# Integrated Systems Modeling of Energy, the Economy, and the Environment

Growing Energy Research Partnerships
UT Austin and Sandia National Laboratories
May 17, 2017

Sandia National Laboratories

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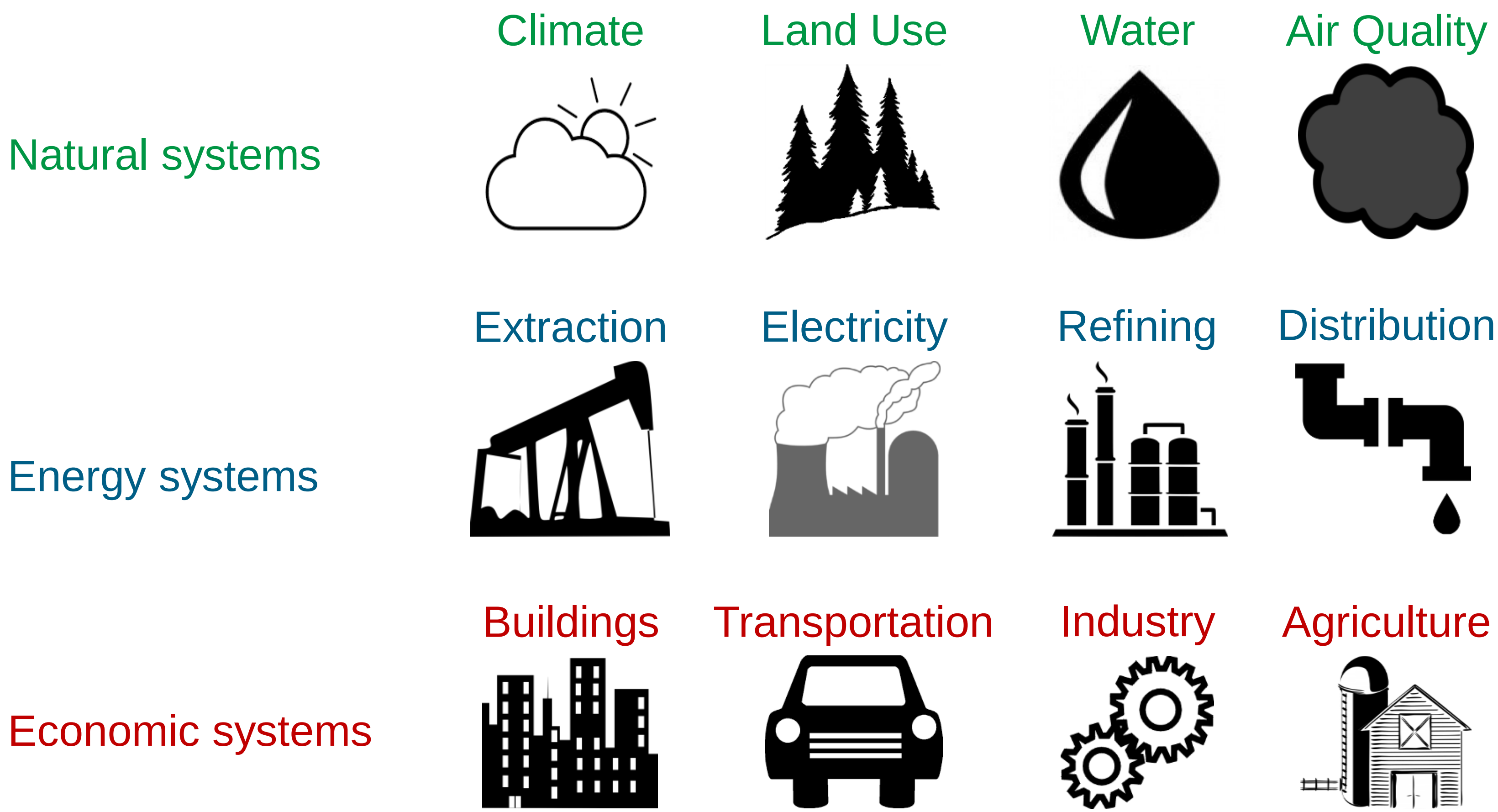
# Integrated Systems Modeling

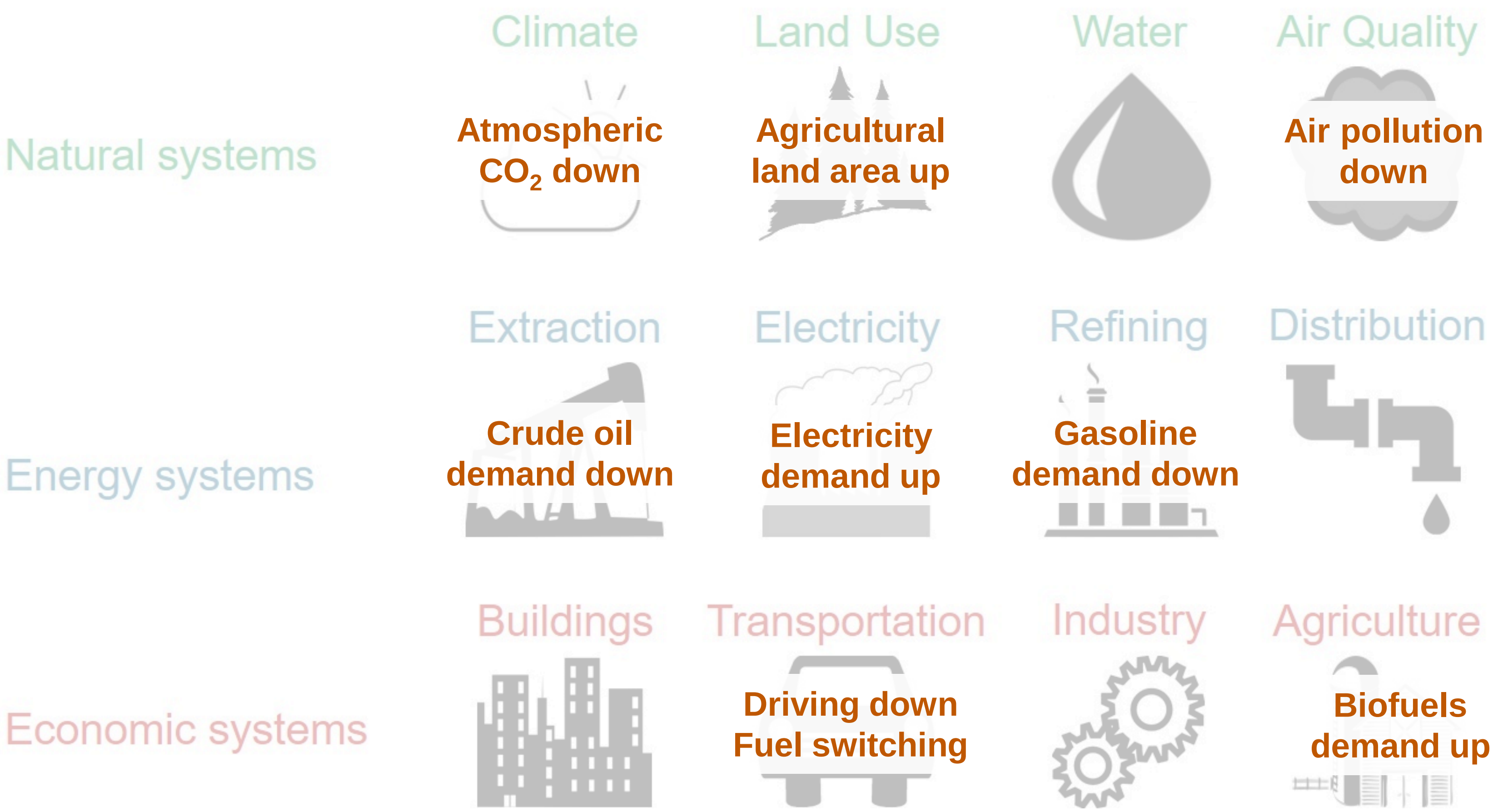
- The traditional modeling approach is to analyze a particular energy system in isolation.

- Through integrated systems modeling (ISM), we represent many energy supply and end-use sectors, as well as broader socioeconomic and natural systems, within a rigorous and cohesive framework.
  - Captures interactions and feedbacks across systems.
  - Highlights valuable synergies.
  - Evaluates full policy and strategy impacts.

# Integrated Systems Modeling



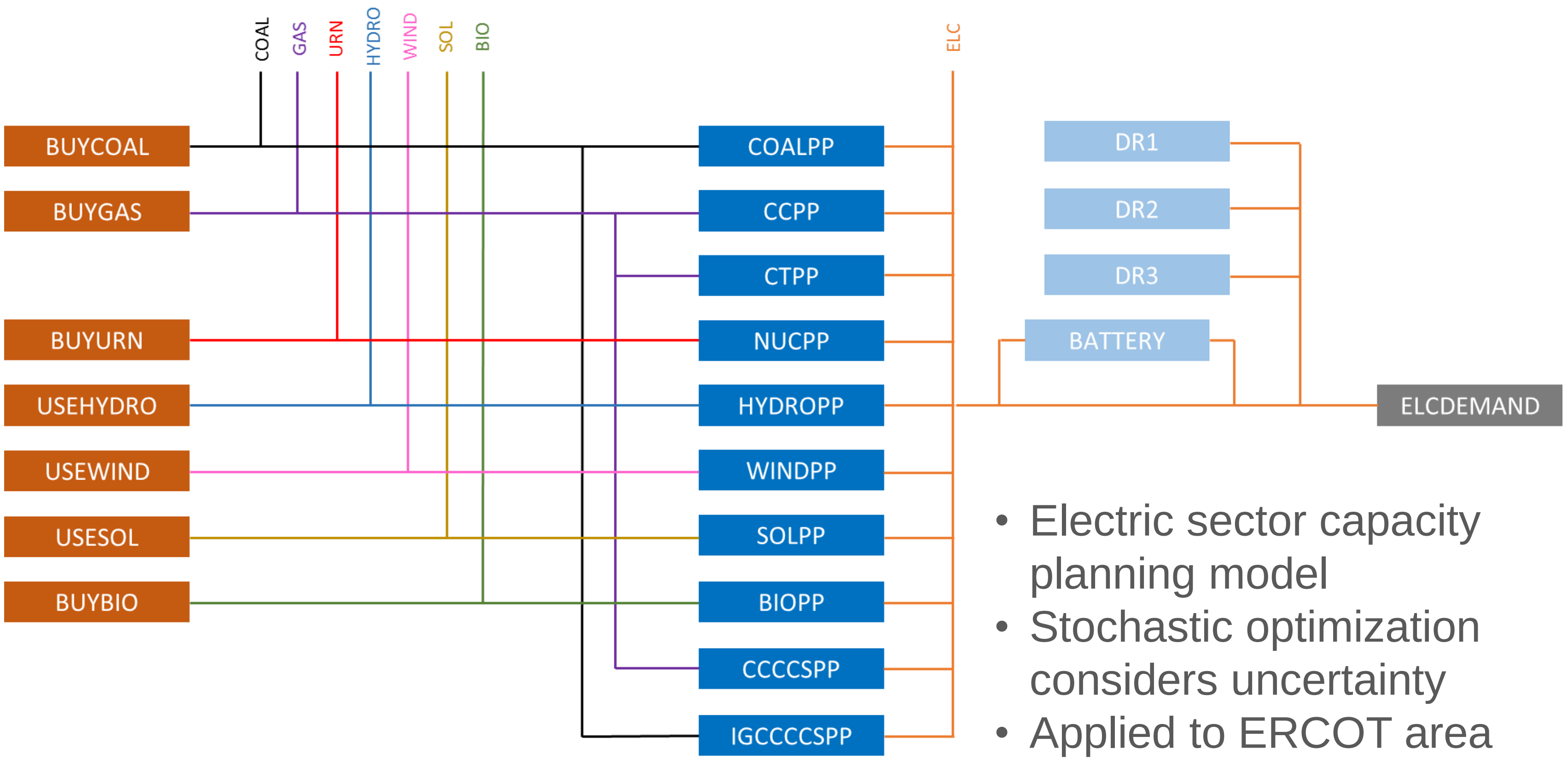
# Example: Gasoline Tax



# ISM Development at UT Austin

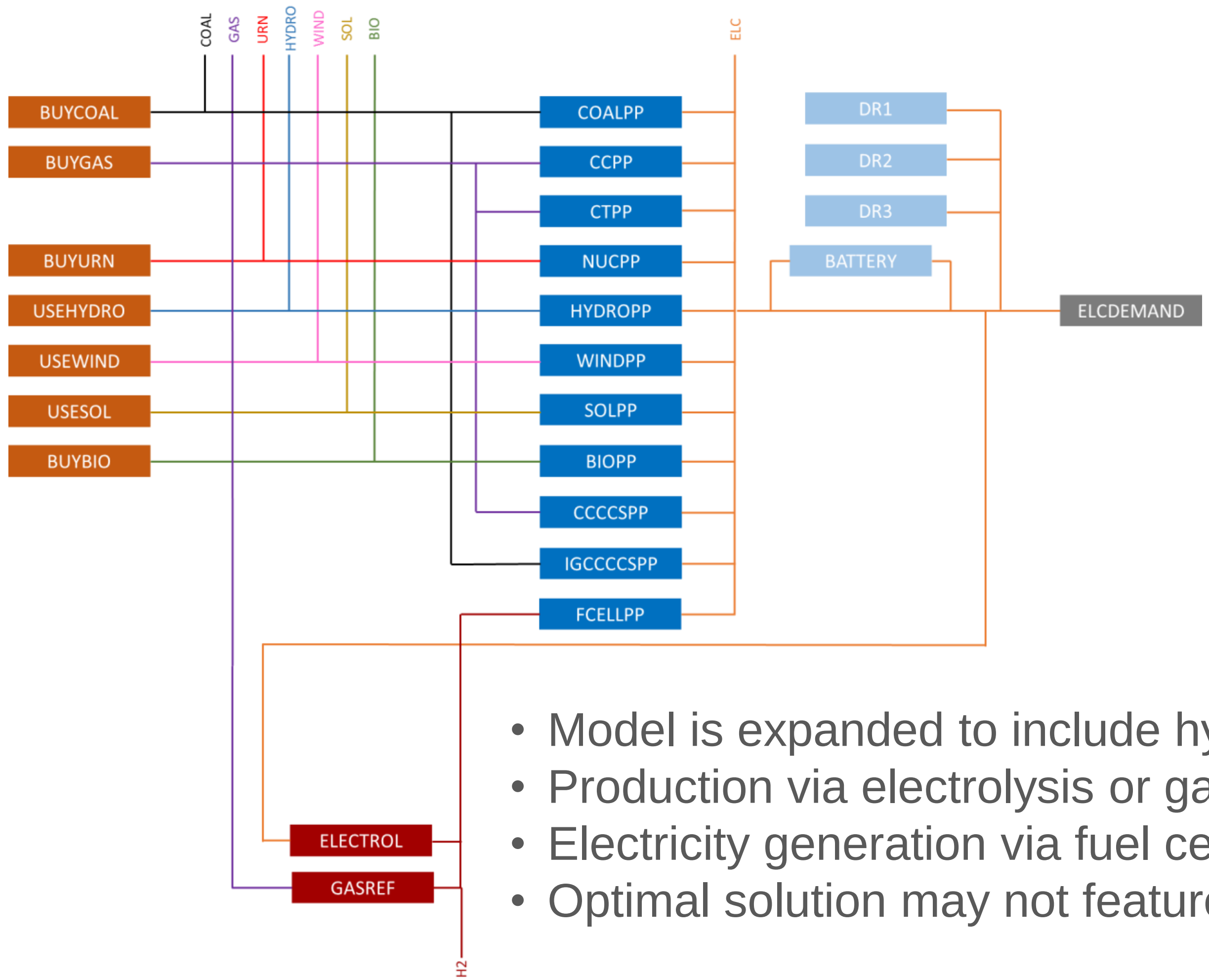
1) Energy supply and end-use sectors
2) Energy and the economy
3) Energy and climate
4) Energy and strategic competition
5) Energy and land use

# Energy Supply and End-Use Sectors



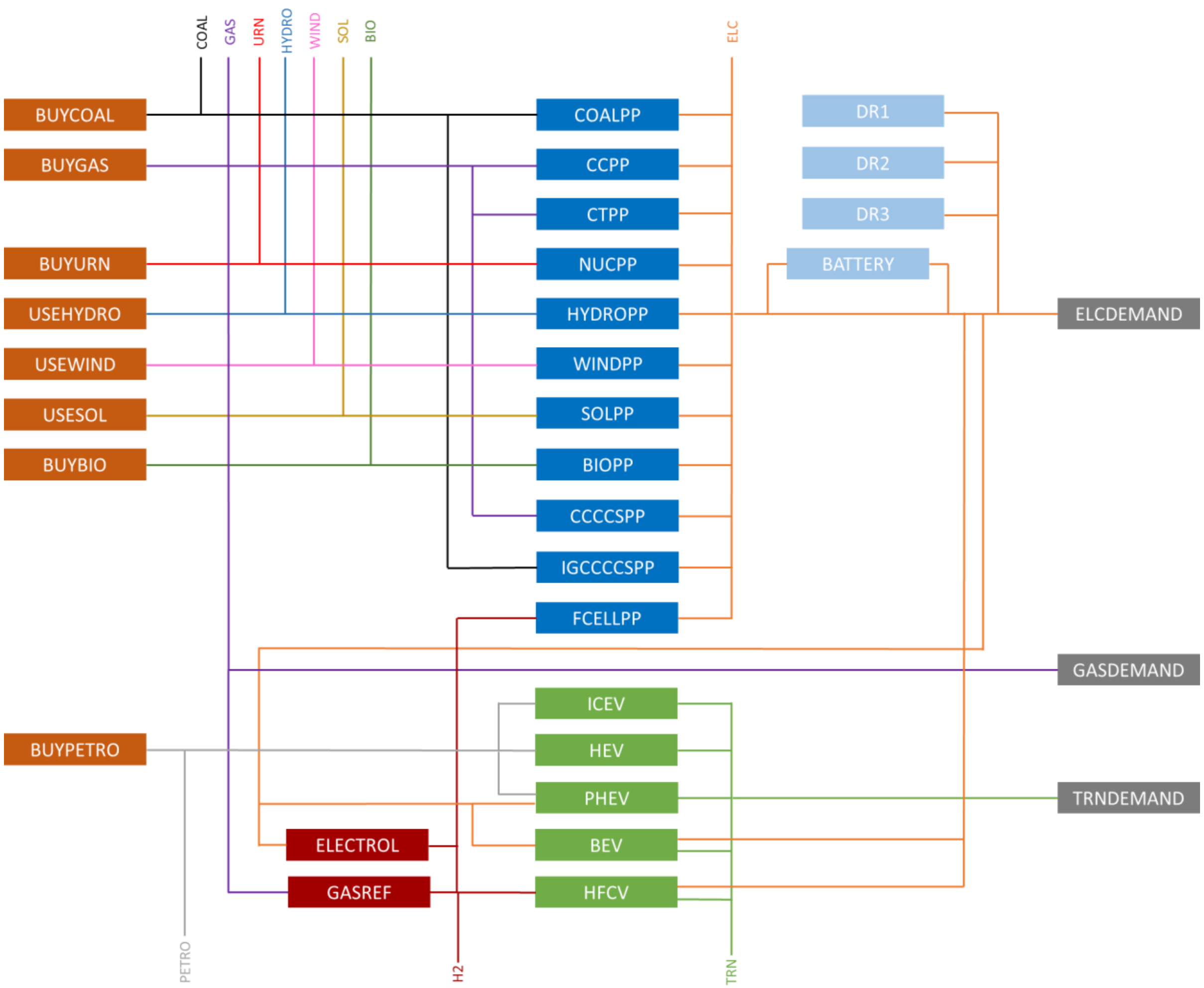

- Electric sector capacity planning model
- Stochastic optimization considers uncertainty
- Applied to ERCOT area
- Flexible and modular structure

# Energy Supply and End-Use Sectors



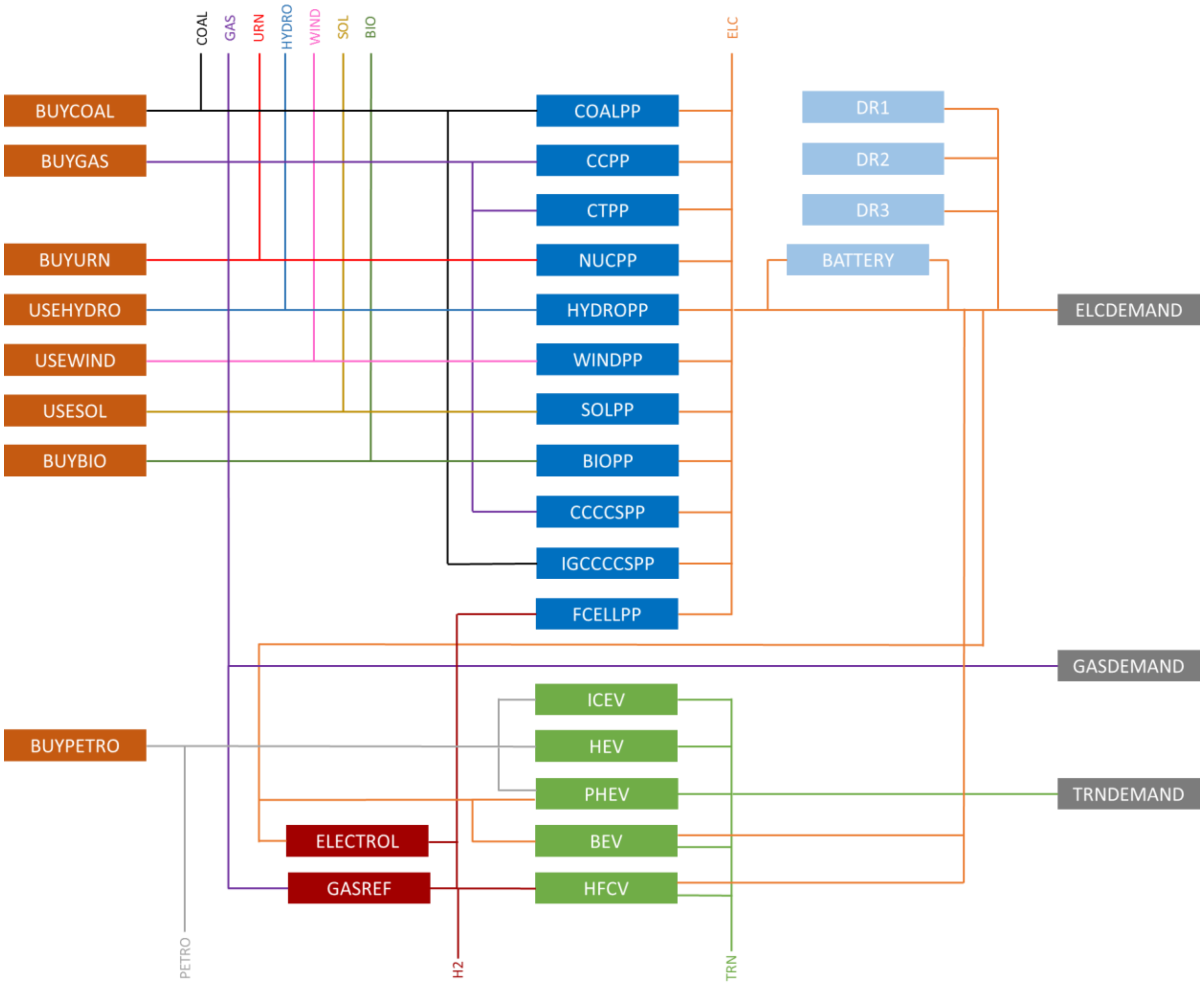

- Model is expanded to include hydrogen
- Production via electrolysis or gas reforming
- Electricity generation via fuel cells
- Optimal solution may not feature hydrogen

# Energy Supply and End-Use Sectors




- Model is expanded to include transportation
- Highlights the advantages of a modular model structure
- Diverse uses of hydrogen and its complementarity with electricity constitute a potentially valuable synergy across sectors
- ISMs are uniquely capable of capturing such synergies

# Energy Supply and End-Use Sectors

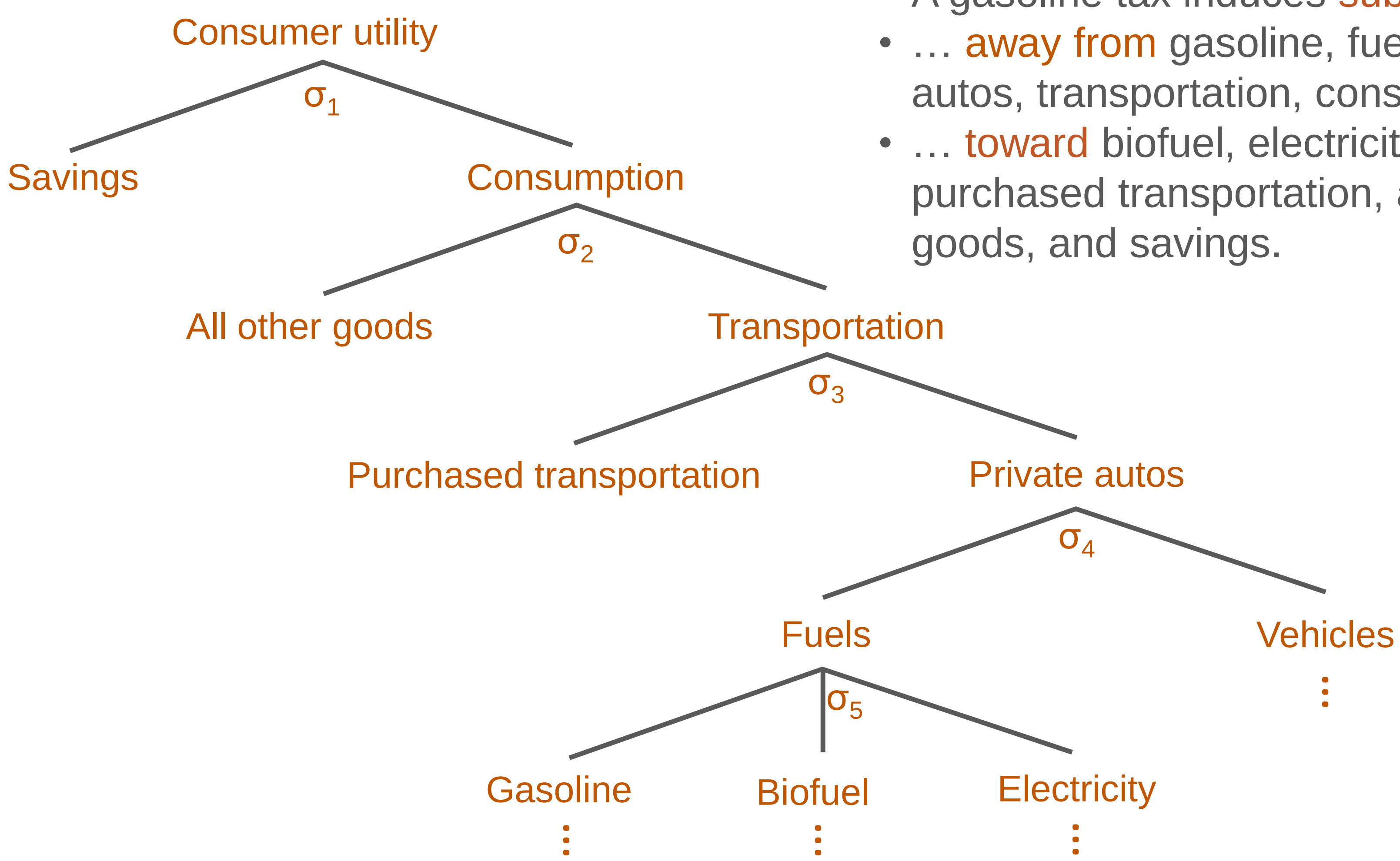



- We are continuing to develop this framework and will apply it to assess optimal pathways for achieving Austin's adopted goal of net-zero emissions by 2050.

# Energy and the Economy

- The ideal framework for evaluating the full economic impacts of energy policies and strategies is a computable general equilibrium (CGE) model.
- Multiple regions and many economic sectors.
- Firms maximize profit, consumers maximize utility.
- Compute prices that equilibrate supply and demand in all markets simultaneously.
- Flexible production and utility functions allow for price-induced input substitutions that reflect price-elastic demand and technological change.

# Energy and the Economy



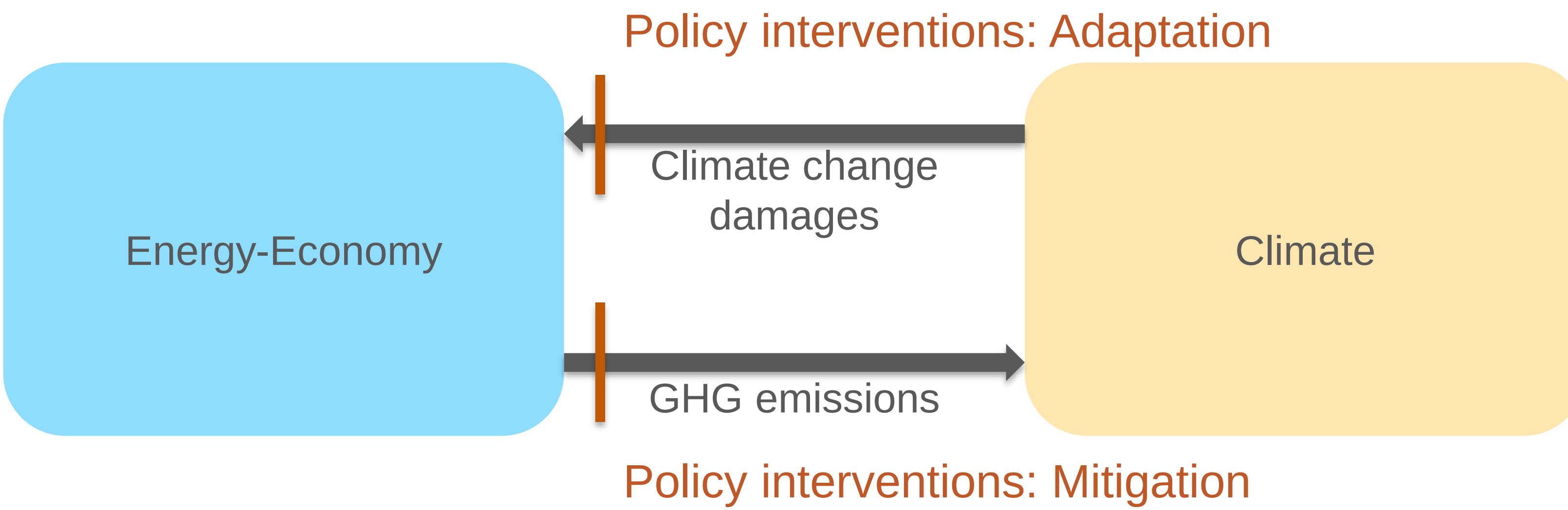

- A gasoline tax induces substitution
- … away from gasoline, fuels, private autos, transportation, consumption.
- … toward biofuel, electricity, vehicles, purchased transportation, all other goods, and savings.

# Energy and Climate

- Suppose we want to analyze a carbon tax.
- We can use an energy-economy model to perform cost-effectiveness analysis and project the impacts of various tax levels.
- But, to determine the optimal tax level, we must perform cost-benefit analysis.
- *What tax level best balances the costs of reducing GHG emissions and the benefits of doing so?*
- The appropriate tool is an integrated assessment model (IAM) that captures interactions between the energy-economy and climate systems.

# Energy and Climate

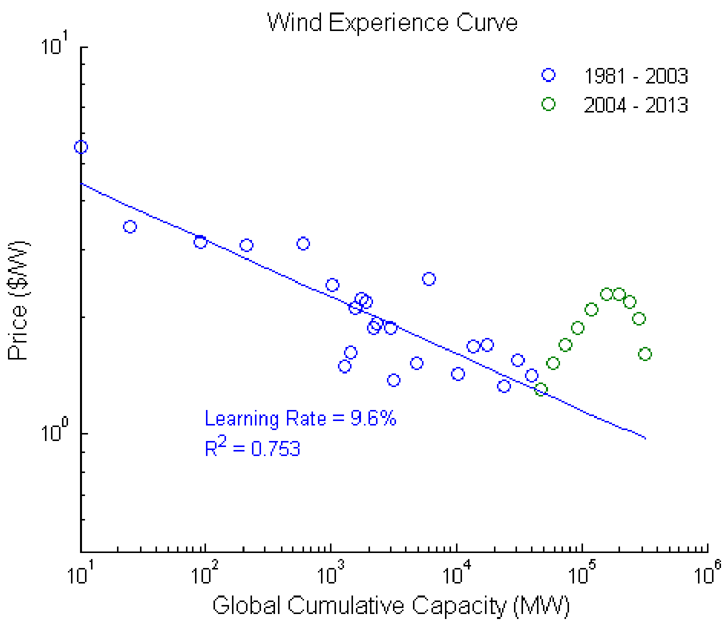
Objective: Maximize welfare (present discounted utility of consumption)

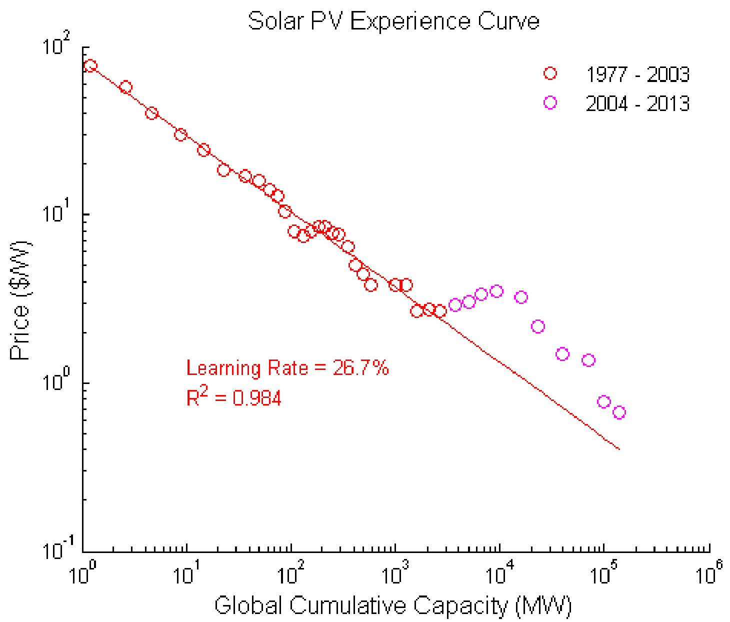



- We have uniquely extensive experience with the most prominent American (GCAM, MERGE, EPPA) and international (MESSAGE) IAMs.

# Energy and Strategic Competition

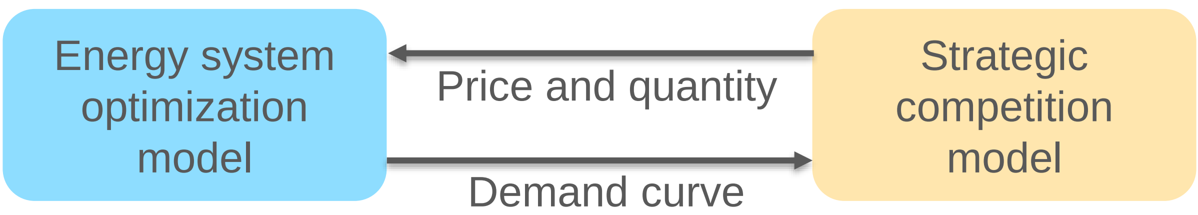
- Market structure and strategic competition strongly influence prices (and therefore adoption) of rapidly evolving technologies such as wind and solar PV.
- Policy stimuli may cause producers to raise prices.



# Energy and Strategic Competition

- Incorporated strategic renewable energy technology producers into an energy and climate policy ISM.




- Optimize the design of an online platform where residential solar PV installers offer competing price quotes to potential customers.

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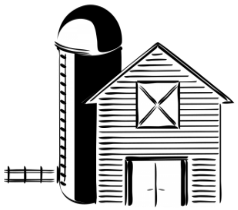
# Energy and Land Use

- There are multiple mechanisms that could induce meaningful changes in land use on a global scale.
  - Expansion of urbanized land area
  - Deforestation and conversion to agriculture
  - Crop switching as climate change adaptation
  - Growing demand for bioenergy
- Some IAMs now incorporate endogenous changes in land use, and associated emissions impacts.


Forest


Desert


Urban

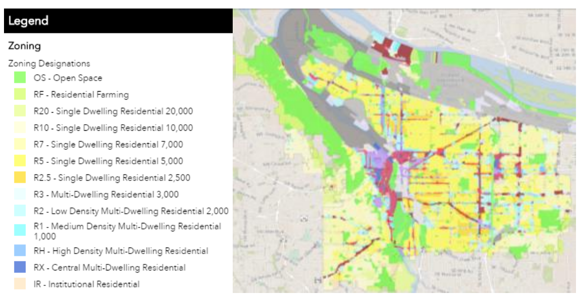

Ag - Food


Ag - BioE

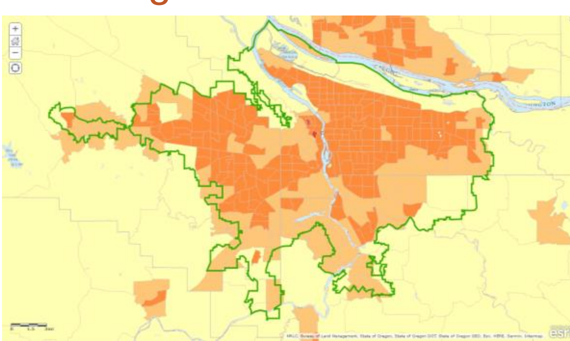
# Energy and Land Use

- We have an innovative model to assess the impacts of urban land-use regulations on GHG emissions, a critical interaction in an increasingly urbanized world.

## Traditional zoning: FAR restriction




## Smart growth control: UGB



# Advantages of ISM

- Primary advantages of ISM
  - Captures interactions and feedbacks across systems
  - Highlights valuable synergies
  - Evaluates full policy and strategy impacts

- Through ISM, we can find an overall solution which is superior to the combination of solutions which are optimal for each individual component system.

System 1

Solution $s_1$

System 2

Solution $s_2$

$s_{ISM}$ will be superior to combining $s_1$ and $s_2$

Systems 1 and 2

Solution $s_{ISM}$

# Thank you for inviting us!