Projecting U.S. climate forcing and criteria pollutant emissions through 2050

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Research Triangle Park, NC, Nov. 8th & 9th, 2012

Results are provided for illustrative purposes only.

Primary contributors to this work

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- The GLIMPSE team:
  - Rob Pinder, Farhan Akhtar, Daven Henze, Brooke Hemming, Dan Loughlin
- The ICLUS team:
  - Britta Bierwagen and Phil Morefield
- Bill Benjey and Chris Nolte of the NERL CIRAQ team
- Limei Ran and Dongmei Yang of UNC-Chapel Hill

A list of acronyms is provided at the end of the presentation.

Objectives of this research

Develop emission projections for U.S. criteria pollutants, greenhouse gases and short-lived climate forcers multiple decades into the future.

Examine how these projections change for different assumptions about emission drivers.

This presentation

Purpose: Convey the status and future directions of ORD's methodology for projecting long-term pollutant and climate forcing emissions

Outline:

Part 1. Scenario modeling framework

Part 2. Energy system modeling with MARKAL

Part 3. Developing emission growth factors from MARKAL outputs

Part 4. Projecting a future-year inventory in SMOKE

Part 5. Decision support tools

Part 1. Scenario modeling framework

An emission scenario is comprised of assumptions regarding critical emission drivers:

- Population growth & migration
- Economic growth & transformation
- Resource availabity & depletion
- Land use change
- Technology innovation
- Climate change
- Energy & environmental Policies

Challenge:

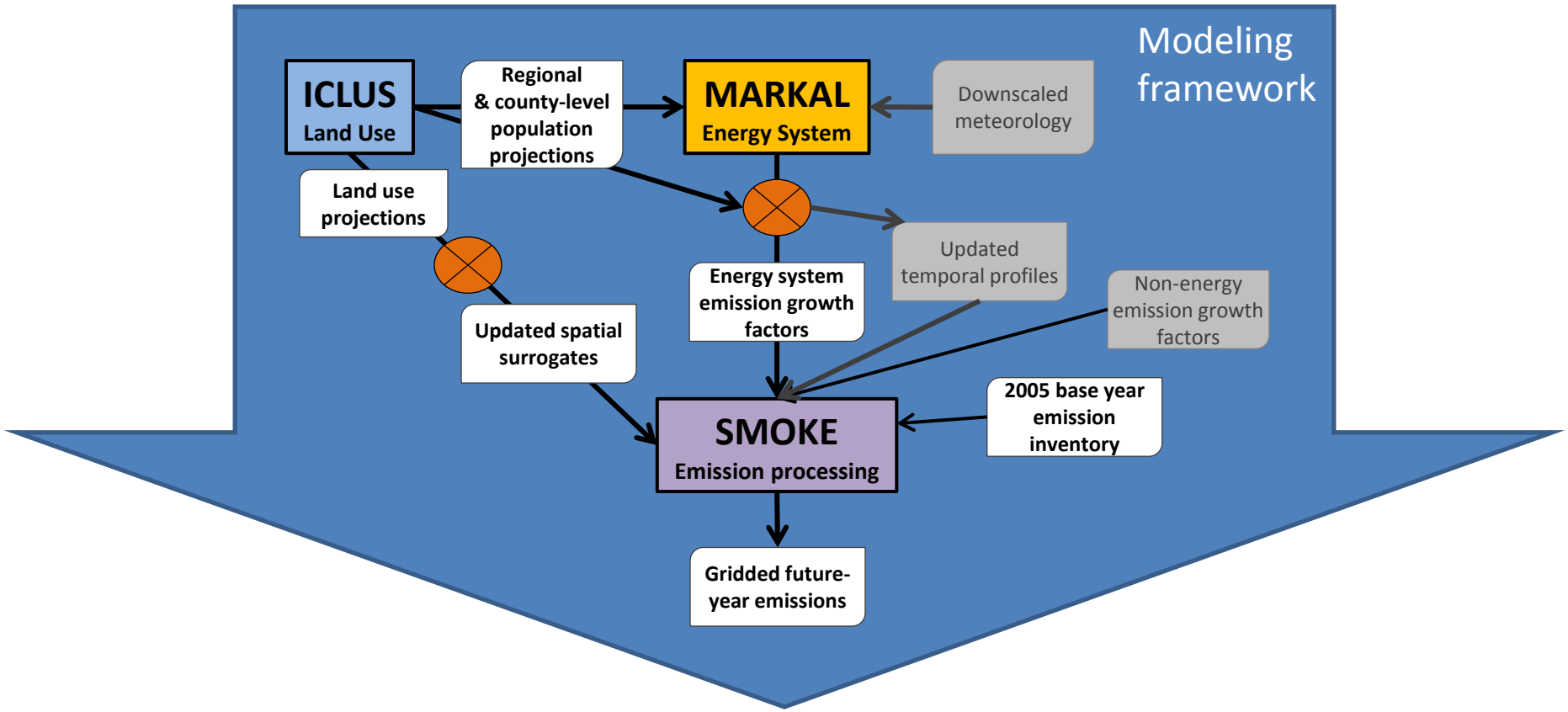
Translate scenarios (plausible combinations of assumptions) into future-year, model-ready emission inventories

Air quality modeling

Part 1. Scenario modeling framework

An emission scenario is comprised of assumptions regarding critical emission drivers:

Population growth & migration	Economic growth & transformation	Resource availabity & depletion	Land use change	Technology innovation	Climate change	Energy & environmental Policies



Air quality modeling

Part 1. Scenario modeling framework

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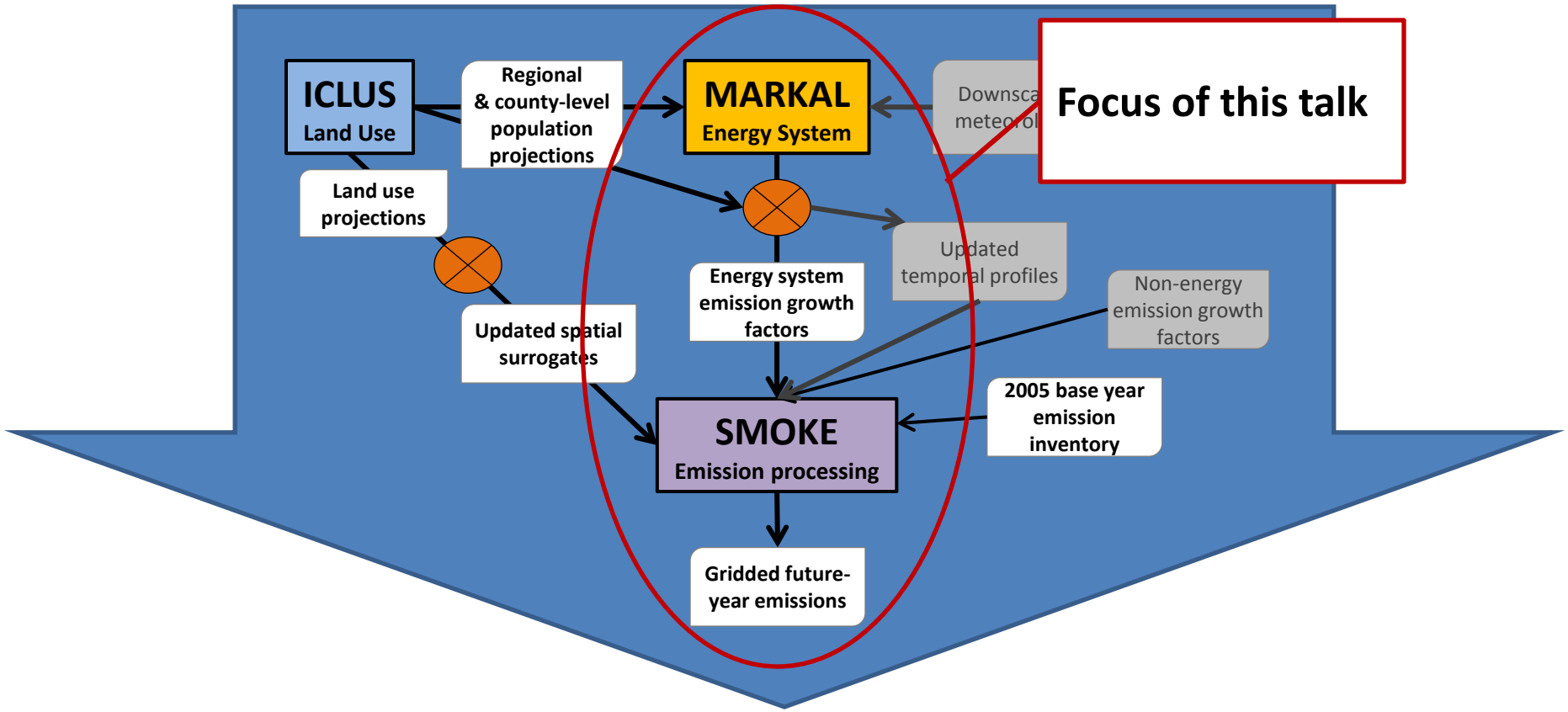
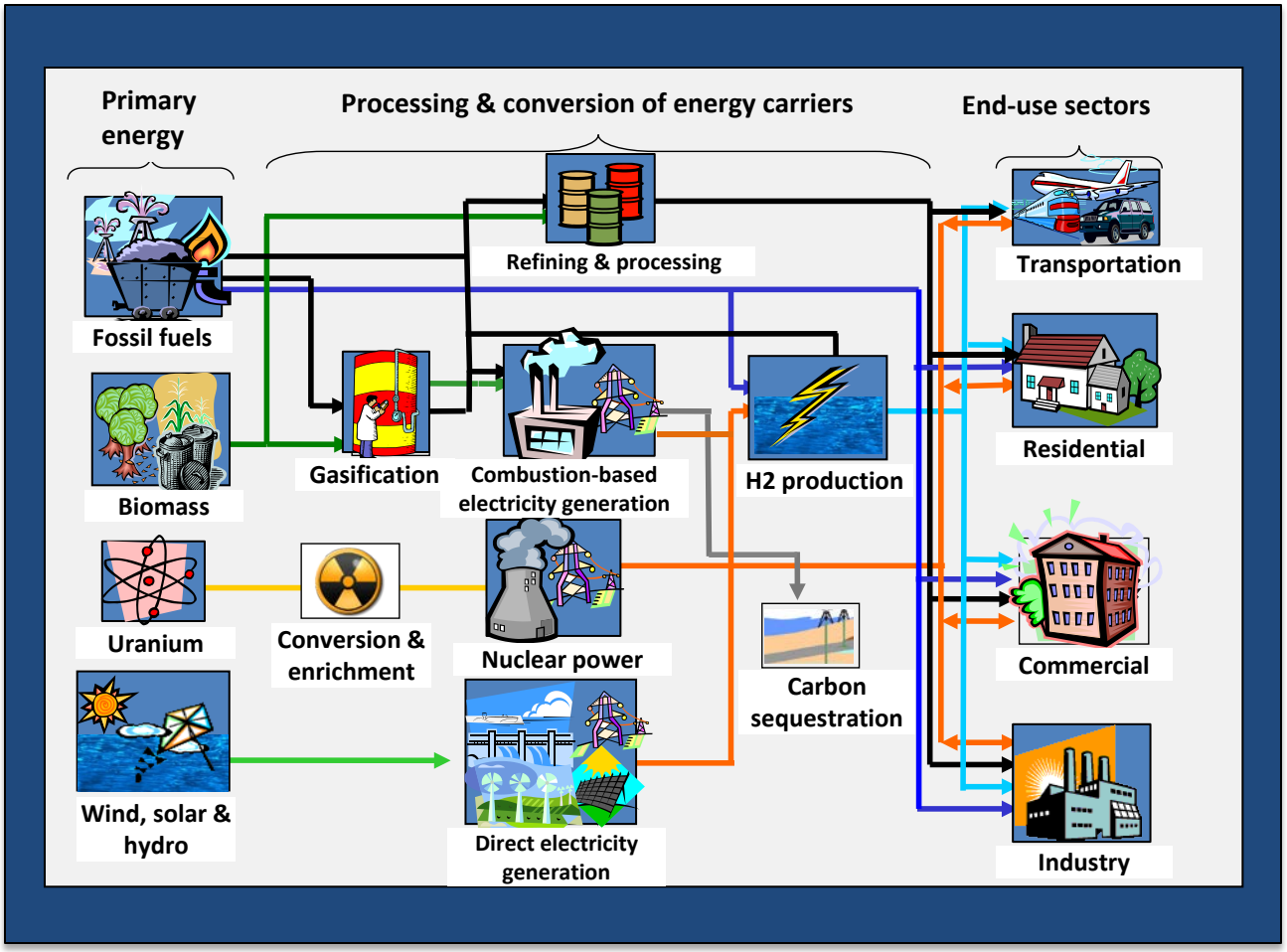


Air quality modeling

Part 2. Energy system modeling with MARKAL

The energy system and the environment

The energy system consists of the fuels and technologies that extend from resource extraction through meeting end-use energy demands (e.g., lighting and space heating)



Impacts

Contribution to U.S. anthropogenic emissions:

CO_2 ~ 94%
NOx ~ 95%
SO_2 ~ 89%
CO ~ 95%
Hg ~ 87%

Environmental concerns:

GHGs & SLCFs
Ozone
PM2.5
Acid deposition
Toxics, mercury
Water use & pollution (39%+ of US water withdrawals)

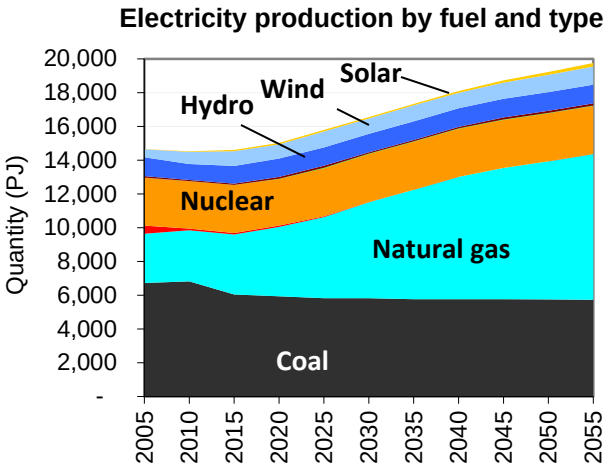
Part 2. Energy system modeling with MARKAL

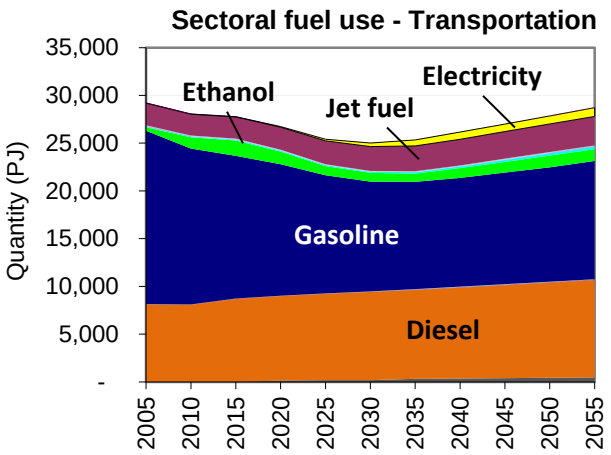
ORD has developed a U.S. EPA MARKAL database

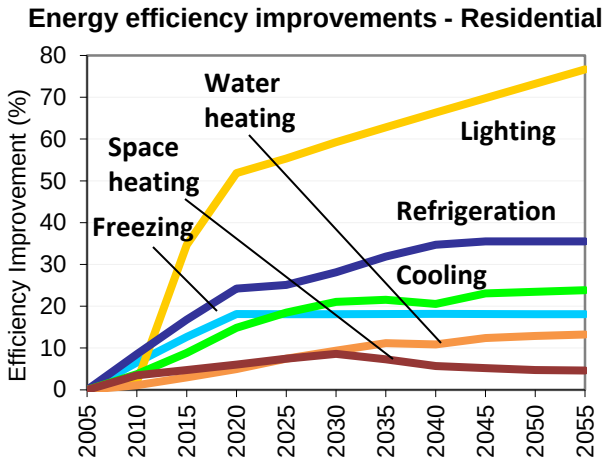
- Time horizon:
  - 2005 through 2055 in 5-year timesteps
- Spatial resolution:
  - 9 U.S. Census Divisions
- Coverage:
  - Resource supply, electricity production, and the industrial, residential, commercial and transportation sectors
- Pollutant coverage:
  - Criteria pollutants: NOx, SO_2, PM_{10}, $PM_{2.5}$, CO, and VOC
  - Greenhouse gases (GHGs): CO_2, CH_4, and N_2O
  - Additional short-lived climate forcers (SLCFs): BC and OC
- Policy coverage in baseline:
  - EGUs: CAIR, MATS, and state and regional RPSs
  - Transportation: Tier 2, Heavy duty fuel & engine rules, CAFE (54.5 mpg by 2025)

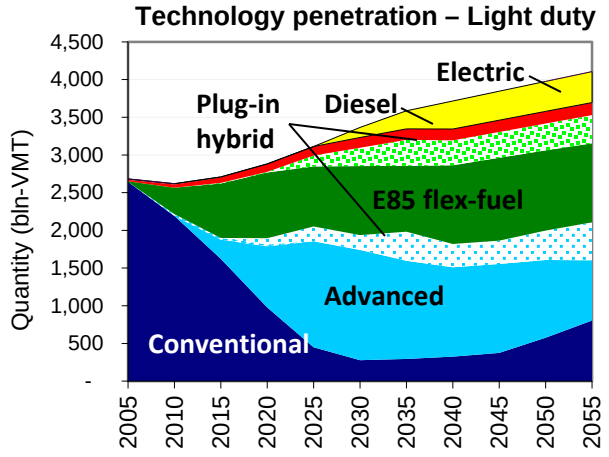
Part 2. Energy system modeling with MARKAL

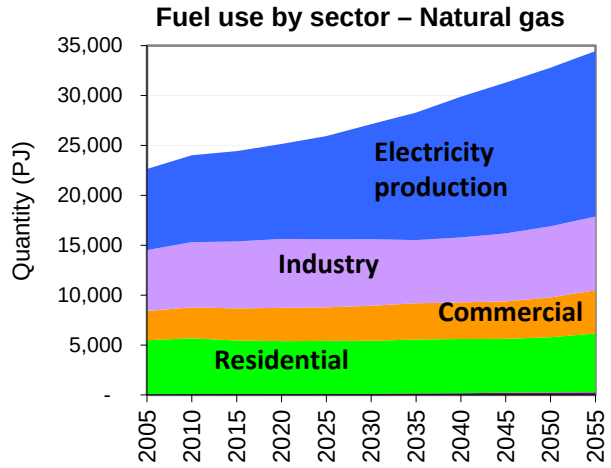
Example model outputs – National and regional

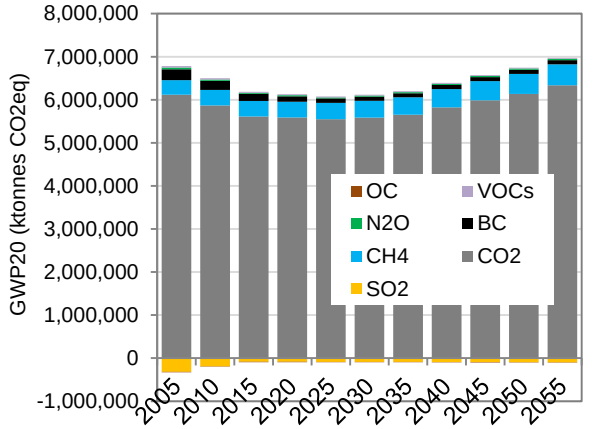








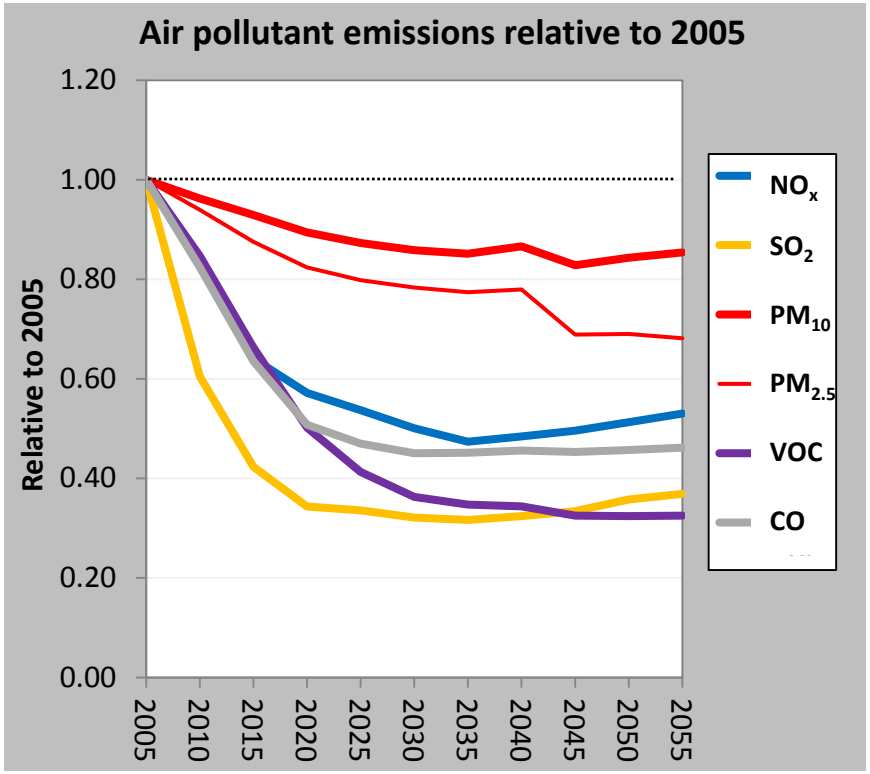


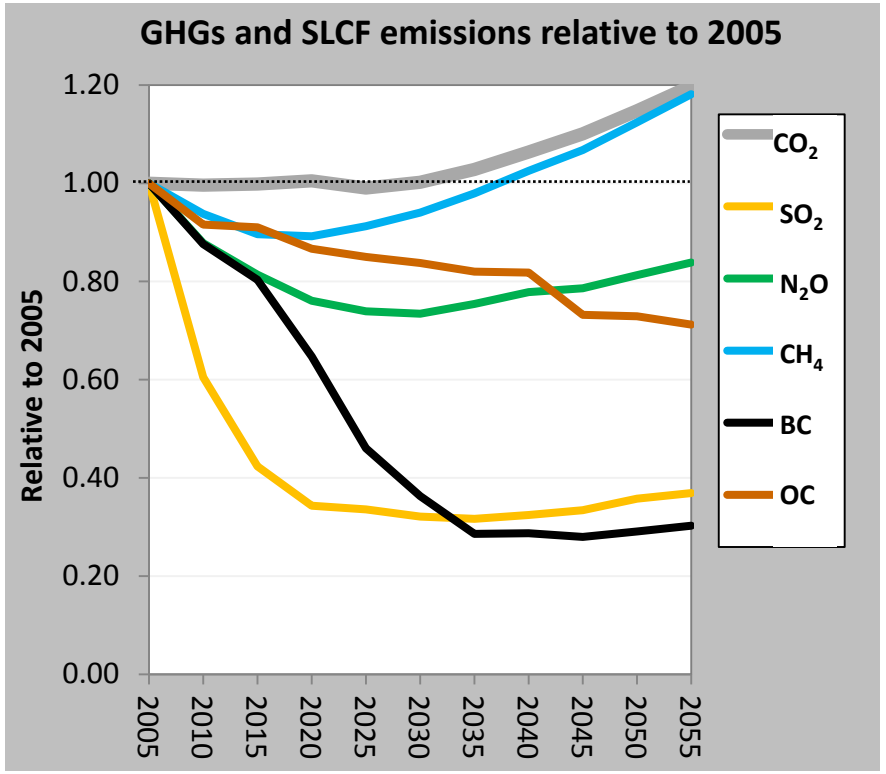


Illustrative results

Part 2. Energy system modeling with MARKAL

Example model outputs – National and regional

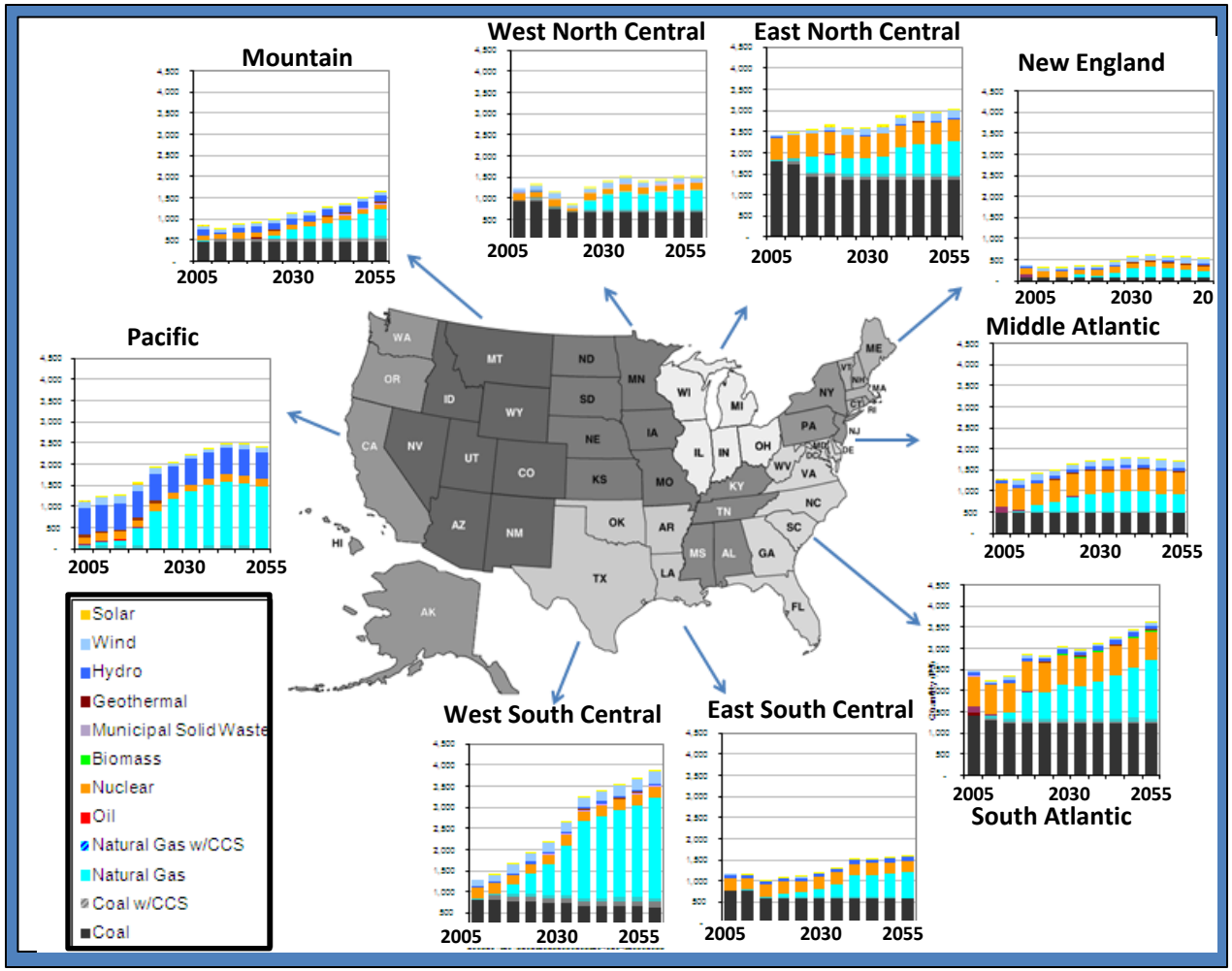




Illustrative results

Part 2. Energy system modeling with MARKAL

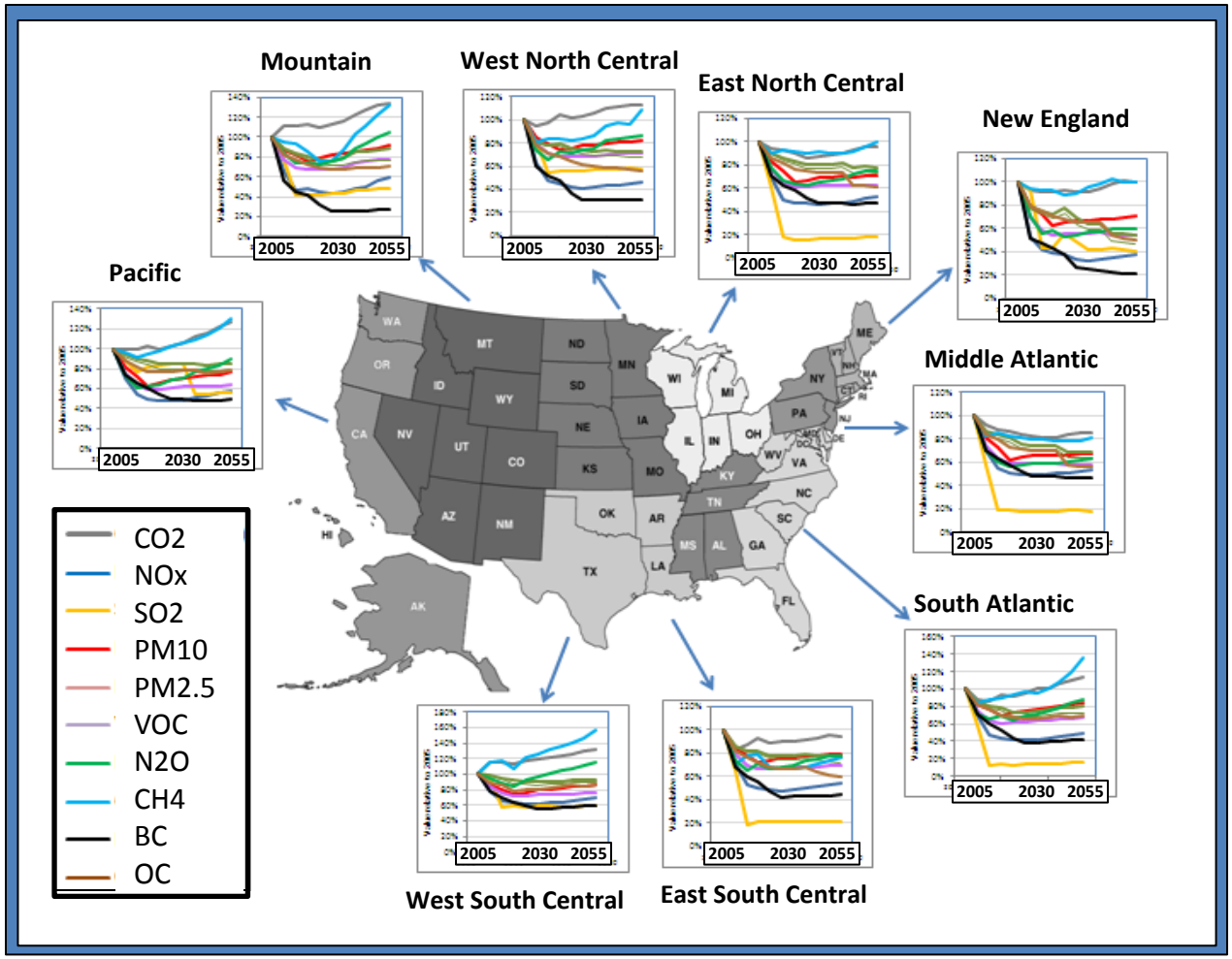
Example of regional differences: Electricity production



Illustrative results

Part 2. Energy system modeling with MARKAL

Regional emissions relative to 2005



Emission trends can vary greatly by region as a function of existing infrastructure, fossil and renewable resources and state- and regional policies.

Illustrative results

Part 3. Developing emission growth factors

Methodology originally described in:

Loughlin, D.H., Benjey, W. G., and C.G. Nolte (2011). "ESP v1.0: methodology for exploring emission impacts of future scenarios in the United States." *Geoscientific Model Development*, 4, 287-297, doi:10.5194/gmd-4-287-2011.

Updates since GMD paper:

- MARKAL
  - Upgrades to the characterization of:
    - existing coal plants, electric vehicles, heavy duty trucks and other nonroad transportation, and biofuels
  - Calibration to AEO 2012
  - New CAFE (54.5 mpg by 2025), reverted from CSAPR to CAIR, updated natural gas resources to account for unconventional sources
  - Pollutant coverage has been expanded to include CO, VOCs, CH_4, N_2O, BC, and OC
  - Pollutant emission factors were reviewed and revised
- Spatial refinements - Carried out by Limei Ran and Dongmei Yang of UNC-CH
  - ICLUS population projections are used to adjust regional growth factors to the county level for many area source categories
  - ICLUS results used to update spatial surrogates

Part 3. Developing emission growth factors

Methodology:

- Emissions are aggregated into the following categories by region and species:
  - Electricity production
  - Industrial combusion
  - Residential combustion
  - Commercial combustion
  - Light duty vehicles
  - Heavy duty trucks and buses
  - Aircraft
  - Marine vehicles
  - Railroads
  - Non-road vehicles

Part 3. Developing emission growth factors

Methodology, cont'd.:

- Future-year emissions for each category are divided by 2005 emissions to generate emission growth factors.
- Regional growth factors for sources with emissions correlated to population are adjusted for each county as a function of population growth.
- Growth factors are matched to source classification codes (SCCs) via a crosswalk.
- County-, SCC-, pollutant-specific emission growth factors are written to a control file for use with SMOKE.

Part 3. Developing emission growth factors

National and regional-scale factors: 2005 – 2050

R5 = South Atlantic, R8 = Mountain

	NOx			SO2			PM10		
Sector	**National**	**R5**	**R8**	**National**	**R5**	**R8**	**National**	**R5**	**R8**
Electricity production	0.56	0.38	0.74	0.19	0.09	0.68	0.88	0.84	1.27
Industrial	1.69	1.83	1.72	0.93	0.84	0.87	1.05	1.52	1.17
Commercial	1.25	1.66	1.69	0.79	1.30	0.92	1.19	1.68	1.59
Residential	0.89	1.14	1.20	0.39	0.56	0.82	0.91	1.00	1.03
Light duty vehicles	0.12	0.12	0.06	0.21	0.18	0.08	0.41	0.61	0.27
Heavy duty vehicles	0.21	0.20	0.22	0.06	0.06	0.06	0.19	0.19	0.19
Aircraft	1.29	1.29	1.29	0.97	0.97	0.97	0.67	0.67	0.67
Marine Vessels	0.81	0.81	N/A	0.05	0.05	N/A	0.86	0.86	N/A
Nonroad engines	0.35	0.35	0.35	0.05	0.05	0.05	0.33	0.33	0.33
Railroads	0.48	0.47	0.43	0.02	0.02	0.02	0.21	0.21	0.19

Observation: Factors can differ greatly by pollutant, source category and region

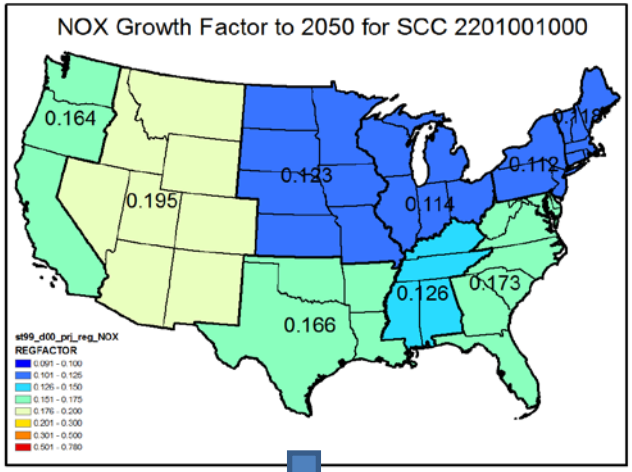
Illustrative results

Part 3. Developing emission growth factors

New feature: county-level growth factors

Illustrative results

Regional emission growth factors



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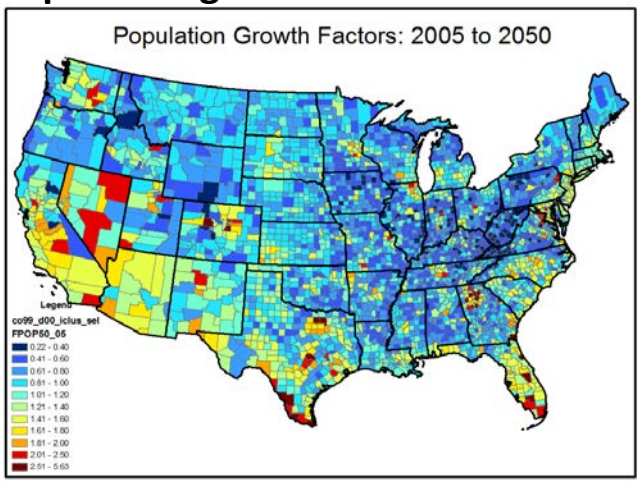
Population growth factors from ICLUS



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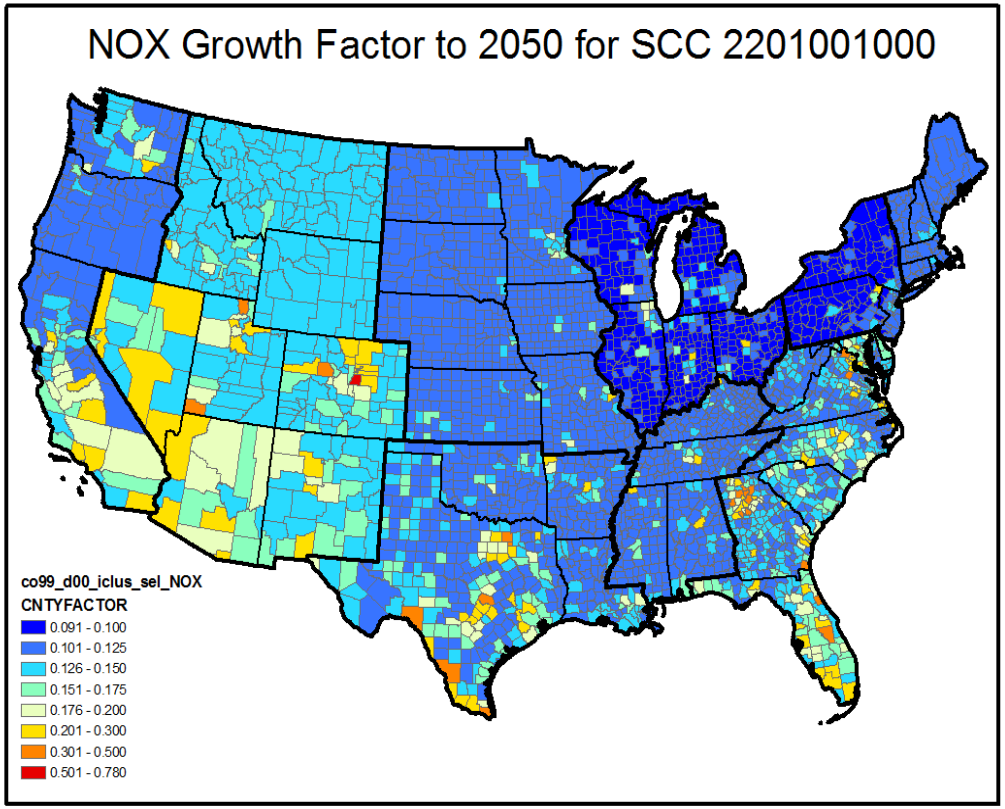
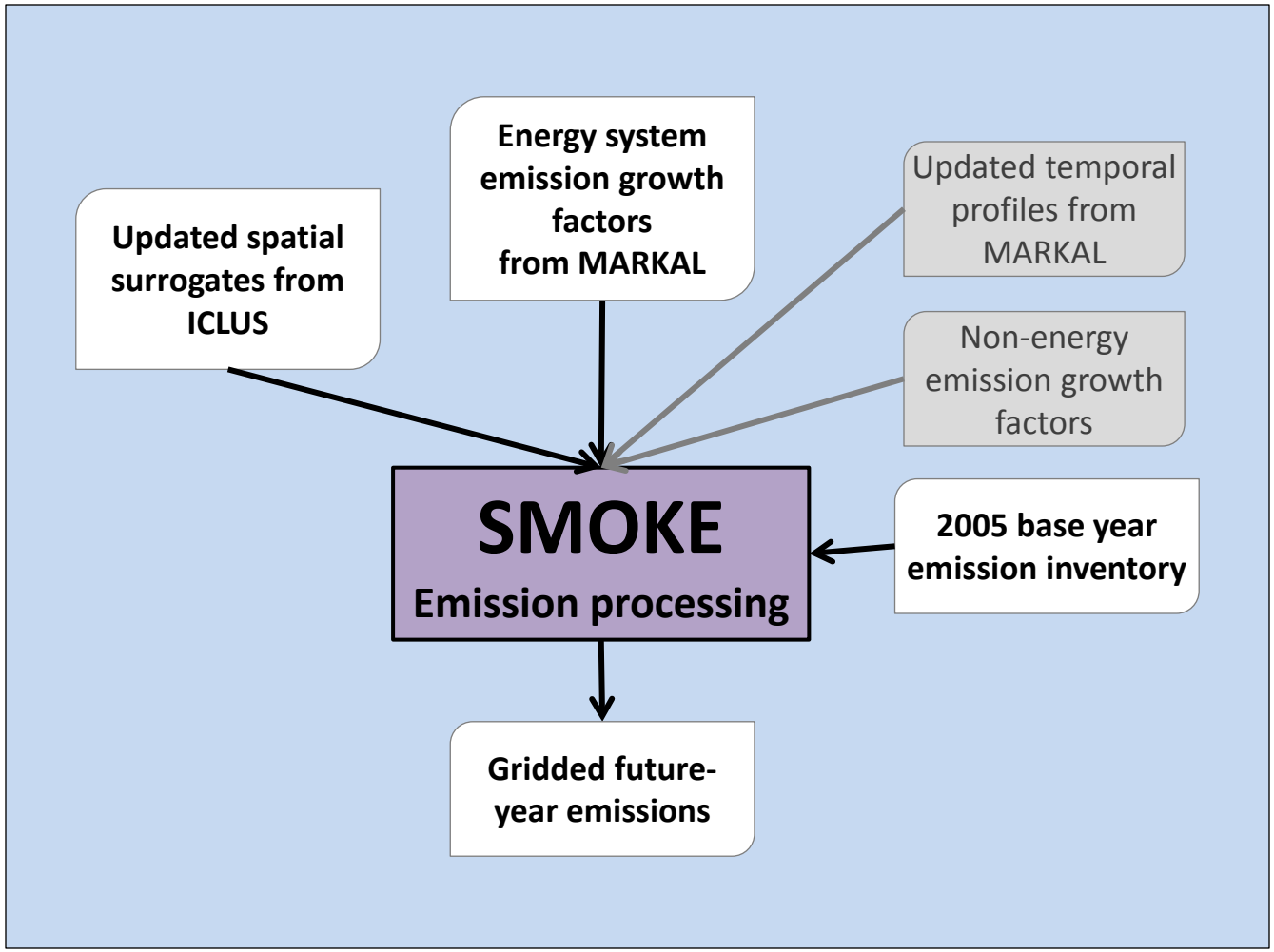
Adjusted county-level growth factor



220100100 is the SCC for light duty gasoline vehicles

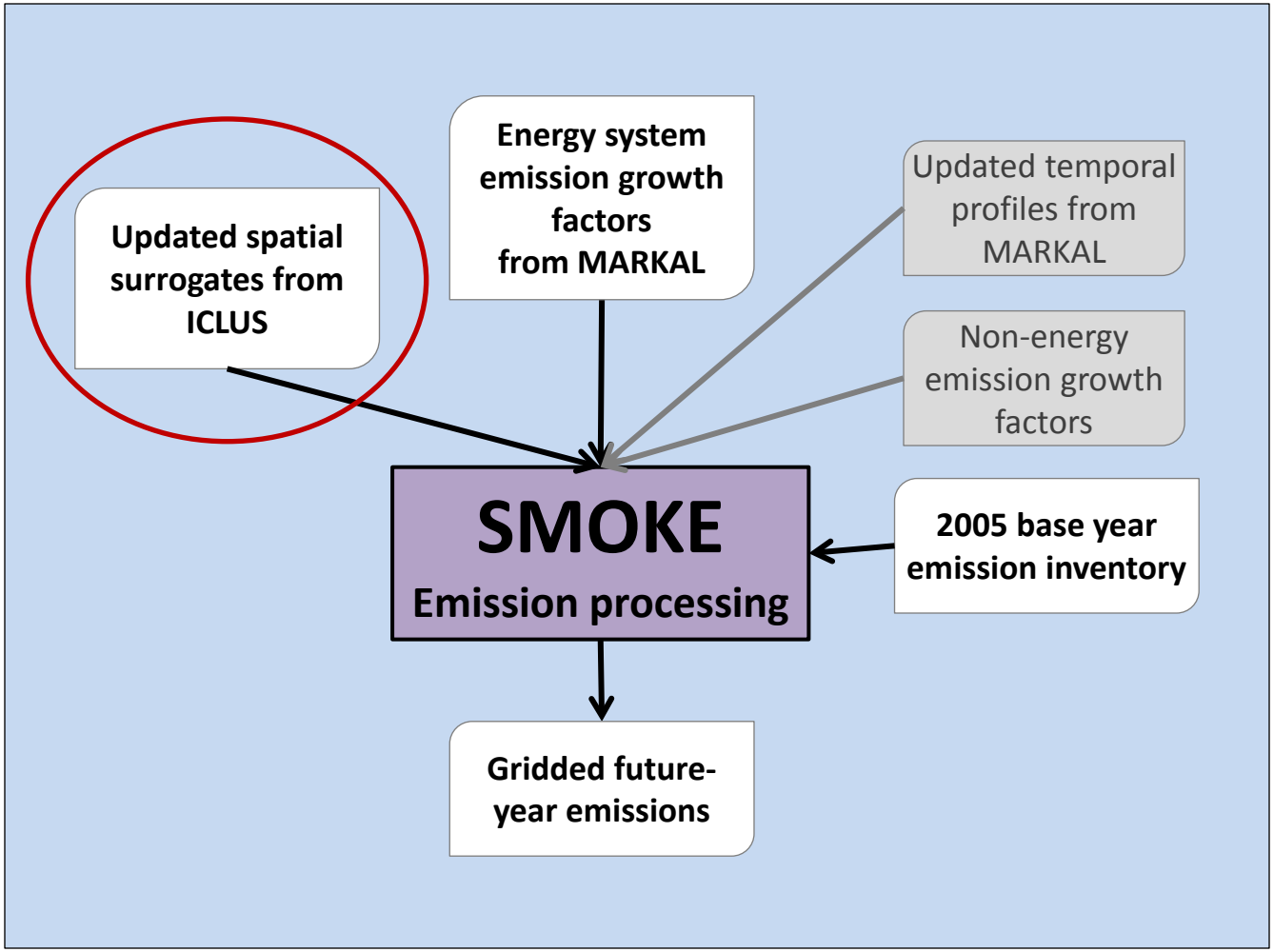
Part 4. Projecting a future-year inventory in SMOKE

Projecting base year emissions via SMOKE



Part 4. Projecting a future-year inventory in SMOKE

New feature: Updated spatial surrogates from ICLUS outputs



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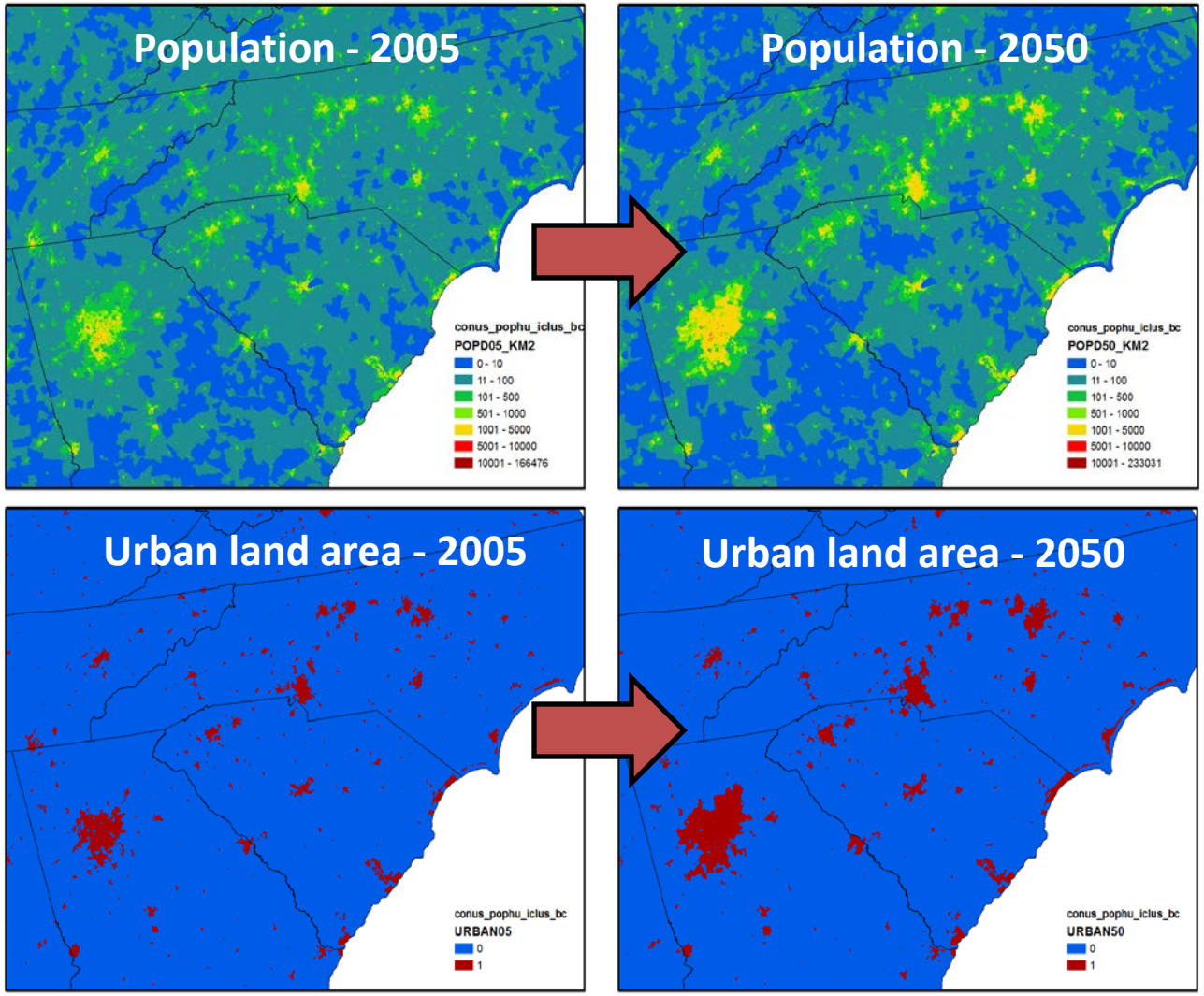


Updated surrogates:

Population
Housing
Urban population
Rural population
Housing change
Population & housing change
Urban primary road miles
Rural primary road miles
Total road miles
Low intensity residential
Rural land area
Residential – High density

Illustrative results

Part 4. Projecting a future-year inventory in SMOKE

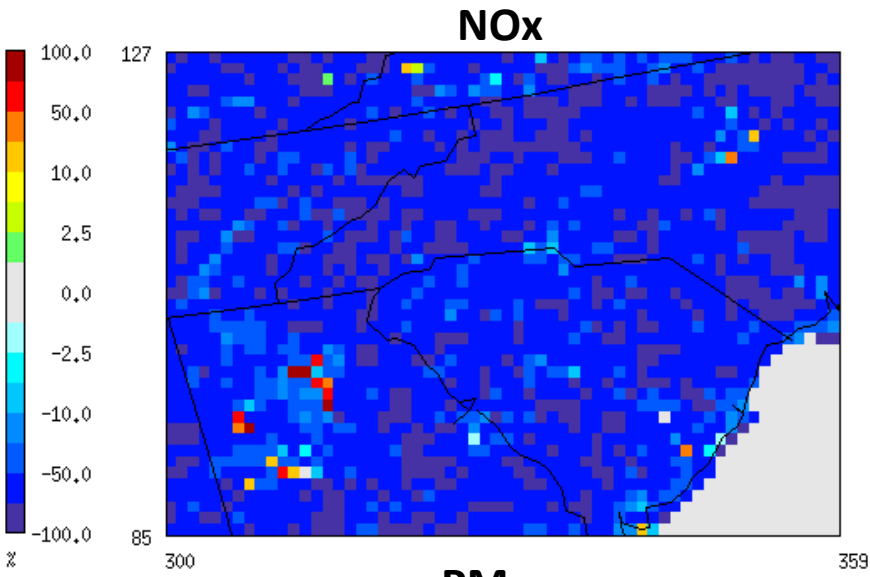
Example results: Percent change, 2005 to 2050

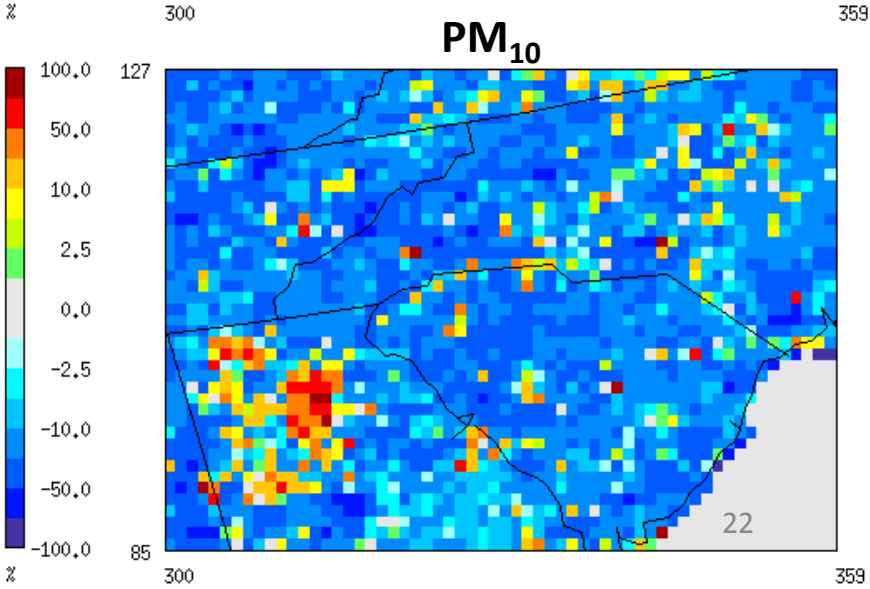
Results account for:
- population growth and migration
- economic growth and transformation
- technology change
- land use change
- on-the-books energy and air quality policies

For NOx, onroad vehicle emission reductions dominate, although this effect is more than offset in areas with intense new urban growth.

Change in PM_{10} emissions is more variable. In some areas, population growth appears to result in substantial increases.

Illustrative results





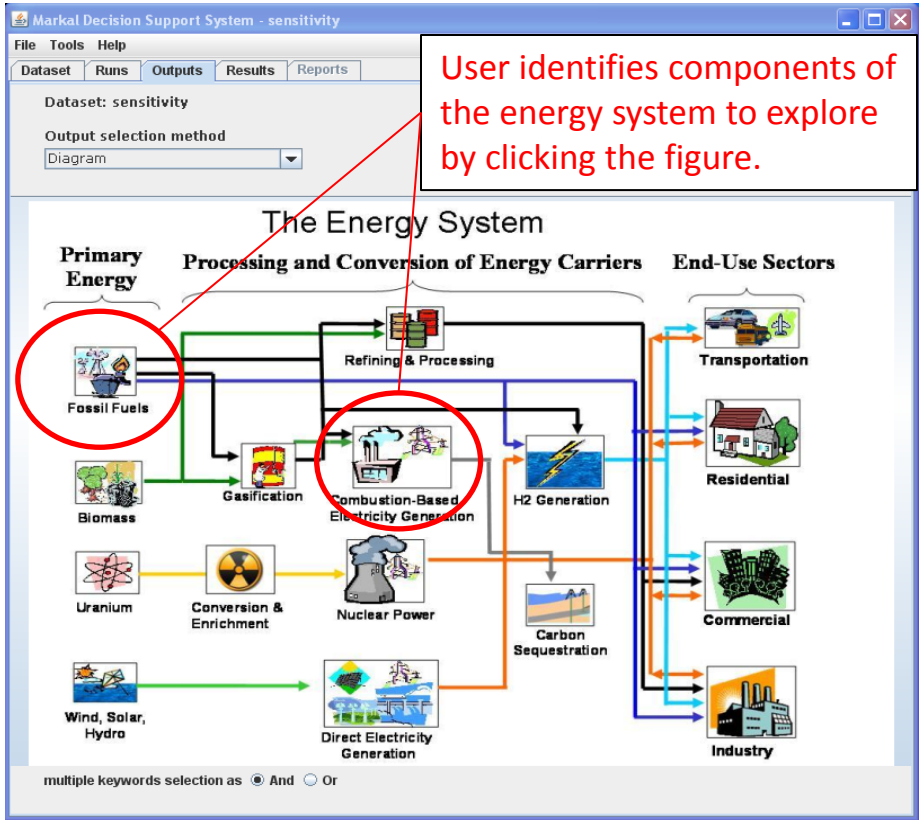
Part 4. Projecting a future-year inventory in SMOKE

Future steps

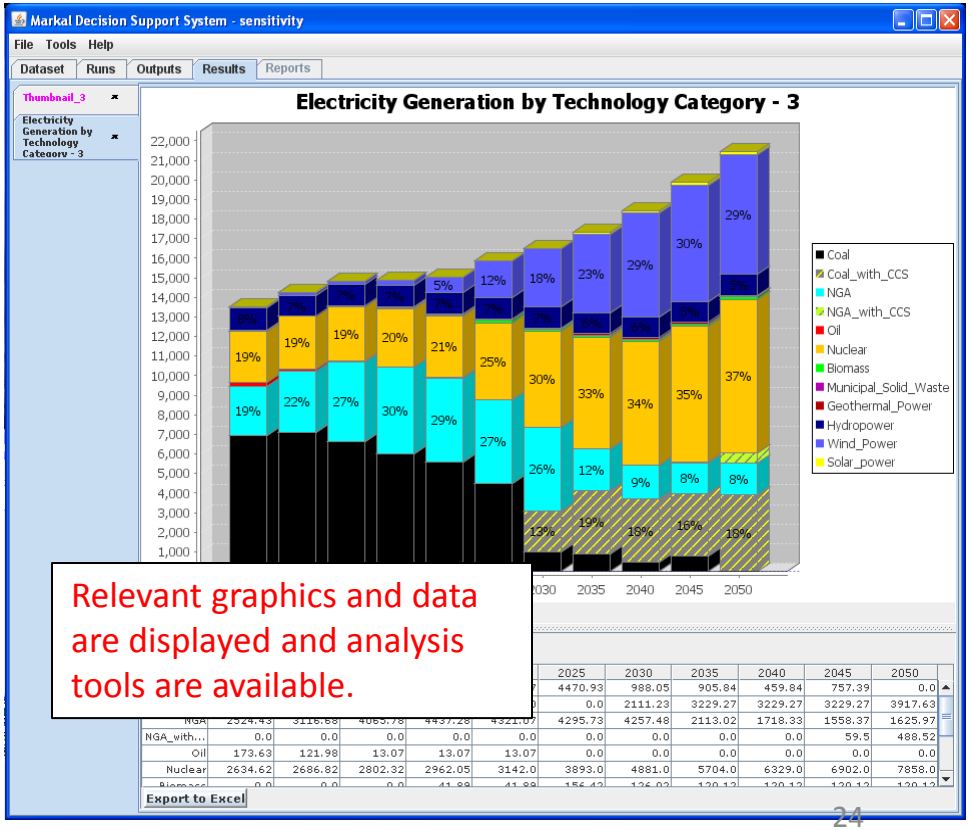
- Adjust temporal profiles to reflect changes in how fuels are used
  - Historically, natural gas has been used in the electric sector to meet peaking loads
  - Combined cycle units will represent much of new gas capacity, and these units likely will be used to meet baseload demands
- Correct for the potential issue in onroad mobile emissions of rural emission densities increasing as rural land use decreases
- Utilize downscaled meteorology to adjust future space heating and cooling demands
- Re-examine options for developing growth factors for non-combustion emissions

Part 5. Decision support tools

A new (soon-to-be) publicly-available exploratory data analysis tool will allow interested parties to examine MARKAL results in more detail.



User identifies components of the energy system to explore by clicking the figure.

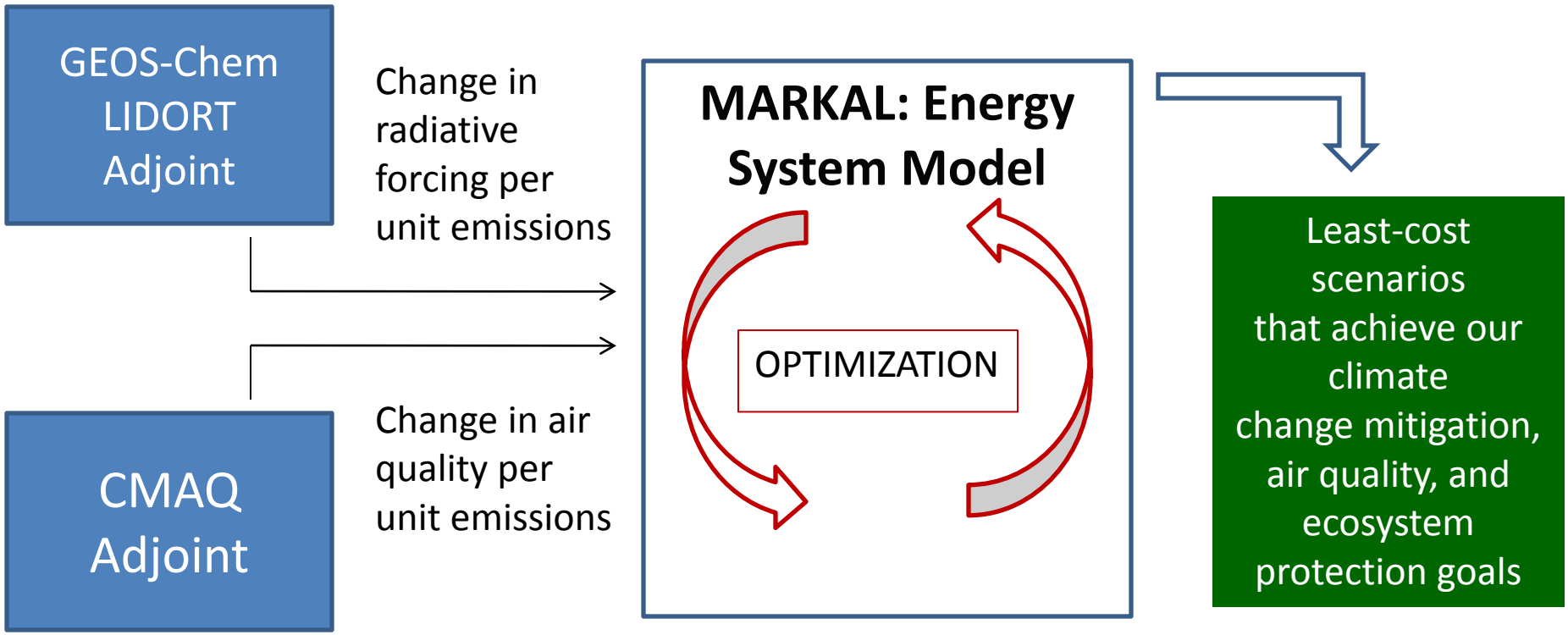


Relevant graphics and data are displayed and analysis tools are available.

Illustrative results

Part 5. Decision support tools

The GLIMPSE tool will support identification of strategies for simulaneously achieving criteria and climate goals.



Questions?

For more information:

General framework or emission projections

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ICLUS

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Additional slides

Acronyms

Acronyms used in this presentation:

- AEO - Annual Energy Outlook
- CAFE – Corporate Average Fuel Economy Standard
- CAIR – Clean Air Interstate Rule
- CIRAQ – Climate Impact on Air Quality project
- CMAQ – Community Multi-scale Air Quality model
- CSAPR – Cross-State Air Pollution Rule
- GEOS-Chem – Goddard Earth Observing System tropospheric chemistry model
- GLIMPSE – Geos-Chem adjoint Lidort radiative transfer model Integrated with MARKAL for the Purpose of Scenario Evaluation project
- GMD – Geoscientific Model Development journal
- GWP100 – 100 year Global Warming Potential (CO2 equivalent)
- ICLUS – Integrated Climate and Land Use Scenarios model
- LIDORT – LInearlized Discrete Ordinate Radiative Transfer model
- MARKAL – MARKet ALlocation energy system model
- NERL – National Exposure Research Laboratory
- NRMRL – National Risk Management Research Laboratory
- ORD – EPA Office of Research and Development
- SCC – Source Classification Code
- SMOKE – Sparse Matrix Operator Kernel Emissions processing model
- TIRF – Total Integrated Radiative Forcing
- UNC-CH – University of North Carolina at Chapel Hill

Acronyms, cont'd

Acronyms used in this presentation, cont'd:

- NO_x – Nitrogen oxides
- SO_2 – Sulfur dioxide
- PM_{10} – Particulat e matter of diameter 10 microns or less
- $PM_{2.5}$ – Particulate matter of 2.5 microns or less, also called fine particulate matter
- CO – Carbon monoxide
- VOC – Volatile Organic Compounds
- CO_2 – Carbon dioxide
- CH_4 - Methane
- N_2O – Nitrous oxide
- BC – Black carbon
- OC – Organic carbon

Comparison of 2005 National Emission Inventory (NEI) and 2005 MARKAL EPAUS9r v1.1 combustion-related emissions

	NO_x		SO_2		PM_{10}	
Sector	**NEI**	**MARKAL**	**NEI**	**MARKAL**	**NEI**	**MARKAL**
Electricity production	3,440	3,317	9,438	9,296	569	176
Industrial	2,047	2,255	1,903	2,081	1,747	1,916
Commercial	662	536	528	330	421	378
Residential	345	366	157	143	366	362
Light duty vehicles	2,927	3,661	61	62	76	92
Heavy duty vehicles	2,962	3,587	71	76	99	204
Aircraft	61	68	6	22	11	9
Marine Vessels	2,454	1,324	1,127	920	167	83
Nonroad engines	1,714	1,828	181	215	191	245
Railroads	1,015	638	68	67	28	23