Measurements at the Food-Energy-Water Nexus

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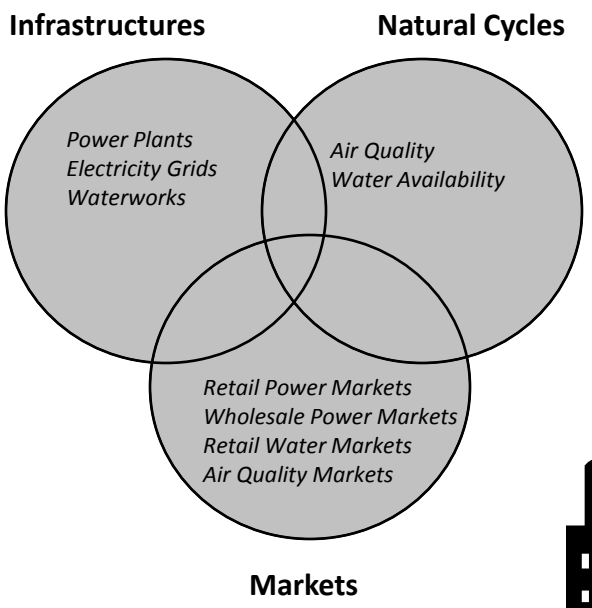
Measurements at the Food-Energy-Water Nexus

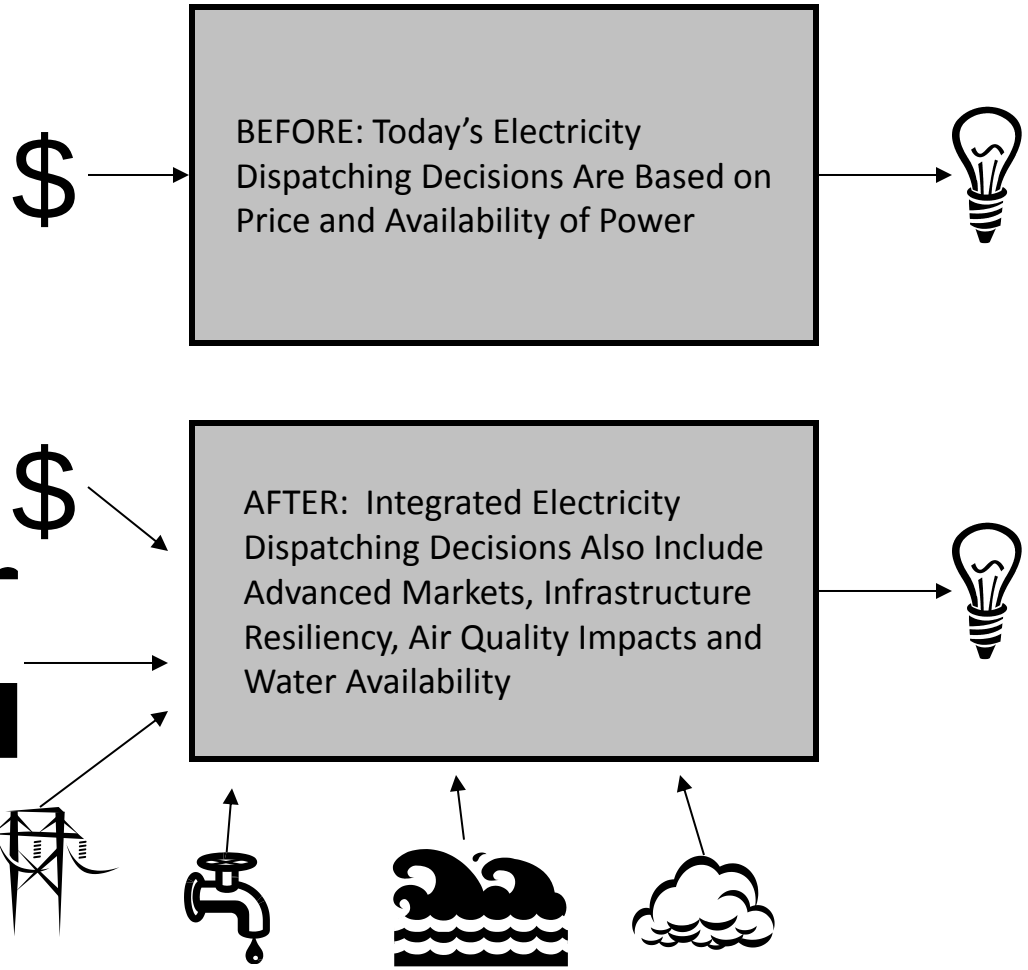
- What?
  - Many lessons learned from decades of experience in Life Cycle Assessments
- Where (at what scale)?
  - Water footprints are at the watershed scale, so Food-Energy-Water analyses are logically done at the regional scale
- Why?

Lessons Learned at the Energy-Water (and the energy-water-air quality) Nexus:

A case study of the challenges of energy and water system integration at the regional scale

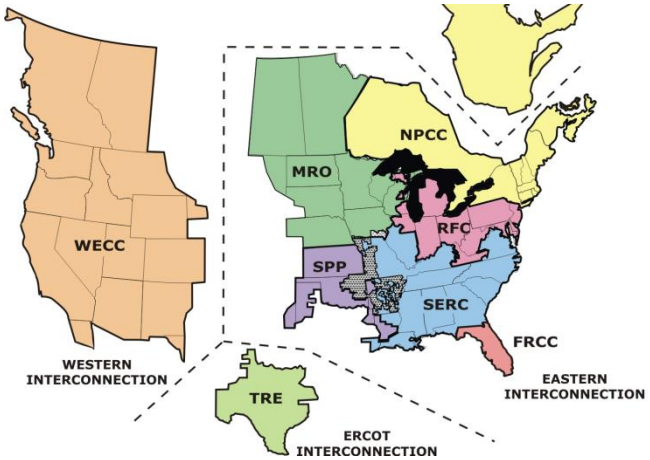
How can a smart electrical grid balance water use, regional air quality, carbon emissions, and electricity demand and cost?

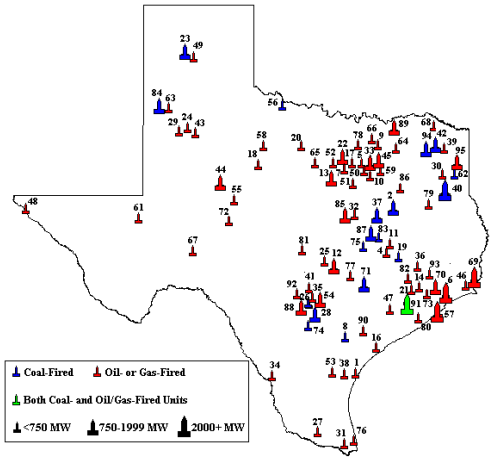




Why Texas?

- Grid entirely contained within the state
- Water-rich east, water-poor west
- Air quality limits in the east but not in the west
- A diverse base of Electricity Generating Units (EGUs), including more installed wind power than any other state
- Large agricultural water demands





Flexibility in Grid Operation

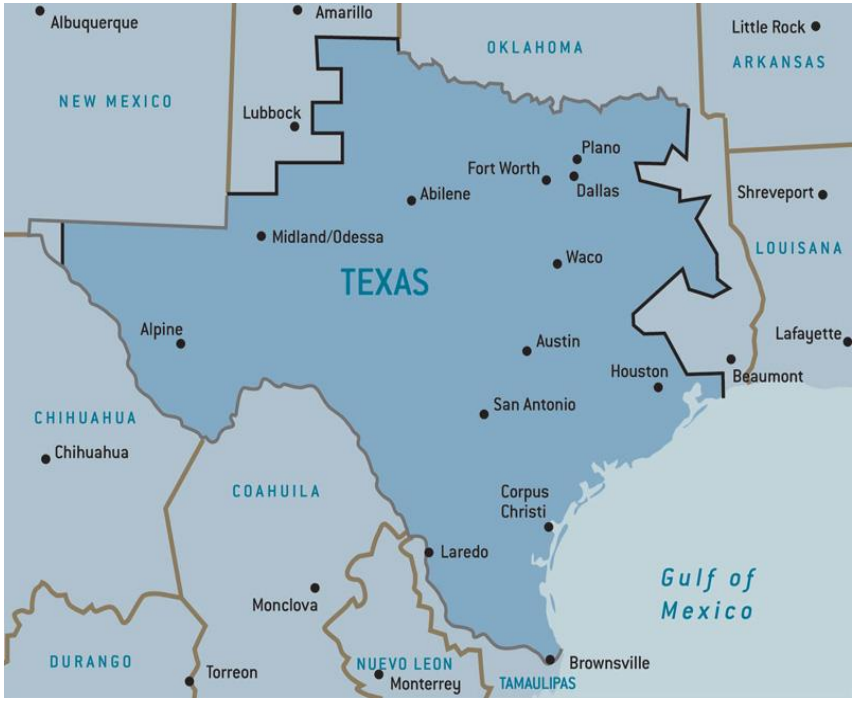
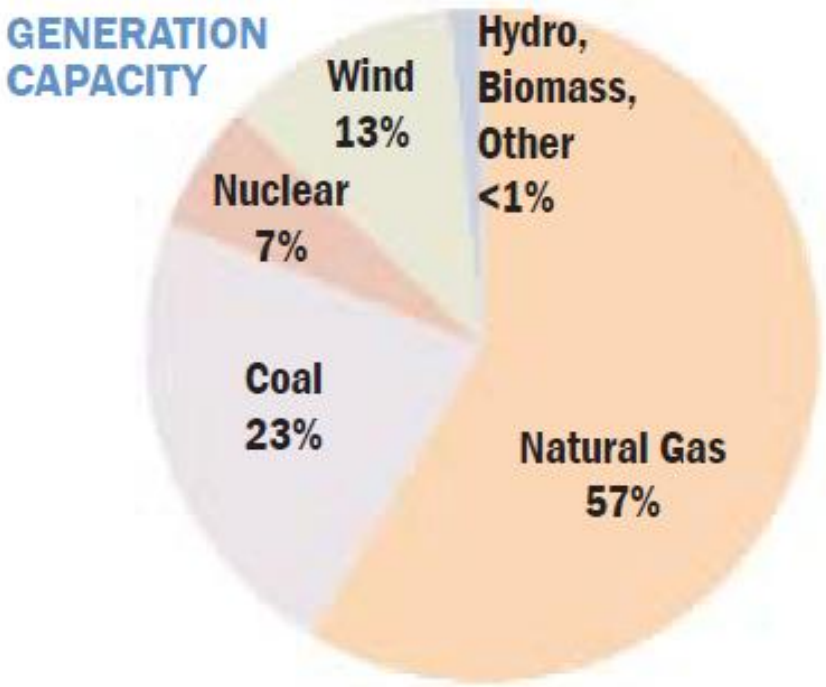


Image courtesy of ERCOT

- Electricity Reliability Council of Texas (ERCOT)
- Installed Capacity: 74,000 MW
- Average Generation: 38,200 MW
- Minimize the cost of meeting demand

Flexibility in Grid Operation



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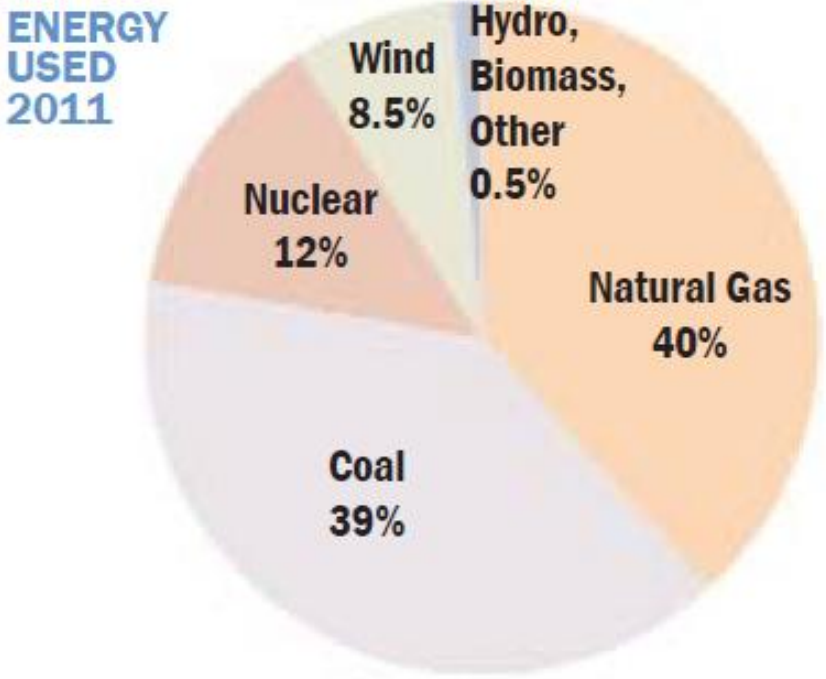

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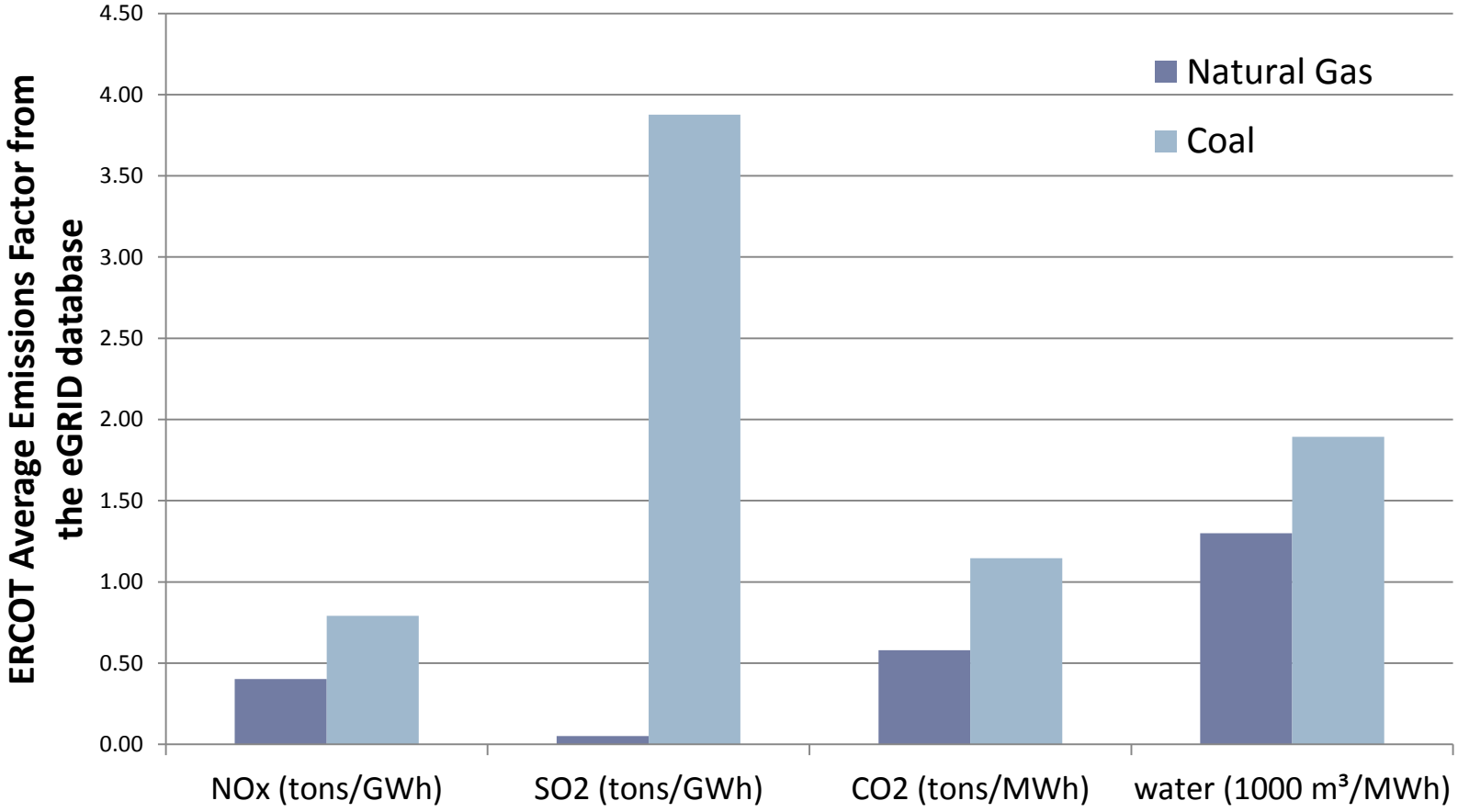
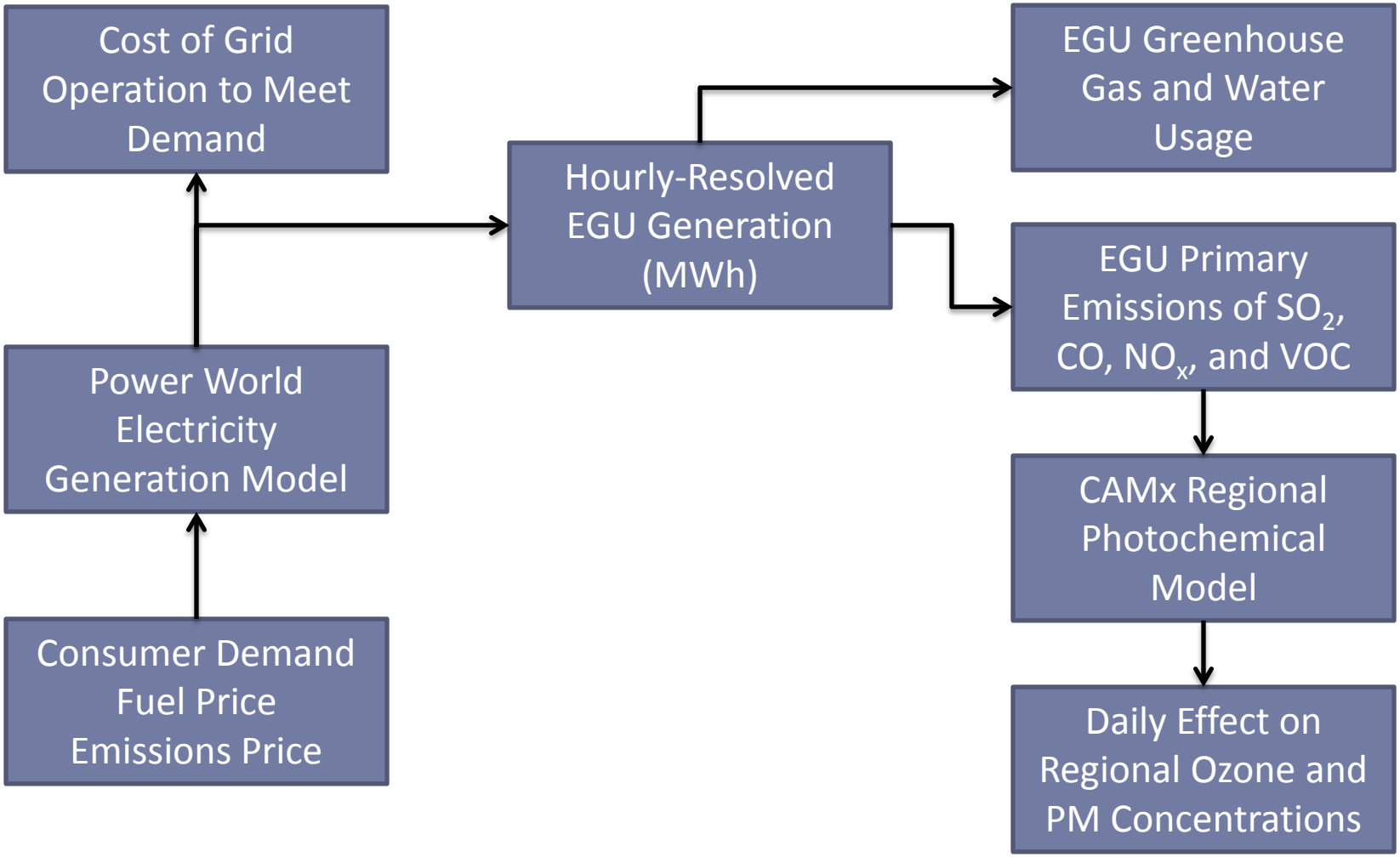
Generation Choices Matter



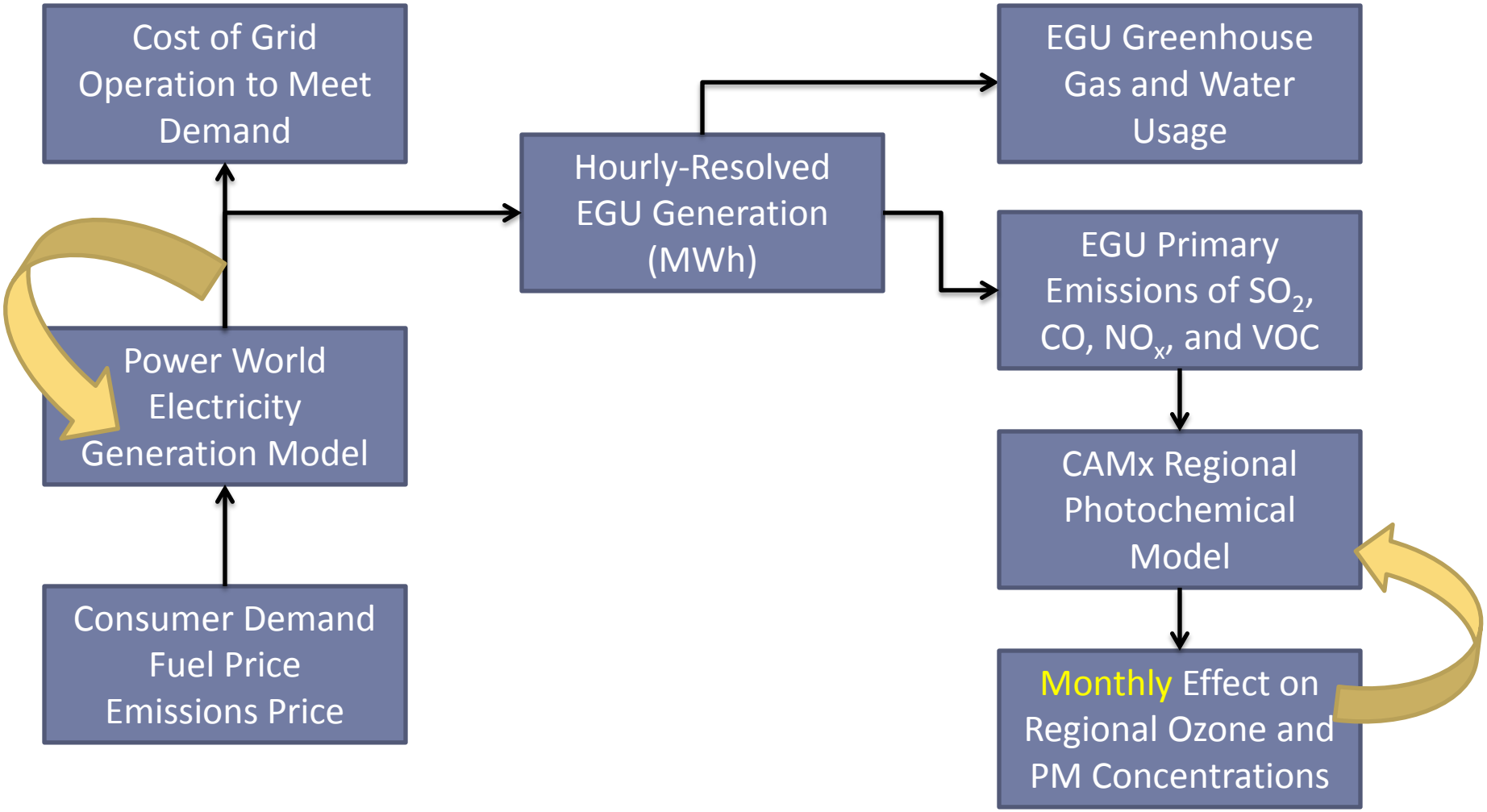
How do we approach this problem?

- Historically, optimal power flow modeling, water modeling and air quality modeling have been in silos, with little exchange of information
- Need to create an integrated analysis system

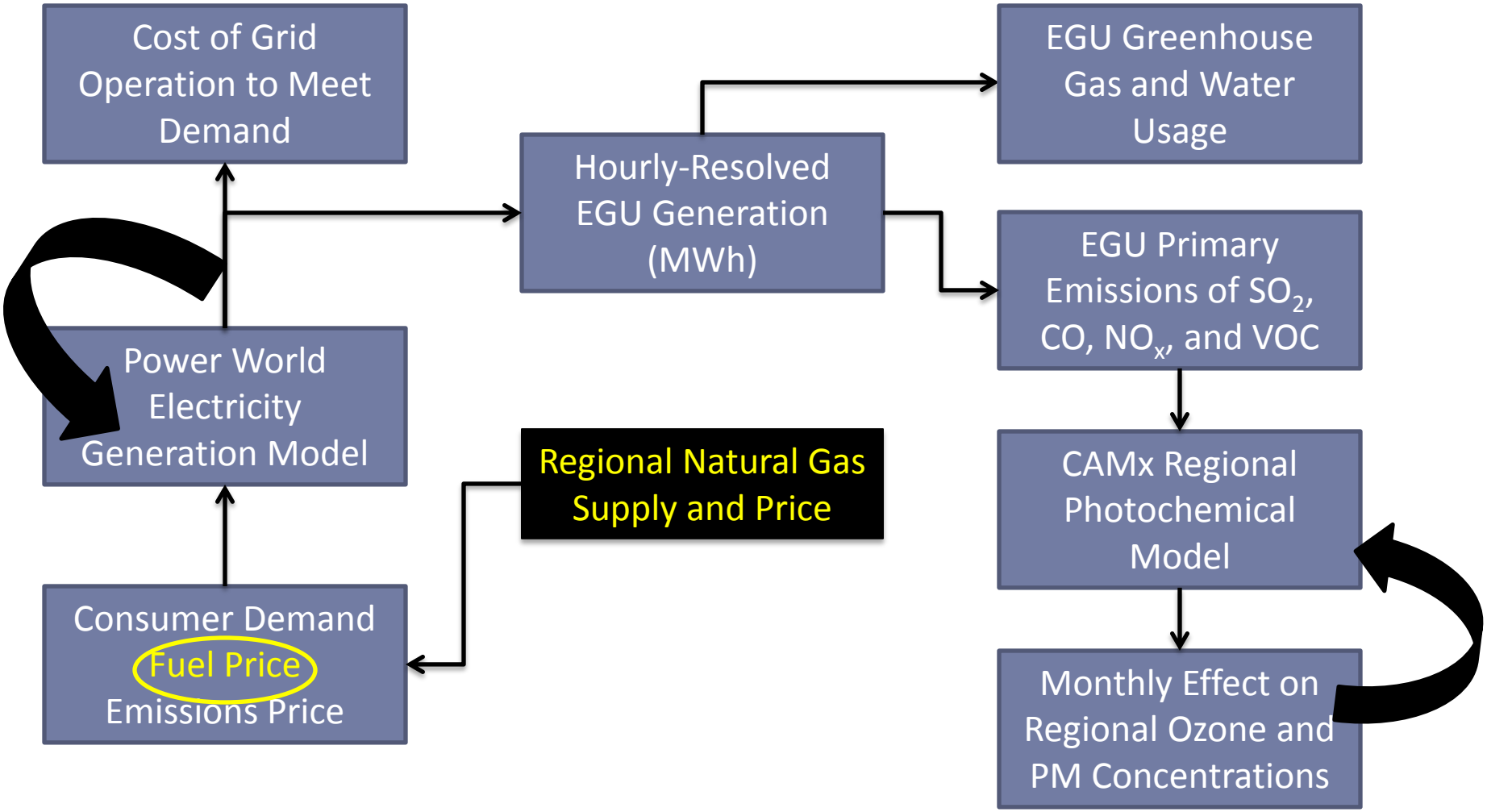
Integrated Model



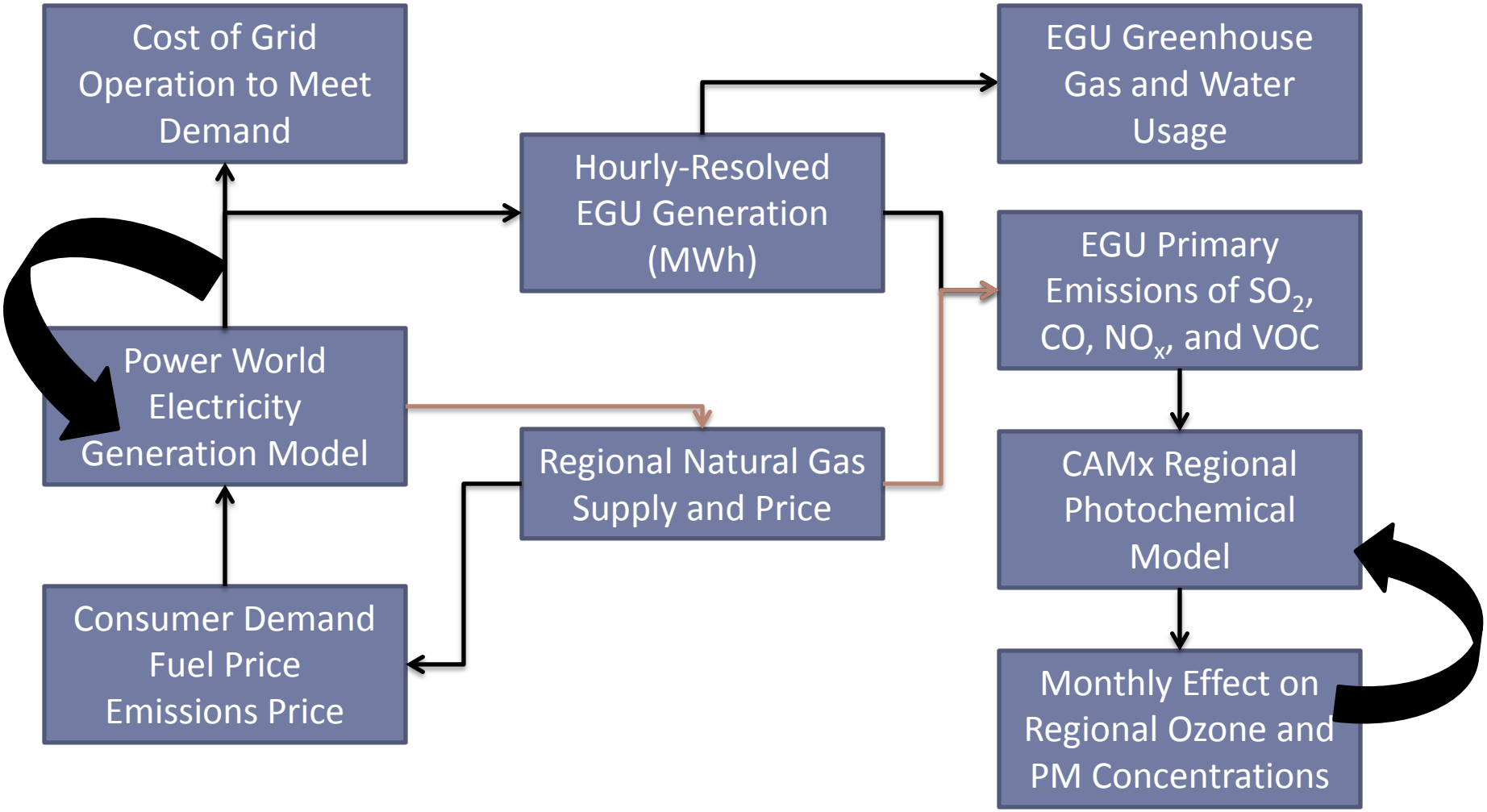
Extension to Multiple Days



Natural Gas Supply and Price Effect

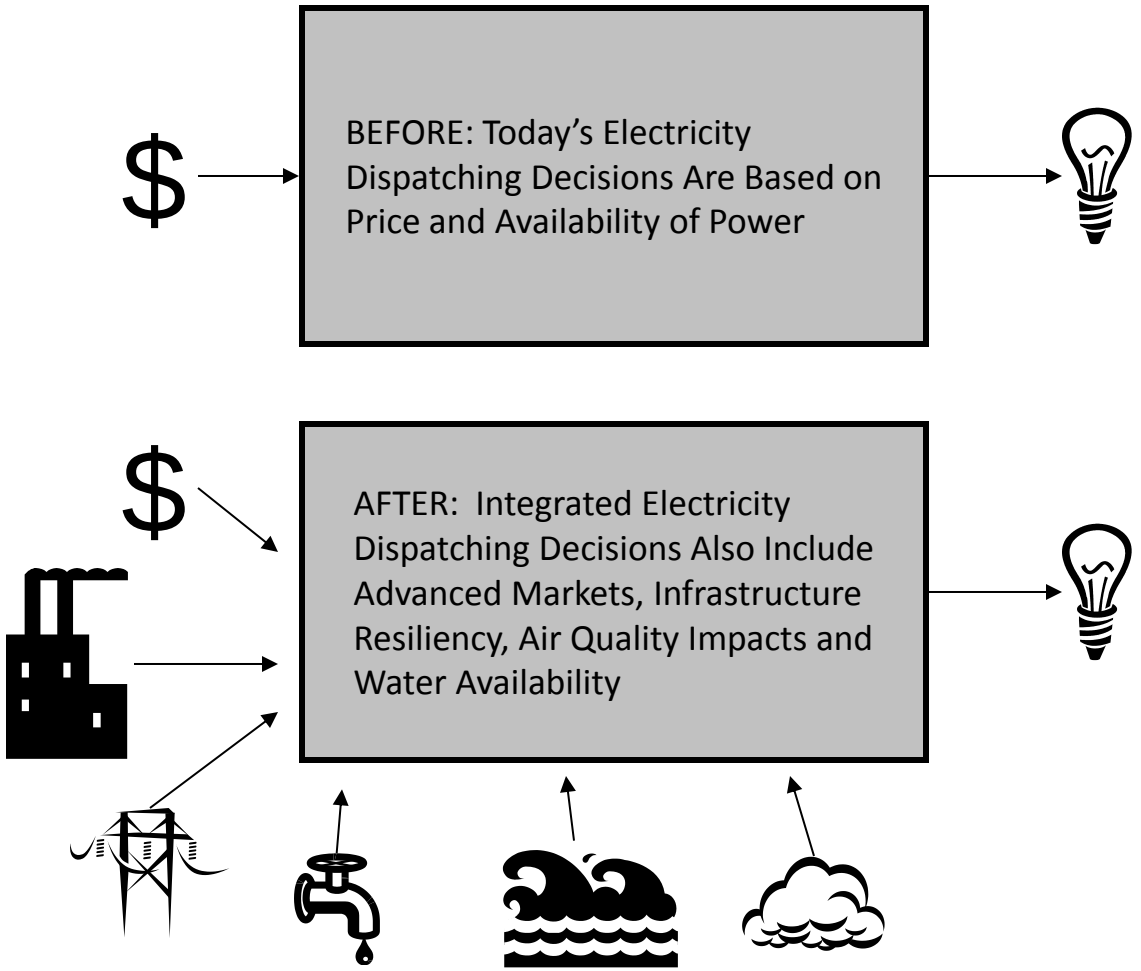


Full Supply Chain Integration



How can a smart electrical grid balance water use, regional air quality, carbon emissions, and electricity demand and cost?

What happens to electricity generation, air quality and water use if we put a price on NOx emissions? On CO_2 emissions? What happens if we change natural gas price, relative to coal?

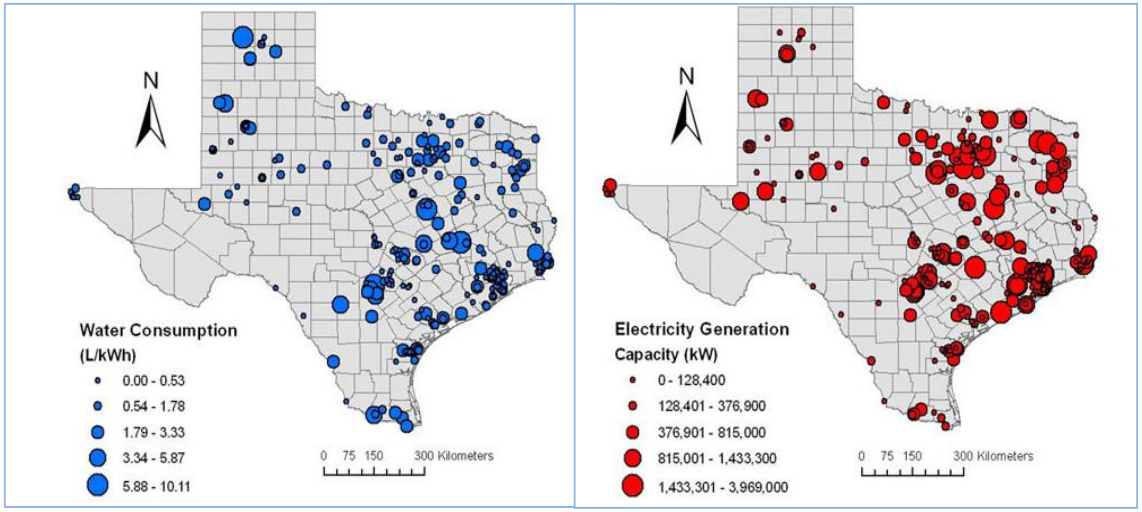


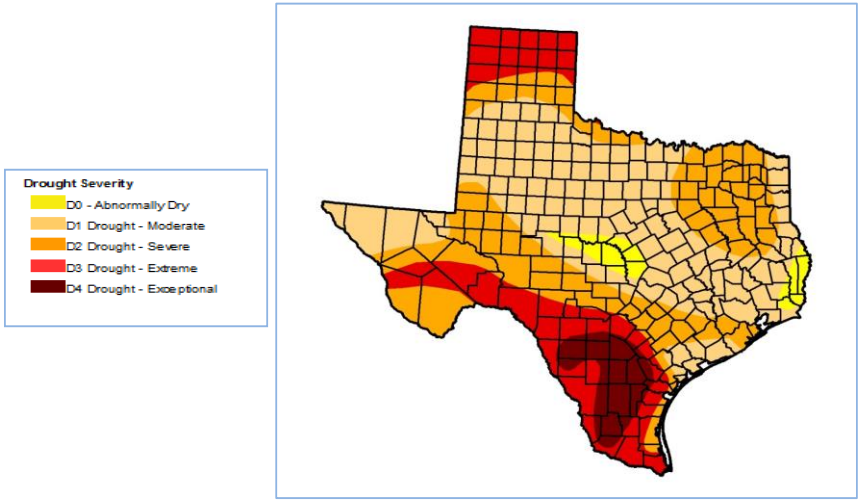
Findings

- Power, water, fuel and air quality model integration was challenging, requiring substantial effort
- Grid has flexibility to respond to fuel and emission price signals; very few transmission constraints
- In general, increases in NOx price, CO_2 price and decreases in natural gas price, relative to coal, all decrease air pollutant emissions, greenhouse gas emissions and water use, to varying degrees
- Similar analyses done for the Pennsylvania, New Jersey, Maryland grid show the same qualitative phenomena
- Although smog reduction, greenhouse gas mitigation and reducing water use in the electrical grid are generally synergistic, these general trends mask a spatial complexity

Spatial Complexity: Overall water use decreases but increases in some watersheds

Can an electrical grid be a virtual water pipeline during drought?

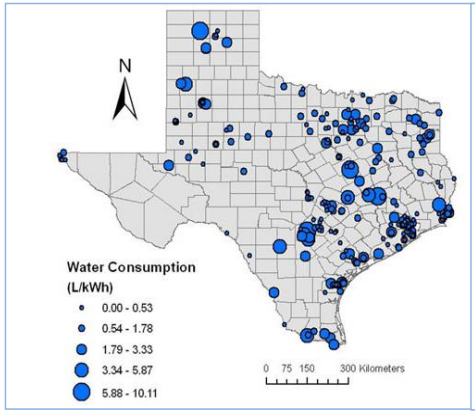


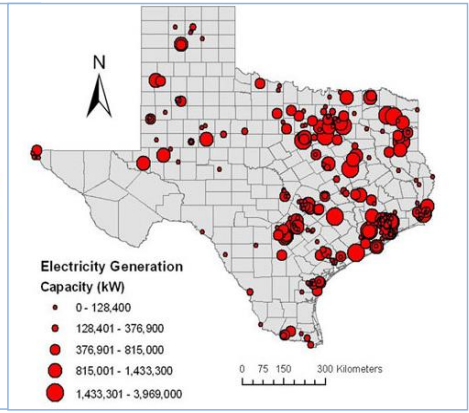


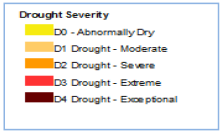
Shift generation from regions of extreme and exceptional drought

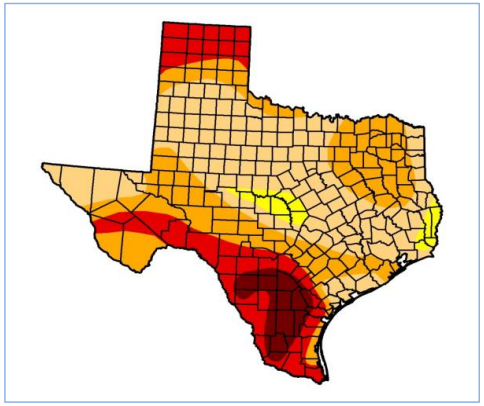
Virtual water pipelines

- Could it be done – yes, with little net change in overall water consumption, even at times of high electricity demand
- At what cost – costs similar to dry cooling technologies









What are the non-monetized costs?

Consider air quality

Virtual water pipelines

- At what cost – increases in SOx, CO_2 and NOx emissions – and in ozone concentrations

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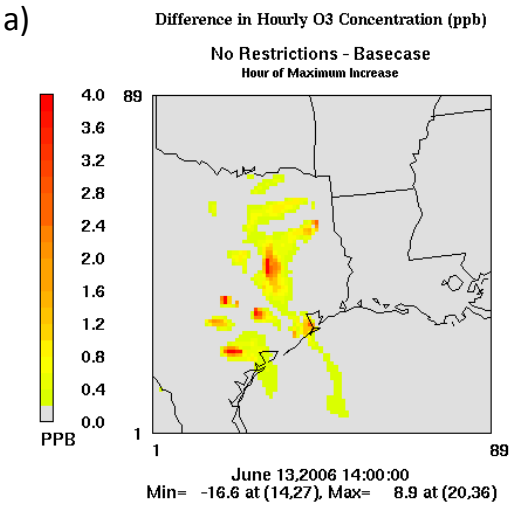

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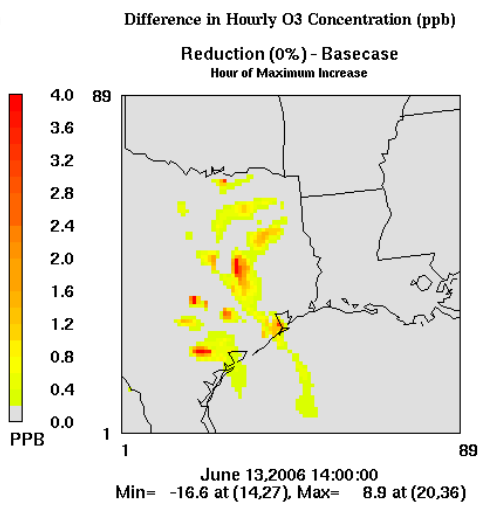

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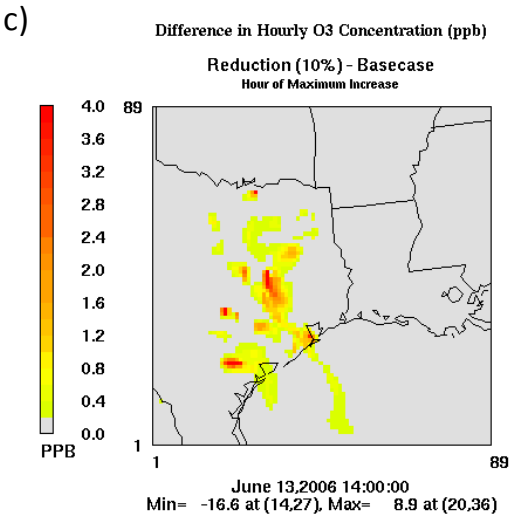

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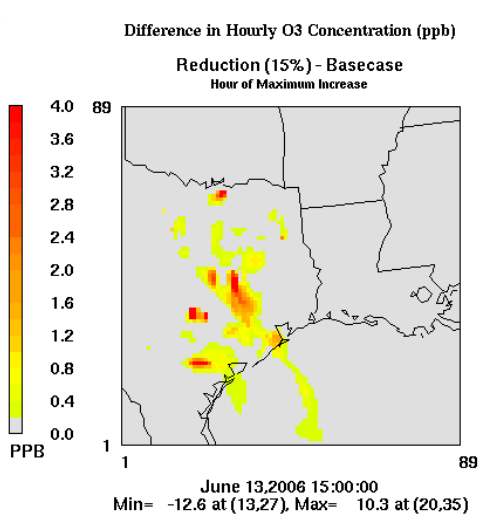
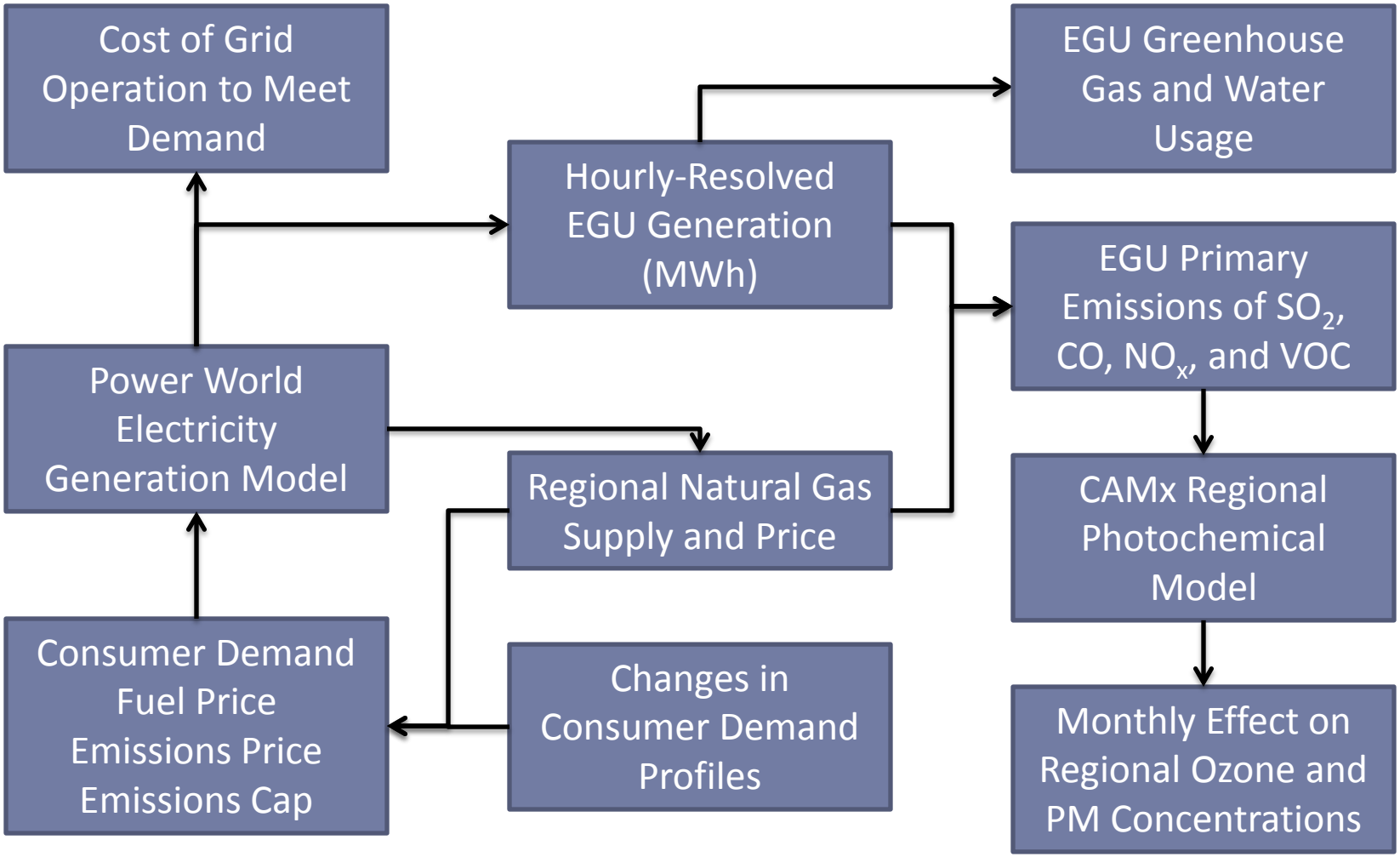


Integrated Model: Many case studies



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- What?
- Where (at what scale)?
- Why?
  - Food-Energy-Water systems analyses are done for decision support; what is measured depends on the decision. Example:
    - Will power plant emission reductions associated with the new ozone standards announced October 1 create or relieve stresses on water systems?

Acknowledgements

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Citations

1. Alhajeri, N.S., Donohoo, P., Stillwell, A.S., King, C.W., Webster, M.D., Webber, M.E., and Allen, D.T. "Using Market-Based Dispatching With Environmental Price Signals to Reduce Emissions and Water Use at Power Plants in the Texas Grid" *Environmental Research Letters* 6, 044018 doi.org/10.1088/1748-9326/6/4/044018 (2011)
2. Pacsi, A.P., Alhajeri, N.S., Zavala-Araiza, D., Webster, M.D. and Allen, D.T., Regional Air Quality Impacts of Increased Natural Gas Production and Use in Texas, *Environmental Science & Technology*, 47, 3521-3527, doi: 10.1021/es3044714 (2013)
3. Pacsi, A.P., Alhajeri, N.S., Webster, M.W., Webber, M.E., and Allen, D.T. Changing the spatial location of electricity generation to increase water availability in areas with drought: a feasibility study and quantification of air quality impacts in Texas, *Environmental Research Letters* 8, 035029 doi: 10.1088/1748-9326/8/3/035029 (2013).
4. Pacsi, A.P., Sanders, K.T., Webber, M.E., and Allen, D.T. The spatial and temporal impacts on water consumption in Texas from rapid shale gas development and use, *ACS Sustainable Chemistry & Engineering*, 2, 2028-2035 (2014).
5. Pacsi, A.P., Kimura, Y., McGaughey, G., McDonald-Buller, E.C., and Allen, D.T., Regional ozone impacts of increased natural gas use in the Texas power sector and development in the Eagle Ford shale, *Environmental Science & Technology*, 49, 3966-3973, doi: 10.1021/es5055012 (2015).