The GLIMPSE project

Exploring strategies for meeting energy, environmental and climate objectives

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Forward

- **Objective of this presentation**

  Describe the GLIMPSE project and illustrate how it can be used to support sustainable energy decision-making.

- **Intended audience**

  Faculty and students at Tsinghua University and the Shanghai Academy for Environmental Sciences interested in air quality management decision support tools.

- **Intended use**

  Modeling results are provided for illustrative purposes only.

- **Disclaimer**

  The views expressed in this presentation are those of the author and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.

Abbreviations

Emission species

- CH_4 - methane
- CO – carbon monoxide
- CO_2 – carbon dioxide
- Hg - mercury
- NOx – nitrogen oxides
- GHG – greenhouse gas
- MTC – Megatonnes of carbon (10^6 tonnes)
- PM – Particulate matter
- SO_2 – sulfur dioxides
- VOC – volatile organic compound

Energy terms and units

- CCS – carbon capture and sequestration
- H_2 – hydrogen
- Units
- EJ – Exajoule (10^18 joules)
- Tg – Teragram (10^12 grams)
- EGU – Electricity generating unit

Models and other computing tools

- ABaCAS – Air Benefit and Cost and Attainment System
- GCAM – Global Change Assessment Model
- GCAM-USA - Global Change Assessment Model with state-level resolution for the U.S.
- GLIMPSE - an energy-environmental-climate decision support tool. Acronym no longer applies.
- IAM – Integrated Assessment Model
- SMOKE – Sparse Matrix Operator Kernel Emissions modeling system
- ICET – International Control Cost Estimate Tool
- RSM – Response Surface Model
- SMAT – Software of Model Attainment Test
- BenMAP - Environmental Benefits and Analysis Mapping and Analysis Program
- CE – Community edition

Other

- INDCs – Intended Nationally Determined Contributions of GHG emission reductions
- csv – comma separated value document format
- xml – extensible markup language document format
- AQ – air quality

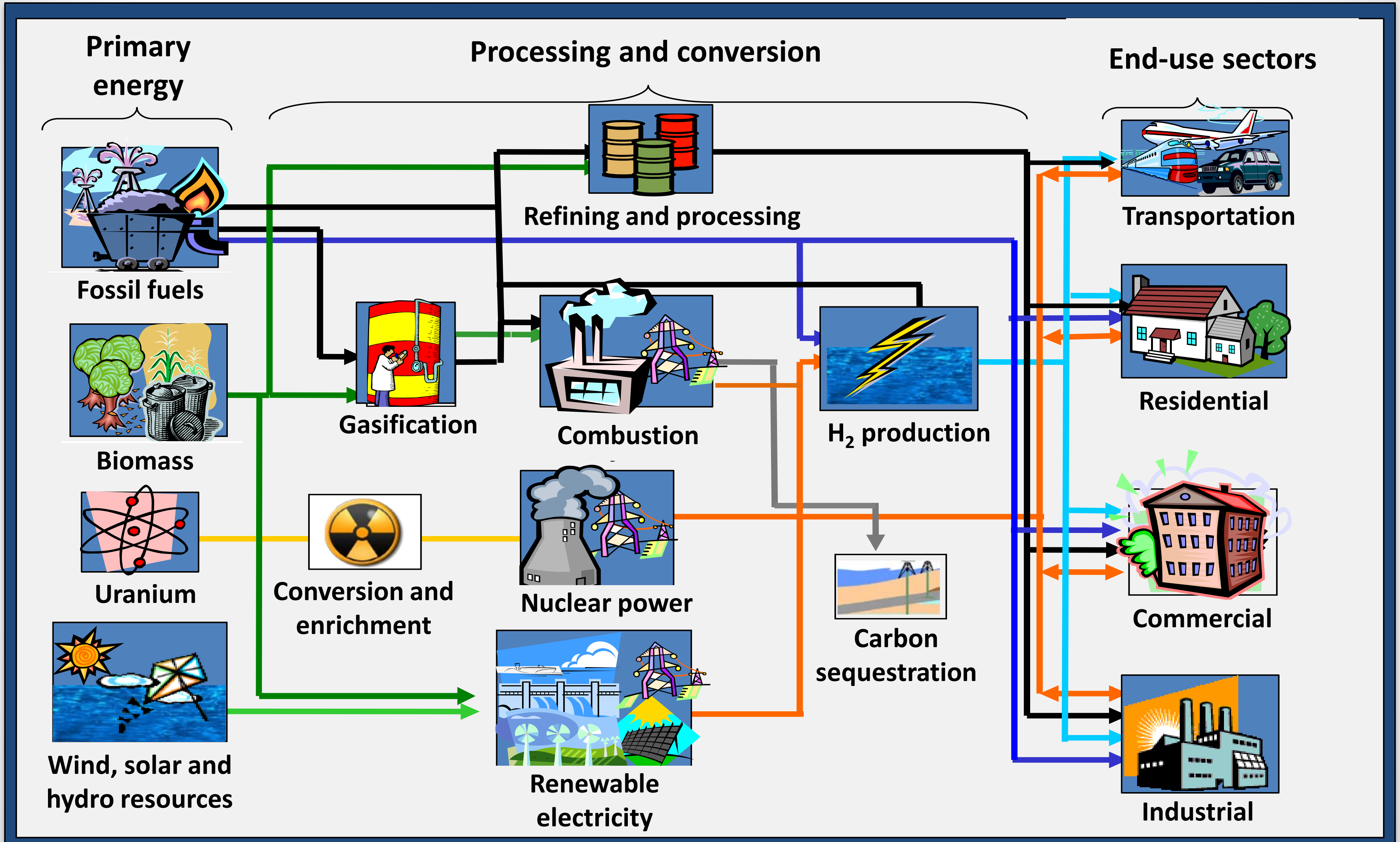
Outline

1. Energy and the environment
2. The GLIMPSE project
3. The Global Change Assessment Model (GCAM)
4. Illustrative application
   - Greenhouse gas (GHG) co-benefits of air pollution targets
   - Air pollution co-benefits of GHG reduction targets
5. Ongoing work and next steps

1. Energy and the environment

Energy and the environment

The energy system



Environmental impacts of energy

Energy system contributions to environmental issues:

- **Air quality**
  - Photochemical smog: 92% of nitrogen oxide (NOx) emissions*
  - Acid rain: 86% of sulfur dioxide (SO_2) emissions*
  - Toxics: 87% of mercury (Hg) emissions*

* Percentage of U.S. anthropogenic emissions due to the energy system

- **Climate change**
  - Greenhouse gas emissions: 97% of carbon dioxide (CO_2) emissions*
  - Major source of short-lived climate pollutants (e.g., black carbon, methane)
- **Water**
  - Demands: electricity production accounts for 51% of fresh water withdrawals
  - Pollution:
    - wastewater from fuel extraction and processing, seepage from waste
    - eutrophication from N deposition, acidification from S deposition
- **Waste production**
  - Mine tailings, combustion residues, agricultural wastes

Complexities of energy planning

- **The pathway taken to reduce air pollutants may:**
  - Increase GHGs (e.g., methane leakage from natural gas extraction), or,
  - Decrease GHGs (e.g., wind and solar emit no GHGs during operation)
- **Similarly, the pathway taken to reduce GHGs may:**
  - Increase air pollutants (e.g., efficiency penalty for CO_2 capture), or,
  - Decrease air pollutants (e.g., natural gas emits fewer air pollutants than coal)
- **There are lifecycle implications of mitigation pathways**
  - Mitigation pathways may require manufacturing (e.g., solar panels and batteries) and construction (e.g., nuclear power plants), which would produce a wide range of impacts (e.g., waste generation, emissions, and water consumption)
  - Reducing fossil fuel use reduces emissions and water pollution associated with extraction activities
- **Other issues**
  - Competition for fuels among sectors
  - Increased electricity demands associated with electric vehicles
  - Solar and wind power provide intermittent generation

Science questions

- How can we simultaneously achieve environmental, climate change mitigation, and energy goals?
- What are the tradeoffs and synergies among these goals?
- Are there unintended consequences that may arise with various management strategies? Can we anticipate and prepare for these?
- What are the broader health, environmental and ecological impacts of different pathways for meeting society's energy needs?
  - Impacts under consideration include:
    - air quality and resulting human health effects,
    - damage to crops and timber, ecosystem impacts from N and S deposition,
    - water use by agricultural and energy sectors, and
    - resilience to drought and other climate change impacts.

2. The GLIMPSE project

The GLIMPSE project

GLIMPSE: a modeling framework for exploring the answers to these questions

Inputs

- Population growth and migration
- Economic growth and transformation
- Climate change impacts on heating and cooling
- Technology development
- Behavior and preferences
- Existing policies (energy, climate, environment)

Energy System Model

Outputs

- Technology market shares
- Fuel use and prices
- Emissions
  - air pollutants
  - GHGs
  - short-lived climate pollutants (SLCPs)
- Water demands
- Climate change
- Human health and ecosystem impacts

Policy, sensitivity, or scenario for evaluation

Iterative design process

Energy system modeling

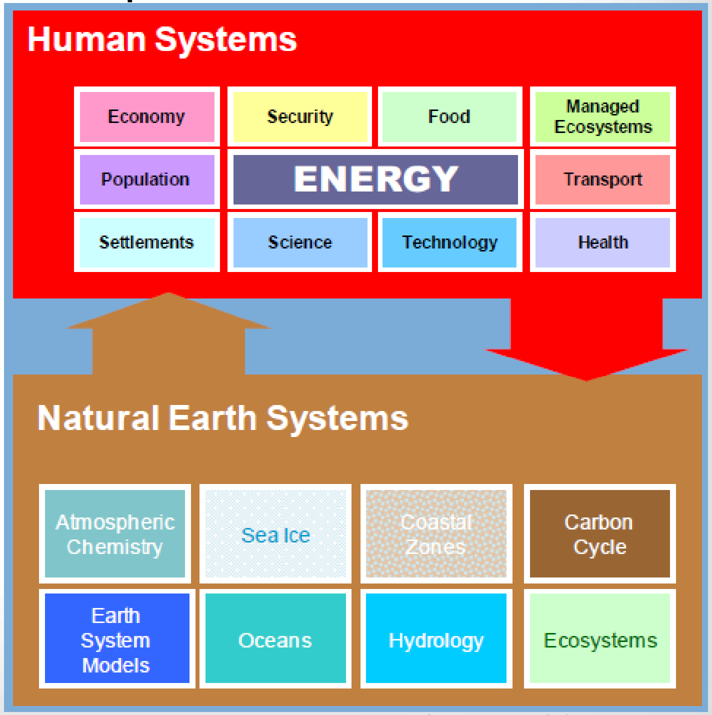
- Two complementary models being used within GLIMPSE
  - **MARKet ALlocation (MARKAL)** energy system optimization model and EPAUS9R MARKAL database
    - Represents U.S. at the Census Division resolution
    - Helps answer question: "How do I achieve energy, environmental and climate goals most cost effectively?"
  - **Global Change Assessment Model (GCAM)-USA**
    - Represents U.S. at state resolution, within an integrated global model
    - Helps answer question: "What may happen under a specific set of assumptions and policies?"
    - Open source and public domain facilitates its inclusion in decision support tools

3. The GCAM Integrated Assessment Model

A role for Integrated Assessment Models?

What is an IAM?

- **IAMs:**
  - Used for 30+ years to assess GHG emissions and climate change mitigation strategies
  - Integrate representations of human and natural systems and their interactions
  - Are global in scope
  - Typically model a time horizon stretching to 2100 or beyond
  - Include anthropogenic sources of GHGs and often other pollutants
- **There is significant variation across IAMs, depending on intended purpose:**
  - Spatial resolution
  - Inclusion of gases and other substances
  - Energy system detail
  - Representation of agriculture and land use
  - Economic assumptions
  - Degree of foresight
  - Sophistication of the climate component



Source: JGCRI, PNNL

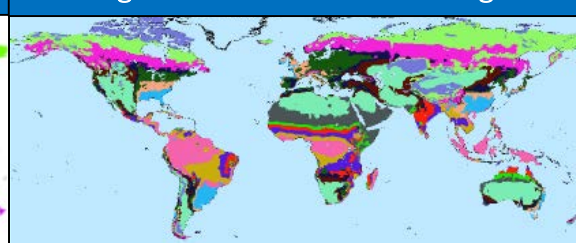
The Global Change Assessment Model

- **Emerging directions in IAM development:**
  - Finer spatial resolution (sub-national)
  - Finer temporal resolution (1-5 years)
  - Inclusion of GHGs and Short-Lived Climate Pollutants, many of which are also air pollutants (e.g., NOx, SO_2, CH_4, CO, and particulate matter)
  - Incorporation of detailed land use and water system linkages
- **Example: The Global Change Assessment Model (GCAM)**
  - Developed by Pacific Northwest National Laboratory
  - Regions: 32 economic and energy; 283 agriculture and land use; 233 water basins
  - 5-year time steps, extending from 2005 to 2100
  - Technology-rich energy system detail
  - Open source and freely available, 1 hour runtime

Source: JGCRI, PNNL

32 economic and energy regions

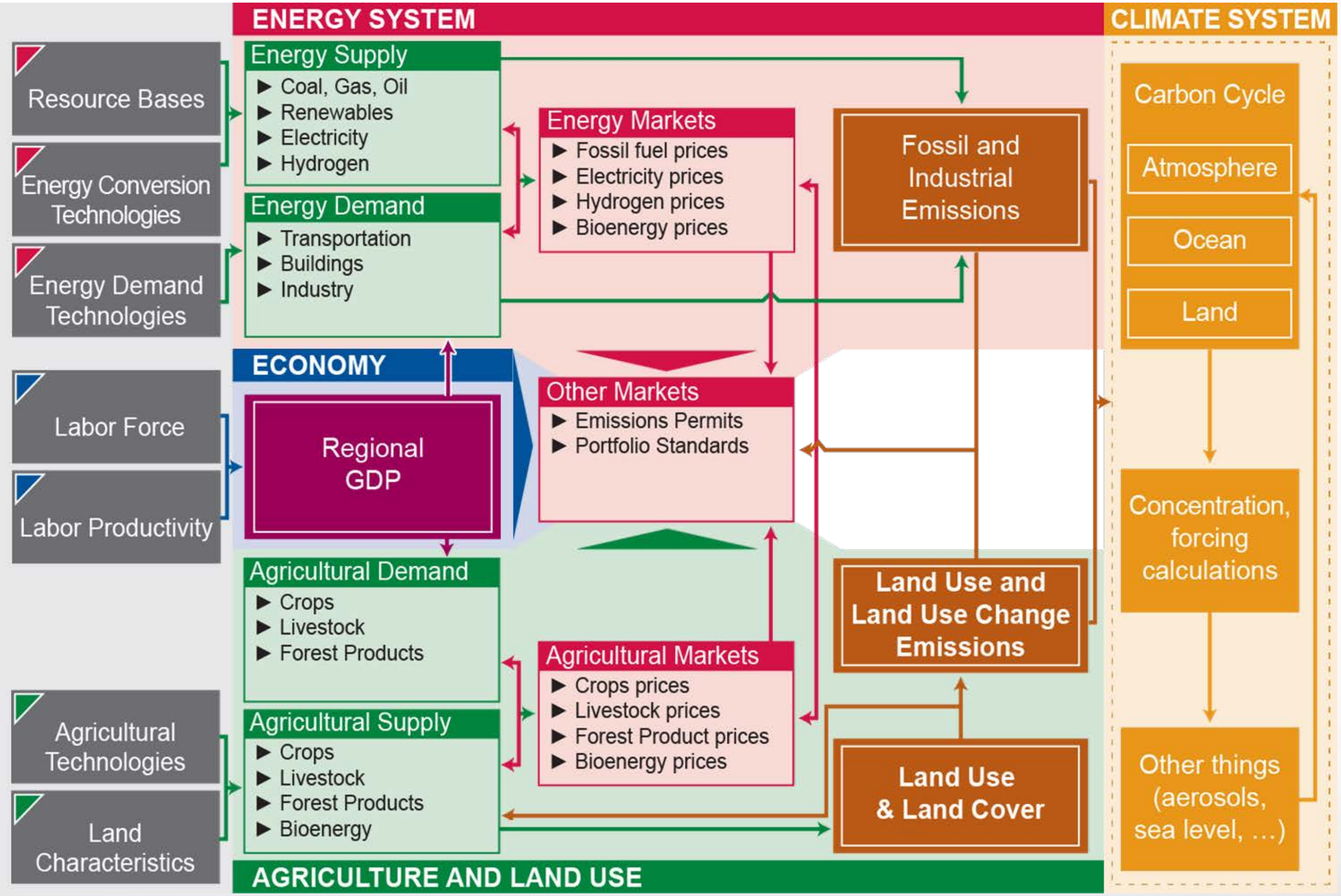
283 agriculture and land use regions



233 water basins

The Global Change Assessment Model

GCAM Components

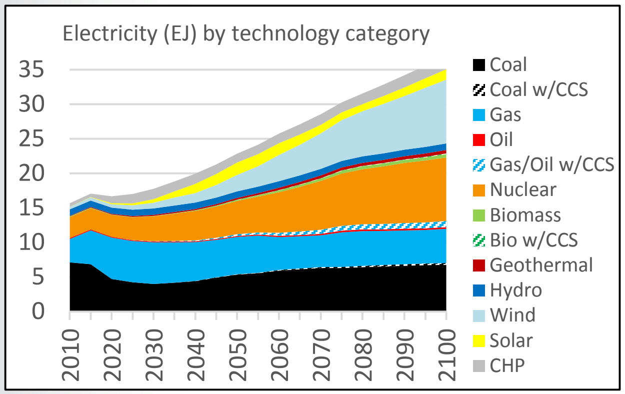


Source: JGCRI, PNNL

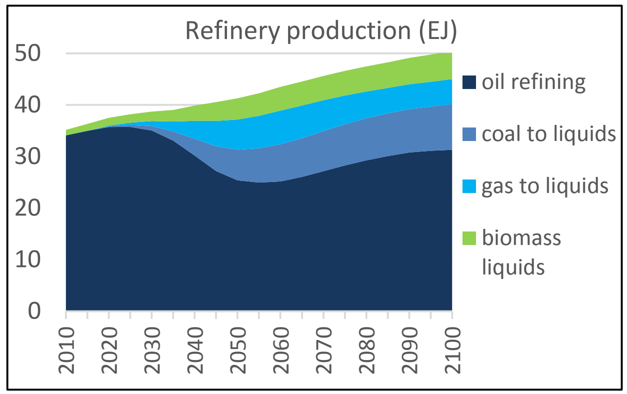
A role for Integrated Assessment Models?
The Global Change Assessment Model

Example GCAM national-scale outputs for a hypothetical scenario

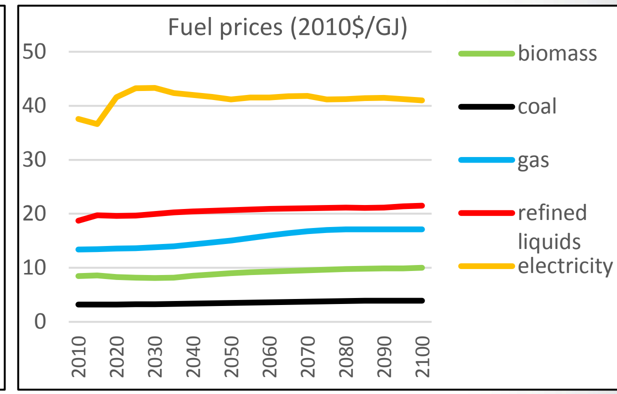
Technology market shares



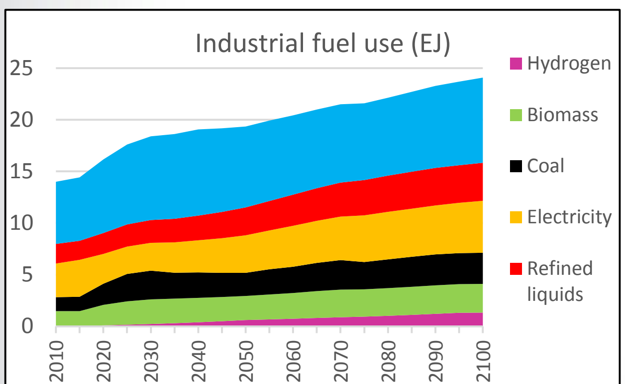
Fuel production



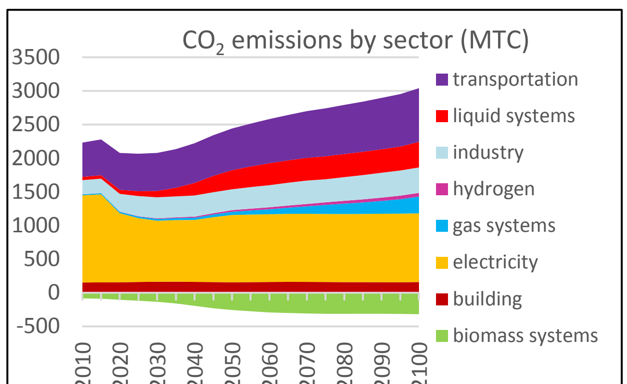
Fuel prices



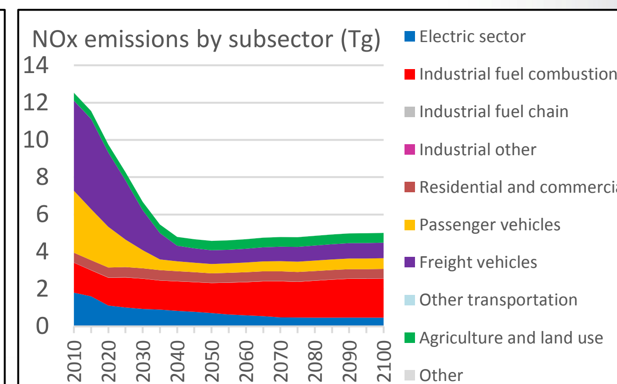
Sectoral fuel use



GHG emissions



Air pollutant emissions



Illustrative results

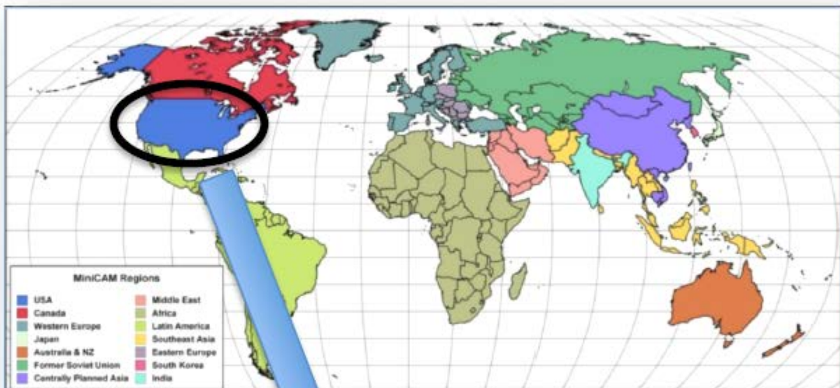
GCAM-USA

Adding spatial resolution to GCAM

GCAM's object-oriented structure facilitates sub-national spatial resolution.

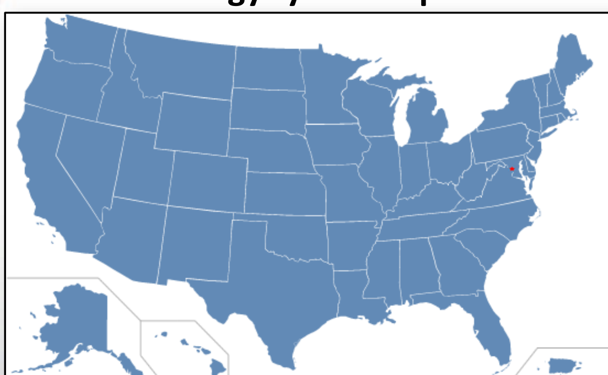
GCAM-USA and GCAM-China are both under development.

GCAM-USA



Source: JGCRI, PNNL

50-state energy system representation



GCAM-USA
- Each U.S. state is represented within a fully global IAM
- GHG and air pollution emissions projections can be produced for various global and U.S. scenarios
- In support of GLIMPSE, we are adding impact factors, including human health and ecosystem impacts from air pollutants
- We are exploring how GCAM-USA can be used within GLIMPSE to support long-term, coordinated energy and environmental planning

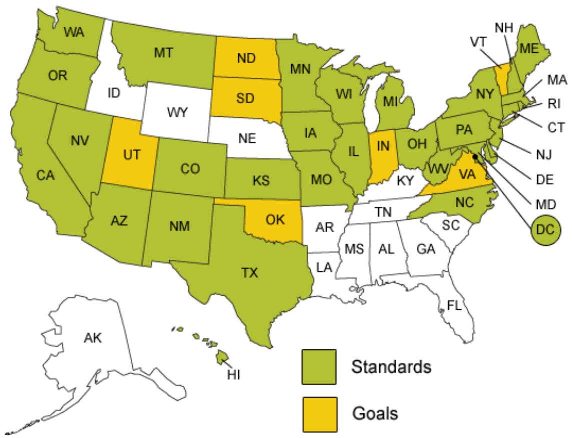
GCAM-USA
Importance of state-level resolution

Emissions and energy policies generally operate at the state-level, and resources vary subnationally

Cross-State Air Pollution Rule

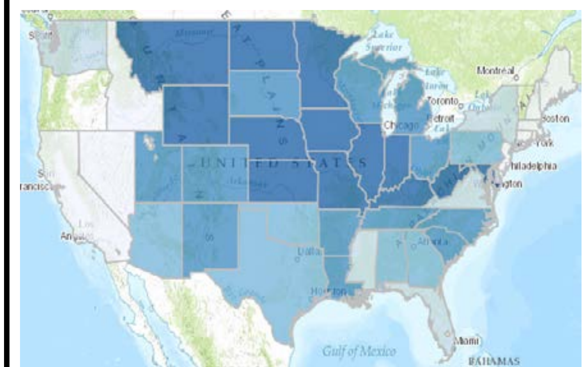
Source: U.S. EPA, http://www3.epa.gov/crossstaterule/

Renewable portfolio standards



Source: U.S. EIA, https://www.eia.gov/todayinenergy/detail.cfm?id=4850#

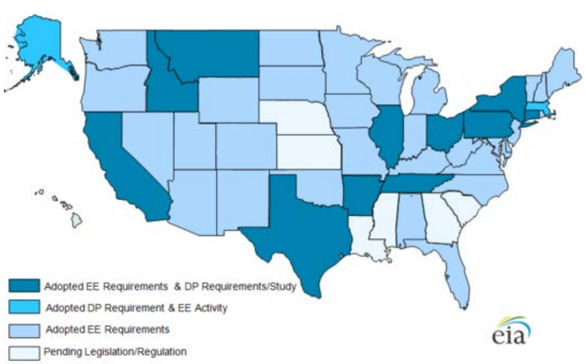
Clean Power Plan



Final emission rate limits

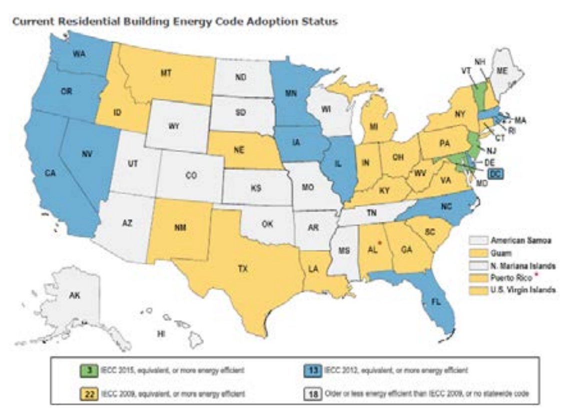
Source: U.S. EPA
www2.epa.gov/cleanpowerplan/clean-power-plan-final-rule-regulatory-impact-analysis

Demand response requirements



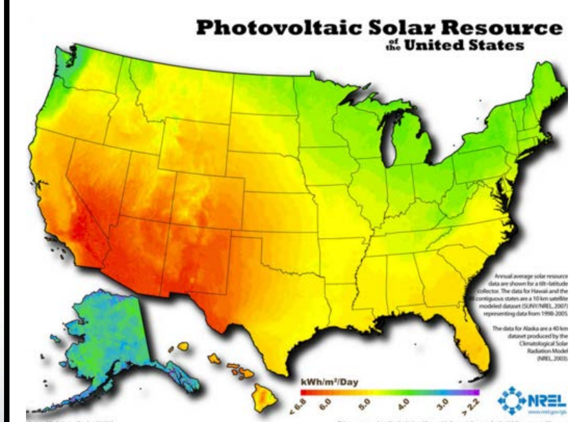
Source: U.S. EIA, https://www.eia.gov/analysis/studies/electricity/

Residential and commercial building codes



Source: U.S. DOE, https://www.energycodes.gov/status-state-energy-code-adoption

Renewable resources



GCAM-USA

Improving emission projections

Limitations for U.S. air pollutant projections	How these limitations are being addressed…
Air pollutant emission factors (EFs) decrease as a function of gross domestic product (GDP) growth (reflecting a more affluent population's preference for a cleaner environment), but do not explicitly reflect U.S. regulations (e.g., Tier 3 and New Source Performance Standards)	Developed base-year and projected EFs from EPA modeling activities: • Integrated Planning Model (IPM) • Mobile Vehicle Simulator of Emissions (MOVES) • EPA EF database • EPA Greenhouse Gas Inventory • Argonne Greenhouse Gases, Regulated Emissions and Energy Use in Transportation (GREET) model
Other regulations that limit state-level emissions are not currently included (e.g., Cross-State Air Pollution Rule, Clean Power Plan)	Added state-level pollutant caps derived from EPA Regulatory Impact Analyses of Cross-State Air Pollution Rule and the Clean Power Plan.
Option to retrofit existing power plants with air pollutant controls is not implemented (e.g., Selective Catalytic Reduction for NOx)	Developed retrofit pollutant controls based upon EPA's Control Strategy Tool (CoST) and MARKet ALlocation (MARKAL) modeling
Development and management of GCAM-USA inputs files could be more user-friendly	Integrating into the GLIMPSE prototype decision support tool, which includes a Scenario Builder and Results Analyzer.

4. Illustrative applications

Provided for illustrative purposes only

Illustrative application #1

GHG co-benefits of air pollutant controls

- **Model:**
  - **GCAM-USA-AQ**: A derivative of GCAM-USA v4.2 that modifies the original model by incorporating emission factor updates, NOx and SO2 controls for coal-fired boilers, and updated solar power costs
- **Approach:**

  Compare the pollutant and GHG emissions for three scenarios:
  - **Scenario 1**:

    Electric sector emission factors are held constant at 2010 levels.

    No additional air pollutant or GHG constraints are included.
  - **Scenario 2**:

    State-level limits on NOx and SO_2 limits are applied to Scenario 1 to approximate the Cross-State Air Pollution Rule (CSAPR).

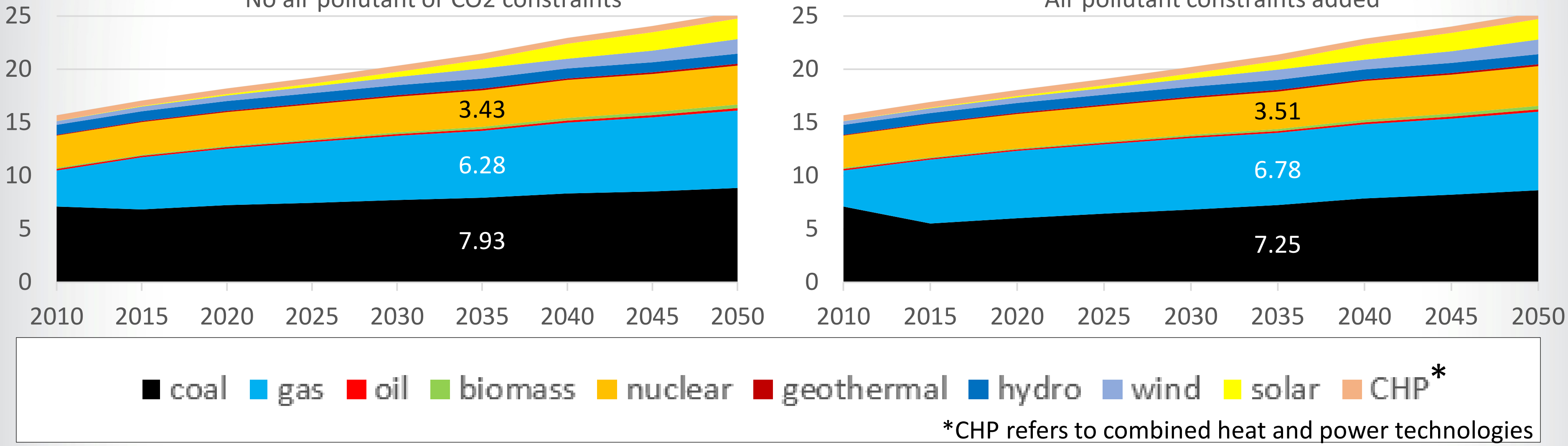
    Available controls are applied before fuel switching and energy efficiency.
  - **Scenario 2a**:

    Similar to Scenario 2, although no additional application of pollutant controls can be made after 2010. This encourages alternative measures, such as fuel switching.

Illustrative application #1
GHG co-benefits of air pollutant controls

Scenario 1 - Electricity production (EJ)
No air pollutant or CO2 constraints

Scenario 2 – Electricity production (EJ)
Air pollutant constraints added



Summary

- Air pollutant targets are met with controls first, then fuel switching from coal to gas and a small quantity of nuclear.
- These changes result in a 5% reduction of 2035 CO_2 emissions.

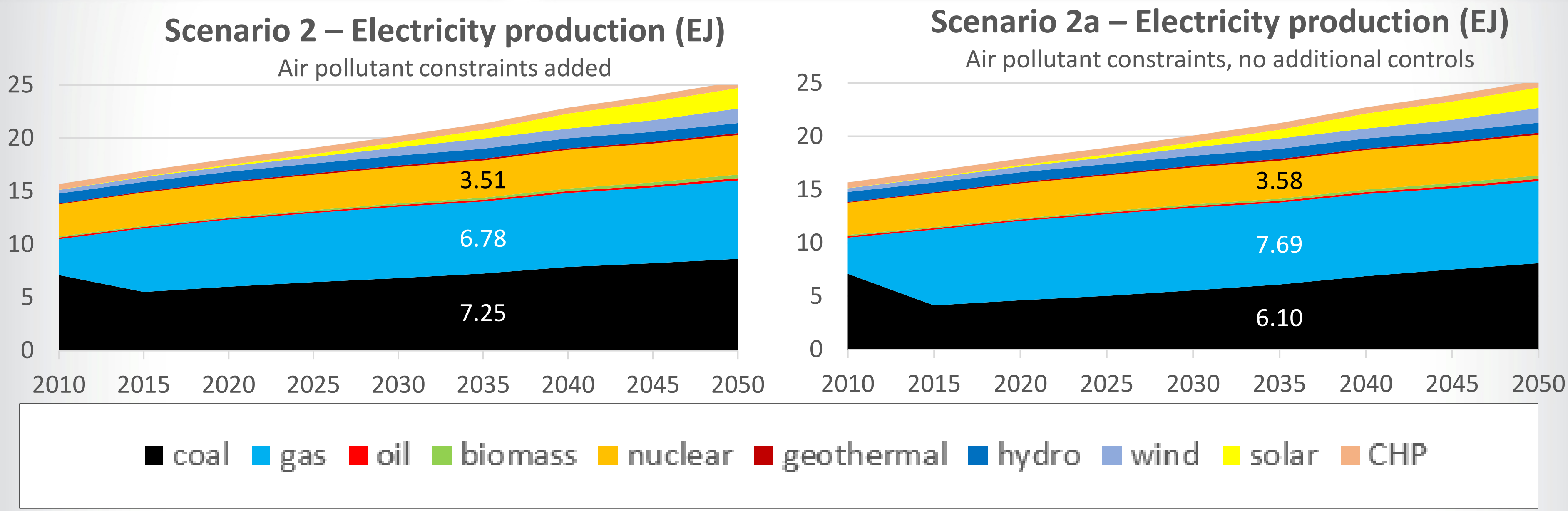
Electric sector emissions in 2035

Scenario	NOx (Tg)	SO2 (Tg)	CO2 (Gt)
1	1.40	2.61	2.72
2	1.23 (-12%)	1.50 (-42%)	2.58 (-5%)

Illustrative results

Illustrative application #1

GHG co-benefits of air pollutant controls



Summary

- An alternative approach for meeting the air pollutant limits, focusing on fuel switching, produced 2.6 times more CO_2 co-benefits in 2035.
- Additional NOx reductions occurred since SO_2 was the limiting pollutant.

Electric sector emissions in 2035

Scenario	NOx (Tg)	SO2 (Tg)	CO2 (Gt)
1	1.40	2.61	2.72
2	1.23 (-12%)	1.50 (-42%)	2.58 (-5%)
2a	1.09 (-22%)	1.50 (-42%)	2.36 (-13%)

Illustrative results

Illustrative application #2

Air pollutant co-benefits of GHG reduction

- **Model:**
  - GCAM-USA-AQ
- **Approach:**

  Compare the pollutant and GHG emissions, as well as other impacts for two scenarios:
  - **Reference case:**

    Includes representations of on-the-books air pollutant and climate regulations
  - **GHG mitigation case**

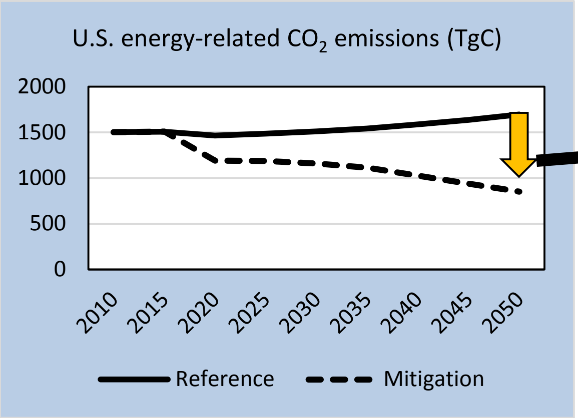
    Imposes a global CO_2 trajectory constraint constructed to limit global CO_2 concentrations to 450 ppm. GCAM-USA-AQ determines how to allocate the necessary reductions to countries and sectors.

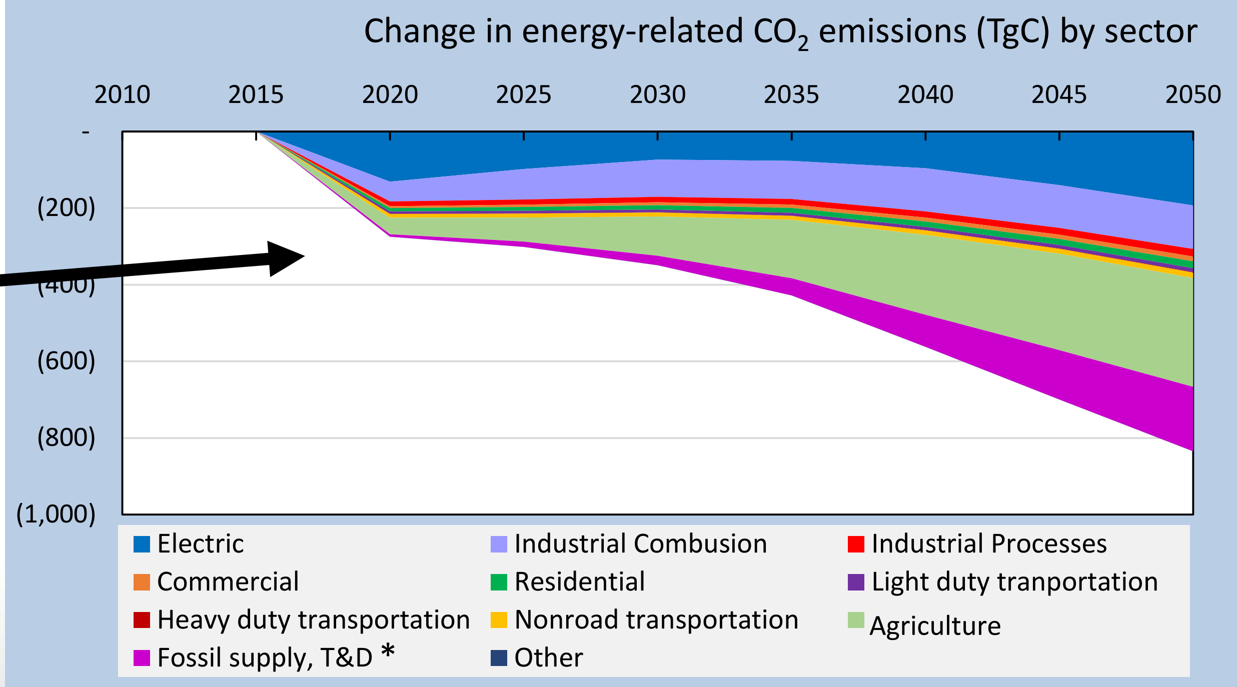
Illustrative application #2

Air pollutant co-benefits of GHG reduction

U.S. CO_2 reductions under the GHG mitigation scenario

- The U.S. has an emission reduction of approximately 45% from 2010 to 2050 in the GCAM-USA GHG mitigation scenario.
- Roughly one-third of these reductions come from the agriculture sector.
- Electricity production, industrial combustion, and fossil fuel supply, transportation, and distribution make up much of the remaining reductions.





Illustrative results

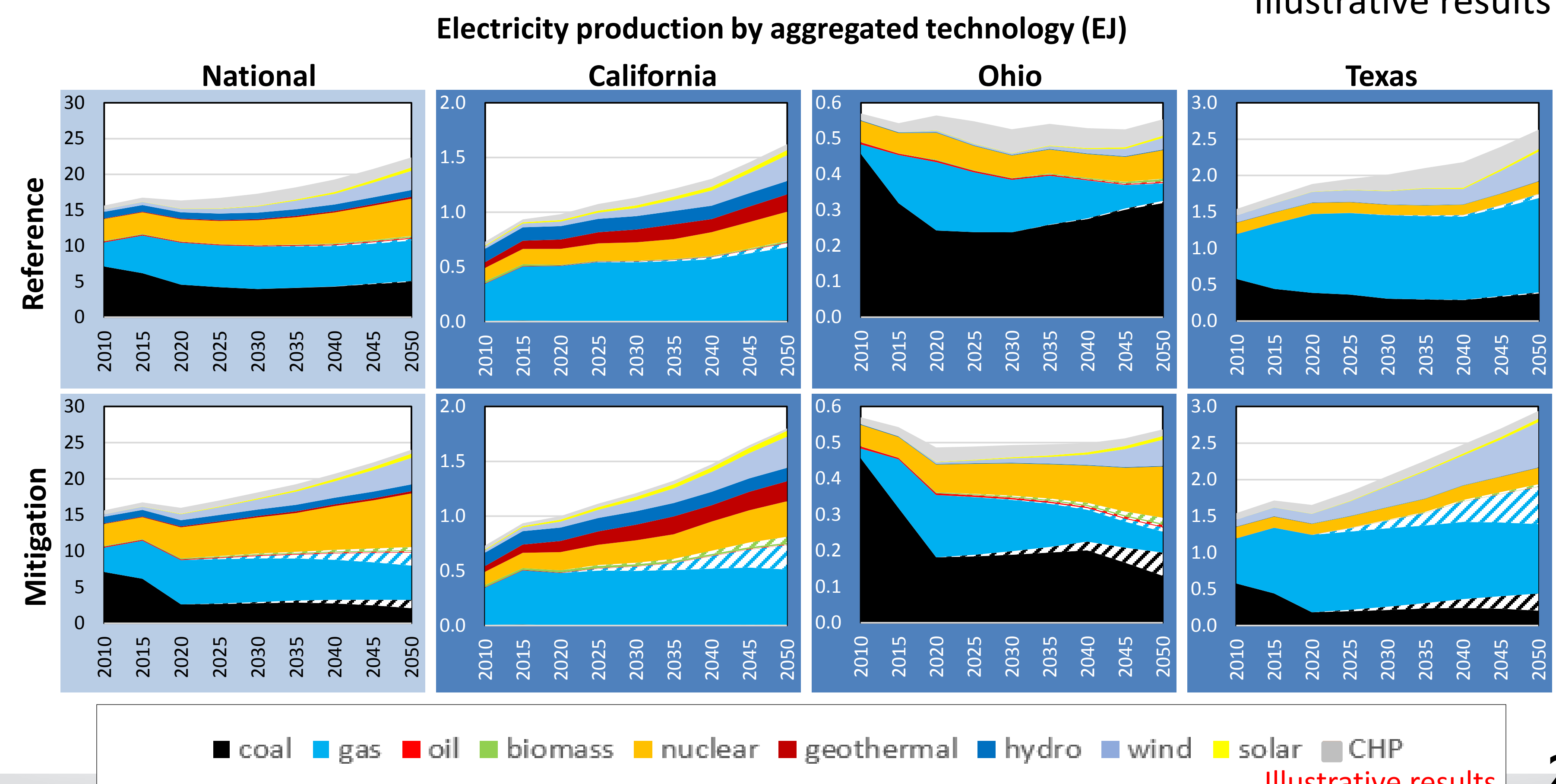
* T&D refers to transmission and distribution

Air pollutant co-benefits of GHG reduction

Underlying changes – Electric sector

- CCS (cross-hatched) is introduced and nuclear and wind capacity are expanded
- However, the electric sector response differs by state

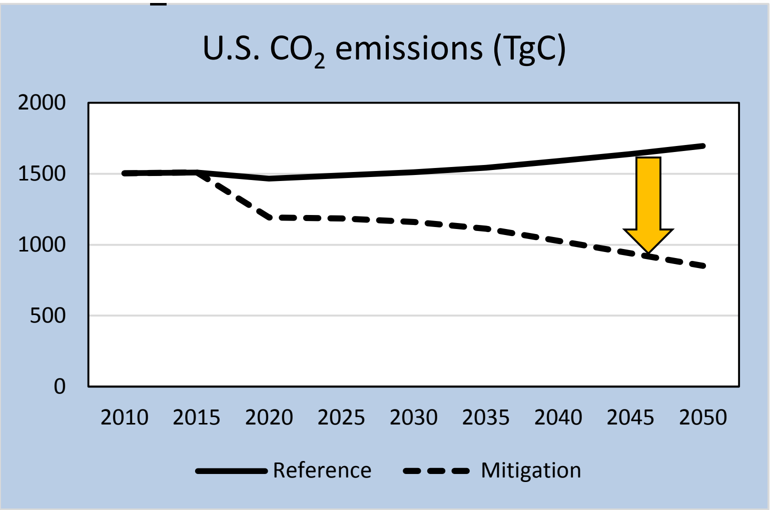
Illustrative results



Illustrative application #2
Air pollutant co-benefits of GHG reduction

Illustrative results

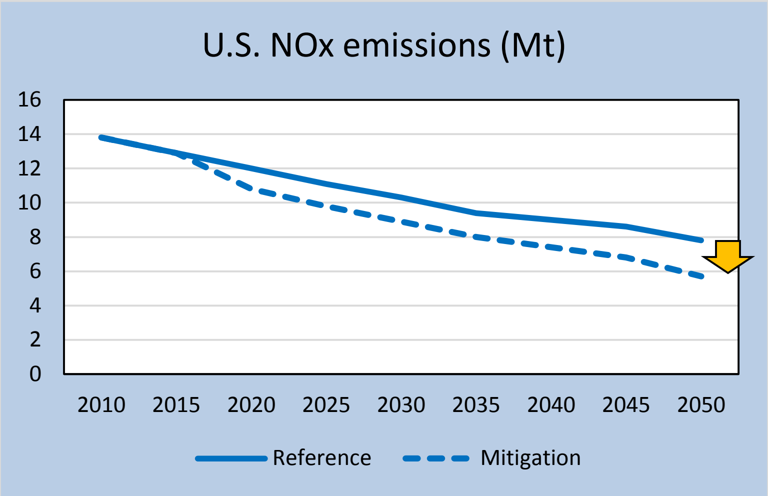
U.S. CO_2 response

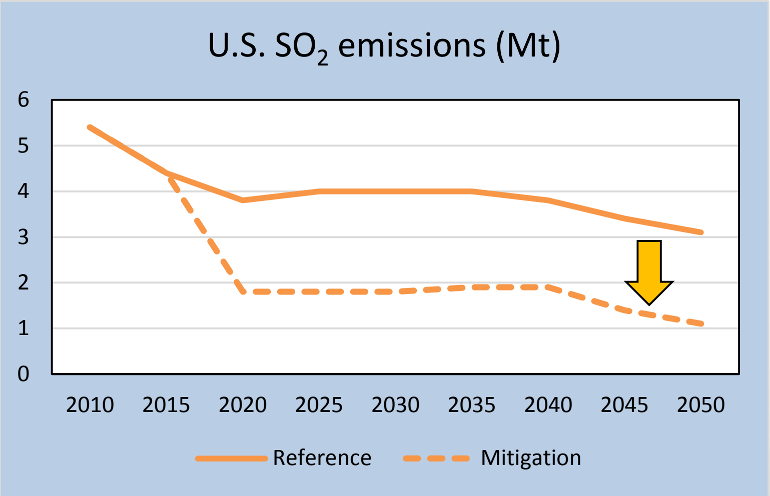


Pollutant emissions:

At the national level, NOx and SO_2 emissions are reduced as a result of the U.S. mitigation pathway.

U.S. air pollutant emissions





Air pollutant co-benefits of GHG reduction

Impacts can be approximated using impact factors

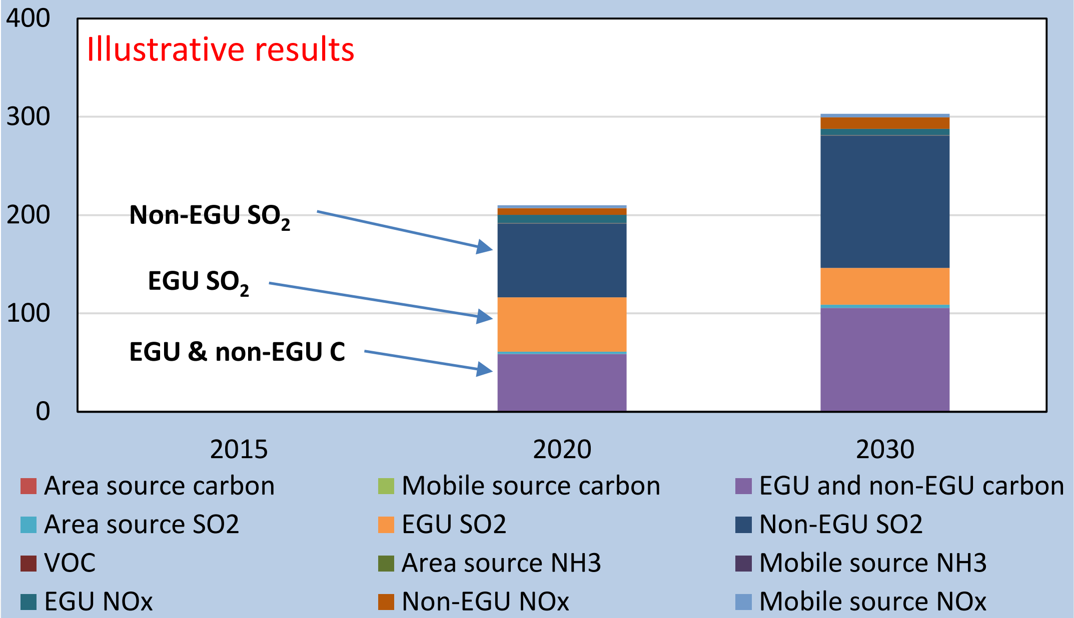
*Impact(region, time) = Emissions(region, time) [Mt] * ImpactFactor(region,time) [$/Mt]*

Applying PM-mortality impact factors from Fann et al., https://www.epa.gov/benmap/response-surface-model-rsm-based-benefit-ton-estimates:

Changes in PM and PM precursor emissions (t)

Category	2020	2030
Area source carbon	0	0
Mobile source carbon	0	0
Stationary source carbon	-103	-160
Area source SO_2	-44	-52
Electric sector SO_2	-551	-312
Non-electric sector SO_2	-1,020	-1,550
VOCs	0	0
Area source NH_3	-8	-8
Mobile source NH_3	-1	-3
Electric sector NOx	-432	-280
Non-electric sector NOx	-569	-828
Mobile source NOx	-211	-243

Approximation of annual U.S. PM-related health benefits ($mil) from the GHG mitigation scenario

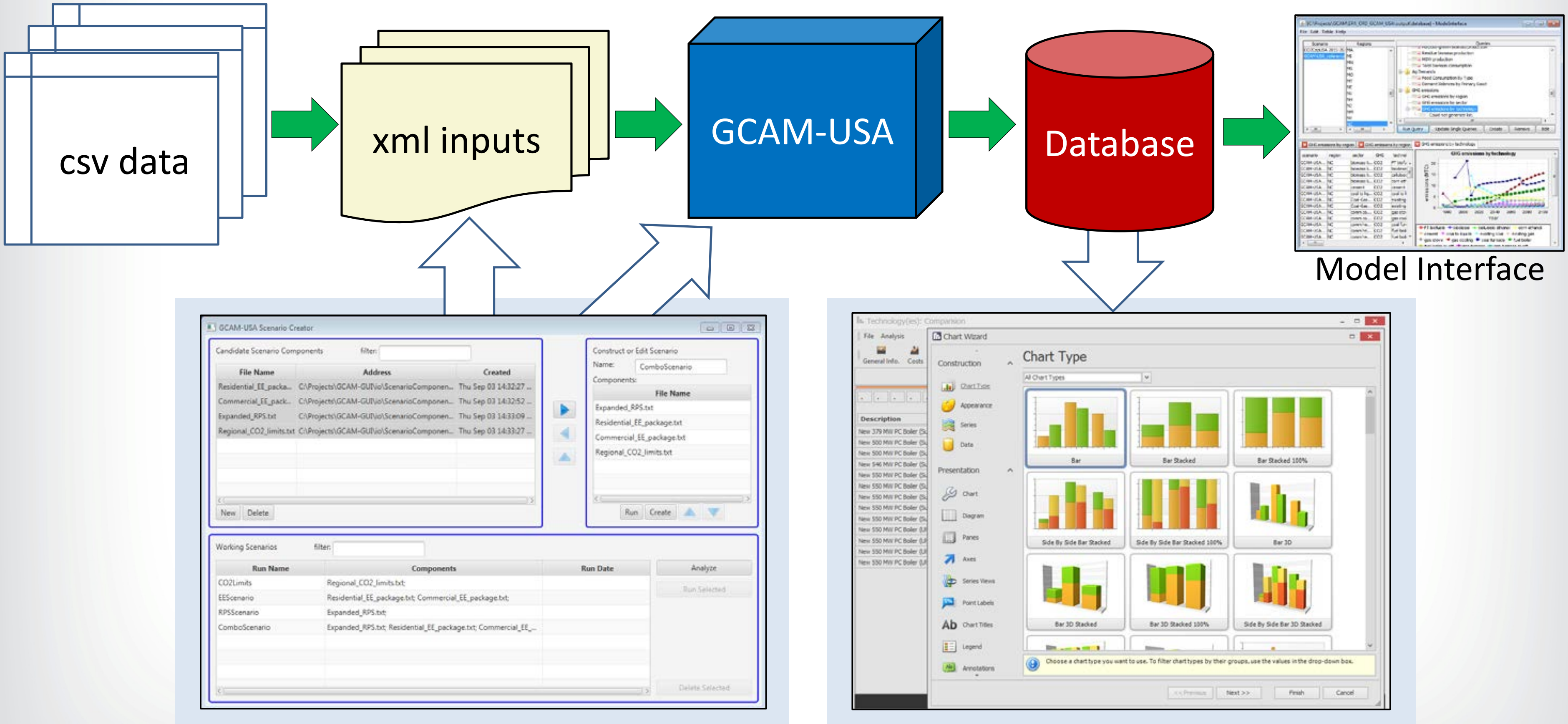


(EGU refers to the electric sector)

5. Ongoing work and next steps

Adding a Graphical User Interface

We are developing a Scenario Builder and Results Analyzer to facilitate use of GCAM for scenario analyses



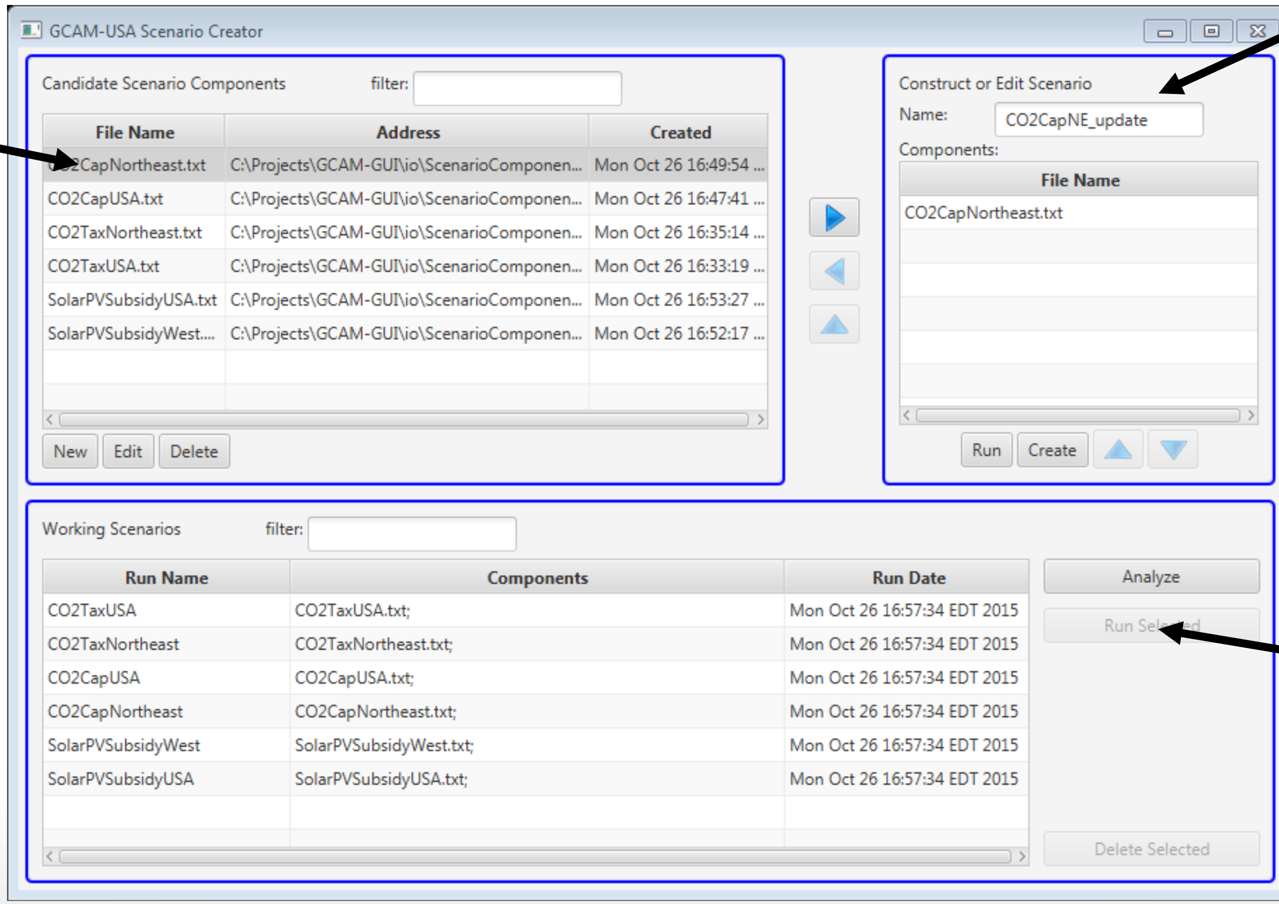
Scenario Builder: Develop, manage and execute scenarios, set model options

Results Analyzer: View, analyze and compare scenario results

Scenario Builder: Managing scenarios

Library of scenario components

Creating a new scenario from existing components

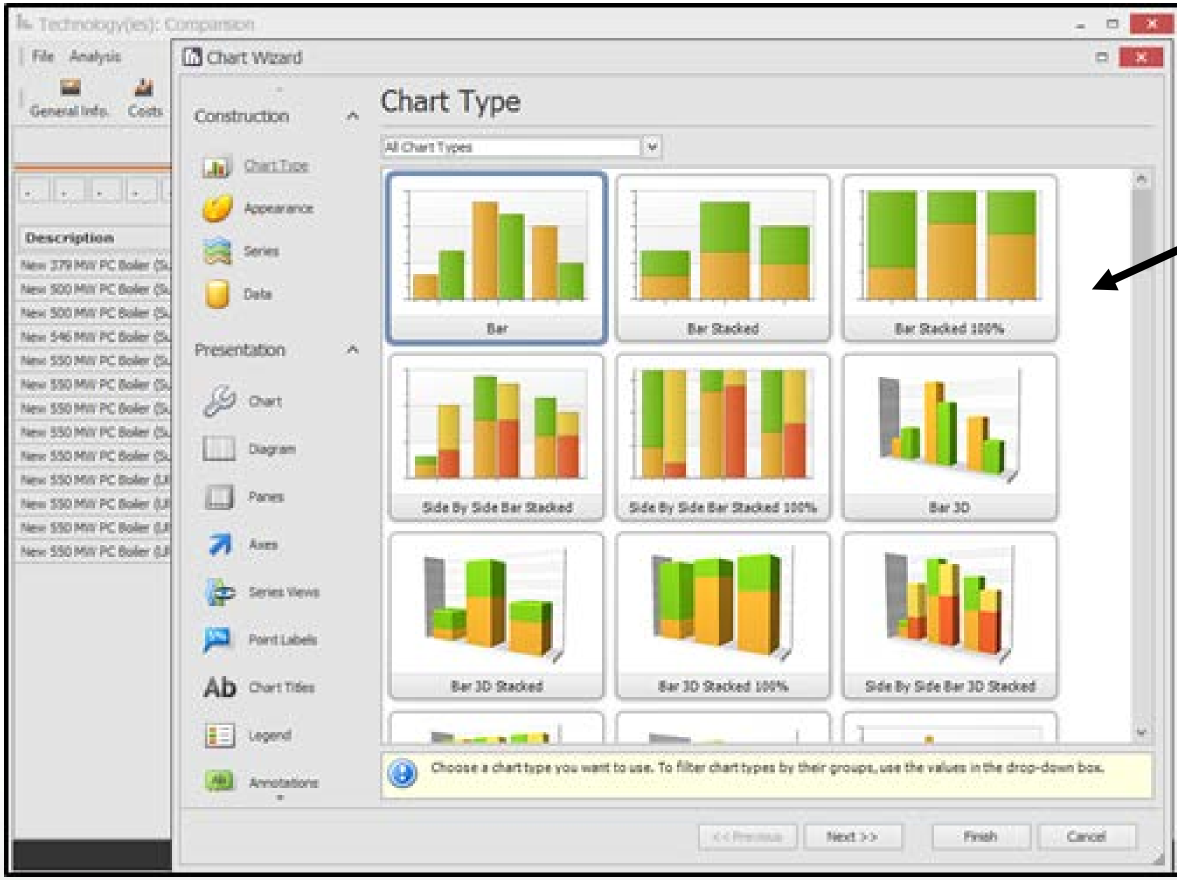


Management and execution of scenarios

Ongoing work and next steps

Results Analyzer

Results visualizer: Exploratory data analysis



Interactive nature facilitates exploratory data analysis

Ongoing work and next steps

Generating emissions growth factors

Post-processing code translates GCAM-USA emission projections to emission growth and control factors that can be used in SMOKE

California

FI	SCC	GF	Pollu
06000	10100000	1.85	NOX
06000	10200000	0.87	NOX
06000	10300000	1.48	NOX
06000	10500000	1.48	NOX
06000	20100000	1.85	NOX
06000	20200000	0.87	NOX
06000	20300000	1.48	NOX
06000	2101000000	1.85	NOX
06000	2102000000	0.87	NOX
06000	2103000000	1.48	NOX
06000	2104000000	1.32	NOX
06000	2201001000	0.14	NOX
06000	2201020000	0.14	NOX
06000	2201040000	0.14	NOX
06000	2201070000	0.65	NOX
06000	2230001000	0.14	NOX
06000	2230060000	0.14	NOX
06000	2230070000	0.65	NOX
06000	2230071000	0.65	NOX
06000	2230072000	0.65	NOX
06000	2230073000	0.65	NOX
06000	2230074000	0.65	NOX
06000	2230075000	0.65	NOX
06000	2275000000	1.33	NOX
06000	2280000000	1.43	NOX
06000	2282000000	1.43	NOX
06000	2283000000	1.43	NOX

Ohio

FI	SCC	GF	Pollu
39000	10100000	0.85	NOX
39000	10200000	1.10	NOX
39000	10300000	0.83	NOX
39000	10500000	0.83	NOX
39000	20100000	0.85	NOX
39000	20200000	1.10	NOX
39000	20300000	0.83	NOX
39000	2101000000	0.85	NOX
39000	2102000000	1.10	NOX
39000	2103000000	0.83	NOX
39000	2104000000	0.91	NOX
39000	2201001000	0.11	NOX
39000	2201020000	0.11	NOX
39000	2201040000	0.11	NOX
39000	2201070000	0.62	NOX
39000	2230001000	0.11	NOX
39000	2230060000	0.11	NOX
39000	2230070000	0.62	NOX
39000	2230071000	0.62	NOX
39000	2230072000	0.62	NOX
39000	2230073000	0.62	NOX
39000	2230074000	0.62	NOX
39000	2230075000	0.62	NOX
39000	2275000000	1.04	NOX
39000	2280000000	1.21	NOX
39000	2282000000	1.21	NOX
39000	2283000000	1.21	NOX

Texas

FI	SCC	GF	Pollu
48000	10100000	0.91	NOX
48000	10200000	0.98	NOX
48000	10300000	1.46	NOX
48000	10500000	1.46	NOX
48000	20100000	0.91	NOX
48000	20200000	0.98	NOX
48000	20300000	1.46	NOX
48000	2101000000	0.91	NOX
48000	2102000000	0.98	NOX
48000	2103000000	1.46	NOX
48000	2104000000	1.36	NOX
48000	2201001000	0.14	NOX
48000	2201020000	0.14	NOX
48000	2201040000	0.14	NOX
48000	2201070000	0.70	NOX
48000	2230001000	0.14	NOX
48000	2230060000	0.14	NOX
48000	2230070000	0.70	NOX
48000	2230071000	0.70	NOX
48000	2230072000	0.70	NOX
48000	2230073000	0.70	NOX
48000	2230074000	0.70	NOX
48000	2230075000	0.70	NOX
48000	2271000000	1.54	NOX
48000	2282000000	1.58	NOX
48000	2283000000	1.58	NOX
48000	2284000000	1.58	NOX

Illustrative results

Tier 1; Tier 2
External Combustion Boilers; Electric Generation
External Combustion Boilers; Industrial
External Combustion Boilers; Commercial/Institutio
External Combustion; Space Heaters
Internal Combustion Engines; Electric Generation
Internal Combustion Engines; Industrial
Internal Combustion Engines; Commercial/Institutic
Stational Source Fuel Combustion; Electric Utility
Stationary Source Fuel Combustion; Industrial
Stational Source Fuel Combustion; Commercial/Insti
Stationary Source Fuel Combustion; Residential
Mobile - On-Road Gasoline Light Duty Vehicles
Mobile - On-Road Gasoline Light Duty Trucks 1&2
Mobile - On-Road Gasoline Light Duty Trucks 3&4
Mobile - On-Road Gasoline Heavy Duty 2b-8b&Buses
Mobile - On-Road Diesel Light Duty Vehicles
Mobile - On-Road Diesel Light Duty Trucks 1-4
Mobile - On-Road Diesel Heavy Duty
Mobile - On-Road Diesel Heavy Duty
Mobile - On-Road Diesel Heavy Duty
Mobile - On-Road Diesel Heavy Duty
Mobile - On-Road Diesel Heavy Duty
Mobile - On-Road Diesel Heavy Duty Buses
Mobile - Aircraft
Mobile - Commercial Marine Vessels
Mobile - Marine Pleasure Craft
Mobile - Marine Military Vessels

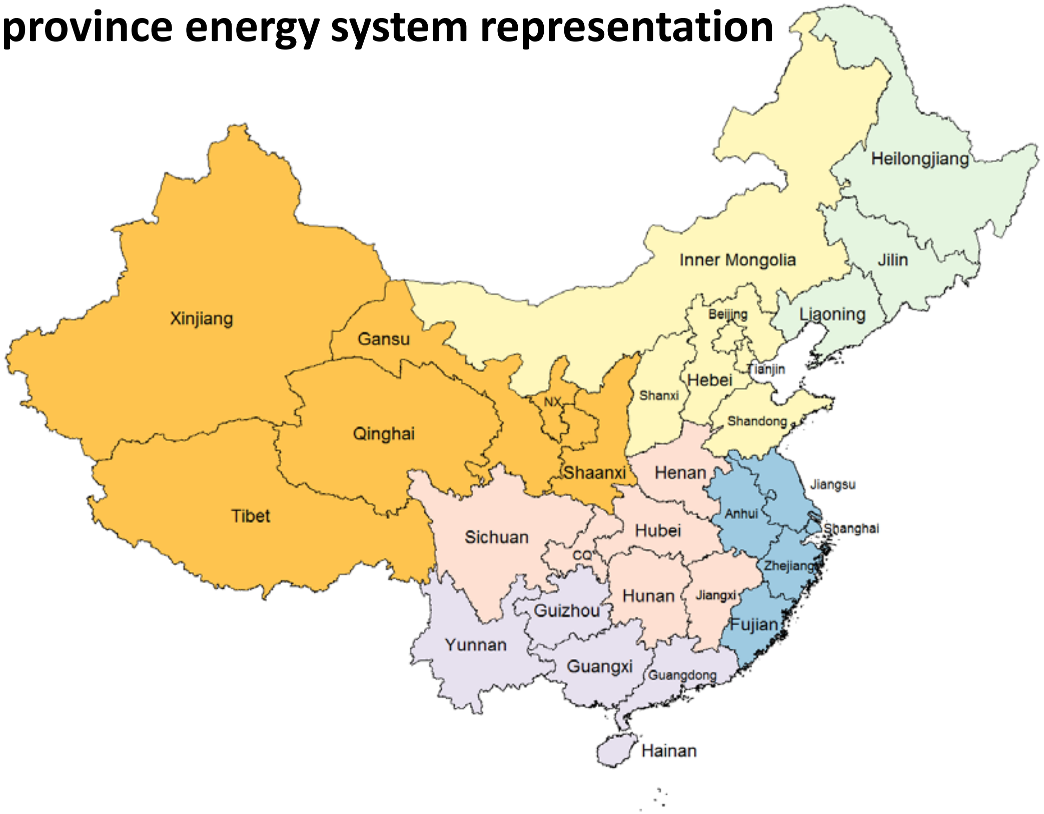
Ongoing work and next steps
GCAM-China development

GCAM-China – a new tool for policy analysis in China

GCAM-China is being developed in collaboration between researchers at Tsinghua University and PNNL (at the Joint Global Change Research Institute)

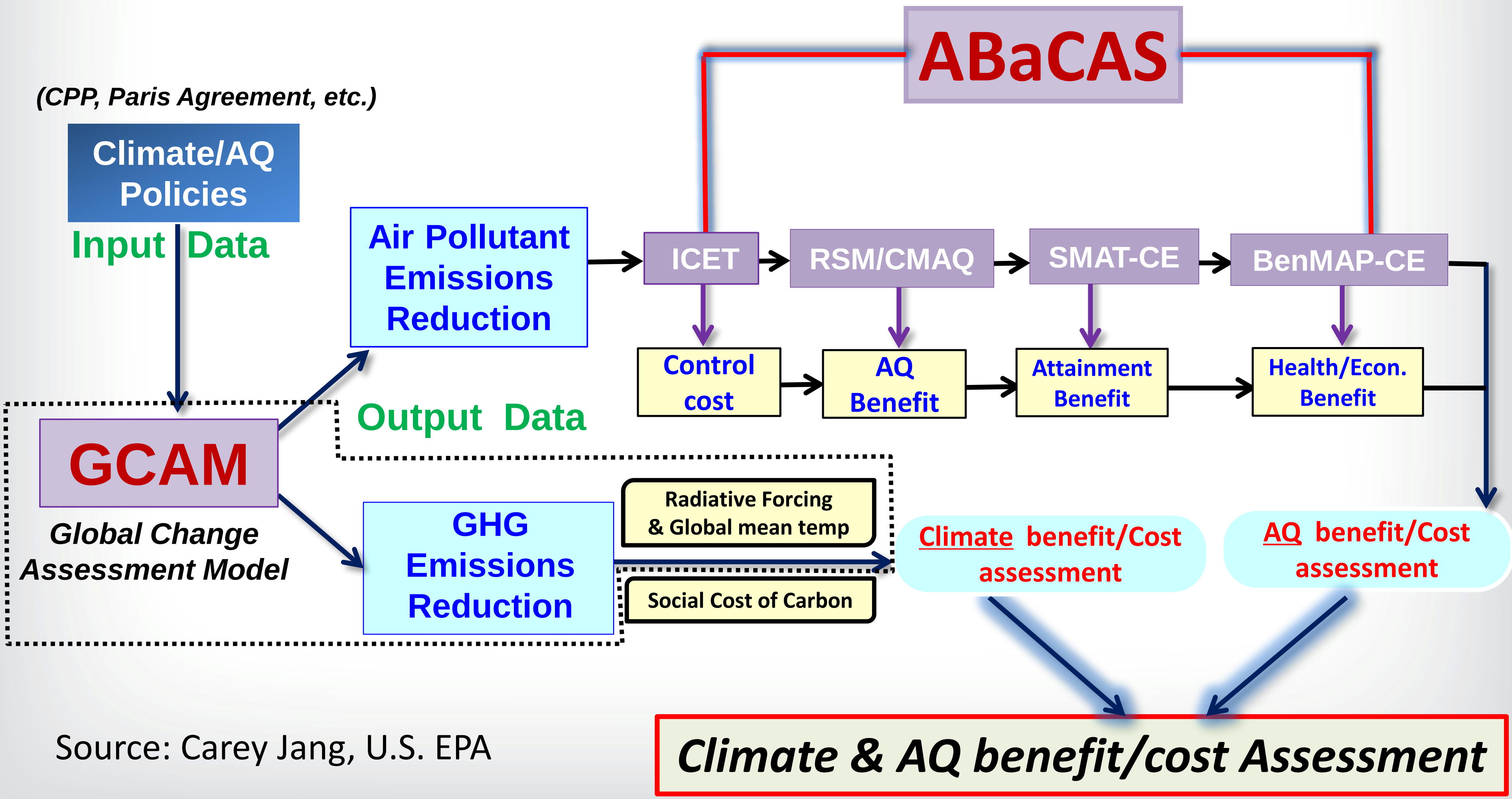
Potential applications of GCAM-China include analysis of national emission reduction targets, projection of air pollution emissions, and assessment of sectoral policies.

31-province energy system representation



Ongoing work and next steps
GCAM-ABaCAS conceptual framework

Emission changes could also be used to develop alternative baseline and policy scenarios for ABaCAS.



Source: Carey Jang, U.S. EPA

Conclusions and additional thoughts

- GCAM-USA and GLIMPSE are allowing researchers to:
  - Generate air pollutant emission projections for alternative scenarios
  - Consider controls, energy efficiency and renewable energy in management strategies
  - Track impacts on additional endpoints, such as GHGs, water use, fuel use, and other system impacts
- GCAM could be used in a similar fashion for national-level analyses in China
- GCAM-China has the potential to support provincial-level analyses
- GLIMPSE could be integrated with ABaCAS, providing the ability to explore a wide range of scenarios.

Questions?

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