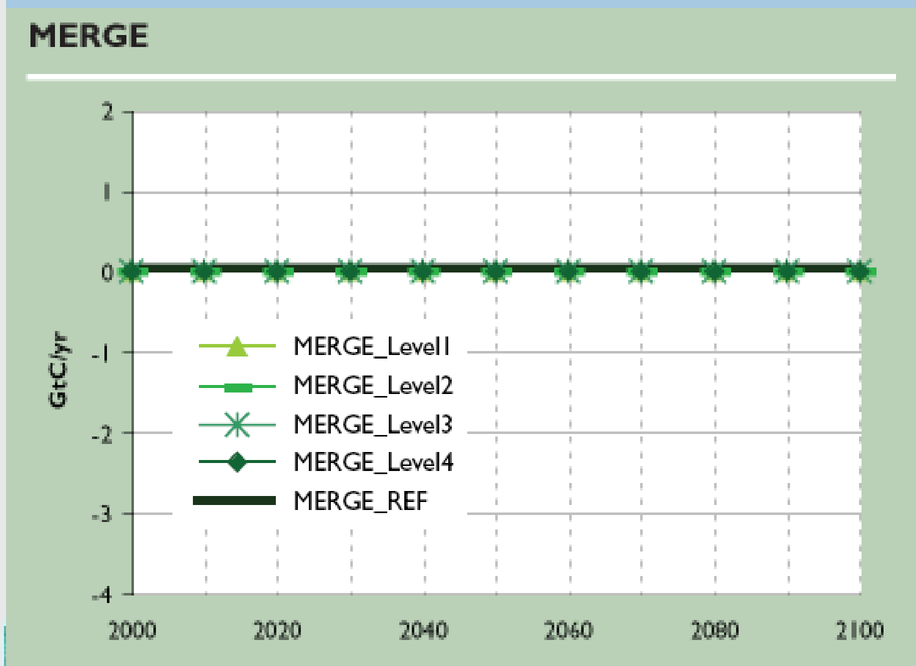


Relationship between cumulative emissions and concentrations

GTSP







NET TERRESTRIAL EMISSIONS

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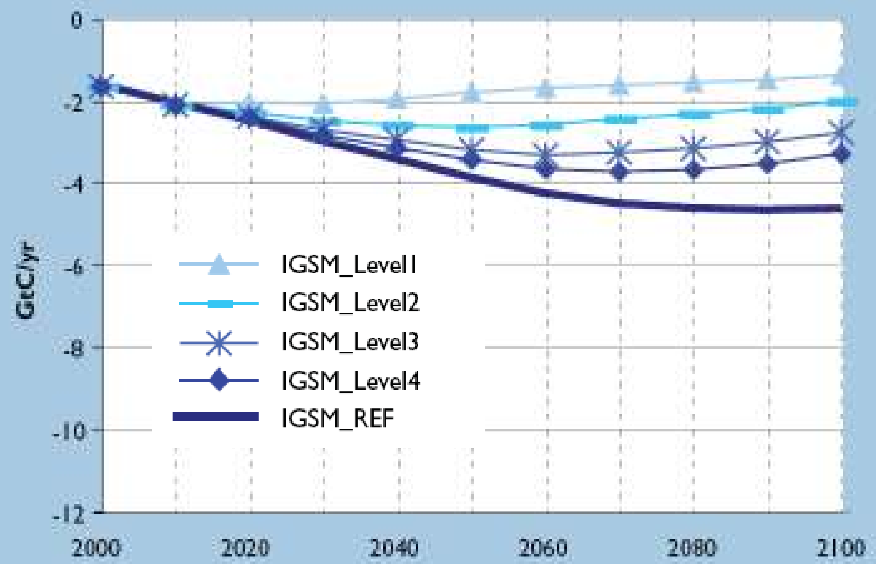
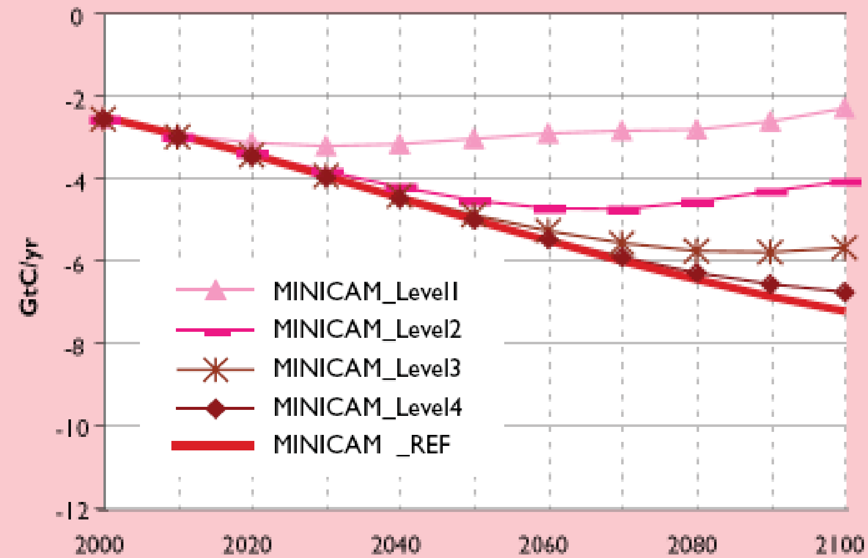
GTSP

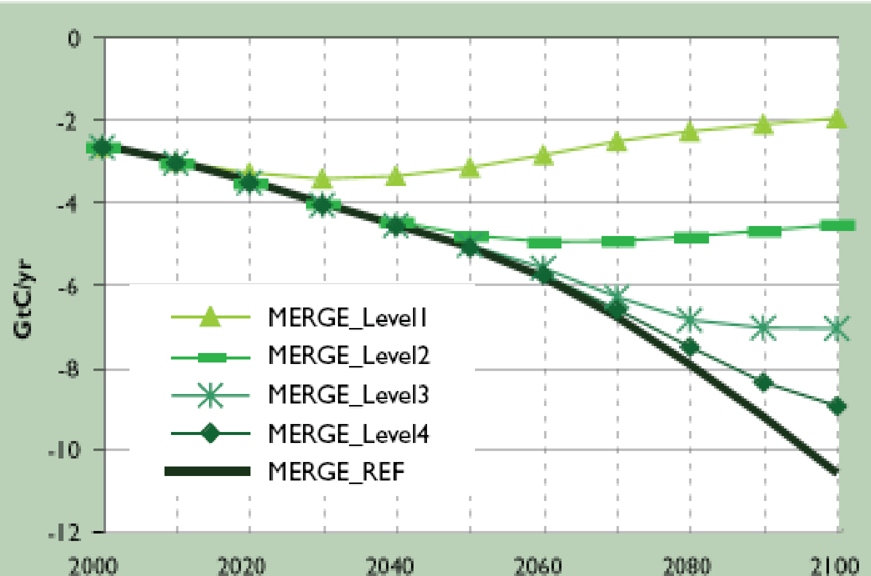
IGSM



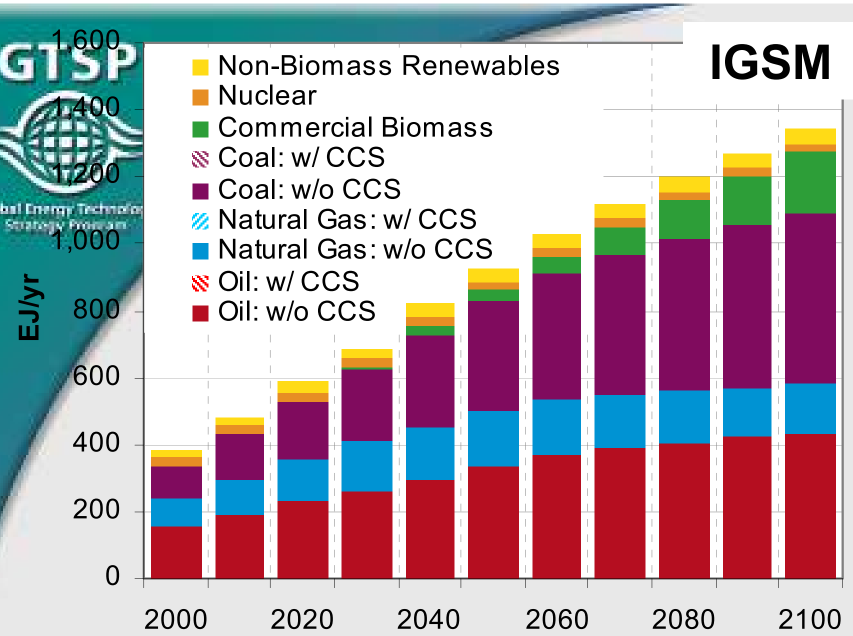
MiniCAM

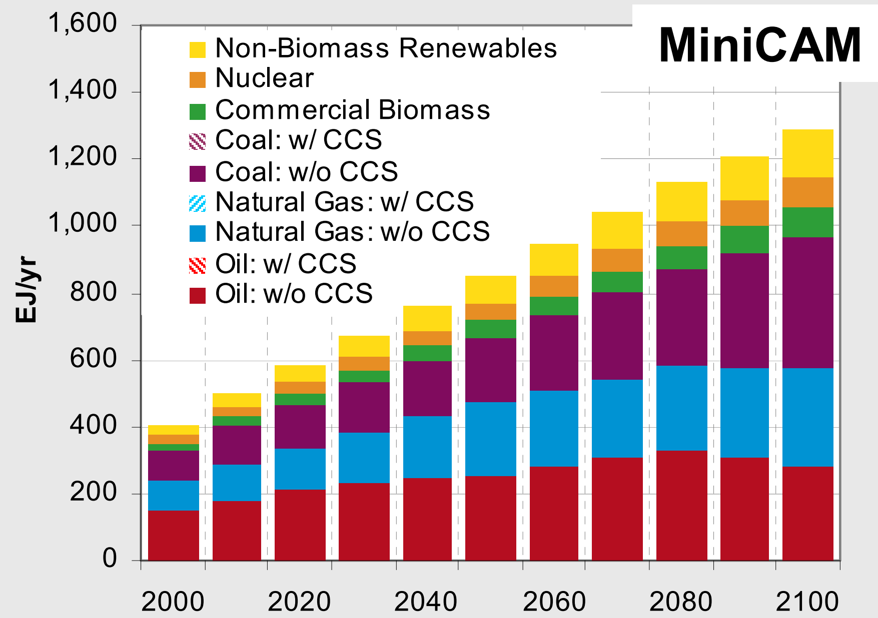


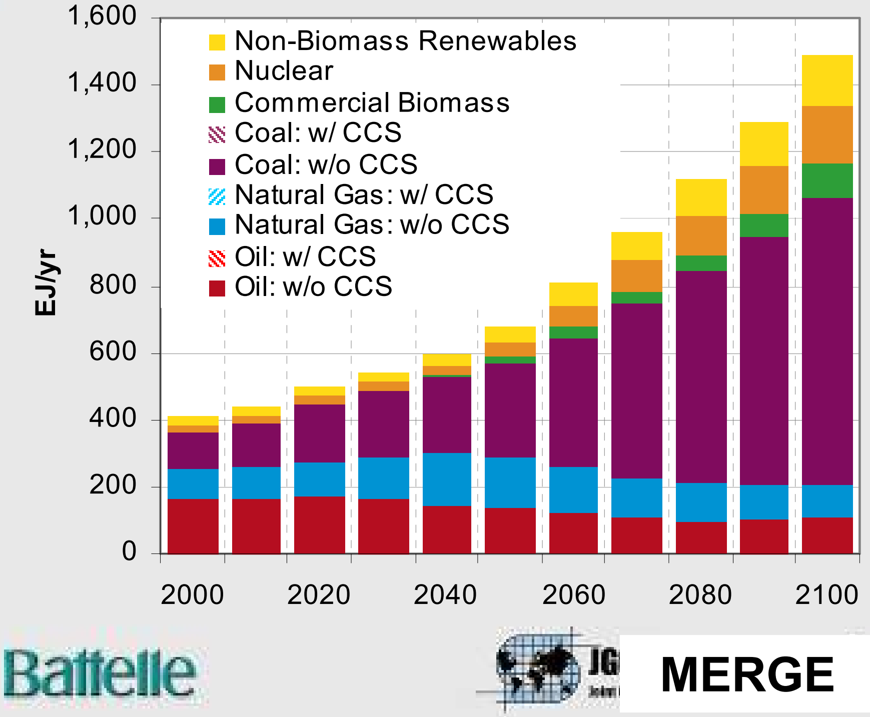
MERGE



OCEAN UPTAKE

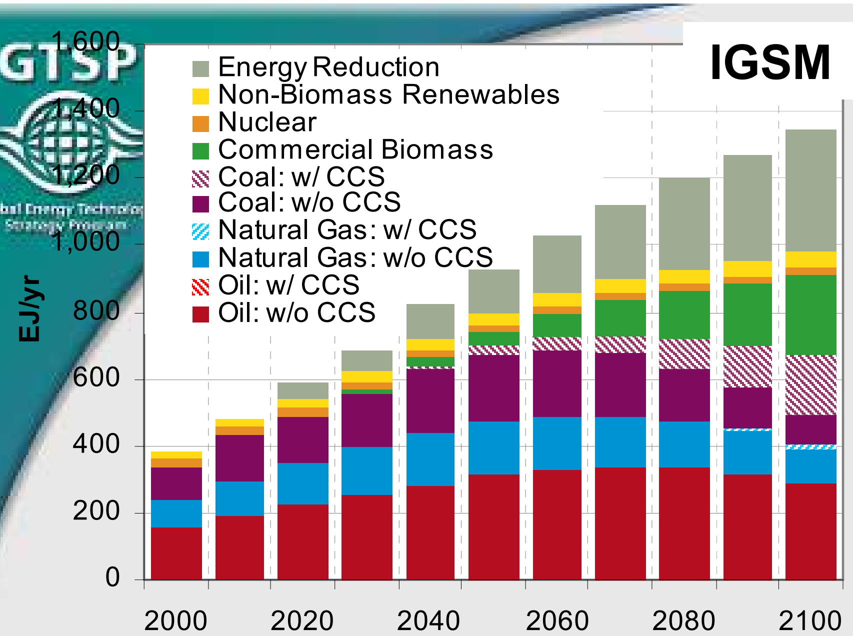


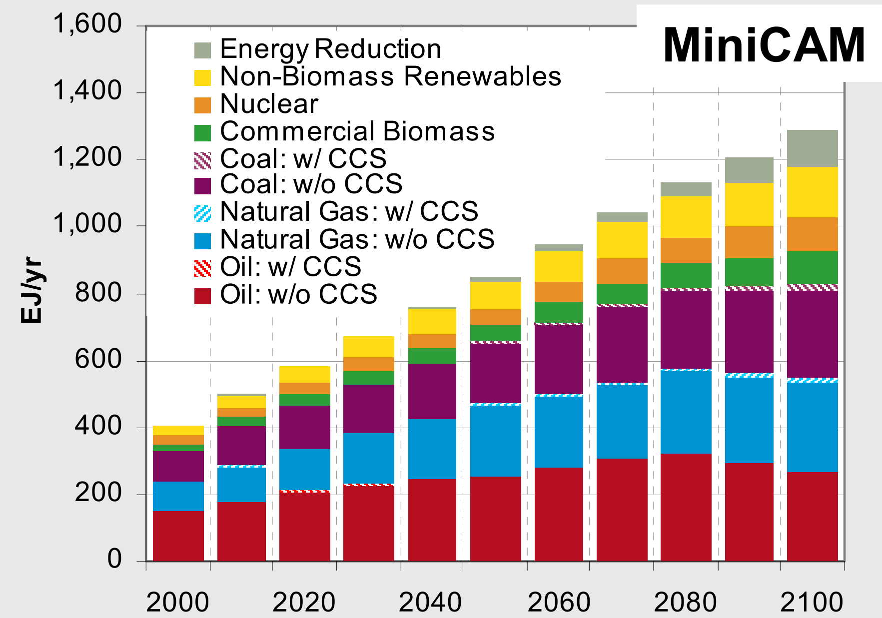




PRIMARY ENERGY (Reference)

- Stabilization requires substantial changes in the energy system
- The models present very different approaches to this evolution
- All of the scenarios maintain a heterogeneous energy mix





PRIMARY ENERGY (Level 4, 750 ppmv)

- Stabilization requires substantial changes in the energy system
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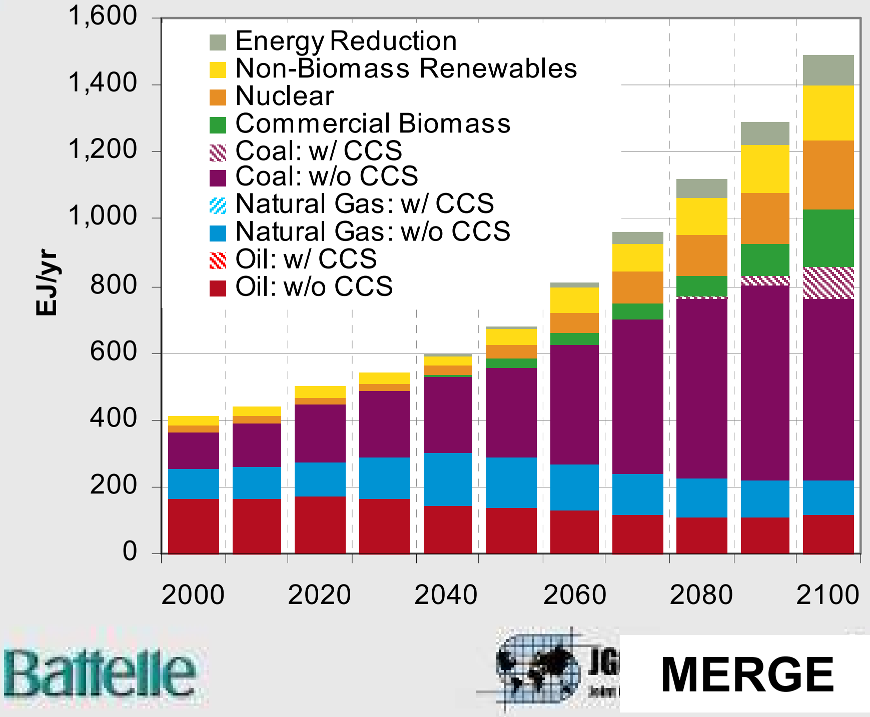
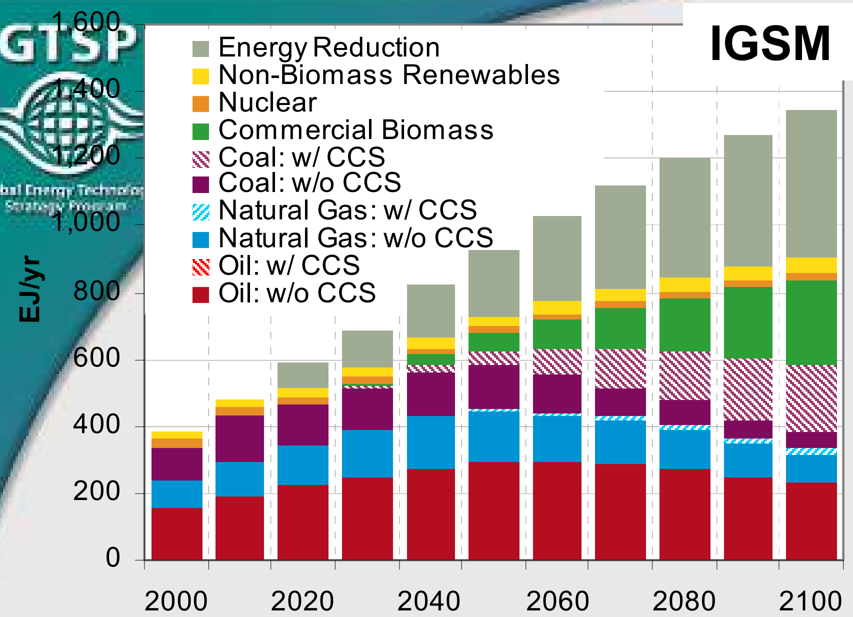
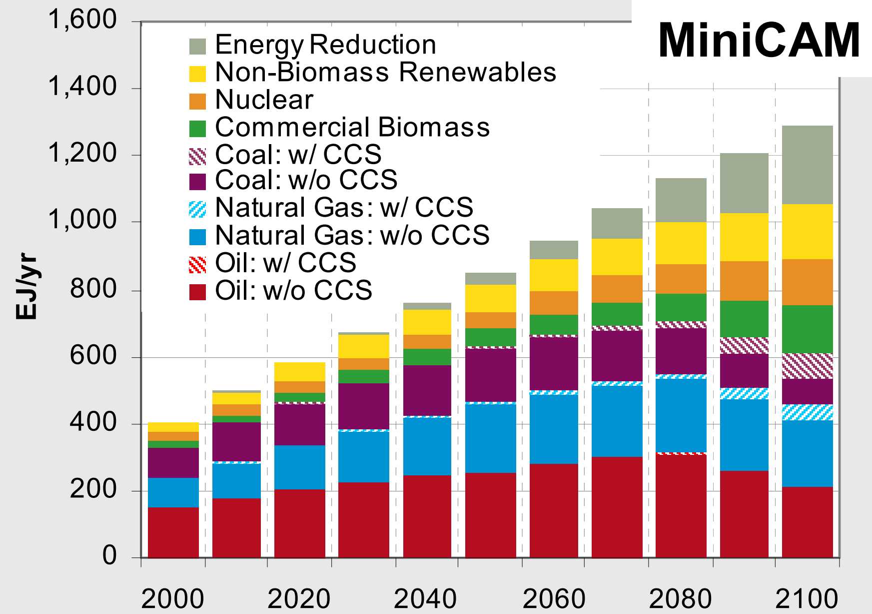
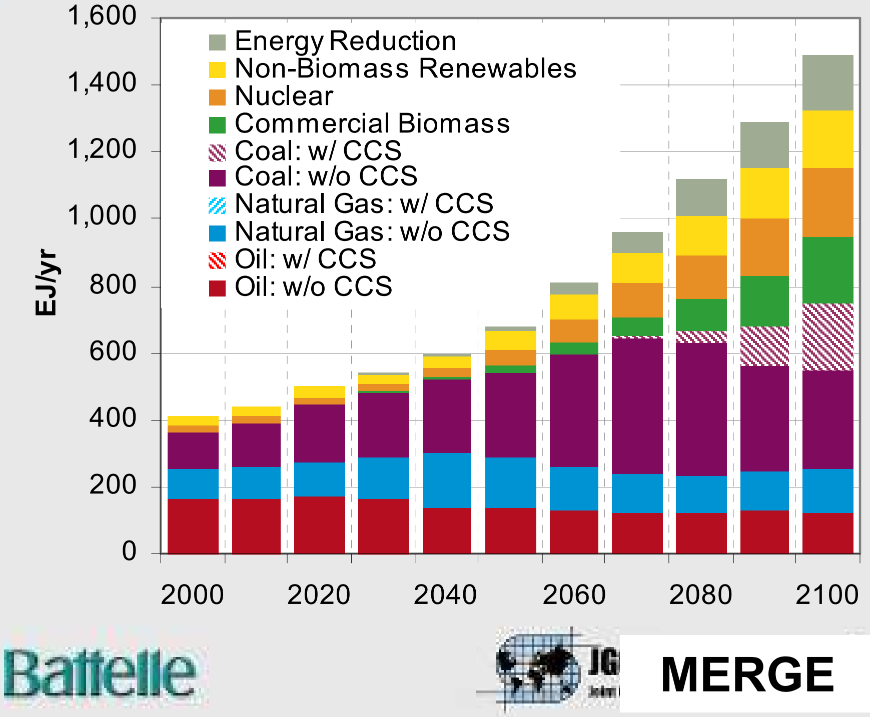
- All of the scenarios maintain a heterogeneous energy mix









PRIMARY ENERGY (Level 3, 650 ppmv)

- Stabilization requires substantial changes in the energy system
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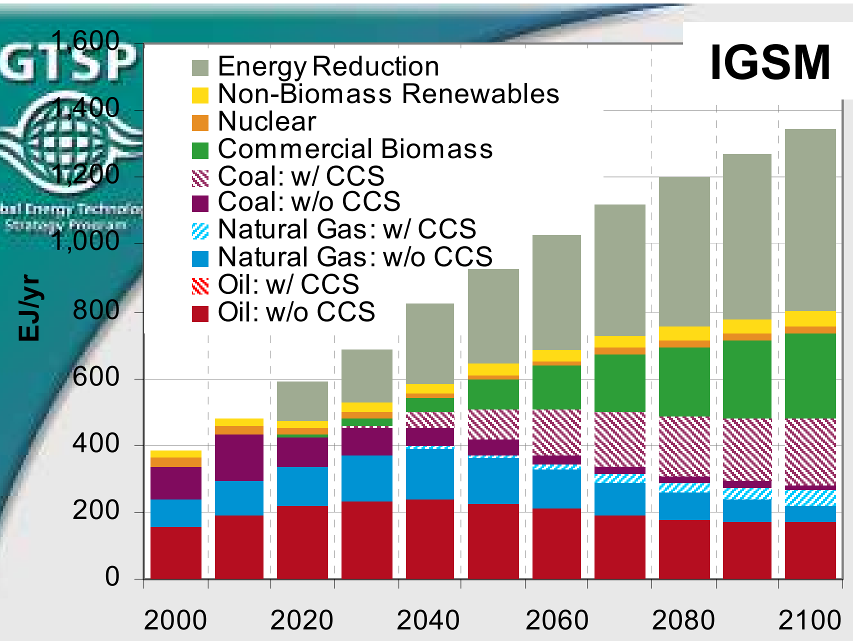

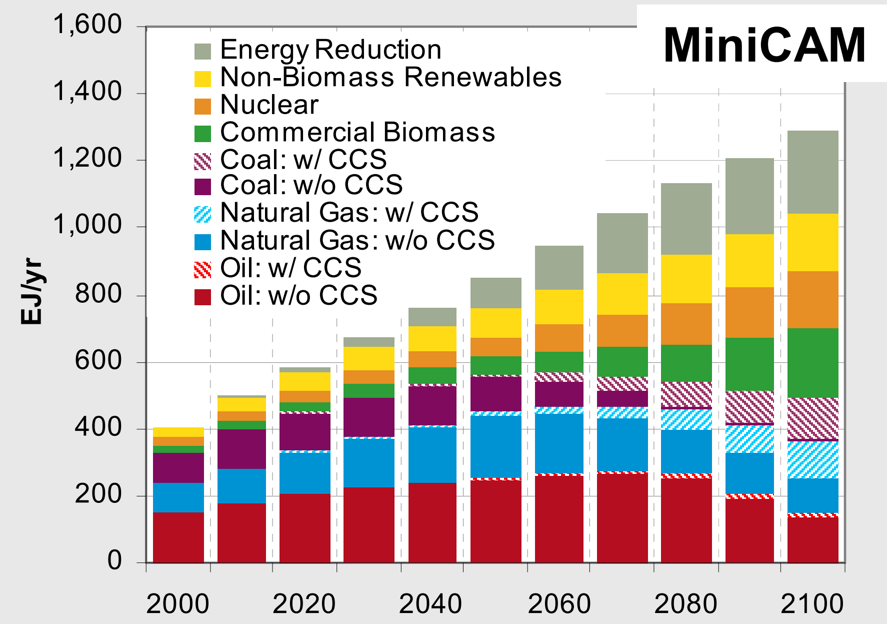

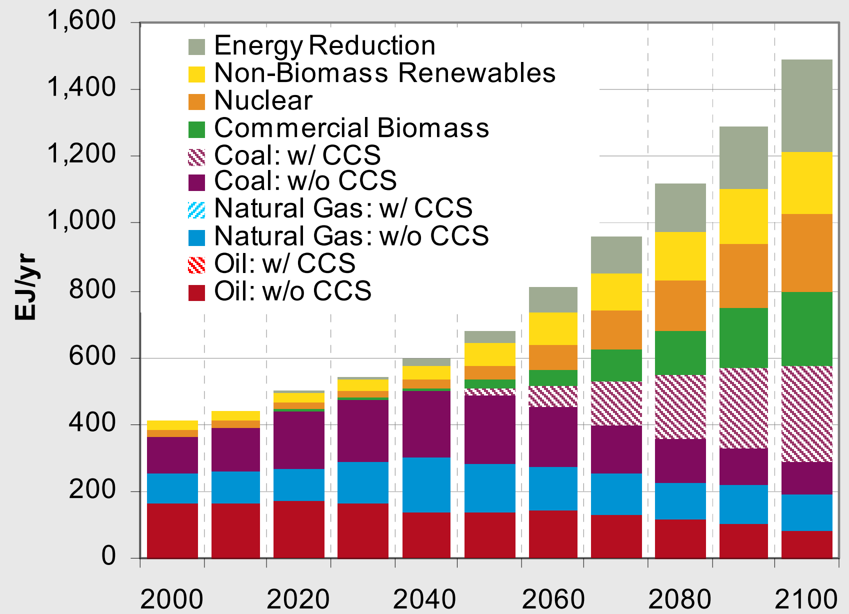

PRIMARY ENERGY (Level 2, 550 ppmv)

- Stabilization requires substantial changes in the energy system
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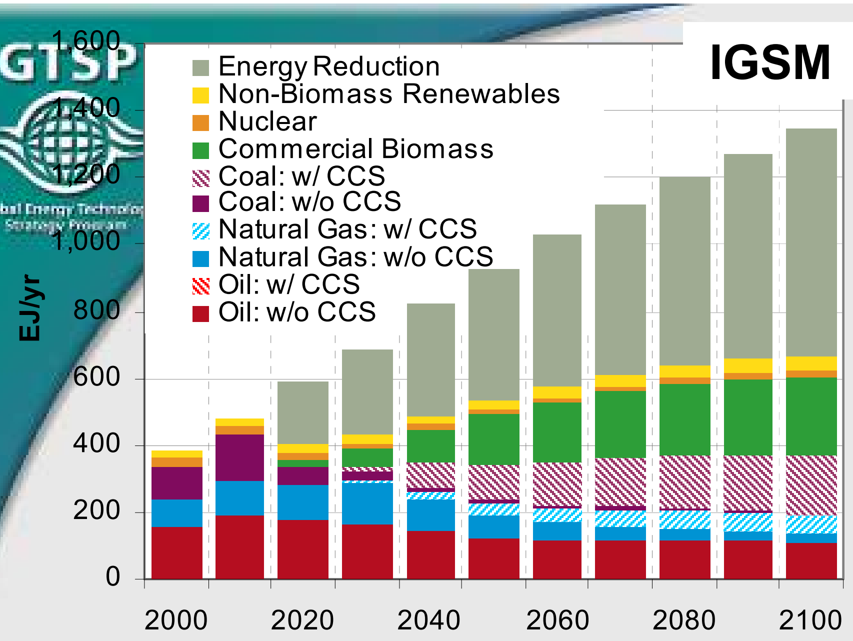
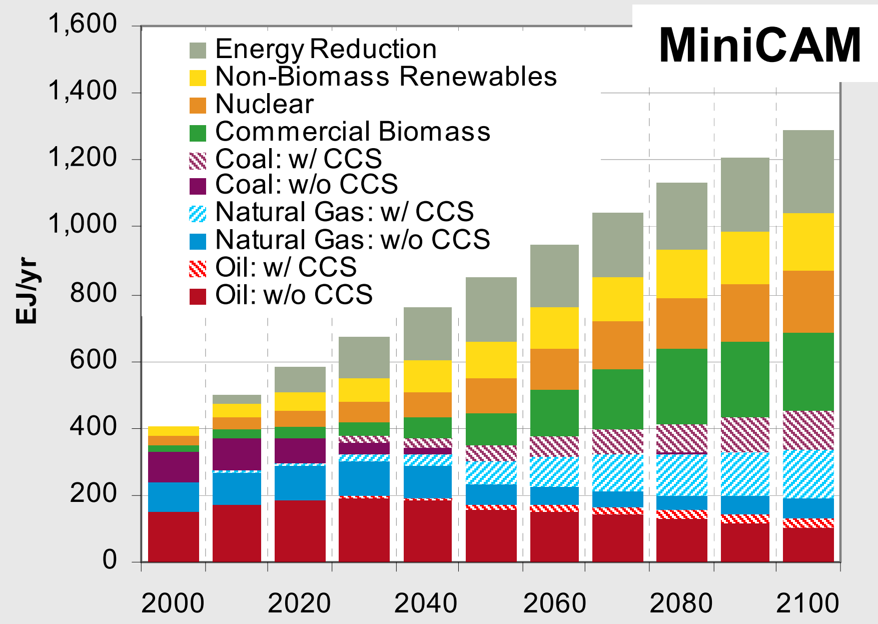
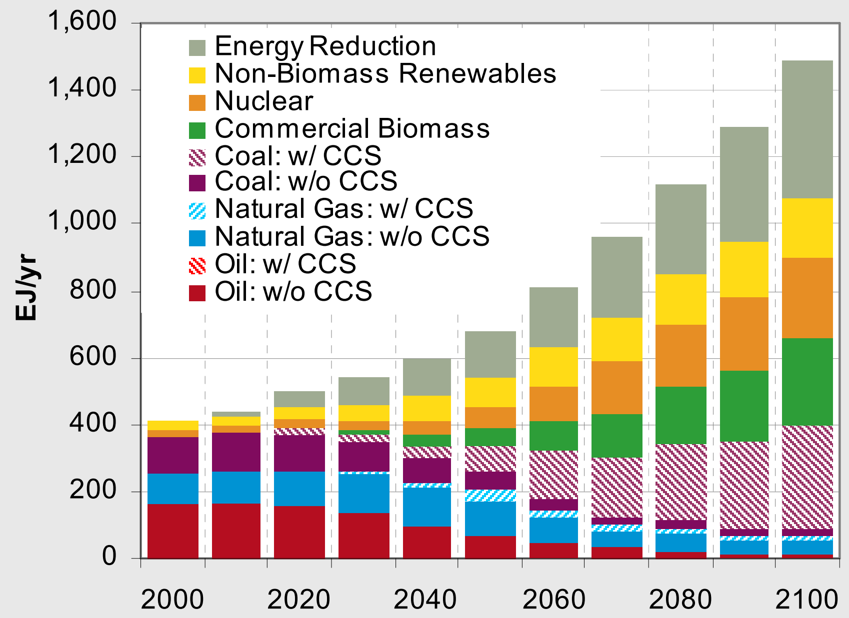
- All of the scenarios maintain a heterogeneous energy mix







PRIMARY ENERGY (Level 1, 450 ppmv)

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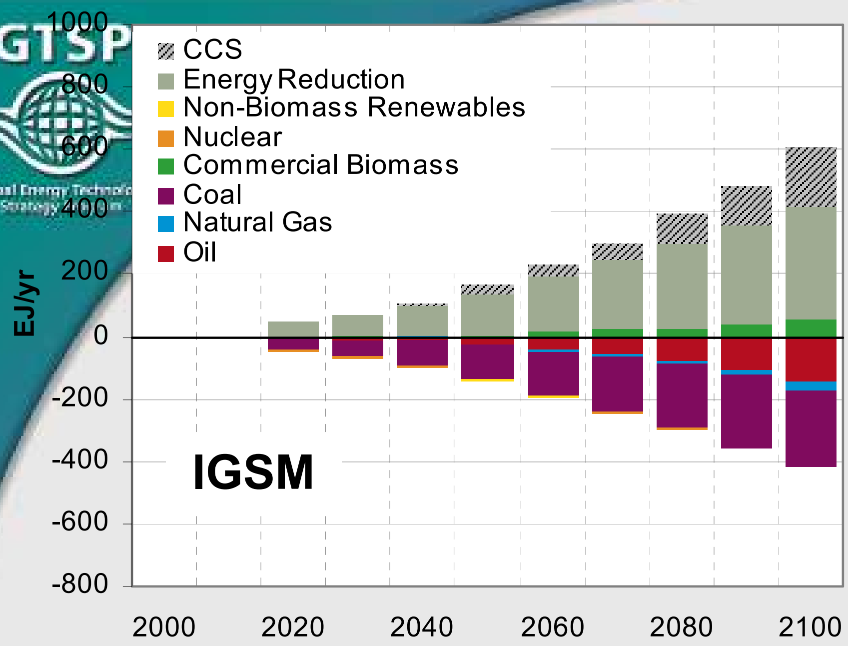

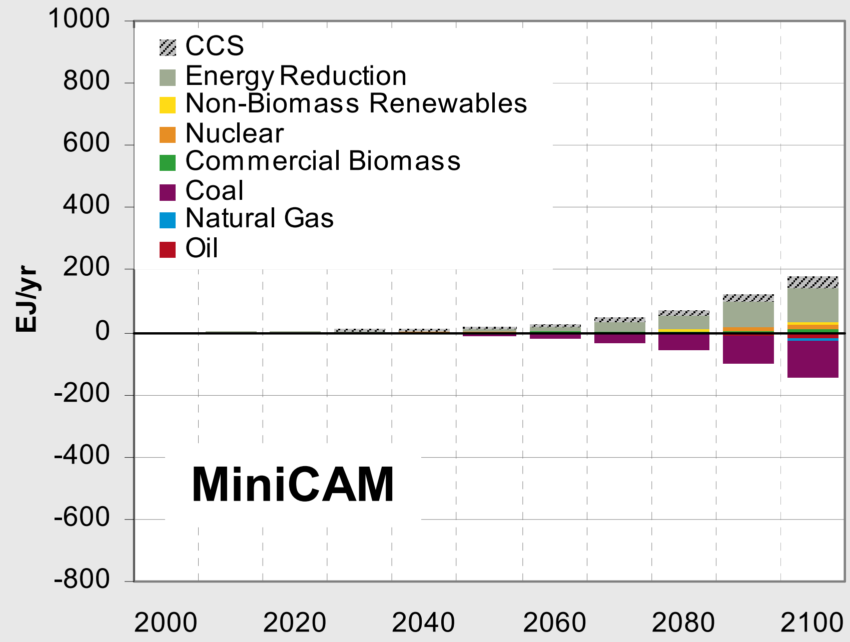

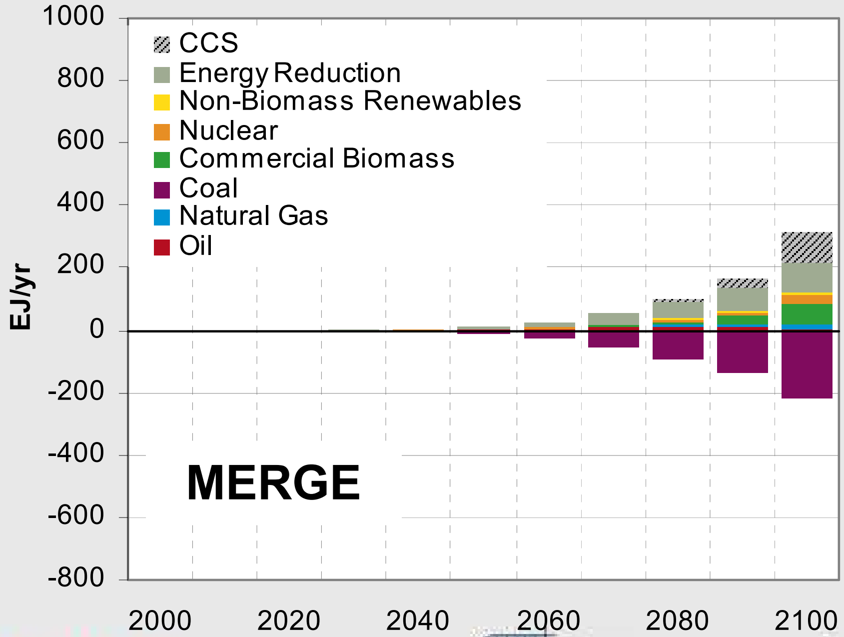

PRIMARY ENERGY (Level 4, 750 ppmv)

- Stabilization requires substantial changes in the energy system
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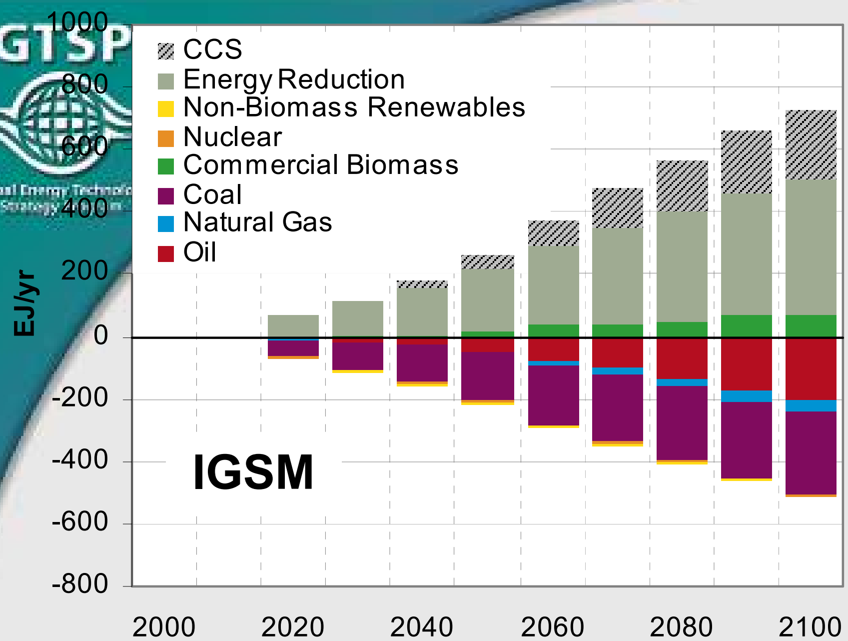

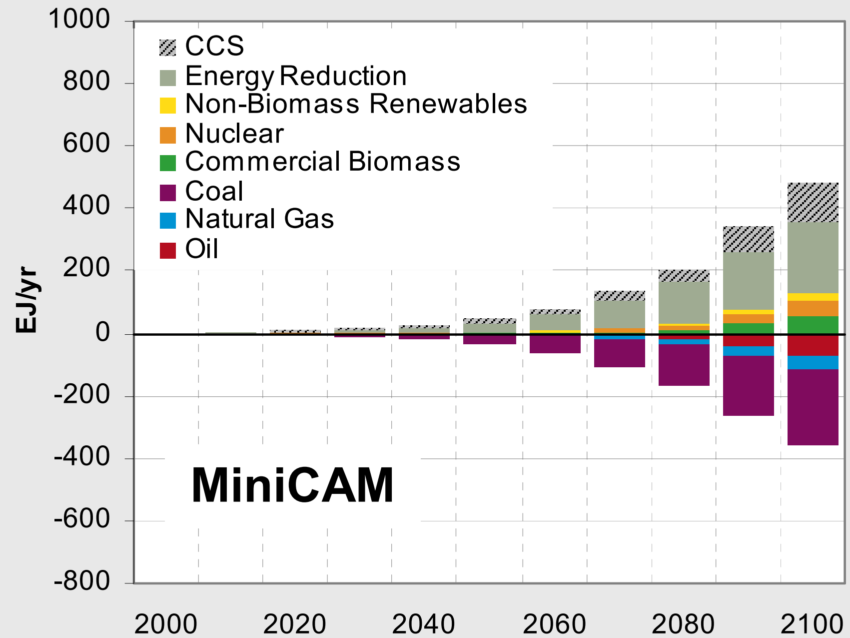

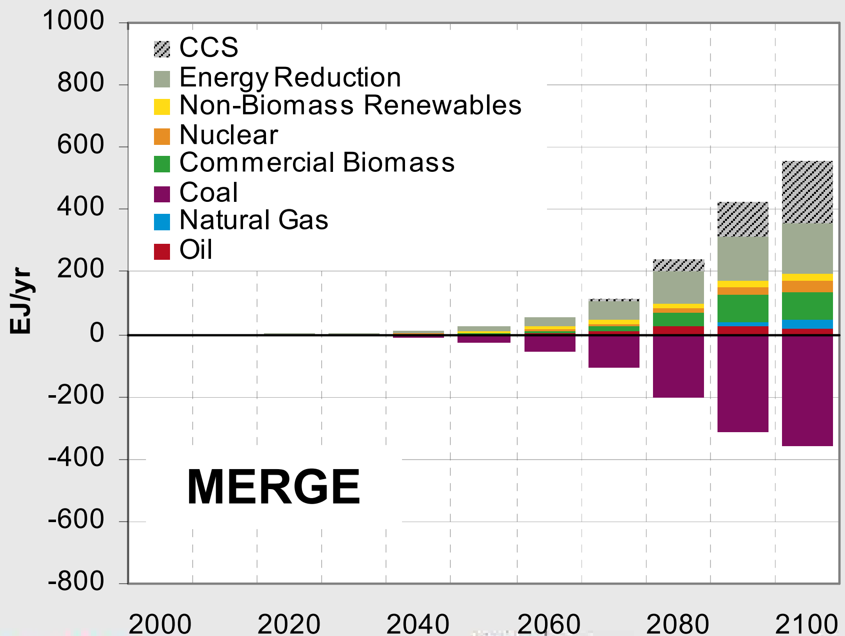

PRIMARY ENERGY (Level 3, 650 ppmv)

- Stabilization requires substantial changes in the energy system
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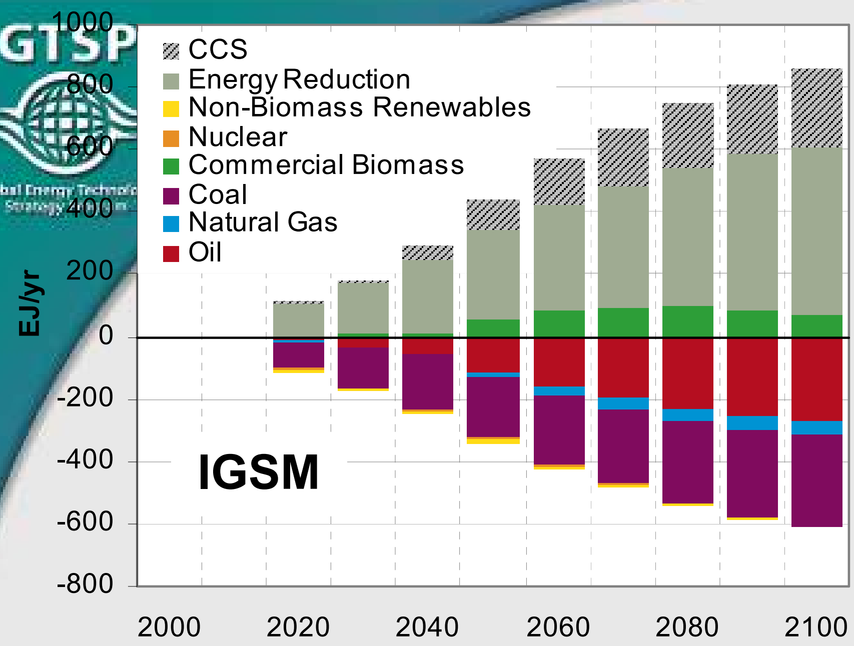
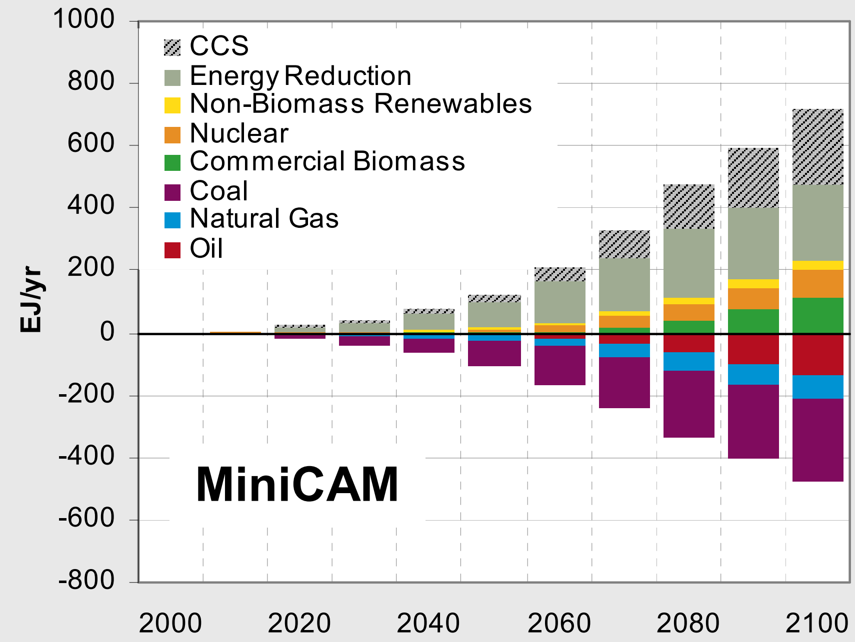
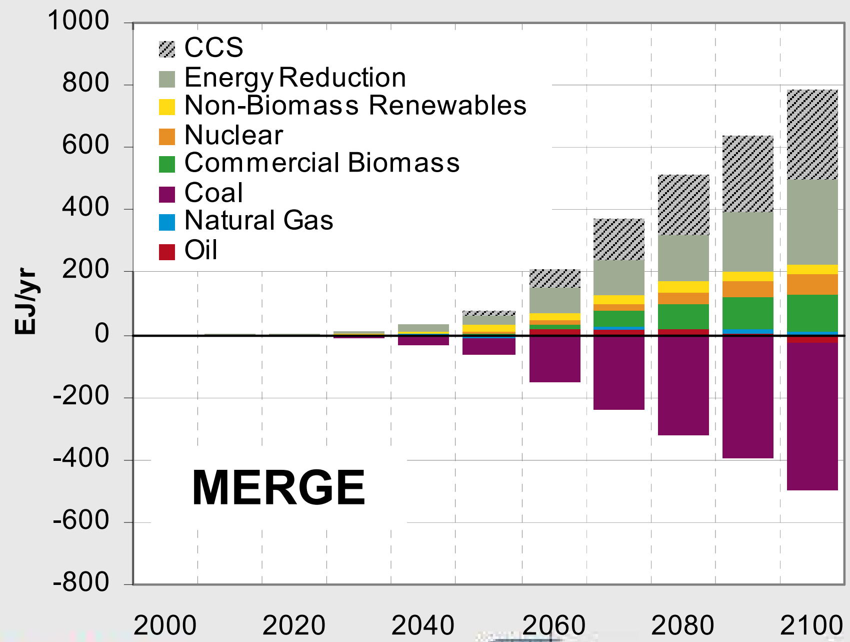
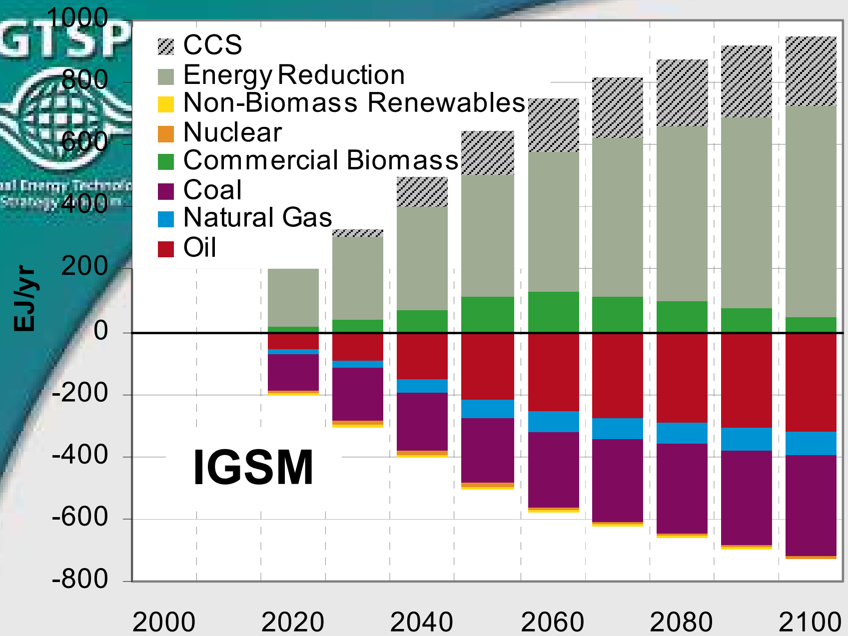


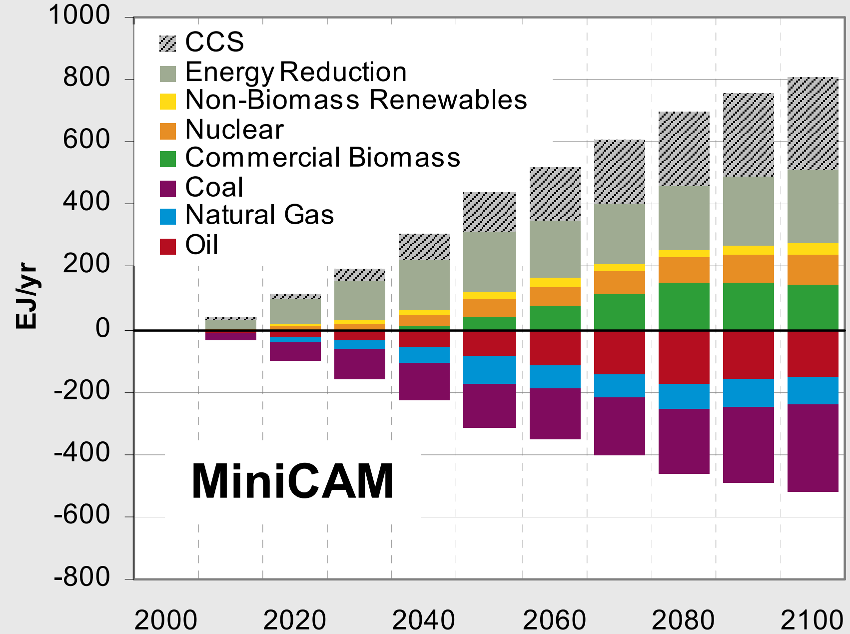


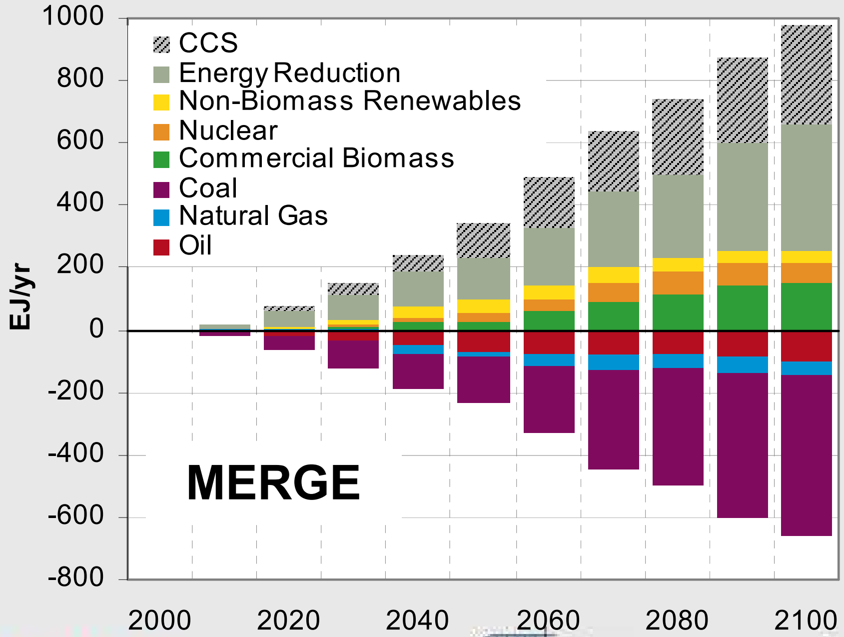


PRIMARY ENERGY (Level 2, 550 ppmv)

- Stabilization requires substantial changes in the energy system
- The models present very different approaches to this evolution
- All of the scenarios maintain a heterogeneous energy mix



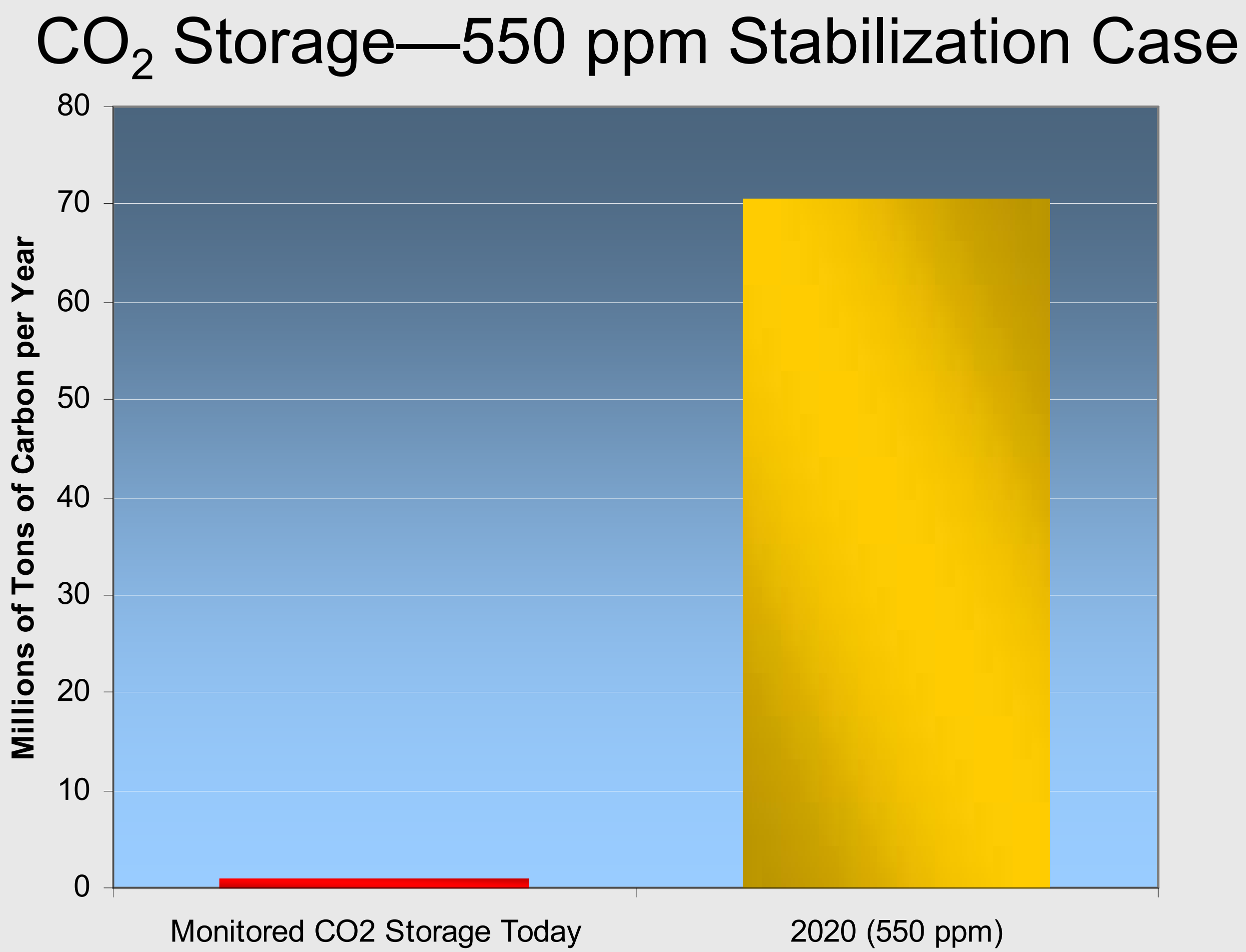




PRIMARY ENERGY (Level 1, 450 ppmv)

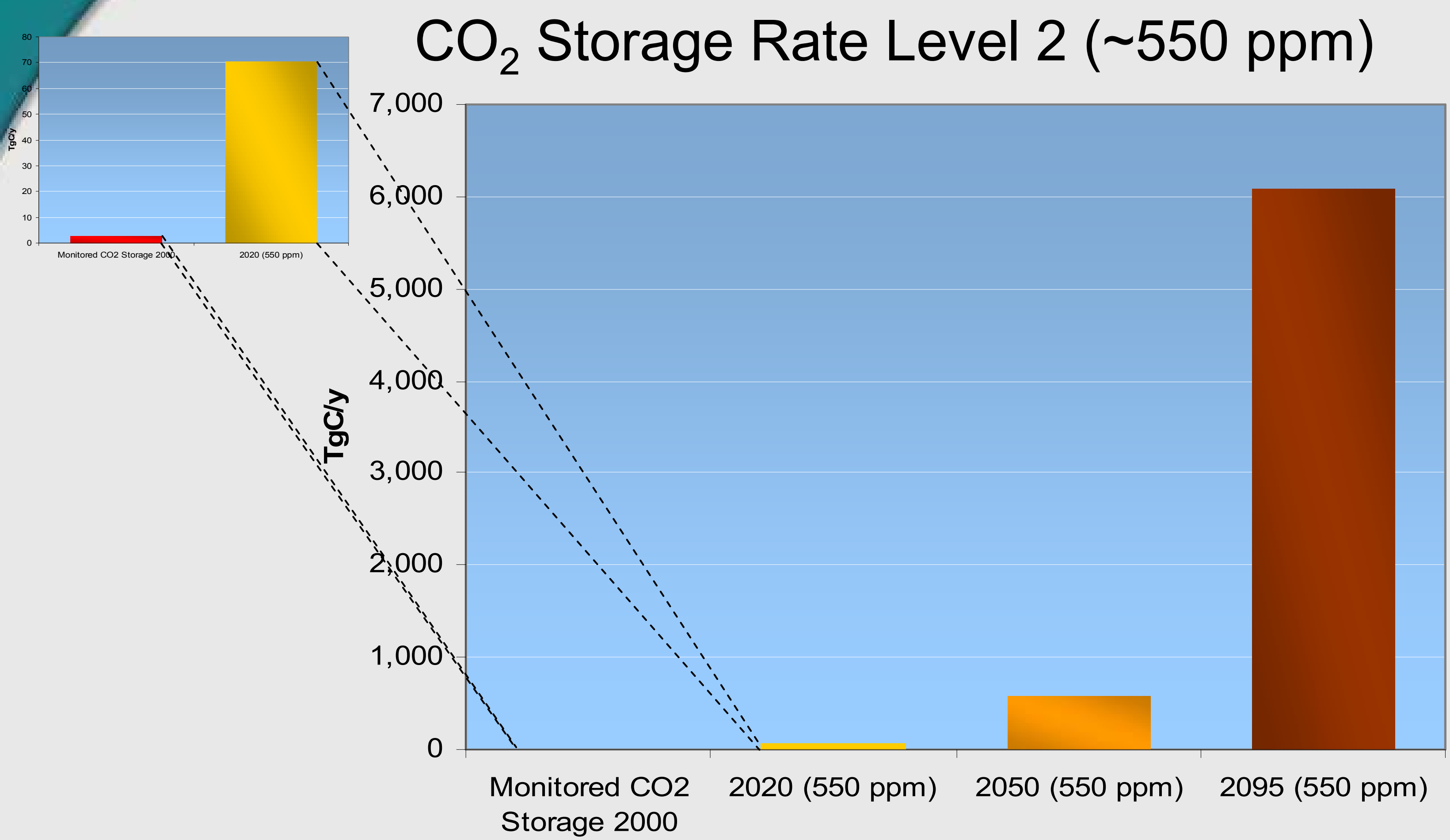
- Stabilization requires substantial changes in the energy system
- The models present very different approaches to this evolution
- All of the scenarios maintain a heterogeneous energy mix

The Challenge of Scale—near term



From Edmonds, J., Wise, M., Dooley, J., Kim, S., Smith, S., Runci, P., Clarke, L., Malone, E., and Stokes, G., 2007, *Global Energy Technology Strategy, Addressing Climate Change: Phase 2 Findings from an International Public-Private Sponsored Research Program*, Battelle Memorial Institute.

In the long-term the challenge grows



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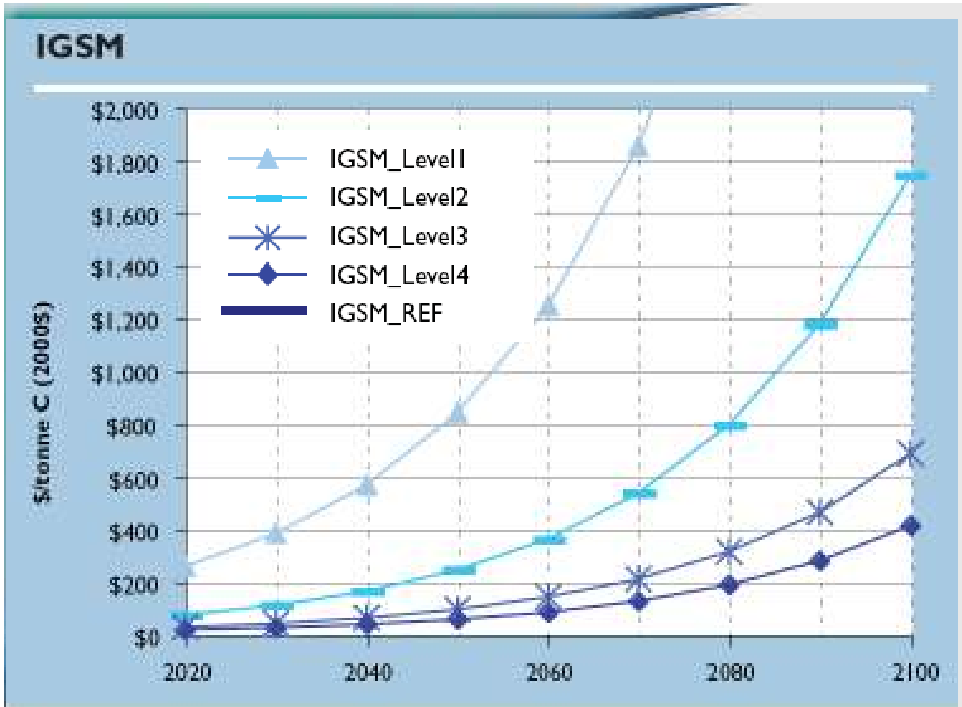
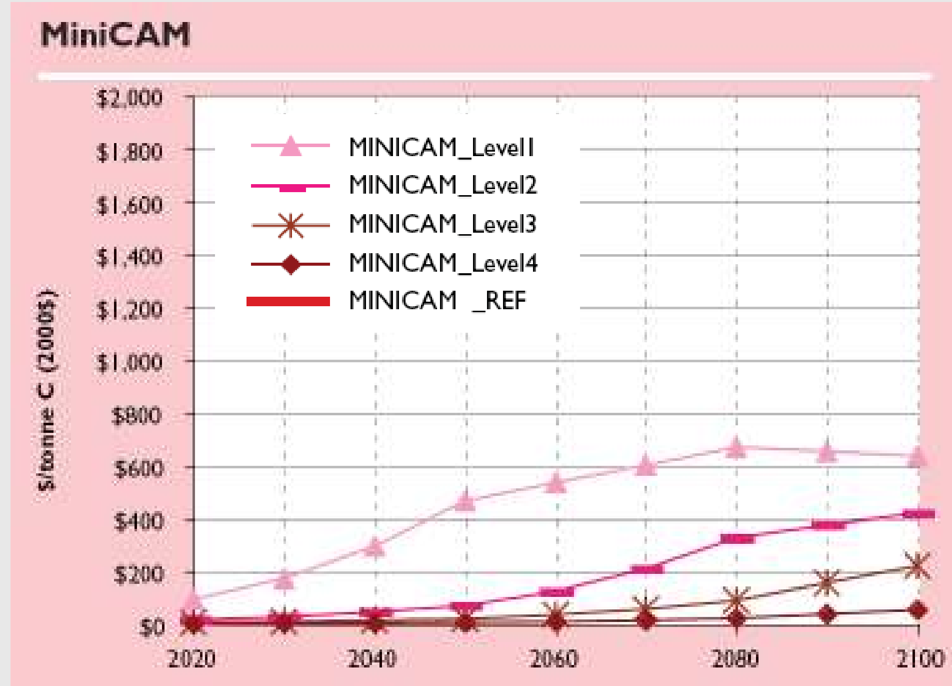
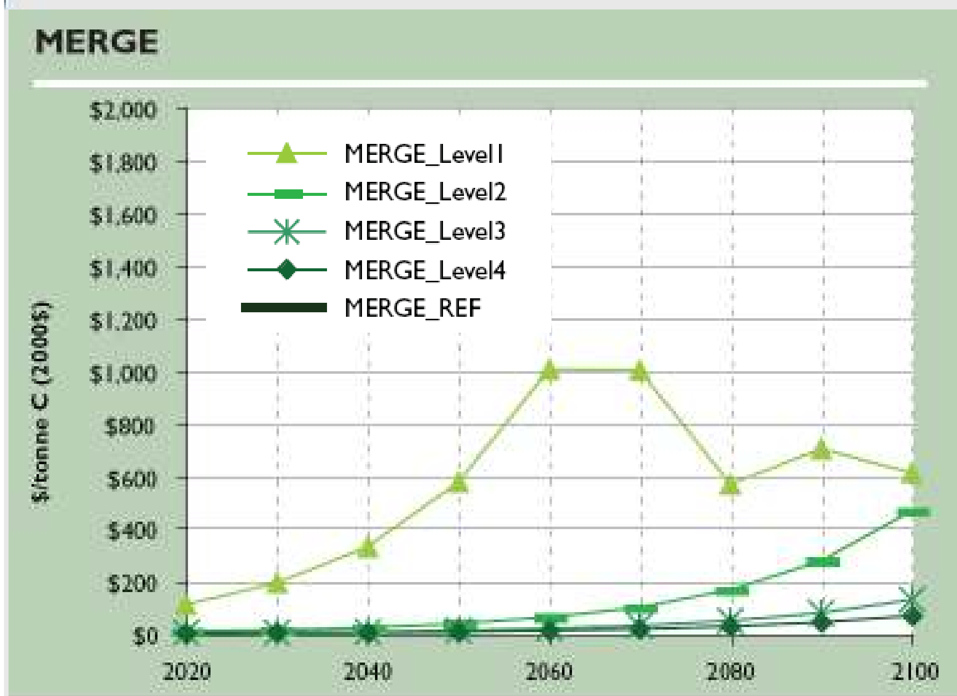
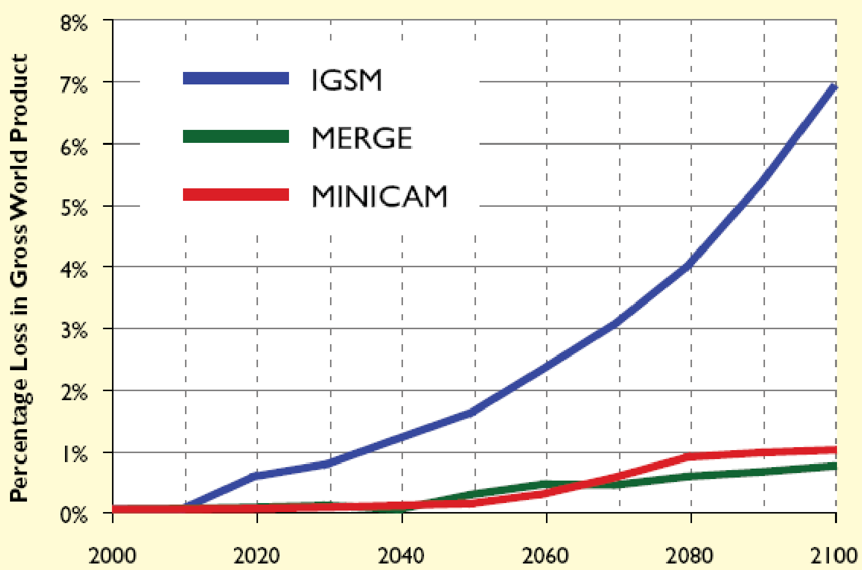




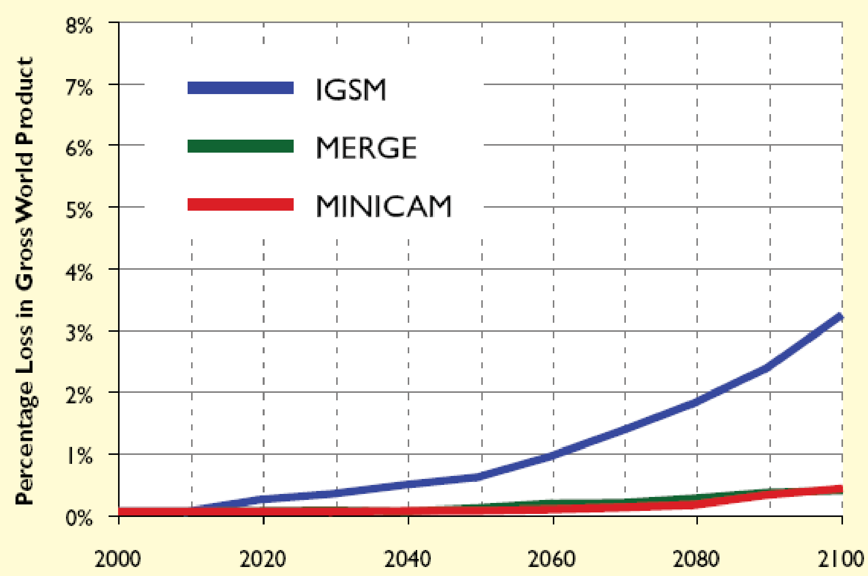


- **Carbon Prices** rise until stabilization is reached.
- Expectations about the future (e.g., technology) influence carbon prices today
- THESE SCENARIOS ASSUME PERFECT WHERE, WHEN, AND WHAT FLEXIBILITY
- NOTE: All carbon prices are in \$/tonne C – Prices in \$/tonne CO_2 would be 3/11 as large

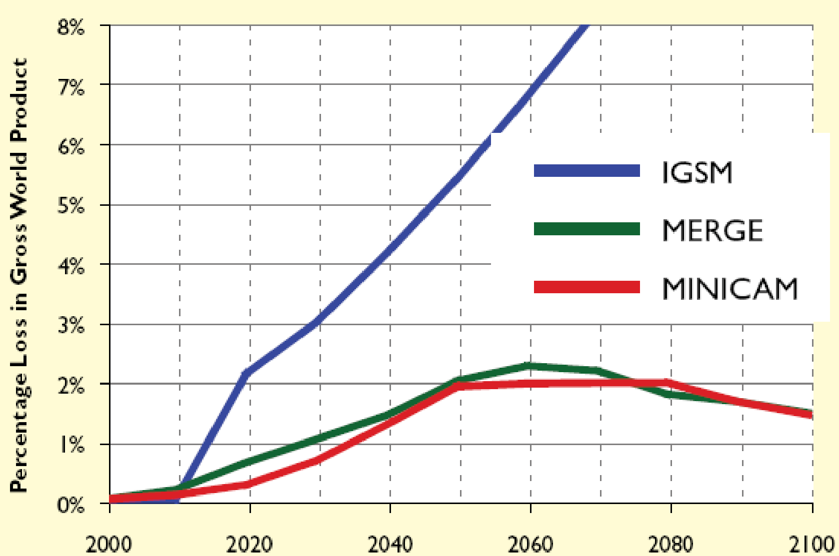
Level 2 Scenarios



Level 3 Scenarios



Level 1 Scenarios



- **The Effects on GDP** have similar characteristics to the carbon price
- Economic impacts would be higher without perfect where and when flexibility

Variation in Economic Implications

1. Required Emissions Reductions

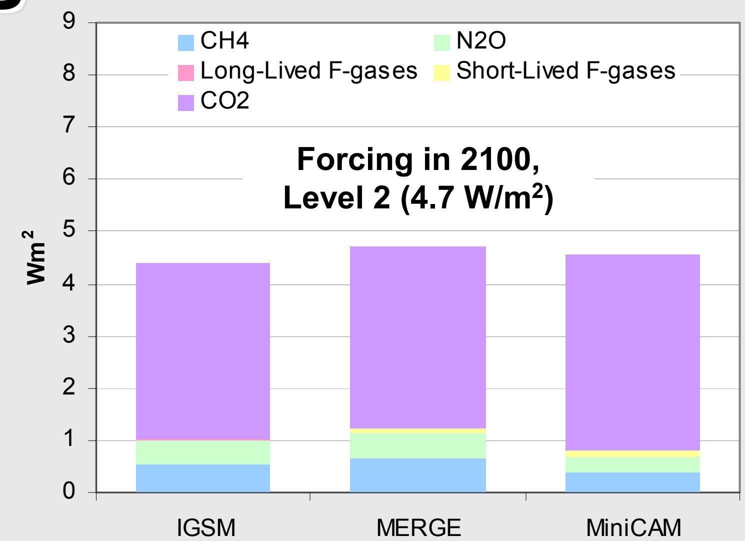
Cumulative Emissions Reduction, 2000 – 2100 (GtC)

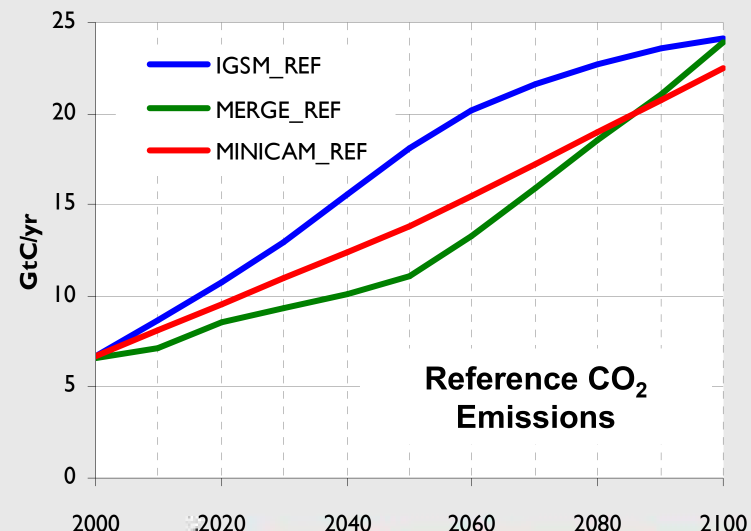
	IGSM	MERGE	MiniCAM
Level 4	472	112	97
Level 3	674	258	267
Level 2	932	520	541
Level 1	1172	899	934

2. Assumptions about future technology

Sources of Differences in Emissions Mitigation

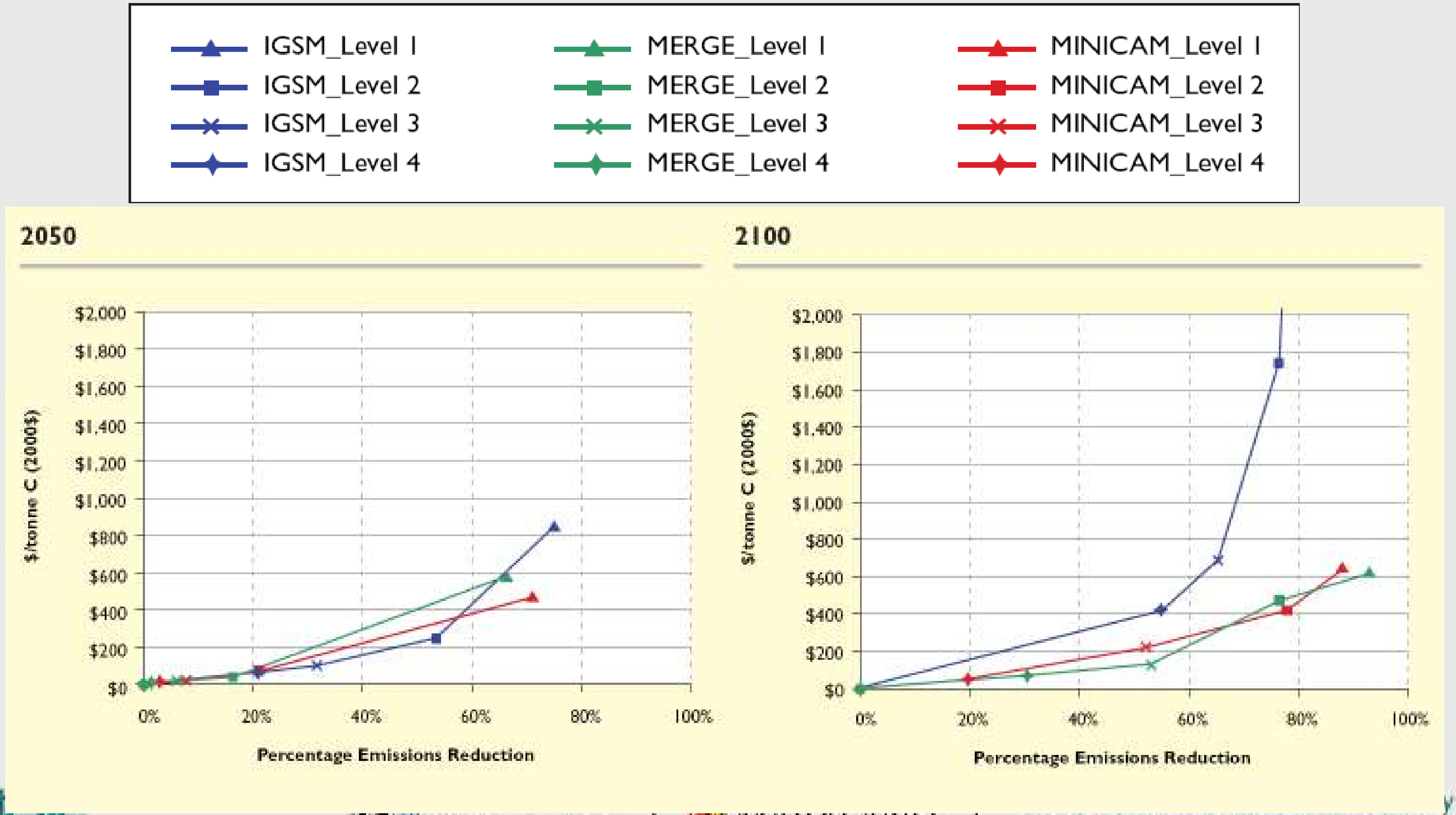
- Reference case emissions
- Carbon cycle
- Non-CO_2 GHG's

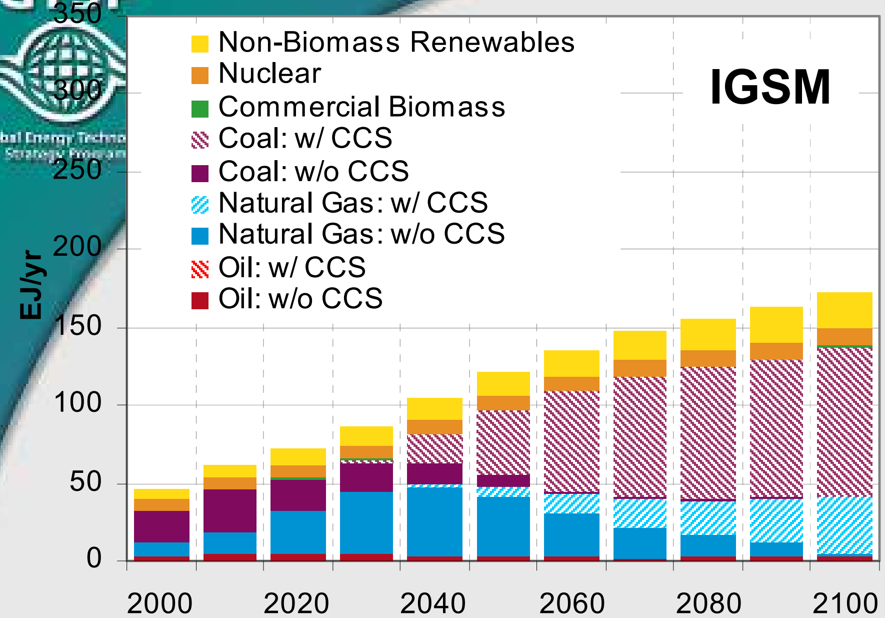


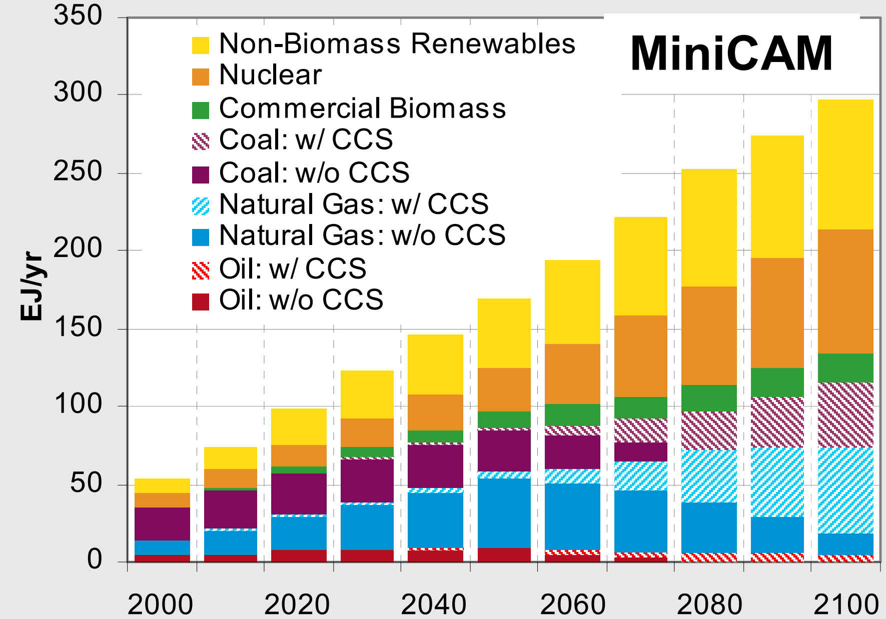


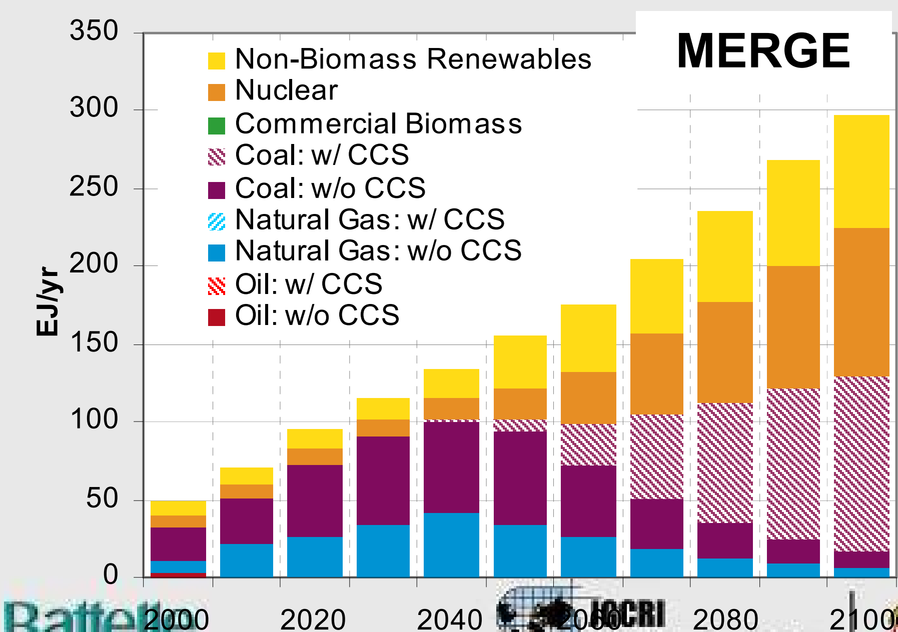
The Role of Post-2050 Technology

While the technology stories for the three modeling teams are similar through 2050, they are different in the far future.









- All of the models have ample opportunities for decarbonizing electricity.
- The ability to switch to low- or zero-carbon fuels in end use sectors plays an important role in cost differences.

End