# Overview of the National Energy Modeling System (NEMS)

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Environment and Sustainability Workshop

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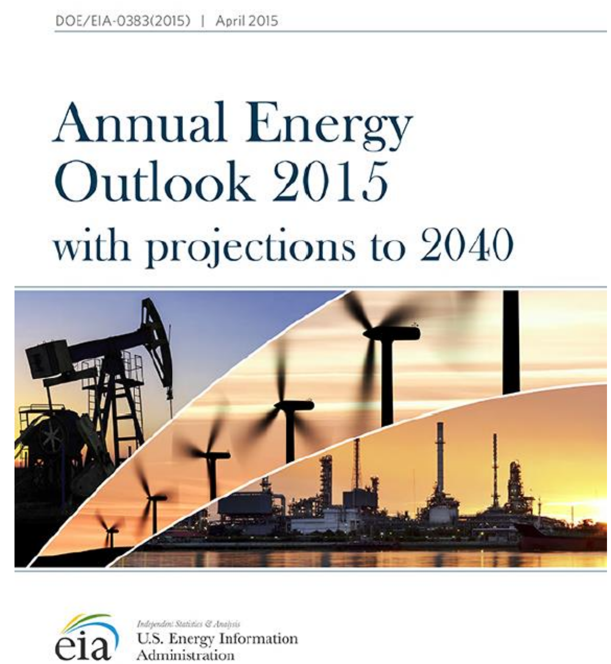
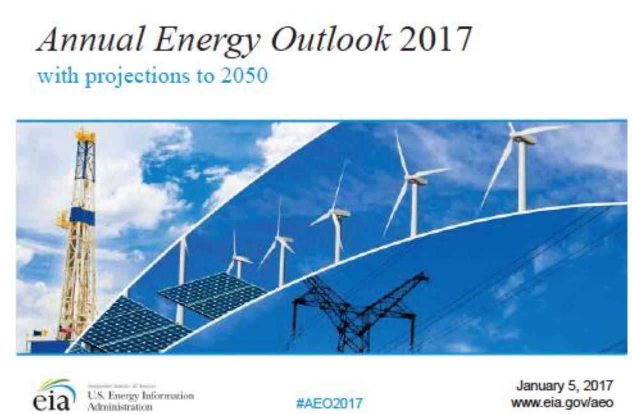
Valuable input from Dr. David Daniels, *Chief Energy Modeler*, *Office of Energy Analysis, Energy Information Administration,* August 29, 2017

# National Energy Modeling System

- NEMS: regional energy-economy model of the United States
- Annual projections to 2040/2050:
  - Consumption by sector, fuel type, region
  - Production by fuel
  - Energy imports/exports
  - Prices
  - Technology trends
  - $CO_2$ emissions
  - Macroeconomic measures and energy market drivers



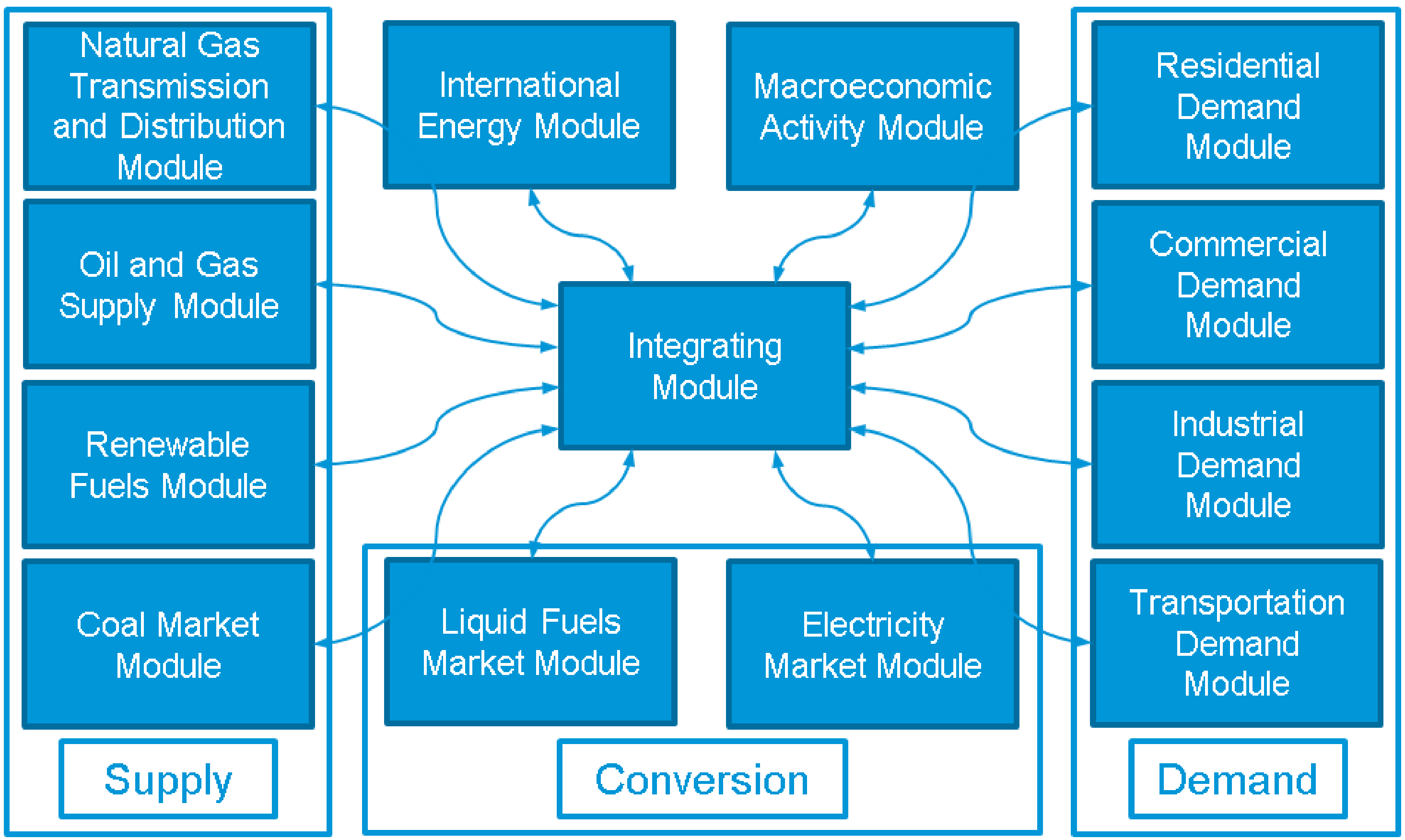



# Key Features of NEMS

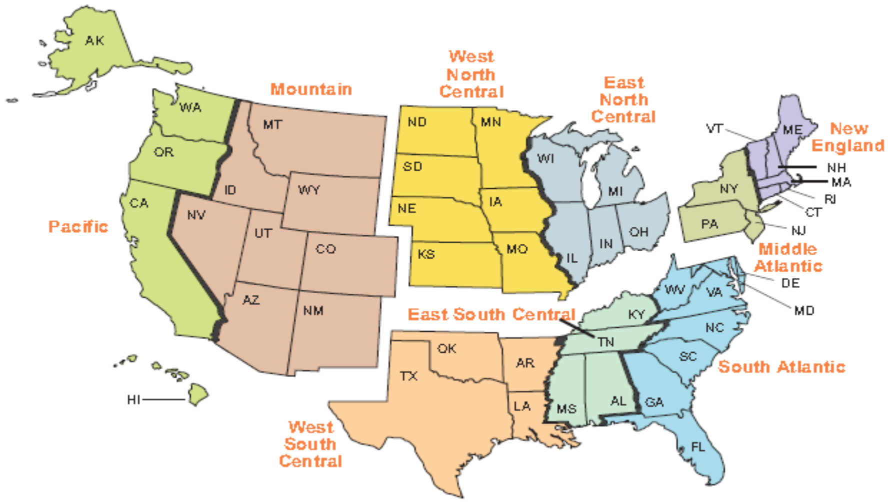
- Represents energy supply, conversion and consumption activities in a unified system with energy-economy feedbacks
- Rich with technology choice decision-making under regulatory constraints
- Solves annually through 2050 for energy-economy equilibrium subject to a number of possible constraints (i.e., regulations, standards, etc.)
- Represents the operational and planning activities in most sectors (such as households in the residential module, power companies and power plants in the electricity module)
- Principal design criterion: to facilitate analysis of energy policies

# NEMS Uses a Modular Structure

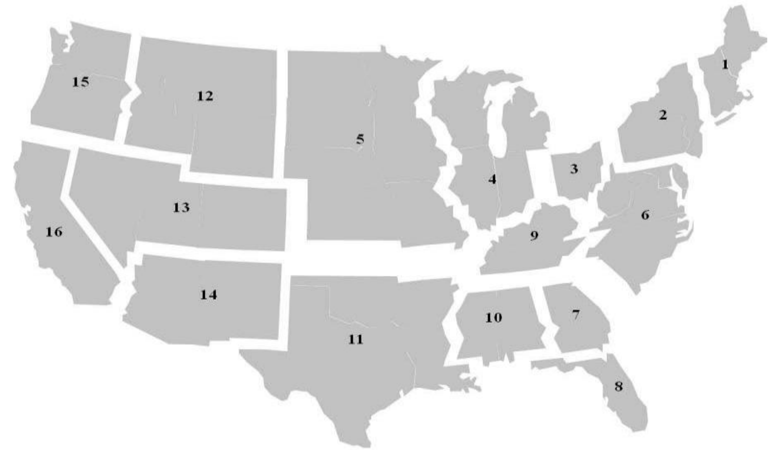
- A key aspect of the NEMS is its modular structure, which allows for individual modeling methodologies for each energy sector and facilitates model management
- Where appropriate and significant information exists, each sector is represented by a detailed structural model of the market.



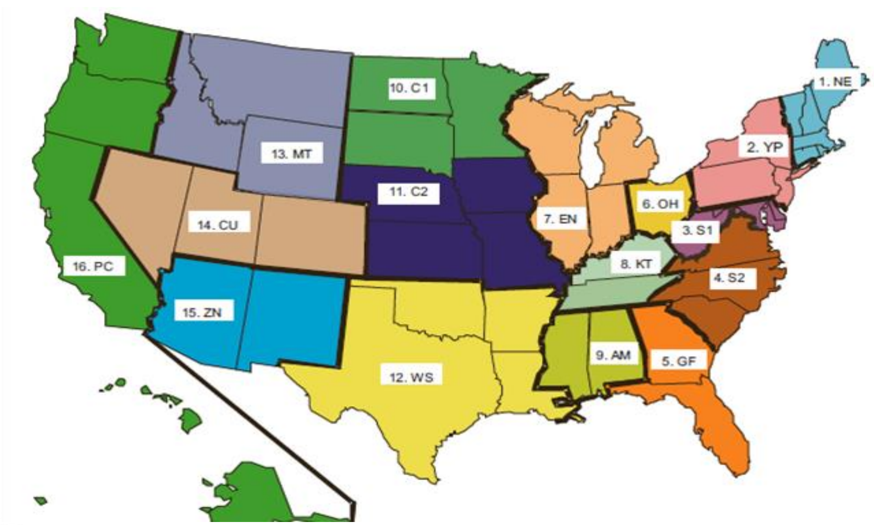
# Modularity of NEMS permits each module to employ custom regional definitions




Demand modules use 9 Census Divisions




Natural gas module uses 16 regions




Coal market module uses 16 regions


Electricity module uses 22 regions based on ISOs

# NEMS is Freely Available to the Public

- NEMS is available through and used by DOE Labs, a few universities, environmental groups, EPRI, and some private companies (often on behalf of trade associations)
- NEMS is tailored to U.S. regions, infrastructure, data sources, and regulations, so not applicable to other countries
- Detailed model documentation on EIA web site (to meet EIA model documentation standards)
- Single-Run "archive" of NEMS available for each AEO and published study (also required by EIA archival standard)
- Some proprietary software and data needed: OML (~$4K/pc), Global Insight Macro Model and Eviews (~$7K/site), Xpress Solver, GAMS (~$3K/license w/o solver), McGraw-Hill data license (~$3K), Intel Fortran ($1.6K)

# Macroeconomic Activity Module

- Uses IHS/Markit macro-econometric models
- Links IHS energy variables with NEMS energy variables: fuel consumption, energy production, prices
- Projects economic and demographic drivers
- Determines economic adjustments to changes in energy markets and energy policies
- MAM Components:
  - **Input/Output model:** projects industrial output by 35 sub-industries
  - **Employment model:** estimates industry-specific employment is a function of current and lagged output, labor productivity, relative factor prices and cyclical variables
  - **Regional model: (**9 Census Divisions) estimates regional production, wages and salaries, disposable income, consumer prices, housing starts, and commercial floorspace based on Census population

# Electricity Market Module (1/2)

- Capacity Planning
  - Estimates amount and types of new generating capacity with detailed, multi-year LP structure
  - Simulates Technology/Fuel Choices, retirement decisions subject to plant characteristics, environmental constraints, technology trends (optimism, learning)
  - Applies market-sharing to allow closely competitive choices to penetrate

- Fuel/Dispatching
  - Allocates capacity to meet time-differentiated demand subject to costs of fuel, variable O&M costs, plant characteristics, emissions constraints, and T&D
  - Estimates regional generation, fuel consumption, emissions, electricity trade, marginal production cost

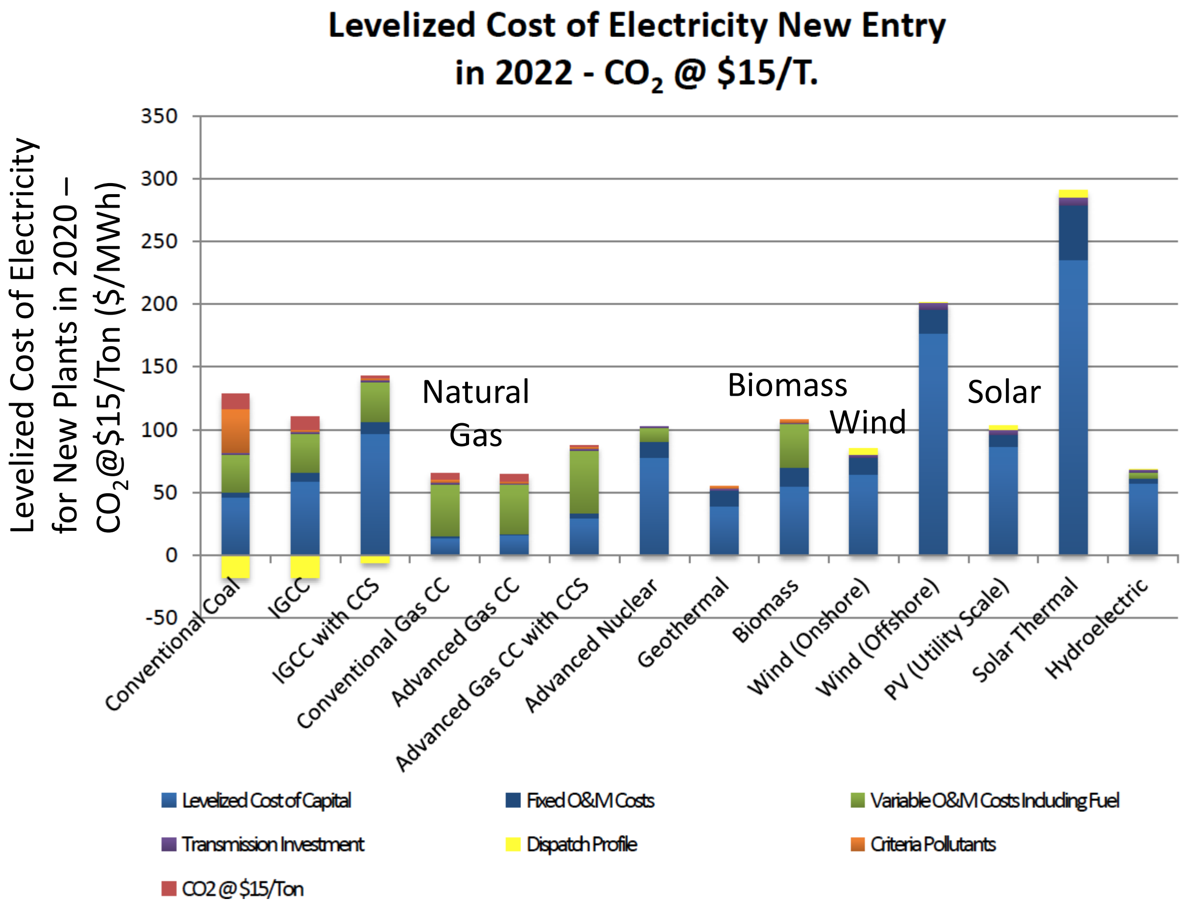
# Electricity Market Module (2/2)

- *Foresight*: Expectations may be derived in several ways (myopic, adaptive, perfect/rational).

- Load and Demand
  - Applies load shapes to create load duration curves from electricity demands by sector and end use

- Finance and Pricing
  - Calculates electricity prices by region. Combines two approaches
    - Cost-of-Service pricing for regulated companies
    - Marginal cost pricing for competitive service, adjusted for reliability and T&D costs

# Levelized Cost of Electricity From NEMS Inputs




(Source: National Academies "The Power of Change", 2016)

# Georgia Tech Uses GT-NEMS to Analyze Energy Policies & Technologies

- Emissions and Capacity Impacts of Demand Response
- Energy Benchmarking and Transparency
- Appliance Standards and Technology Development
- Modeling Climate-Driven Changes in Energy Demand
- Job Generation Impact of CHP
- Modeling the Potential for Electricity Savings
- Climate Policies Can Cut $CO_2$ and Reduce Energy Burdens
- Climate Policy Winners & Losers: Policy Design Matters

# Emissions & Capacity Impacts of Demand Response

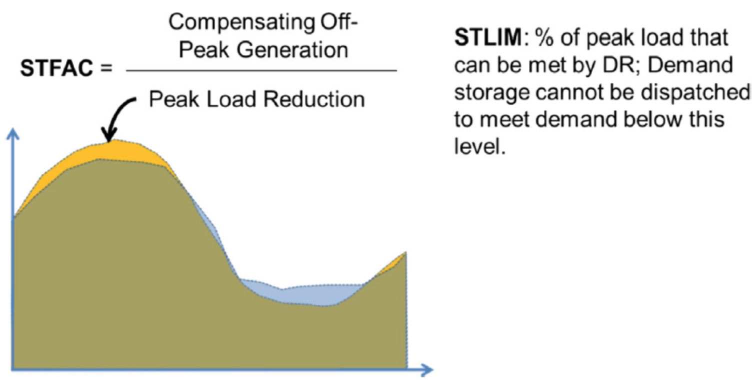
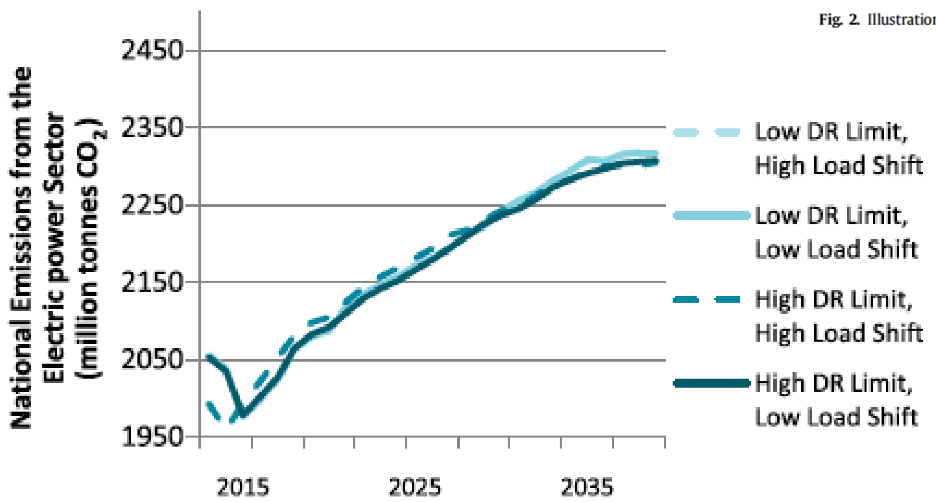
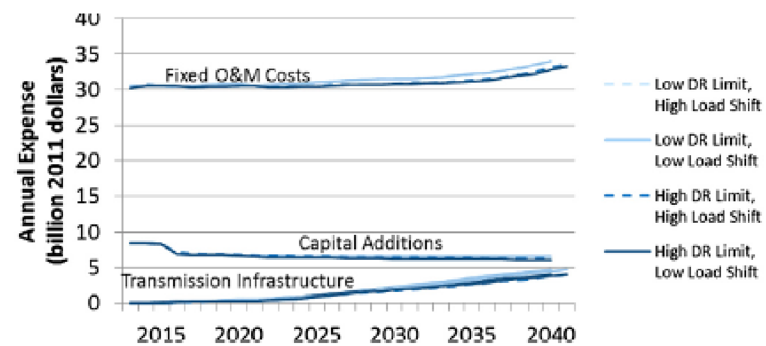



Fig. 2. Illustration of key DR parameters in GT-NEMS.

National Carbon Emissions




Electricity System Costs




- Demand response appears to be a "carbon-neutral capacity safety net," relieving the need for new peak capacity construction without increasing emissions

Smith, Alexander M. and Marilyn A. Brown. 2015. "Demand Response: A Carbon-neutral Resource?" *Energy*. 85: 10-22.

# Energy Benchmarking Delivers

## Benefit-Cost Analysis of Commercial-Sector Benchmarking (Billion 2009-$)

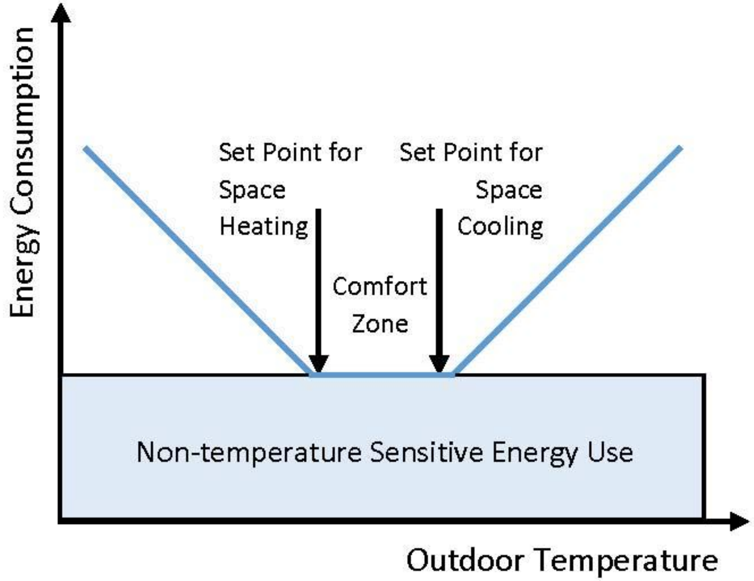
| | Cumulative Social Benefits | | | | | Cumulative Social Costs | | Benefit/Cost Analysis |
|---|---|---|---|---|---|---|---|---|
| Year | Energy Expenditure Savings | Value of Avoided $CO_2$ | Value of Avoided Criteria Pollutants | Lower Equipment Outlays | Total Benefits | Compliance Costs | Total Costs | Net Social Benefits |
| **2020** | 6.3–2.8 | -0.4–0.1 | 1.4–3.4 | 6.4–5.4 | 13.7–11.7 | 0.1 | 0.1 | |
| **2035** | 28.3–22.0 | 0.6–1.6 | 3.1–7.3 | 18.0–21.7 | 50.0–52.6 | 0.1 | 0.1 | |
| **Total Impact** | 39.7–31.7 | 0.9–2.3 | 3.0–8.2 | 18.0–21.7 | 61.5–63.8 | 0.1 | 0.1 | 61.4–63.7 |

- Synergies between building codes and benchmarking documented.
- Direct outcome: Atlanta is now the first southern city with energy benchmarking.

Cox, Matt, Marilyn A. Brown, and Xiaojing Sun. 2013. “Energy Benchmarking of Commercial Buildings: A Low-cost Pathway for Urban Sustainability,” *Environmental Research Letters,* Vol. 8 (3).

# Modeling Climate-Driven Changes in Energy Demand

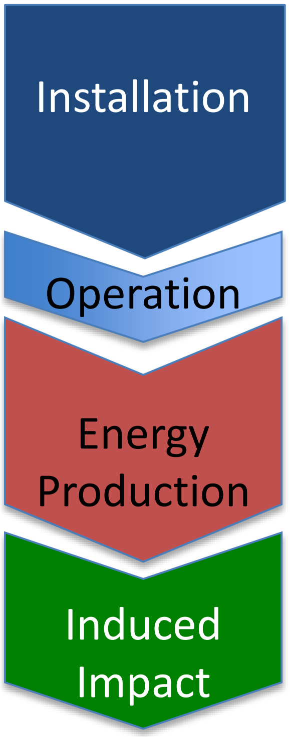
- Improve modeling of climate-driven demand changes in the National Energy Modeling System (NEMS)

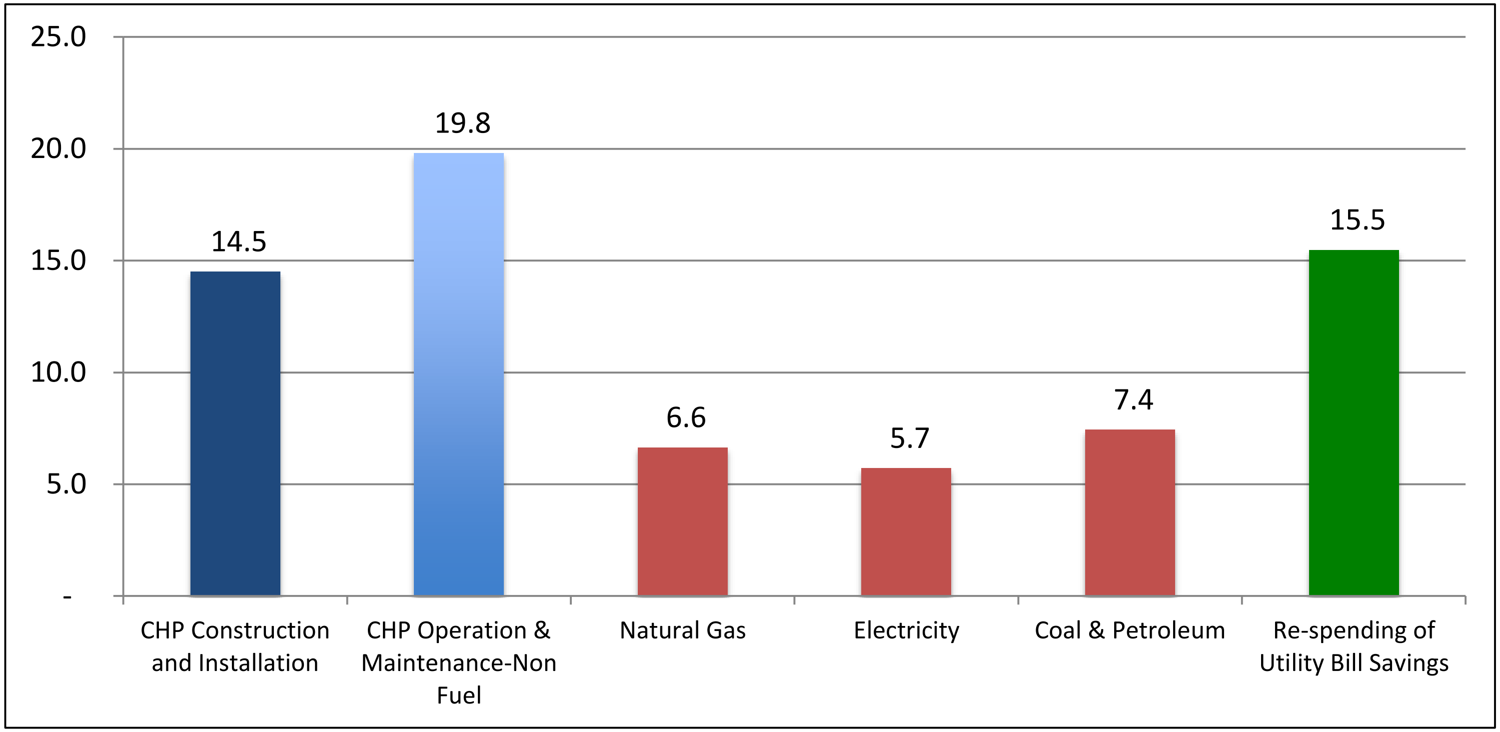



- Our "best fit" analysis of set points and exponents suggests that NEMS underestimates the climate sensitivity of building energy use.

Brown, MA, M. Cox, B. Staver, and P. Baer. 2016. "Modeling Climate-Driven Changes in U.S. Buildings Energy Demand," *Climatic Change,* 134:29–44, DOI: 10.1007/s10584-015-1527-7

# Job Generation from Expanding Industrial Cogeneration



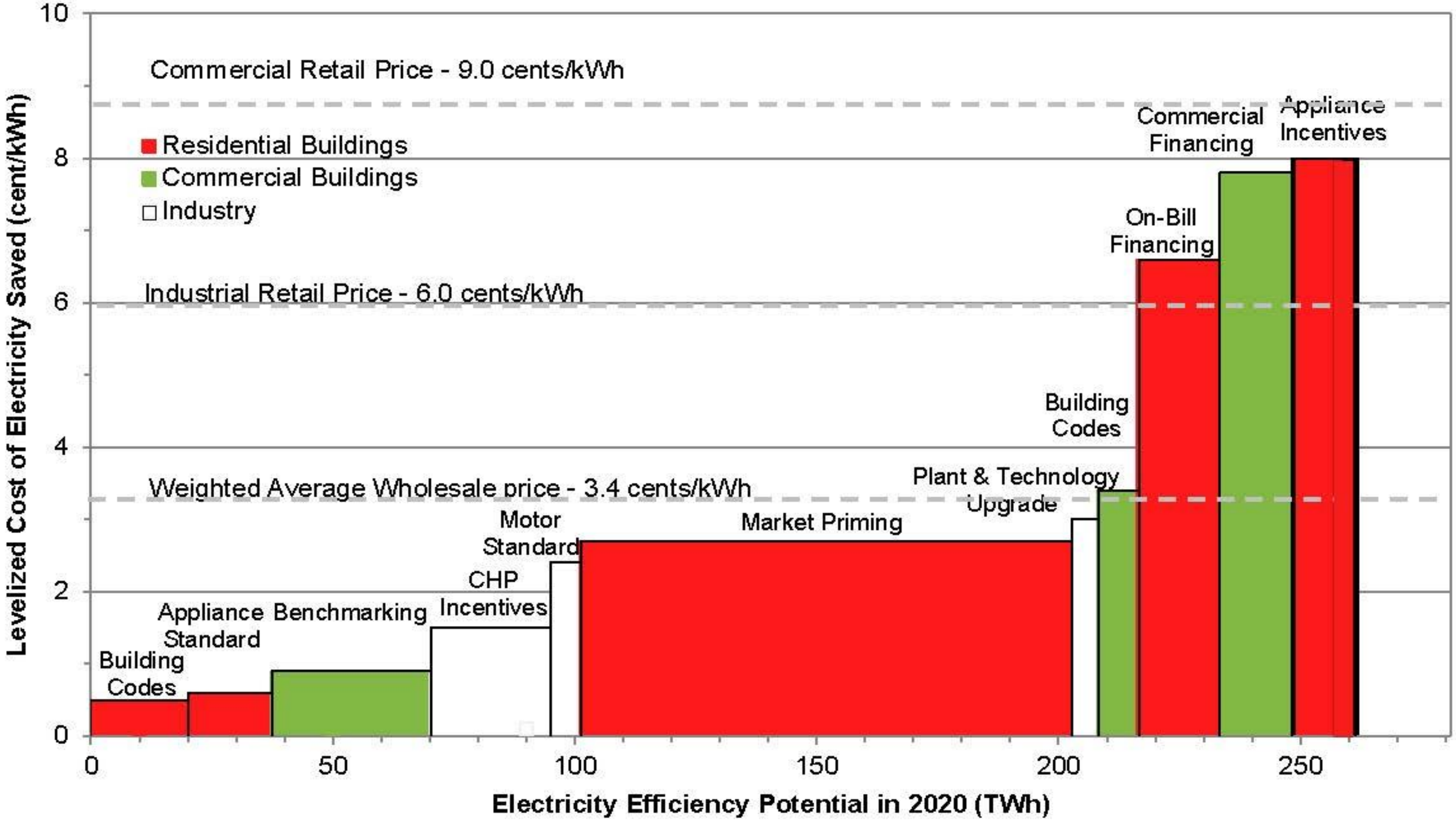




- The CHP construction bill of goods produces a job coefficient of 14.5.
- Second-order impacts are estimated based on the redirection of energy-bill savings accruing to consumers; on a jobs-per-GWh basis, they are approximately twice as large as the first-order impacts.

Source: Baer, Paul, Marilyn A. Brown, and Gyungwon Kim. 2015. “The Job Generation Impacts of Expanding Industrial Cogeneration,” *Ecological Economics,* 110 (2015) 141–153.

# U.S. Policy Supply Curve for EE in 2020

- Our policy analysis for EPSA has focused on the LCOE of many EE policies.




- Cited by EPA in Clean Power Plan technical documentation.

Source: Wang, Yu and Marilyn A. Brown. 2014. "Policy Drivers for Improving Electricity End-Use Efficiency in the U.S.: An Economic-Engineering Analysis". *Energy Efficiency,* 7(3): 517-546. M. A. Brown and Y. Wang. *Green Savings: How Policies and Markets Drive Energy Efficiency,* Praeger, September.

# Climate Policies can Cut $CO_2$ & Reduce Energy Burdens

**Types of Policies studied:**

- Carbon caps: "Clean Power Plan"
- Carbon taxes: "Carbon Dividends Plan"
  - redistribute taxes on a per capita basis vs
  - redistribute per source of $CO_2$.

**Supply & Demand Policies can Work Well Together:**

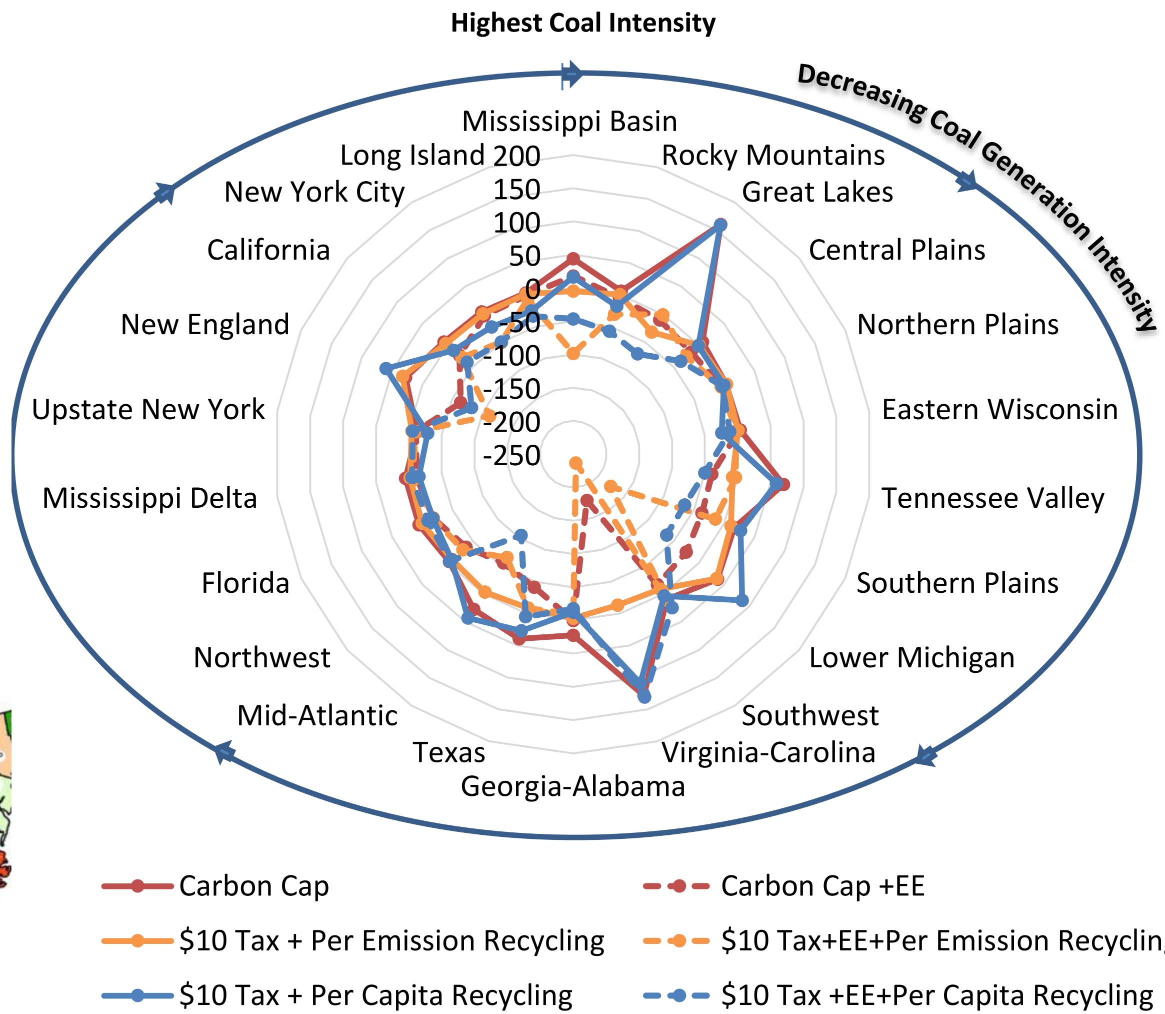
| Climate Policy: | Cost per ton of $CO_2$ Reduction |
|---|---|
| Carbon Cap | $39.13 |
| Carbon Cap + EE | -$26.30 |
| $10 Carbon Tax | $8.11 |
| $10 Carbon Tax + EE | -$28.63 |

**Cost of climate policy** = utility resource costs + EE costs + administrative costs – carbon tax recycling (in $2013)

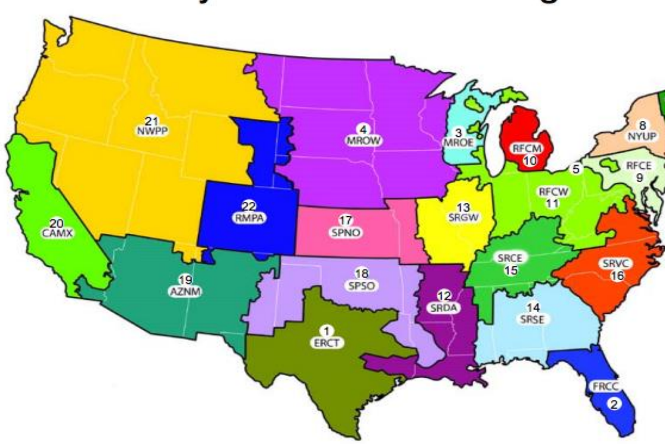
Source: Brown, M. A., Kim, G., Smith, A. M., & Southworth, K. (2017). Exploring the impact of energy efficiency as a carbon mitigation strategy in the US. Energy Policy, 109, 249-259.

# Climate Policy Winners and Losers: Policy Design Matters

**Climate policy costs per capita across regions in 2030**




Electricity Market Module Regions



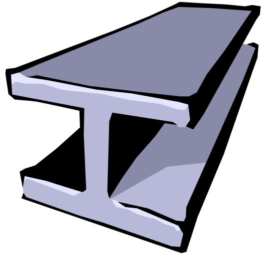

**Estimated impacts in Georgia-Alabama range from a cost of ~$25 per capita to a benefit of ~$250 per capita.**

# EXTRA INFO on NEMS

# Residential and Commercial Demand Modules

- Tracks changes to building stock and equipment/appliance stock
- Chooses new or replacement equipment for each energy service based on cost, performance and economic behavior
- Technology characteristics reflect future cost reductions and performance improvements, mandated efficiency standards and building regulations

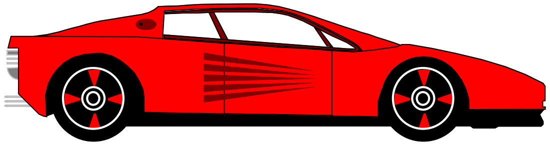
# Industrial Demand Module



- Industry sector decomposed into multiple manufacturing industries, agriculture, construction, and mining
- Energy use estimated by major process steps or end uses based on major technology bundles in some industries
- Energy intensity for each bundle declines based on time, rate of capacity additions, and energy prices
- Expanded explicit technology detail in recent years:
  - Technology choice simulation for energy-intensive raw material industries (steel, paper, cement, glass, aluminum)
  - Model of electric motor choice included for 10 manufacturing industries
  - Combined heat and power (CHP) model

# Transportation Demand Module

- Distinct approaches for light-duty vehicles, trucks, rail, shipping, and air travel.
- Energy use in light-duty vehicles
  - Vehicle-miles traveled estimated based on cost of driving, income, and demographics
  - Tracks light-duty vehicle stocks by type and age
  - Fuel-saving technologies selected for cost effectiveness and compliance with fuel economy standards
  - Alternative-fuel and advanced technology vehicle sales are a function of technology attributes, costs, and fuel prices
- Freight truck and air are also vintaged stock models
  - Commercial, medium, and heavy trucks
  - Regional, narrow, and wide body aircraft



# Coal Market Module

- Determines coal prices and least-cost supply of coal to meet demand, subject to environmental constraints (mercury, $SO_2$) using LP

- Coal Costs
  - Production costs represented by econometrically-derived coal supply curves differentiated by region, rank, sulfur, mining method
  - Transportation costs between coal supply and demand regions

- Estimates mine-mouth and delivered coal prices, regional production quantities, and coal distribution between supply and demand regions.

# Oil and Gas Modules

- Oil and Gas Supply Module
  - Estimates oil & gas proved reserves, drilling activity, domestic oil production
  - Represents imports of pipeline and liquefied natural gas
- Natural Gas T&D Module
  - Matches supplies and demands of natural gas
  - Estimates domestic production, interregional flows, and imports, pipeline capacity additions, and tariffs
  - Estimates delivered and wellhead natural gas prices
  - Estimates lease & plant and pipeline fuel consumption
- Petroleum Market Module
  - Simulates refining activity and expansion, oil supply balance (crude and product imports, domestic sources)
  - Estimates product prices and refinery fuel consumption

# Some NEMS Modeling/Processing Details

- NEMS finds an equilibrium one "projection year" at a time using an iterative block Gauss-Seidel solution algorithm
- NEMS *cycles* over all projection years until inter-temporal convergence is achieved
- NEMS uses custom convergence metrics
- *Foresight*: Expectations may be derived in several ways (myopic, adaptive, perfect/rational).
- For *perfect foresight*, expectations are obtained from the solution values from the prior cycle, and we seek a solution where expectations from the prior cycle converge with the realized solution in the current cycle.
- NEMS can be run in a two-part parallel processing model