Energy Modeling Capabilities in ORD's Air, Climate and Energy (ACE) Program

Presentation to ACE Centers Kick-Off Meeting

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Office of Research and Development

U.S. Environmental Protection Agency

Goals

- Provide an overview of energy modeling efforts in ORD
- Describe models and tools available
- Provide a snapshot of different analyses and audiences

"You are here"

Office of Research and Development

Air, Climate and Energy (ACE) National Research Program

- Climate Impacts, Vulnerability, and Adaptation (CIVA)
- Protecting Environmental Public Health and Wellbeing (PEP)
- Atmospheric and Integrated Modeling Systems (AIMS)
- Emissions and Measurements (EM)
- **Sustainable Energy and Mitigation (SEM)**

The research in the SEM topic area relies on an integrative approach to bring together data and analyses to evaluate and assess the environmental impacts of energy from the systems and lifecycle viewpoint, including dynamics between the energy sectors and crossing the energy continuum from extraction to end-use.

Motivation

- ***WHY?*** *The production and use of energy touches on multiple aspects of our economy and our lives and has a highly diverse and complex set of impacts on the environment. There is also deep uncertainty regarding how our energy system will unfold over time.*
- **A long-range energy systems approach can address:**
  - interactions among sectors
  - impacts across media
  - trade-offs and co-benefits
  - deep uncertainty
  - technology breakthroughs
- **We do analyses for specific Program and Regional Office needs and build capacity to address cross program office questions**

Energy modeling in ORD

We provide the long-view on energy to support near-term decision-making

Providing longer-range capabilities to address future questions that will come down the pipeline

More near-term, directly relevant hand-off to partners

Working with EPA partners using energy system modeling tools

Collaborative work with EPA Program and Regional Offices on air and climate-related analysis

Providing tools and databases for external users

Developing new frameworks

Exploring and enhancing new tools, such as GCAM

Moving to new scales of analyses

Enhancing our MARKAL modeling: water-energy, coupling with LCA

Enhancing the long view on the environmental implications of our changing energy system

Assessing cross sector, multimedia, life cycle impacts of our actions

Providing foresight regarding potential trade-offs, co-benefits and surprises

Energy modeling tools and analyses

Tools, Decision Support Systems and Methods

MARKAL/TIMES
Community scale MARKAL
GCAM-USA
ESP2.0

Policy Analysis

Air quality futures,
Marginal Abatement Curves,
RPS

Emerging Topics

Agriculture-energy nexus
Water-energy nexus
LCA-energy system integration

Tools, Decision Support Systems and Methods

MARKAL energy model

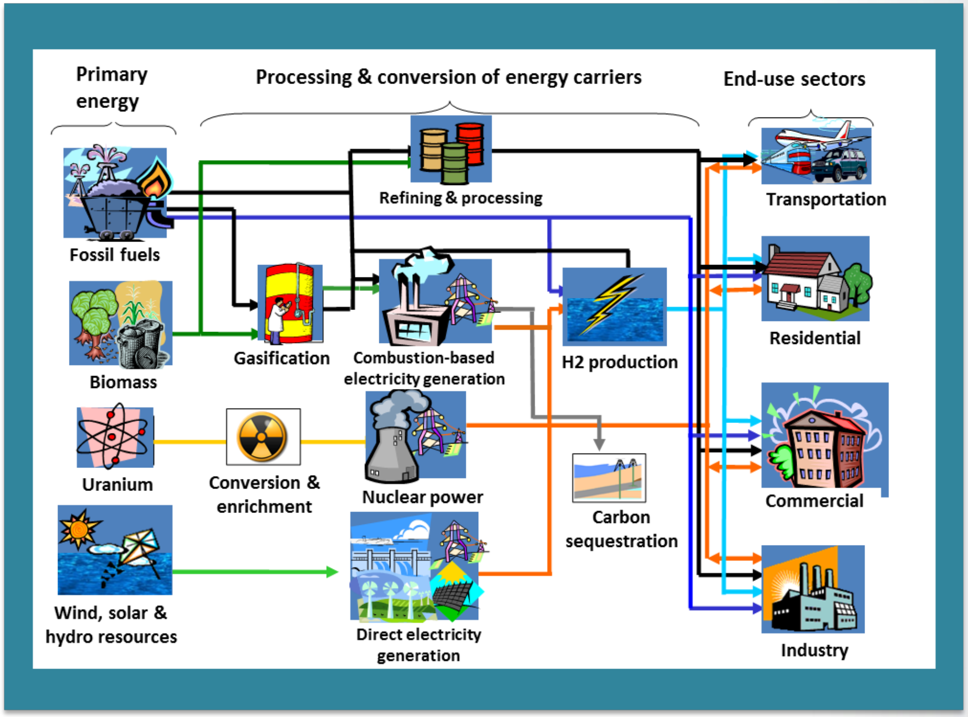
Community scale MARKAL

GCAM-USA

ESP2.0

Energy system model: MARKAL

- **Bottom-up** and **technology-rich**
  - Captures the full **system** from energy resource supply/extraction technologies to end-use technologies in all sectors
  - **Energy technologies** (existing and future techs) are characterized by cost, efficiency, fuel inputs, emissions
  - Technologies are connected by **energy flows**
- **Optimization**
  - The model picks the "best" way (lowest system-wide cost) to meet energy demands choosing from the full "menu" of energy resources and technologies
  - The model makes these choices from 2005 to 2055, giving us a snapshot of possible future energy mixes



- **Emissions and impacts**
  - All technologies and fuels have air and GHG emissions characterized
  - Standards and regulations are included in the baseline, and additional policies can be modeled

Internal and external publication using EPA's MARKAL framework

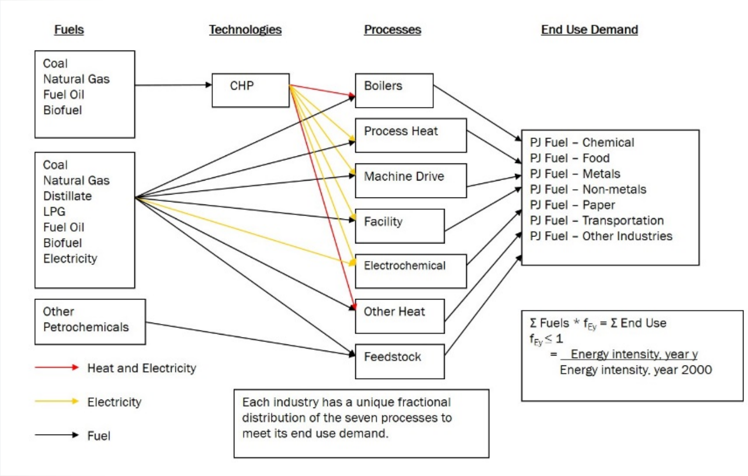
Peer-reviewed publications in 2015 (through Oct.)

Stanford	•	Bistline, J.E. (2015). Electric sector capacity planning under uncertainty: Climate policy and natural gas in the US. *Energy Economics*, 51(Sept), pp. 236-251. doi: 10.1016/j.eneco.2015.07.008.
Wash. St.	•	Gonzalez-Abraham, R., Avise, J., Chung, S.H., Lamb, B., Lalathe Jr., E.P., Nolte, C.G., Loughlin, D., Guenther, A., Wiedinmyer, C., Duhl, T., Zhang, Y., and Streets, D.G. (2015). The effects of global change upon United States Air Quality. *Atmospheric Chemistry and Physics* (Accepted for publication).
DOE-NETL	•	Nichols, C., and Victor, N. (2015). Examining the relationship between shale gas production and carbon capture and storage under CO2 taxes based on the social cost of carbon. *Energy Strategy Reviews*, 7(April 2015), pp 39-54. doi: 10.1016/j.esr.2015.03.005
Ga. Tech.	•	Trail, M., Tsimpidi, A.P., Liu, P., Tsigaridis, K., Hu, Y., Nenes, A., Stone, B., and Russell, A.G. (2015). Reforestation and crop land conversion impacts on future regional air quality in the Southeastern U.S. *Agricultural and Forest Meteorology*, 209-210: 78-86. doi: 10.1016/j.agrformet.2015.05.001
Iowa St.	•	Elobeid, A. (2015). Capturing dynamic linkages between agriculture and energy in biofuel assessment: The case of Iowa. *Agricultural Policy Review*. Vol. 2015(2/2). http://lib.dr.iastate.edu/agpolicyreview/vol2015/iss2/2/ (Accessed 8/26/15)
ORD	•	Aitken, M., Loughlin, D.H., Dodder, R., and Yelverton, W. (2015). Economic and environmental evaluation of coal-and-biomass-to-liquids-and-electricity plants equipped with carbon capture and storage. *Clean Technology and Environmental Policy*. doi: 10.1007/s10098-015-1020-z
ORD	•	Dodder, R., Kaplan, P.O., Elobeid, A., Tokgoz, S., Secchi, S., and Kurkalova, L.A. (2015) Impact of energy prices and cellulosic biomass supply on agriculture, energy and environment: an integrated modeling approach. *Energy Economics* 51:77-87. doi:10.1016/j.eneco.2015.06.008
Purdue	•	O'Rear, E.G., Sarica, K., and Tyner, W.E. (2015). Analysis of impacts of alternative policies aimed at increasing US energy independence and reducing GHG emissions. *Transport Policy*, *37*, 121-133. doi:10.1016/j.tranpol.2014.10.016
OAR/ORD	•	Gamas, J., Dodder, R., Loughlin, D.H. and Gage, C. (2015). Role of future scenarios in understanding deep uncertainty in long-term air quality management. *Journal of the Air & Waste Management Association*. doi: 10.1080/10962247.2015.1084783 (pre-Version of Record)
ORD/OAR	•	Loughlin, D.H., Kaufman, K., Lenox, and Hubbell, B. (2015). Analysis of alternative pathways for reducing nitrogen oxide emissions. *Journal of the Air & Waste Management Association*, *65*(09), 1083-1093. doi: 10.1080/10962247.2015.1062440
UNC-CH	•	Ran, L., Loughlin, D.H., Yang, D., Adelman, Z., Baek, B.H., and Nolte, C.G. (2015). ESP v2.0: enhanced method for exploring emission impacts of future scenarios in the United States - Addressing spatial allocation. *Geoscientific Model Development, 8, 1775-1787*, doi: 10.5194/gmd-8-1775-2015
NESCAUM	•	Rudokas, J., Miller, P.J., Trail, M., and Russell, A. (2015). Regional air quality management aspects of climate change: Impact of climate mitigation options on regional air emissions. *Environmental Science & Technology*, *49(8)*, 5170-5177, doi:10.1021/es505159z
Ga. Tech.	•	Trail, M., Tsimpidi, A.P., Liu, P., Tsigaridis, K., Hu, Y., Rudokas, J., Miller, P.J., Nenes, A., and Russell, T. (2015). Impacts of potential CO2-reduction policies on air quality in the United States. *Environmental Science & Technology*, *49(8)*, 5133-5141, doi:10.1021/acs.est.5b00473

Improved industrial sector representation

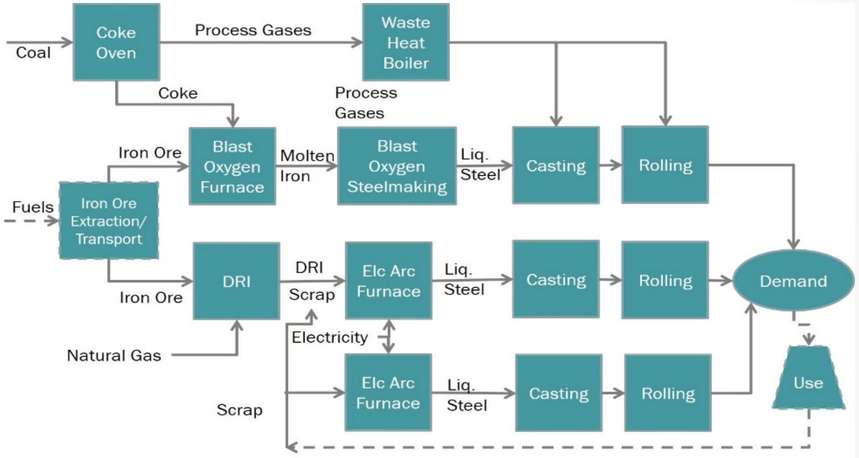
Homogenous modeling → Hybrid modeling

all industrial sectors represented with energy service demands



- Represent 20 energy intense industries at NAICS levels
- SCC as well as NAICS level emissions projection analysis
- Demands are from AEO – Value of shipments translated to total energy demand

facility level modeling allows for structural changes and tracking of both physical goods and energy flows

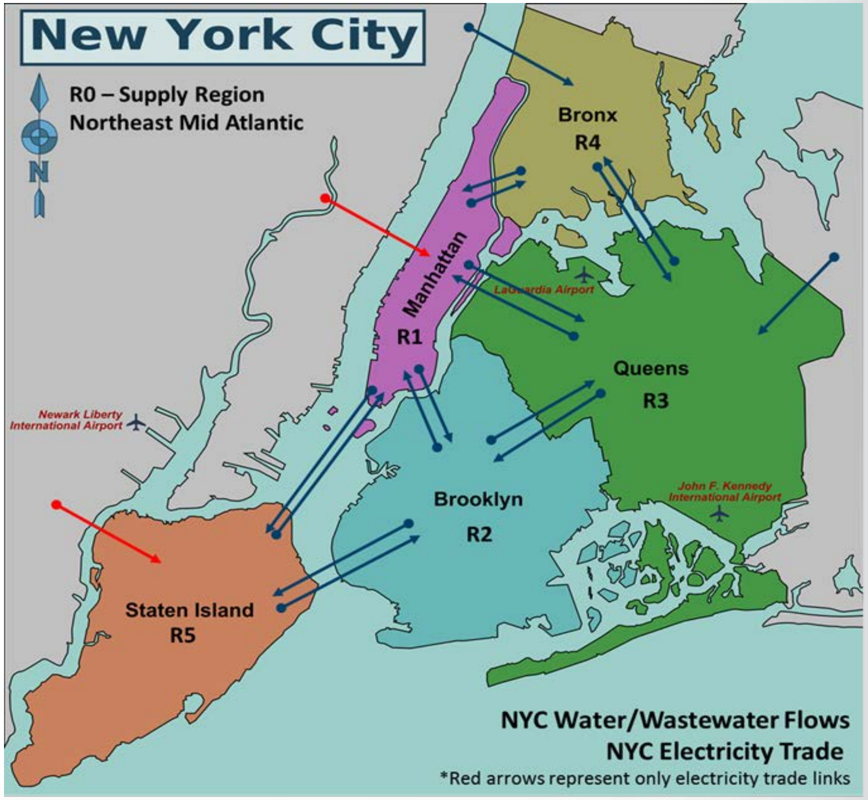


- Represent 20 energy intense industries at NAICS levels with paper, iron and steel, aluminum, cement, and agricultural chemicals represented at facility level with demand projections in tons of goods.
- NAICS level emissions projection analysis
- Developing a linkage between MARKAL with an I/O economic model to simulate structural changes to industry

Community Scale MARKAL Database for New York City: EPANYC5r

Kaplan, P.O. and Kaldunski, B. (2016). An Integrated Approach to Water & Energy Infrastructure Decision Making Using the MARKAL Framework: A Case Study of New York City. *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings in Asilomar, CA., August, 22-26, Paper ID 11-617.*

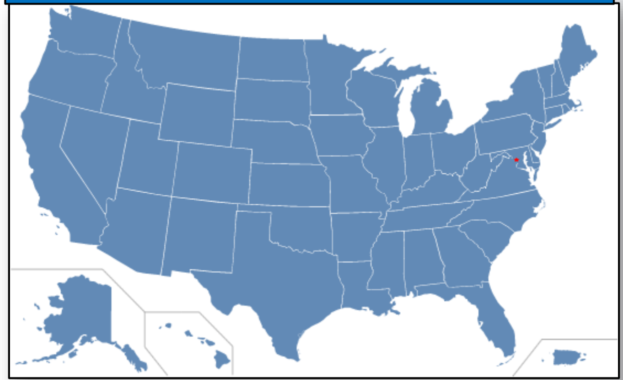
- Goal is to address long-term planning questions and issues related to sustainability, resilience, equity and growth in the **energy and water sectors**:
  - Urban heat island mitigation through peak load shaving
  - Building energy and water technology evaluations
  - Micro grid and distributed energy applications
  - Resilience to sea level rise and storm surge
  - Energy and water infrastructure planning
    - Buildings, EGUs, transportation
- **Why NYC?**
  - Immense availability of data required for energy-water nexus modeling (PlutoDB, PlaNYC, NYC GHG Inventory)
  - Early adopter of GHG reduction goals,
  - Awareness of vulnerabilities to climate change
  - Ongoing activities in resilience efforts.



Ventures in integrated assessment models

- **The Global Change Assessment Model (GCAM)**
  - Developed by Pacific Northwest National Laboratory
  - 5-year time steps, extending from 2005 to 2100
  - Technology-rich energy system detail
  - Pollutant species
    - Climate forcers: CO_2, CH_4, SO_2, N_2O, BC, OC, HFCs
    - Air pollutants: NO_x, SO_2, VOC, CO, NH_3, direct PM
  - Open source and freely available, 1 hour runtime
  - *Working with PNNL to better represent emissions factors and control options for EGU and industrial sector emissions*

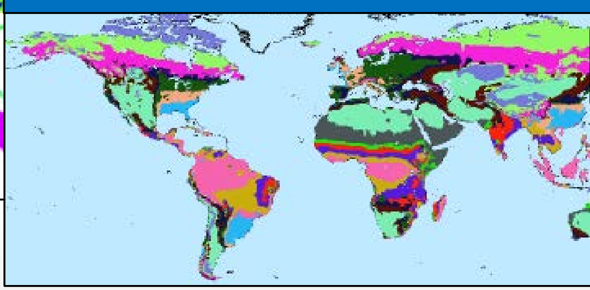
GCAM-USA 50-state U.S. energy system



32 economic and energy regions

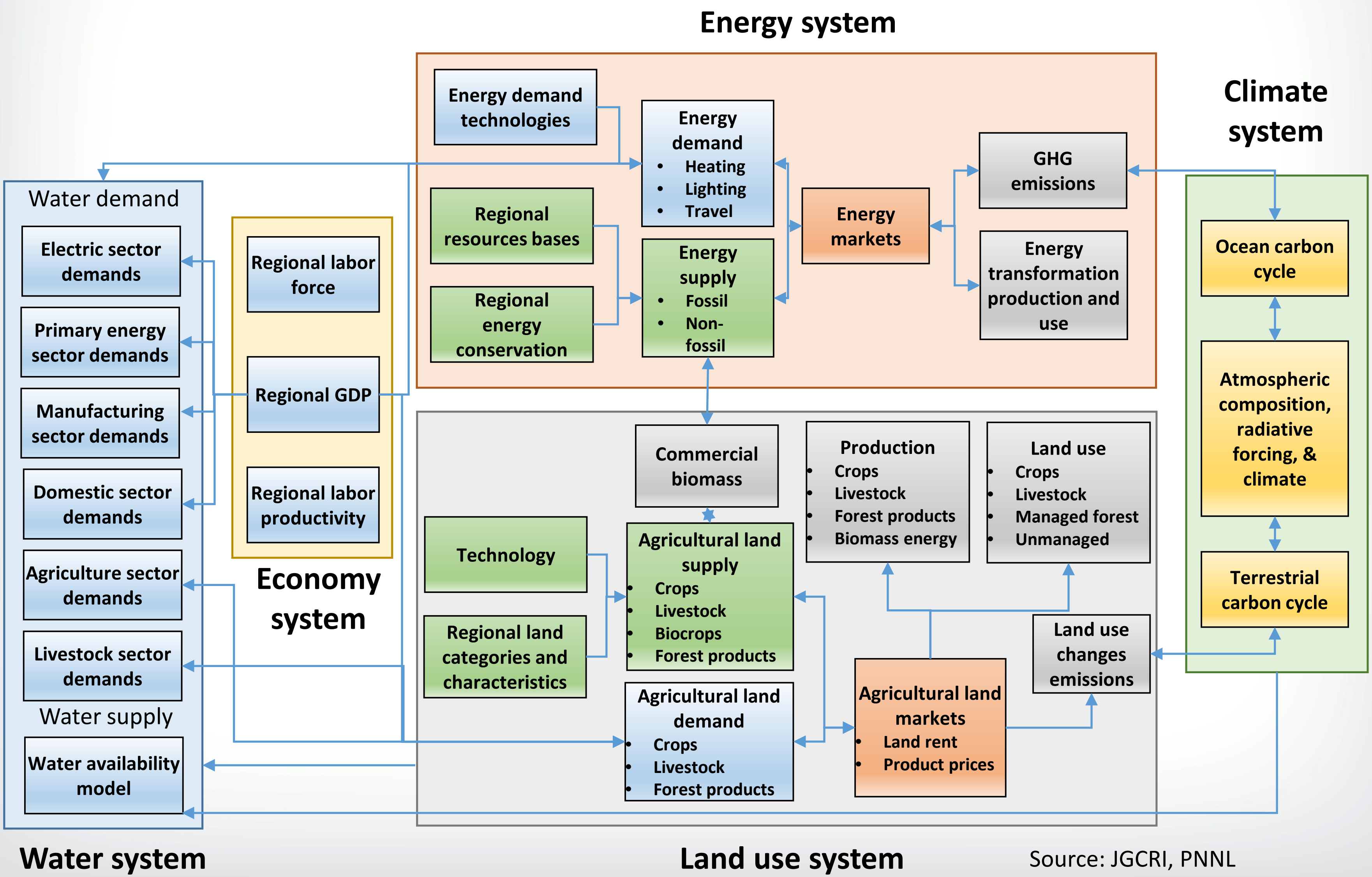
Source: JGCRI, PNNL

283 agriculture and land use regions



233 water basins

GCAM-USA Components



Source: JGCRI, PNNL

Technology assessment with MARKAL and GCAM-USA

- From a technology assessment standpoint, MARKAL and GCAM-USA let us:
  - examine the market penetration potential of new and emerging technologies
  - identify performance "tipping points" that lead to market competitiveness
  - examine technologies under very different contexts

    (e.g., alternative assumptions about oil prices, CO2 targets, economic growth, water availability)
  - characterize a wide range of system-wide impacts

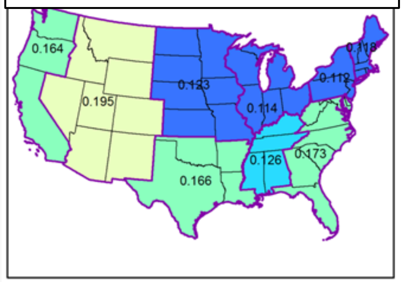
    (e.g., CAPs, SLCFs and GHGs, 1st order health and crop damages)
- Potential utility
  - prioritize technologies for detailed sector-specific modeling
  - produce penetration scenarios as basis for broader impact assessments

	MARKAL	GCAM-USA
Type	Optimization (How should I?)	Simulation (What might happen if?)
Foresight	Perfect	Myopic
Spatial	U.S., Census Div. resolution	Global, state-level resolution
Temporal	2005-2055	2010-2100
Sectoral	Energy system	Energy, ag., land use, climate
Technologies	High number	Medium number

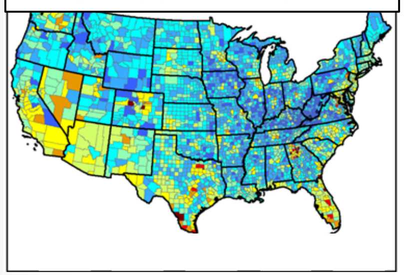
ESP2.0: Emission projections including spatial redistribution

Ran, L., Loughlin, D.H., Yang, D., Adelman, Z., Baek, B.H., Nolte, C., and W.G. Benjey (2015). "ESP2.0: Revised methodology for exploring emission impacts of future scenarios in the United States – Addressing spatial allocation." *Geoscientific Model Development, 8*, 1775-1787, doi: 10.5194/gmd-8-1775-2015

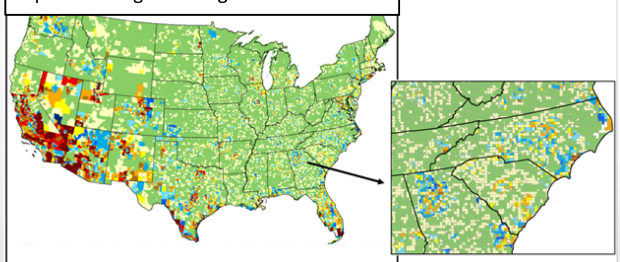
Regional emission growth factors



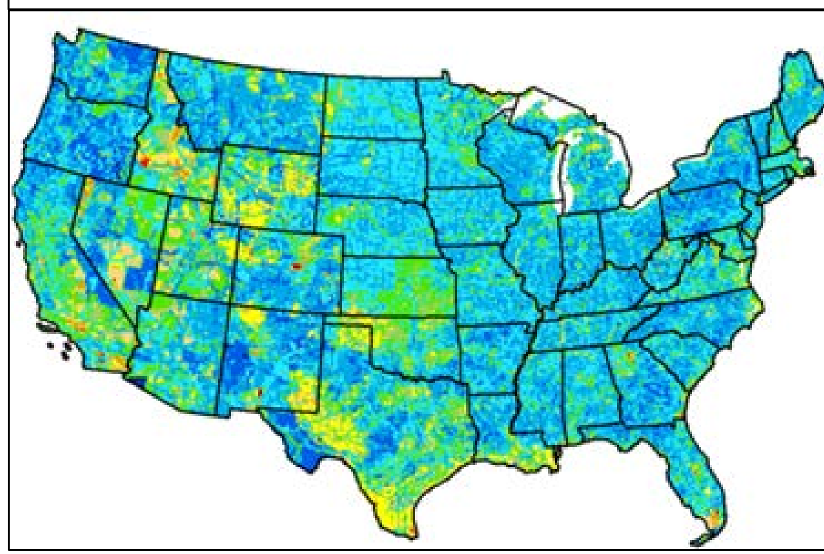
County-level population changes



Spatial surrogate changes



Future-year, spatially re-distributed inventory



Policy Analysis

Air Quality Futures

Marginal Abatement Curves

Energy Modeling Forum: Natural Gas Study

Renewable Portfolio Standards

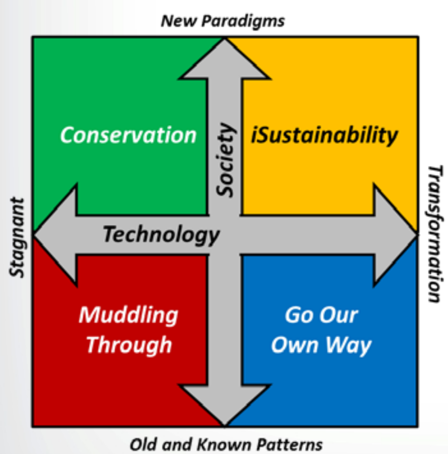
Air quality futures

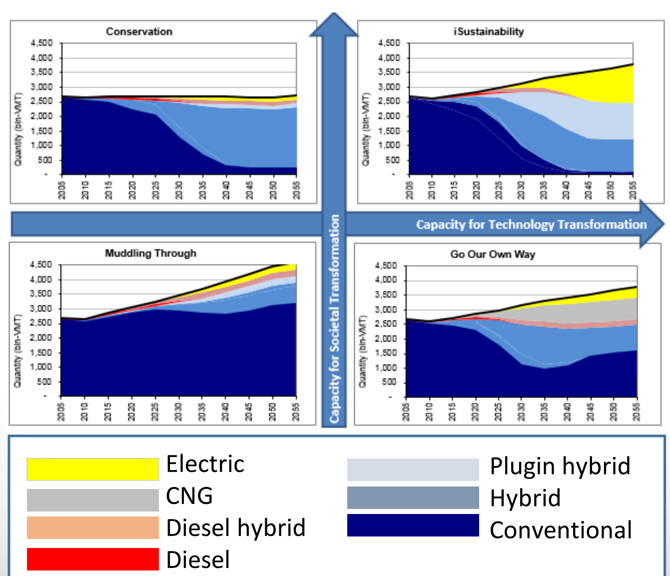
Gamas, J., Dodder, R., Loughlin, D.H. and C. Gage (2015). "Role of future scenarios in understanding deep uncertainty in long-term air quality management." *Journal of the Air & Waste Management Association*, 65(11), 1327-1340. doi: 10.1080/10962247.2015.1084783

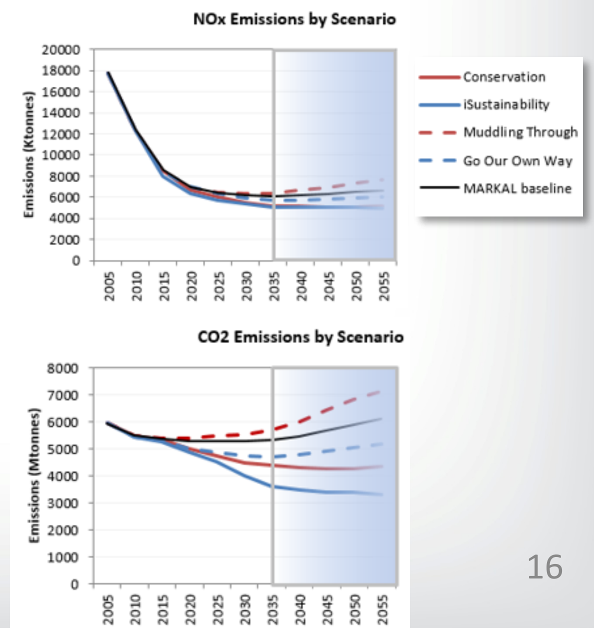
Working with OAQPS, we developed qualitative narratives for alternative futures

- Kicked-off with a co-organized workshop on scenario planning
- Explored robust strategies for air quality management to perform well across a range of futures
- Translated these "future scenarios" into modeled changes in future emissions

Four future scenarios → ***Technology and fuel mixes for all sectors*** → ***Air emissions***





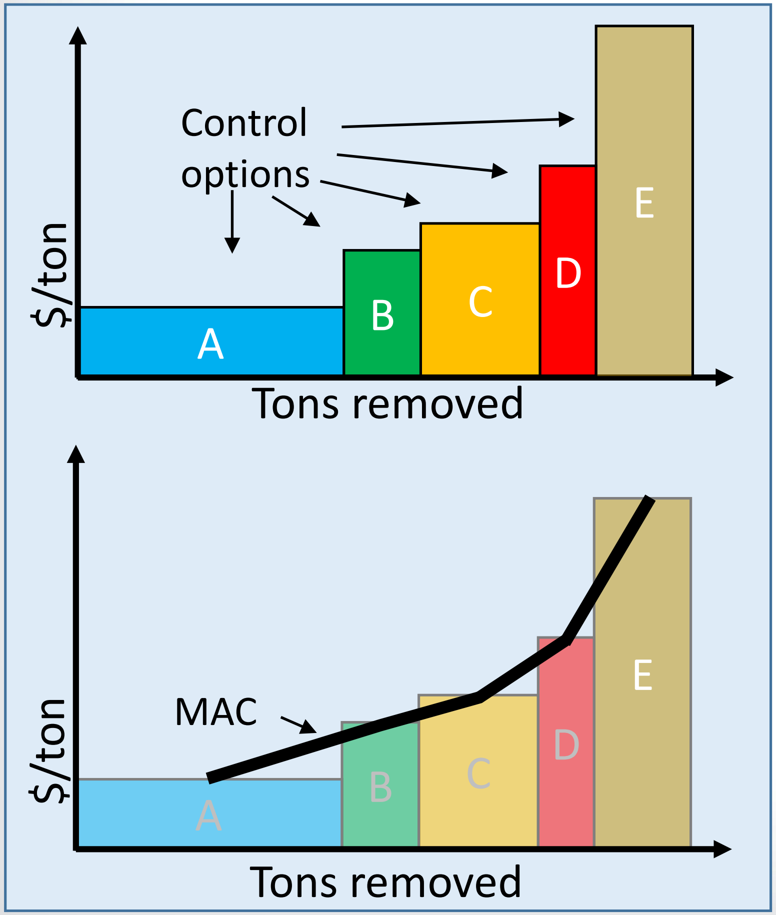


Illustrative results

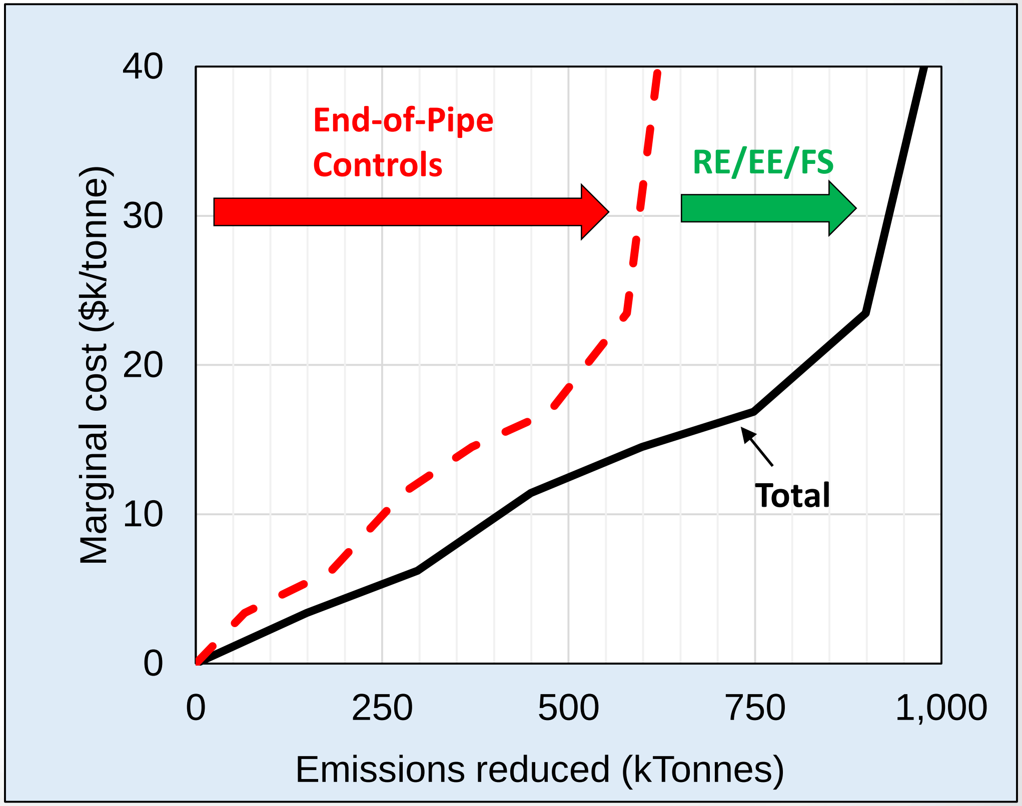
Marginal abatement curves

Loughlin, D.H., Kaufman, K., and A. Macpherson. "Characterization of a marginal abatement cost curve for NOx that incorporates control measures, renewable energy, energy efficiency and fuel switching." In *Proceedings of A&WMA's 108th Annual Conference and Exhibition, Raleigh, N.C. June 22-25, 2015.*

Background: Marginal Abatement Curves



National MAC, with additional reductions via Renewable Electricity, Energy Efficiency and Fuel Switching (RE/EE/FS)

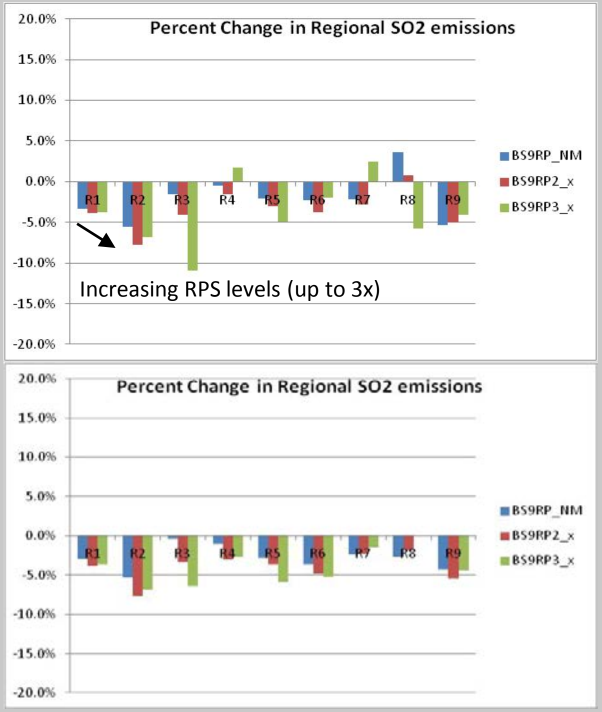


Illustrative results

Energy and emissions implications of Renewable Portfolio Standards

- **Background:** Assessing the energy system-wide changes related to RPS and associated emissions changes
- **Approach taken:**
  - MARKAL model scenarios look at the system-wide implications of RPS at the regional level
  - The scenarios were run to analyze the CO_2, NO_x, and SO_2 emissions changes from current RPS policy levels and increased RPS goals (up to 3x current regional share of renewables with a max of 50% renewables)
- **Results:** The analysis highlighted the model assumptions and choices that affect criteria pollutant emissions. These include:
  - Limits to electricity trading between regions
  - Assumptions about the cost and penetration of industrial CHP
  - Assumptions about the use of SO_2 and NO_x controls on existing coal facilities
  - Results highlights the importance of renewable technology choices and the potential for increases in NO_x and SO_2 under some scenarios in some regions

Differences in SO_2 emissions for increasing levels of RPS when different assumptions are made about **SO_2 controls** and which techs meet the RPS in the electric sector



Emerging Topics

Biomass and Biofuels

Water-Energy Nexus

LCA-Energy Integration

Biomass, biofuels & agriculture

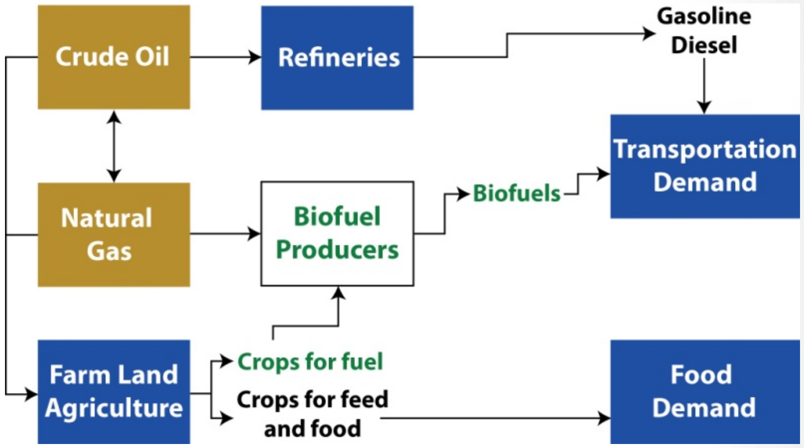
Agricultural and energy markets are more tightly linked through biofuels

Understanding the market dynamics

- Collaboration between energy modelers and agricultural economists
- Energy (e.g., oil) and agriculture (e.g., corn) interact through markets for transportation fuels and inputs to agricultural production
- Alternative scenarios of energy prices and availability of advanced cellulosic biofuels affect corn markets and total CO_2 benefits

Translating this into environmental impacts

- Farm-level production decisions are affected by fuel prices and crop prices
- Prices from our integrated scenarios feed them into models of land use and land management
- Outputs can be multimedia



Elobeid, A., et al. 2013. Integration of agricultural and energy system models for biofuel assessment. *Environmental Modelling and Software*

Dodder, R.S., et al. 2015. Impact of energy prices and cellulosic biomass supply on agriculture, energy and environment: an integrated modeling approach. *Energy Economics.*

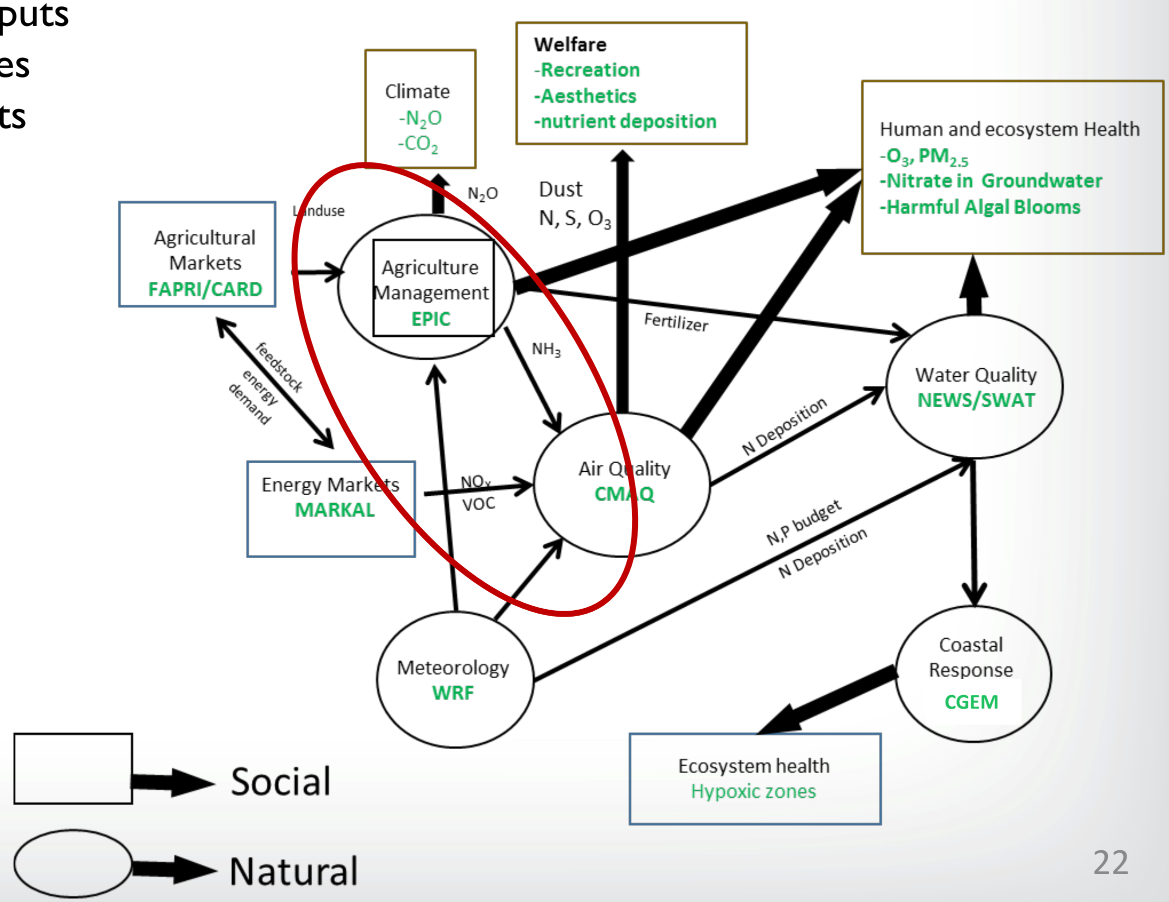
Cooter, E., et al. 2015. Integrated Multimedia Modeling System Response to Regional Land Management Change. *American Geophysical Union (AGU) Fall Meeting.*

Secchi, S., et al. (under review) The potential of continuous no till carbon offsets as a climate mitigation strategy.

Translating between models

Linking techno-economic modeling of energy and agricultural markets to models of natural systems

- Integration of the markets models provides multiple inputs to EPIC and CMAQ
- Challenges are in translation of outputs
    - Providing land use, yields, prices as "internally consistent" inputs
    - Lots of moving pieces:
        - Siting decisions for biofuels plants
        - Emissions changes
        - Land use change and management

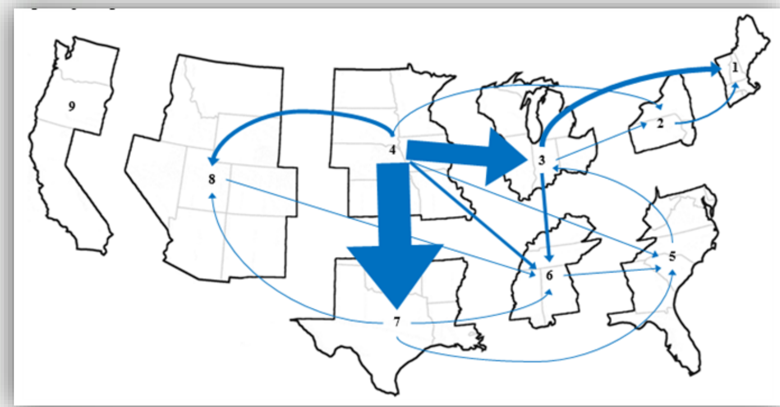


FAPRI/CARD: Food and Agricultural Policy Research Institute/Center for Agricultural and Rural Development (Iowa State Uni)
EPIC: Environmental Policy Integrated Climate Model (USDA)
MARKAL: MARKet ALlocation model – US 9-region database (EPA)
CMAQ: Community Multiscale Air Quality (EPA)
WRF: Weather Research Forecast (NCAR)
NEWS: Nutrient Export from Watersheds (Washington State Univ)
SWAT: Soil and Water Assessment Tool
CGEM: Coastal Gulf Ecology Model (EPA)

Water-energy nexus

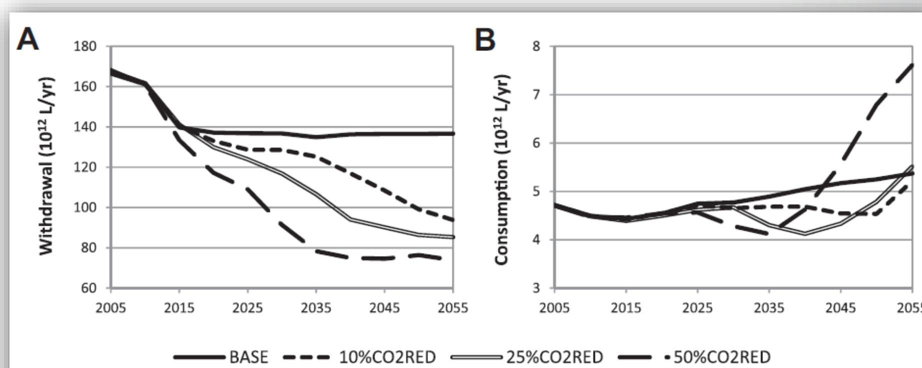
As the energy system changes, so will the water demands...

regional water intensity of energy production as well as **virtual transfers of water** between regions



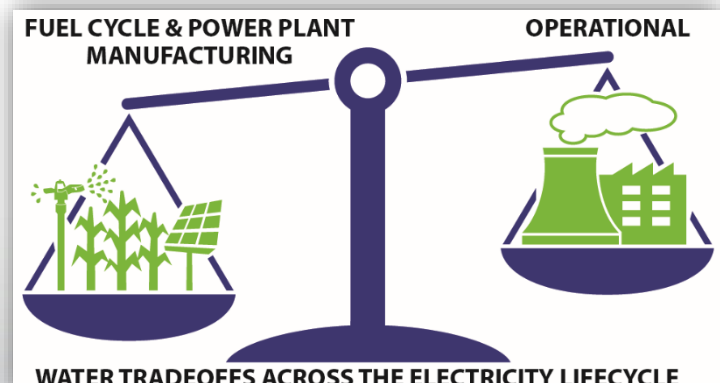
Dodder, R., et al. 2011. Water and greenhouse gas tradeoffs associated with a transition to a low carbon transportation system. *Proceedings of IMECE2011*

tradeoffs in **withdrawals** and **consumption** for electric power



Cameron, C., et al. 2014. Strategic responses to CO_2 emission reduction targets drive shift in U.S. electric sector water use. *Energy Strategy Reviews*

tradeoffs across the **electricity life cycle**, some of which are highly uncertain for new generation technologies



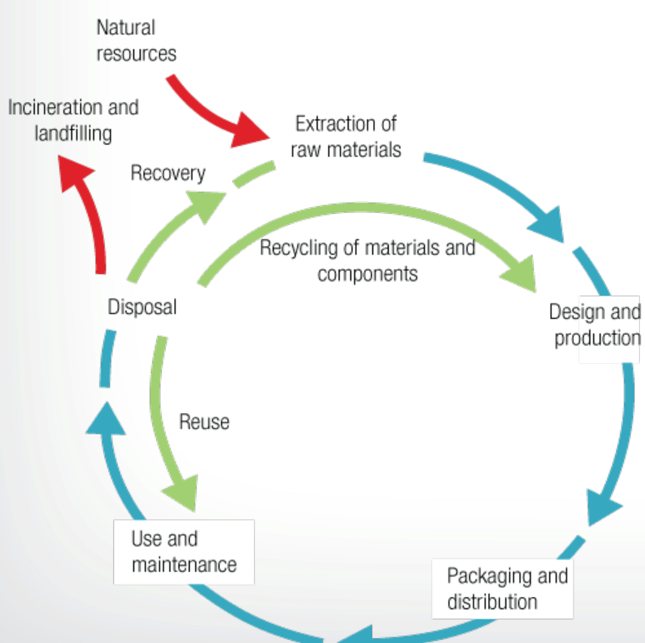
Dodder, R., et al. (revisions pending). Scenarios for low carbon and low water electric power plant operations: implications for upstream water use. *ES&T*

LCI and LCIA

Bridging Life Cycle Assessment and Energy Modeling

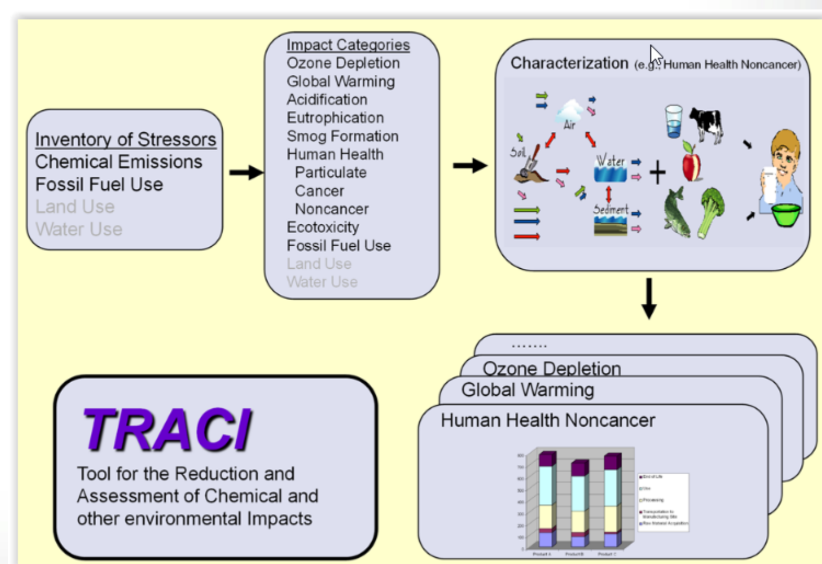
Life Cycle Inventory (**LCI**):

Updated information for power and transportation technologies, to better understand upstream demands (e.g., raw materials) of energy systems



Life Cycle Impact Assessment (**LCIA**)

New, spatially resolved factors for acidification and eutrophication (e.g., applicable to NOx emissions from power or transport)



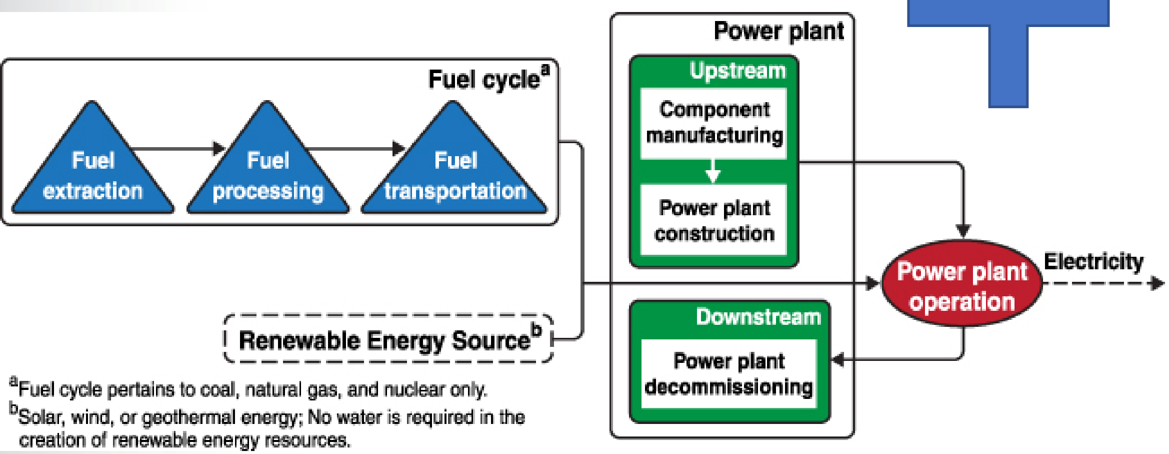
Source: http://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/

LCA and energy modeling

Bridging Life Cycle Assessment and Energy Modeling

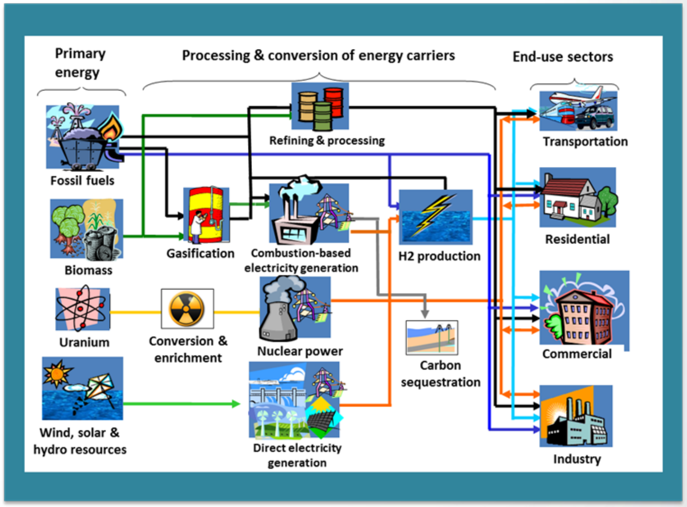
- Collaboration between ORD researchers in RTP and Cincinnati
- **Energy modeling** provides the broader system context and can look at future scenarios
- **LCA** data and tools provide information regarding the environmental impacts associated with all the stages of a product's life from cradle to grave

Life cycle assessment



Source: Meldrum, et al. (2013)

Energy modeling



What are we working on these days?

Technology Assessment

- Updates to GCAM-USA to resolve following limitations
  - Emission factors are function of GDP and do not reflect NSPS; No representation of state-level electric sector emission caps; No end-of-pipe control options for reducing EGU and industrial emissions
- Modeling assessment of natural gas with CCS to examine the penetration potential and broader implications

Community and Regional Decision Support

- Develop case studies with community scale NYC MARKAL

Energy system modeling tools

- TIMES, new version of MARKAL, conversion will bring features currently not employed in MARKAL, such as
  - variable length time periods, flexible time slices and storage processes, investment and dismantling lead-times and costs, commodity related variables, more accurate and realistic depiction of investment cost payments
- Development of industrial emissions growth scenarios
- Work with OTAQ on advanced light-duty vehicles (electrification)

Life cycle assessment of energy technologies

- Energy systems life cycle inventory
- LCA of materials for mass reduction for light duty vehicles

Water-energy nexus

- Developing energy system scenarios to inform drivers of changes in water quality

Modeling for multiple audiences

- **Collaboration with Program/Regional Offices on tailored tools and analyses**
  - Work with OAQPS on Future Scenarios for air quality, industrial sector emissions, alternative pathways to attainment, etc.
  - Starting work with OTAQ on advanced light-duty vehicles (electrification, lightweighting)
  - Developing community-scale MARKAL database for NYC to analyze energy-water infrastructure decisions (with Region 2)
  - Presenting analysis of natural gas with carbon capture retrofits to OAR staff

- **Cross-ORD and external collaborations**
  - Collaborating with NERL on the GLIMPSE project (integrated modeling assessment)
  - Work with PNNL to update emission factors and air pollution control options in GCAM

- **Bringing a unique energy system perspective and expertise to:**
  - Development of external grant and center work through NCER
  - Internal EPA workgroups on rulemaking and other Agency actions

- **Data and tools for a broader community leading to impactful analyses**
  - Participation in the Energy Modeling Forum: including the natural gas study (EMF#31)
  - U. of Colorado (climate and air quality damages)
  - Nat. Energy Tech. Lab (natural gas)
  - Purdue (biofuels and land use)
  - NESCAUM + GA Tech (climate-air quality co-benefits)

Contacts

- **EPA Staff:**
  - **Rebecca Dodder** (water-energy, biofuels/biomass, LCA-energy system integration)
  - **Ozge Kaplan** (industrial sector, NYC MARKAL, decision support)
  - **Carol Lenox** (MARKAL database, transition to TIMES, building sectors, RPS, energy efficiency, nat gas)
  - **Dan Loughlin** (electric sector, GCAM, emissions projections, tech assessment, scenarios)
  - **Andrew Henderson** (LCA of energy technologies)

- **Post-docs and students**
  - **Samaneh Babaee**
    - ORISE Post-doc (energy system modeling, tech assessment, vehicle electrification, natural gas w. CCS)
  - **Rubenka Bandyopadhyay**
    - ORISE Post-doc (energy scenarios, ports community sustainability and resilience)
  - **Jessica Barnwell**
    - Student Service Contractor (water-energy nexus, water impacts of RPS, GIS analysis)
  - **Kristen Brown**
    - Federal Post-doc (energy system modeling, air quality modeling, monetization of damages)
  - **Troy Hottle**
    - ORISE Post-doc (LCA-energy system integration, LCA of vehicle mass reduction)

Thank you!