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State-Level Energy and Emissions Projections from GCAM-USA

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Outline

- Introduction to Integrated Assessment Models
  - Wide variety of IAMs
- GCAM Overview
  - Flexible, technologically detailed (for an IAM), global -> regional model
- GCAM-USA Overview
  - US State-level detail
  - Example applications (that don't involve air pollutants)
- Air Pollutant Emissions in GCAM-USA
  - Methodology and Data Sources
  - Comparison to EPA Inventories
  - Example analysis - RPS
- Questions

Please ask clarifying questions during the talk!

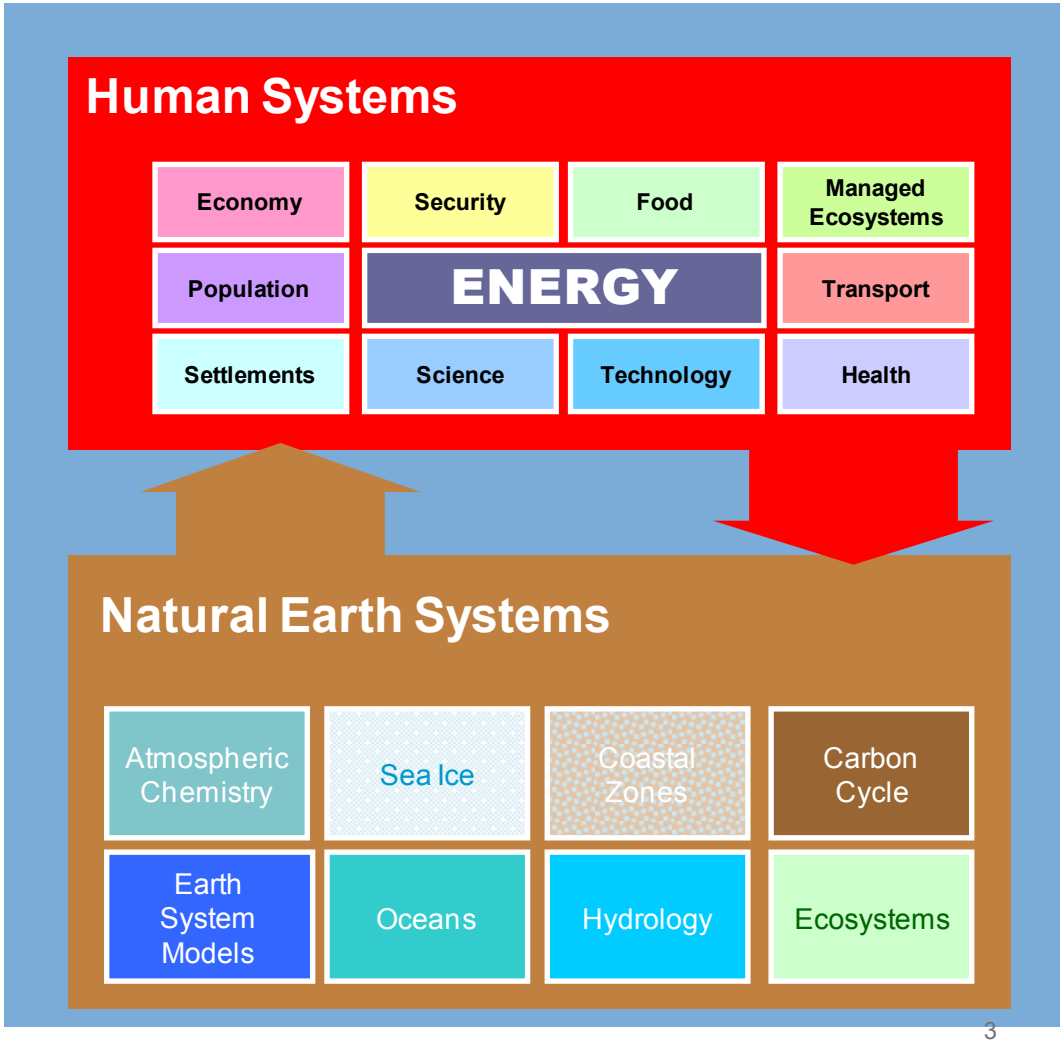
What is an Integrated Assessment Model (IAM)?

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



IAMs – "Big Picture" Analysis With "Just Enough" Detail

- IAMs were designed to provide strategic insights
  - Not designed to model very fine details (unemployment, electrical grid operation, daily oil market price paths)
- IAMs are:
  - Global in scope
  - Generally include all anthropogenic sources of emissions
  - Include some representation of the climate system
- However, there is significant variation across models as to their:
  - Spatial resolution (countries to regions to global)
  - Inclusion of gases and substances
  - Energy system detail
  - Representation of agriculture and land-use
  - Economic assumptions and technological change
  - Degree of foresight
  - Sophistication of the climate model component
- There is a big difference between highly-aggregated IAMs used for cost-benefit analysis (and social-cost of carbon estimates) and higher-resolution IAMs used for analysis of system dynamics such as GCAM (which does not produce a social-cost of carbon

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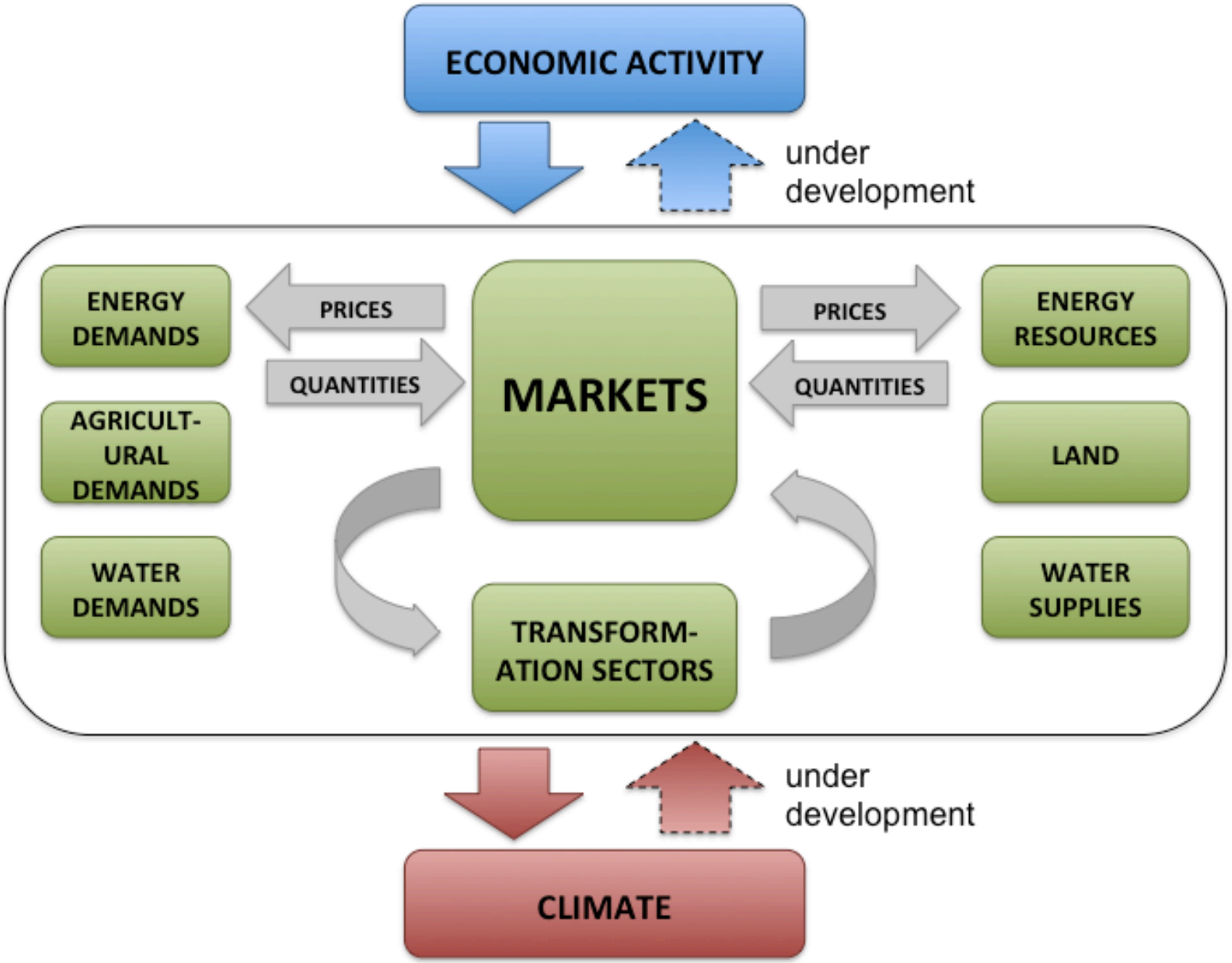
The Global Change Assessment Model (GCAM)

The Global Change Assessment Model



The Global Change Assessment Model

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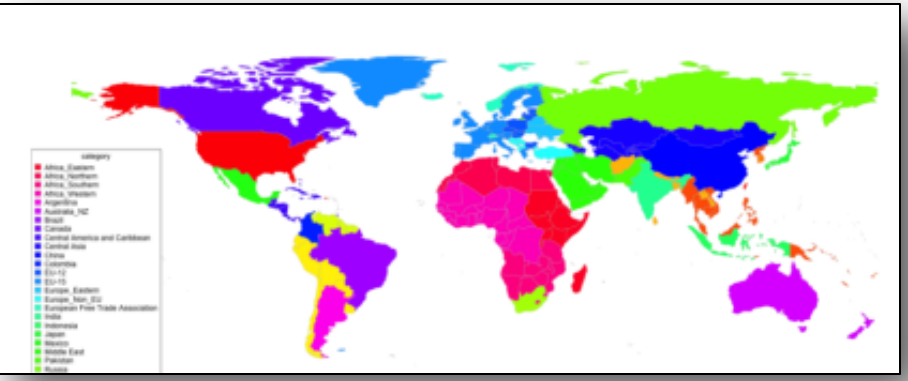
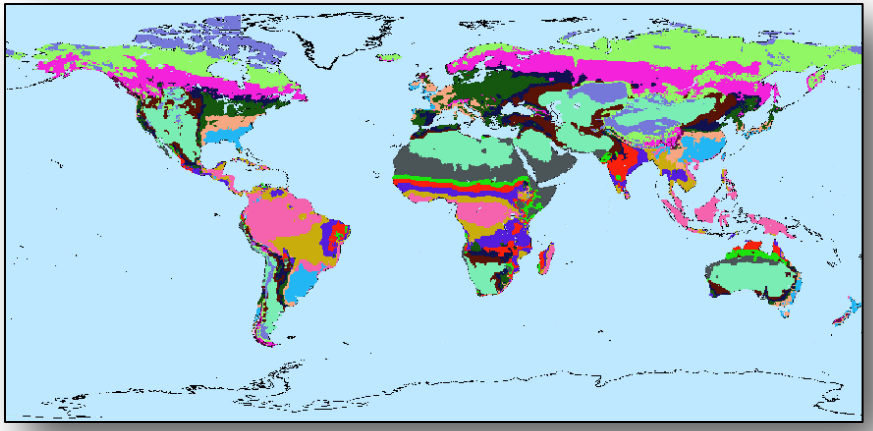
32 Region Energy/Economy Model



283 Agriculture and Land Use Regions

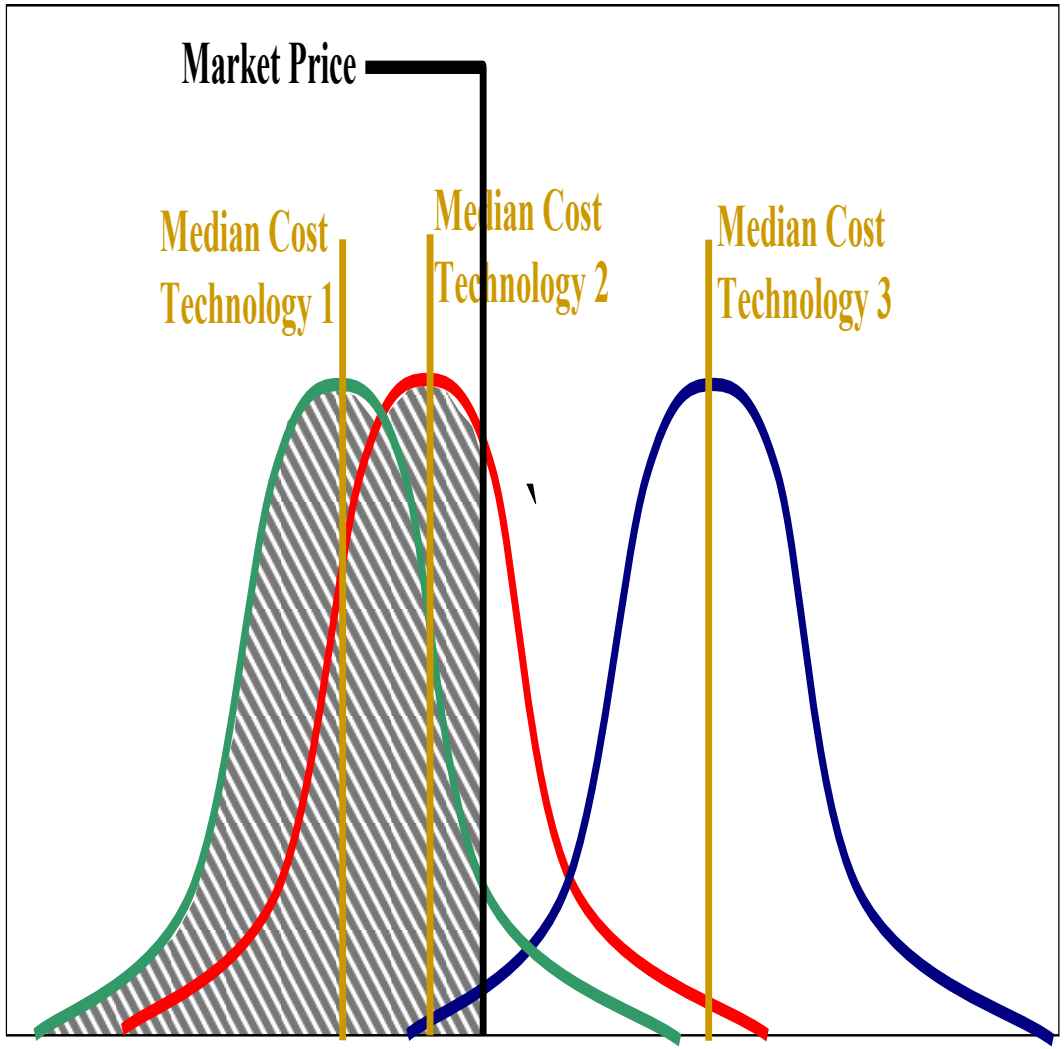


233 Water Basins

- 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 complex system that links economy, energy, agriculture, land-use, and climate
- Technology-rich model (for an IAM)
- Emissions of carbonaceous aerosols, reactive gases, sulfur dioxide, ozone precursors, and 16 greenhouse gases
- Runs through **2100** in **5-year time-steps**
- Documentation available at: **wiki.umd.edu/gcam**
- Also a GCAM Community Listserve and an annual GCAM community meeting

Technology Competition: Logit Choice Model

A Probabilistic Approach



$$share_i = \frac{\alpha_i \cos t_i^{\sigma}}{\sum_j \alpha_j \cos t_j^{\sigma}}$$

- Economic competition among technologies takes place at many sectors and levels.
- Assumes a distribution of realized costs due to heterogeneous conditions.
- Market share based on probability that a technology has the least cost for an application.
  - Avoids a "winner take all" result.
  - "Logit" specification.
    - Relative and absolute cost technology choice models implemented.

The Global Change Assessment Model

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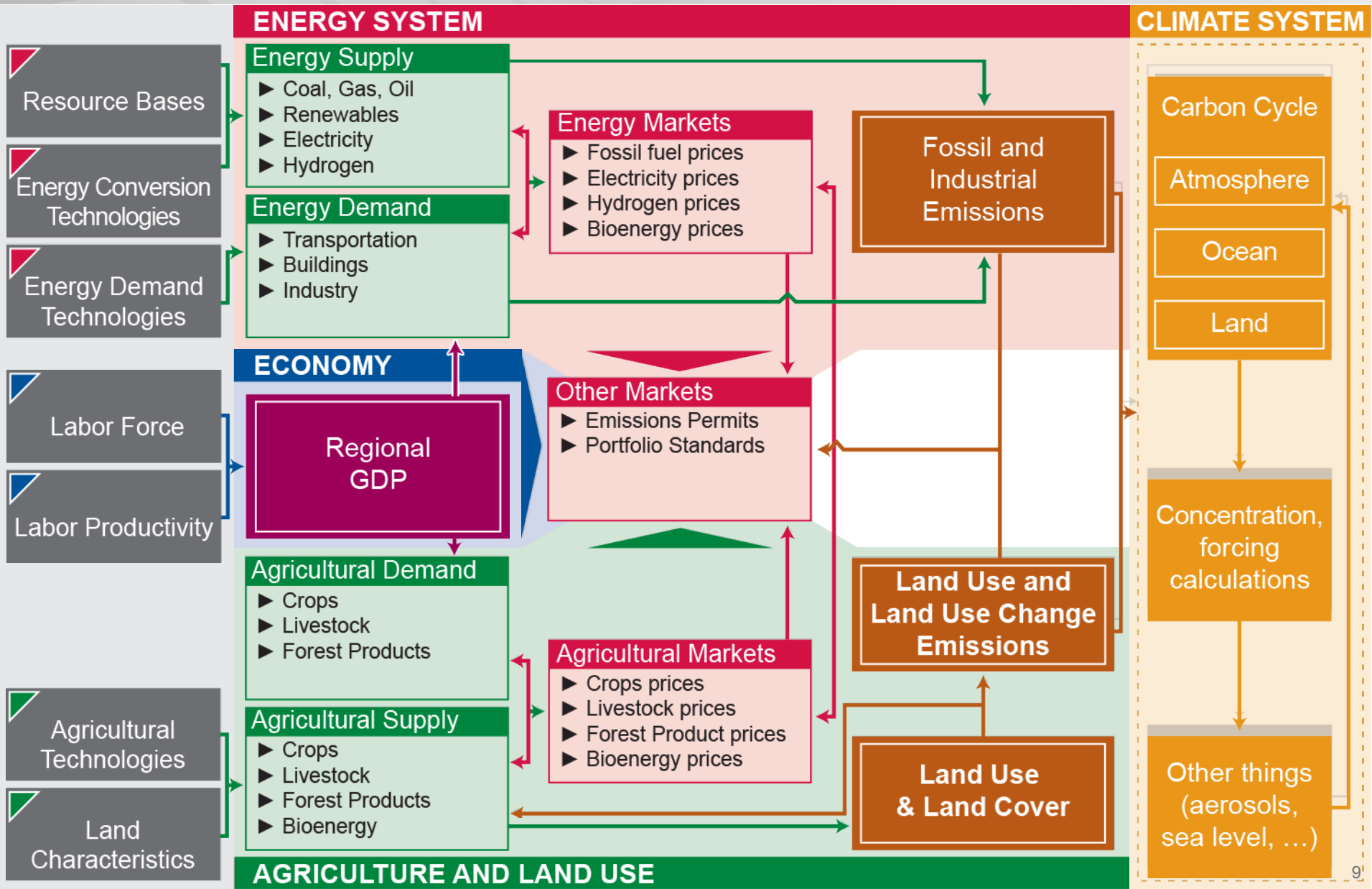
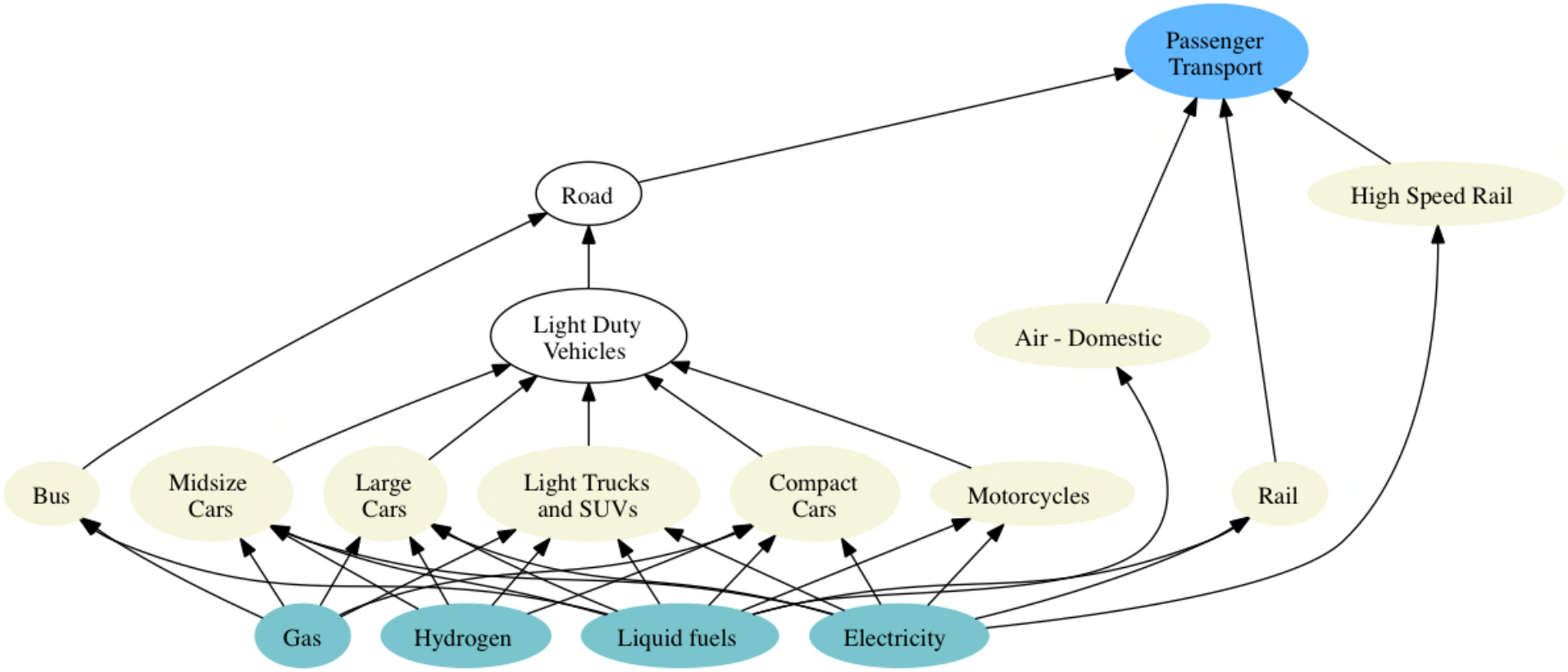


Example Detail: Transportation

- The choice among modes of transportation in the passenger sector is a function of the ***cost*** of travel, the ***time*** it takes, and ***income***.
  - Vehicles are also vintaged



Similar level of detail for freight transport

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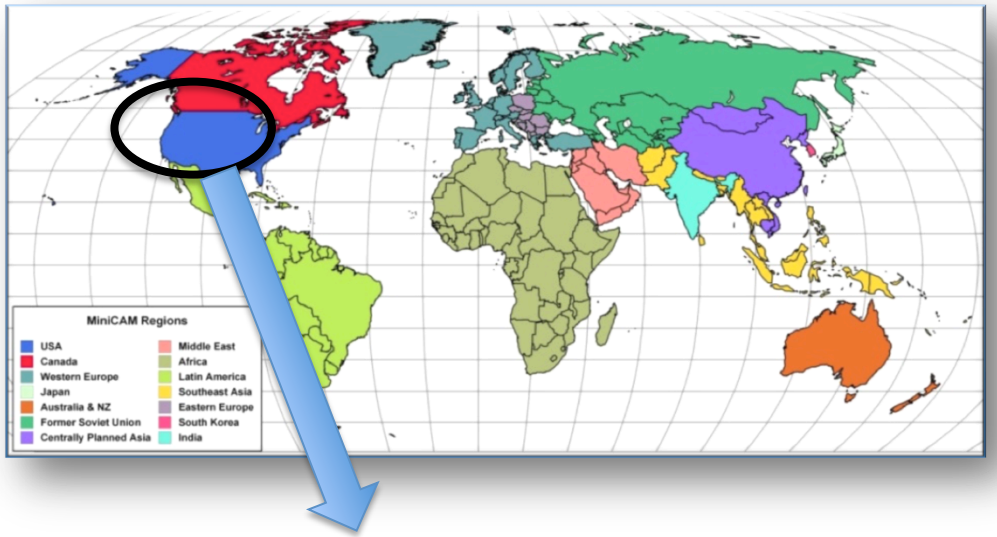
GCAM USA

GCAM-USA: Overview

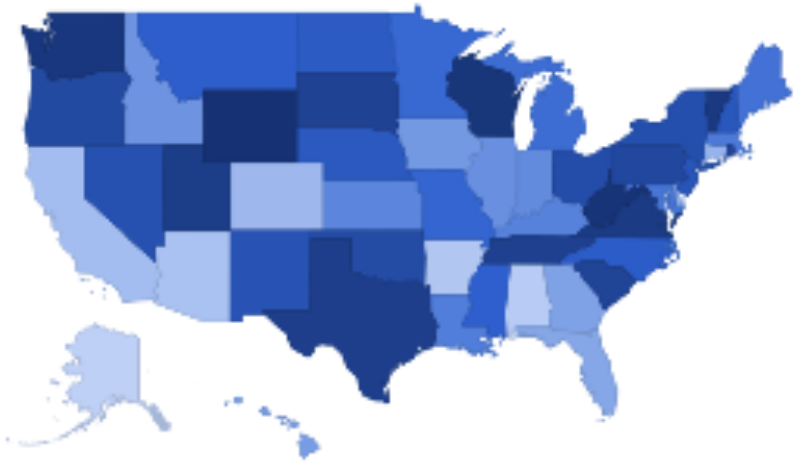
- GCAM-USA is a version of GCAM with sub-regional detail in the United States.
- GCAM-USA is a full, global integrated assessment model (IAM).
- It is actively being used to explore energy-water-land interactions

See bibliography at end of this talk

GCAM



GCAM - USA



Part of an overall trend in our work to add greater spatial and sectoral detail (where needed)

GCAM-USA Detail

- Socioeconomic projections are input at state level
  - Population
  - GDP (as labor productivity growth)
- 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 PV, rooftop PV, solar thermal), 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 (process model in progress)

Not modeled at the state level

- Fossil Resources/Fossil resource production
- Agricultural demand (USA total) & supply (10 agro-economic zones AEZ)

Future Water Consumption

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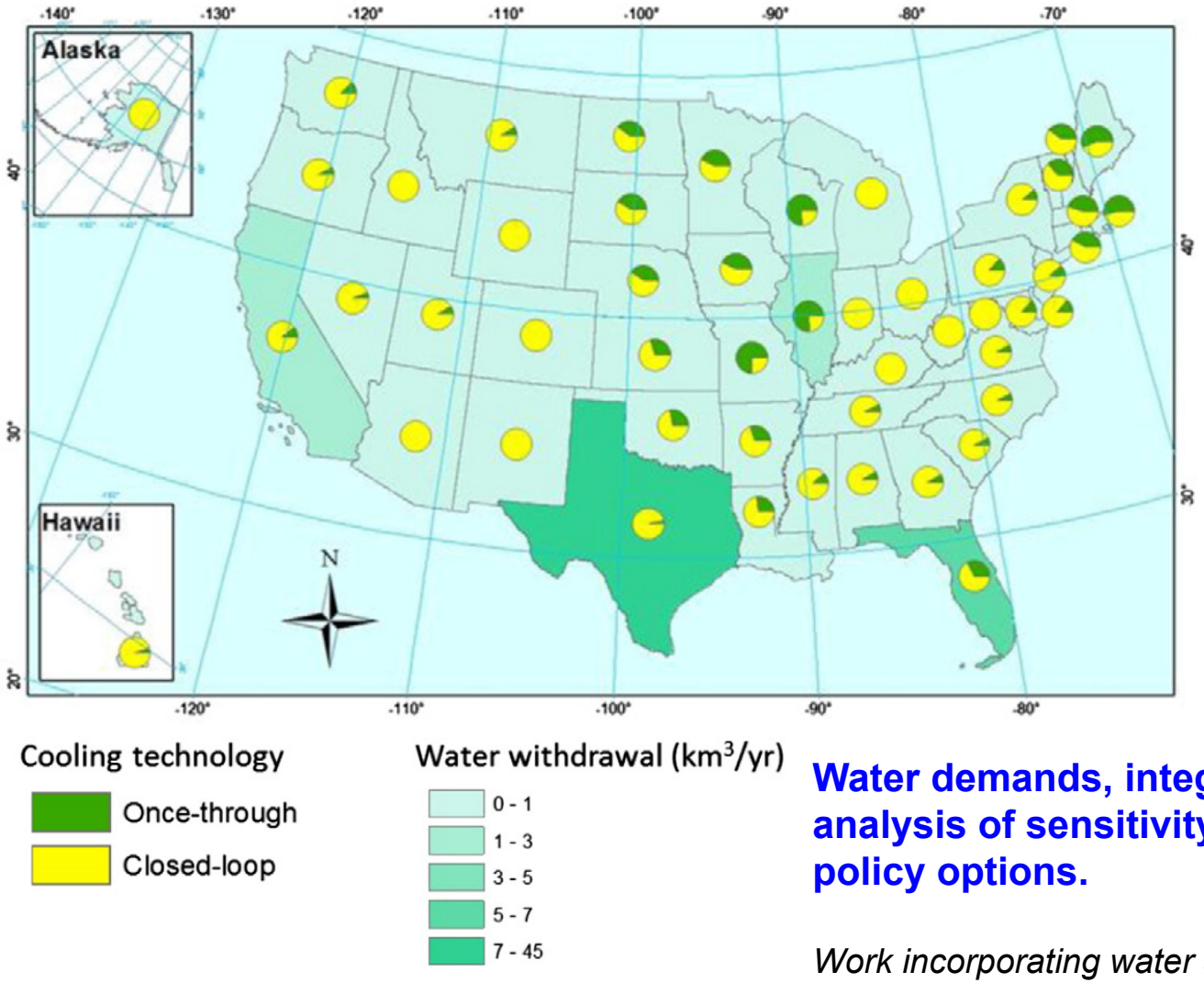
2095 Water withdraw for Electric Generation



- Reference scenario water withdraw where the prevalence of closed-loop cooling increases over time for electric generation.
- Withdraw rates are up to ~ 10 km^3/yr larger at the state level under a "frozen cooling technology" scenario.

Water demands, integrated into the model, allow analysis of sensitivity to assumptions including policy options.

Work incorporating water supply and demand in prep.

Liu et al. (2015) "Water demands for electricity generation in the U.S.: Modeling different scenarios for the water–energy nexus" Technological Forecasting & Social Change 94 (2015) 318–334. doi: 10.1016/j.techfore.2014.11.004

Future Water Consumption

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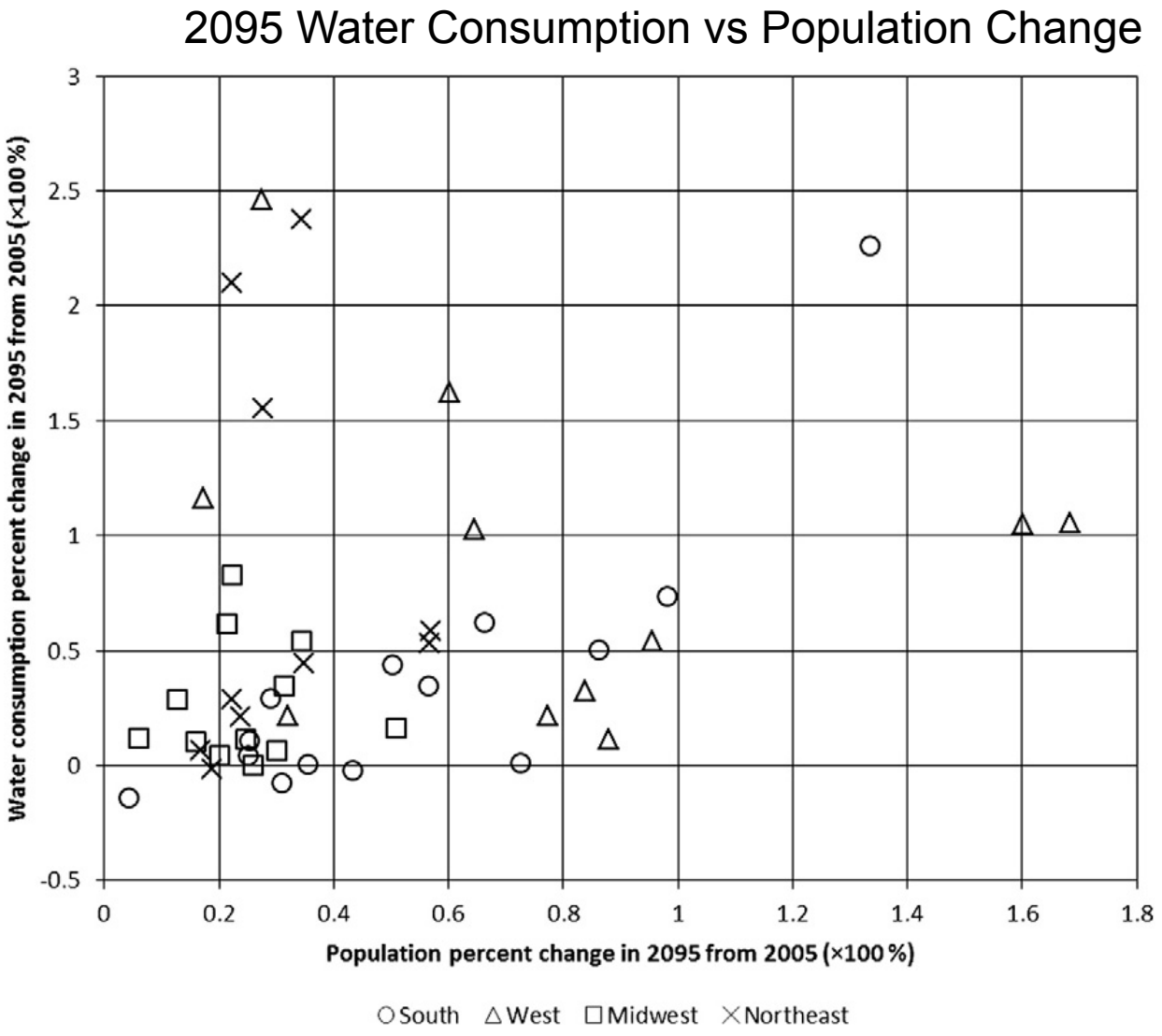
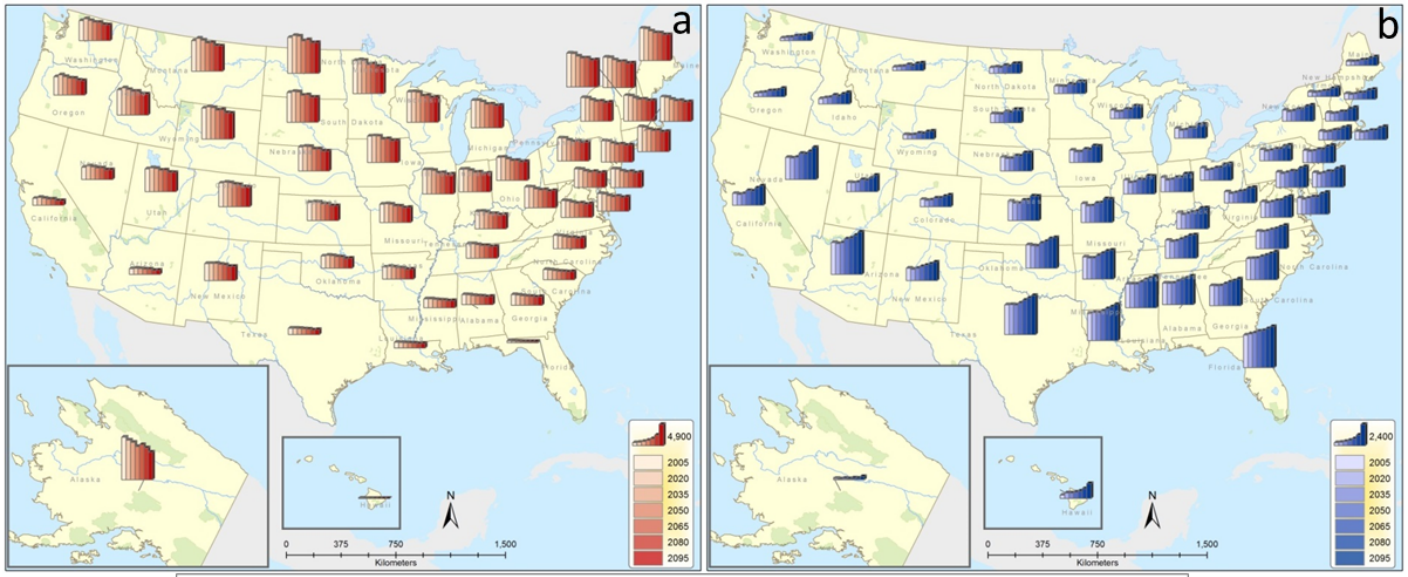
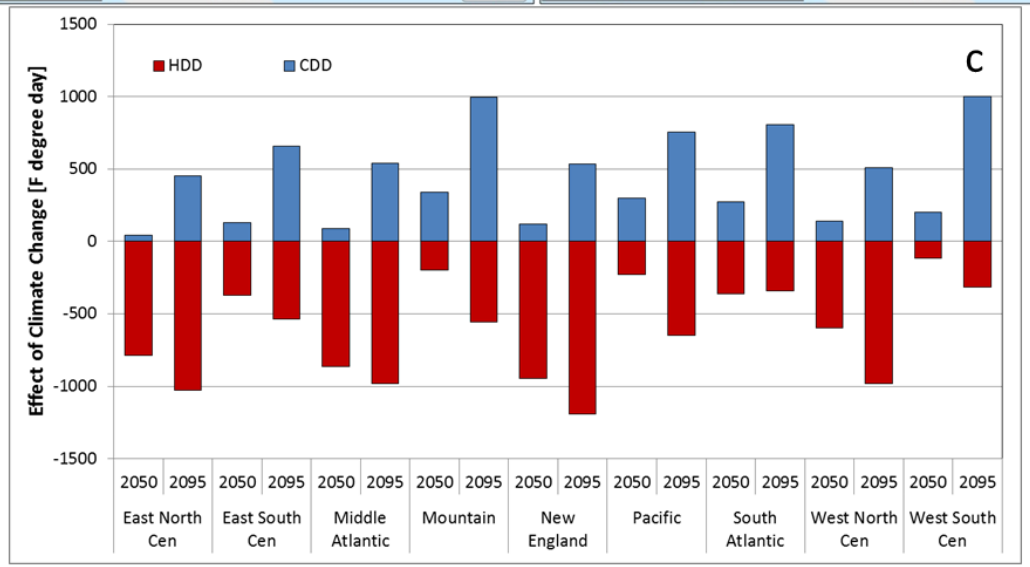


- Population is not the only factor driving water consumption.
- Increases in the prevalence of closed-loop cooling technologies reduce water demands over time relative to a frozen tech scenario.
- Shifts in electric generation technologies also change water demands

Liu et al. (2015) "Water demands for electricity generation in the U.S.: Modeling different scenarios for the water–energy nexus" Technological Forecasting & Social Change 94 (2015) 318–334. doi: 10.1016/j.techfore.2014.11.004

Future Building Energy Consumption



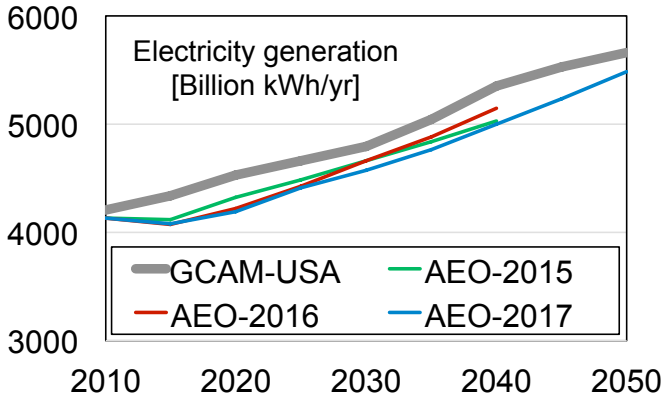


A more detailed representation of the U.S. at the 50 state level, embedded within the global model allows for improved modeling of issues such as the impact of changing climate on US building energy consumption.

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

Recent and In-Progress Improvements

- Harmonization to EIA's Annual Energy Outlook
  - Follows similar trend other than overestimate in 2015
    - Will be corrected w/ calibration year is updated to 2015
- Air pollutant emissions updates
  - (see next slides)
- Electricity load segments
  - Generation segments: peak, sub-peak, intermediate, baseload
- Detailed Industrial Energy Model
  - ~12 sectors and & ~8 services (boilers, process heat, electro-chemical, feedstocks, etc.)
  - Brings industry sectors into similar level of detail as buildings and transportation
- Natural gas supply and infrastructure
  - State supply curves. Natural gas trade/transport between states
- More detailed regional representation of land-use change
  - Better aligned with water basins/states
- Energy-Water-Land interactions
  - Water demand, supply and associated markets
- New Technologies
  - Offshore Wind (collaboration with Z. Cramer)



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Air-Pollutant Emissions in GCAM-USA

State-level criteria pollutant emissions

In collaboration with EPA ORD, air pollutant emissions in GCAM-USA have been updated.

- Calibrated to NEI 2011 emissions at the state-level
- Emission factors (EFs) incorporate impact of on-the books regulations (CSAPR), new source performance standards (NSPS2), MACT requirements, consent decrees, etc. for new capital stock

  Data sources:

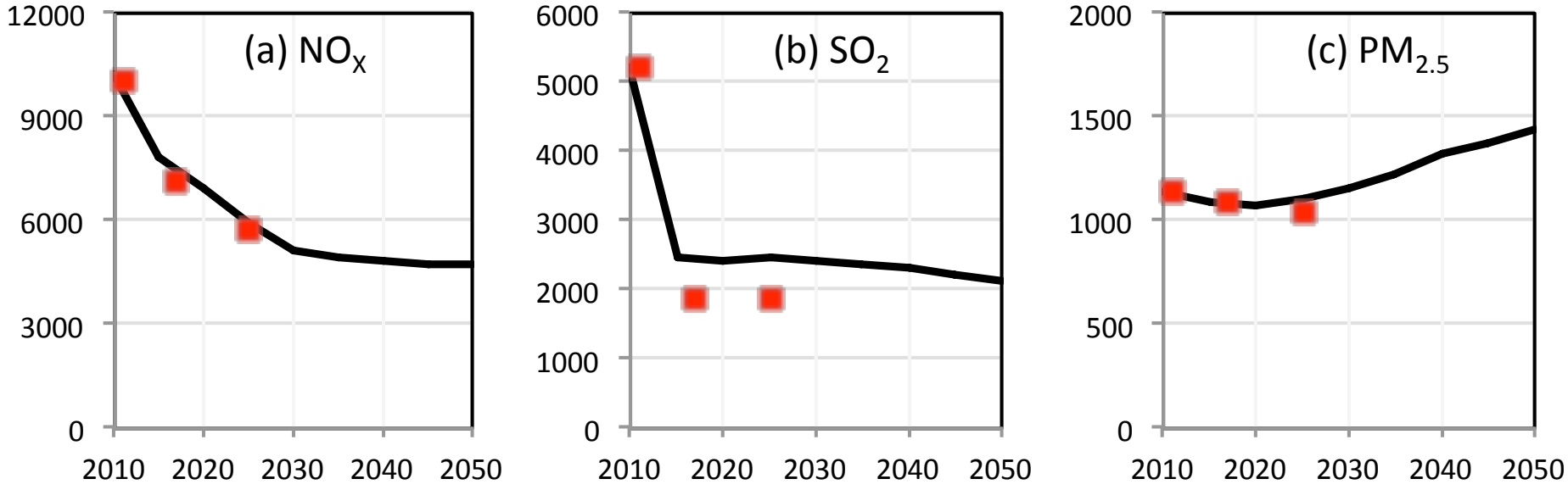
  - ✓ Electric generation: IPM version 5.13, GREET 2014, with technology-specific New Source Performance Standards (NSPSs).
  - ✓ Industrial fuel consumption: derived from EPAUS9r2014 MARKAL energy modeling framework
  - ✓ Refineries: GREET (which was developed from EPA inventories and approximates the effects of NSPSs)
  - ✓ Light- and heavy-duty vehicle: Mobile Vehicle Emissions Simulator (MOVES)
- Add emission factors for fuel/technology combinations not represented separately in NEI or other inventory data

Part of this process have been evaluating/updating other GCAM assumptions so as to better model energy-system dynamics over 1-3 decade time horizons.

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

Comparison With EPA Inventories

In general, GCAM-USA projections are now similar to EPA regulatory inventories.

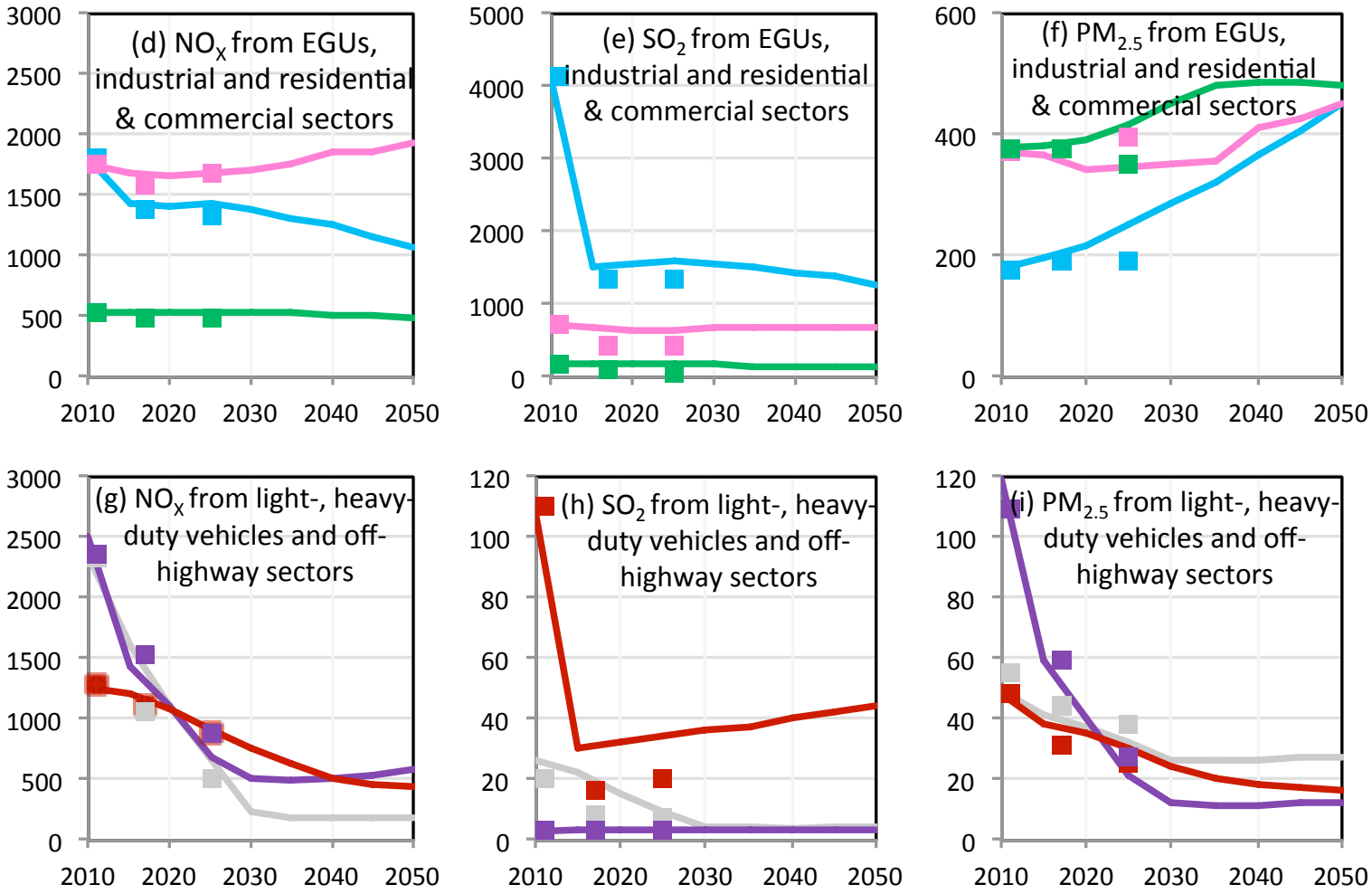


Solid Lines – GCAM-USA projections

Because these projections includes only policies currently in place, some emissions can ultimately increase in the long-term as energy demands or other drivers increase over time.

Shi, W. et al. 2017. "Projecting state-level air pollutant emissions using an integrated assessment model: GCAM-USA" Submitted, *in Review*

Comparison With EPA Inventories

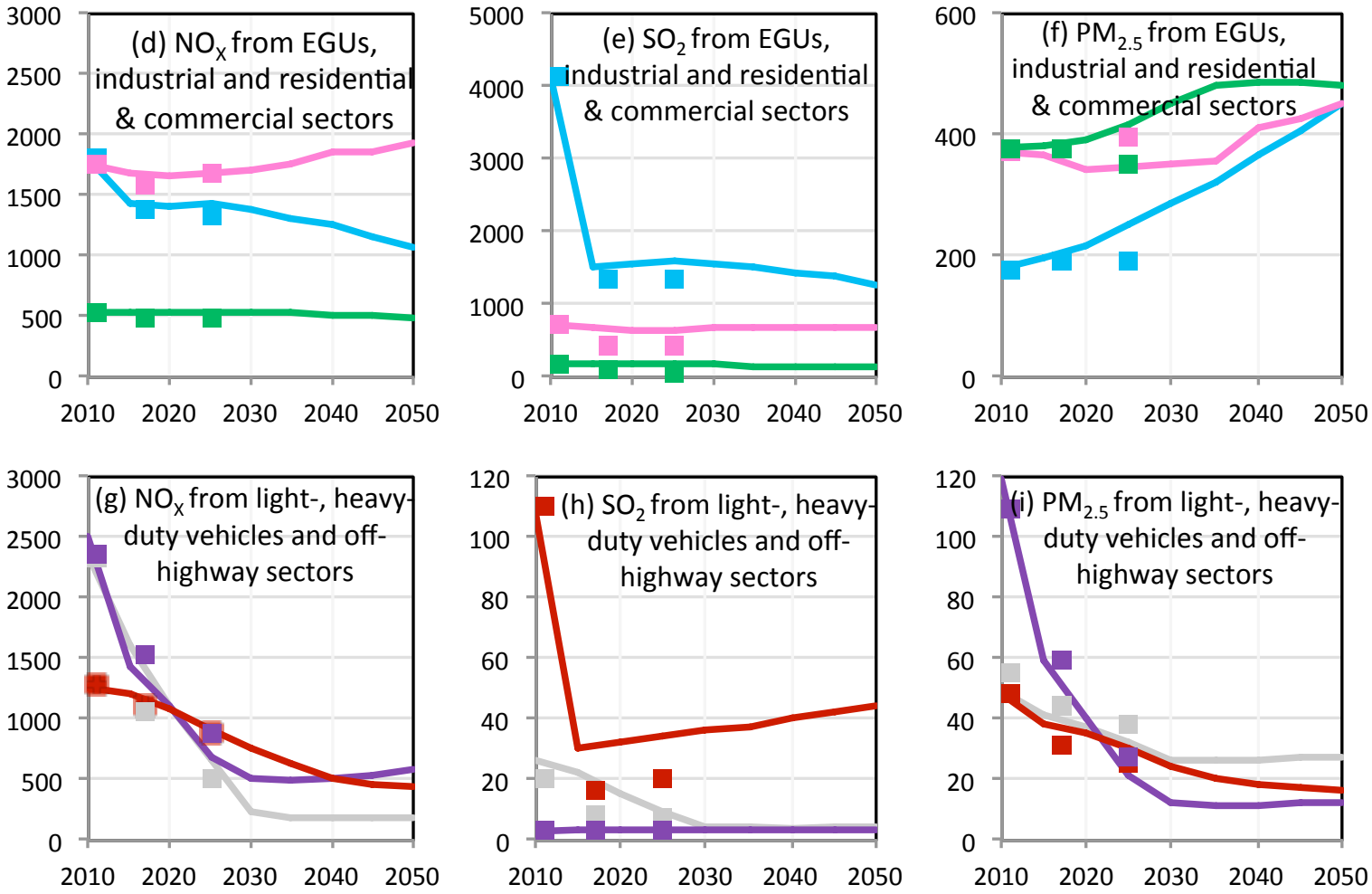


Emissions match well for most sectors/ fuels.

Some emission differences due, to differences in the underlying energy projection or sector definitions.

Shi, W. et al. 2017. "Projecting state-level air pollutant emissions using an integrated assessment model: GCAM-USA" Submitted, *in Review*

Comparison With EPA Inventories



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State level comparison

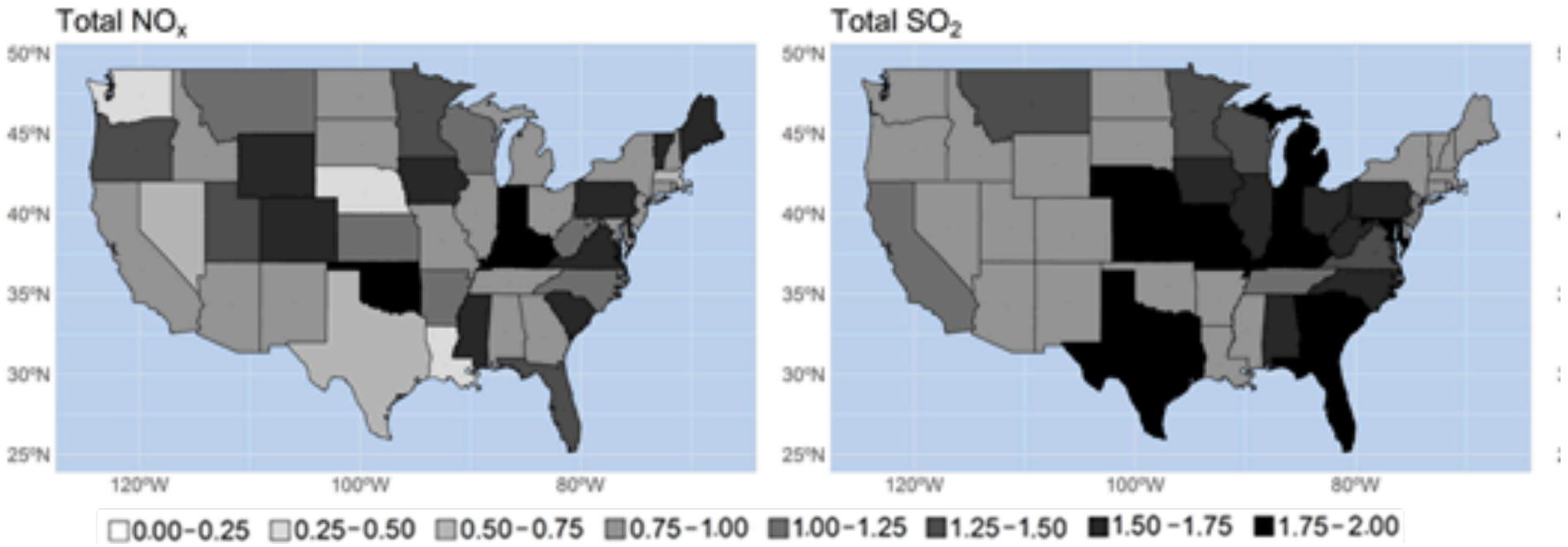

Figure shows a "quality metric" that is equal to 2 when both base-year and 2025 values match EPA's inventories for that state.

There are larger differences at the state level. State level energy projections have not been harmonized. Emissions agree better in CSAPR states since electric sector emissions are required to match IPM modeled values through an emissions market within the model.

Shi, W. et al. 2017. "Projecting state-level air pollutant emissions using an integrated assessment model: GCAM-USA" Submitted, *in Review*

Analysis: Air Pollution Co-benefit of Efficiency and Renewable Energy Measures

Analysis examining the impact on state pollutant emissions due to a renewable energy standard requiring that specified percentage of new generation be supplied by renewable power (wind, solar, biomass, geothermal).

This leads to various analysis set-up choices and additional questions.

- Applied RPS constraint at the grid region level (roughly equal to NERC regions).
  - From a modeling standpoint, this is a clean set-up since model freely trades electricity within a grid-region.
  - Question: what would differing state level RPS standards mean in the context of interconnected AC grids where net state-level electricity import/export is generally not zero?
- Might renewable portfolio standards ultimately be set high enough that existing capacity would be either prematurely retired or under-utilized? (Set-up in this analysis assumes not.)
- Results are often in a context of relatively low projected growth in electricity demand
  - Often this implies relatively low levels of new capacity addition.

Electricity System Projections

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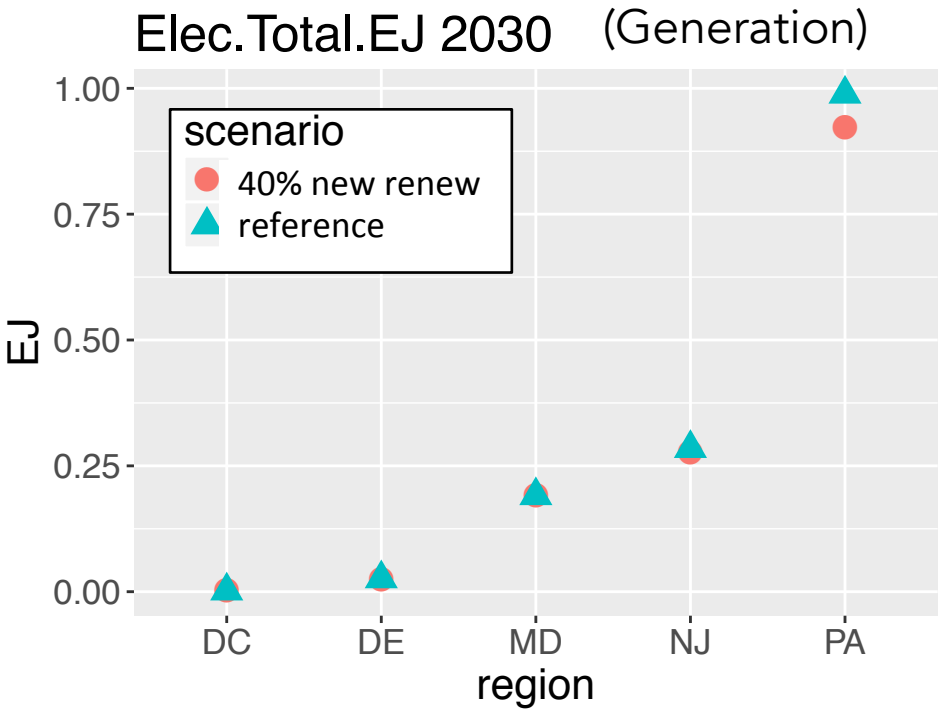
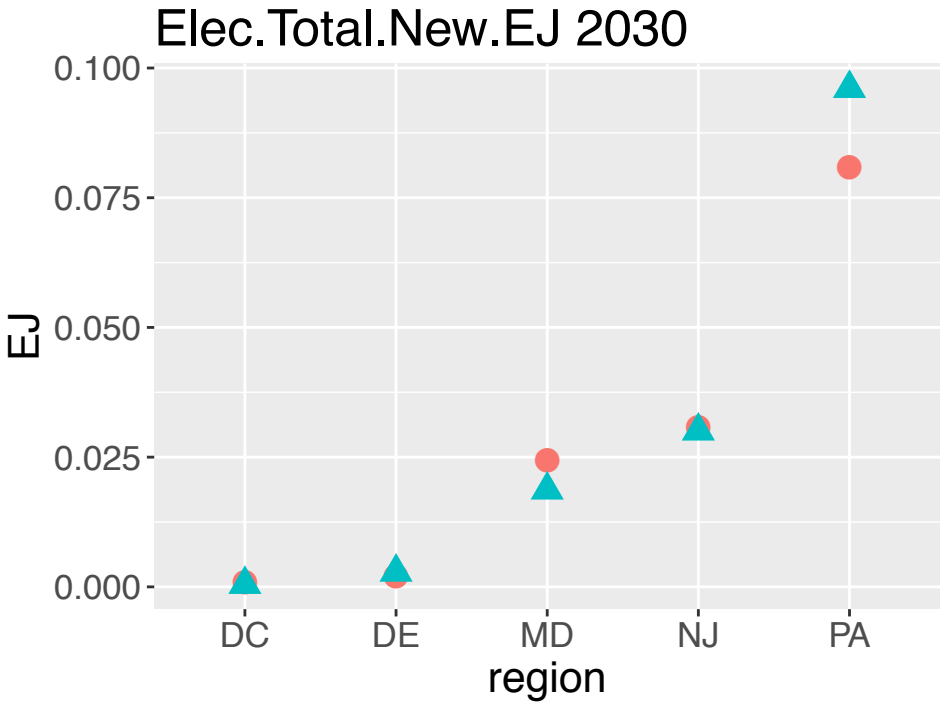
System size varies between states.



Electricity demand decreases too much in these results – something we are fixing.

Under a region-wide RPS, generation shifts (although shifts are modest in this case).



Preliminary Results

Renewable Generation

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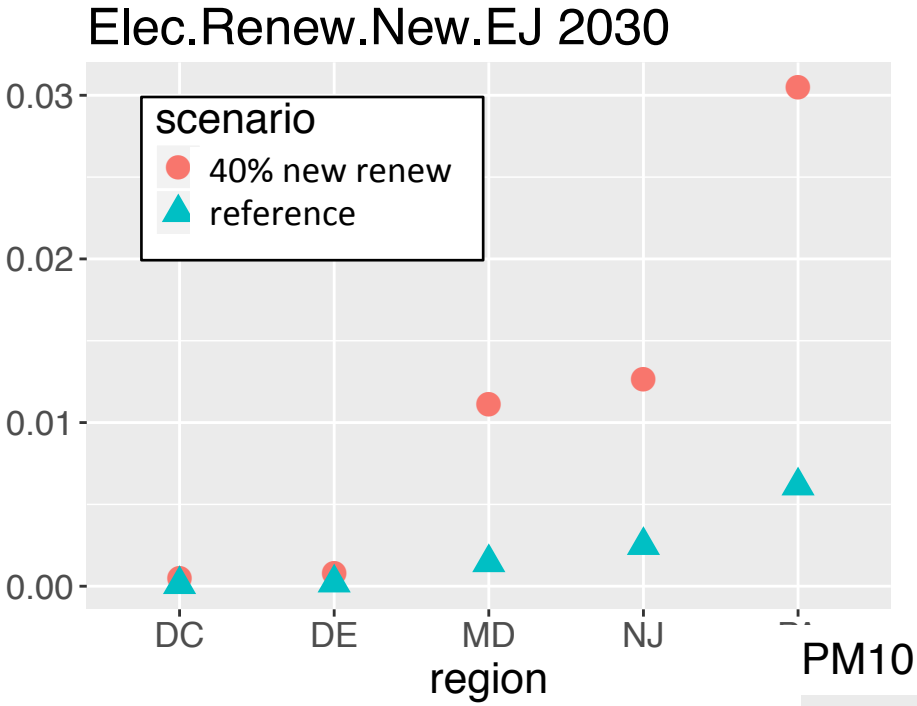
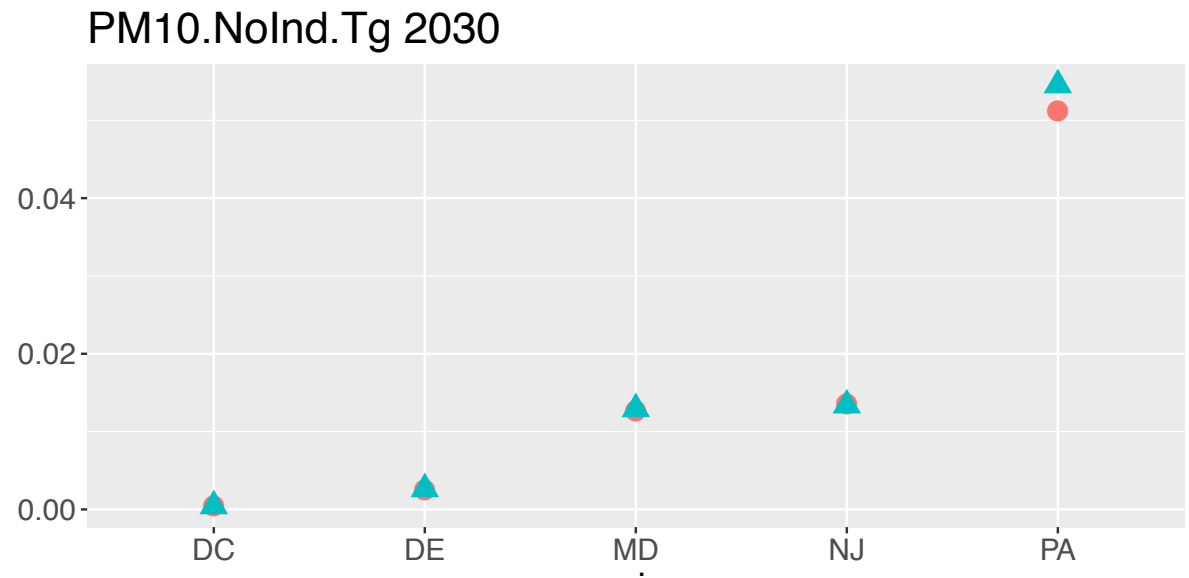


New builds of renewable capacity increase

Criteria pollutant emissions decrease, although change is small in this case



Assumptions for biomass (both transformation side and end-use) can impact these results.

Preliminary Results

Summary

- GCAM-USA is a flexible modeling tool that can now be applied to energy and air pollution analysis at the state level.
- At the national level, air pollution projections agree well with regulatory inventories. As with any model, results at finer scales are increasingly sensitive to assumptions and model behavior.
  - State level air pollutant emissions show larger differences at this level.
- This tool does not replace the need for more detailed modeling
  - Regulatory impact analysis often requires more detailed tools that consider the system "as it is now" and might evolve in the near-term.
  - GCAM-USA can be a useful tool to allow flexible analysis with multiple scenarios with different driver (e.g. Population, Shi et al. in prep), technology (Ou et al. in prep), or policy assumptions.

GCAM-USA Bibliography

Zhou Y, LE Clarke, J Eom, GP Kyle, PL Patel, SH Kim, J Dirks, E Jensen, Y Liu, J Rice, L Schmidt, and T Seiple. 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.

Scott MJ, DS Daly, Y Zhou, JS Rice, PL Patel, HC McJeon, GP Kyle, SH Kim, J Eom, and LE Clarke. 2014. "Evaluating sub-national building-energy efficiency policy options under uncertainty: Efficient sensitivity testing of alternative climate, technological, and socioeconomic futures in a regional integrated-assessment model. ." Energy Economics 43(2014):22-33. doi:10.1016/j.eneco.2014.01.012

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Liu L, M Hejazi, P Patel, P Kyle, E Davies, Y Zhou, L Clarke, and J Edmonds (2015) “Water demands for electricity generation in the U.S.: Modeling different scenarios for the water–energy nexus" Technological Forecasting & Social Change 94 (2015) 318–334. doi: 10.1016/j.techfore.2014.11.004.

McFarland J, Y Zhou, LE Clarke, P Sullivan, J Colman, W Jaglom, M Colley, PL Patel, J Eom, SH Kim, GP Kyle, P Schultz, B Venkatesh, J Haydel, C Mack, and J Creason. 2015. "Impacts of rising air temperatures and emissions mitigation on electricity demand and supply in the United States: a multi-model comparison." Climatic Change 131(1):111-125. doi:10.1007/s10584-015-1380-8

Hejazi MI, N Voisin, L Liu, LM Bramer, DC Fortin, JE Hathaway, M Huang, GP Kyle, LYR Leung, H Li, Y Liu, PL Patel, TC Pulsipher, JS Rice, TK Tesfa, CR Vernon, and Y Zhou. 2015. "21st Century United States Emissions Mitigation Could Increase Water Stress more than the Climate Change it is Mitigating." Proceedings of the National Academy of Sciences of the United States of America 112(34):10635-10640. doi:10.1073/pnas.1421675112

Iyer, G., Ledna, C., Clarke, L., McJeon, H., Edmonds, J., & Wise, M. (2017). GCAM-USA Analysis of US Electric Power Sector Transitions (PNNL-26174).

Iyer G., C Ledna, LE Clarke, JA Edmonds, HC McJeon, P Kyle and J Williams. Measuring Progress from Nationally Determined Contributions to Mid-Century Strategies. Nature Climate Change (accepted in principle).

The End

Contributions from:

Wenjing Shi, Yang Ou, Christopher G. Nolte, Daniel H. Loughlin