Considerations in linking energy scenario modeling and Life Cycle Analysis

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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

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)

- 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

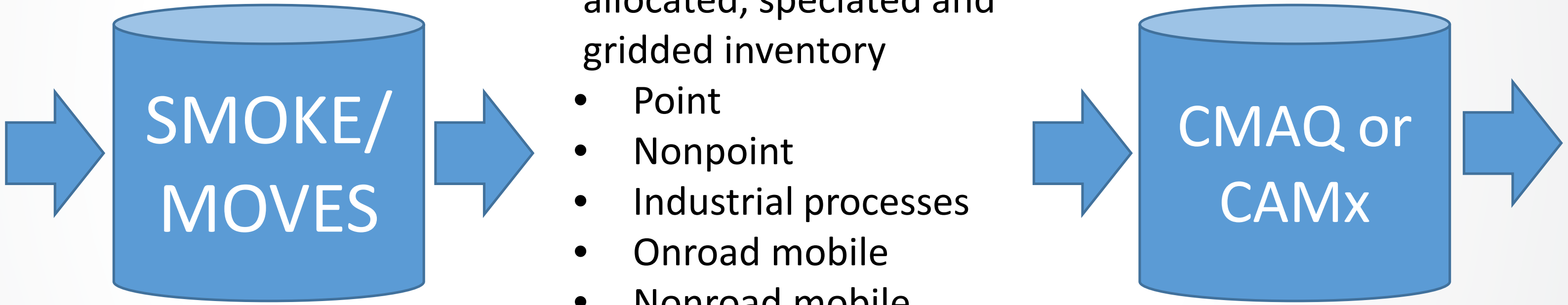
- From the emissions modeling perspective

Inputs

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

These should reflect the scenario assumptions about the future

Emissions processing



Spatially- and temporally-allocated, speciated and gridded inventory

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

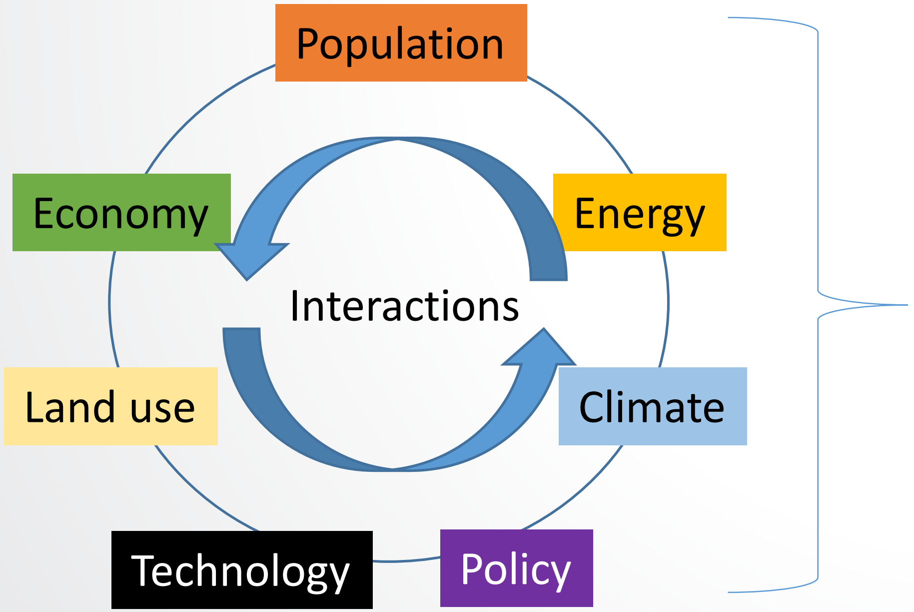
Air quality modeling

Gridded air quality projection

Part 1. Emission Scenario Projection

- Long-term vision

Integrated emission projection system



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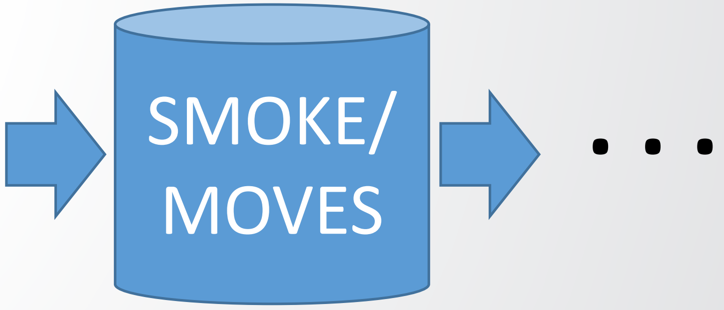
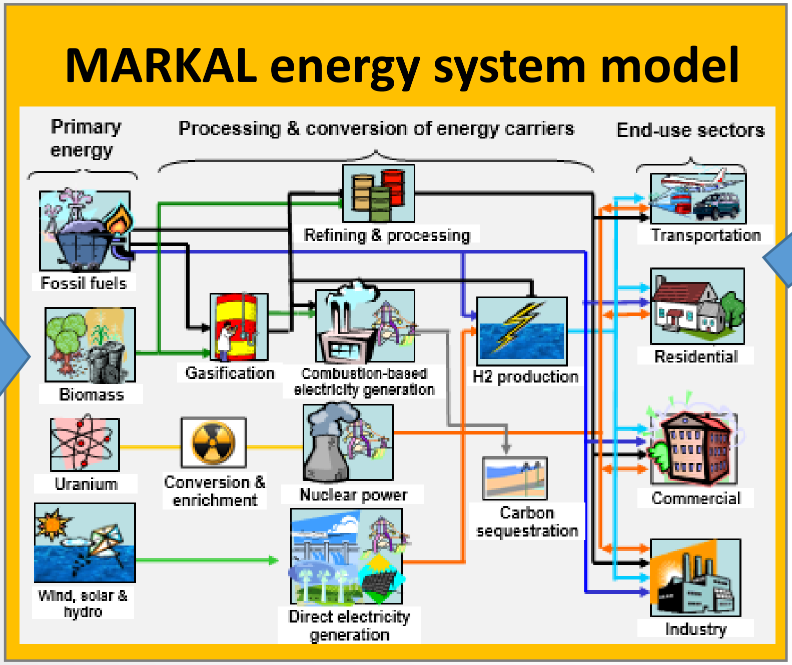


Part 1. Emission Scenario Projection

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

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

Assumptions
- Population
- Technologies
- Energy demand
- Policies



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Emissions processing

SMOKE/ MOVES

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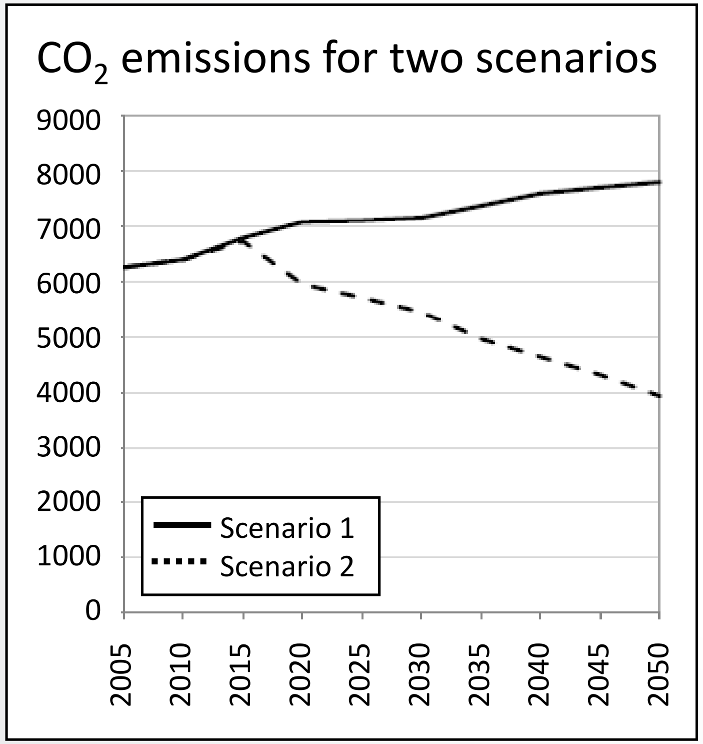
Loughlin, D.H., Benjey, W.G., and C.G. Nolte (2011). "ESP v1.0: methodology for exploring emission impacts of future scenarios in the United States." *Geoscientific Model Development*, 4, 287-297.

Part 1. Emission Scenario Projection

- ESPv1.0 (2011), cont'd

Application:
Evaluation of a Business as Usual (Scenario 1) and a 50% CO_2 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

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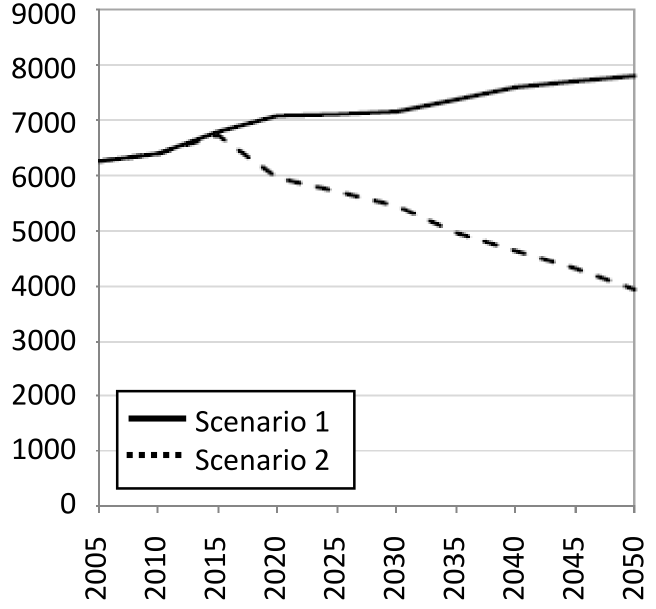

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Method captured scenario, pollutant, and sector-specific trends

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.

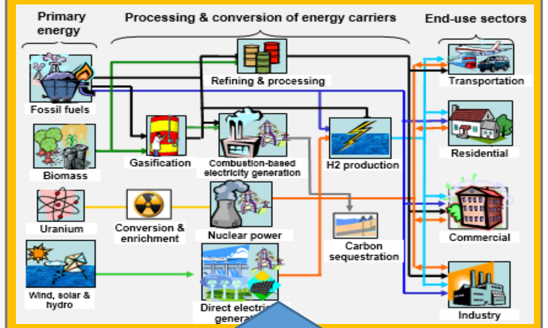
Part 1. Emission Scenario Projection

- ESPv2.0 (2015)

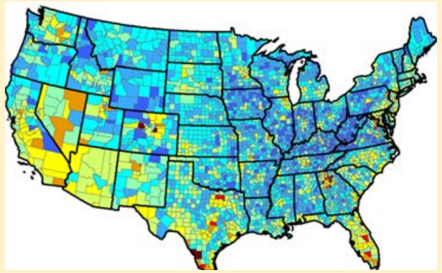
Spatially allocate future-year emissions to account for population growth and migration and land use change

Assumptions
- Population
- Technologies
- Energy demand
- Land use drivers
- Policies

MARKAL (Energy)



ICLUS
(Population and land use)



Inputs
National Emissions Inventory
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Temporal profiles
Speciation profiles
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Temperature fields
Spatial surrogates

Emissions processing

SMOKE/ MOVES

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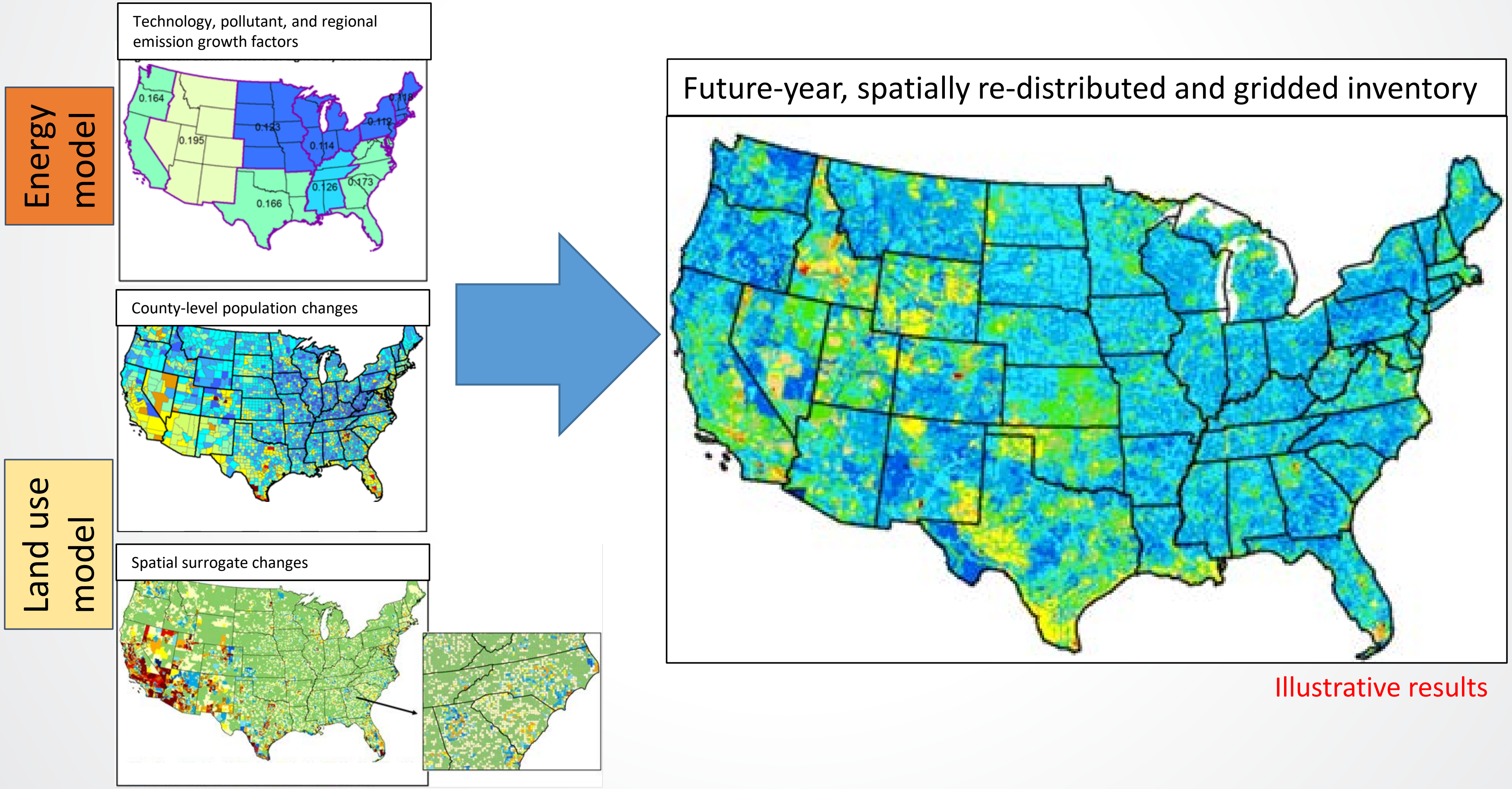
Ran, L., Loughlin, D.H., Yang, D., Adelman, Z., Baek, B.H., and C. Nolte (2015). “ESP2.0: enhanced method for exploring emission impacts of future scenarios in the United States – addressing spatial allocation.” *Geoscientific Model Development*, *8,* 1775-1787.

Part 1. Emission Scenario Projection

- ESPv2.0 (2015), cont'd



Illustrative results

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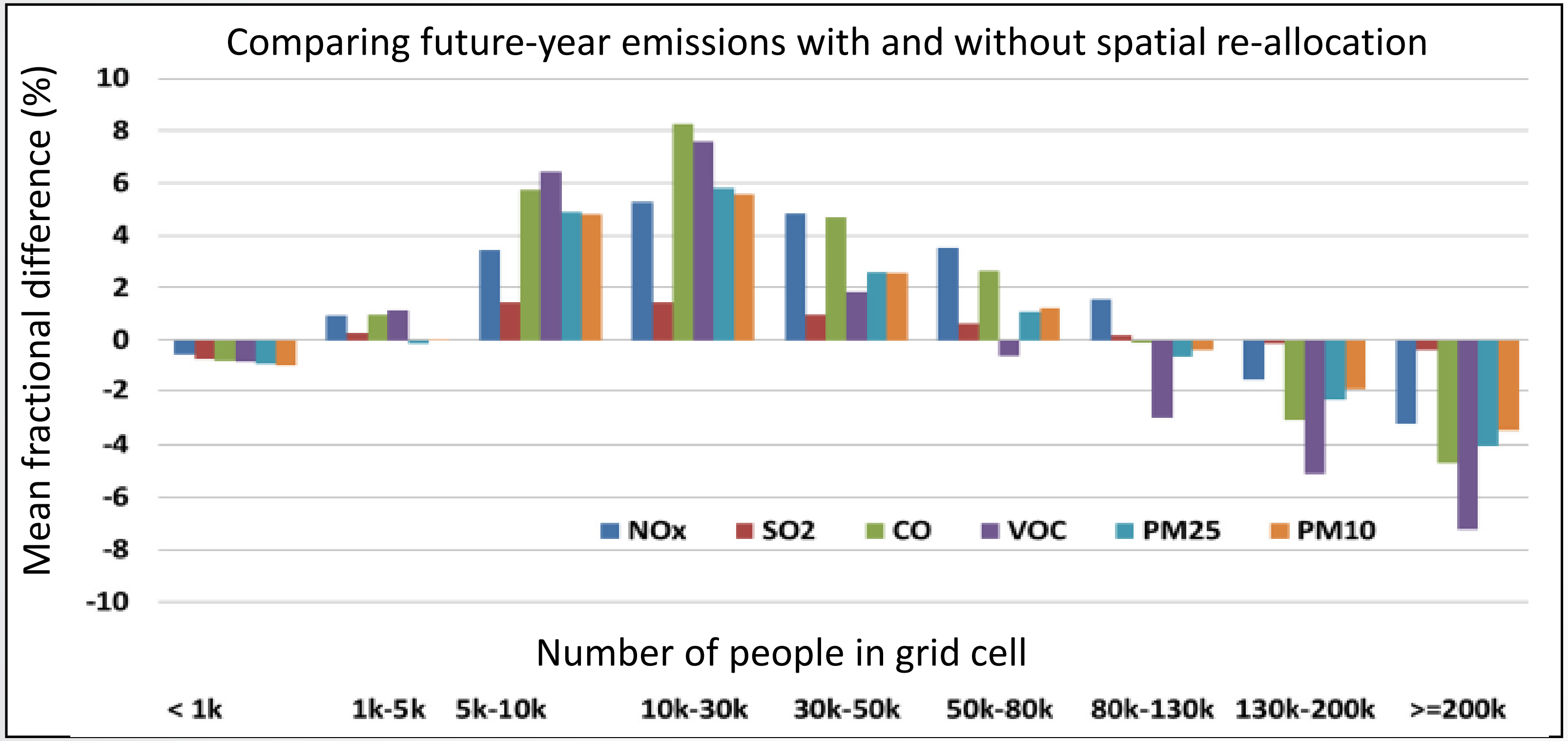
Part 1. Emission Scenario Projection

- ESPv2.0 (2015), cont'd

Application:

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



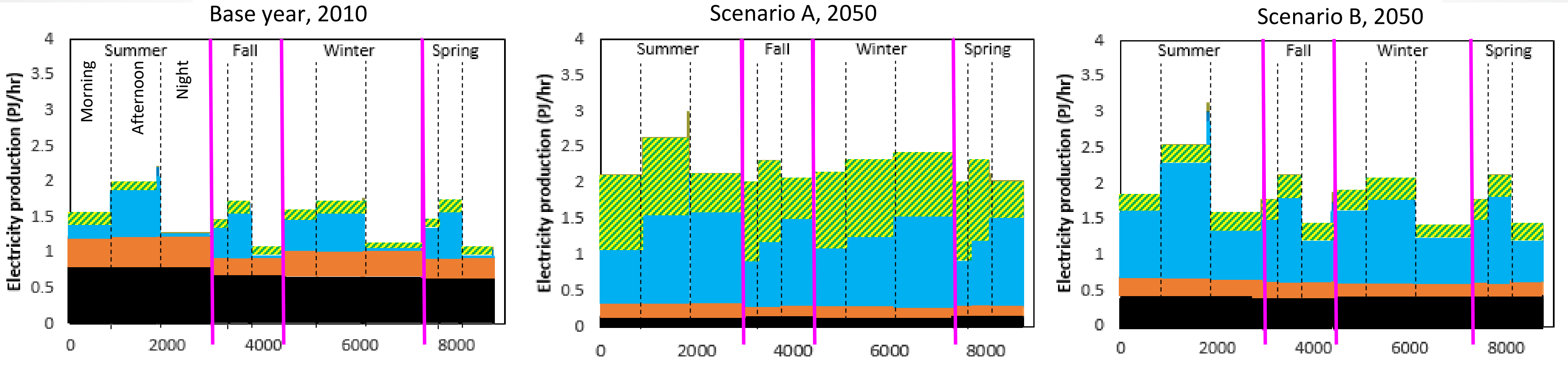
Emissions show relative increases in counties with moderate population density, but decreases in rural and urban areas.

Ran, L., Loughlin, D.H., Yang, D., Adelman, Z., Baek, B.H., and C. Nolte (2015). "ESP2.0: enhanced method for exploring emission impacts of future scenarios in the United States – addressing spatial allocation." *Geoscientific Model Development*, *8,* 1775-1787.

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

Legend
Renewables
Natural gas
Nuclear
Coal



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

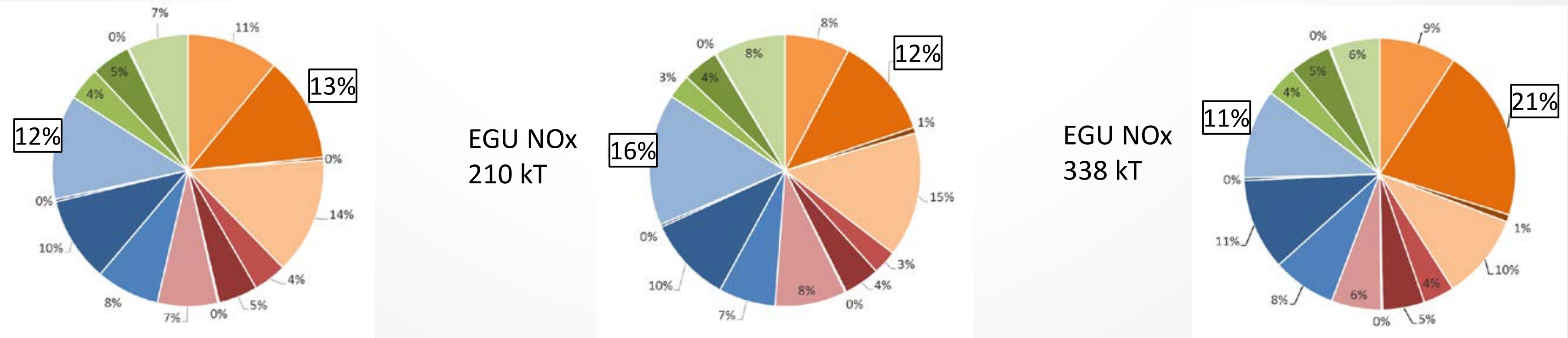
Legend
Summer AM
Summer PM
Summer Peak
Summer Night
Fall AM
Fall PM
Fall Peak
Fall Night
Winter AM
Winter PM
Winter Peak
Winter Night
Spring AM
Spring PM
Spring Peak
Spring Night

EGU NOx apportioned by time slice

EGU NOx 2770 kT

EGU NOx 210 kT

EGU NOx 338 kT

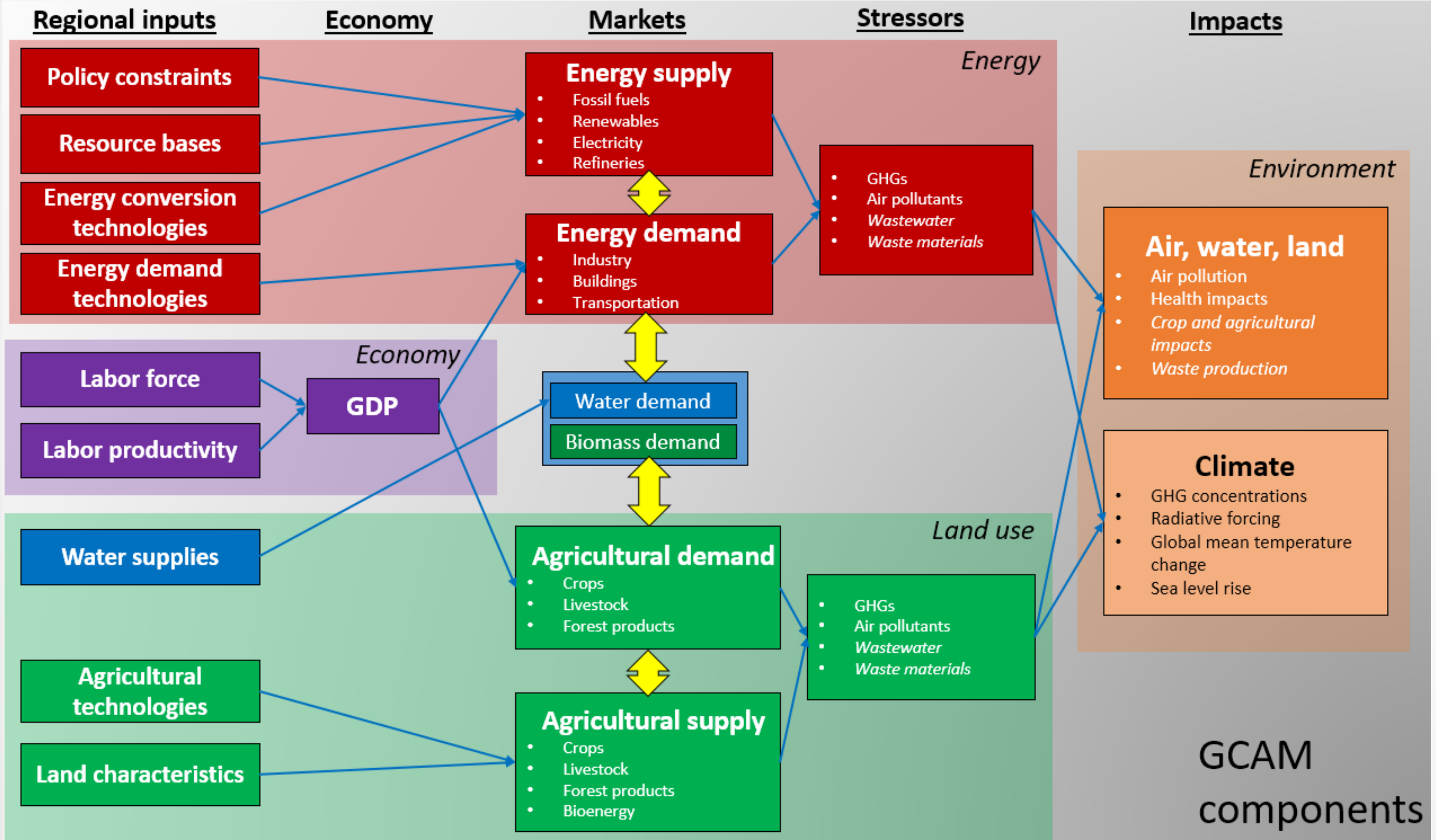


Illustrative results

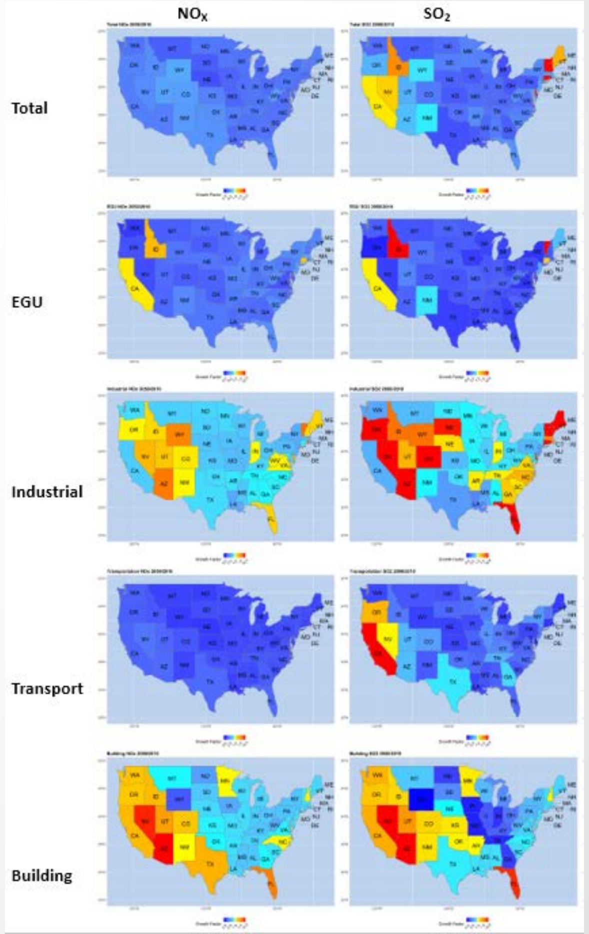
Part 1. Emission Scenario Projection

Illustrative results

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



State-level, sectoral emission growth factors



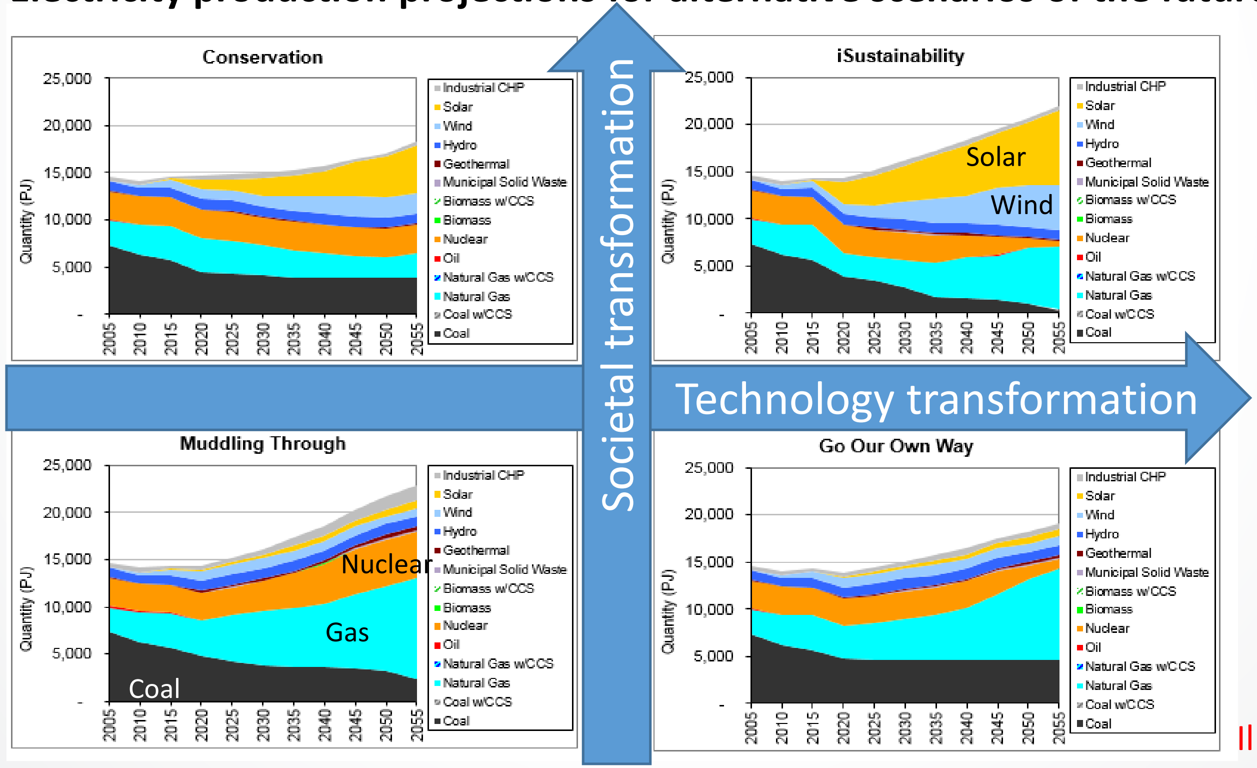
Italics represent possible additions

Adapted from graphic supplied by PNNL

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

Gamas, J., Dodder, R., Loughlin, D.H. and C. Gage (2015). "Role of future scenarios in understanding deep uncertainty in long-term air quality management." *Journal of the Air & Waste Management Association*, 65(11), 1327-1340.

Part 1. Emission Scenario Projection

- Also under consideration for ESPv3.0
  - 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
  - Impact factors estimate 1st order environmental effects of emissions
    - $PM_{2.5}$ mortality costs
    - O_3 mortality costs
    - Crop and timber damage due to ozone
    - Damages from N deposition
  - Water supply constraints on the evolution of the energy system
- Wish list for a future version of ESP: ESPvX?
  - Site new emission sources
  - Dynamic road networks with attributes (capacity, speed, travel demand) that interact in land use and population modeling

Part 2.
Scenarios and Life Cycle Analysis

Part 2. Scenarios and Life Cycle Analysis

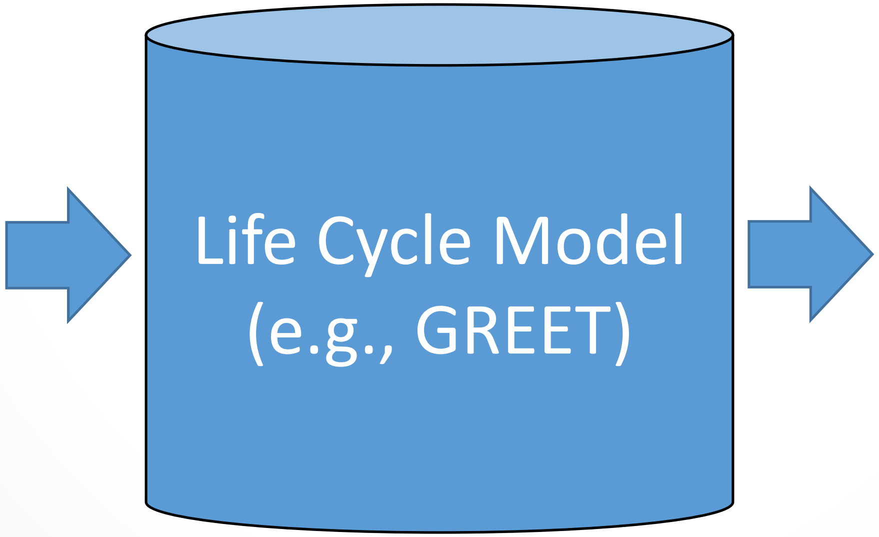
- One type of Life Cycle Analysis:

Compare the net life cycle impacts of competing technologies

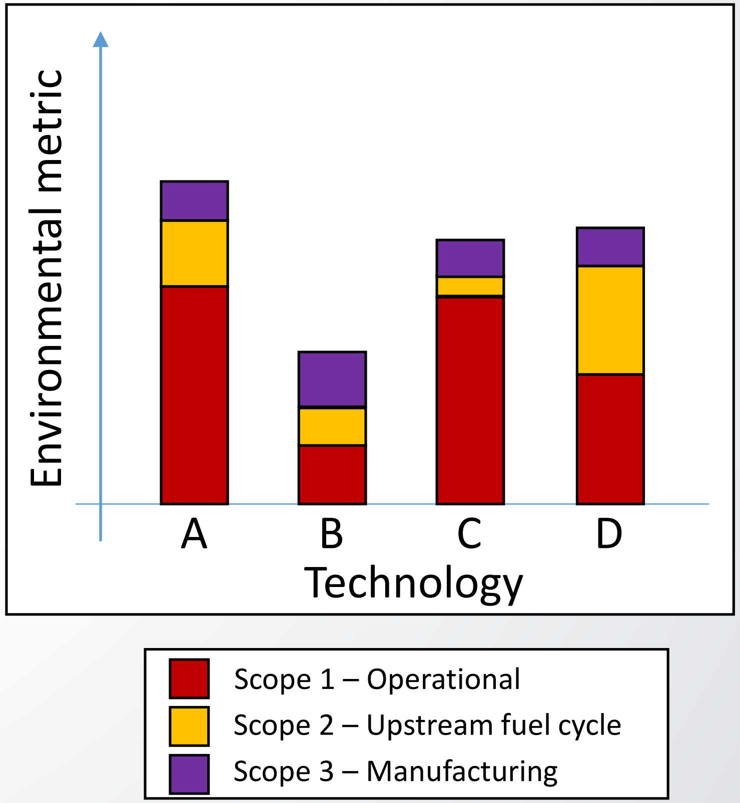
Assumptions
Future-year electric grid mix
Technology characteristics
- efficiency
- emission factors
- fuels

Upstream technologies
(e.g., transportation, conversion, manufacturing)
- mix
- efficiency
- emission factors
- fuels

Fuels
- origin (un/conventional)
- composition



Comparison of four technologies



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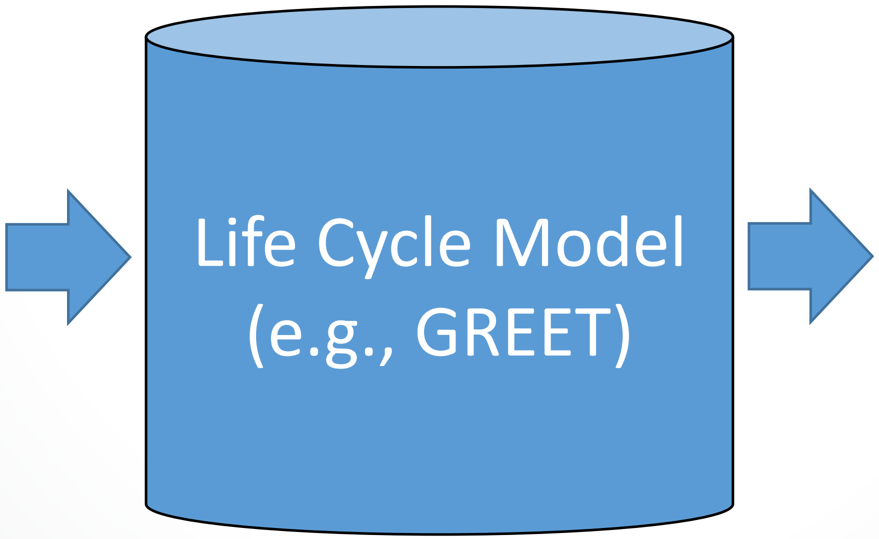
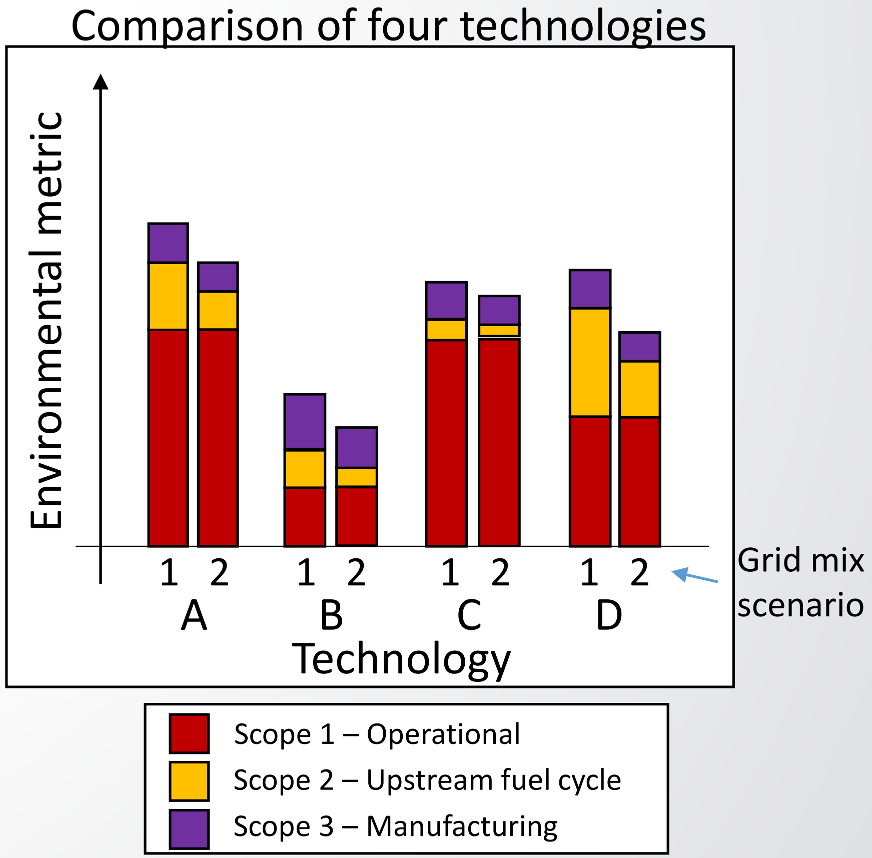




Part 2. Scenarios and Life Cycle Analysis

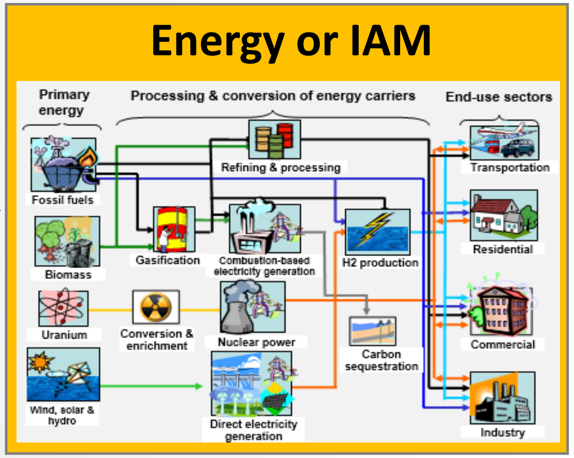
- Some limitations
  - Stationarity of system
    - Evaluates impact of the technology, considering fixed set of electric grid and fuel chain assumptions
    - What if adoption of the technology is widespread? Those specific conditions may change
  - Example: Widespread adoption of electric vehicles
    - 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 light-weighting, 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
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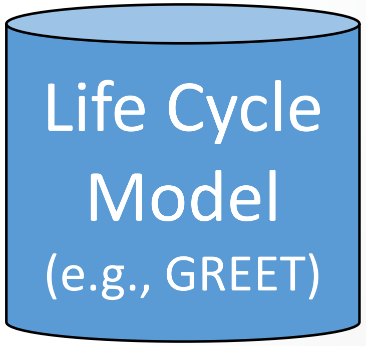
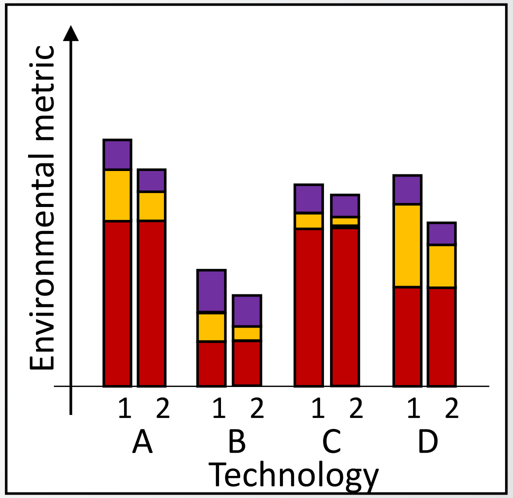


Comparison of four technologies



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

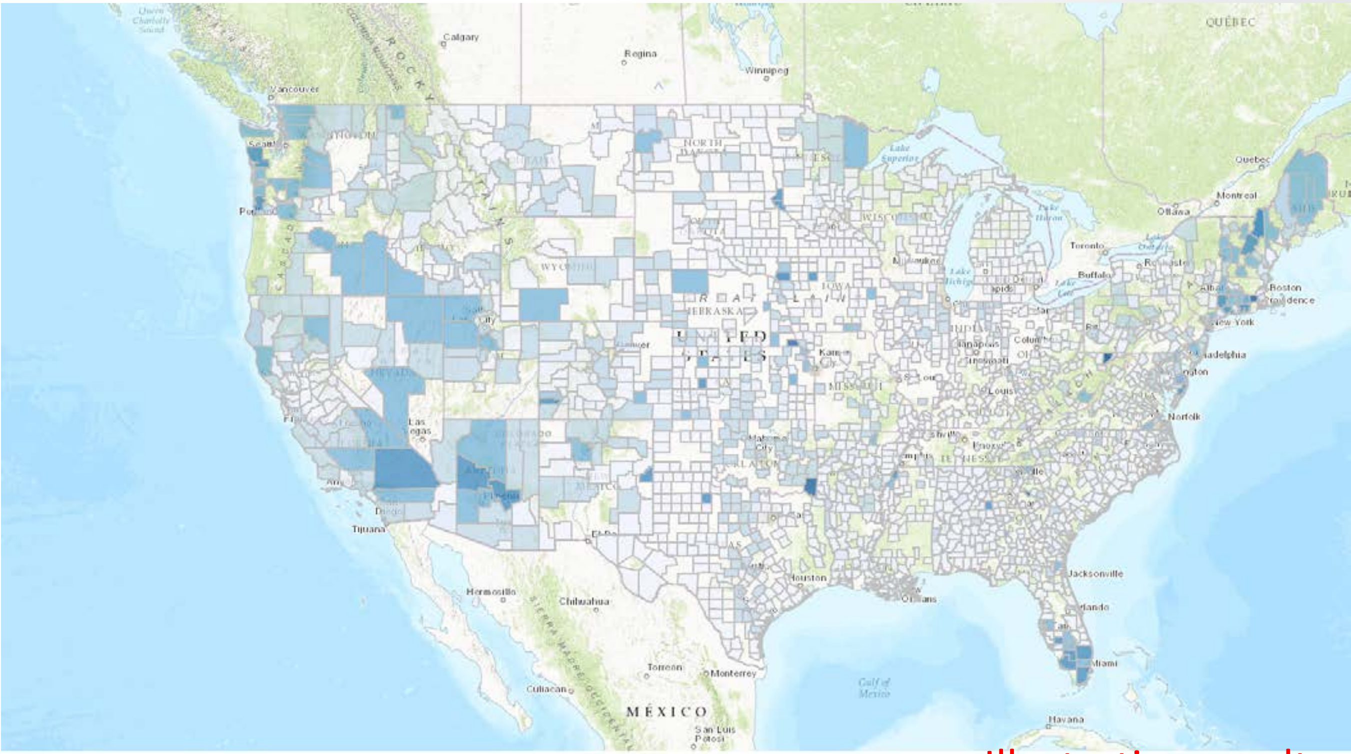
Example

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

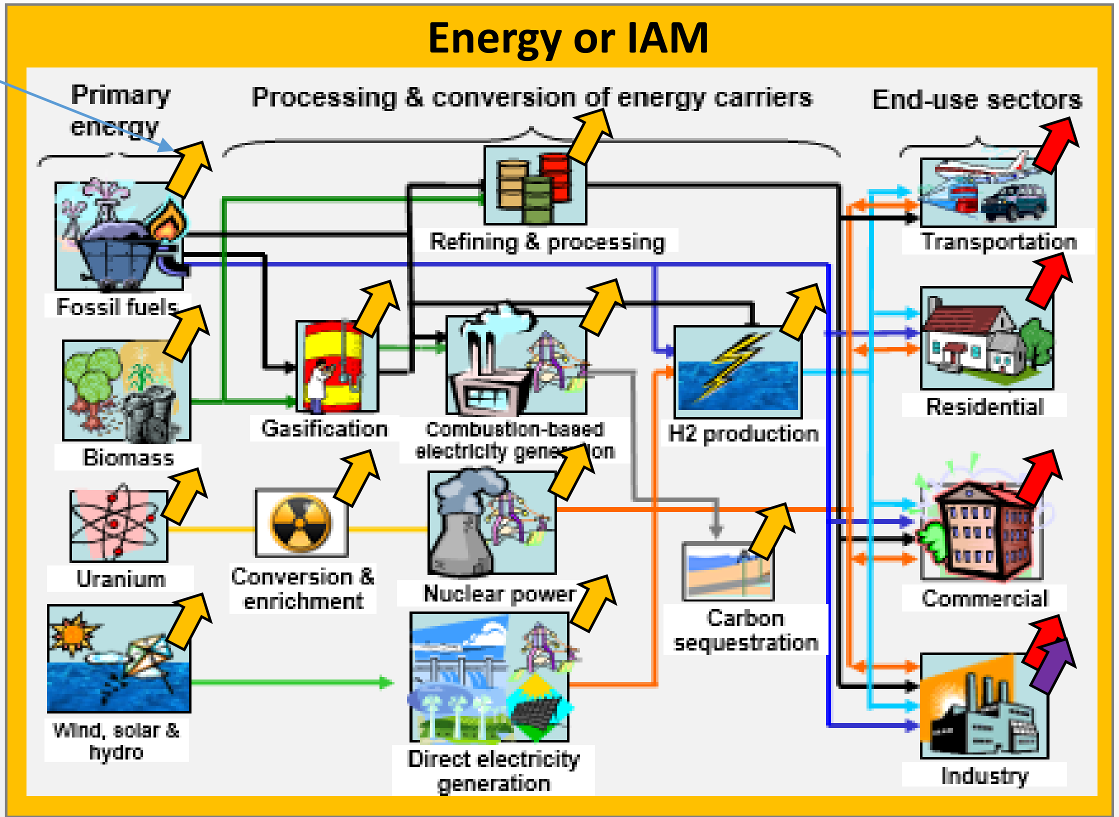
Part 2. Scenarios and Life Cycle Analysis

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

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

LC factors

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



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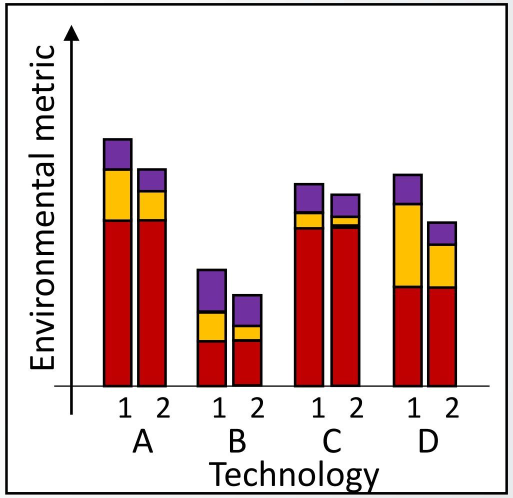

ESP Spatial and temporal allocation

Analysis of emissions

Emissions and air quality modeling

Summary

- 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:

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Abbreviations

- AEZ – Agricultural Economic Zone
- BAU – Business As Usual
- CAMx – Comprehensive Air Quality Model with Extensions
- CMAQ – Community Multi-scale Air Quality model
- CO_2 – 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
- O_3 – 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