



Considerations in linking energy scenario modeling and Life Cycle Analysis

Dan Loughlin, Limei Ran, and Chris Nolte

U.S. EPA Office of Research and Development

Research Triangle Park, NC



Foreword

- Objectives of the presentation
 - Describe ORD efforts to develop long-term air pollutant emissions projections
 - Discuss how the tools used in those efforts could be used to support Life Cycle Analysis
- Intended audience
 - Life cycle analysts
 - Emission inventory developers and modelers
 - We assume this audience is familiar with models and terms used in emissions modeling
- Additional contributors
 - EPA – Rebecca Dodder, Ozge Kaplan, Carol Lenox, William Yelverton
 - ORISE – Samaneh Babaee, Troy Hottle, Yang Ou, Wenjing Shi
 - PNNL – Steve Smith, Catherine Ledna
- Disclaimers
 - While the material presented here has been cleared for publication, it does not necessarily reflect the views nor policies of the U.S. EPA
 - Results are provided for illustrative purposes only



Abbreviations

- AEZ – Agricultural Economic Zone
- BAU – Business As Usual
- CAMx – Comprehensive Air Quality Model with Extensions
- CMAQ – Community Multi-scale Air Quality model
- CO₂ – Carbon dioxide
- EGU – Electricity generating unit
- EPA – Environmental Protection Agency
- ESP – Emission Scenario Projection method
- GCAM-USA – Global Change Assessment Model with U.S. spatial resolution
- GHG – Greenhouse gas
- GREET – Greenhouse gases, Regulated Emissions and Energy use in Transportation model
- I/O – Input-output
- IAM – Integrated Assessment Model
- LC – life cycle
- LCA – life cycle analysis
- MARKAL – MARKet ALlocation energy system model
- MOVES – MOtor Vehicle Emissions Simulator model
- O₃ – ozone
- ORISE – Oak Ridge Institute for Science and Education
- ORD – Office of Research and Development
- PM_{2.5} – Particulate matter with diameter smaller than 2.5 micrometers
- PNNL – Pacific Northwest National Laboratory
- N – nitrogen
- SMOKE – Sparse Matrix Operator Kernel Emissions modeling system



Outline

- Part 1. Emission Scenario Projection (ESP) methods and models
- Part 2. Scenarios in Life Cycle Analysis (LCA)
 - Approach 1: Using ESP to inform LCA inputs
 - Approach 2: Using the spatial allocation component of ESP to gain insight into the location of LCA emissions
 - Approach 3: Incorporating LC factors into energy and Integrated Assessment Models (IAMs)



Part 1.

Emission Scenario Projection



Part 1. Emission Scenario Projection

- Multi-decadal air pollutant emission projections (e.g., through 2050) have a variety of real world applications:
 - Benefit-cost analysis
 - evaluating and comparing potential management strategies
 - Long-term planning
 - identifying emerging source categories or other environmental issues
 - evaluating the synergies and co-benefits among environmental, climate and energy goals
 - characterizing the robustness of regulations under wide-ranging conditions
 - Technology assessment
 - calculating the net environmental impact of new and emerging technologies



Part 1. Emission Scenario Projection

- Generating these projections poses many challenges, however:
 - Underlying drivers are complex, interrelated, dynamic, and uncertain
 - Population growth and migration
 - Economic growth and transformation
 - Technology development and adoption
 - Land use and land cover change
 - Climate change
 - Behavior, preferences and choices
 - Policies (energy, environmental and climate)
- Goal
 - Evaluate scenarios defined by internally consistent assumptions to obtain future-year emission inventories

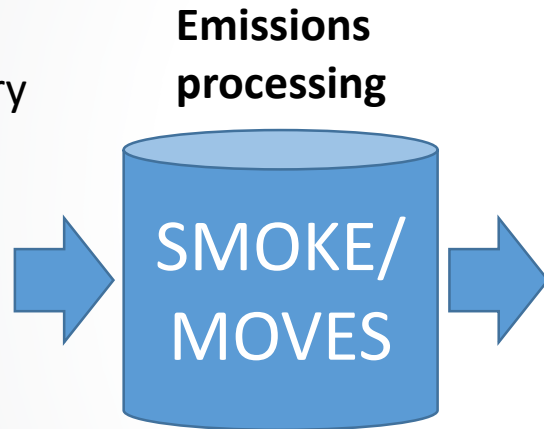


Part 1. Emission Scenario Projection

- From the emissions modeling perspective

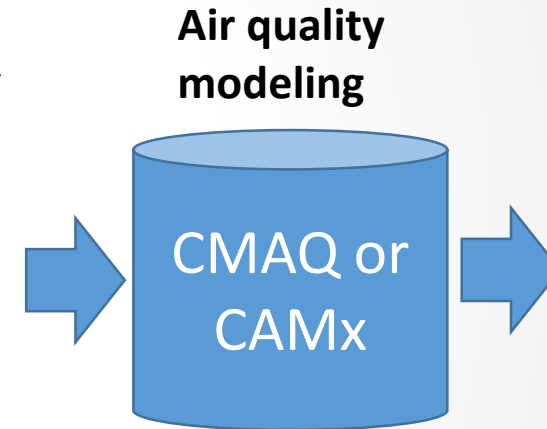
Inputs

National Emissions Inventory
Growth and control factors
Temporal profiles
Speciation profiles
Road network
Temperature fields
Spatial surrogates



Spatially- and temporally-allocated, speciated and gridded inventory

- Point
- Nonpoint
- Industrial processes
- Onroad mobile
- Nonroad mobile
- Biogenic/land use
- Wildfire



Gridded air quality projection

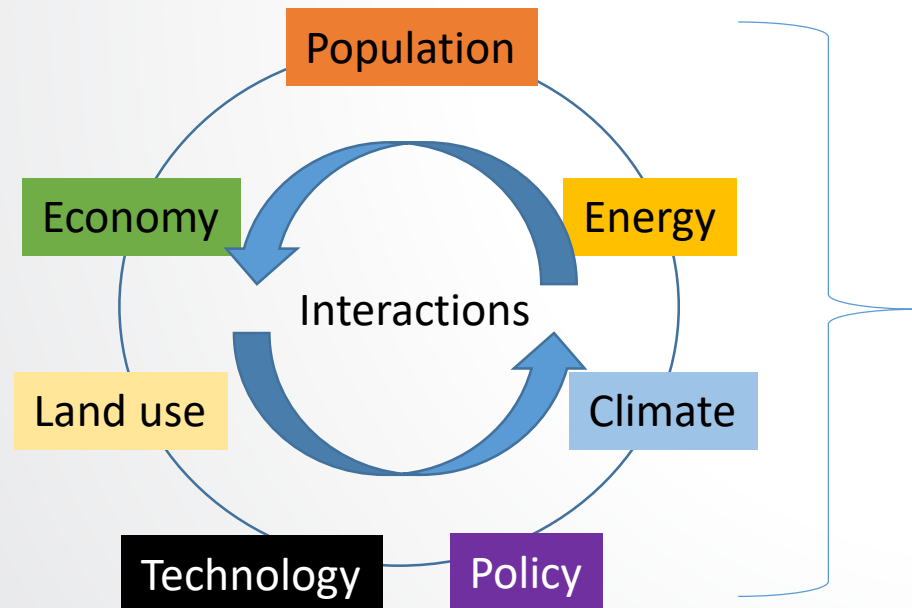
These should reflect the scenario assumptions about the future



Part 1. Emission Scenario Projection

- Long-term vision

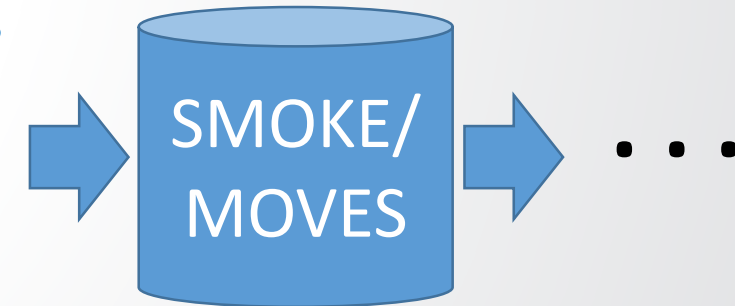
Integrated emission projection system



Inputs

National Emissions Inventory
Growth and control factors
Temporal profiles
Speciation profiles
Road network
Temperature fields
Spatial surrogates

Emissions processing

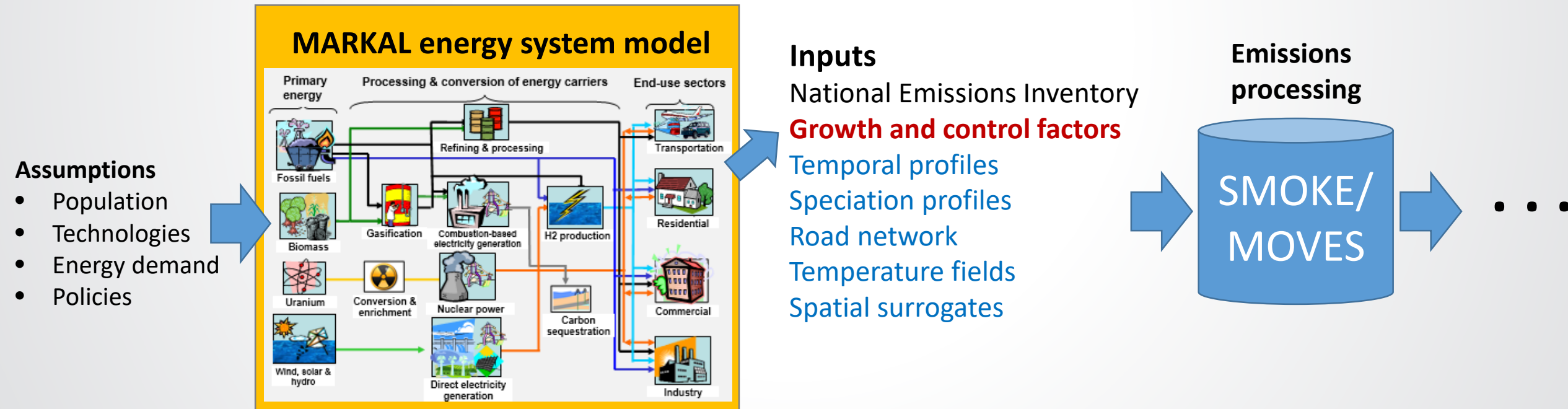




Part 1. Emission Scenario Projection

- Emission Scenario Projection (ESP) v1.0 (2011)

Develop regional-, technology-, pollutant-specific emission growth factors using an energy system model



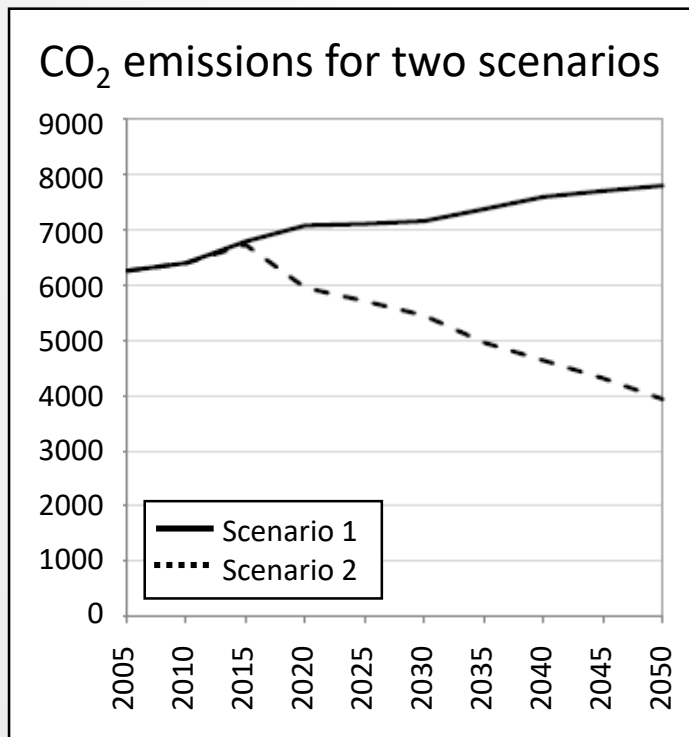


Part 1. Emission Scenario Projection

- ESPv1.0 (2011), cont'd

Application:

Evaluation of a Business as Usual (Scenario 1) and a 50% CO₂ reduction Scenario (Scenario 2)



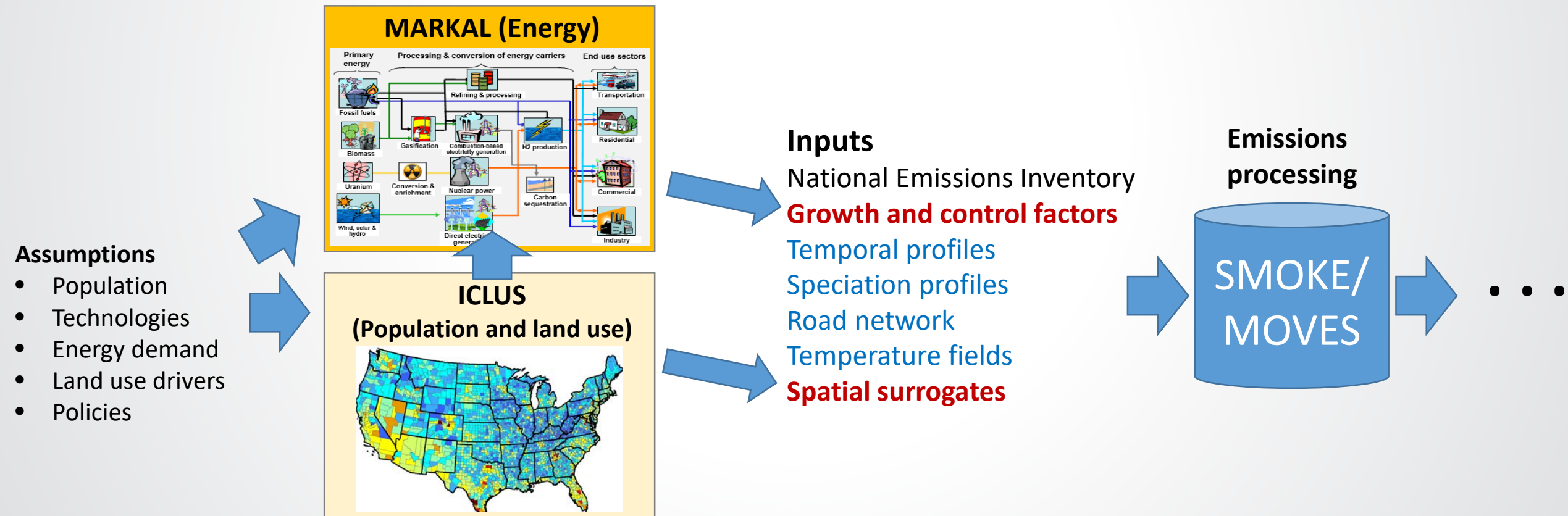
Sectoral growth and control factors, Southeast US						
	Scenario 1			Scenario 2		
	CO ₂	NO _x	PM ₁₀	CO ₂	NO _x	PM ₁₀
Electric sector	0.91	0.35	0.61	0.04	0.24	0.41
Industrial combustion	1.51	1.43	1.25	0.99	0.92	0.56
Residential combustion	1.06	1.11	0.95	0.97	1.03	1.06
Commercial combustion	1.66	1.65	1.50	1.21	1.17	0.89
Light duty transportation	1.44	0.24	1.94	0.71	0.11	1.64
Heavy duty transportation	1.62	0.06	0.11	1.57	0.06	0.11
Airplanes	1.76	1.76	1.76	1.76	1.76	1.76
Rail	1.72	1.72	1.72	1.71	1.72	1.72
Domestic shipping	1.35	1.35	1.35	1.35	1.35	1.35



Part 1. Emission Scenario Projection

- ESPv2.0 (2015)

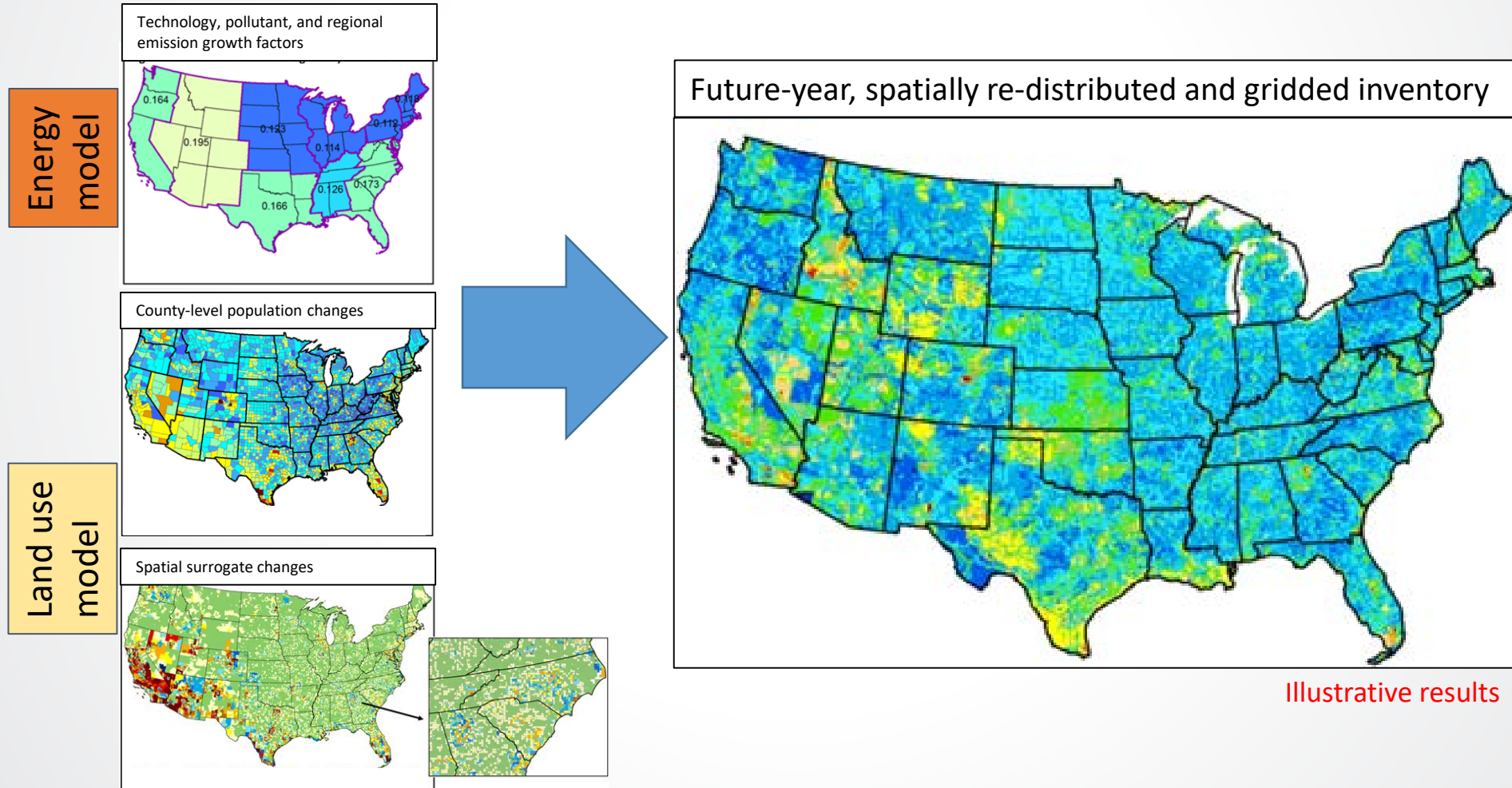
Spatially allocate future-year emissions to account for population growth and migration and land use change





Part 1. Emission Scenario Projection

- ESPv2.0 (2015), cont'd



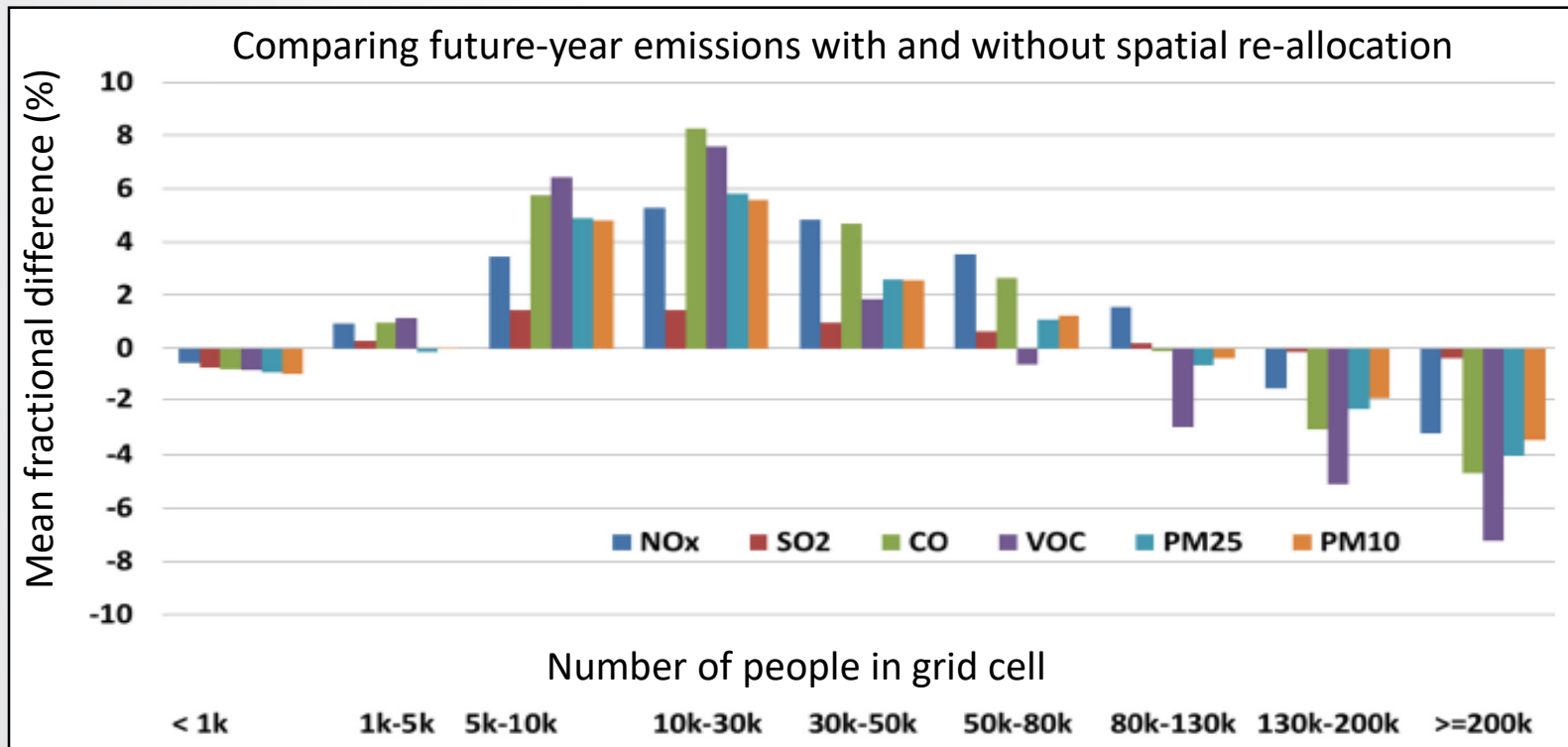


Part 1. Emission Scenario Projection

- ESPv2.0 (2015), cont'd

Application:

Explore impact of accounting for population migration and land use change on exposure

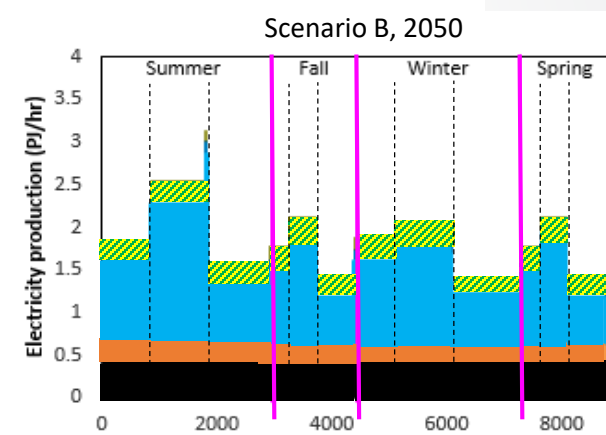
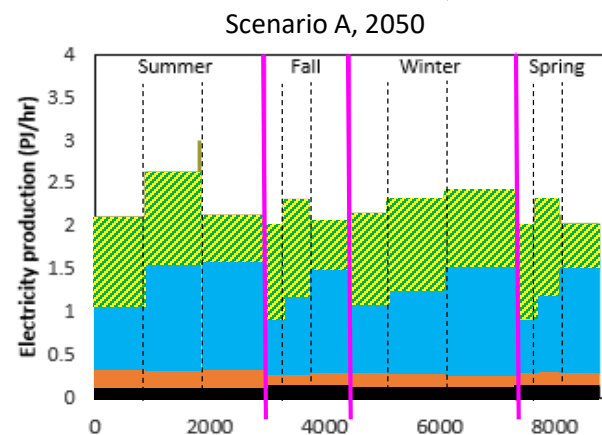
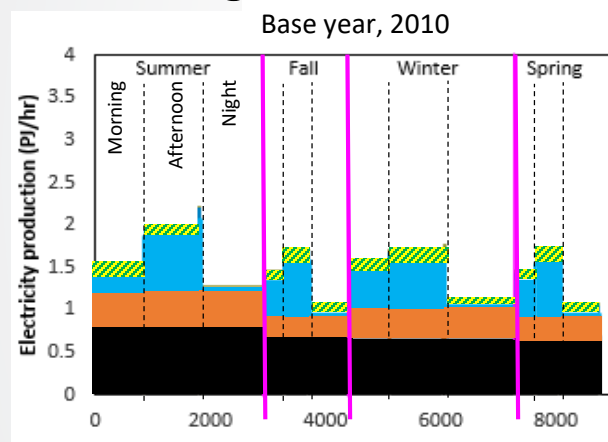


Emissions show relative increases in counties with moderate population density, but decreases in rural and urban areas.

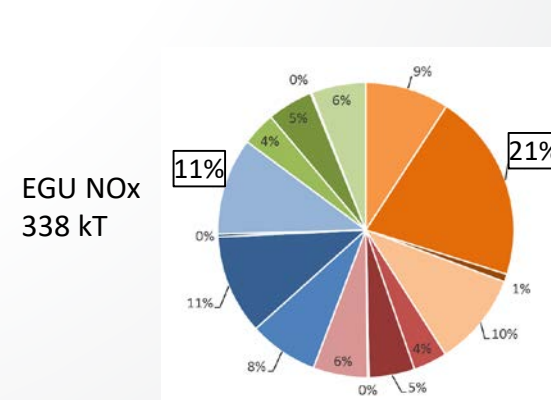
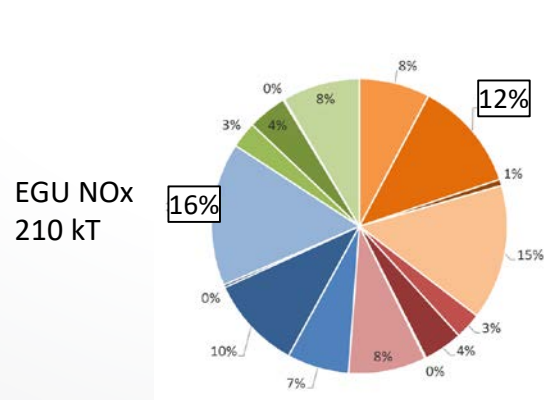
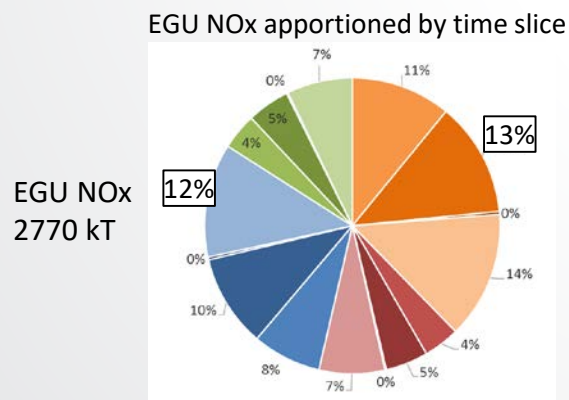
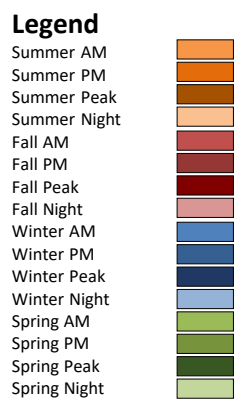


Part 1. Emission Scenario Projection

- Next steps: ESPv3.0?
 - Adjust temporal distribution of emissions to capture changing roles of technologies
 - Natural gas transitions to a baseload technology



Electric sector NO_x decreases substantially, but the temporal allocation shifts.



Illustrative results

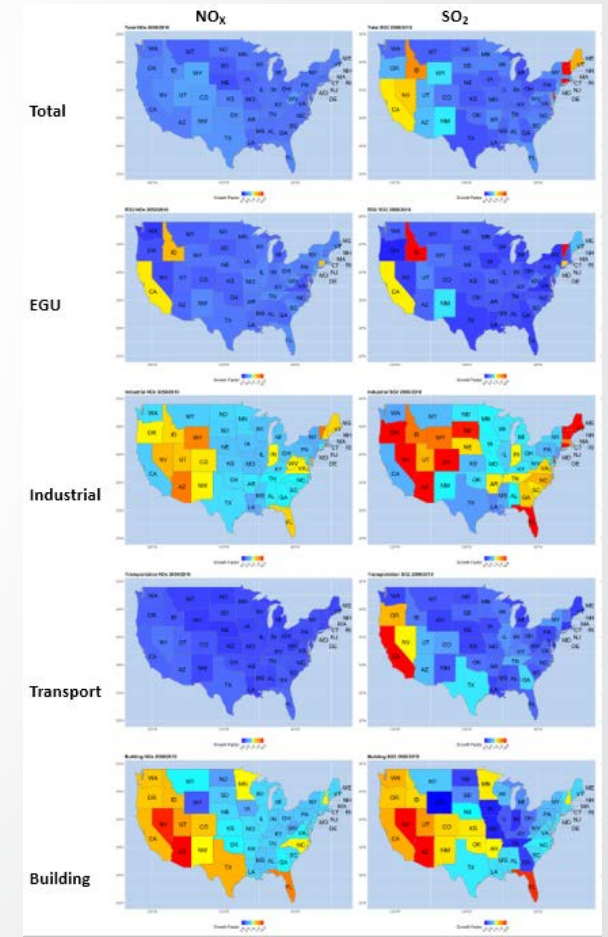
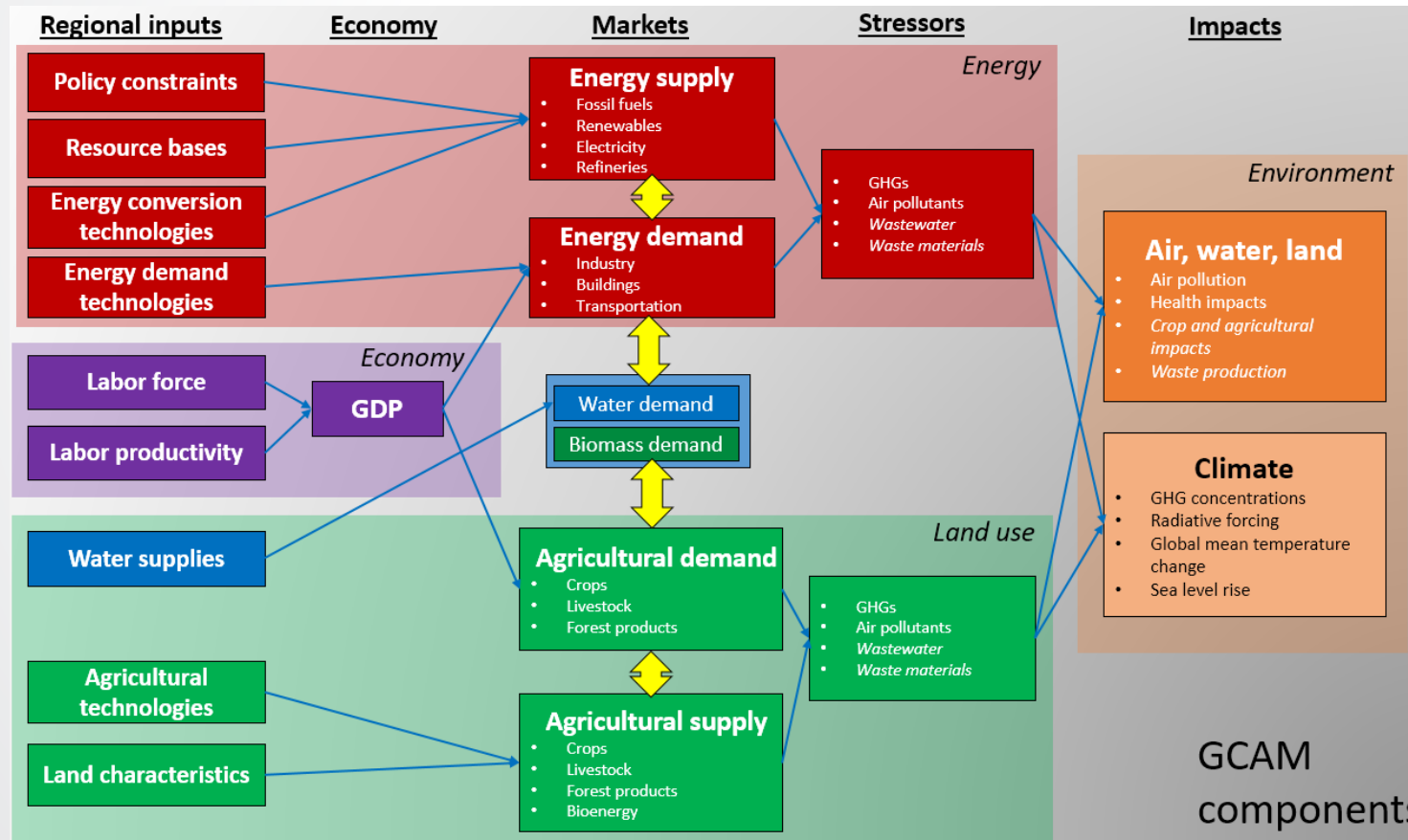


Part 1. Emission Scenario Projection

- Next steps: ESPv3.0?
 - Incorporate integrated assessment model (e.g., GCAM-USA)
 - Adds agriculture, water system, land use, climate impacts

Illustrative results

State-level, sectoral emission growth factors

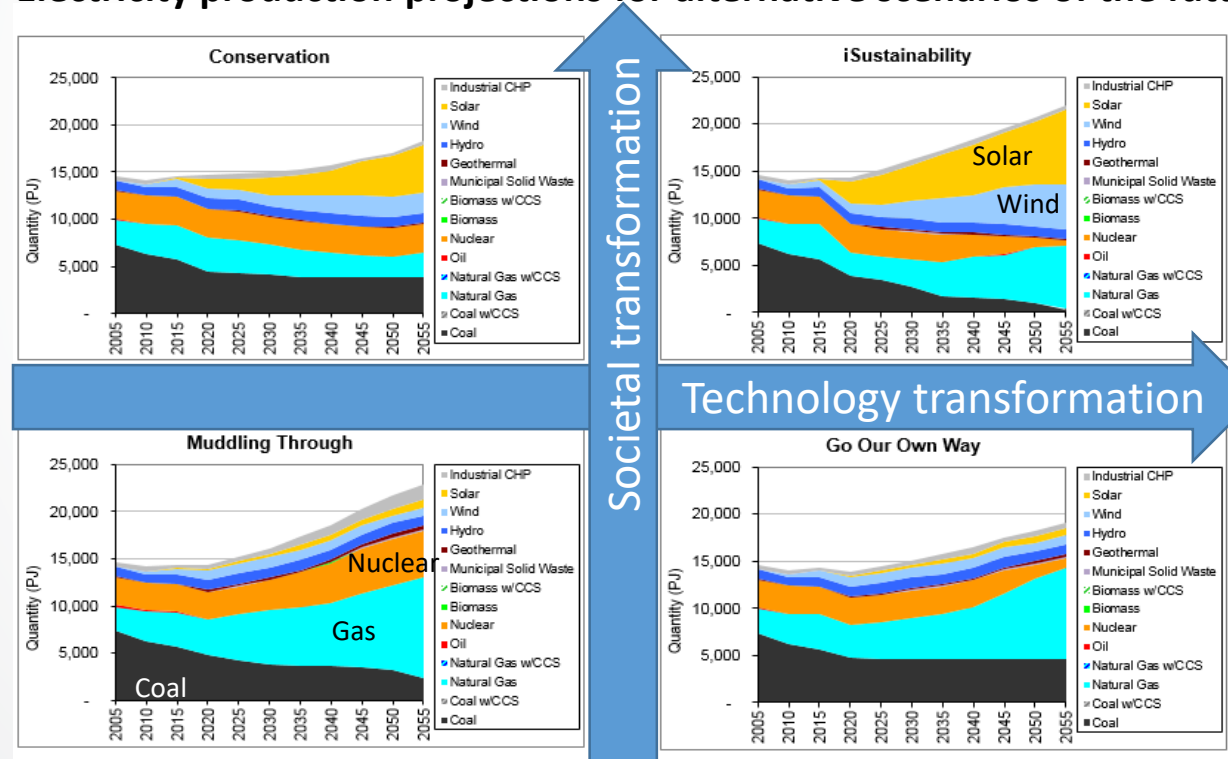




Part 1. Emission Scenario Projection

- Next steps: ESPv3.0?
 - Provide examples of very different alternative scenarios

Electricity production projections for alternative scenarios of the future



Illustrative results



Part 1. Emission Scenario Projection

- Wish list for a future version of ESP: ESPvX?
 - Consideration of commercial and industrial land uses within land use modeling
 - Industrial I/O tables
 - translate scenario assumptions to industrial production
 - E.g., a transition from conventional vehicles to electric vehicles would result in shifts in output in the metal and chemical industries
 - Capability to site new emission sources
 - Dynamic road networks with attributes (capacity, speed, travel demand) that interact in land use and population modeling
 - Impact factors estimate 1st order environmental effects of emissions
 - PM_{2.5} mortality costs
 - O₃ mortality costs
 - Crop and timber damage due to ozone
 - Damages from N deposition
 - Water supply constraints on the evolution of the energy system



Part 2.

Scenarios and Life Cycle Analysis



Part 2. Scenarios and Life Cycle Analysis

- One type of Life Cycle Analysis:
Compare the net life cycle impacts of competing technologies

Assumptions

Future-year electric grid mix

Technology characteristics

- efficiency
- emission factors
- fuels

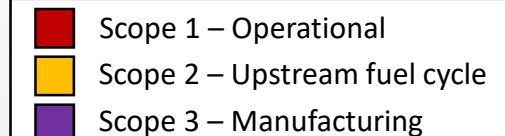
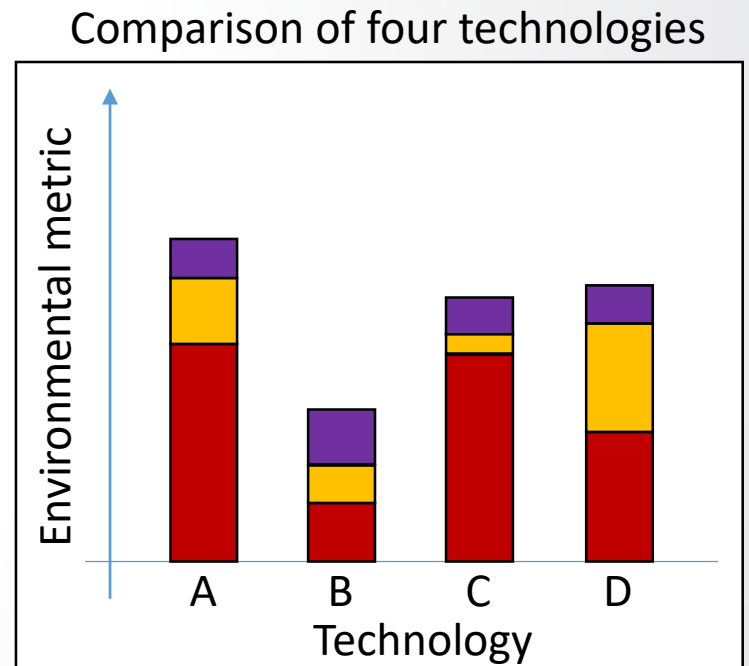
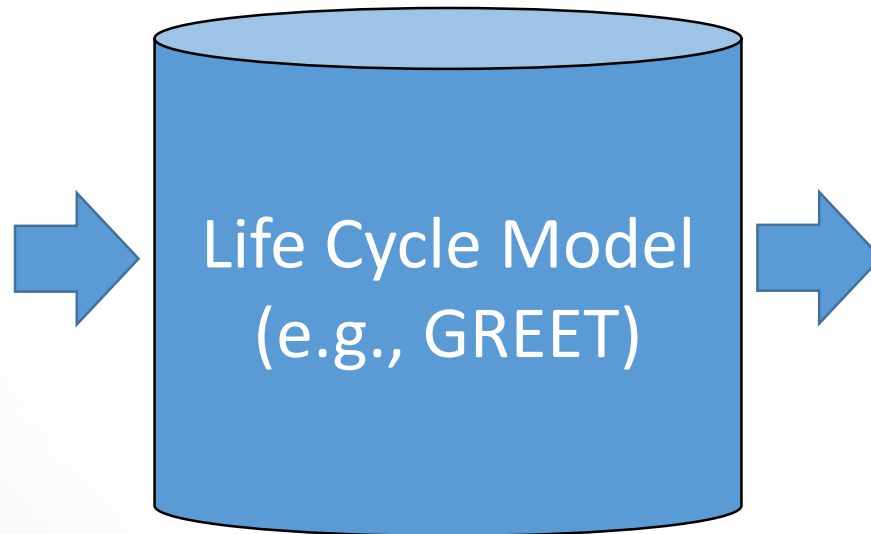
Upstream technologies

(e.g., transportation, conversion, manufacturing)

- mix
- efficiency
- emission factors
- fuels

Fuels

- origin (un/conventional)
- composition





Part 2. Scenarios and Life Cycle Analysis

- One type of Life Cycle Analysis:

Evaluate impacts over a set of sensitivities (e.g., electric grid mix)

Assumptions

Future-year electric grid mix

Technology characteristics

- efficiency
- emission factors
- fuels

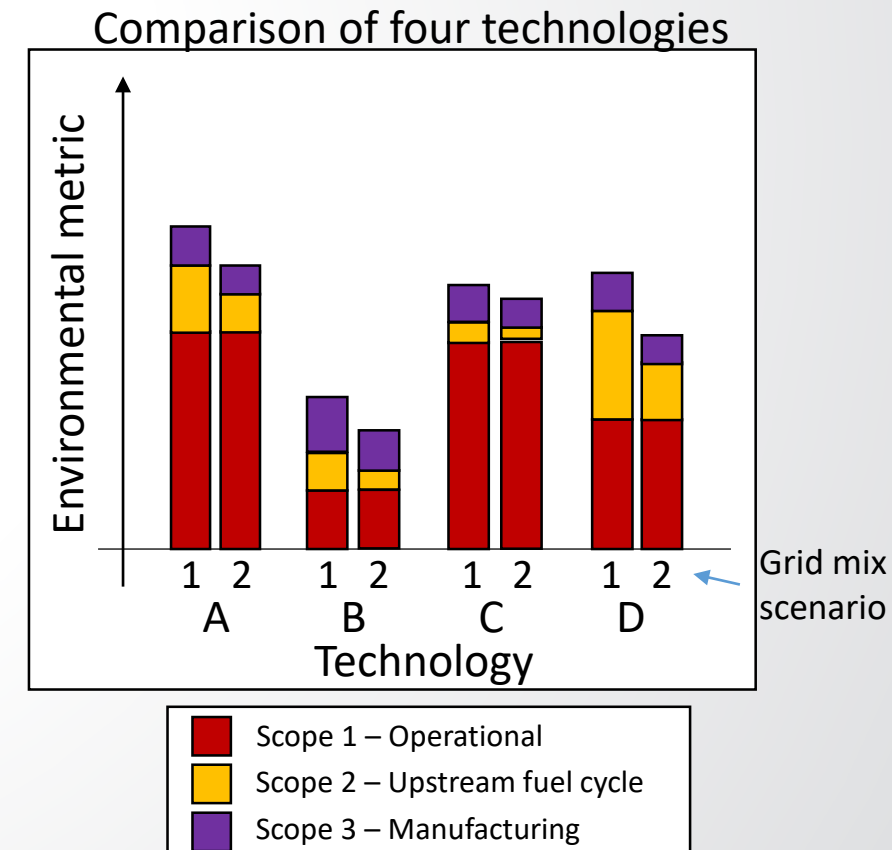
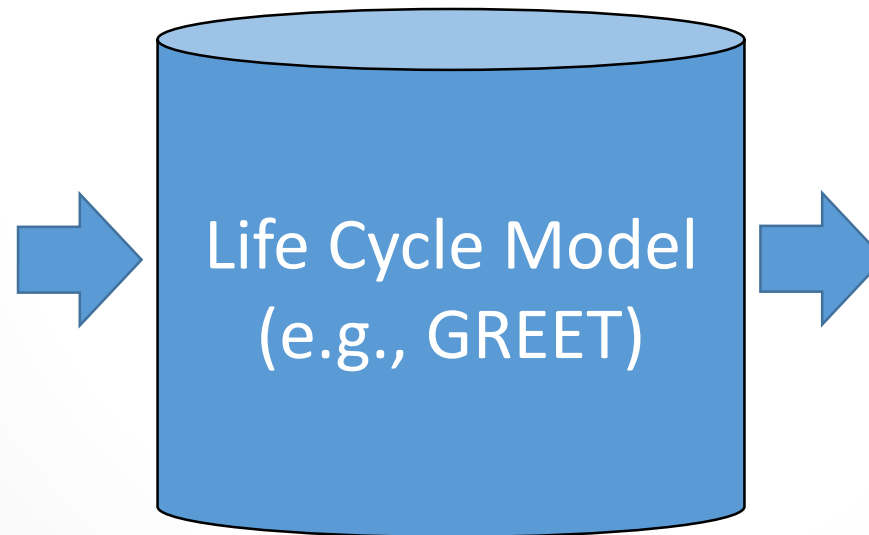
Upstream technologies

(e.g., transportation, conversion, manufacturing)

- mix
- efficiency
- emission factors
- fuels

Fuels

- origin (un/conventional)
- composition





Part 2. Scenarios and Life Cycle Analysis

- Some limitations
 - Stationarity of system
 - Evaluates impact of the technology, considering fixed set of electric grid and fuel chain assumptions
 - What if adoption of the technology is widespread? Those specific conditions may change
 - Example: Widespread adoption of electric vehicles
 - Expansion of electric sector capacity
 - When calculating the impact of the vehicles, the environmental signature of the capacity expansion may be more appropriate than that of the existing electric sector capacity
 - Reduction in demand for gasoline and diesel in the light duty sector
 - Reduced demand will impact the mix of conventional and unconventional fuels, refinery operations, and biomass production for biofuels
 - Prices of competing fuels
 - Gasoline, diesel, and biofuels prices will be affected, which may result in fuel switching in other sectors
 - Change in energy demands related to manufacture of vehicles
 - shifts from conventional to alternate fuel vehicles, vehicle lightweighting, etc., affect industrial energy demands
 - Typically lack support for evaluating wide-ranging scenarios
 - Models like GREET provide a large set of inputs that could be tweaked
 - However, it may be difficult for users to tweak these in ways that are **internally consistent**

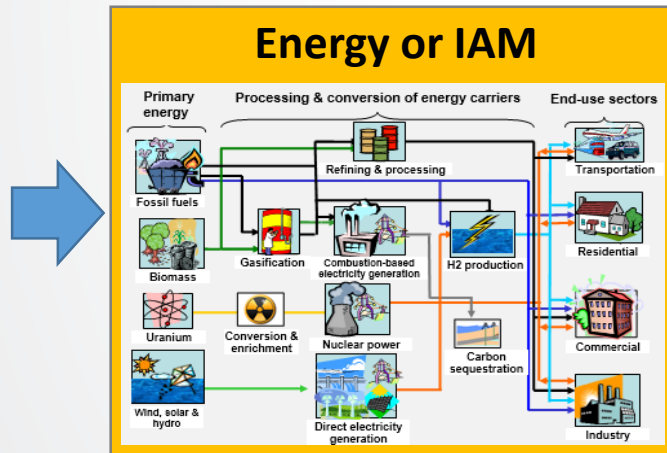
Part 2. Scenarios and Life Cycle Analysis

• Approach 1: Using ESP to inform LCA inputs

Use an energy system or integrated assessment model to develop contextual assumptions

Scenario assumptions

Population growth and migration
Economic growth and transformation
Technology change
Land use / land cover
Climate change
Behavior
Policy (environmental, climate, energy)



LCA assumptions

Future-year electric grid mix

Technology characteristics

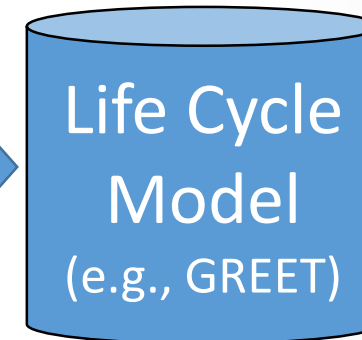
- efficiency
- emission factors
- fuels

Upstream technologies

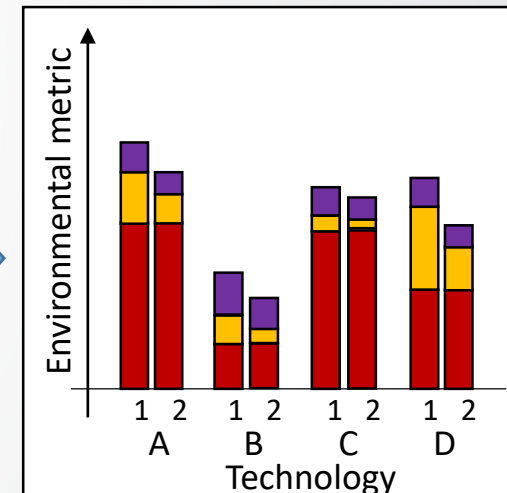
- mix
- efficiency
- emission factors
- fuels

Fuels

- origin (un/conventional)
- composition



Comparison of four technologies





Part 2. Scenarios and Life Cycle Analysis

Approach 2: Using the spatial allocation component of ESP to gain insight into the location of LCA emissions

Energy system modeling could be used to provide insights into where impacts occur

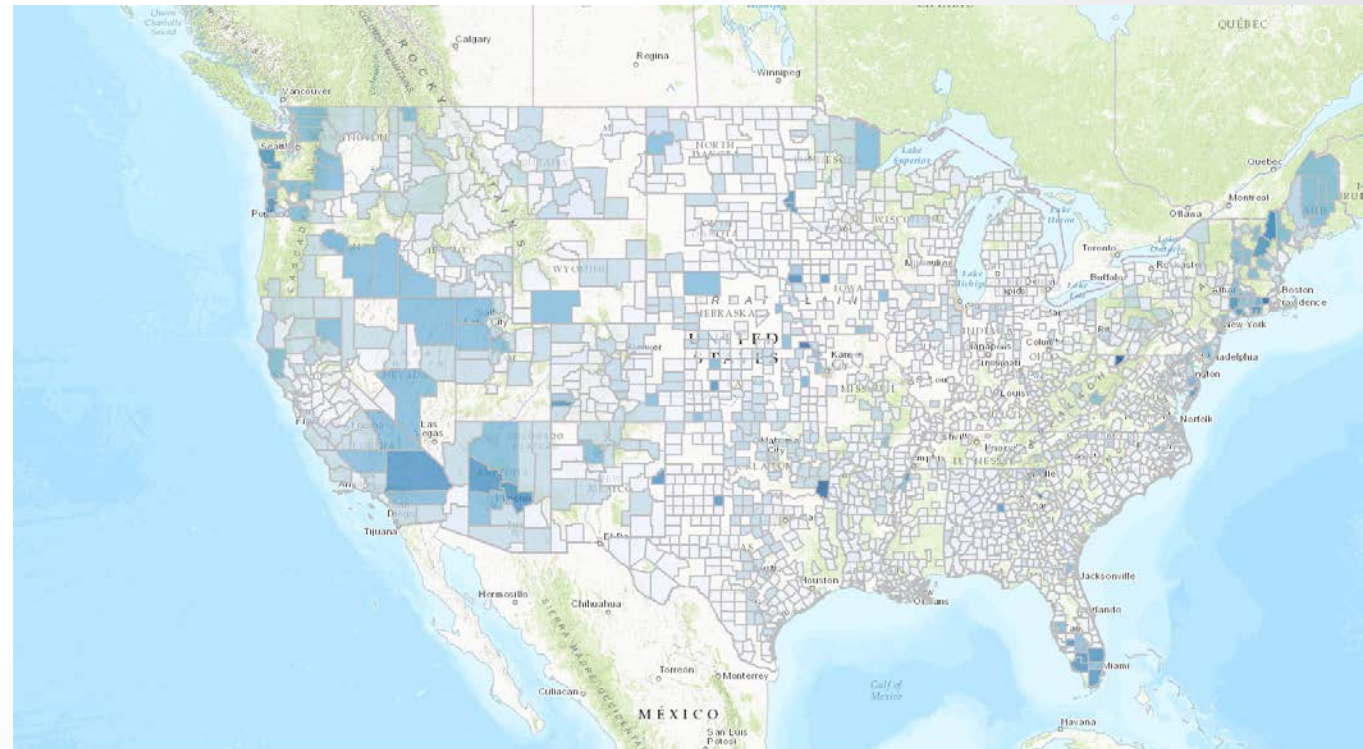
Example

GCAM-USA agricultural production is reported by Agricultural Ecological Zone (AEZ).

If we assume production per unit area is constant across an AEZ, we can use county-AEZ mappings to estimate county-level biomass production activity.

These county-level production estimates could be used to allocate LC emissions in an LCA.

Dedicated biomass production for bioenergy, 2050



Illustrative results

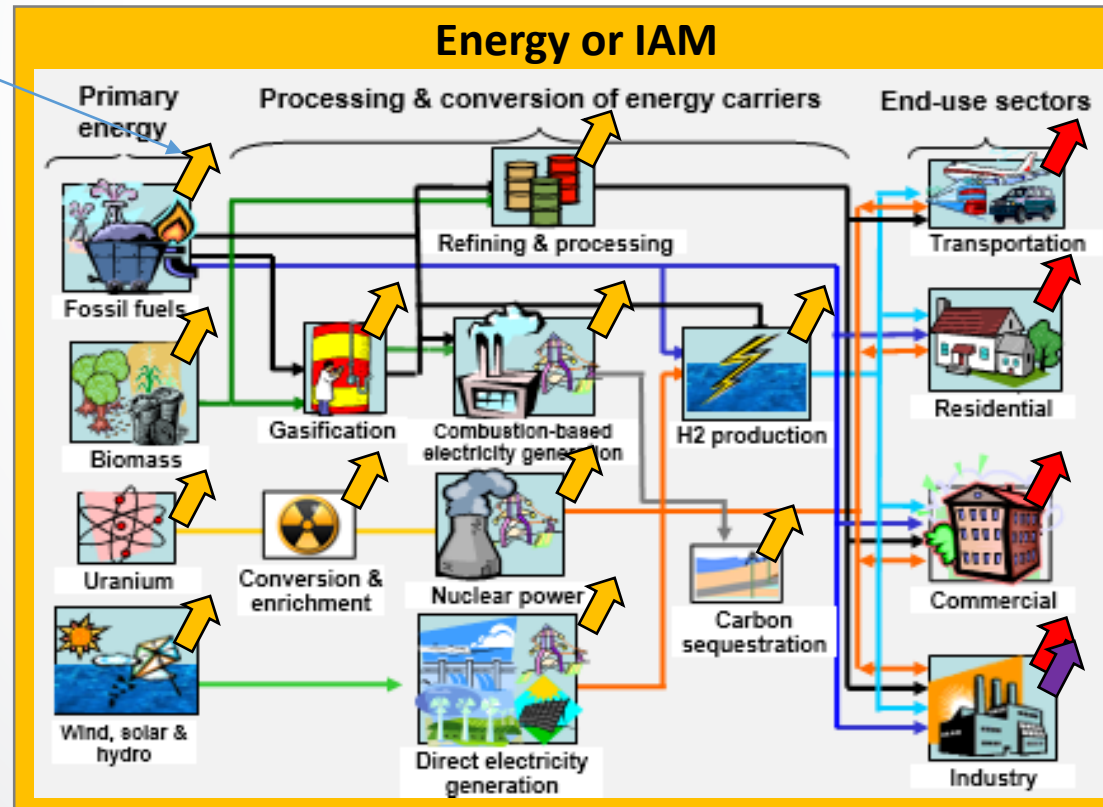
Part 2. Scenarios and Life Cycle Analysis

- Approach 3: Incorporate LC factors into energy models and IAMs

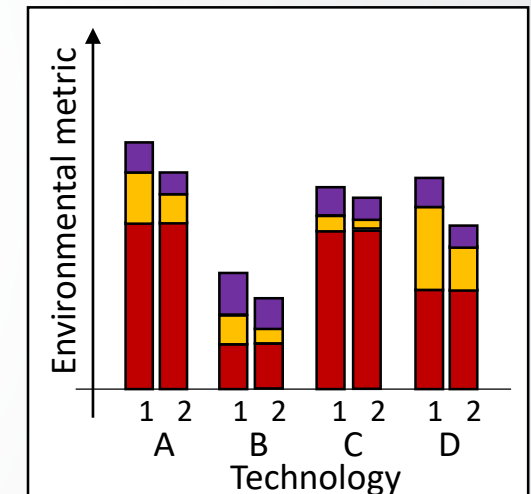
Conduct LCA using an energy system model, capturing contextual considerations, cross-sector dynamics, etc.

Scenario assumptions
 Population growth and migration
 Economic growth and transformation
 Technology change
 Land use / land cover
 Climate change
 Behavior
 Policy (environmental, climate, energy)

LC factors



Comparison of four technologies



ESP Spatial and temporal allocation

Analysis of emissions
 Emissions and air quality modeling

- ESP methods and tools have the potential to link with LCA
 - Approach 1: Using ESP to inform LCA inputs
 - Approach 2: Using the spatial allocation component of ESP to gain insight into the location of LCA emissions
 - Approach 3: Incorporating LC factors into energy and Integrated Assessment Models (IAMs)
- Additional methods and tools being investigated in ESP should be of use in LCA as well:
 - High-resolution integrated assessment modeling
 - Siting new sources
 - Scenario modeling



Questions?

Contact:

Dan Loughlin Loughlin.Dan@epa.gov