CCSP SAP 2.1A:

Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations

EMF, Tsukuba, 2006

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Acknowledgements

- The organizers of EMF 22.
- The authors of CCSP Product 2.1A,
  - Jae Edmonds
  - Jake Jacoby
  - Hugh Pitcher
  - John Reilly
  - Rich Richels

Background

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.

Who and what are these scenarios for?

0. Focus on Stabilization

"The scenarios are intended primarily for decisionmakers and analysts who might benefit from enhanced understanding of the potential characteristics and implications of stabilization. For example, technology planners might be interested in enhanced understanding of the potential energy systems implications of stabilization. The scenarios are also intended to serve as a point of departure for further CCSP and other analyses, such as climate scenarios or analyses of mitigation and adaptation options. The development of these scenarios will enhance the capabilities for future scenario analyses that might be conducted by CCSP or related agencies, such as those involved in CCTP."

1. Solidify and Enhance the Knowledge Base for Decision-makers

2. Inputs to Further Analyses

3. Furthering the Tools and Methods

The Scenarios will provide insights into questions such as the following:

Emissions Trajectories:

- What emissions trajectories over time are consistent with meeting the four alternative stabilization levels?
- What are the key factors that shape the emissions trajectories that lead toward stabilization?

Energy Systems:

- What energy system characteristics are consistent with each of the four alternative stabilization levels?
- How might these characteristics differ among stabilization levels?

Economic Implications:

- What are the possible economic implications of meeting the four alternative stabilization levels?

Study Design

Participants

- MIT (IGSM)
  - Henry Jacoby, John Reilly
- PNNL (MiniCAM)
  - James Edmonds, Hugh Pitcher
- EPRI (MERGE)
  - Richard Richels
- Coordinator
  - Leon Clarke

Study Design

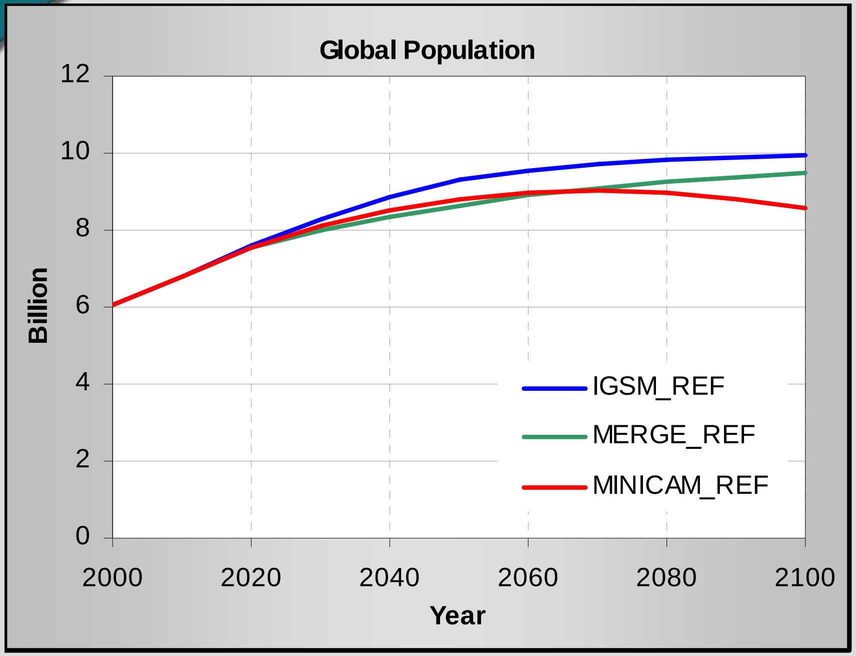
- Stabilize total radiative forcing from CO_2, N_2O, CH_4, HFCs, PFCs, and SF_6
  - Other radiatively-important substances (e.g., aerosols) not included
- Long-term (many century) stabilization; study period through 2100.
- Four stabilization scenarios roughly consistent with 450 ppmv through 750 ppmv CO2, along with one reference case.

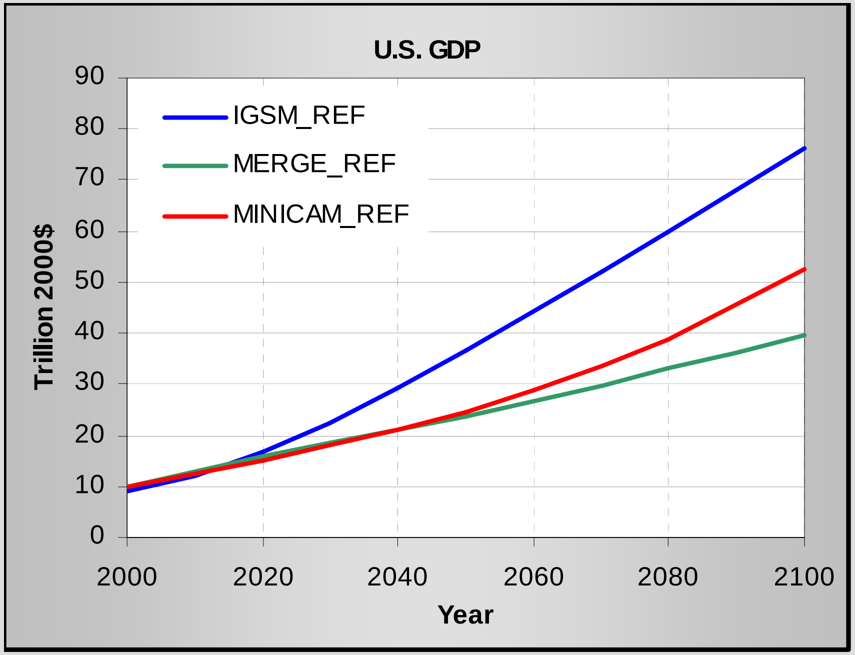
	Total Radiative Forcing from GHGs (Wm^{-2})	Approximate Contribution to Radiative Forcing from non-CO_2 GHGs (Wm^{-2})	Approximate Contribution to Radiative Forcing from CO_2 (Wm^{-2})	Corresponding CO_2 Concentration (ppmv)
Level 1	3.4	0.8	2.6	450
Level 2	4.7	1.0	3.7	550
Level 3	5.8	1.3	4.5	650
Level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

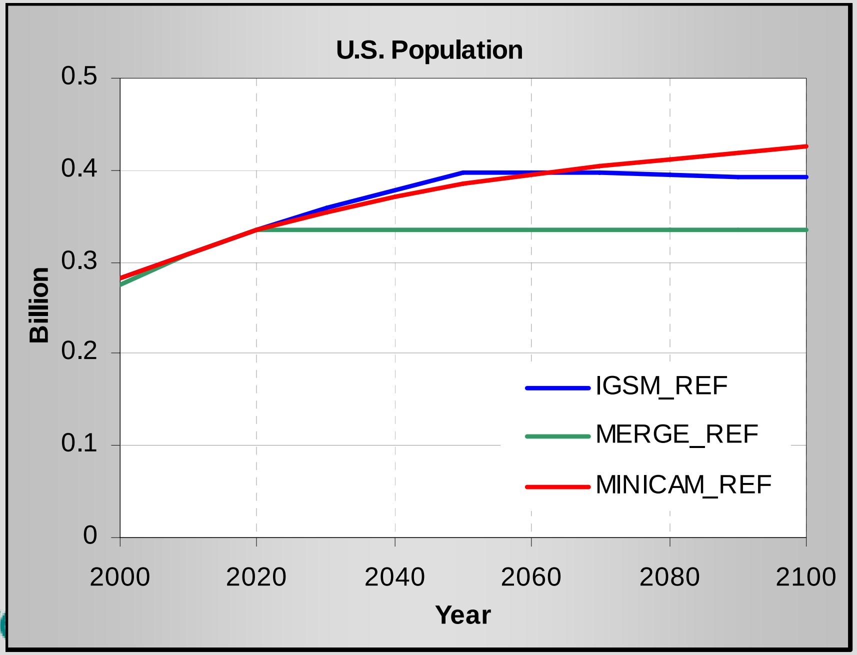
Study Design

- 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.

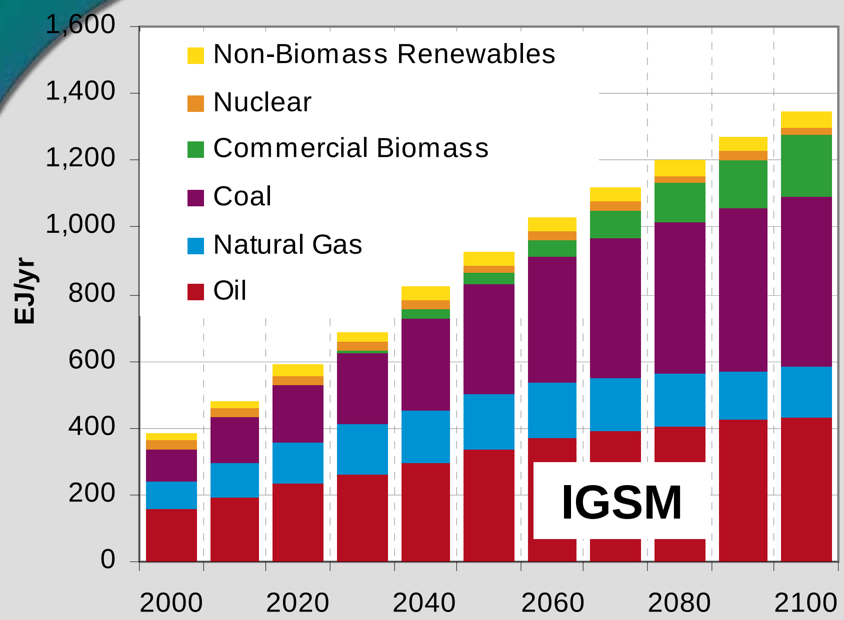
The Reference Scenarios

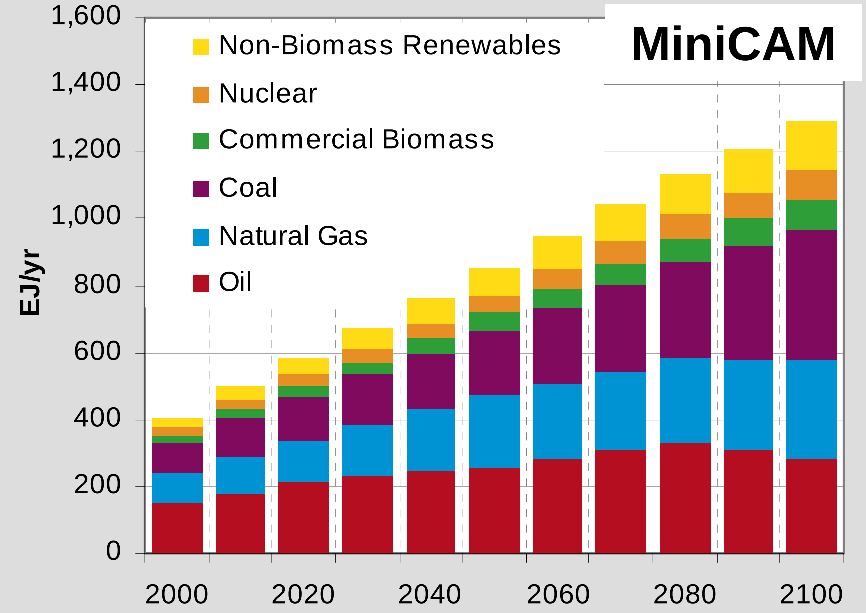


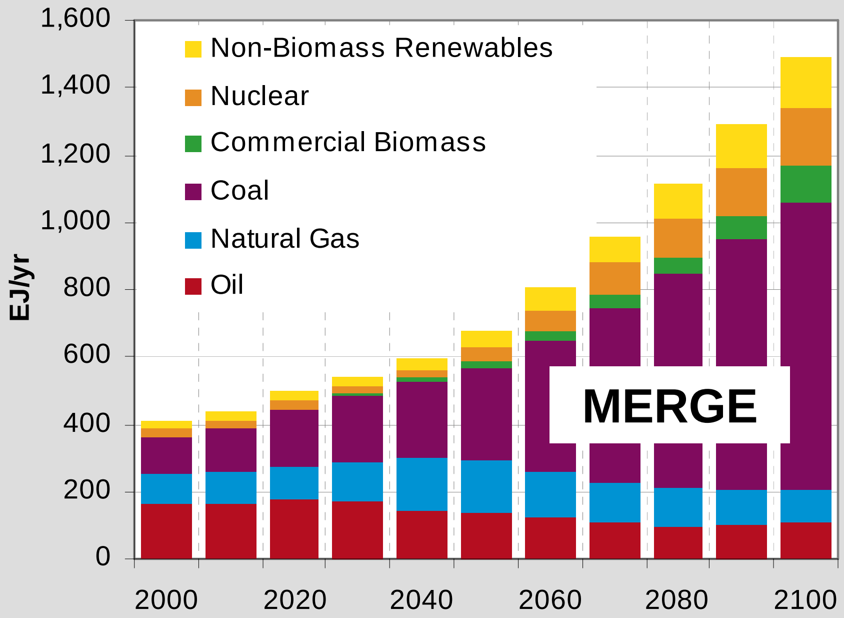




All the reference scenarios include strong drivers for emissions increases

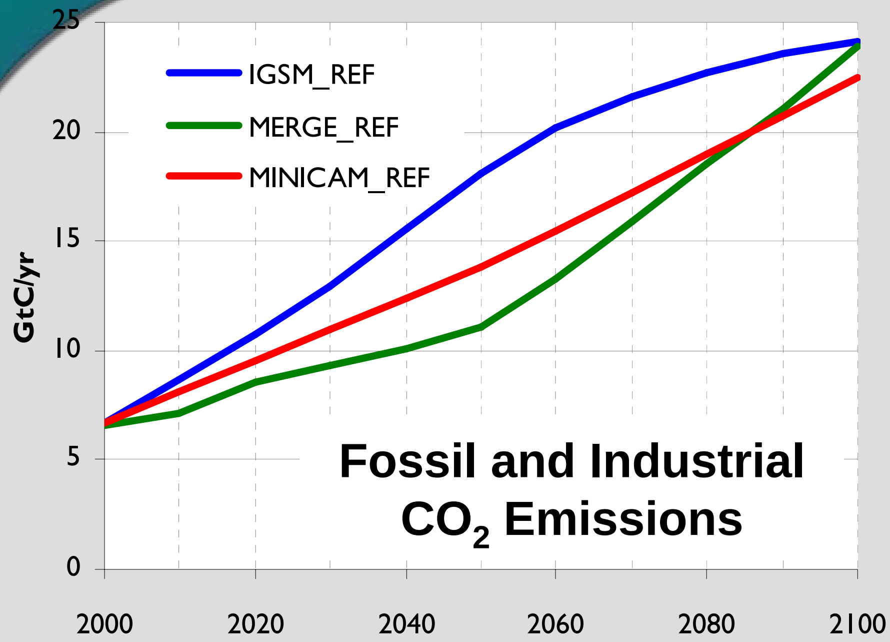


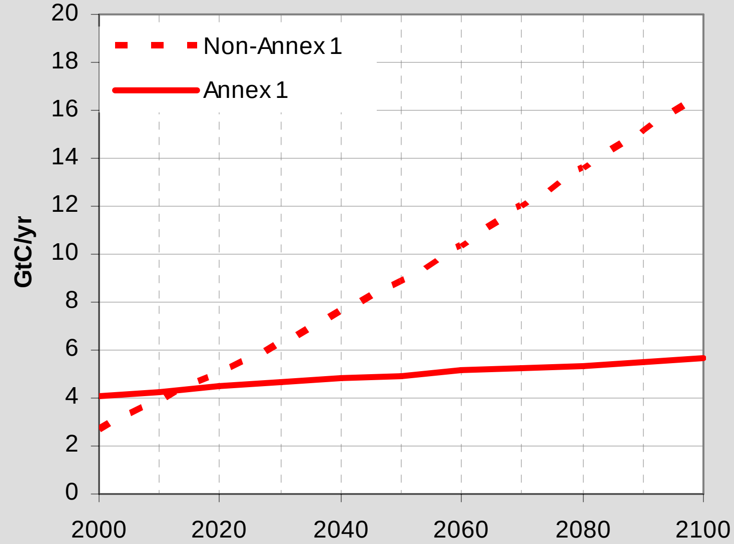


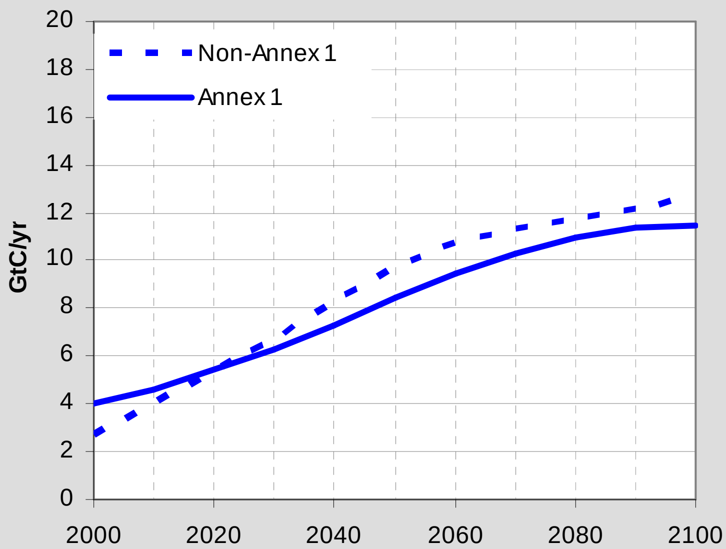


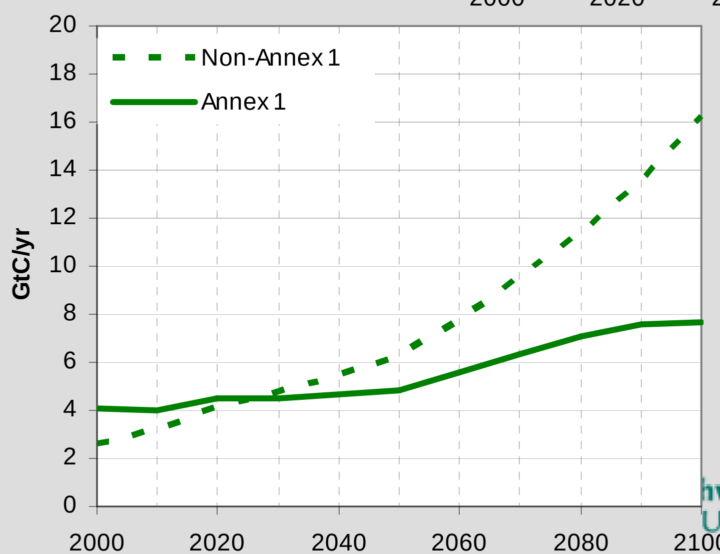
- **Primary energy** grows to between three and four times today's levels by the end of the century.
- All models envision penetration of fossil alternatives for conventional oil
- Transition away from conventional oil sources
- Substantial growth in sources that don't emit carbon
- But fossil fuels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

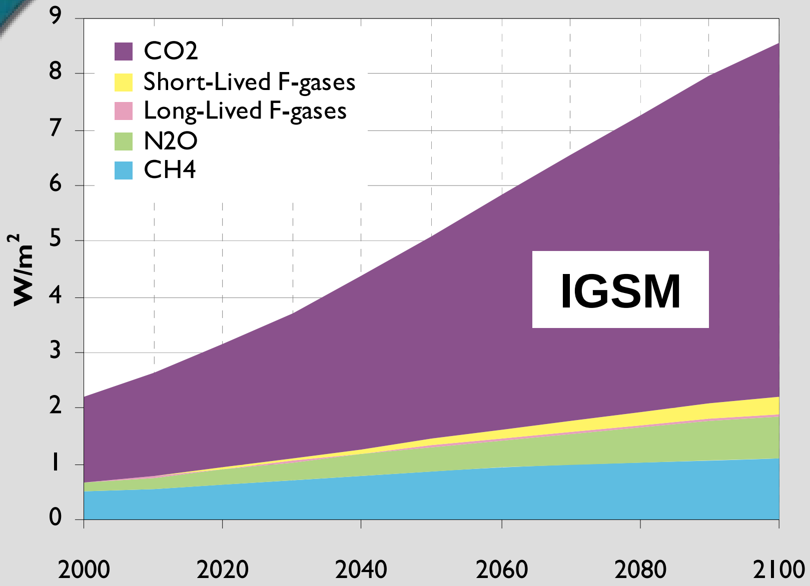
The result is continually increasing CO_2 emissions over the century, with important transition in emitting countries.

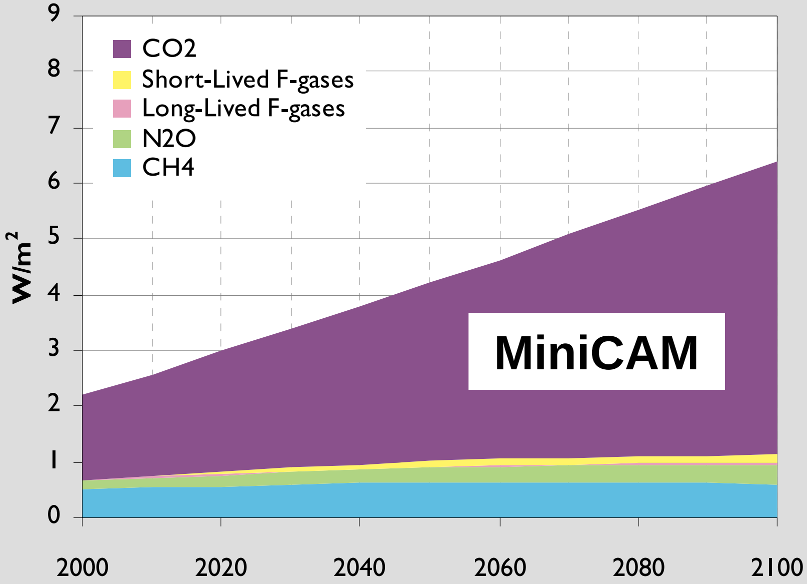


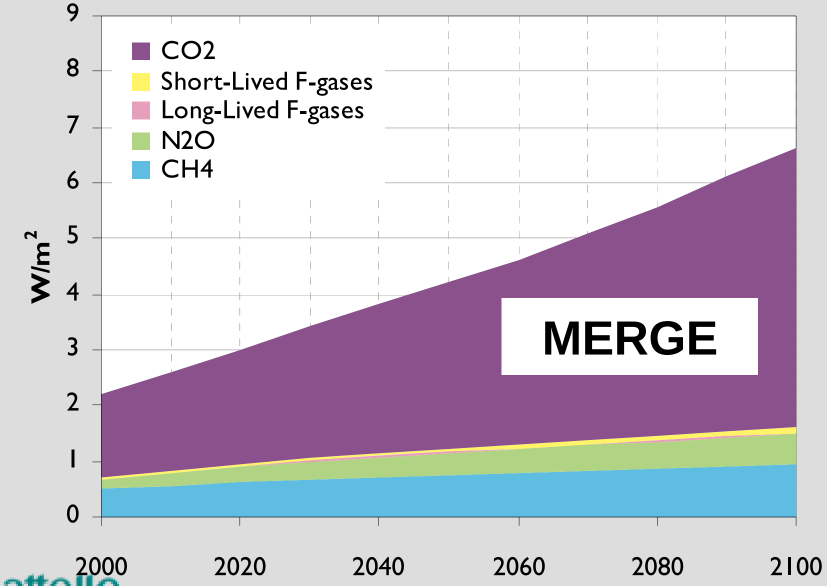






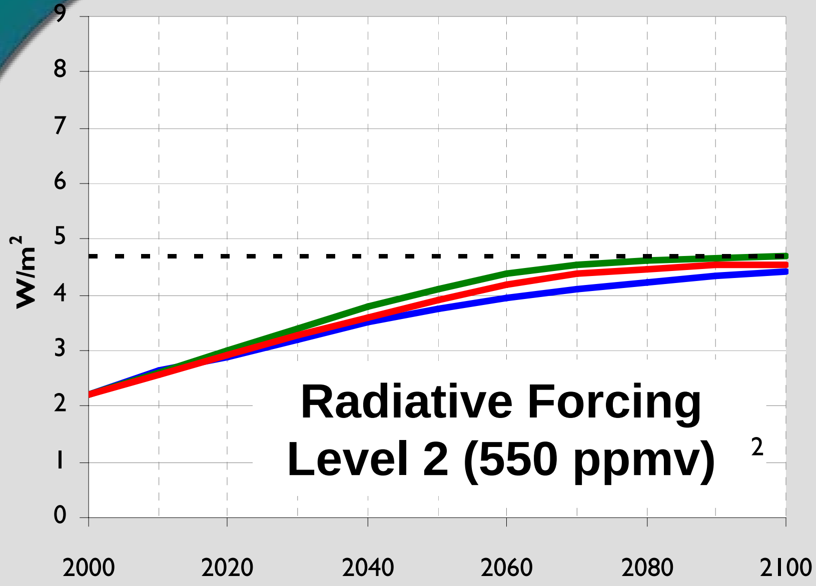


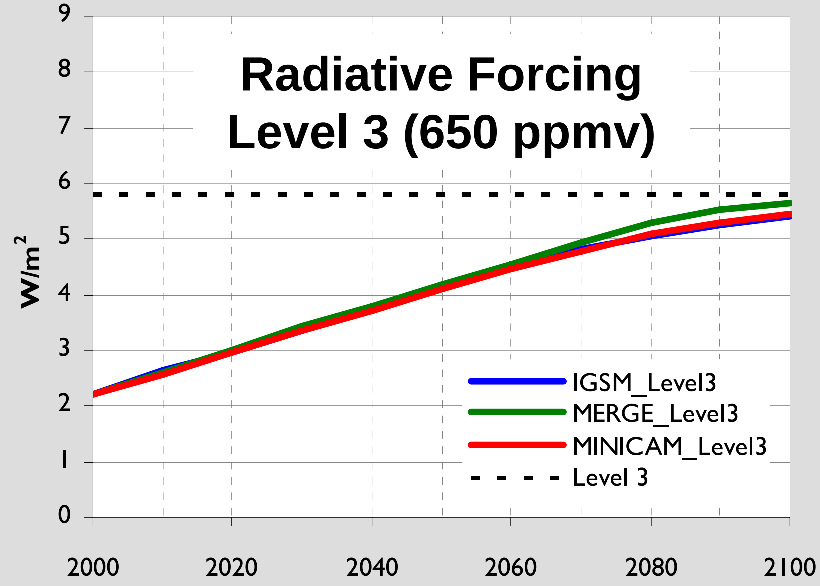


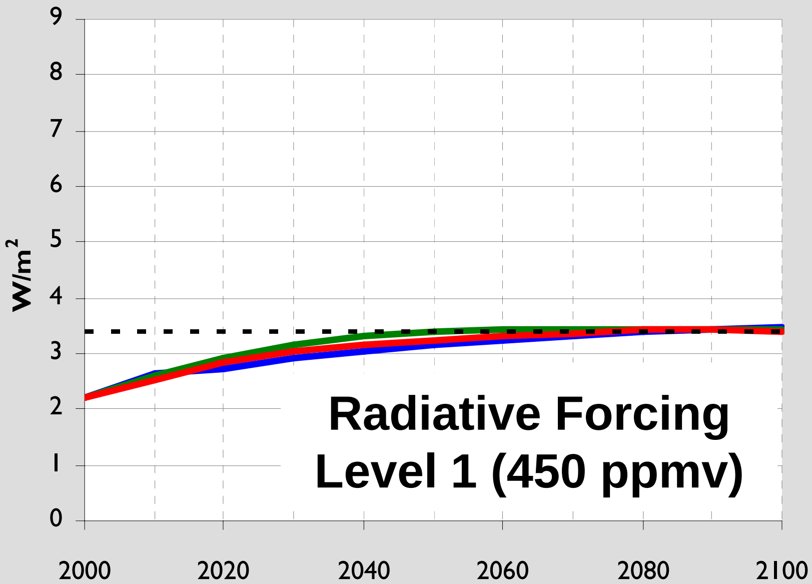


- **Radiative forcing** trajectories are not consistent with stabilization at any of the four levels considered in the exercise
- CO_2 takes on an increasingly large share of radiative forcing in all three scenarios
- Contributions of non-CO_2 GHGs vary among the models

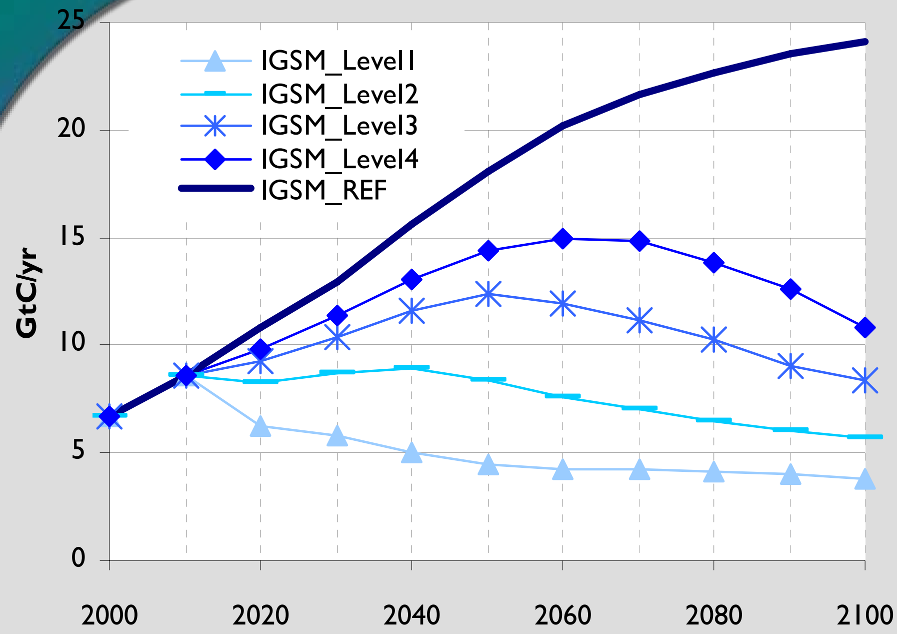
The Stabilization Scenarios

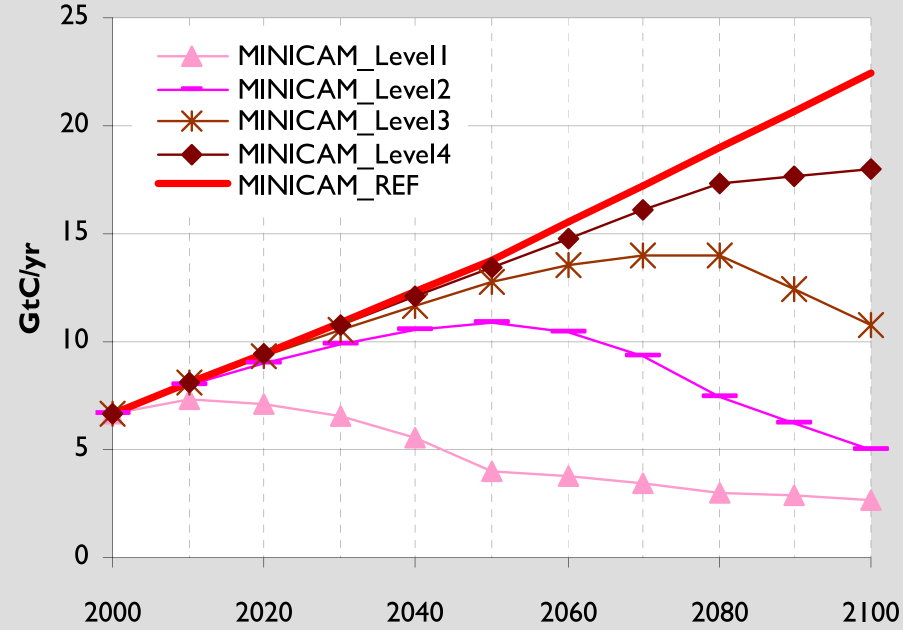


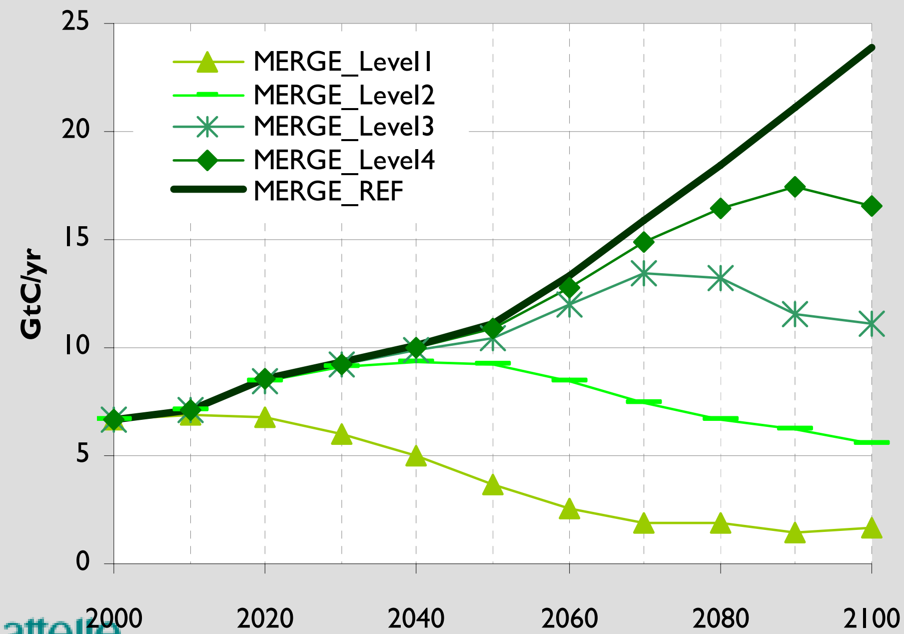




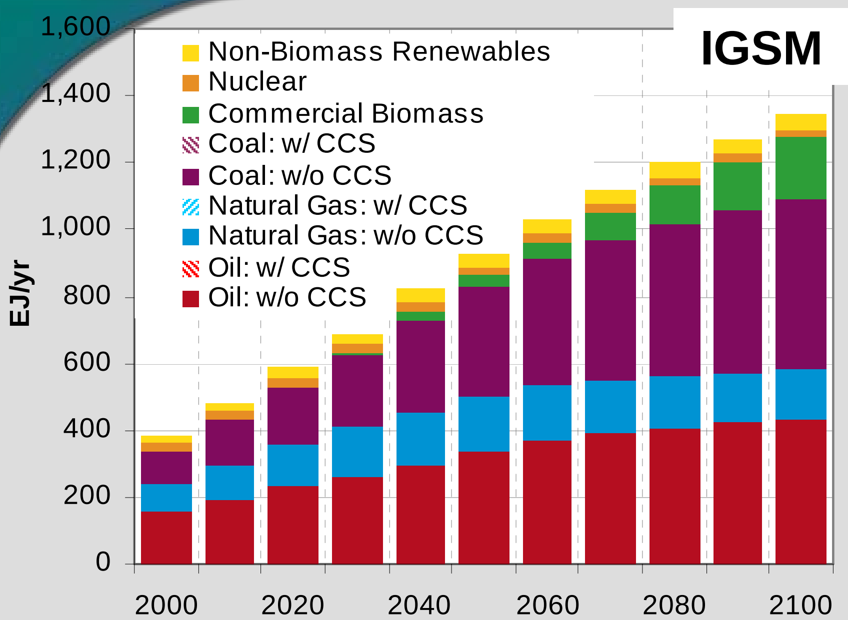
- Radiative forcing trajectories are similar across the models

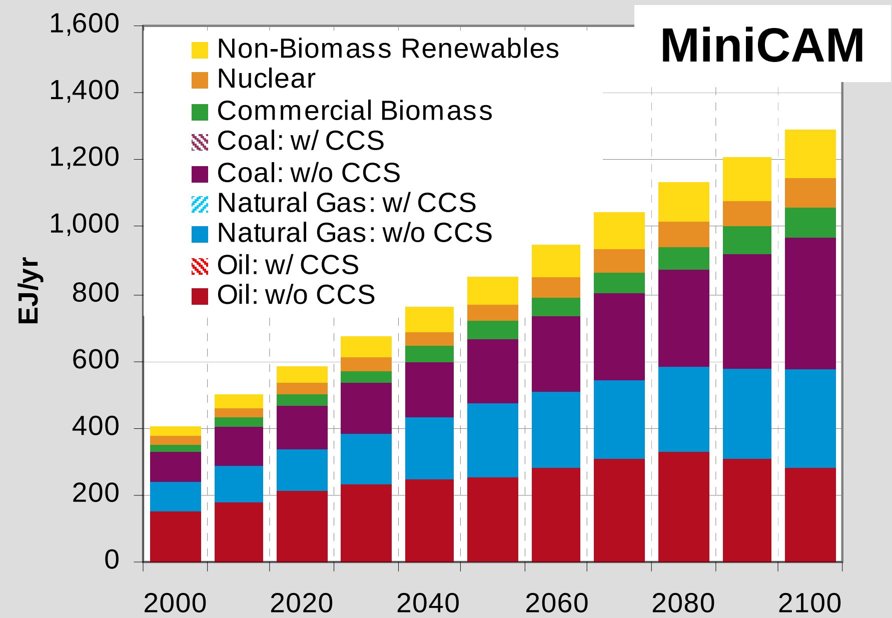


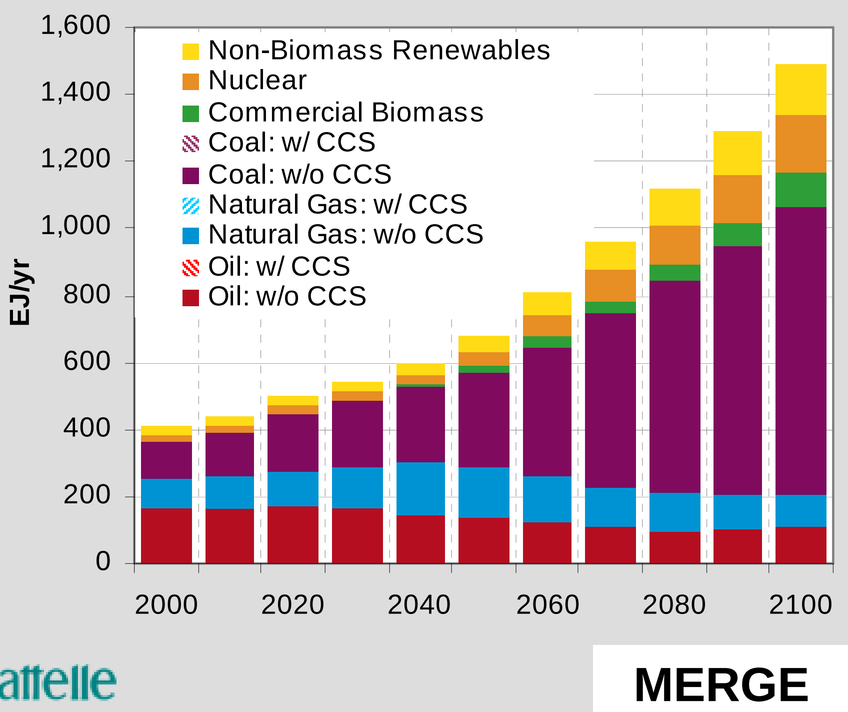




- Emissions ultimately decline toward the rate at which emissions are balanced by removal processes.
- Timing depends on the stabilization level
- Emissions trajectories vary because of differences in (1) ocean uptake, (2) net terrestrial emissions, and (3) contributions from non-CO_2 GHGs

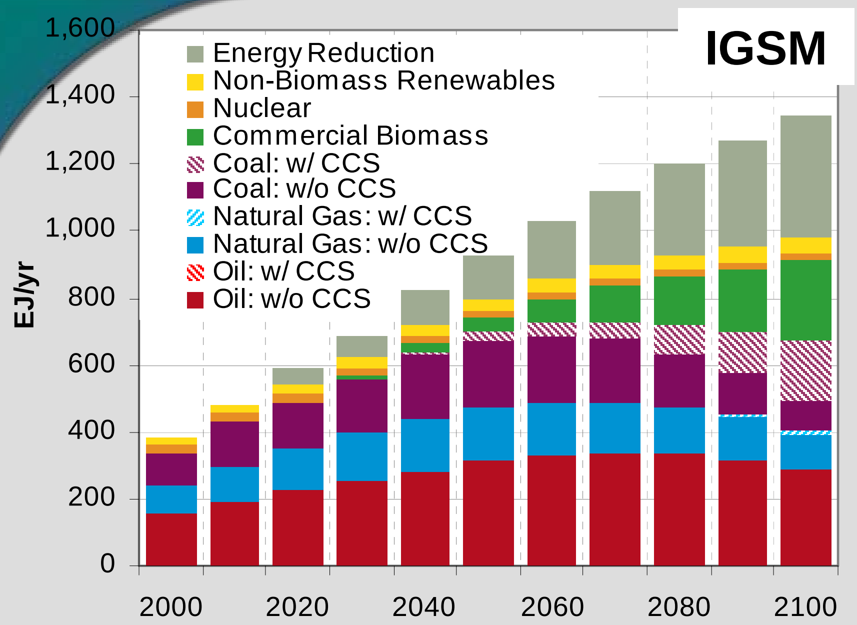


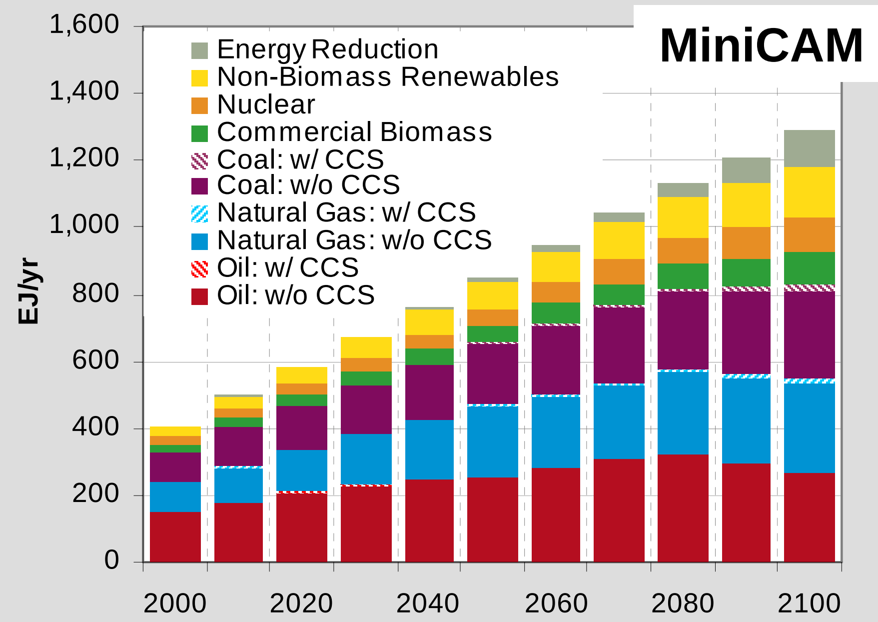


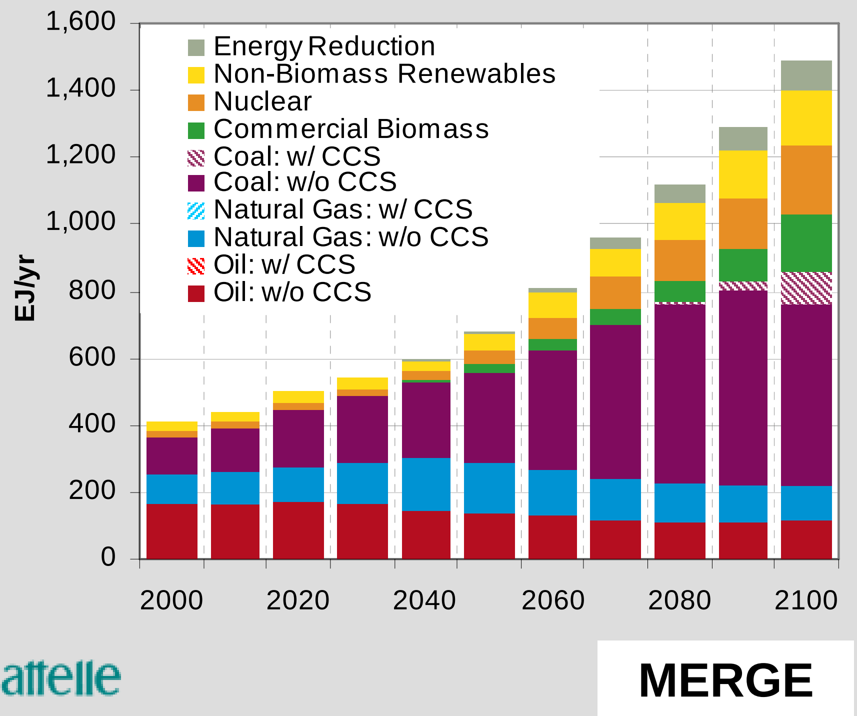


PRIMARY ENERGY (Reference)

- 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

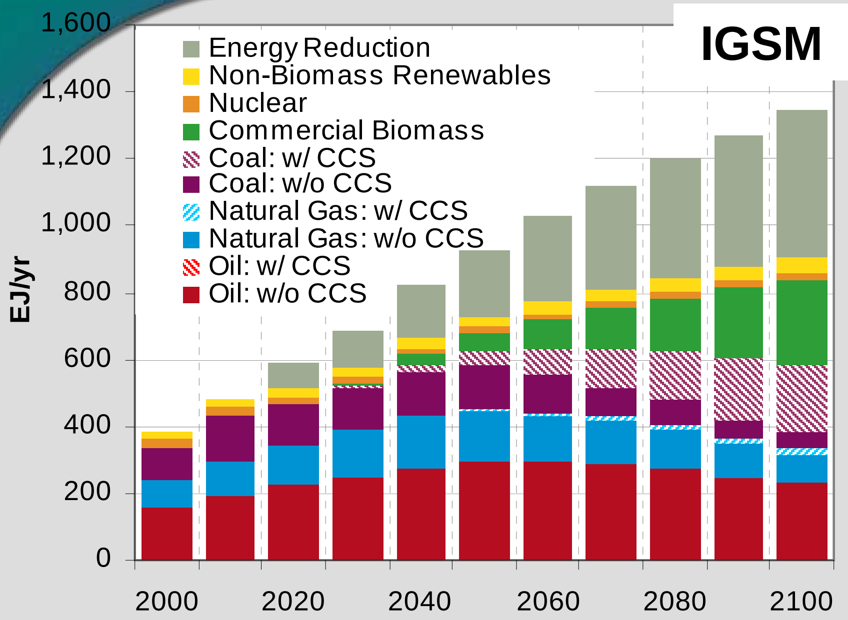


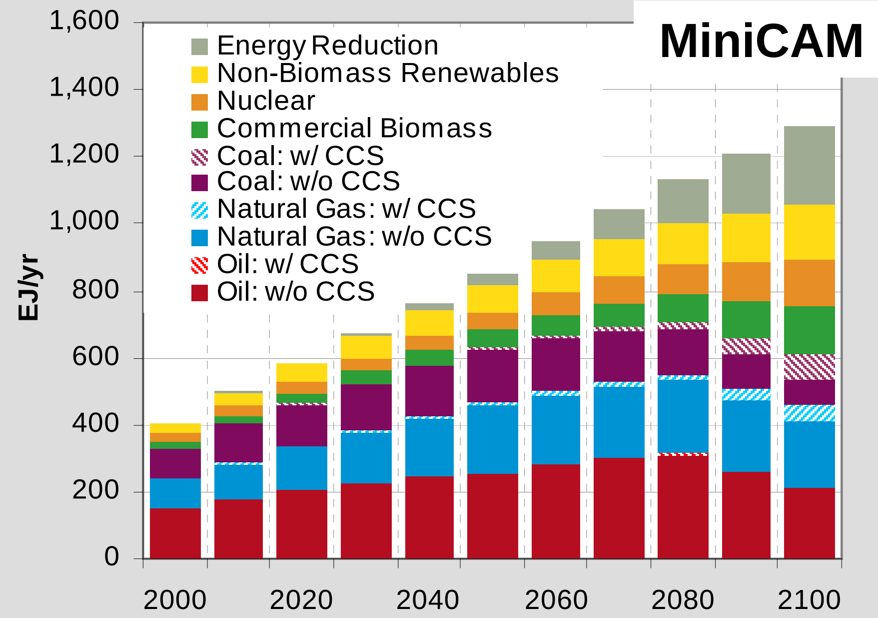


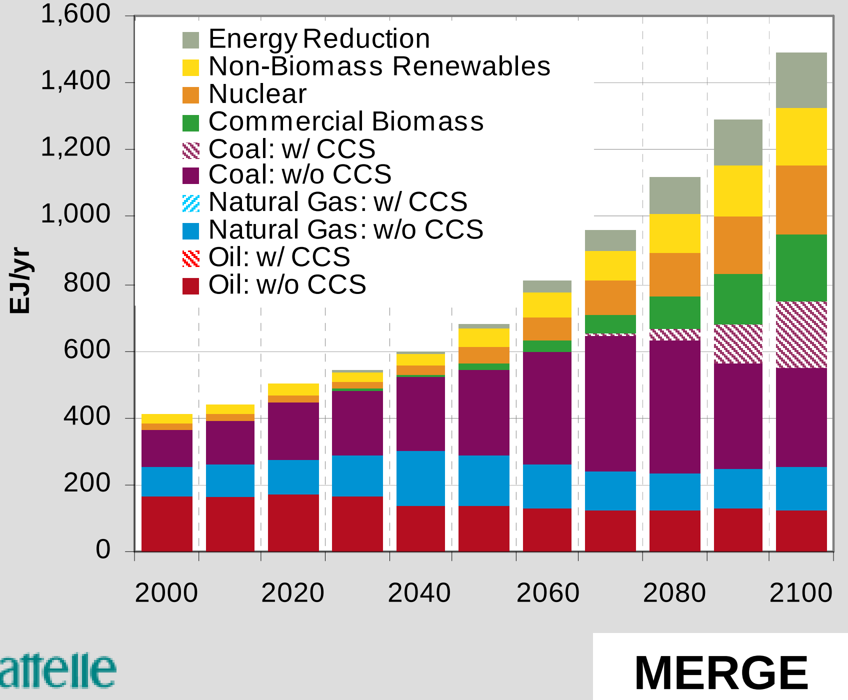


PRIMARY ENERGY (Level 4, 750 ppmv)

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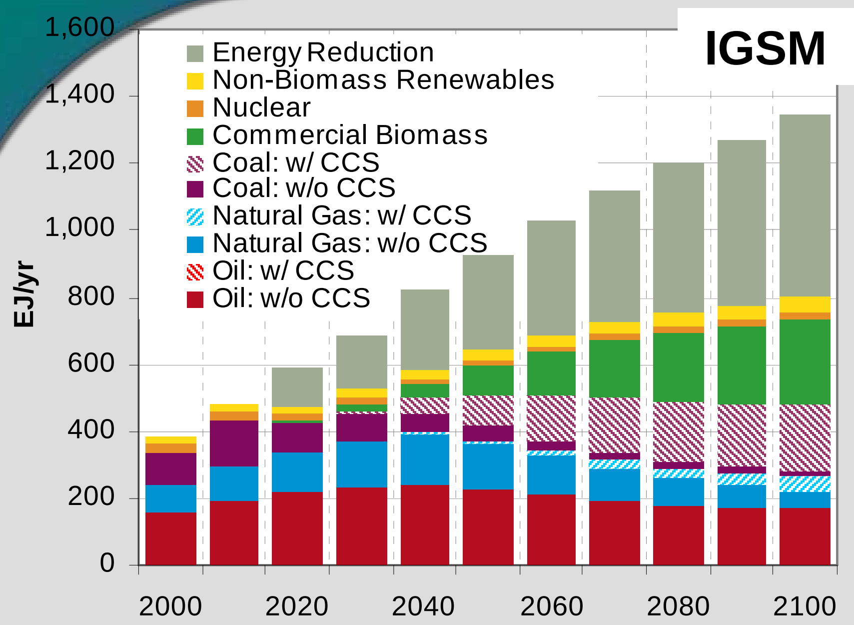
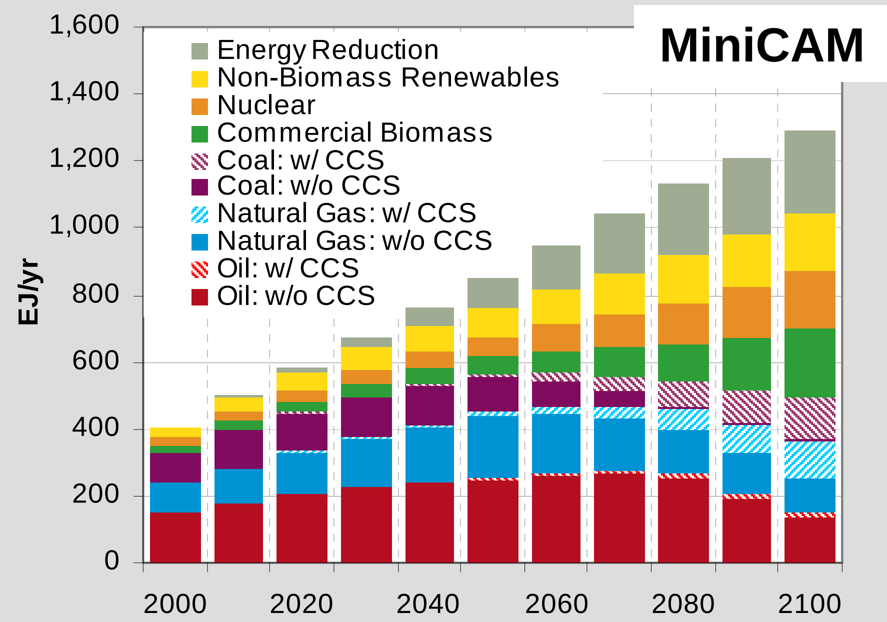
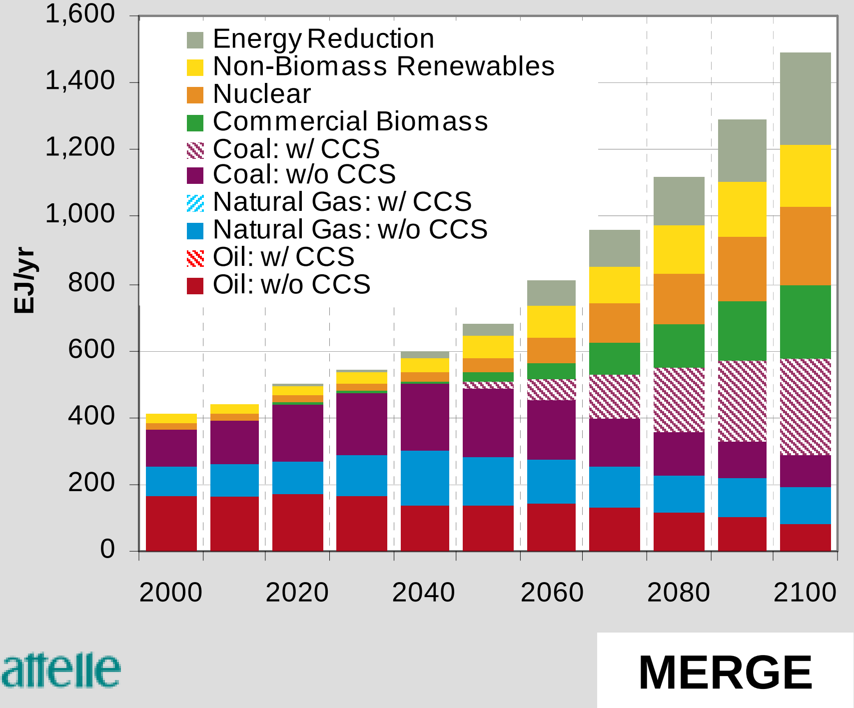
- All of the scenarios maintain a heterogeneous energy mix

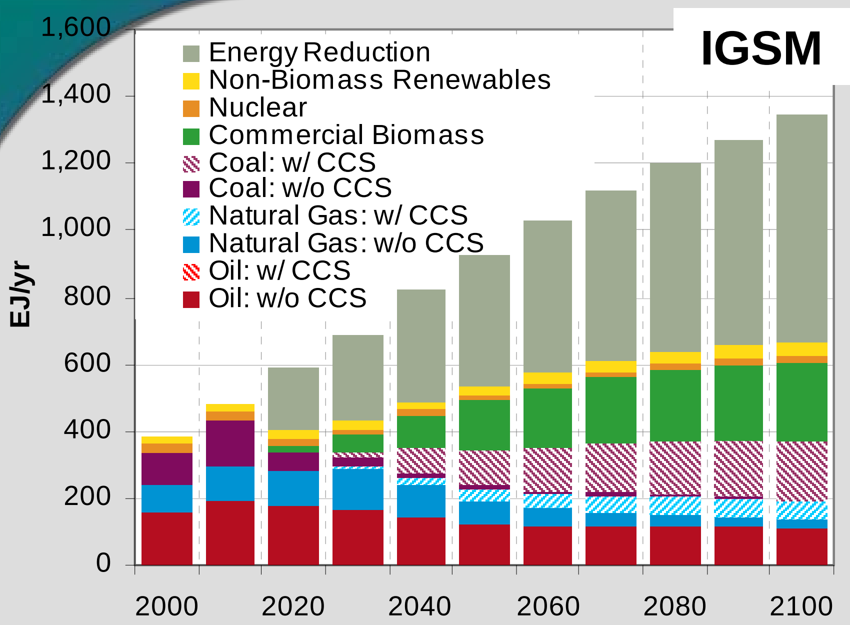


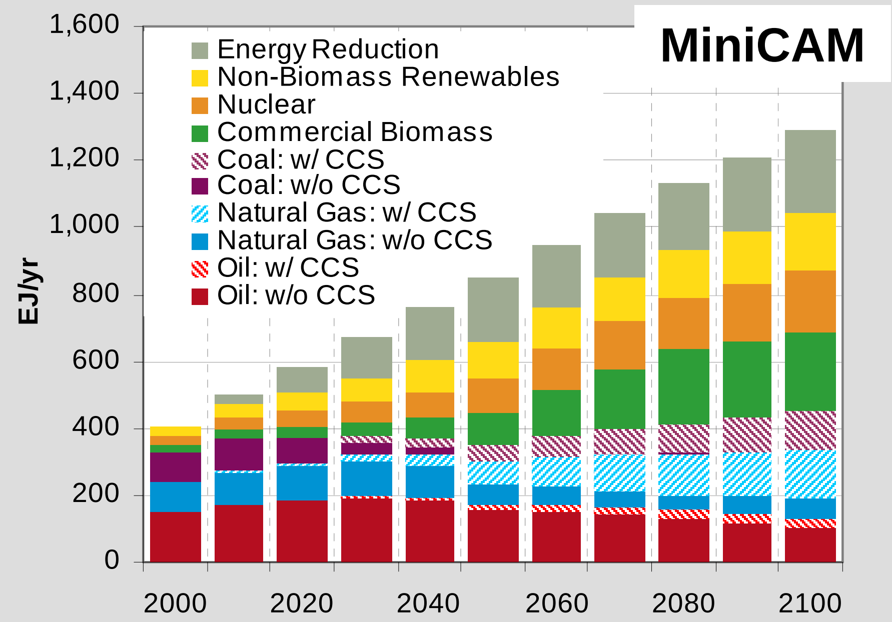


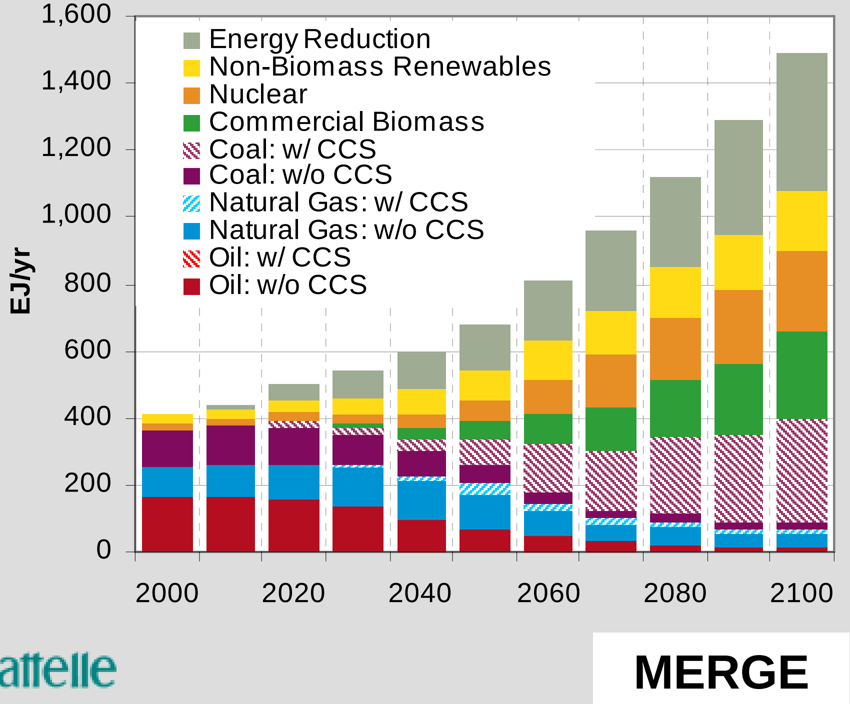


PRIMARY ENERGY (Level 2, 550 ppmv)

- 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

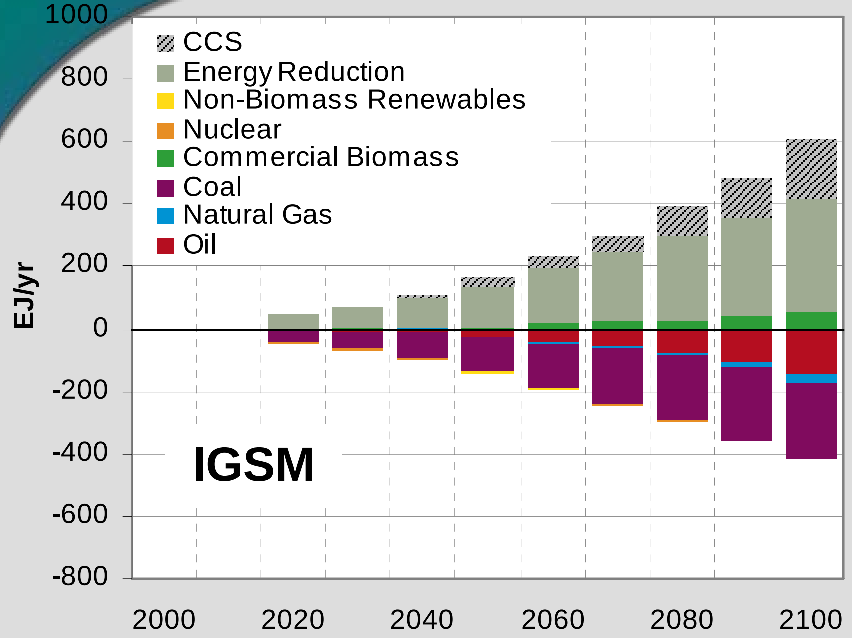


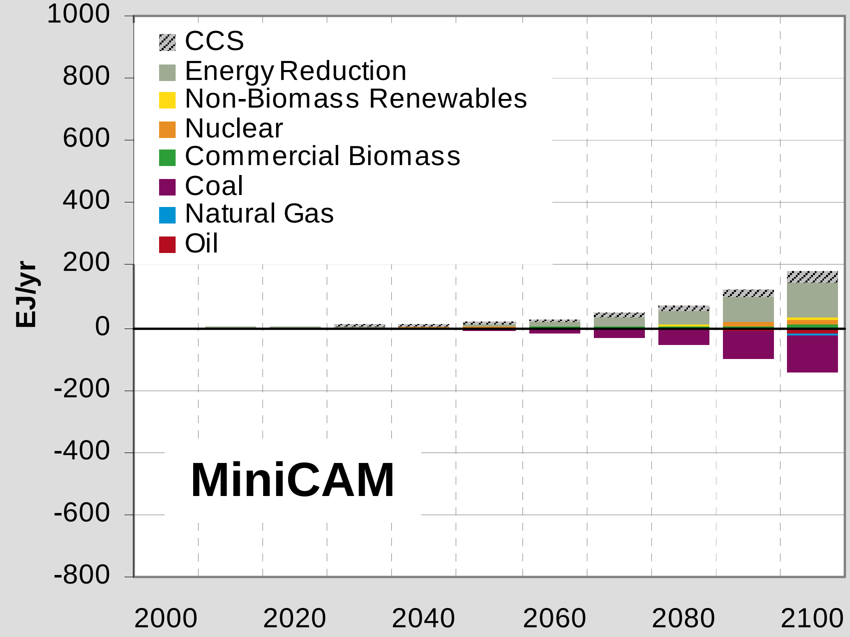


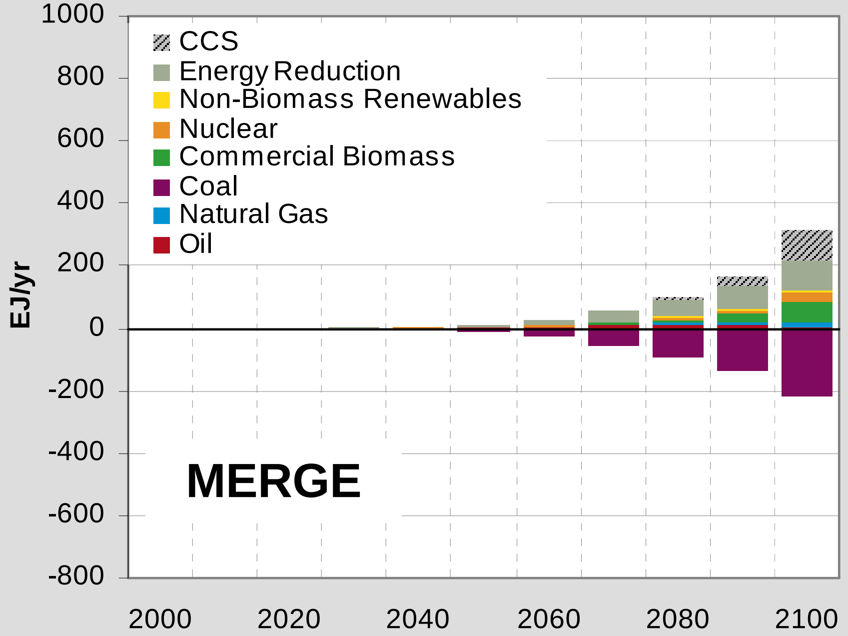


PRIMARY ENERGY (Level 1, 450 ppmv)

- 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







PRIMARY ENERGY (Level 4, 750 ppmv)

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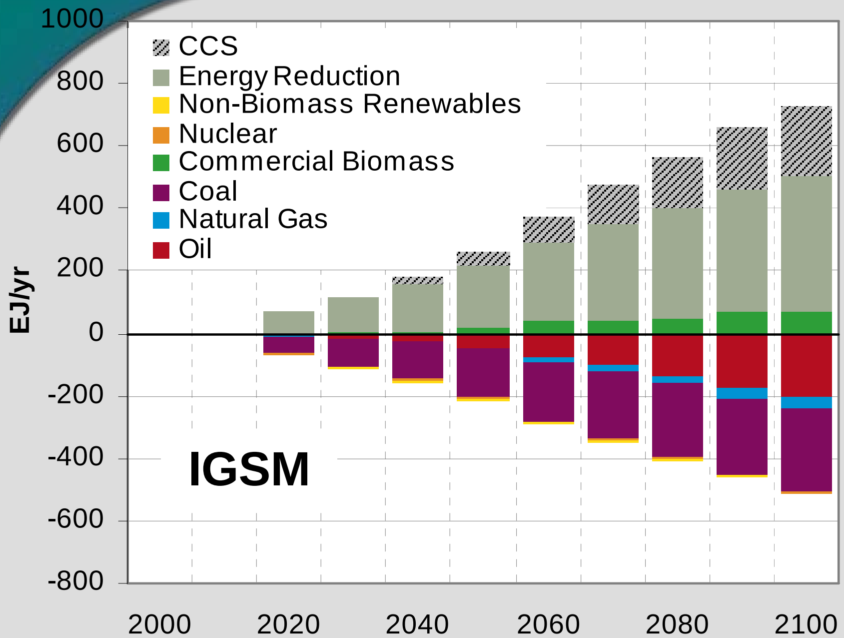

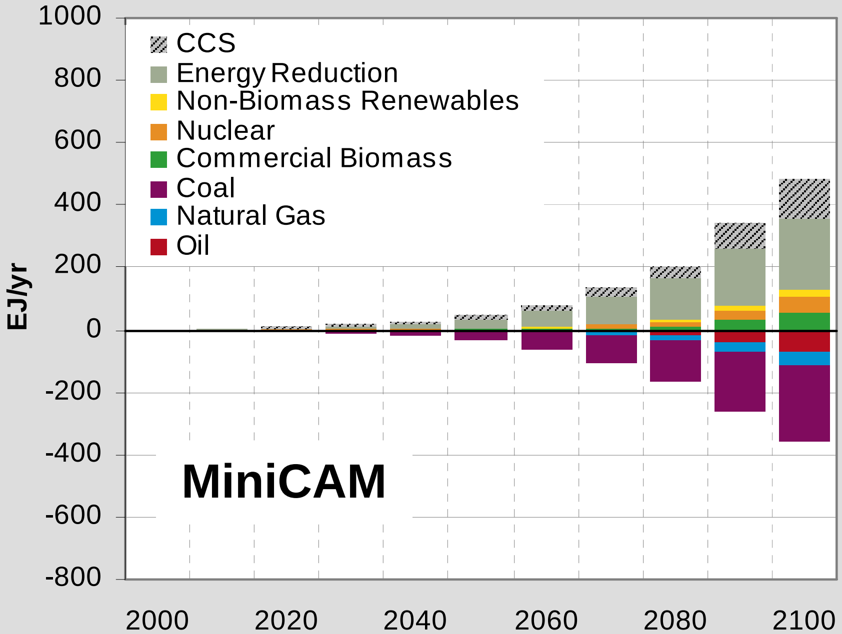

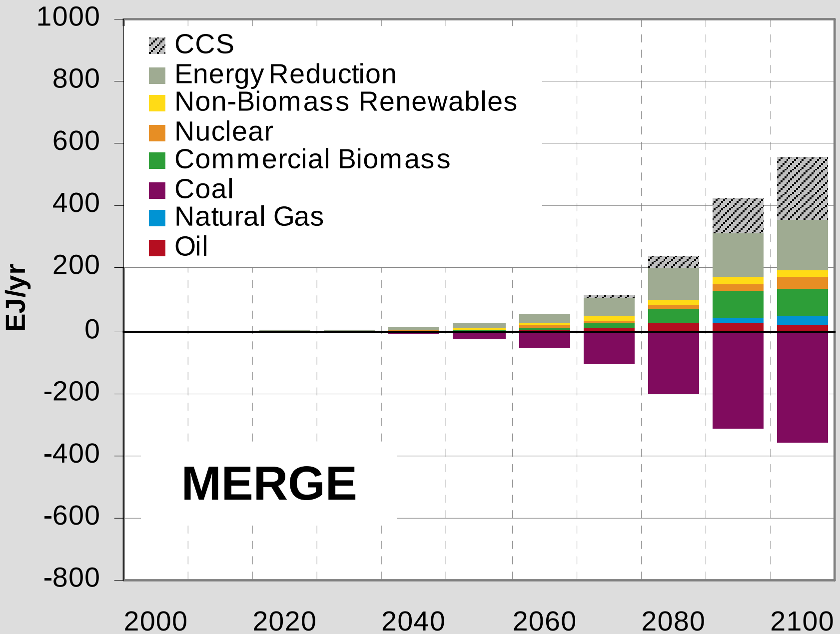

PRIMARY ENERGY (Level 3, 650 ppmv)

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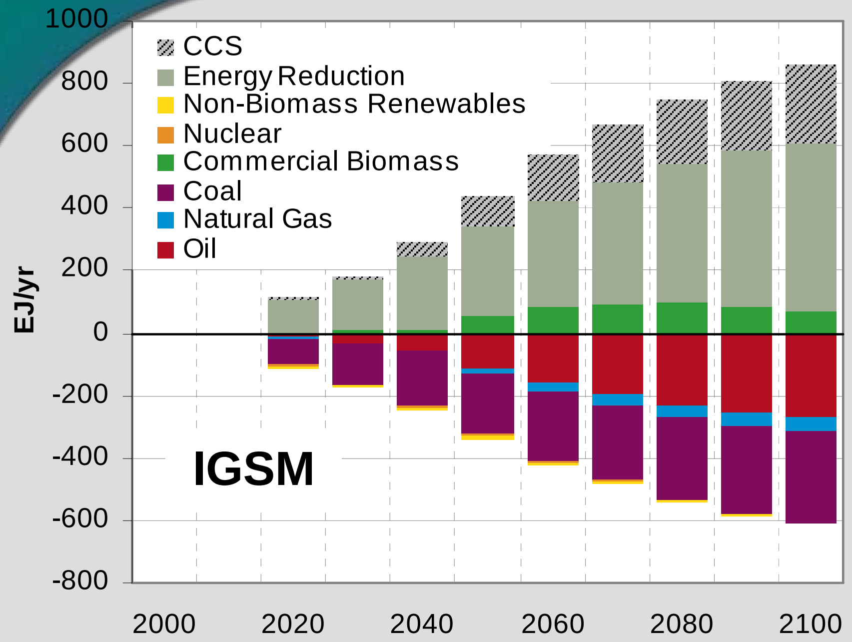
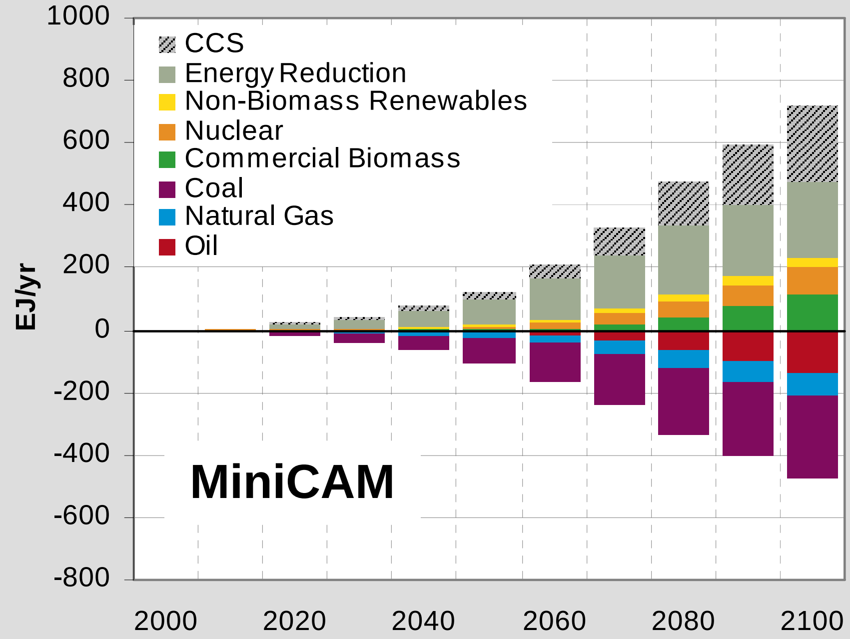
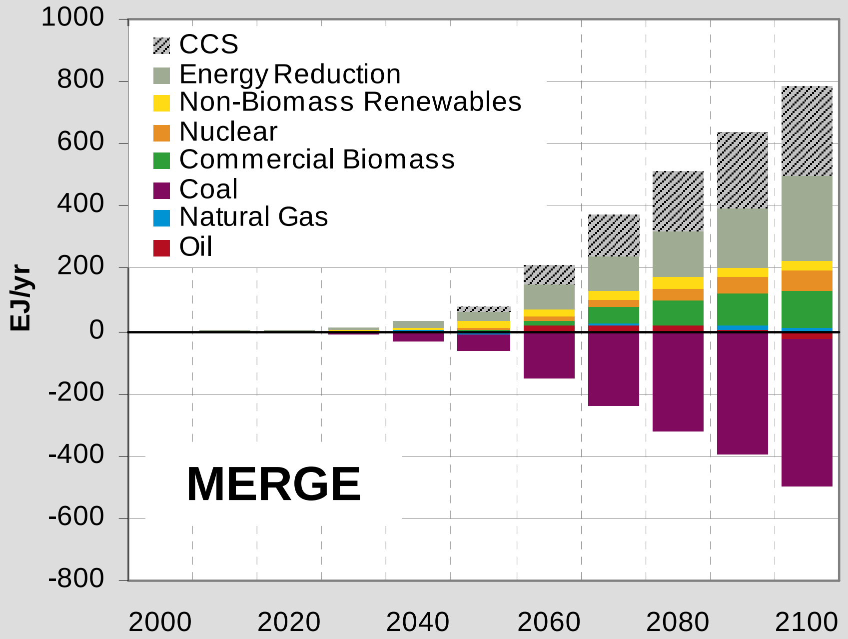
- All of the scenarios maintain a heterogeneous energy mix







PRIMARY ENERGY (Level 2, 550 ppmv)

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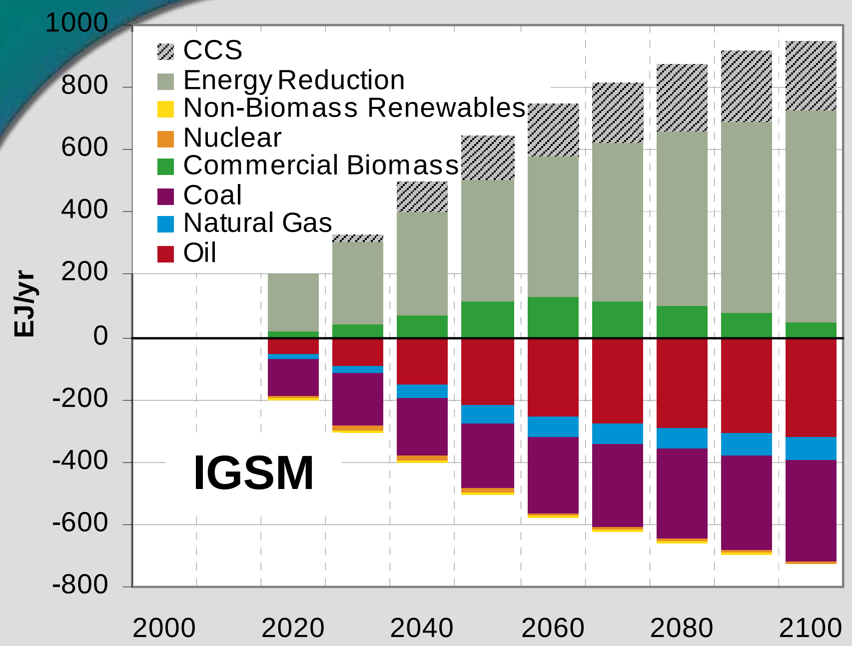

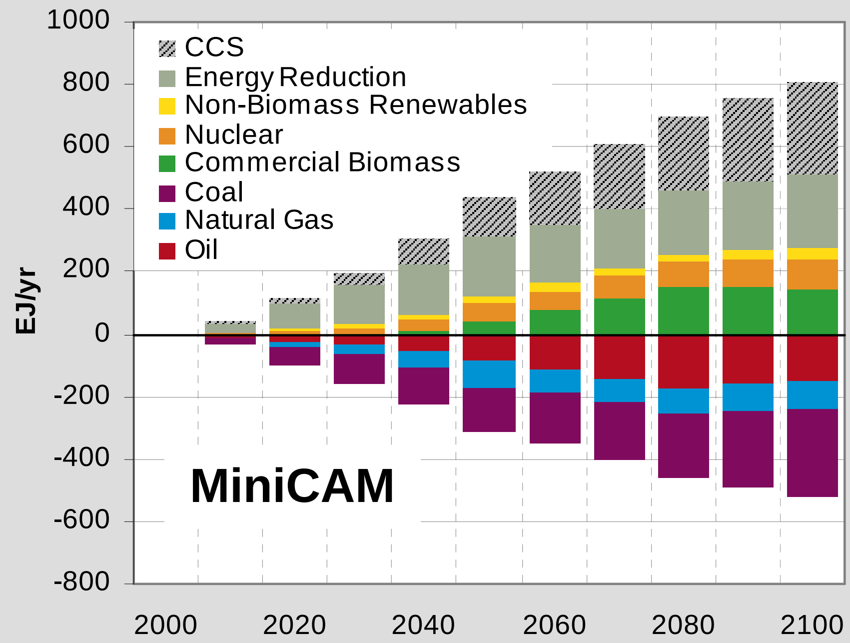

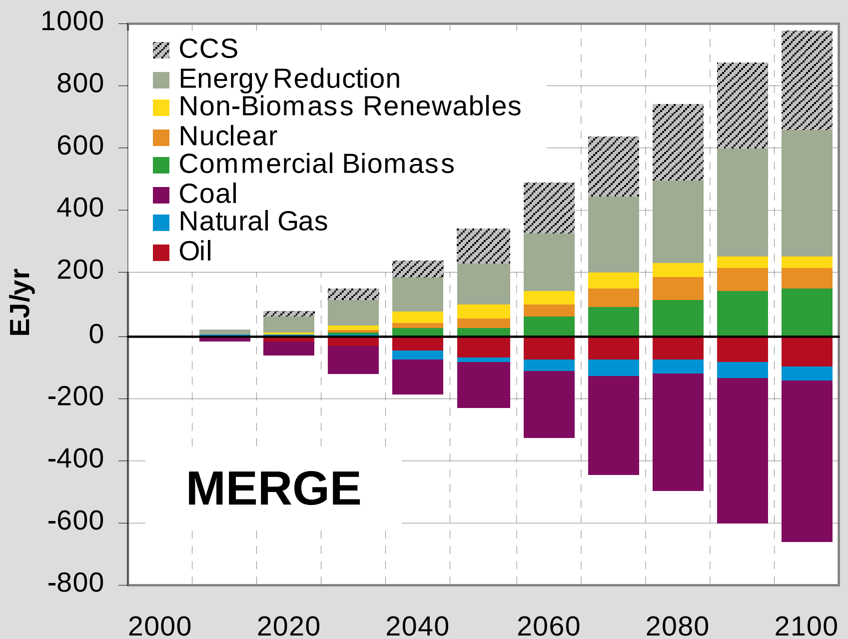

PRIMARY ENERGY (Level 1, 450 ppmv)

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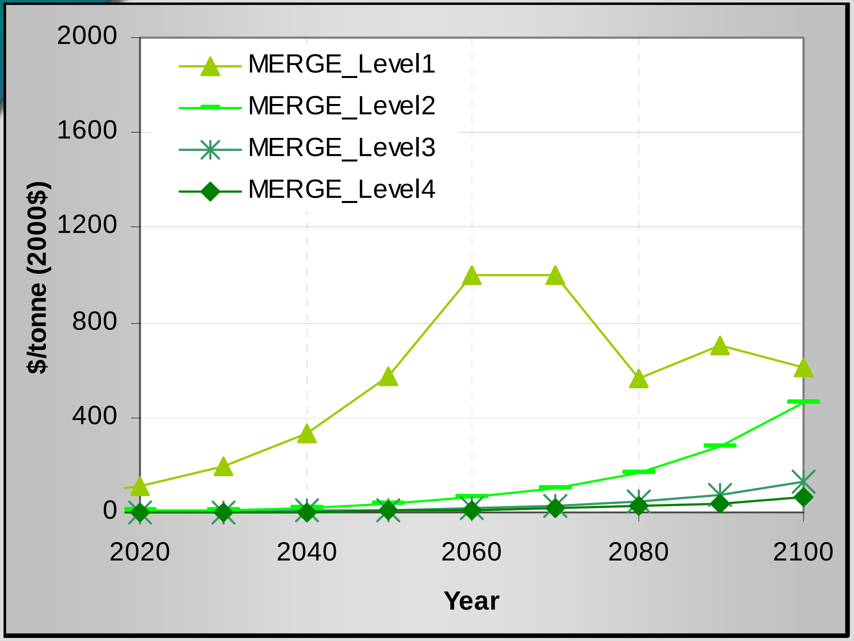
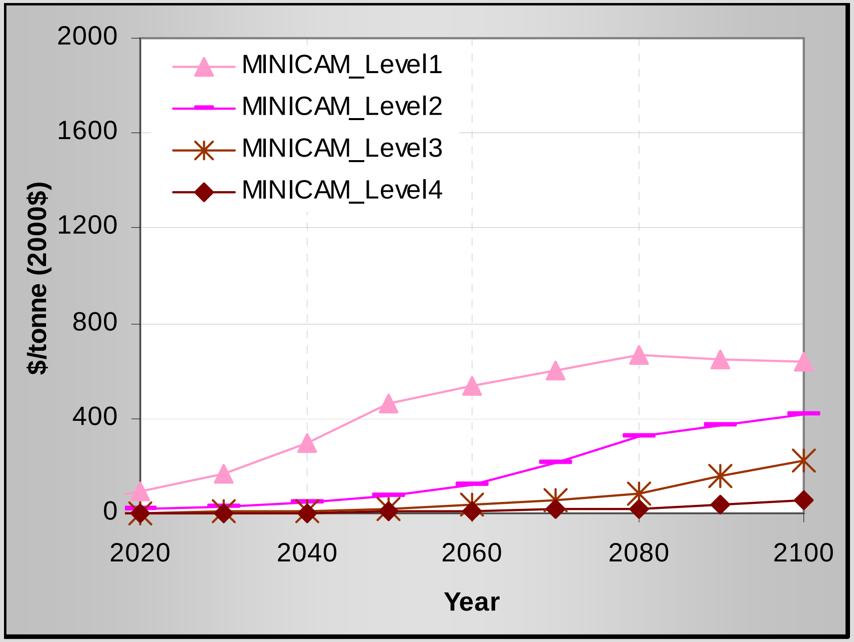
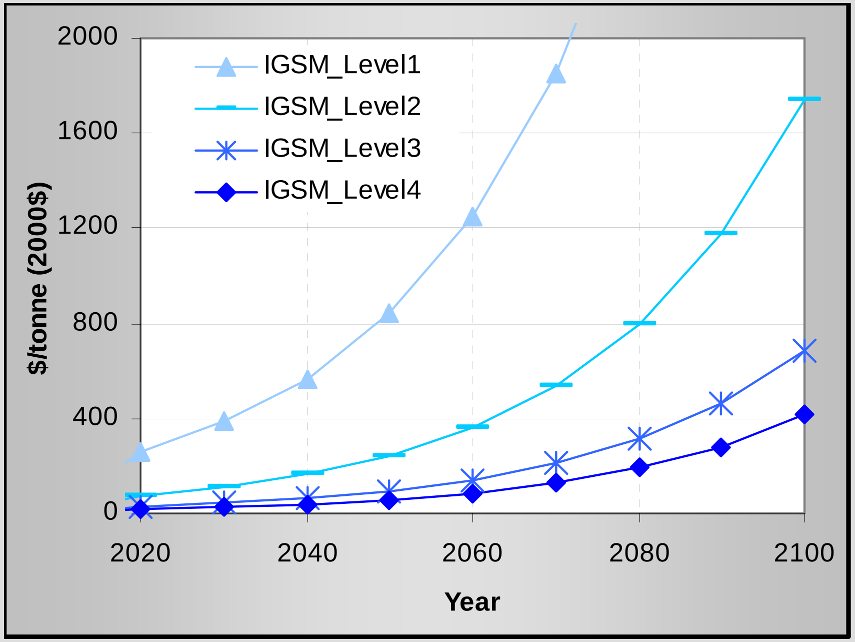
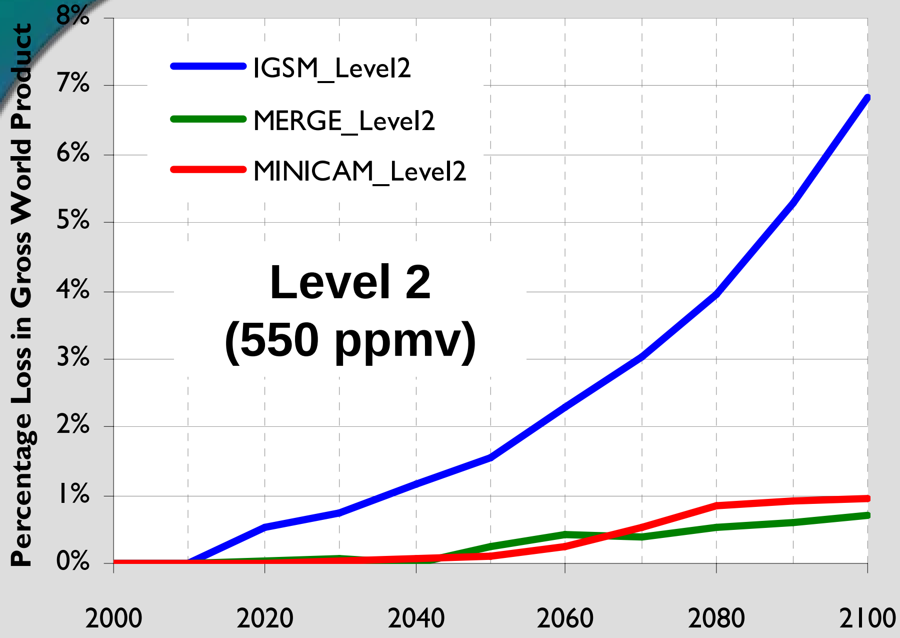


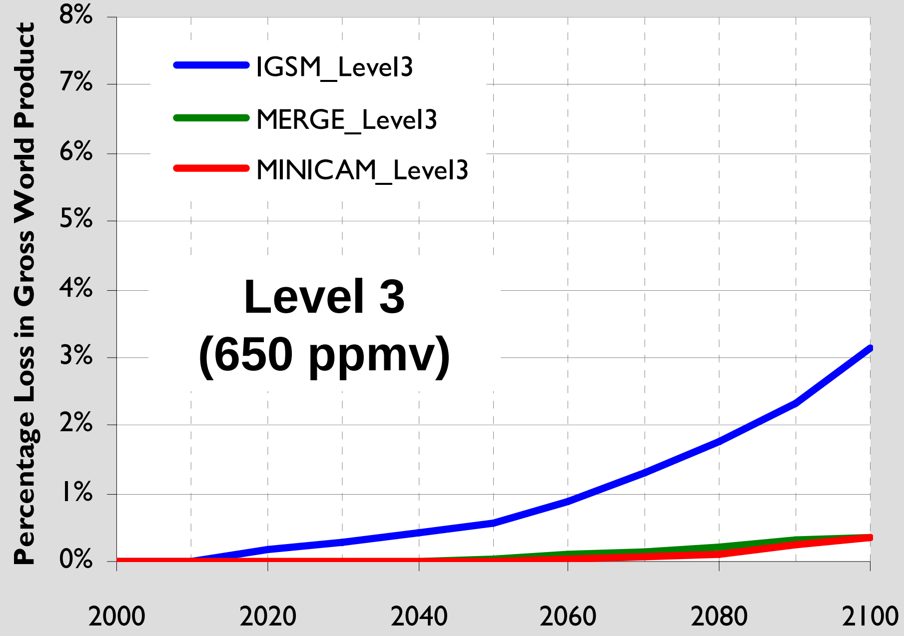


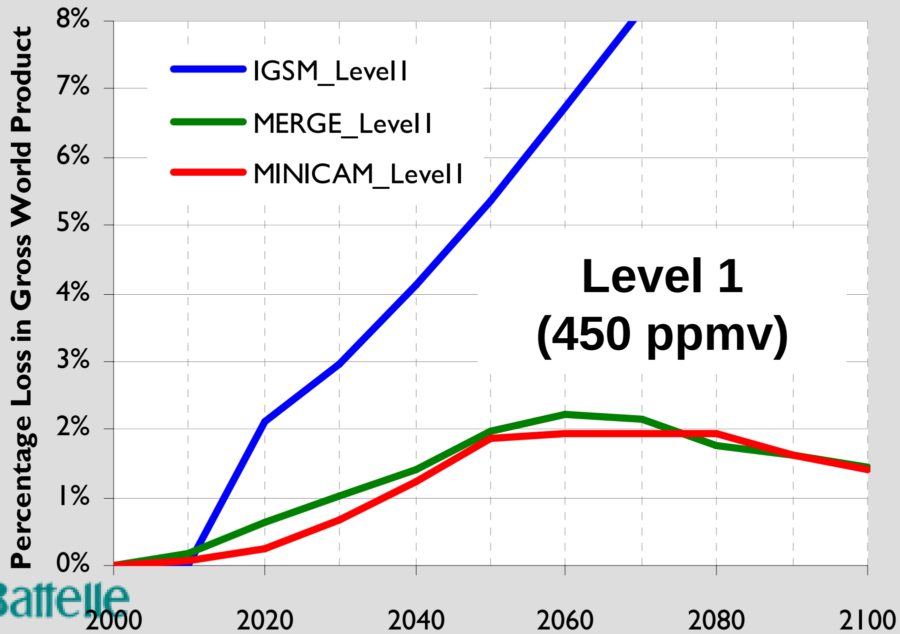


CARBON PRICES

PERCENTAGE LOSS IN GROSS WORLD PRODUCT (MER)







The Main Drivers

The issue—why is there a difference in estimates of costs across the three models? Two factors appear to play prominent roles.

1. Degree of Emissions Reductions, and

2. Assumptions about post-2050 technology

Emissions Reductions

While both the degree to which models reduce emissions matters in all stabilization scenarios, differences in the degree of emissions mitigation are particularly important in stabilization Levels 3 and 4.

Relative Cumulative Emissions Reductions from the Reference Scenarios 2000 to 2100

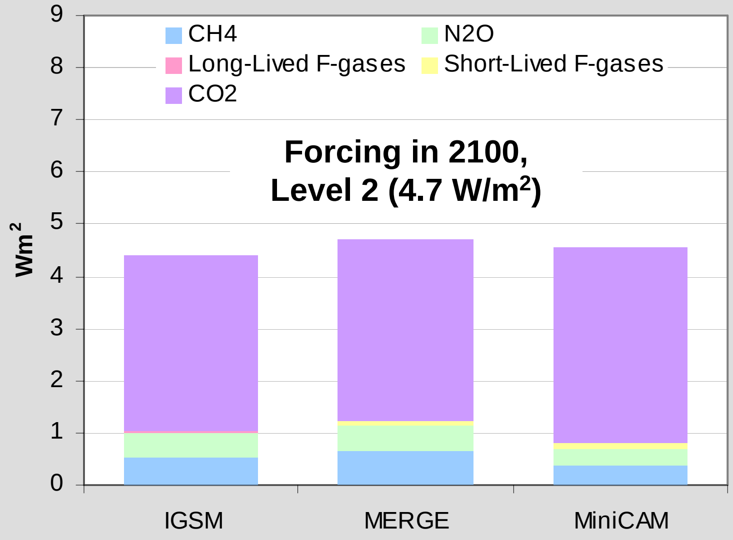
	IGSM	MERGE	MiniCAM
Level 4	**28%**	**9%**	**7%**
Level 3	**40%**	**20%**	**19%**
Level 2	55%	40%	38%
Level 1	69%	69%	66%

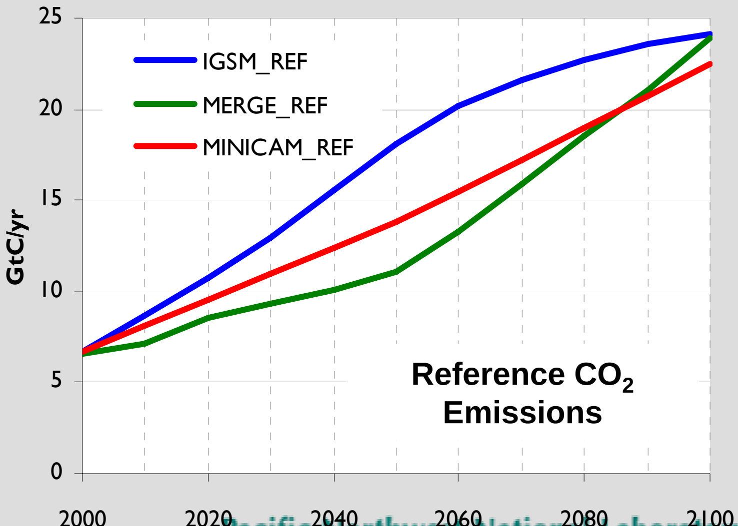
Sources of Differences in Emissions Mitigation

- Reference case emissions

- Carbon cycle

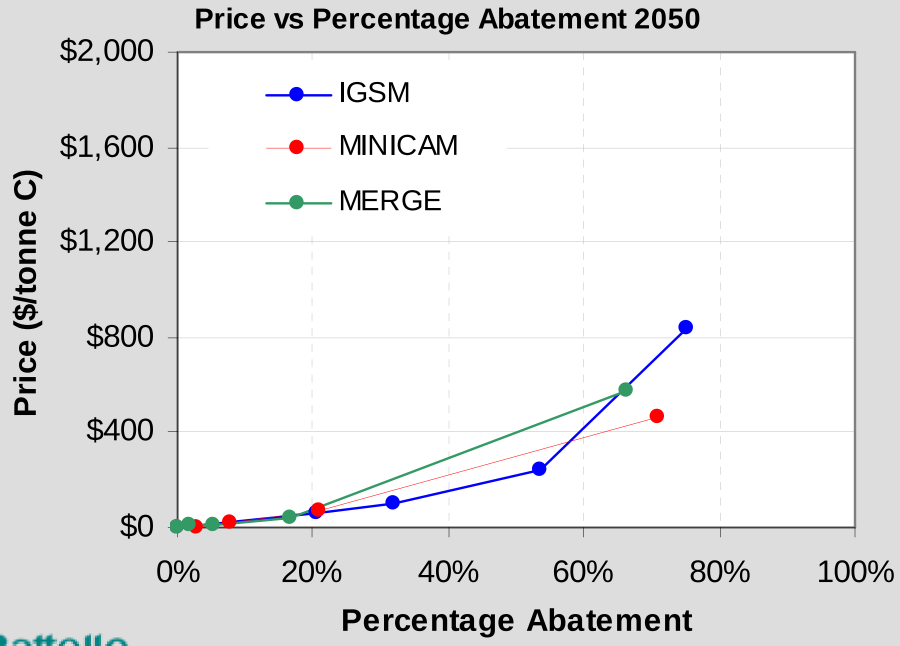
- Non-CO_2 GHG's

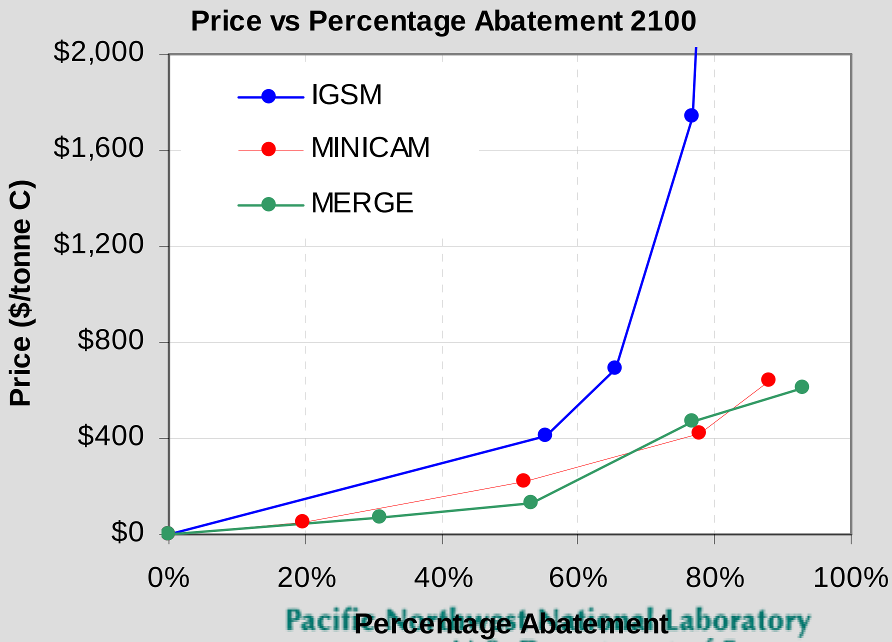


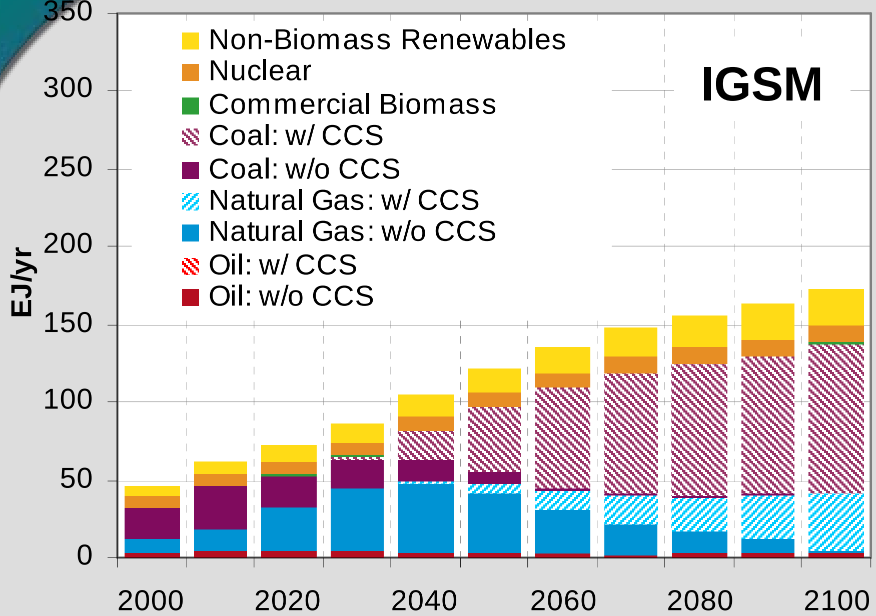


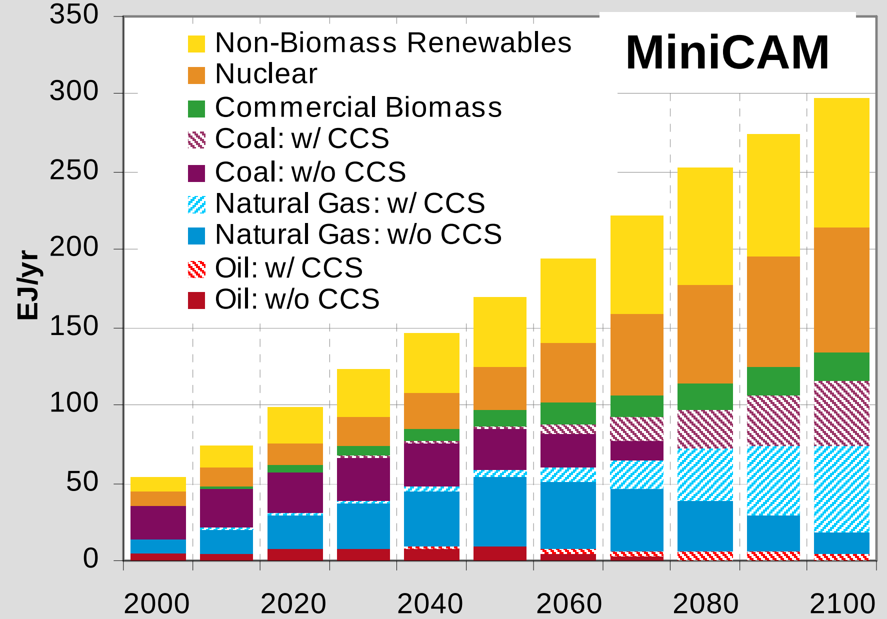
The Role of Technology

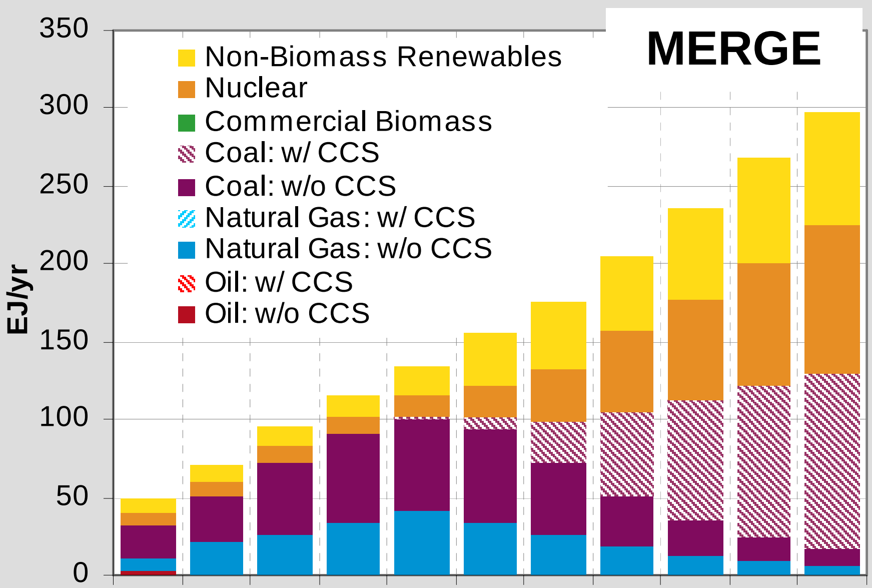
- The cost behavior of the scenarios behavior is relatively similarly in 2050.
- Technology in the post 2050 time frame has strong cost implications
- The approach to when flexibility links the short and long term









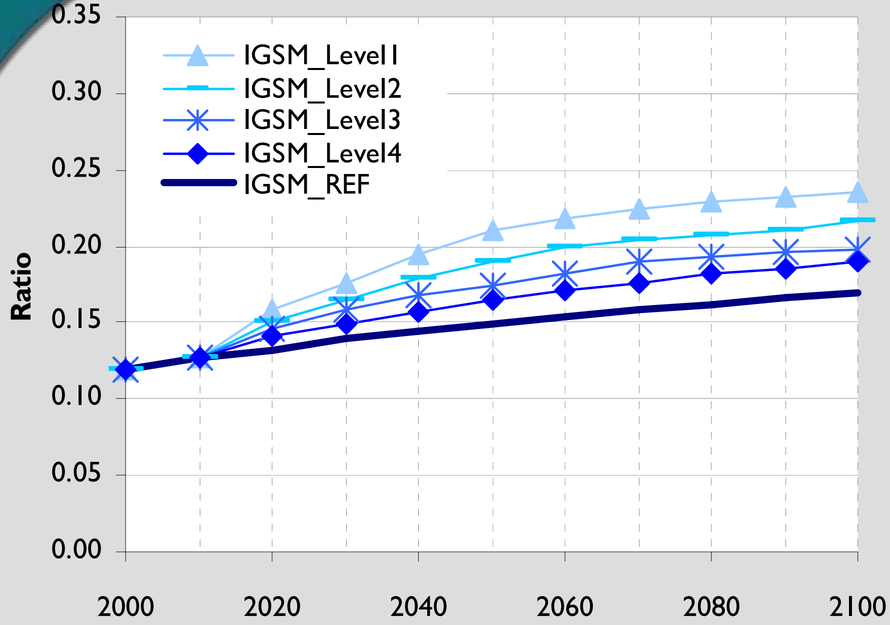


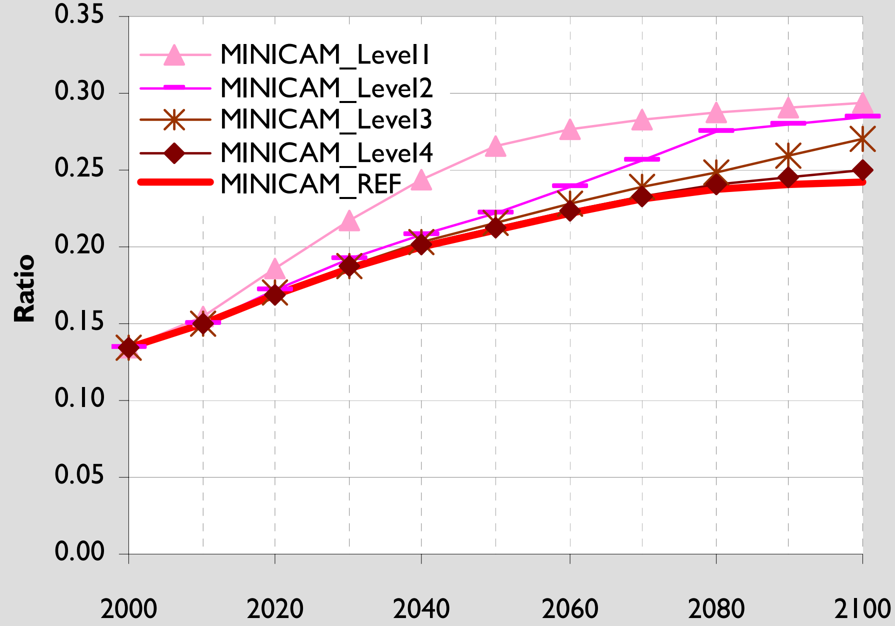
All of the models have ample opportunities for decarbonizing electricity.

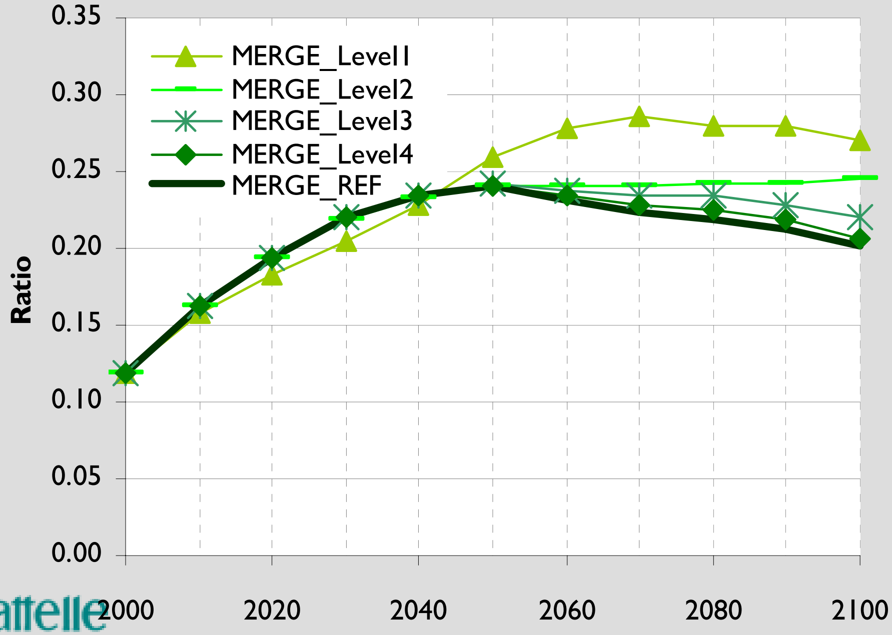
- In the Level 1 scenarios, the electricity sector is almost completely decarbonized.

Post-2050 Technology

- What is the bioenergy resource base?
- Are there other low-carbon sources such as low-carbon hydrogen?
- How far can electricity move into new end uses?
  - None of the scenarios seriously electrify the transportation sector.



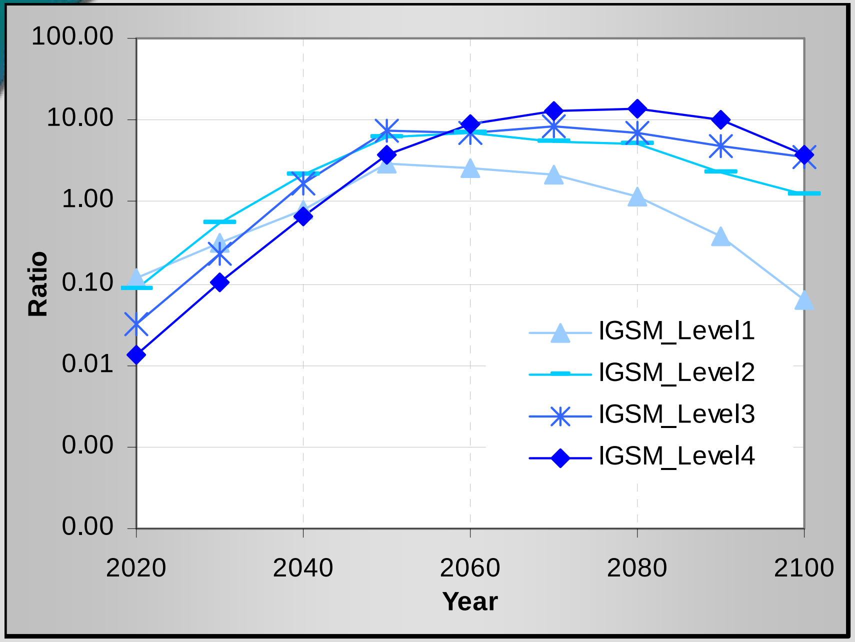


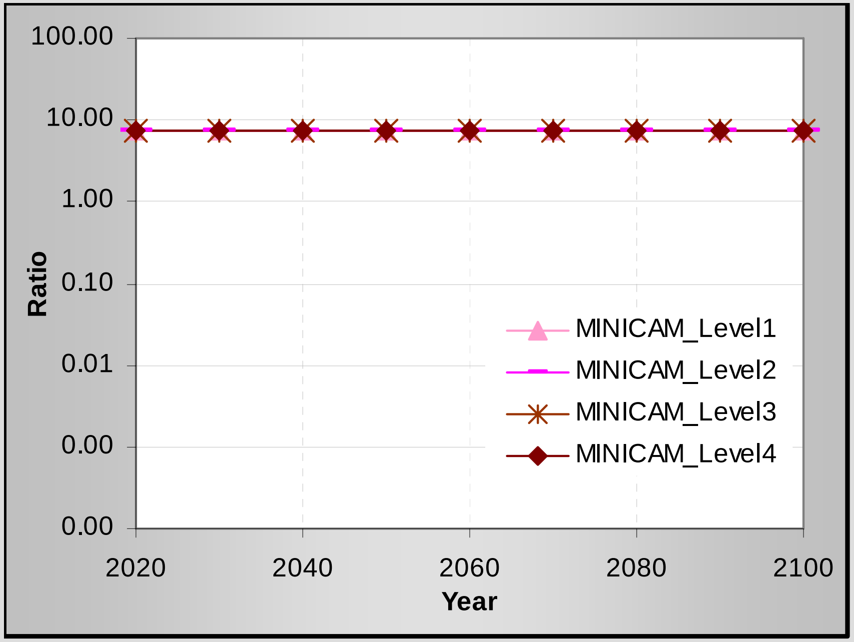


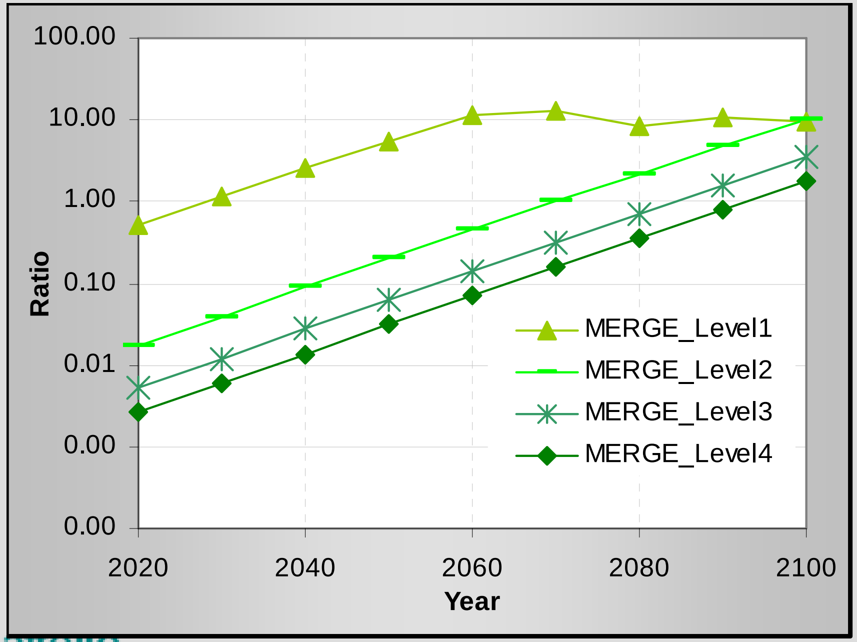
RATIO OF ELECTRICITY TO PRIMARY ENERGY

Other Factors

- Emissions reductions in other sectors (e.g. cement)
- Model structure
- Effects on capital accumulation

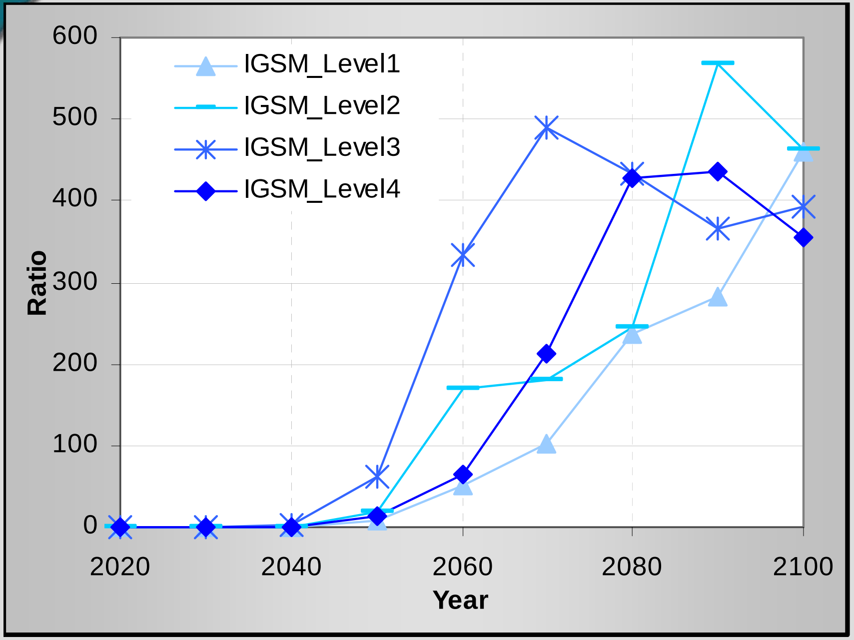


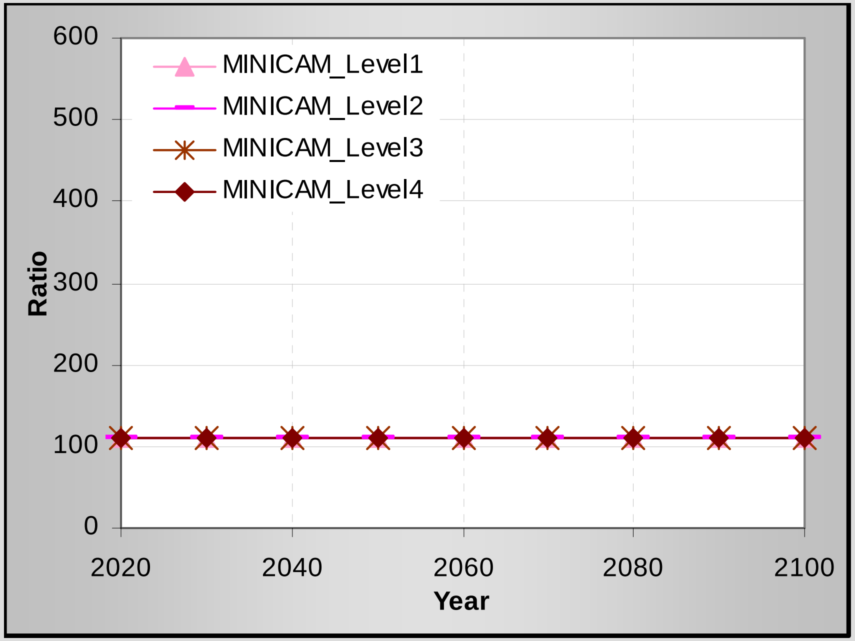


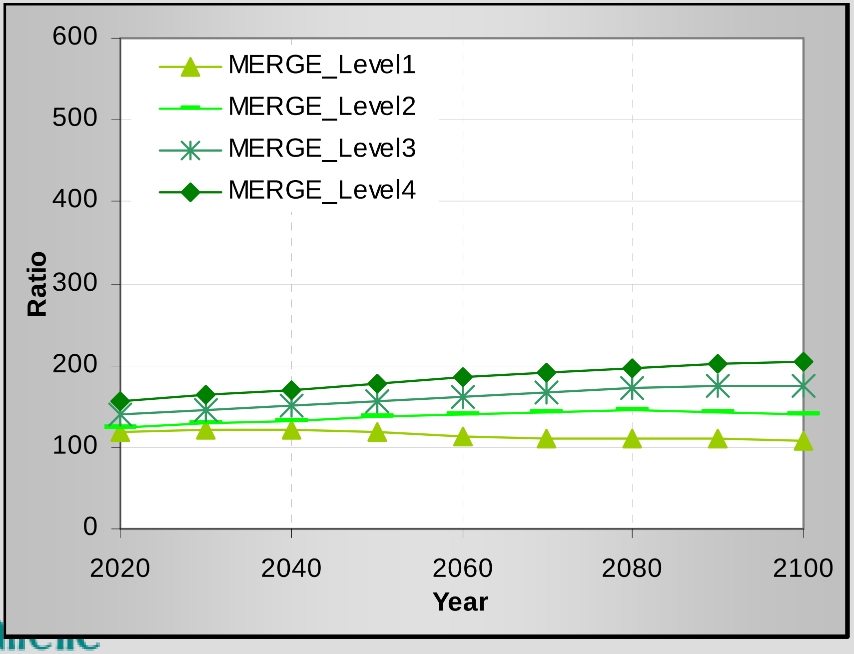


Ratio of the Price of CH_4 to the Price of Carbon

The models take very different approaches to the treatment of non-CO_2 greenhouse gases







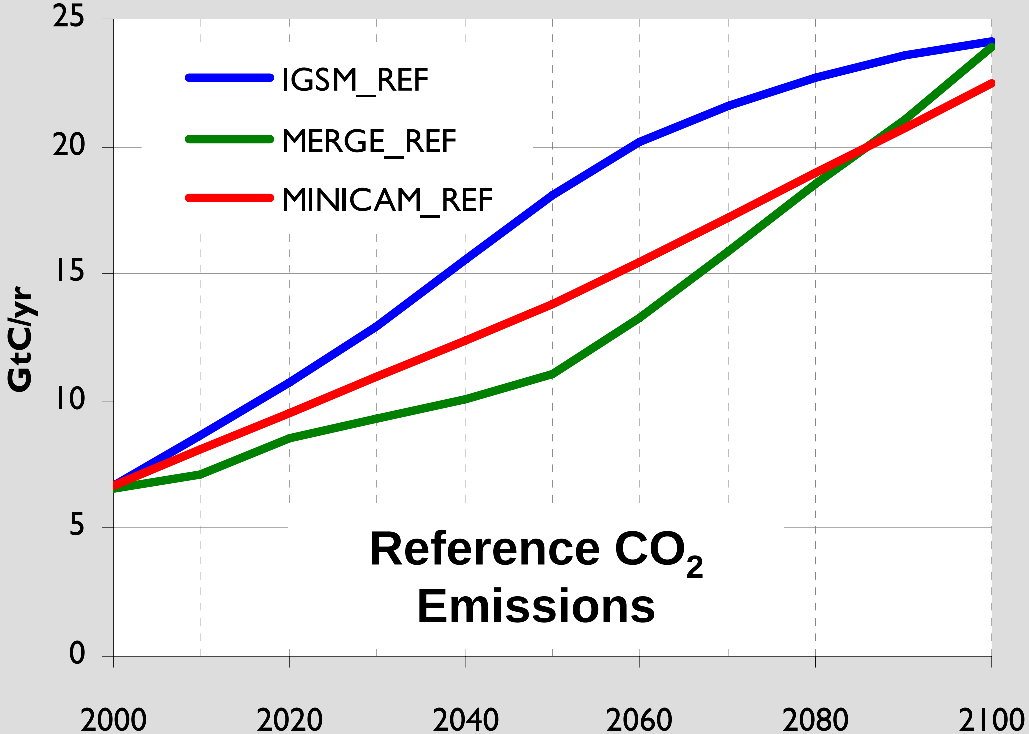
Ratio of the Price of N_2O to the Price of Carbon

The models take very different approaches to the treatment of non-CO_2 greenhouse gases

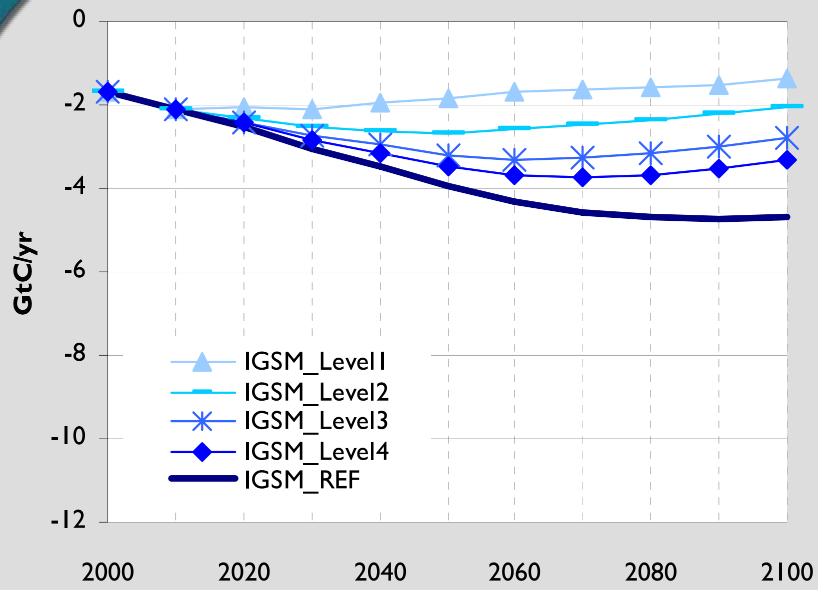
Limitation/Areas for Future Work

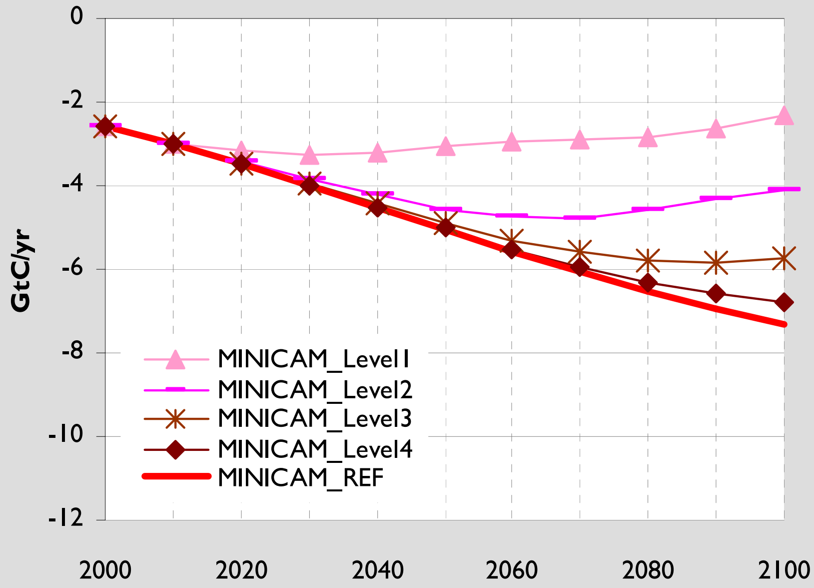
- Technology and other sensitivity analysis
- Consideration of less optimistic policy regimes
- Improvement/enhancement of the land use components of the models
- Inclusion of other radiatively-important substances
- Decision-making under uncertainty

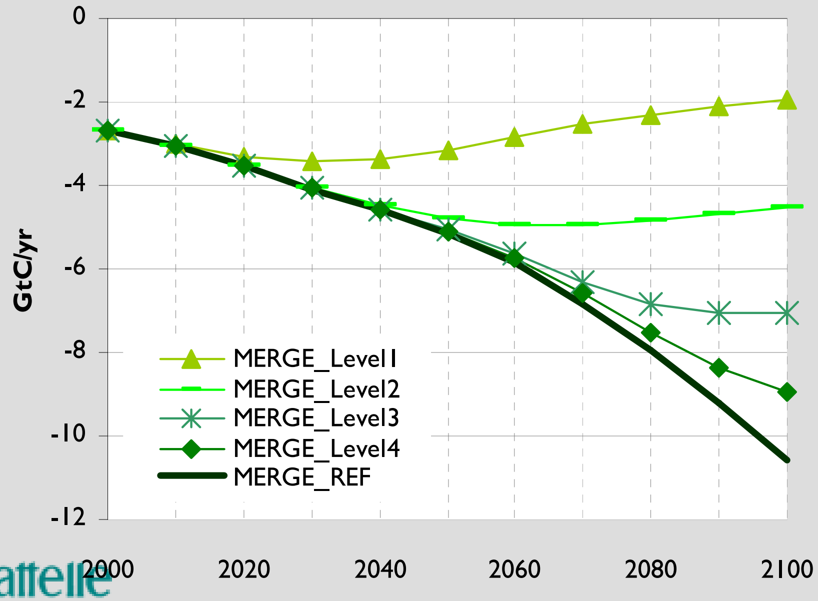
END



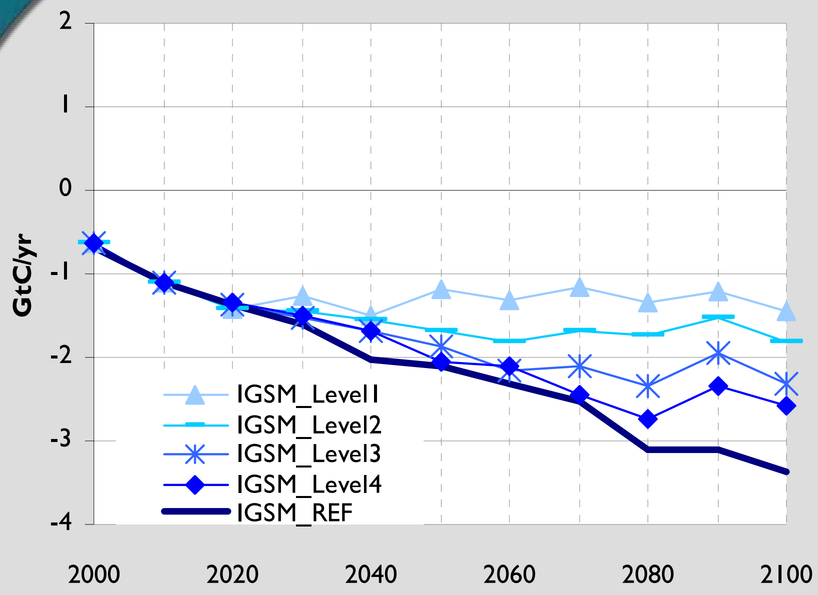
Although the reference scenarios end up at roughly the same place, they take very different pathways over the century.

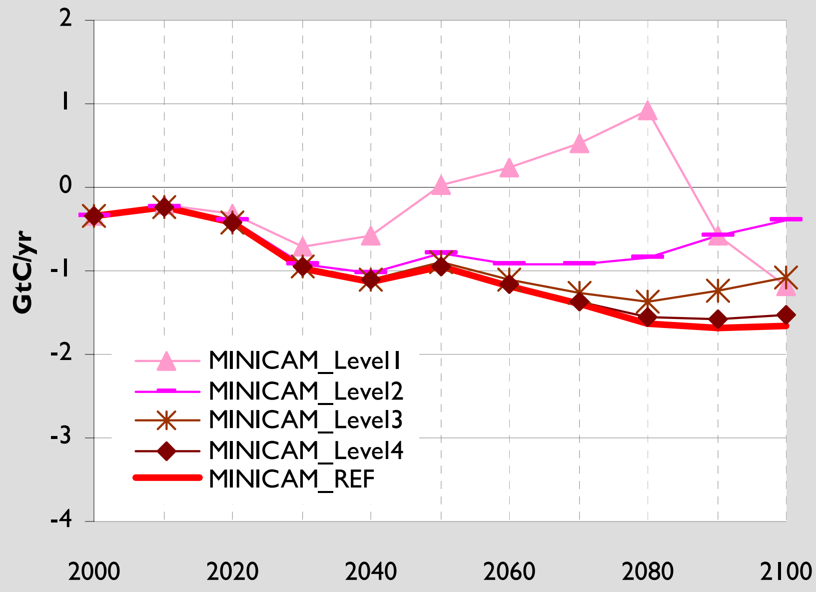


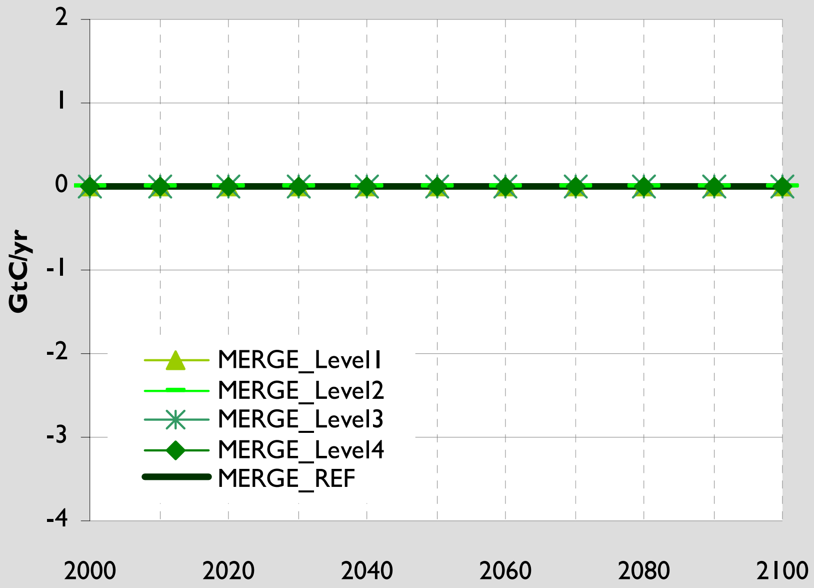




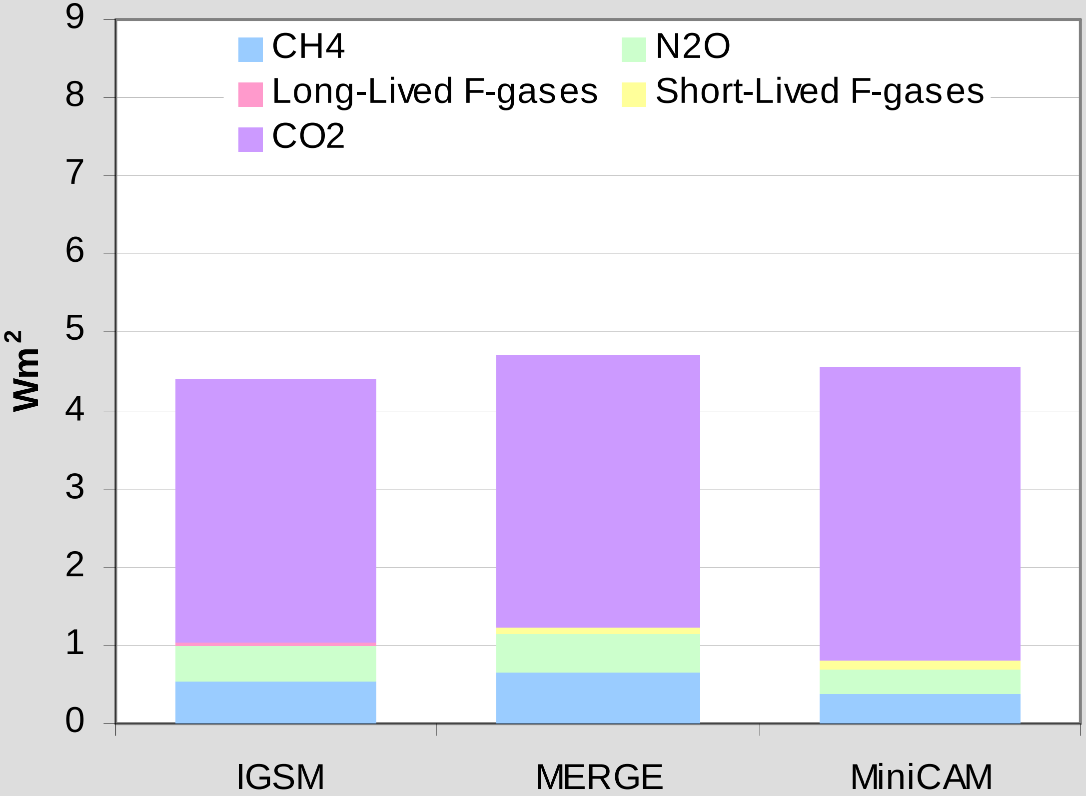
OCEAN UPTAKE







NET TERRESTRIAL EMISSIONS



Differing contributions from non-CO_2 greenhouse gases

Stabilization at 4.7 W/M^2 (Level 2, 550 ppmv)