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A Community Emissions Data System (CEDS) For Historical Anthropogenic Emissions

(And the GCAM-USA)

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College Park, MD

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Outline

This talk will be in two parts.

1) *The first portion will give a brief overview of the GCAM-USA modeling system.*

2) *The second portion will focus on a new project to produce consistent historical emissions data for global modeling and research.*

PART 1

GCAM USA

A Integrated Assessment Model For State-Level Energy and Emissions Projections and Analysis

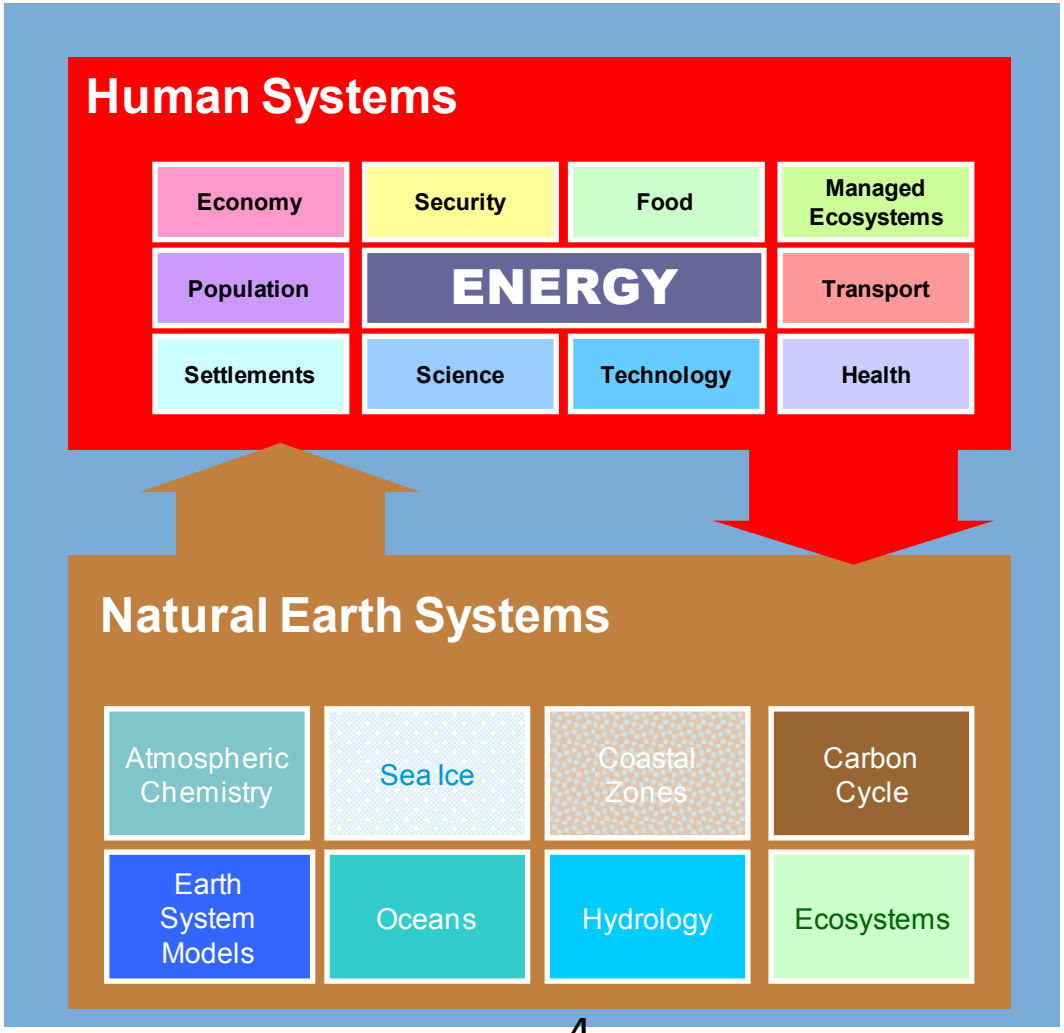
What is an Integrated Assessment Model (IAM)?

IAMs are research tools that integrate human and natural systems

- IAMs provide insights that would be otherwise unavailable from disciplinary research
- IAMs focus on interactions between complex and nonlinear systems
- **IAMs are not substitutes for disciplinary research or more detailed modeling**

IAMs are also science-based decision support tools

- IAMs support national, international, regional, and private-sector decisions



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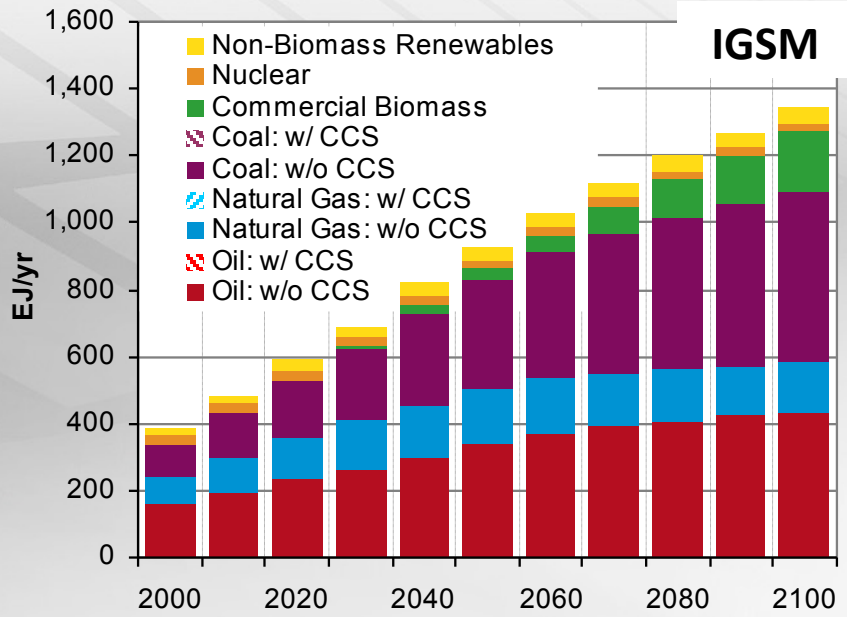
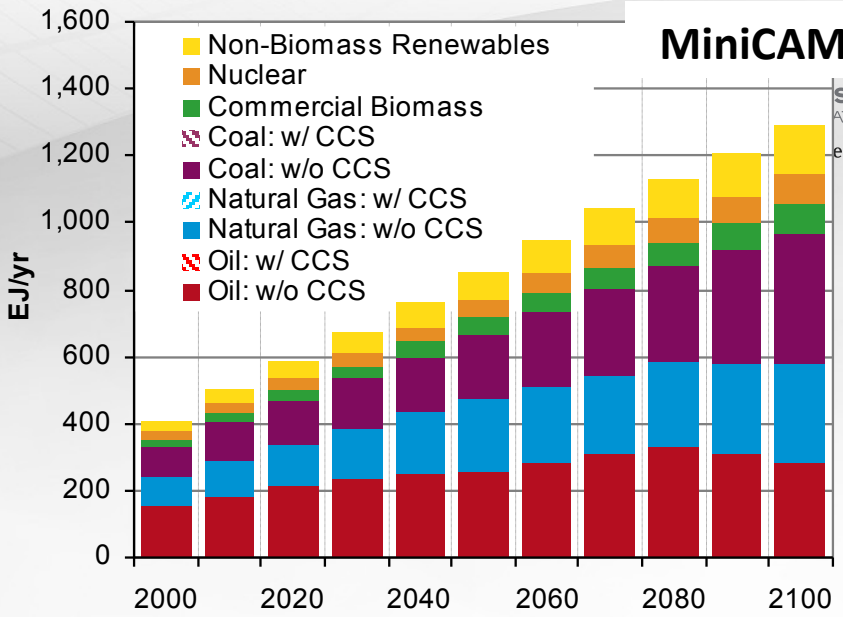
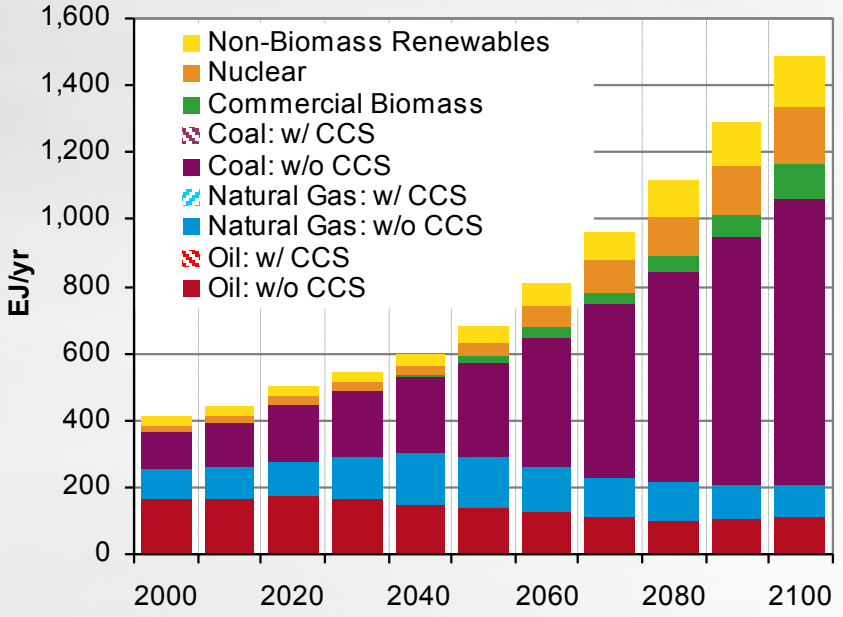




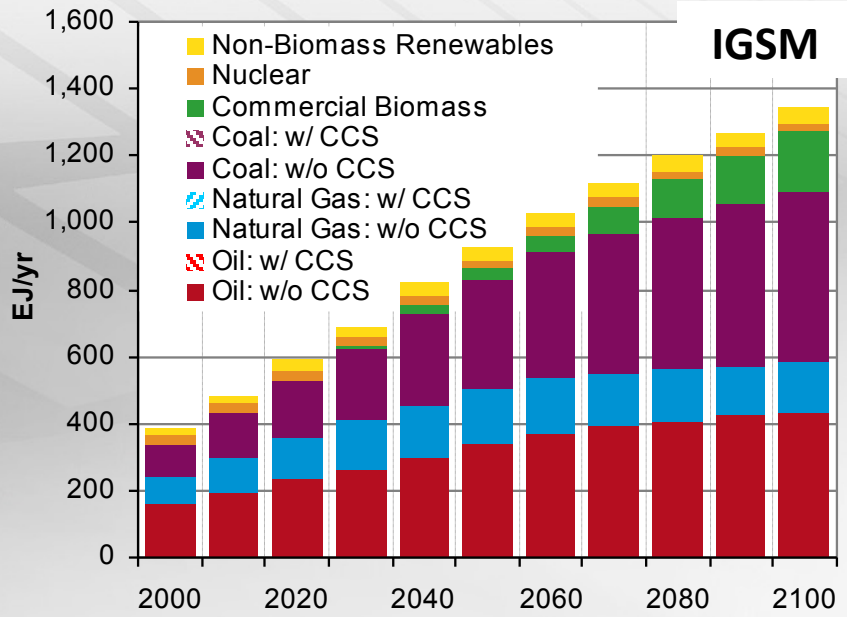


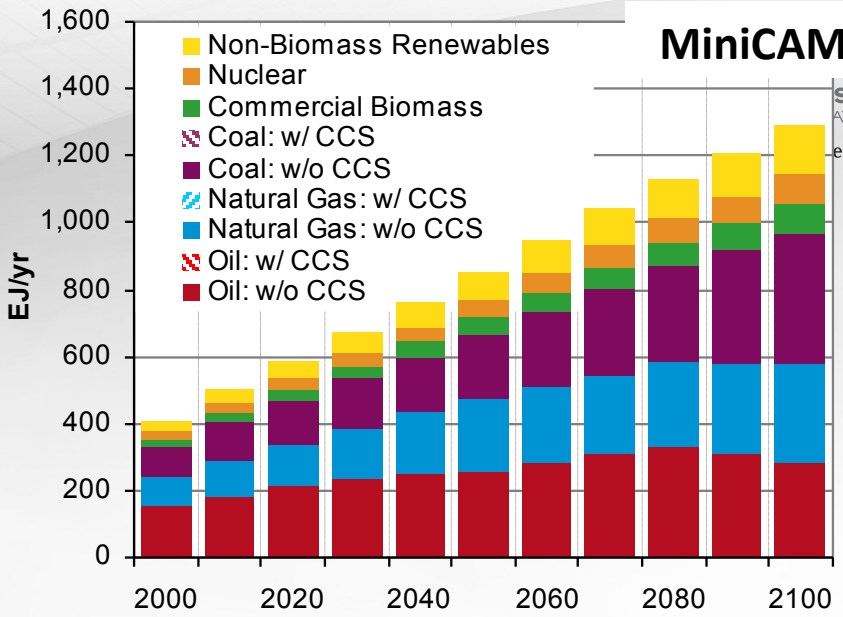
MERGE

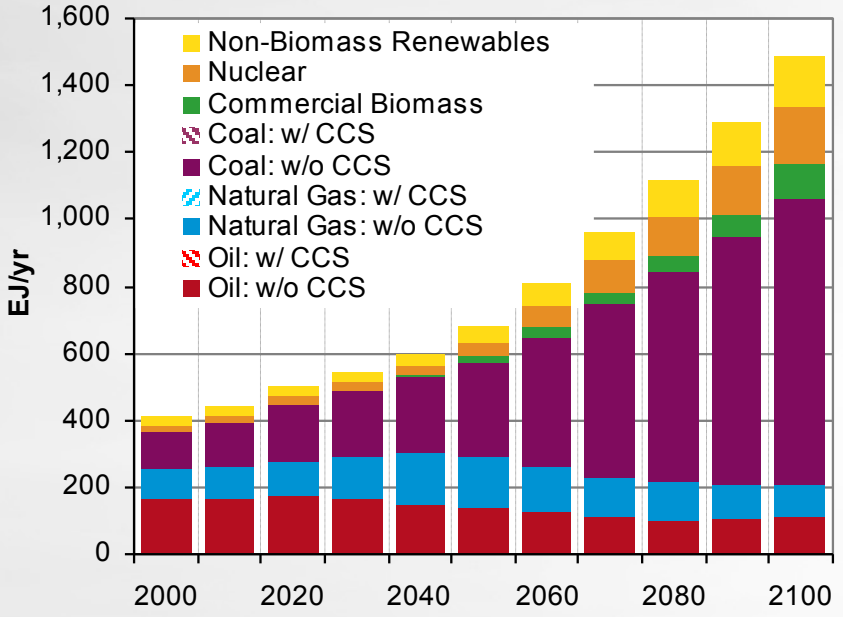
IAMs have been used extensively to support energy-related decision making at national and international scales.

Traditionally for century-scale time periods.

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***



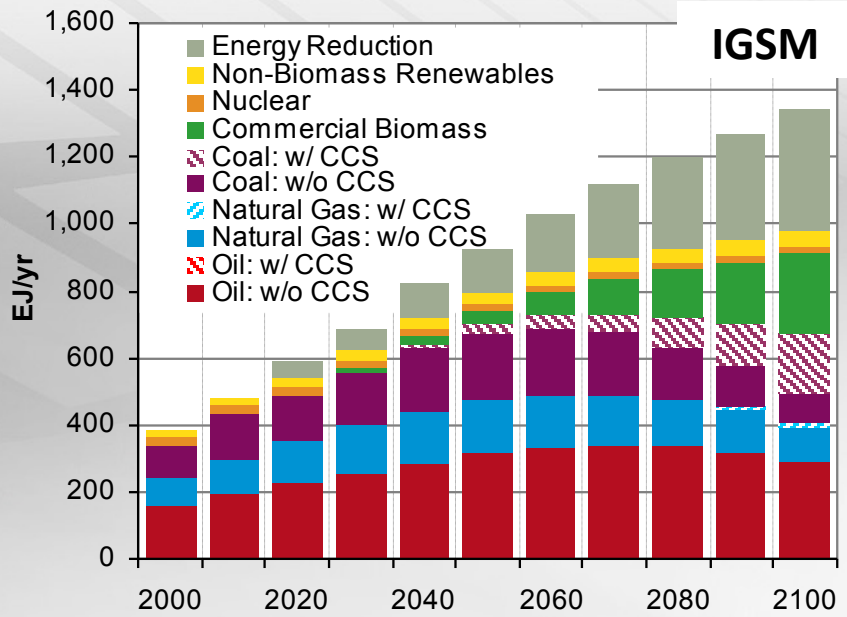


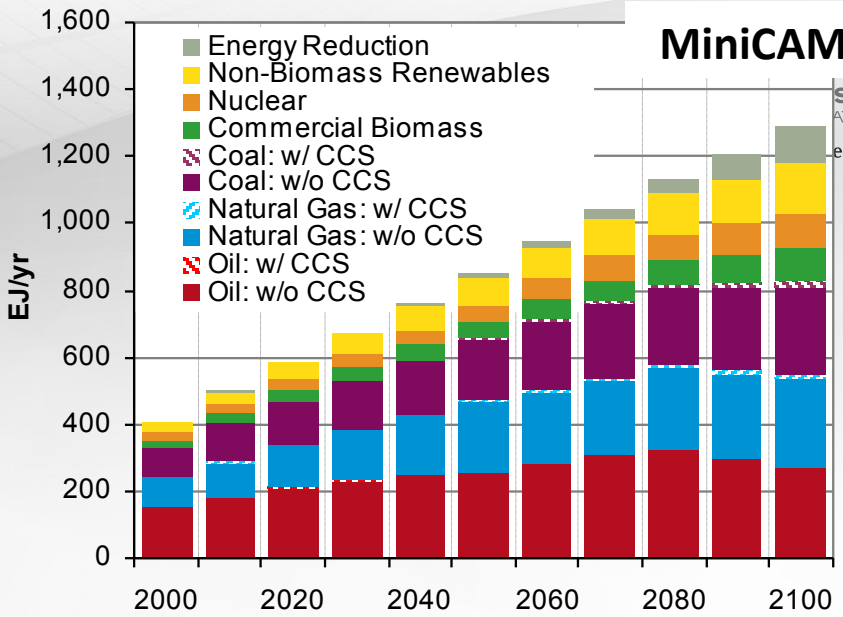


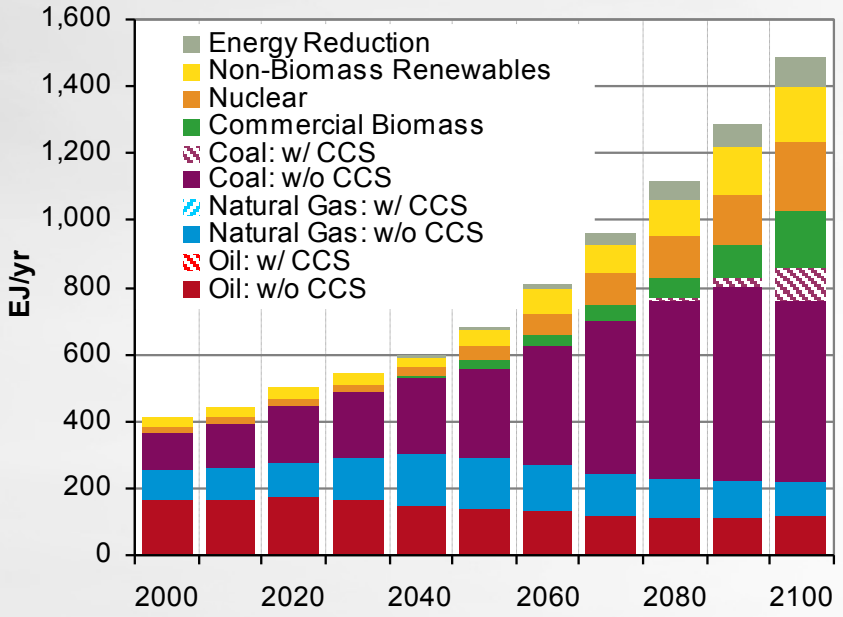
Primary Energy from the CCSP Scenarios

(Reference Scenario)

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***



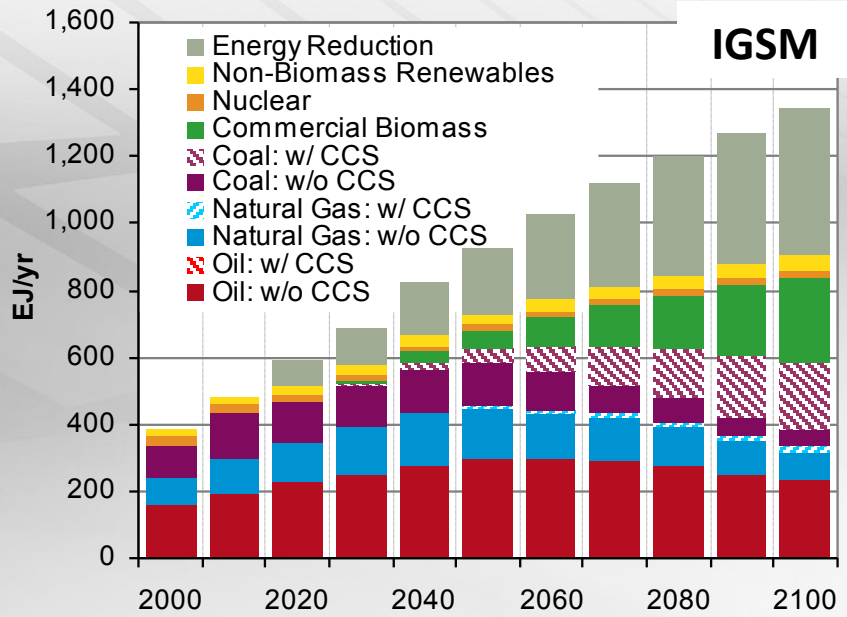


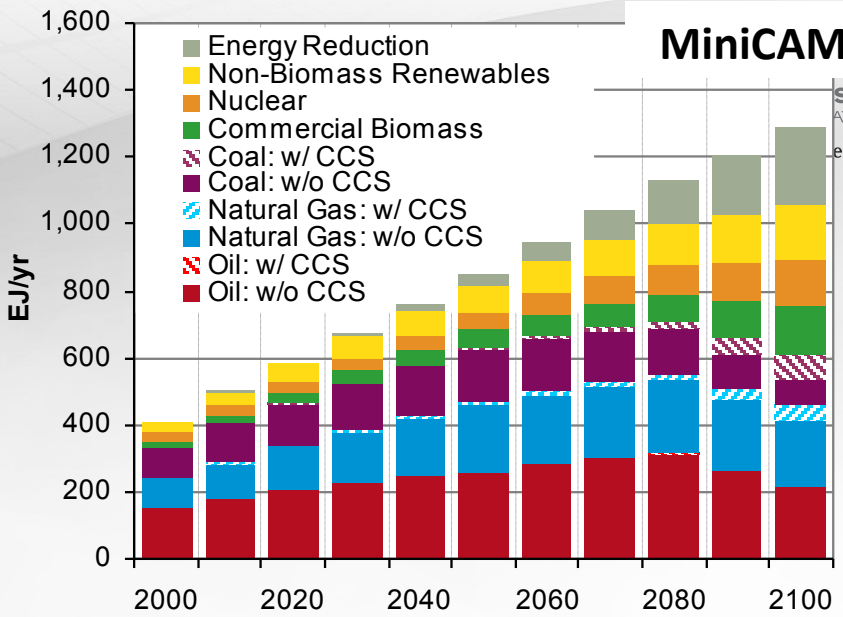


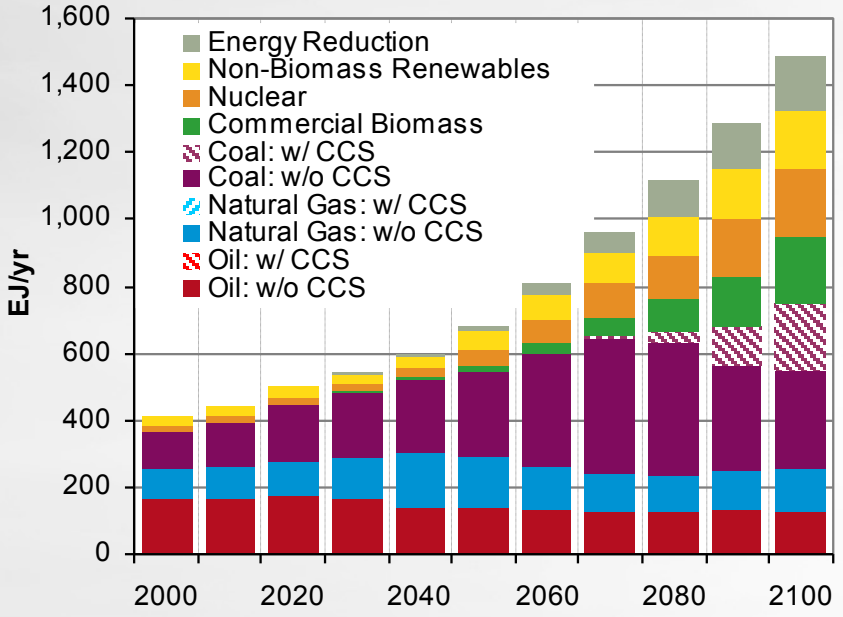
Primary Energy from the CCSP Scenarios

(≈ 750 ppmv CO_2)

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***







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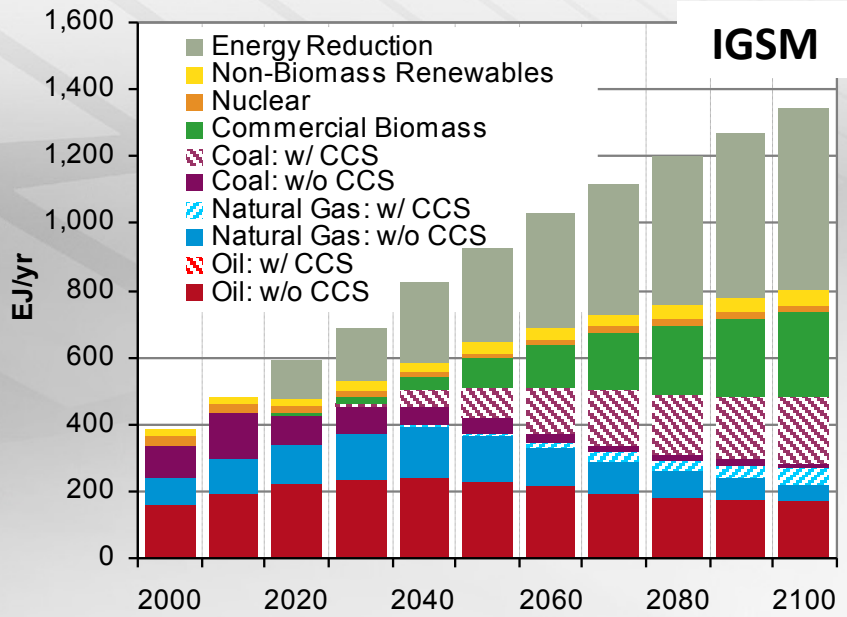

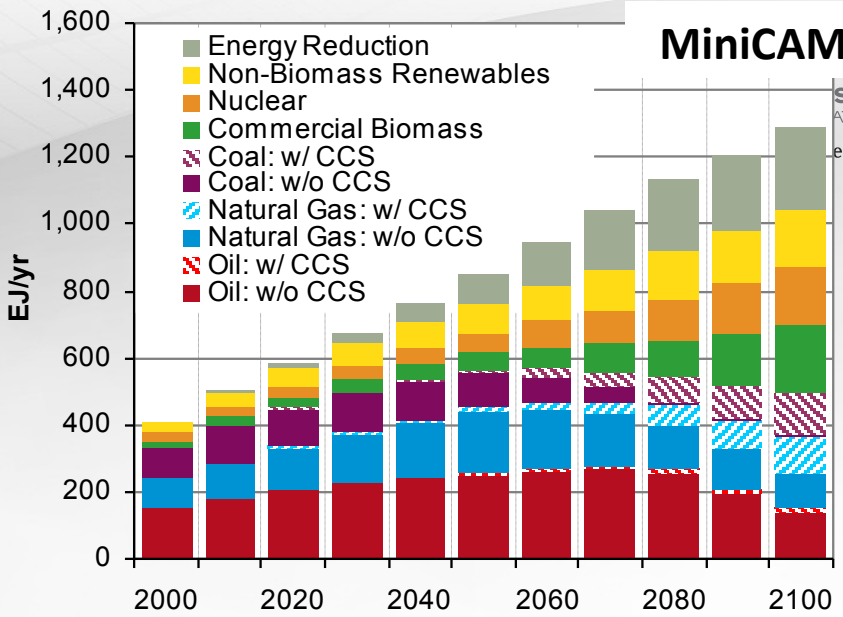

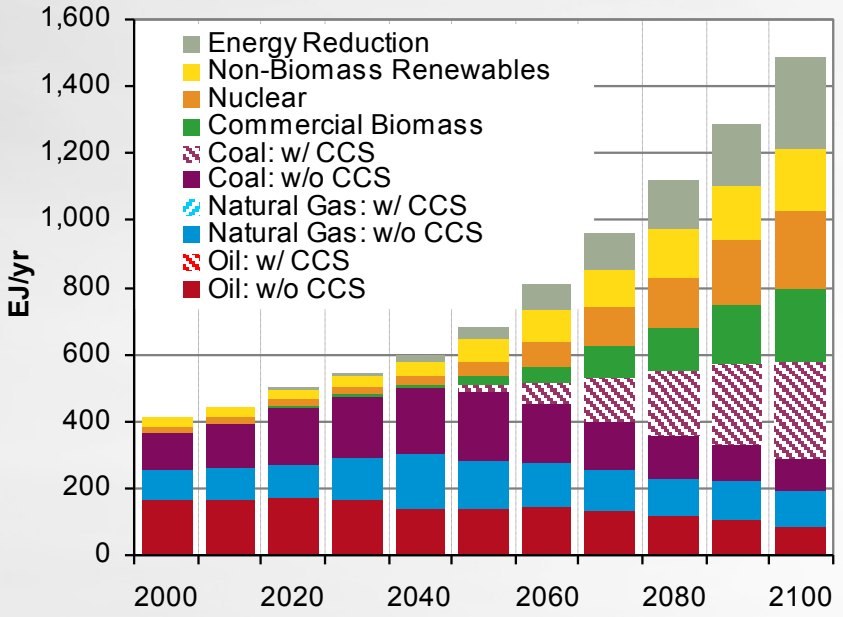

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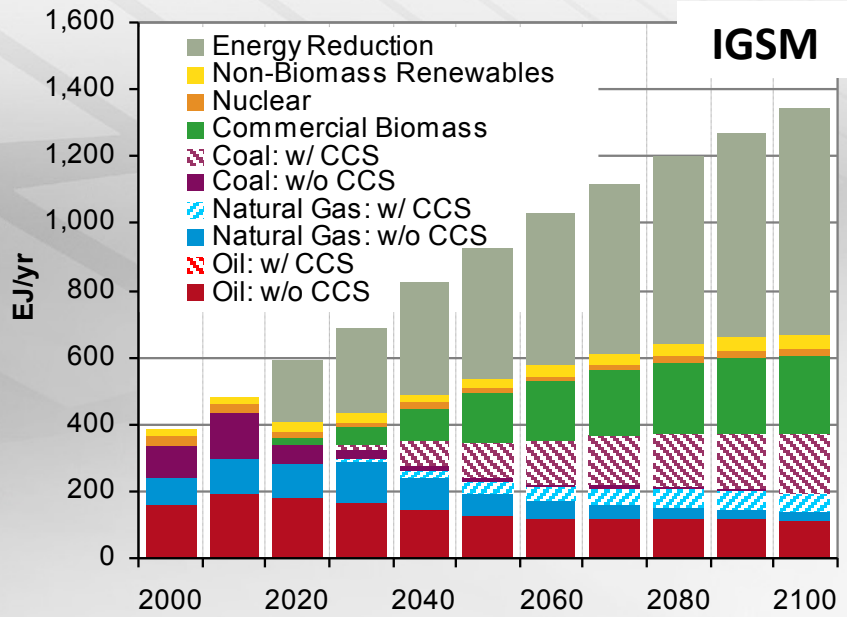

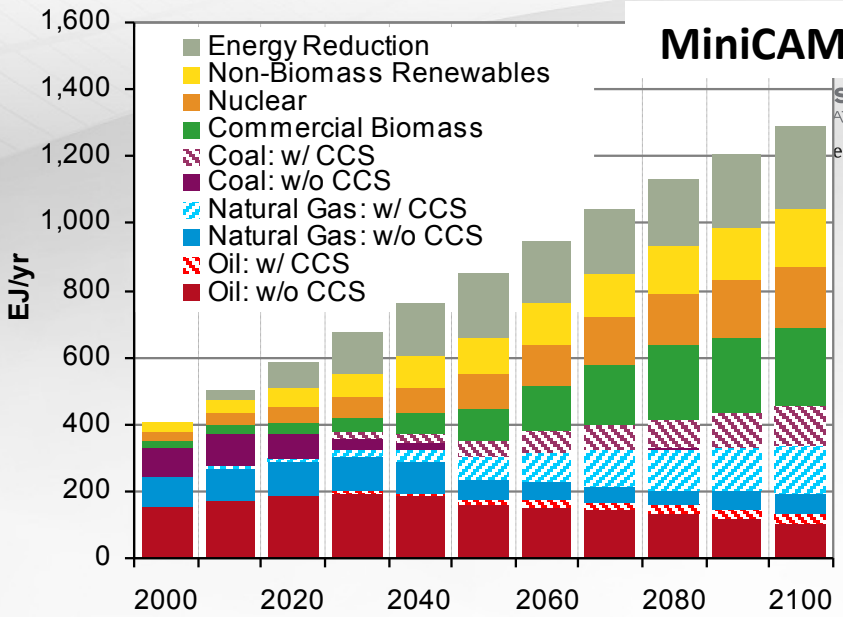

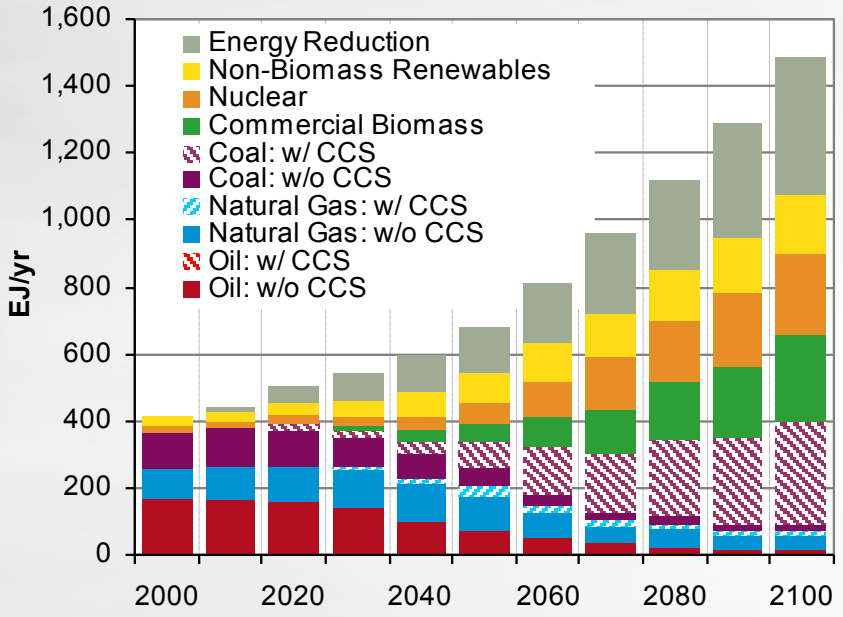

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The Global Change Assessment Model (GCAM)

previously MiniCAM

The Global Change Assessment Model (GCAM)

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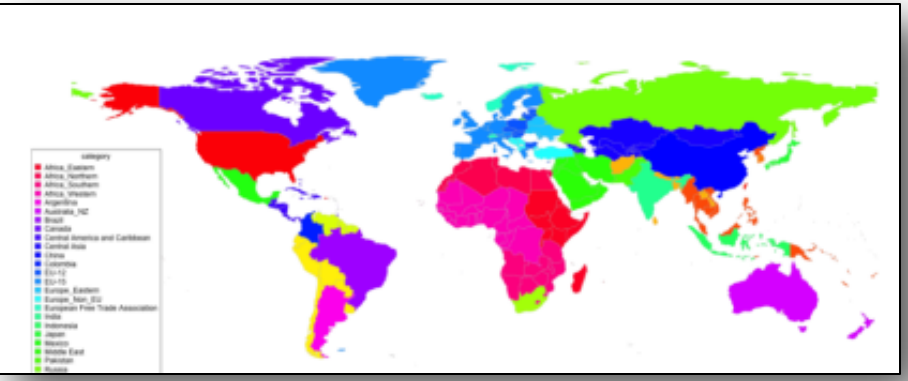
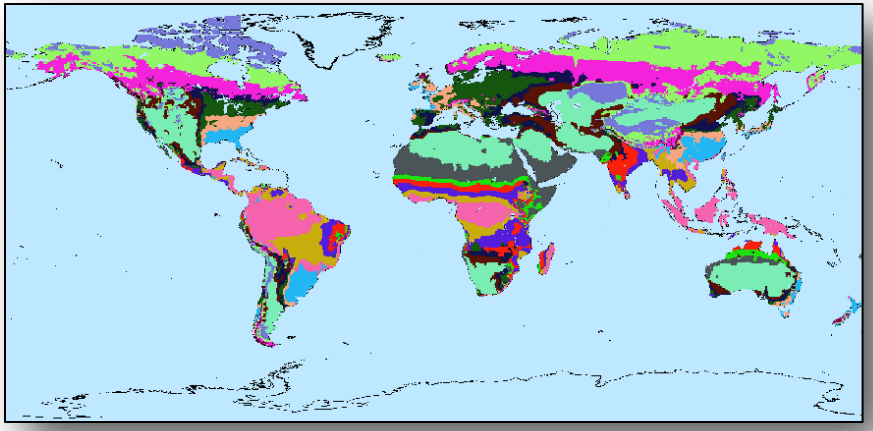
32 Region Energy/Economy Model



283 Agriculture and Land Use Regions



233 Water Basins

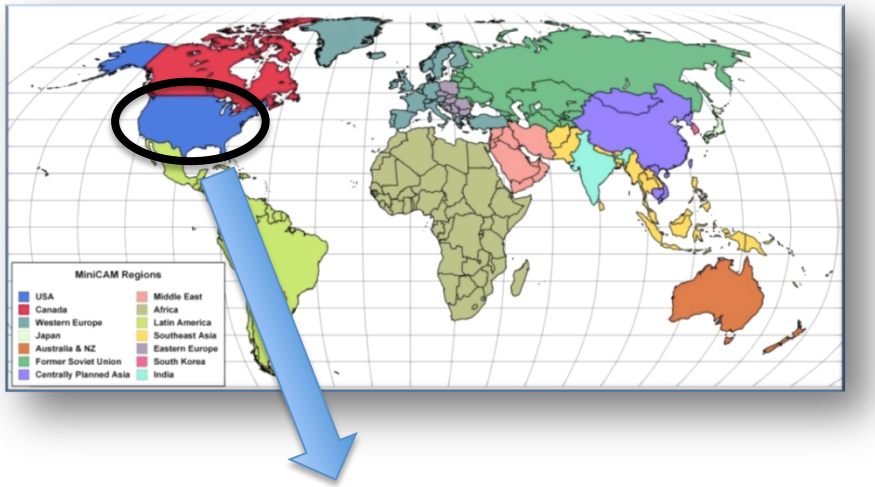
- GCAM is an **open-source**, global integrated assessment model
- GCAM links **Economic**, **Energy**, **Land-use**, and **Climate** systems (and now **Water**)
- Typically used to examine the effect of socioeconomic scenarios, technology, and policy on the economy, energy system, agriculture and land-use, and climate
- Technology-rich model (for an IAM)
- Emissions of 16 greenhouse gases and short-lived species: CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide
- Runs through **2100** in **5-year time-steps**
- Documentation available at: **wiki.umd.edu/gcam**
- Also a GCAM Community Listserve

GCAM USA

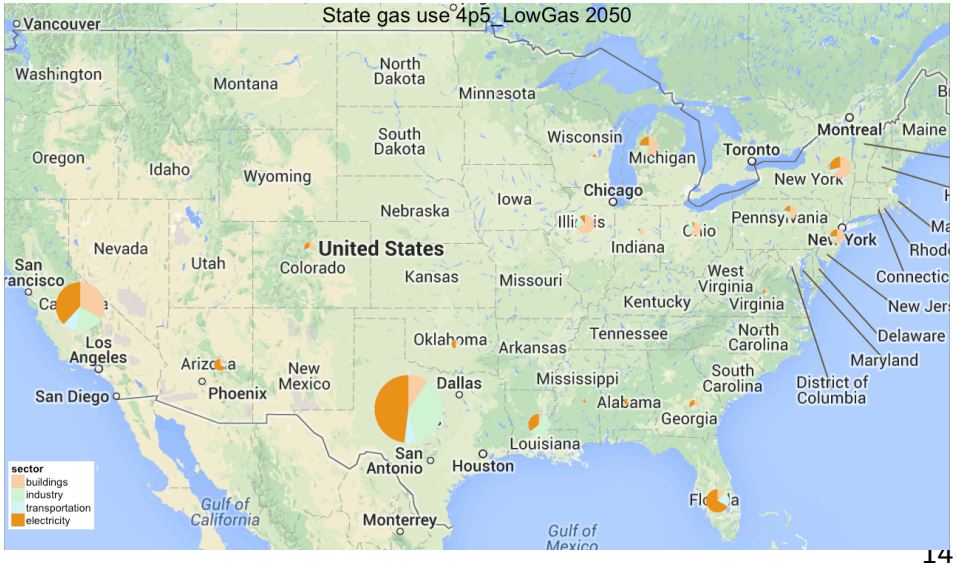
GCAM-USA: A Summary

- GCAM-USA is a version of GCAM with subregional detail in the United States.
- GCAM-USA is a full, global integrated assessment model (IAM) that resolves 50 states + DC
- It is actively being used to explore energy-water-land interactions
- This is a new capability with many possible applications, **and many areas for further development**
- GCAM-USA development has been supported by PRIMA and the Integrated Assessment Research Program at the Office of Science.

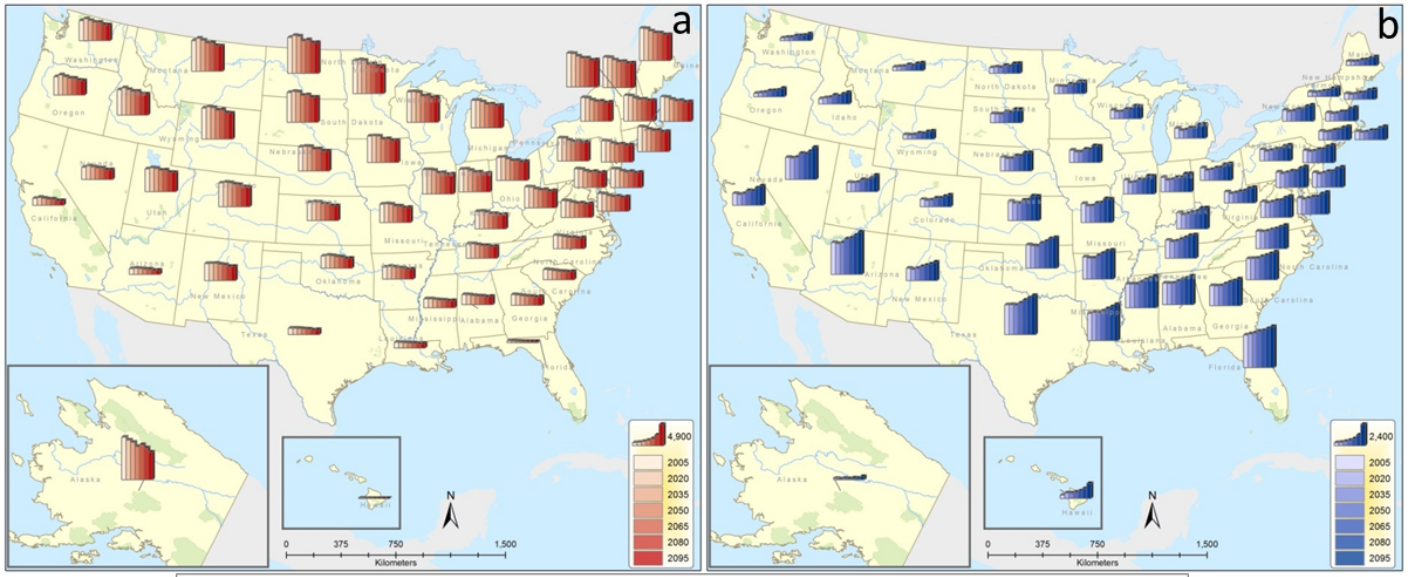
GCAM

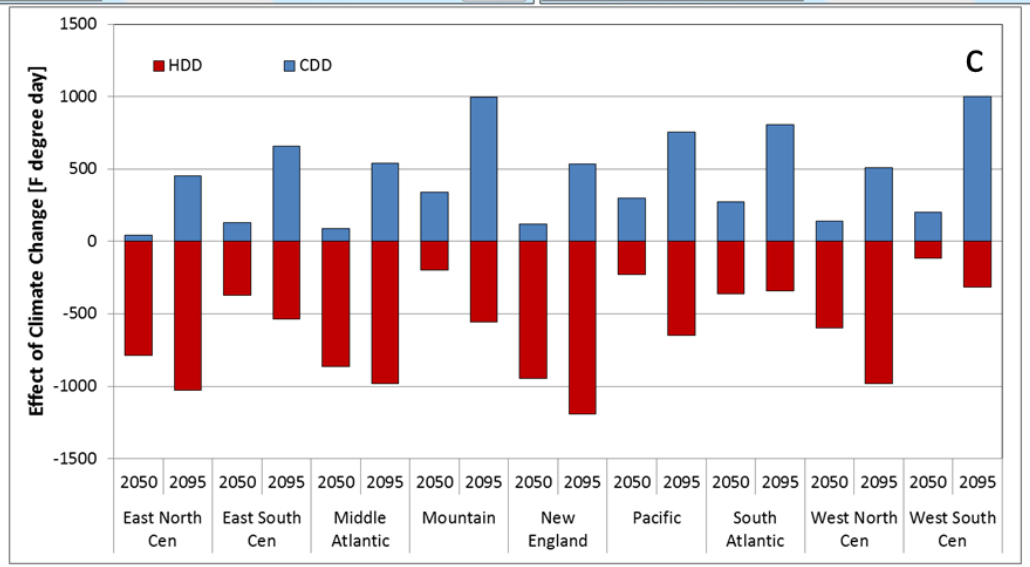


GCAM - USA



GCAM-USA





A more detailed representation of the U.S. at the 50 state level, embedded within the global model allows for improved modeling of issues such as the impact of changing climate on US building energy consumption.

Zhou Y, et al. 2014. "Modeling the effect of climate change on U.S. state-level buildings energy demands in an integrated assessment framework." Applied Energy 113:1077-1088. doi:10.1016/j.apenergy.2013.08.034

The Energy System: Buildings

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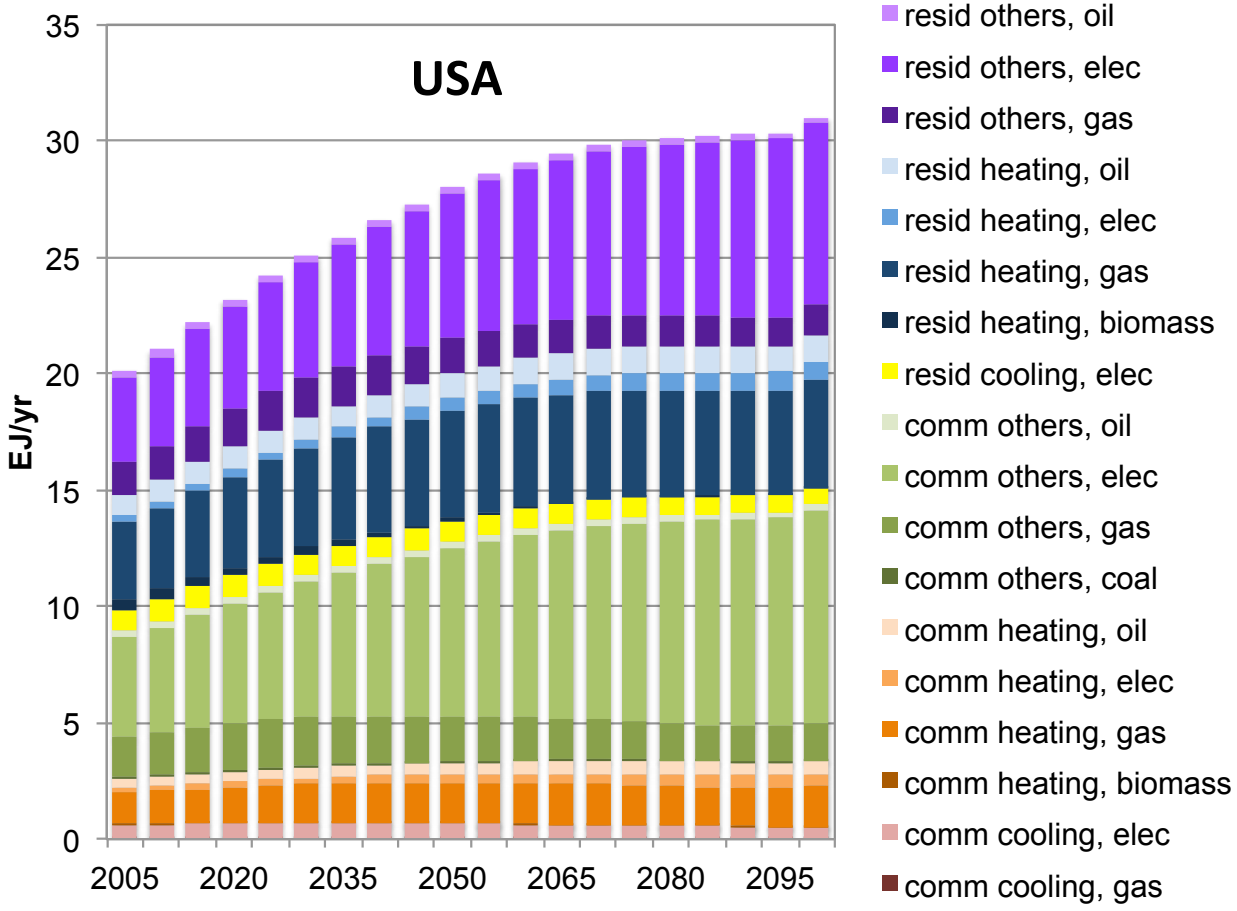
The energy system in each state is represented.

- Each state currently has a representative residential and commercial building with the following services.



Heating/Cooling depend on HDD/HDD, building shell thermal characteristics, & internal gains

Six residential building service demands.

Many services can be supplied by multiple technologies

- Heating: gas, oil, elec resistance, elec heat pump
- Lighting: incandescent, fluorescent, LED

Pilot Project: State-level criteria pollutant emissions

We have started a research project to explore how this modeling tool might be useful to examine the emissions implications of state-level air-, energy-, and climate-related actions.

> *For example: What is the potential for energy efficiency and renewable energy actions to reduce criteria air pollutants and GHG emissions?*

We are currently enhancing the GCAM-USA state model to:

- Calibrate to NEI 2011 emissions at the state-level
- Incorporate impact of on-the books regulations, new source performance standards, MACT requirements, consent decrees, etc.
- Work with EPA to use GCAM emissions outputs to evaluate health & ecosystem impacts

Perform exploratory analysis to evaluate the potential usefulness of this tool for providing insights at the state level regarding pollutant emissions and impact of various policies.

Funding for this work provided by the US EPA Office of Research and Development.

Summary

- Integrated assessment models (IAMs) are moving to finer spatial and temporal scales in order to provide useful information and insights.
  - This project is an example of movement in this direction.
- **An IAM such as GCAM offers some potential advantages** for examining links between energy, land, policies, emissions, and impacts
  - Flexibility to examine a large number of scenarios over time: socio-economic drivers, technology options, and policies
  - Consistent representation across sectors and spatial scales. (Feedbacks between sectors, regional electricity markets, international trade, endogenous prices)
- **This does not replace the need for more detailed modeling**
  - Regulatory impact analysis requires more detailed tools that consider the system “as it is now” and might evolve in the near-term.

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PART 2

Community Emissions Data System (CEDS)
For Historical Anthropogenic Emissions

Outline

This effort grew out of experience producing historical emissions for the RCP/CMIP5 process several years ago.

Overview

Data Products

Methodology

- **Uncertainty Estimates**
- **Sub-regional estimate and evaluation**

Summary

Funding for this project Provided by the US Department of Energy Office of Science and the National Aeronautics and Space Administration

CEDS Goals:

Emissions with the same standards of timeliness, openness, and uncertainty quantification as other key model inputs.

Motivation

Emissions estimates (aggregate & gridded) for aerosol (BC, OC) and aerosol precursor compounds (SO_2, NO_x, NH_3, CH_4, CO, NMVOC) are key inputs for aerosol and air pollution research and Earth System Models

- Needed for historical and future simulations, validation/comparisons with observations, historical attribution, and uncertainty quantification

---

The current historical dataset used by GCMs/ESMs (Lamarque et al. 2010) was a major advance in terms of consistency and completeness. This data, however, has a number of shortcomings.

- Only extends to 2000 with coarse temporal resolution (10-years)
- Time series for many of the species formed by combining different data sets leading to inconsistencies
- No comprehensive uncertainty analysis provided (available only for SO_2 – Smith et al. 2011 and earlier BC/OC datasets – Bond et al. 2007)
- Underlying driver data not made available with emissions data set
- Methodology not consistent across emission species
- Process was not designed to be repeatable and easily updated

Community Emissions Data System

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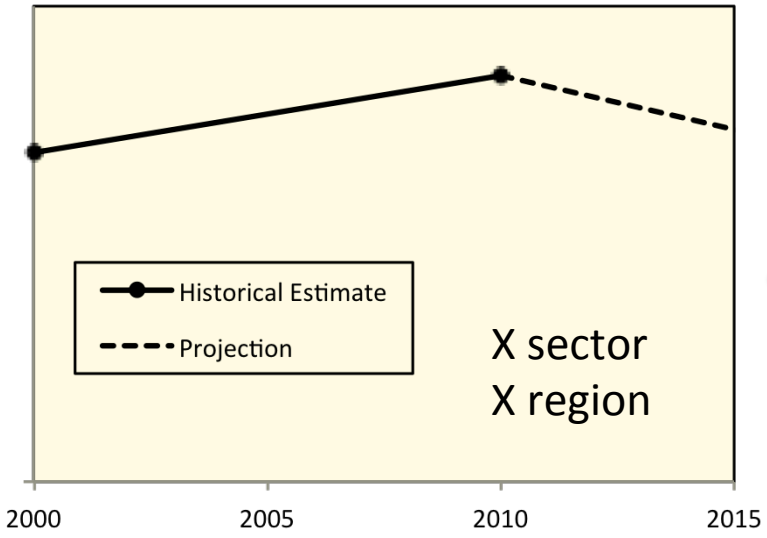
Timely "research" estimates for emissions of aerosol (BC, OC) and aerosol precursor compounds (SO_2, NO_x, NH_3, CH_4, CO, NMVOC) are key inputs for aerosol research and Earth System Models

Needed for historical and future simulations, validation/comparisons with observations, historical attribution, uncertainty quantification, IAM calibration and validation, and economic/policy analysis.

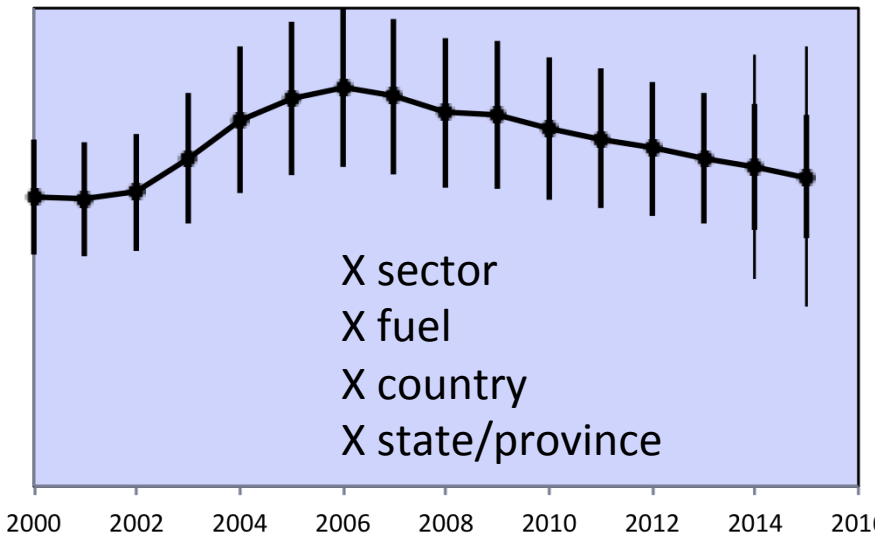
Instead of this



Produced using an open-source data system to increase data transparency and facilitate research advancements.

Produce

Uncertainty essential for estimates of more recent years.



Better start for projections!

Project Outcomes

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Global Emissions by Country, Sector, and Fuel

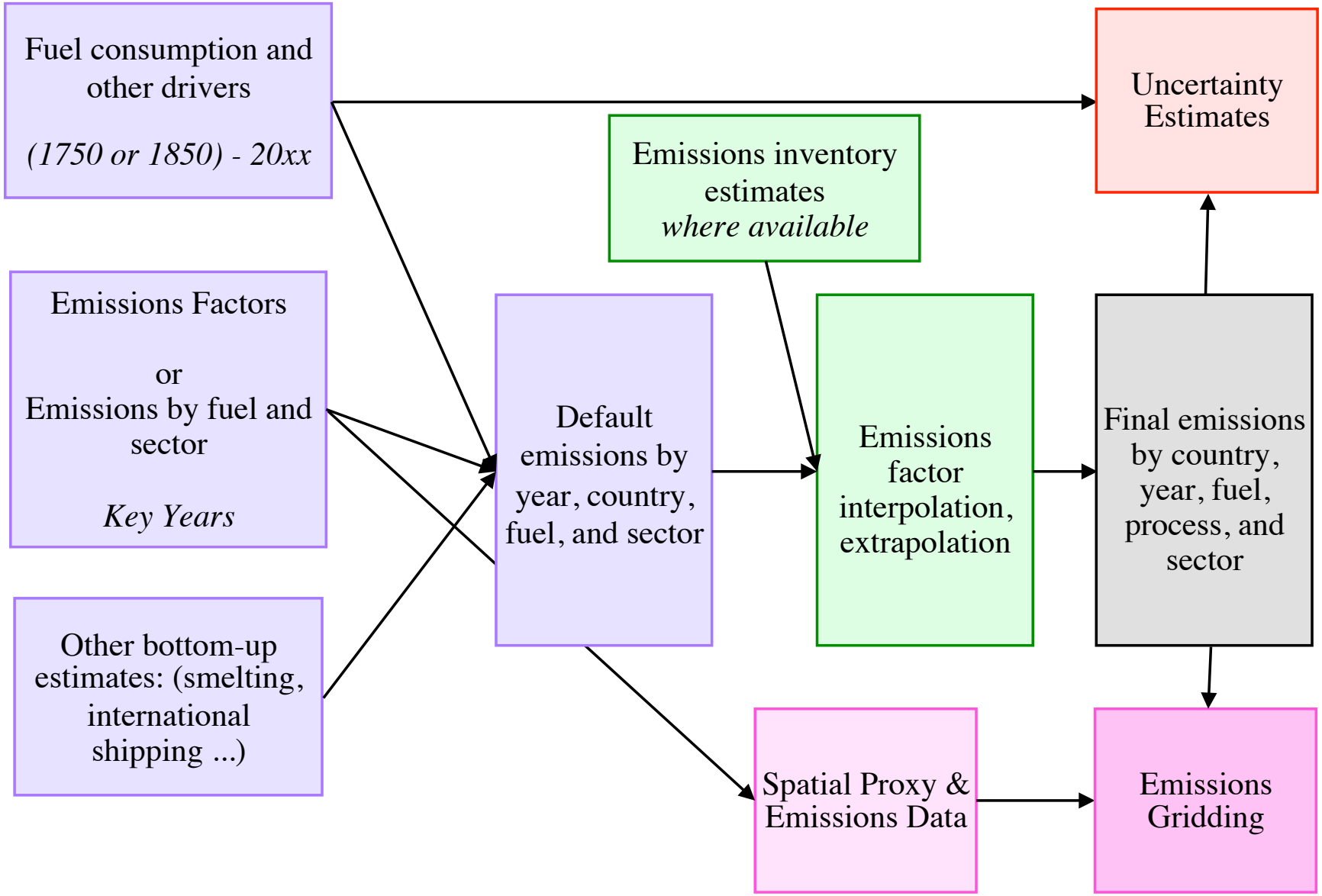
- Annual estimates of anthropogenic emissions (not open burning) to latest full calendar year of chemically reactive species and CO_2 (as reference) over the entire industrial era. Readily updated every year.
  - With greater spatial detail (state/province) for large countries
  - Emission extrapolation at a roughly Tier 2 level (+ by fuel)
- Uncertainty estimated at the same level (Country, fuel, sector)
- Seasonal cycle (monthly), aggregate NMVOCs by sector/sub-sector
- Gridded emissions (0.1°) w/ sub-national resolution for large countries

Goals

- Consistent extrapolation at the aggregate sector level over time (prevent spurious discontinuities)
- Community data review: aggregate (country, sector, ...) & gridded
- Facilitate cross-country comparison (EF consistency, trends)
- Transparent emission results (assumptions -> emissions)

Complementary project coordinated with existing, more detailed work

System Diagram



Methodology

General approach

- Develop a default dataset (GAINS emission factors, EDGAR, etc.)
- Calibrate to country-level inventories at the broad sectoral level (at least) where available and reliable (e.g., most policy-relevant). Similar to approach in RCP and EDGAR-HTAP
- Most of the effort is in gathering input data
  - Driver data (historical energy, agricultural output, other sectors)
  - Default emissions factors. Sectoral emissions for calibration.
- Methodologies similar to Smith et al. (2011) & Klimont et al. (2013)

Produce "a" best estimate, not a fully independent estimate

- In most OECD countries much effort goes into estimating emissions, so use those. Important when control levels are changing over time.
- Emissions factors are changing less rapidly in many developing countries (but are less well known in many cases).
- Some countries (e.g. China, SE Asia) – changes are also rapid –are also more uncertain. Challenging. Wider community involvement can improve results.

Implementation Details

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Implementation

- Modular, data-driven system, in the **R open-source platform**
- Consistent with country-level inventories (where desired/appropriate)
- Open source code and input data
  - IEA energy statistics not open source (but can be "plugged in" by users)
  - Public release of emissions data to as high level of detail as practical
- Tool for emissions research more broadly

Timeline

2014 & Winter 2015	Spring – Summer 2015	Fall 2015	2016-2018	Future On-Going
Initial code design and prototyping	Data collection and processing focused on recent decades	*Community review* **Updated global data for CMIP6**	*Com. review* **Uncertainty** & adl history	*Com. review* **Annual Updates**
		State & other Sub-Regional data	Satellite eval: recent trends	

Uncertainty Estimates

Overall Approach

All bottom-up emission uncertainty estimates contain a substantial element of expert judgment

- Guide assumptions with literature & comparisons between inventories
- Reduce dimensionality by a "tiered" approach to group assumptions

  Otherwise: ~10 sectors X 200+ countries X 5 fuels X ~10 emissions
- Consider correlations across sectors and countries (spatially)
- Result: consistent uncertainty estimates across species and regions

Uncertainty For Most Recent Years

It is critical that emissions for recent years are coupled with uncertainty estimates

- The additional uncertainty in the most recent years can be rigorously assessed by applying the extension methodologies to past data

  Although "past uncertainty does not guarantee future uncertainty"

Sub-Regional Emissions Trends

Previous global emission datasets have often used one spatial distribution for each country. For large countries such as the United States, this can lead to in accuracies in regional emission trends over time.

In this portion of the project we will produce estimates of sub-regional emissions for large countries (e.g., USA, China, Canada, etc.).

- Collect emissions estimates where available (e.g. US NEI)
- Process state/province level historical energy consumption data
- Will likely need to eventually use some spatial defaults for earlier time periods where statistics are not available

Implement a methodology for data processing so that sub-regional detail can be expanded as data becomes available

Evaluation with Satellite Data

- Compare modeled aerosol optical depth trends (using CAM5) over recent years with satellite data
- Use to better constrain emission trends where particularly uncertain (e.g. China).

Project Summary

We are building an open-source emissions data system to produce up-to-date anthropogenic aerosol and aerosol precursor emissions estimates.

Emissions Data

- Estimates out to most recent full calendar year
- Annual (& monthly) emission estimates in order to 1) capture timing of regional trends and 2) to provide as up-to-date estimates as possible
- Consistent uncertainty estimates
- Build on existing efforts (GAINS, EDGAR, REAS, country-level inventories) to provide data products and analysis needed for: modeling & climate/air quality work, and advance emissions estimation science.

Data System and Process

- Open data processes for community buy-in and verification
- Publish methodology and results in peer-reviewed literature
- As an open source system, other groups can add/modify code and data
- International steering committee

END

BACKUP SLIDES

The Global Change Assessment Model

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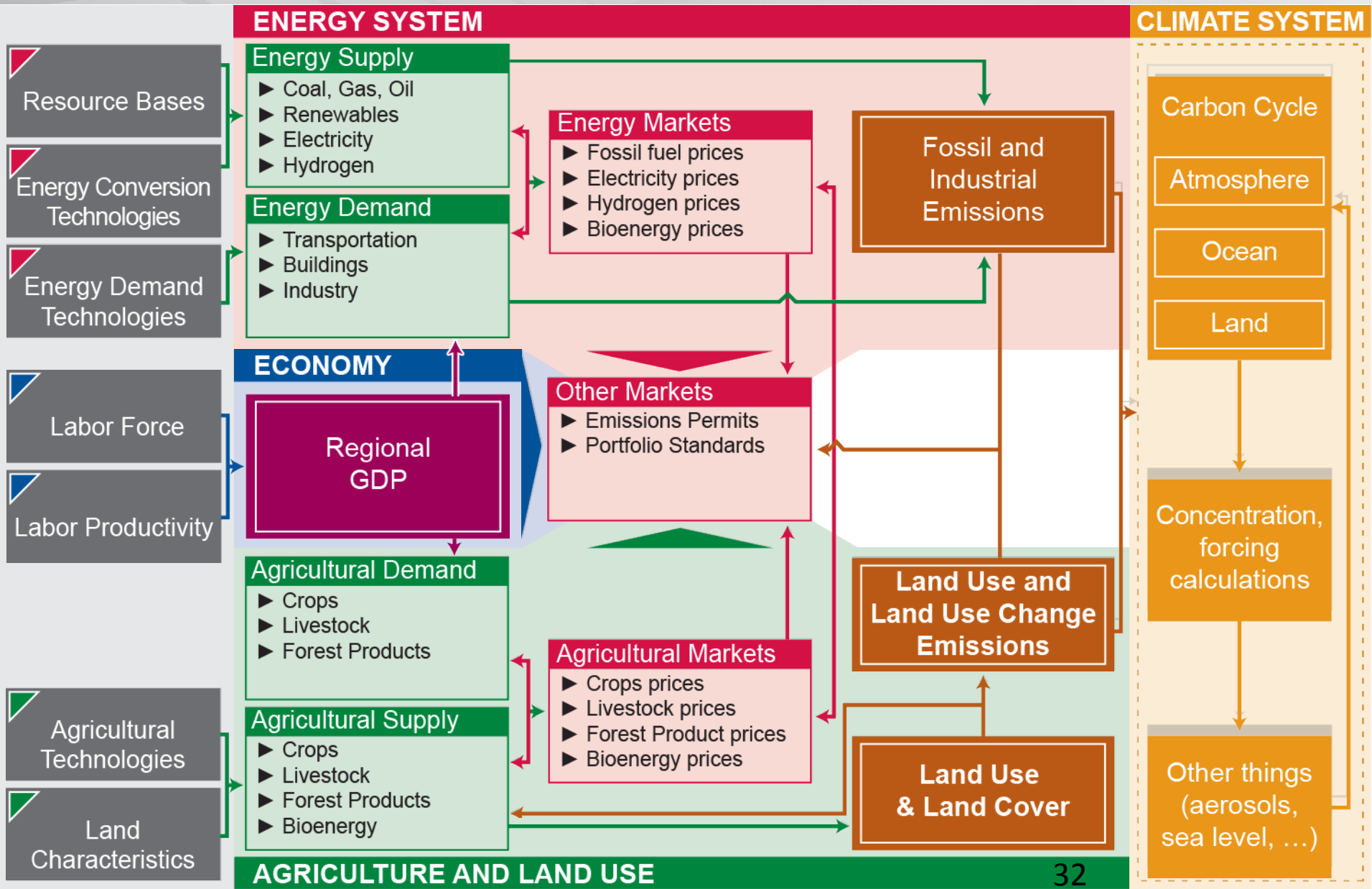

GCAM Studies:
Impact of Land-Use Policies on Climate Policy Costs

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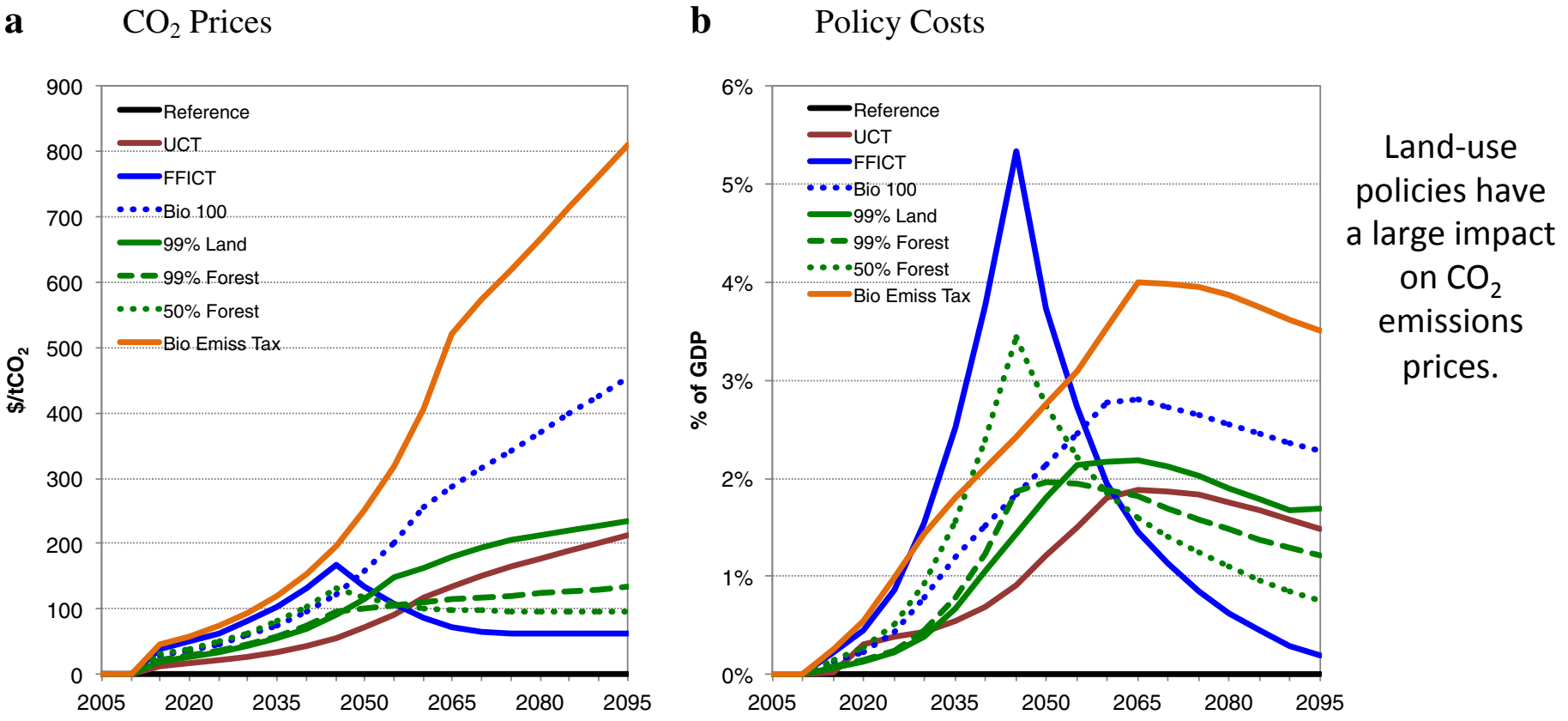
Cost of a global climate policy to limit total radiative forcing to 3.7 W/m²



Land-use policies have a large impact on CO_2 emissions prices.

Fig. 5 CO_2 prices and policy costs (Area under MAC curve) across bioenergy and land policy scenarios

Calvin, K., Wise, M., Kyle, P., Patel, P., Clarke, L. & Edmonds, J. 2013. Trade-offs of different land and bioenergy policies on the path to achieving climate targets. *Climatic Change,* 123**,** 691-704, 10.1007/s10584-013-0897-y

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Study using GCAM data:
Health and Air-Quality Co-Benefits of GHG Mitigation

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Objective

- Quantify health and air quality co-benefit due to the pollutant emission reductions that occur from the implementation of a comprehensive climate policy over the 21st century.

Methods

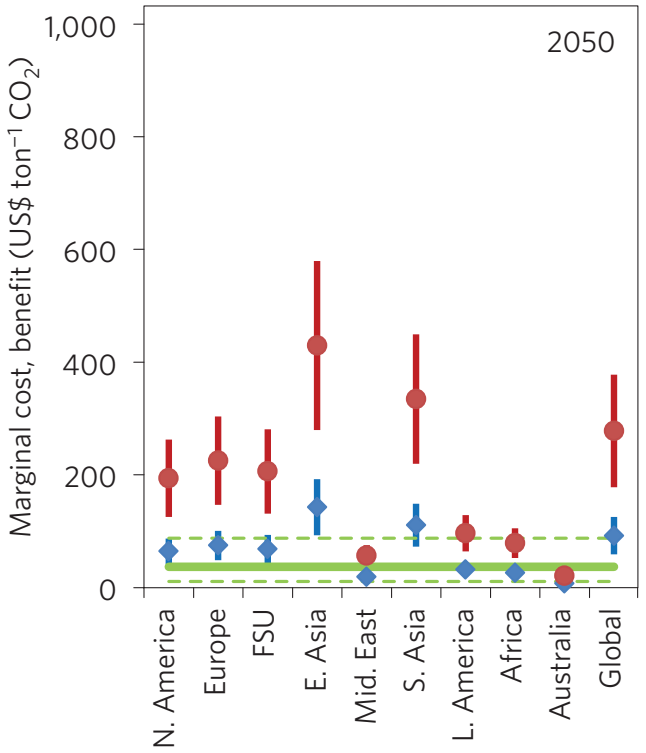
- Emissions of air pollutants decrease under a comprehensive climate policy. Examine the air quality implications of these reductions using the GCAM Reference and RCP4.5 scenarios, together with the MOZART-4 global chemical-transport model.

Findings

- Lower air pollution levels due to a climate policy scenario result in one million fewer deaths in 2050.
- The monetized value of the mortality reduction is generally larger than climate policy costs up until at least 2050.

Implications

- The air quality improvements that result from a comprehensive global climate policy are a substantial additional benefit of a global policy to reduce greenhouse gas emissions.



Monetized value of mortality reduction in 2050 due to pollutant emission reductions (low and high value of statistical life assumptions: blue and red bars) as compared to a range of climate policy costs.

West, J. J., Smith, S. J., Silva, R. A., Naik, V., Zhang, Y., Adelman, Z., Fry, M. M., Anenberg, S., Horowitz, L. W. & Lamarque, J.-F. 2013. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Clim. Change,* 3, 885-889, 10.1038/nclimate2009

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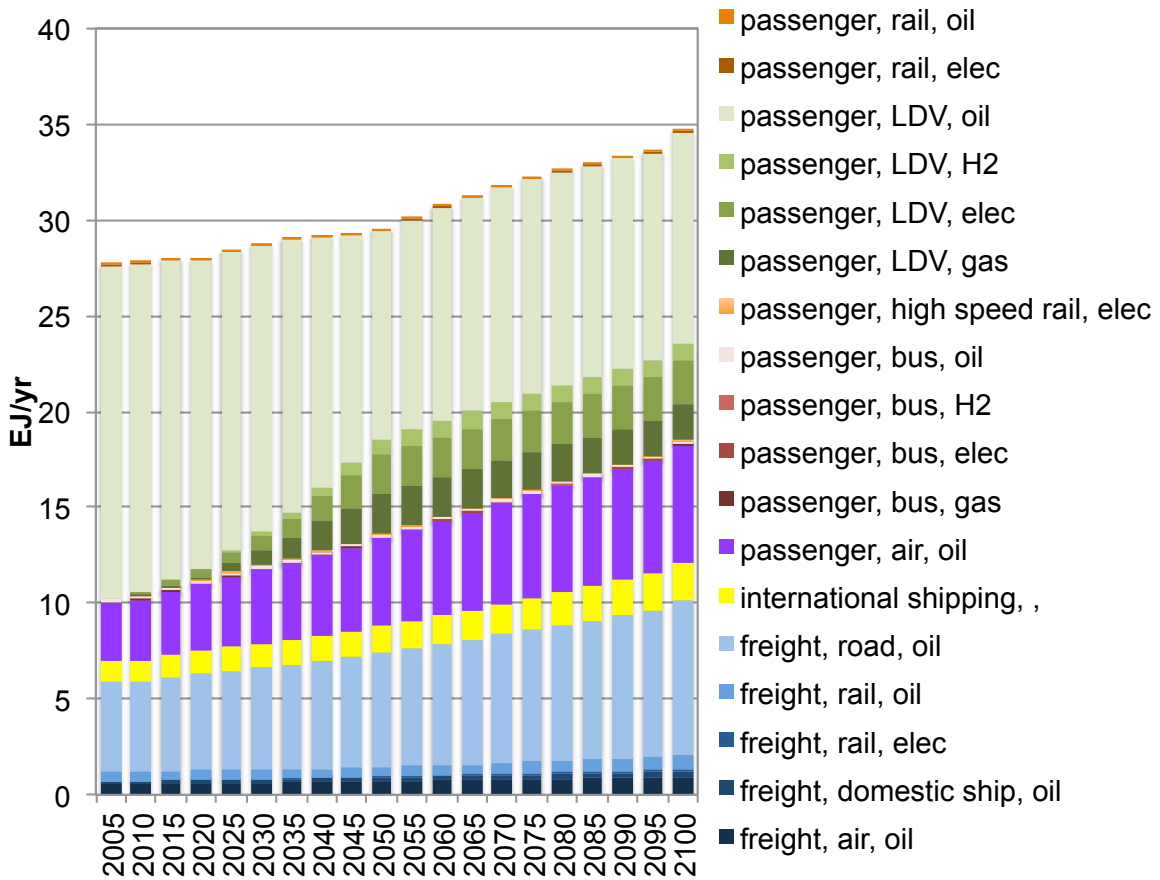
Current GCAM-USA Detail

- Socioeconomics at state level
  - Population
  - GDP
- Energy transformation at state level
  - Electricity generation & Refining by state
  - Full electricity (and CO_2 storage) trade within modified NERC regions
- Renewable and carbon storage resources at state level
  - Wind, Solar (central and rooftop PV), geothermal
  - Carbon storage
- Energy final demands at state level
  - Buildings: representative commercial * residential building in each state
  - Transportation: passenger & freight with detailed technologies
  - Industry: aggregate energy demands (also have agr-USA process model)
- Currently run on 5-year time steps
  - Planed research over the next few years will move to 1 year time steps in order to incorporate the impacts of climate variability
- Not modeled at the state level
  - Fossil Resources
  - Agricultural demand (USA total) & supply (10 agro-economic zones AEZ)

The Energy System: Transportation

- We first determine passenger and freight demands by state
- Then track final energy by sector, mode, and fuel



Many sub-sectors can be supplied by multiple technologies

- Electric or liquid LDVs
- Conventional or high speed rail

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Issues: Producing a community inventory

- Discrepancies w/ different versions of country inventories (e.g. Janssens-Maenhout, EDGAR-HTAP 2012)

CO	2000	2001	2002	2003	2004	2005
AUT	0.84	0.85	0.84	0.85	0.86	0.88
BEL	1.04	1.01	1.06	1.28	1.32	1.78
BGR	0.00	1.06	1.03	1.09	1.11	1.14
BLR	0.00	2.40	0.40	2.59	2.40	1.72
CAN	0.00	0.00	0.00	0.00	0.00	0.00
CHE	0.92	0.94	0.95	0.95	0.95	0.95
CYP	0.00	0.00	0.00	0.00	0.00	0.00
CZE	0.00	0.95	0.94	0.93	0.93	0.93
DEU	0.98	0.98	0.97	0.98	1.00	0.96
DNK	1.03	1.04	1.05	1.06	1.05	1.02
ESP	0.91	0.89	0.92	0.87	0.89	0.92
EST	0.92	0.87	0.89	0.84	0.79	0.75
FIN	0.00	1.04	1.05	1.01	1.01	1.02
FRA	0.93	0.96	0.95	0.93	0.93	0.92
GBR	1.01	1.01	1.01	1.01	1.01	1.02
GRC	0.00	0.00	0.93	0.98	0.56	1.02

Table 3 (portion: Ratio of the total emissions for CO reported to UNFCCC to those reported to EMEP.

Zero indicates no reported emission inventory for EMEP was available. Green colors are ratios between 0.98 and 1.02, red colors indicate larger deviations.

How much of this is uncertainty (estimates changing year-to-year) and how much reporting issues? (Sectoral definitions, etc.)