MRN-NEEM Technical Session

November 9, 2010

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Structure of Technical Session

- Introduction to MRN
- MRN-NEEM Integration Approach
- PHEV Example
- NEEM Examples
  - SO_2 and NO_x (CAIR)
  - Local Renewable Portfolio Standard (New England RPS)
  - Differentiating remote wind resources (by wind quality and cost of interconnection)
- Remaining Questions about NEEM?

Example Objectives

- To illustrate modeling approaches to specific aspects of a given future
- To explain the relevant model inputs and data needs
- To discuss the impact on results
- To answer related questions from stakeholders and have discussion

Introduction to MRN

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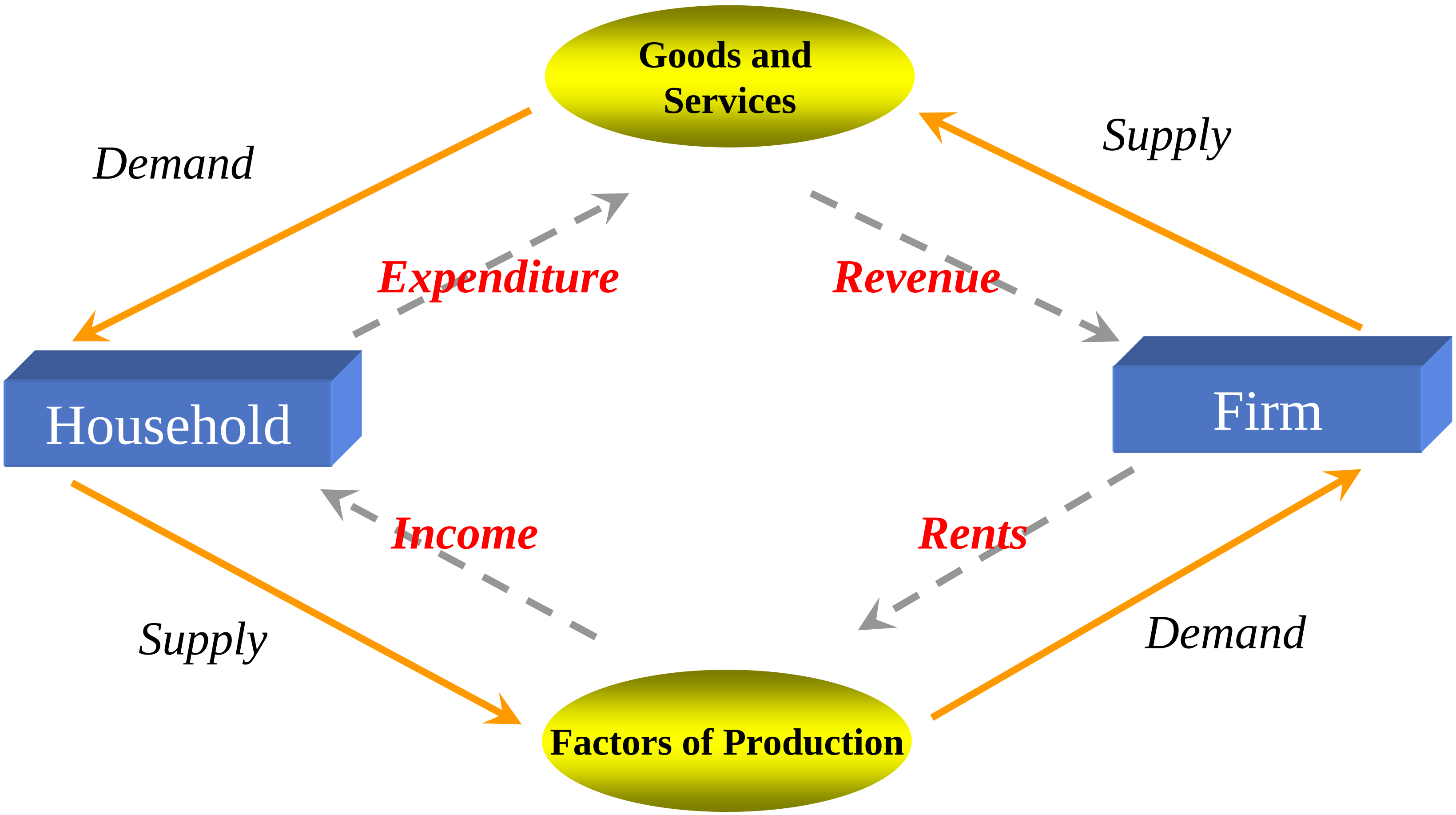
Underlying Principles of General Equilibrium

- Arrow-Debreu general equilibrium model
  - An economic model of production and consumption based on neoclassical assumptions
  - Consumers are endowed with primary factors (labor and capital)
  - Producers take market prices as given
  - Markets clear, no excess profits, budgets balance
  - Consumers and producers make choices as though they have “perfect foresight”

Simple Static Economy Representation



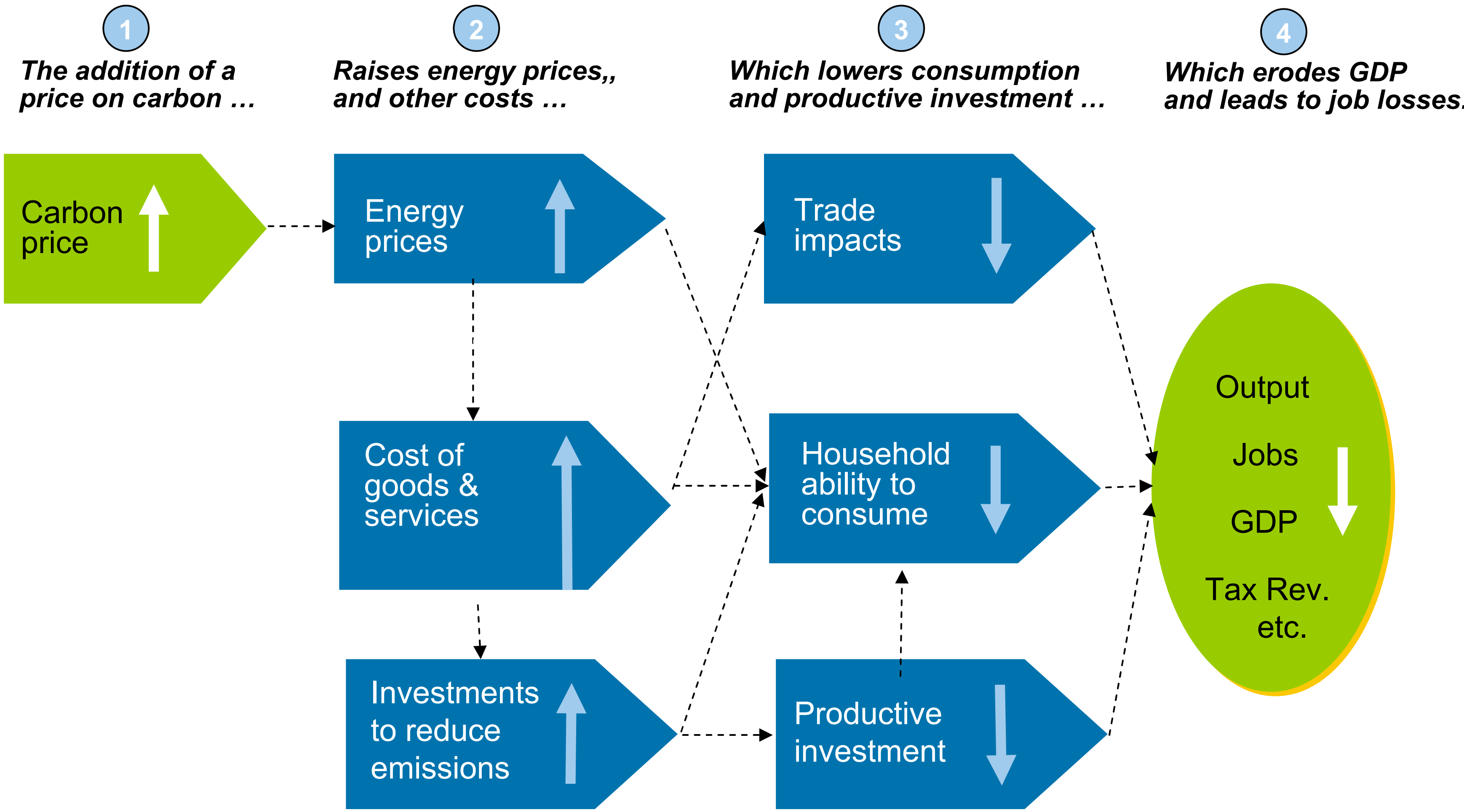
What is a CGE model?

- Features of any CGE model
  - Account for all agents (households, firms, government)
  - Accounts for all goods and services
  - Firms hire factors of production and maximize profits subject to a production function
  - Consumers own all factors of production and maximize utility subject to a budget constraint
  - There is interaction between agents and markets in the economy
  - Accounts for all resources that constrain output in an economy
  - Assumes all markets clear, with prices adjusting so that supply = demand
  - Markets are all connected, so that changes in one market affect prices in all markets

Representation of firm or consumer behavior

- Firm's technology is modeled by a production function
  - Producers take prices as given.
  - Capital accumulation responds to rates of return.
  - Capital-labor-energy-material KLEM production functions characterize cost of production.
  - Producers minimize cost of production, responding to changes in the relative prices of KLEM, based on technologies *calibrated* to base year statistics.
- Consumer behavior is modeled by a utility function
  - Households maximize utility subject to a budget constraint

Understanding the ripple effect of the impacts



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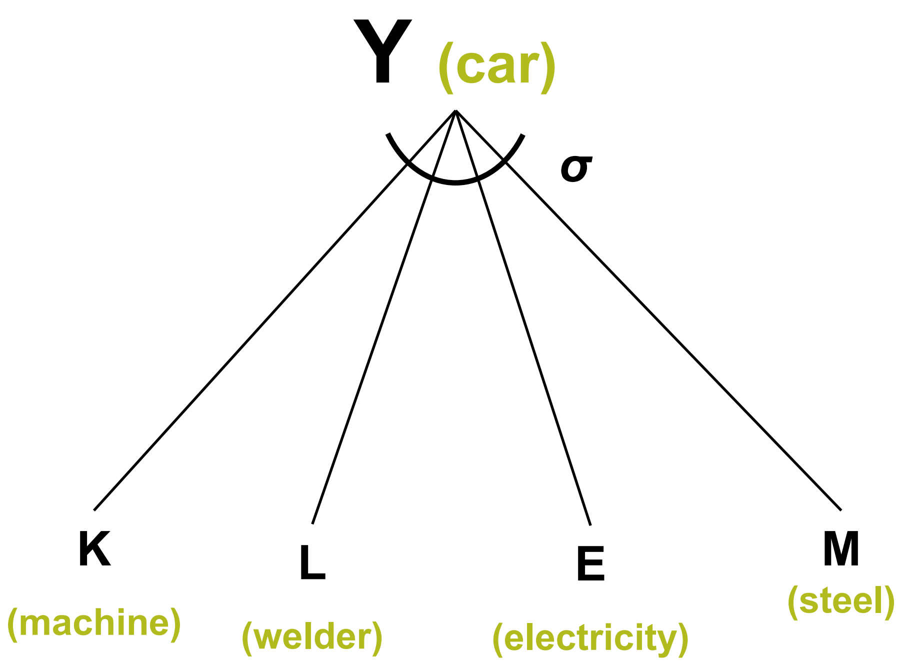
Simple production function representation

$$K + L + E + M = Y$$



- Suppose Capital (K), Labor (L), Energy (E), and Material (M) are required to produce good Y
- Inputs can be used in fixed proportions or, to produce the same amount of Y, we can not use more of one input and less of the other (e.g., more K and less L)
- The substitution of inputs is limited by the elasticity of substitution (σ). Note: in NEEM this elasticity is zero so no substitution is allowed and to double output means doubling all inputs.

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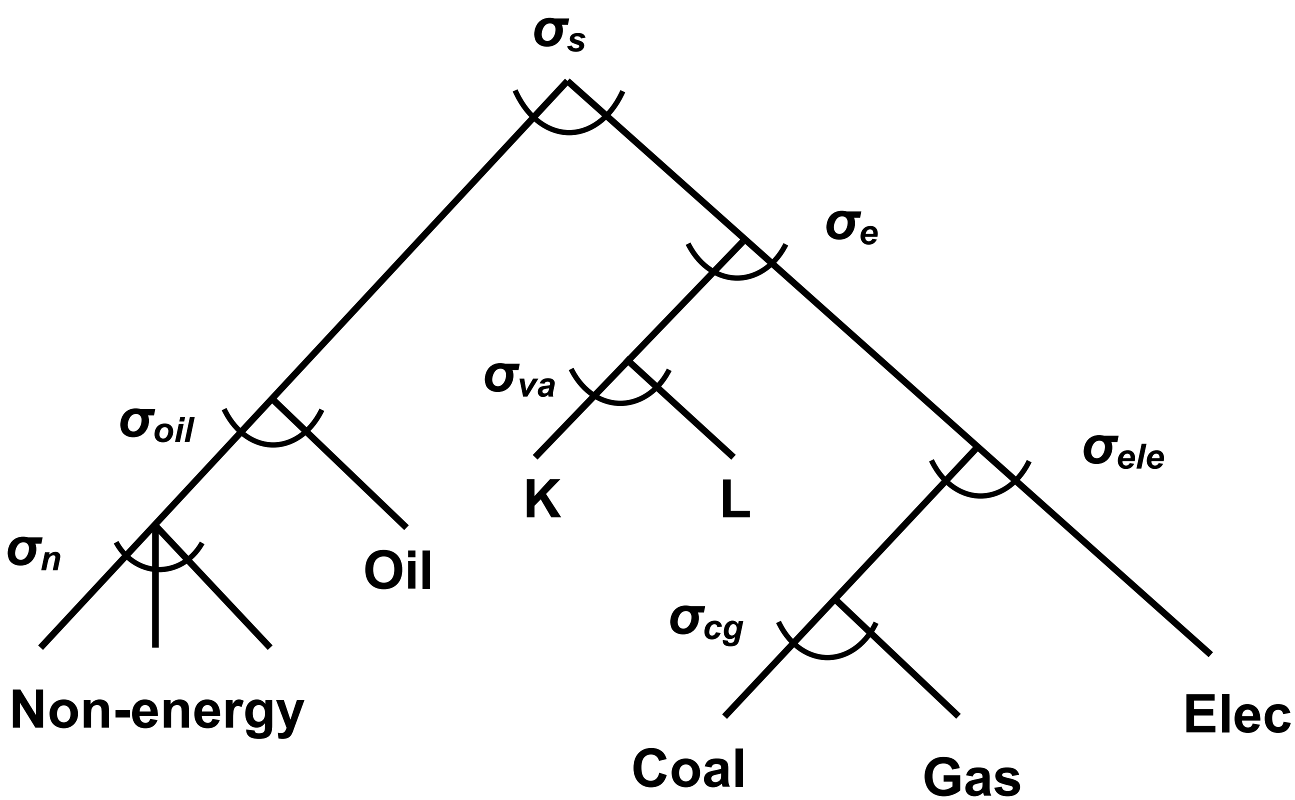
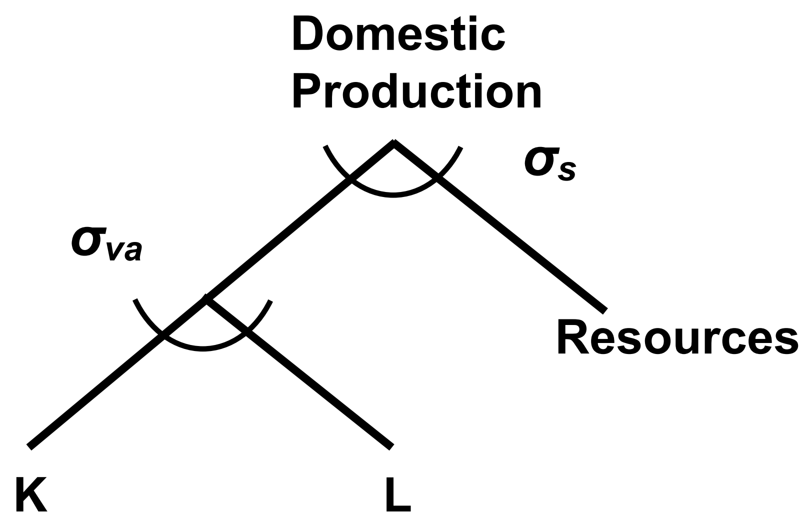
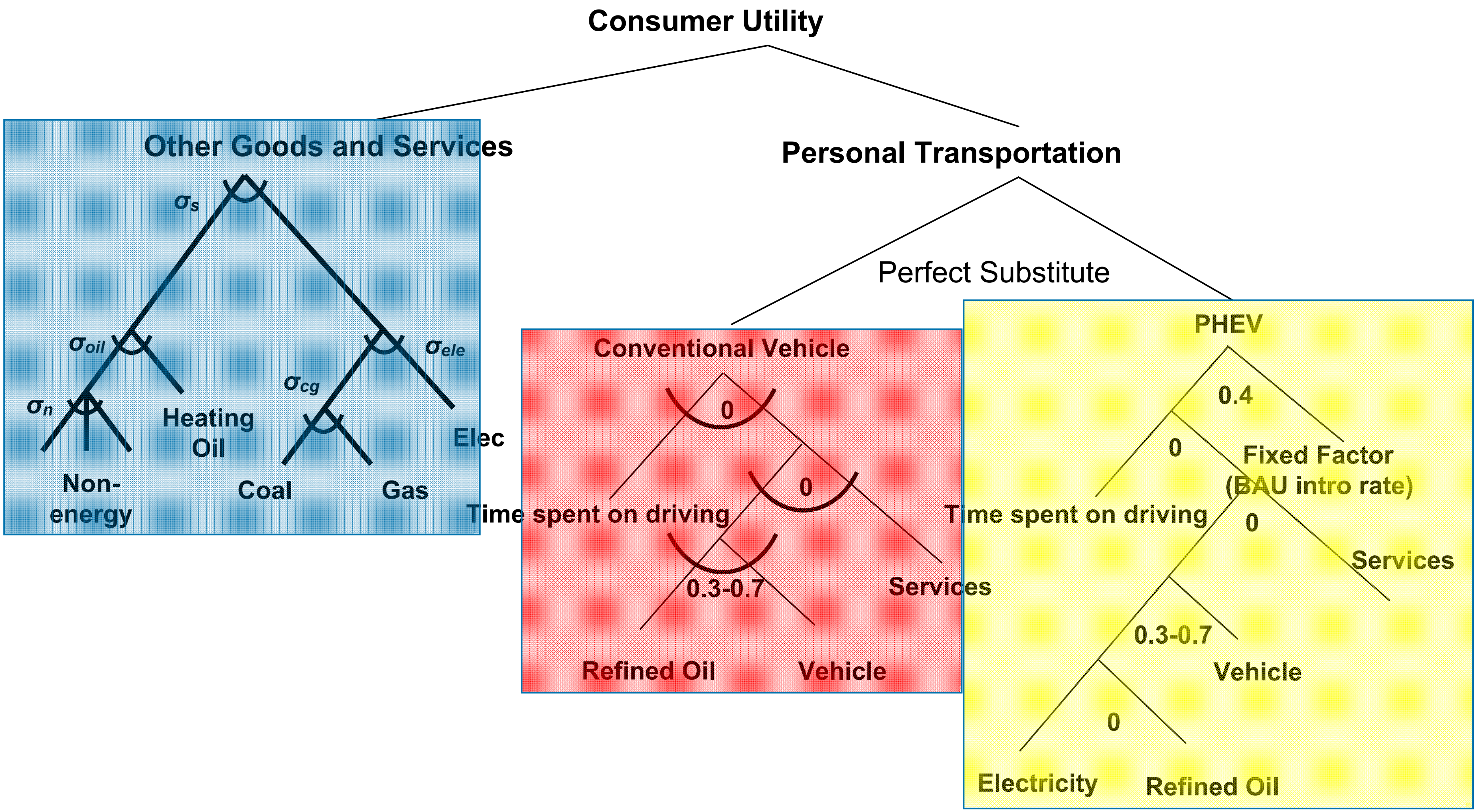
Production Structure – a nested CES structure



Production Structure - Resource Sectors



Consumption - Household Behavior



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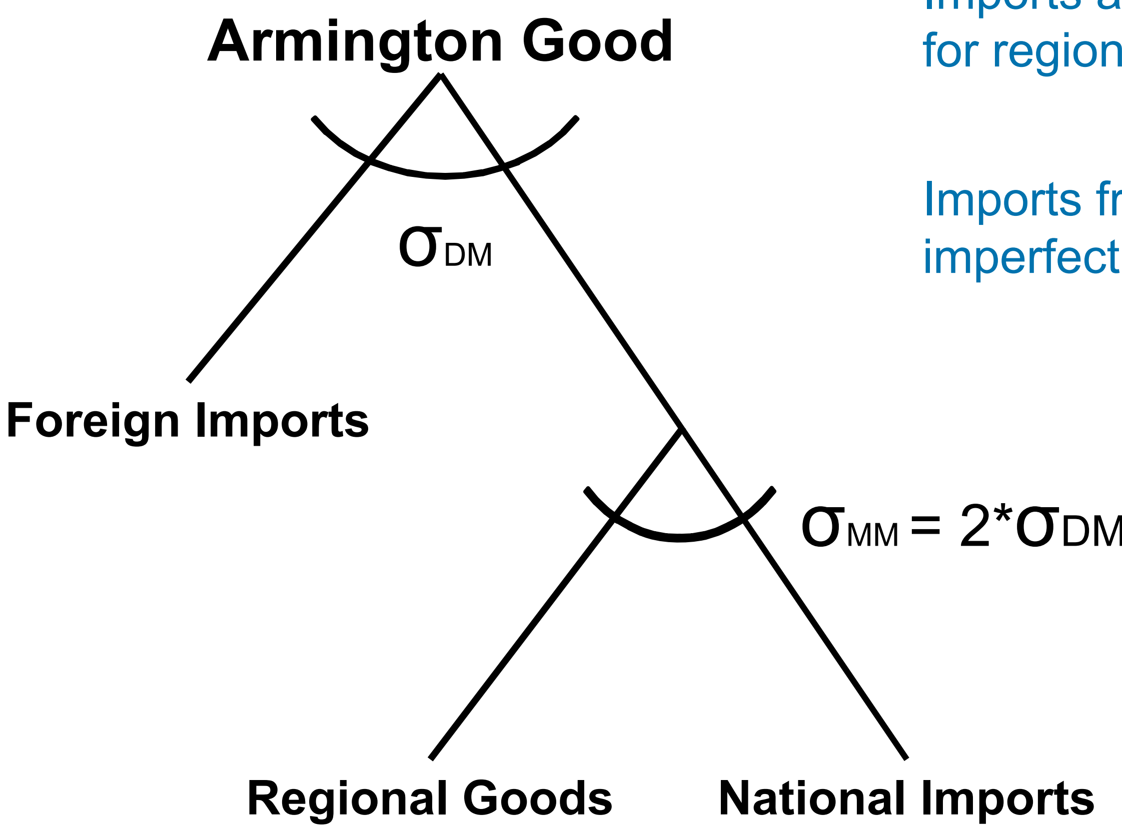
Trade Representation – Armington

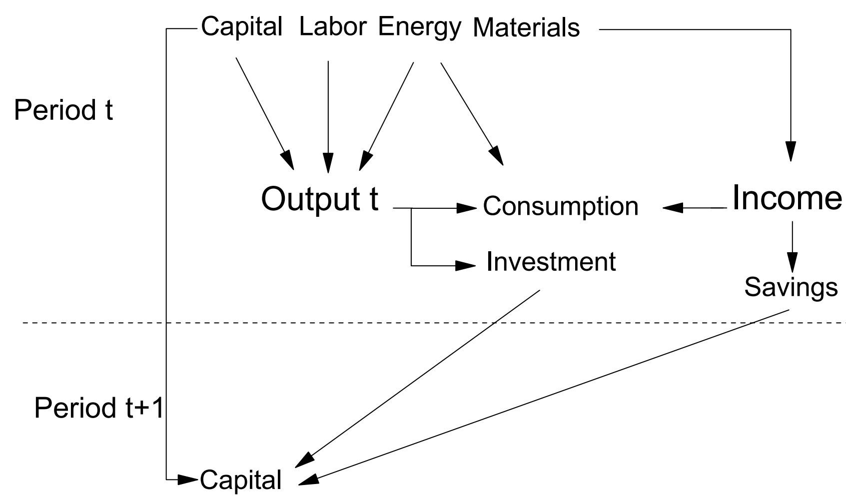


Imports are imperfect substitutes for regionally produced goods.

Imports from different regions are imperfect substitutes for each other.

Investment Dynamics in MRN

- Primary factors produce output
- Output divided between consumption and investment
- Investment augments capital stock
- Savings equals investment
- Fully dynamic
  - Consumers choose to allocate lifetime income across consumption in different time periods.



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How is MRN-NEEM model programmed?

- MRN is written in GAMS (Generalized Algebraic Modeling System) and solved with a mixed complementarity (fixed point) program
- MPSGE software automates process of writing CGE model
  - Follows basic format of Arrow-Debreu model
  - Define sets for industries, commodities and regions
  - Specify functional form for production functions and utility functions
  - Choose nesting structure for commodities and industries
  - Declare elasticity values
  - MPSGE writes down first order conditions and uses SAM to benchmark

MRN Regional Coverage

9 Regions

50 States & DC

MRN Region		States included
CALI	California	CA
ECRR	ECAR	MI, IN, OH, KY, WV
MAPP	MAPP-US	IA, ND, SD, NE, KS, MN
MSVL	Mississippi Valley	IL, MO, AR, LA, WI
NYNE	NY and NEISO regions	MA, ME, NH, NY, RI, VT, CT
OKTX	Oklahoma and Texas	TX, OK
PJME	PJM	PA, MD, DC, NJ, DE
SEST	South East	MS, AL, TN, GA, SC, VA, NC, FL
WEST	West except California	WA, OR, AK, HI, ID, MT, NV, UT, CO, WY, AZ, NM

MRN Sectoral Coverage

509 SECTORS

* Energy Sectors
  - 1 COL Coal
  - 2 CRU Natural Gas and Crude
  - 3 ELE Electric Generation
  - 4 GAS Natural Gas Distribution
  - 5 OIL Refined Petroleum
* General Sectors
  - 6 AGR Agriculture
  - 7 CNS Construction
  - 8 DWE Owner-occupied dwellings
  - 9 MIN Metal and Nonmetal Mining
  - 10 M_V Motor Vehicles -- SIC 371
  - 11 SRV Services
  - 12 TRN Transportation Services
* MECS Energy Sectors
  - 13 ALU Aluminum
  - 14 CHM Chemicals
  - 15 COM Computer and Electronic Products
  - 16 ELQ Electrical Equipment and Appliances
  - 17 FAB Fabricated Metal Products
  - 18 FOO Food and Kindred Products
  - 19 I_S Iron and Steel
  - 20 MAC Machinery
  - 21 MSC Miscellaneous Manufacturing
  - 22 OPM Other Primary Metals
  - 23 PAP Paper and Pulp Mills
  - 24 PRN Printing and Related Support
  - 25 RUB Plastics and Rubber
  - 26 SCG Nonmetallic Mineral Products
  - 27 TEX Textiles and Apparel and Leather
  - 28 TRQ Transportation Equipment
  - 29 WOO Wood Products and Furniture

11 Industrial Sectors

* Energy Sectors
  - 1 COL Coal Production
  - 2 CRU Crude Oil
  - 3 ELE Electricity Generation
  - 4 GAS Natural Gas Distribution
  - 5 OIL Refined Petroleum Products
* Non-energy Sectors
  - 6 AGR Agriculture
  - 7 EIS Energy Intensive Sectors
  - 8 MAN Manufactured and Processed Goods
  - 9 TRN Transportation Services - Commercial
  - 10 SRV Services
  - 11 M_V Motor Vehicles
* Final Demand Sectors
  - C Households
  - G Government
  - I Investment

MRN inputs based on public macroeconomic data

Data	Source
Input-output tables of US economy at state level	IMPLAN *
Energy flows and prices	EIA
Tax rate and revenue data	National Bureau of Economic Research's TAXSIM model
Forecasts of energy prices and quantities	EIA (AEO)

*** CRA corrects IMPLAN's regional economic data to make them usable for energy analysis**

- **Raw IMPLAN data are inconsistent with energy quantities and prices reported by EIA**
- **CRA modifies the IMPLAN energy accounts to match EIA's state-level energy data**

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Typical MRN Outputs

- Welfare change (Hicksian Equivalent Variation)
- Carbon
  - Total emissions
  - Carbon price
- Macroeconomic
  - Consumption
  - Investment
  - GDP
  - Wages
  - Real consumption per household
  - Employment
- Sectoral
  - Output by region
  - Prices by region
  - Employment by region
- Energy (Crude oil, refined products, natural gas, coal and electricity)
  - Wellhead (and ex-refinery prices) by region
  - Delivered prices by sector and region
  - Quantity produced by region
  - Quantity consumed by region
- Government Budget
  - Required tax change to maintain budget balance
- Trade
  - Terms of trade with other regions and abroad
  - Imports and exports
  - Capital flows

MRN-NEEM Integration Approach

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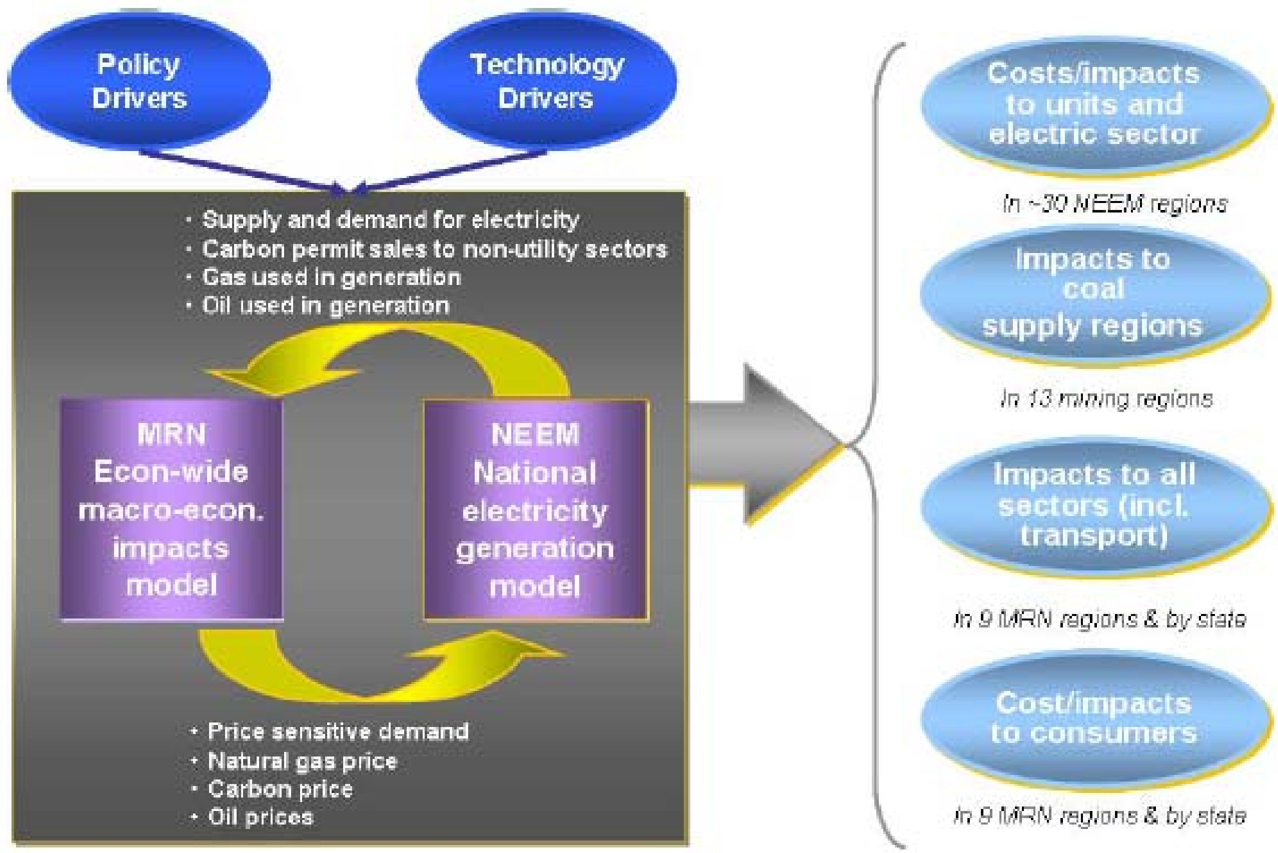
Integration of MRN and NEEM*



* Based on: Bohringer, C. and Thomas F. Rutherford, 2005, "Combining Top-Down and Bottom-up in Energy Policy Analysis: A Decomposition Approach"

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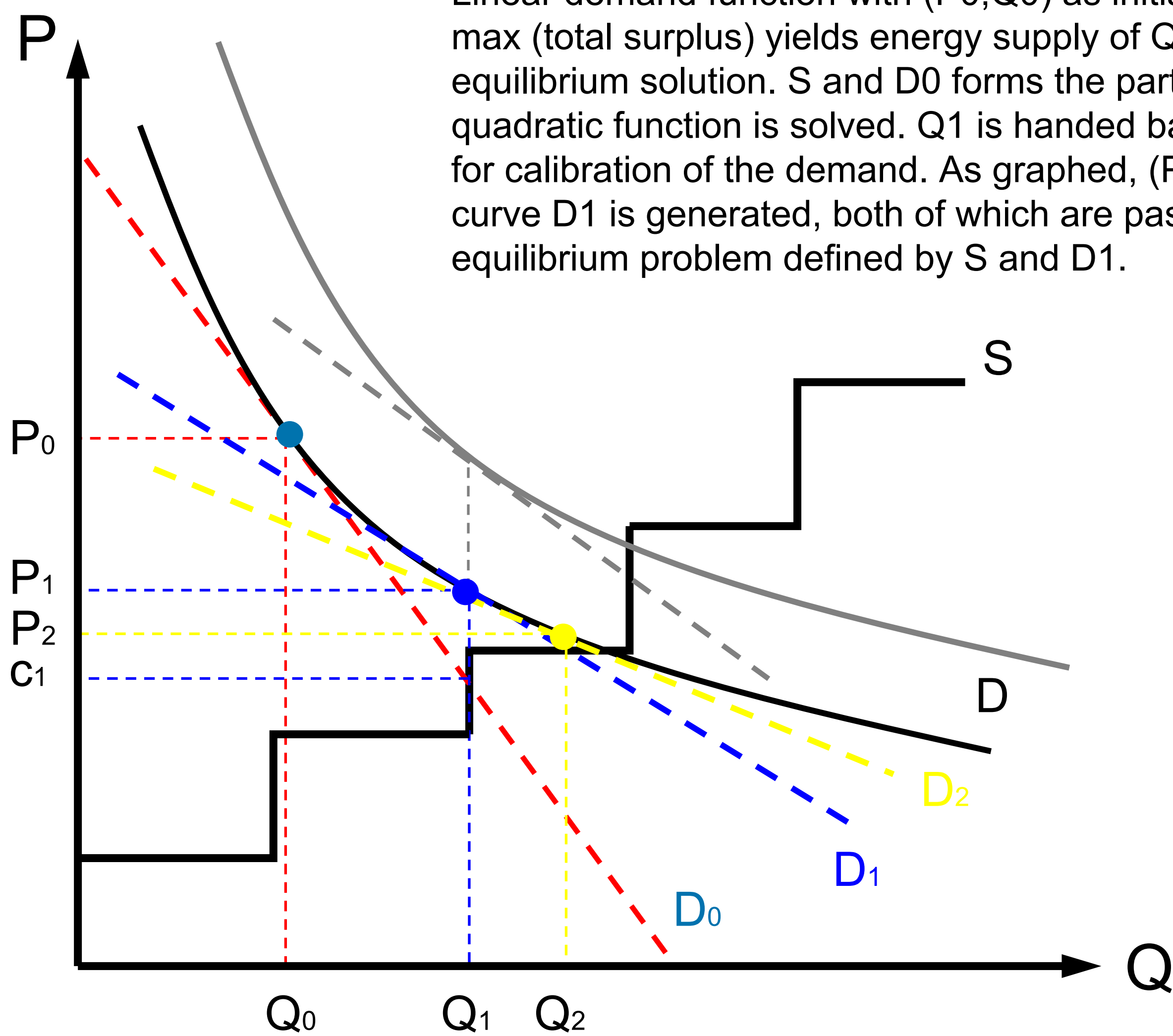
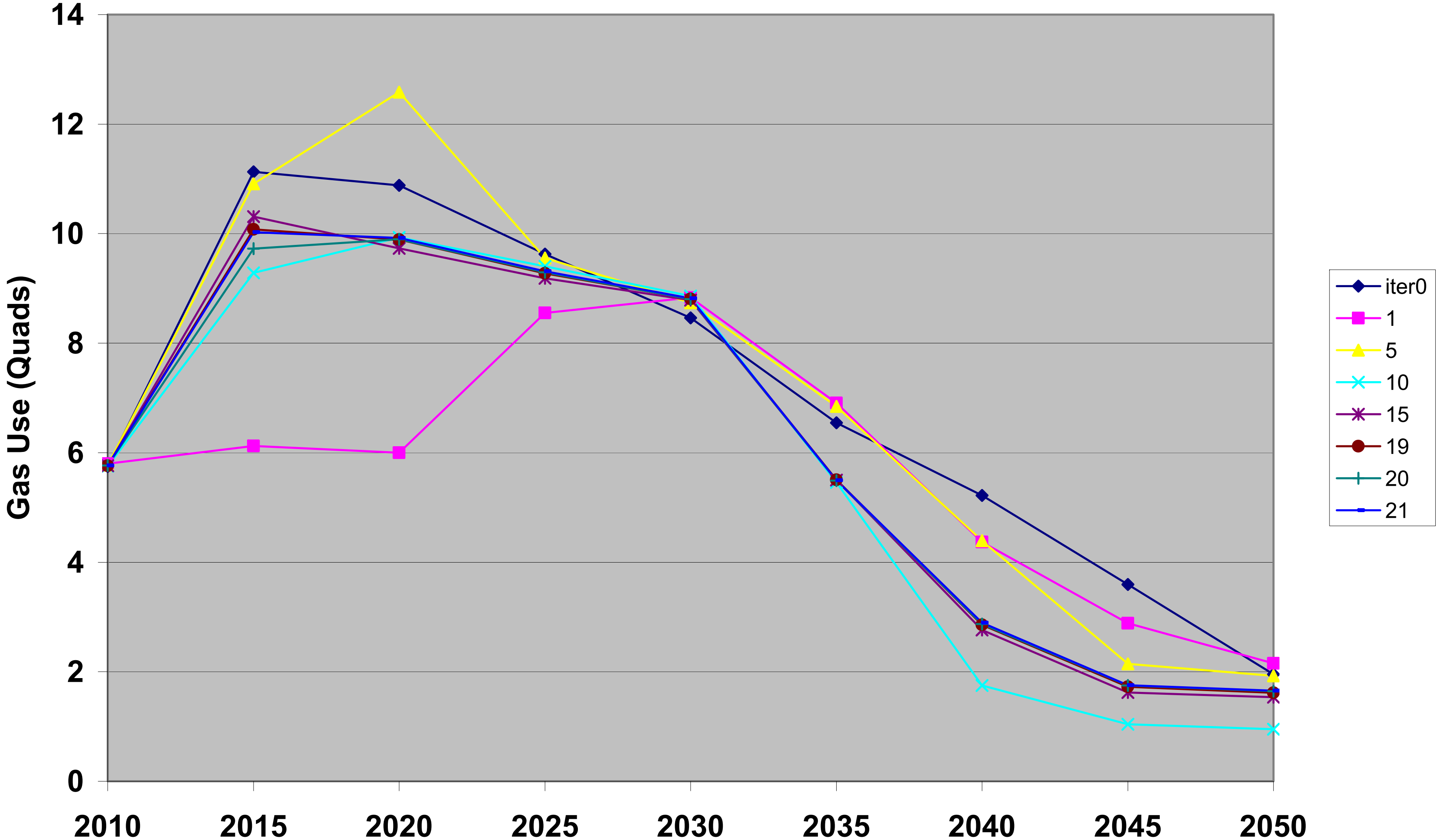
Iterative Process Diagram

Linear demand function with (P0,Q0) as initial guess is handed to NEEM where max (total surplus) yields energy supply of Q1 at a marginal cost of c1 as equilibrium solution. S and D0 forms the partial equilibrium model where a quadratic function is solved. Q1 is handed back to MRN as a reference quantity for calibration of the demand. As graphed, (P1, Q1) is solved and linear demand curve D1 is generated, both of which are passed back to NEEM to solve a partial equilibrium problem defined by S and D1.



This process is repeated till NEEM supplied demand function and MRN supply schedule converge to a consistent equilibrium price-quantity pair.

Gas Use In Electricity Sector by Iteration



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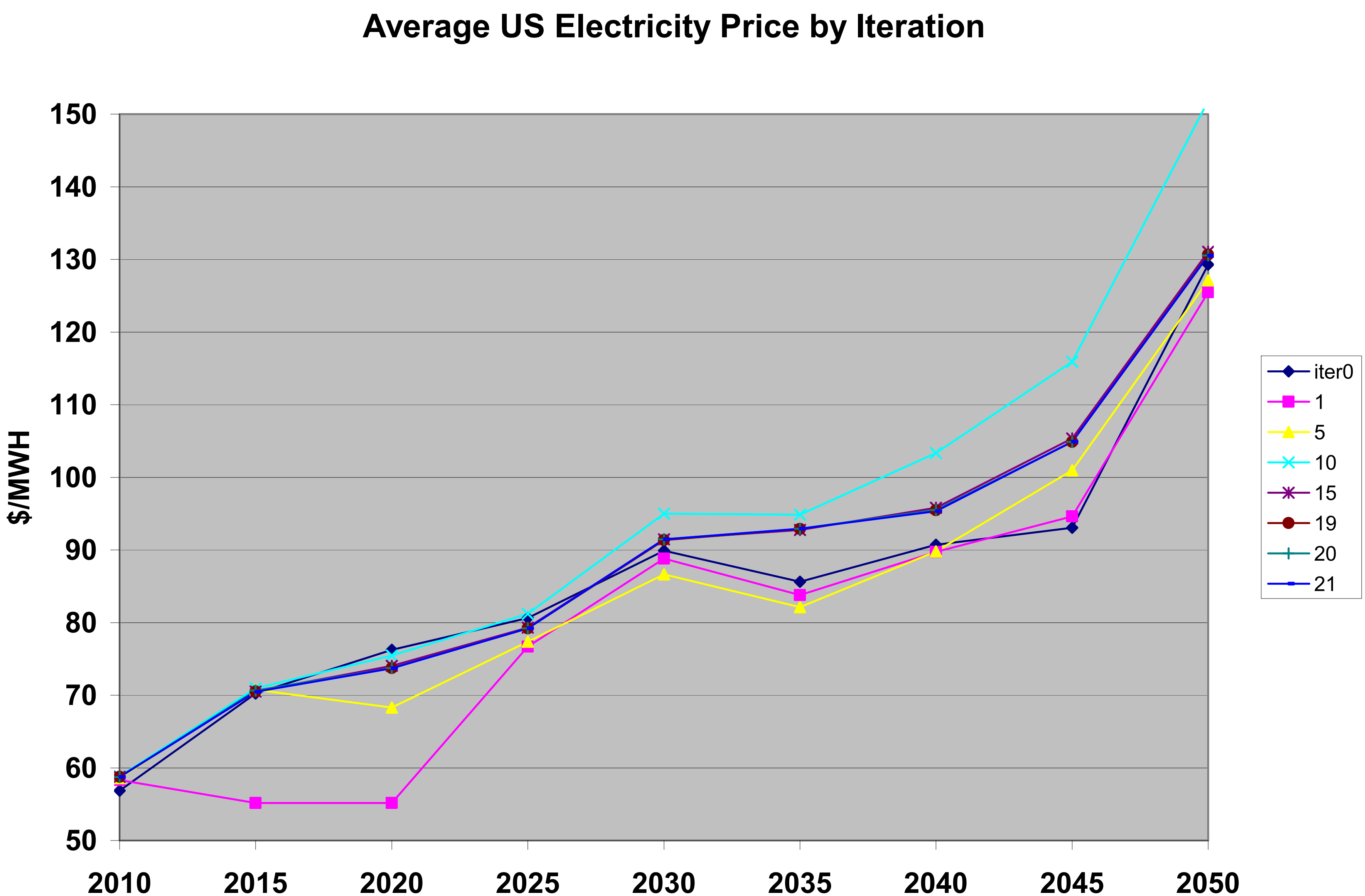

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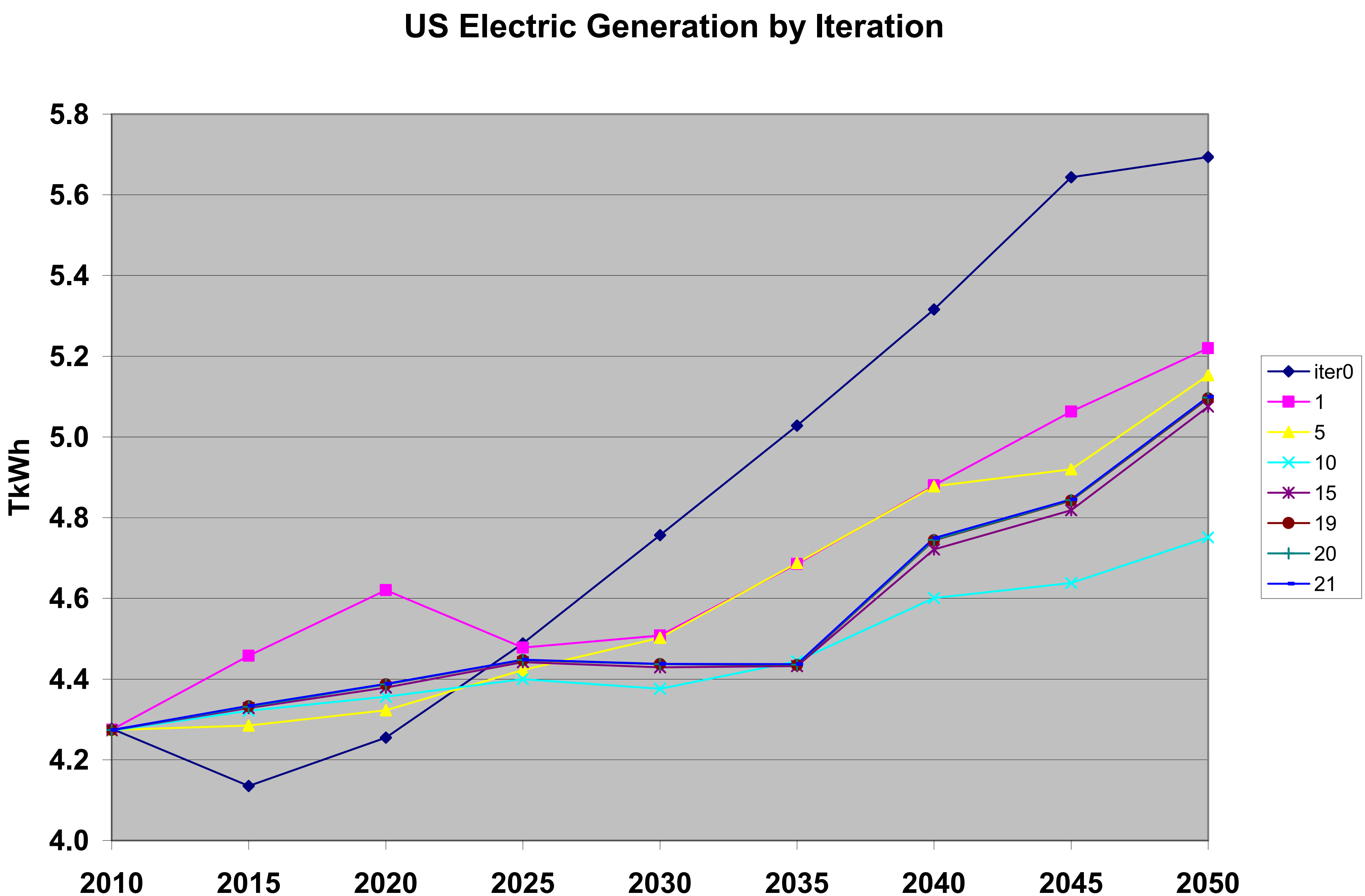

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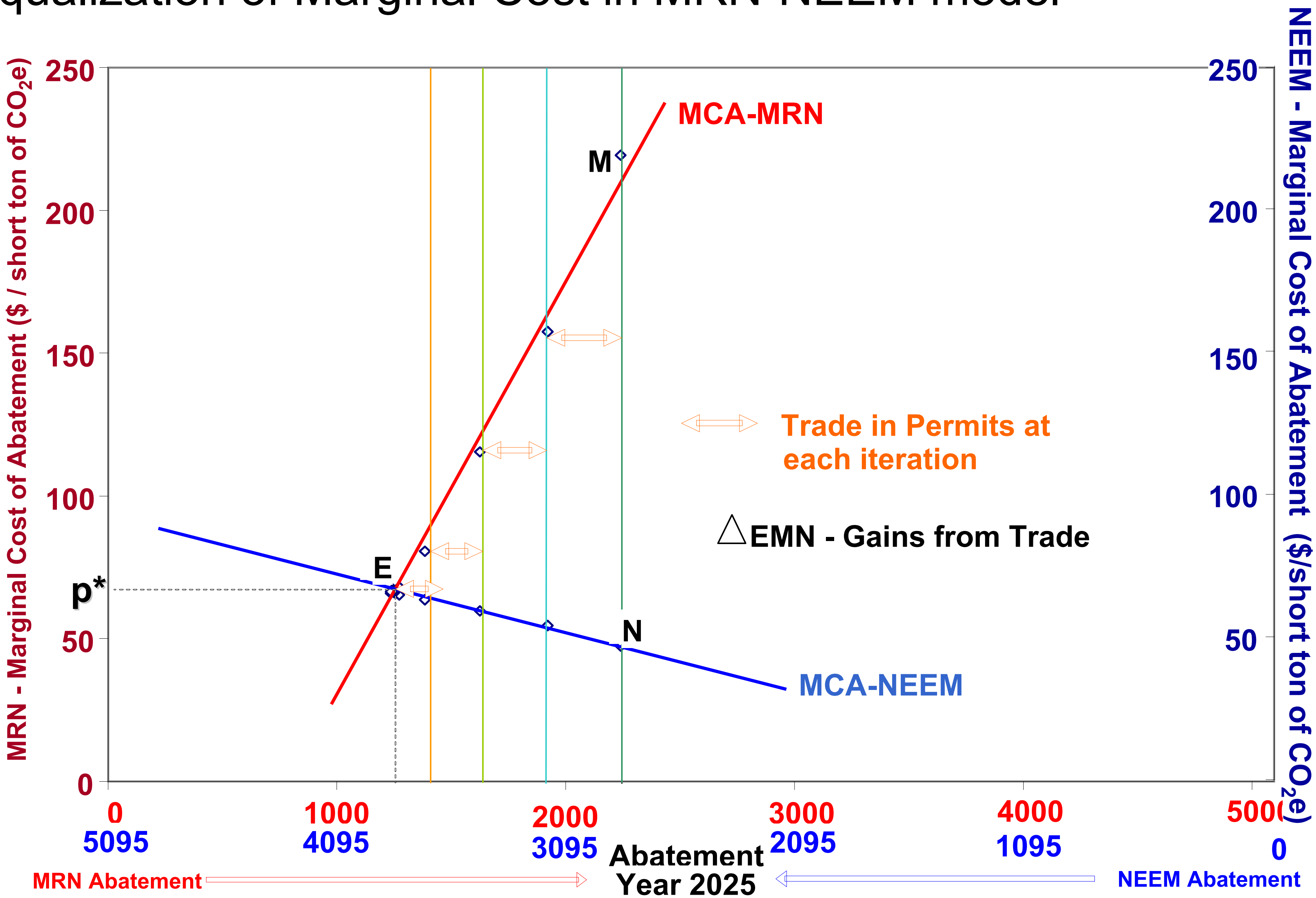
Equalization of Marginal Cost in MRN-NEEM model



PHEV Example

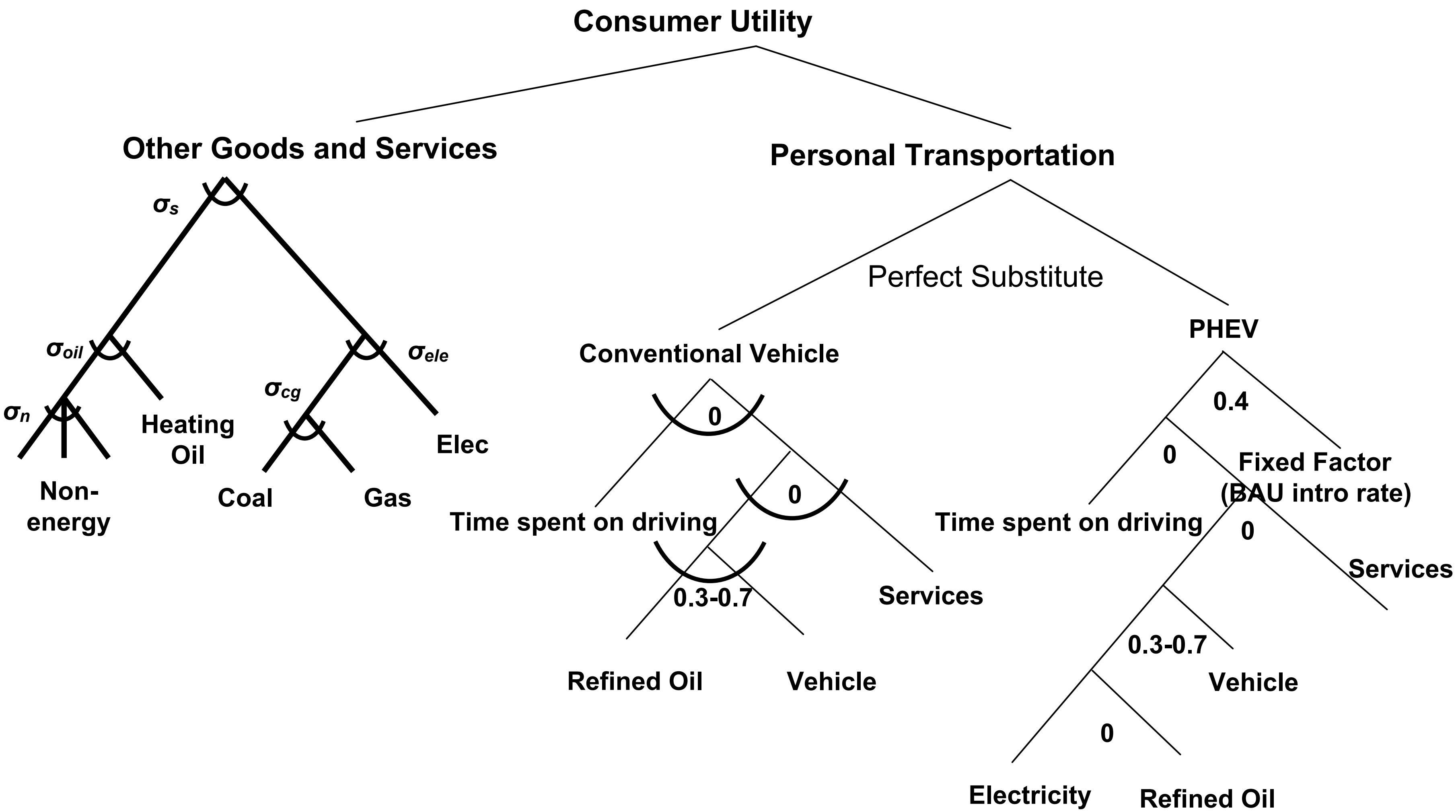
Modeling Plug-In Hybrid Vehicle (PHEV)

- How are PHEVs modeled in MRN-NEEM?
- Characteristics of PHEVs
- Illustrative examples of PHEV modeling
- Some insights on model results

Modeling of the Plug-In Hybrid Vehicle (PHEV)

- Consumers demand transportation services from conventional vehicles or/and from PHEV vehicles
- PHEV competes against conventional vehicle based on internal combustion engine (ICE) powered by gasoline
  - PHEV and conventional vehicle are assumed to be perfect substitute
- The PHEV is characterized by:
  - ICE component with a fuel economy of 43 MPG
  - 60% of miles driven on electricity (0.3 kWh/mile)
  - 15% cost mark-up on vehicle purchase
- PHEV penetration is driven by **economic decisions** that depends on:
  - Cost profile of PHEV vehicles compared to a conventional vehicles
    - Vehicle Cost
    - Fuel Cost
  - Consumer preference

Consumption - Household Behavior



Illustrative Example of PHEV Scenario design

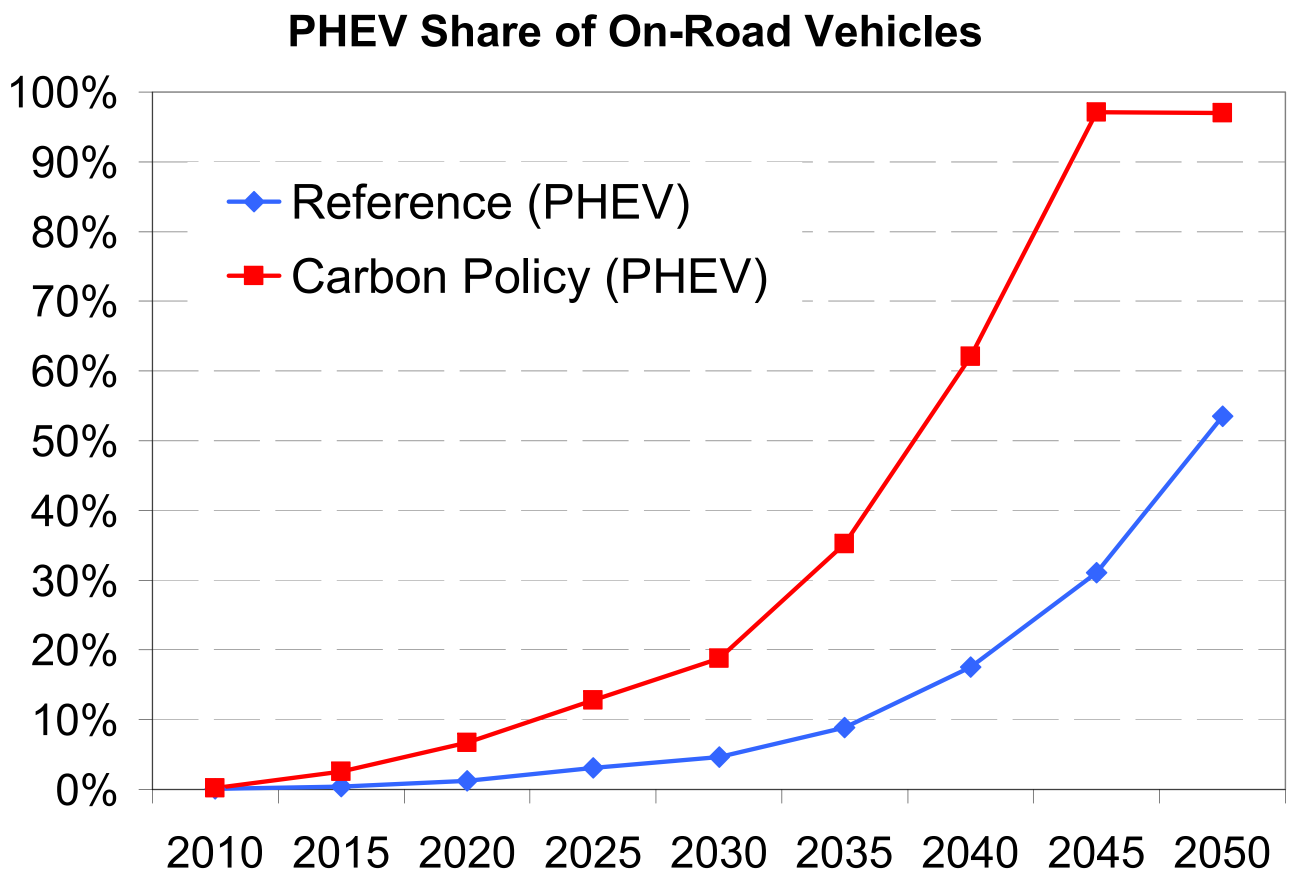
	Without PHEV	With PHEV
Reference **(No Carbon Policy)**	• Calibrated to AEO Stimulus – Energy Prices – Energy Demand – GDP Growth – End-use efficiency – Fuel economy and VMT	• Calibrated to AEO Stimulus • PHEV expands to 5% of the vehicle fleet by 2030 and 50% by 2050
Scenario **(Carbon Policy)**	• Carbon tax of $30 in 2015 and rising at 5%	• Carbon tax at $30 in 2015 and rising at 5% • PHEV expansion based on economic decision

Some modeling insights

- Demand for refined oil decreases as PHEVs replacing petroleum-based vehicles
- Electricity generation increases to support more PHEVs
- Economy-wide carbon emissions decreases
  – Carbon emissions in the electricity sector increases
  – Carbon emissions in the transportation sector decreases
- Generation portfolio changes with the PHEV expansion
- Retirement of fossil-based generating units is delayed

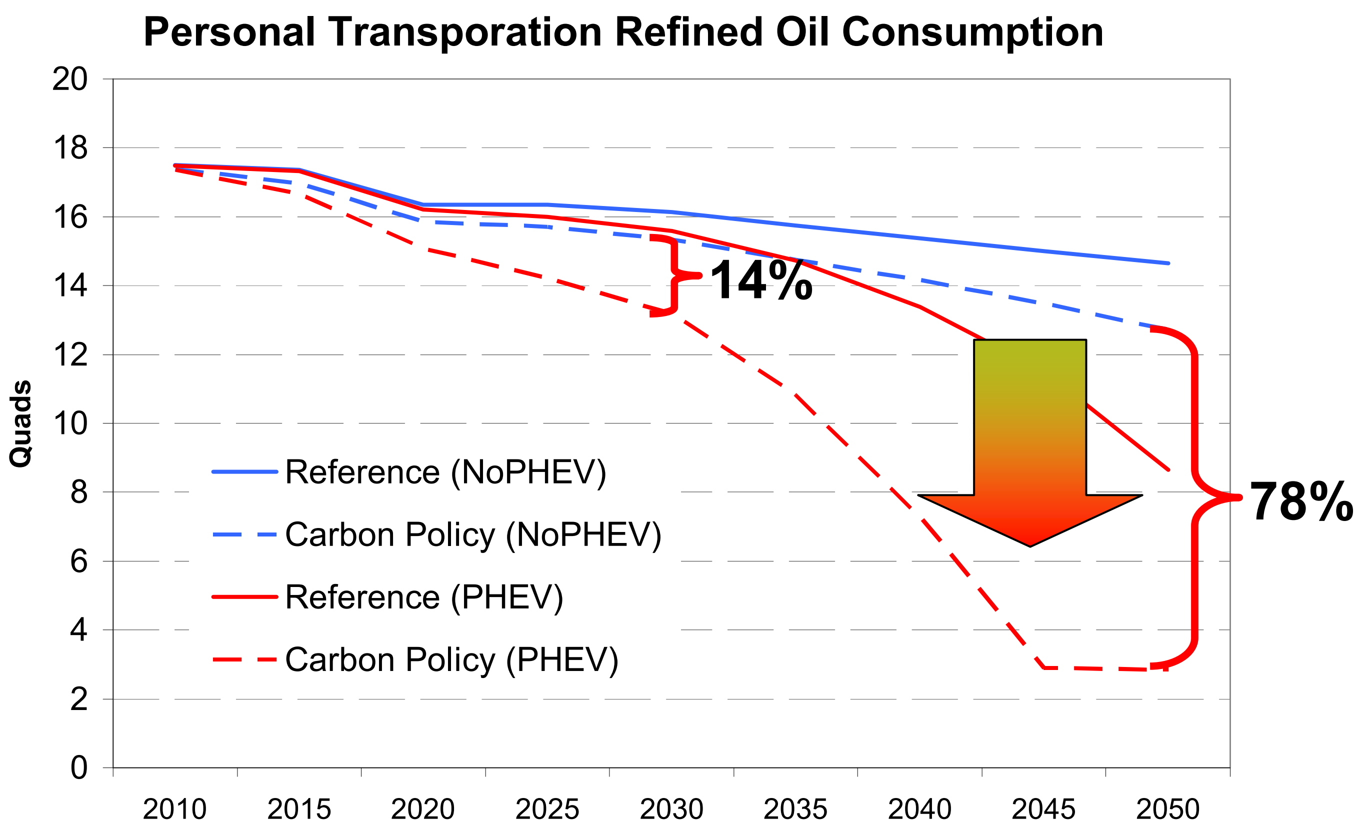
Expansion path

Carbon policy provides incentive for PHEV to come a decade earlier



Refined Oil Consumption

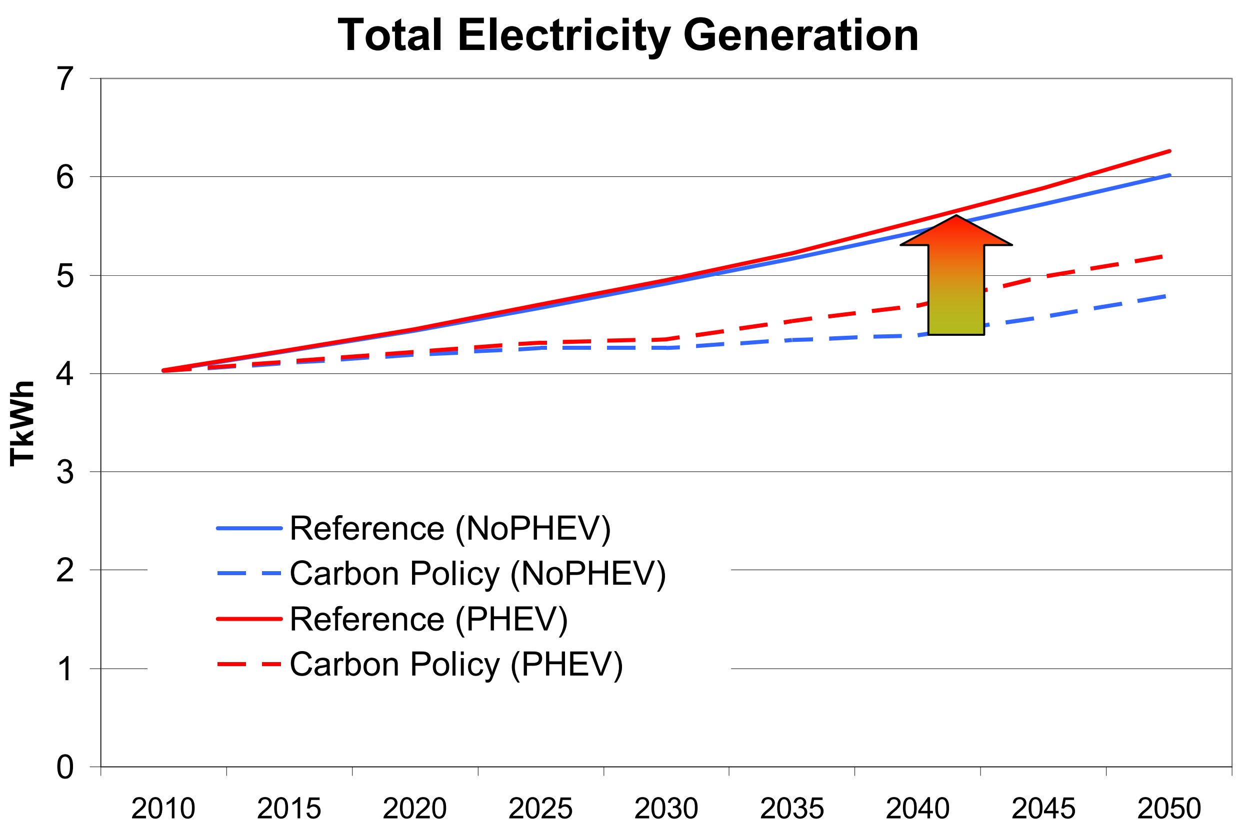
PHEV offers great potential to cut oil consumption



Personal transportation oil consumption drops to 14% in 2030 and 78% in 2050 below what it would have otherwise been in the absence of the PHEV. This translates to reduced carbon emissions from gasoline consumption

Electricity demand

Total demand increases despite the decreased non-PHEV demand due to higher electricity prices



Electricity demand increases by 4% in 2050 in the reference case compared to 8.6% in the carbon policy case

Carbon Emissions

Economy-wide emissions decrease as the low-carbon electrification option is adopted

Cumulative Emission Changes (2010-2050) (MTCO2)

	Reference	Carbon Policy
Electric Sector	-726	1,959
Personal Transportation	-4,275	-11,329
Other sectors	4,063	-833
Economy-wide	**-938**	**-10,203**

- The magnitude of the emission abatement increases with the PHEV expansion
- In the reference case, the PHEV introduction pushes up the electricity demand and price which leads to substitution away from electricity consumption towards natural gas in other non-electric sectors
- In the carbon policy scenario, more fossil-based units are operating to meet the additional demand to support the PEHV
- Electric sector and non-electric sectors compete for natural gas leading to higher gas prices and the flipping sign of the cumulative emissions

Generation Technology Mix

More fossil-based units stay online to support PHEV recharge

Increase in Generation by Type (TWh)

		2030	2050
Reference	Gas Units	14	22
	Coal Units	29	145
	Other Units	-5	74
	All Units	**38**	**242**
Carbon Policy	Gas Units	44	194
	Coal Units	39	20
	Other Units	11	198
	All Units	**95**	**412**

Retirement Plan (MegaWatts)

	Gas Units	Coal Units	Other Units
Reference	-2206	-3638	-145
Carbon Policy	-34396	-3572	-252

- **By 2030, most of the demand increases are supplied by the fossil-based units. Nuclear and renewables come to serve the rising demand post-2030**
- **Rising uptake of natural gas units reflects the relative cost-effectiveness of carbon compliance**
- **Retirement of fossil-based units is delayed**
- **In the carbon policy case, 34GW natural gas units which would have otherwise been retired stay in operation**

NEEM Examples:
SO_2 and NO_x (CAIR)

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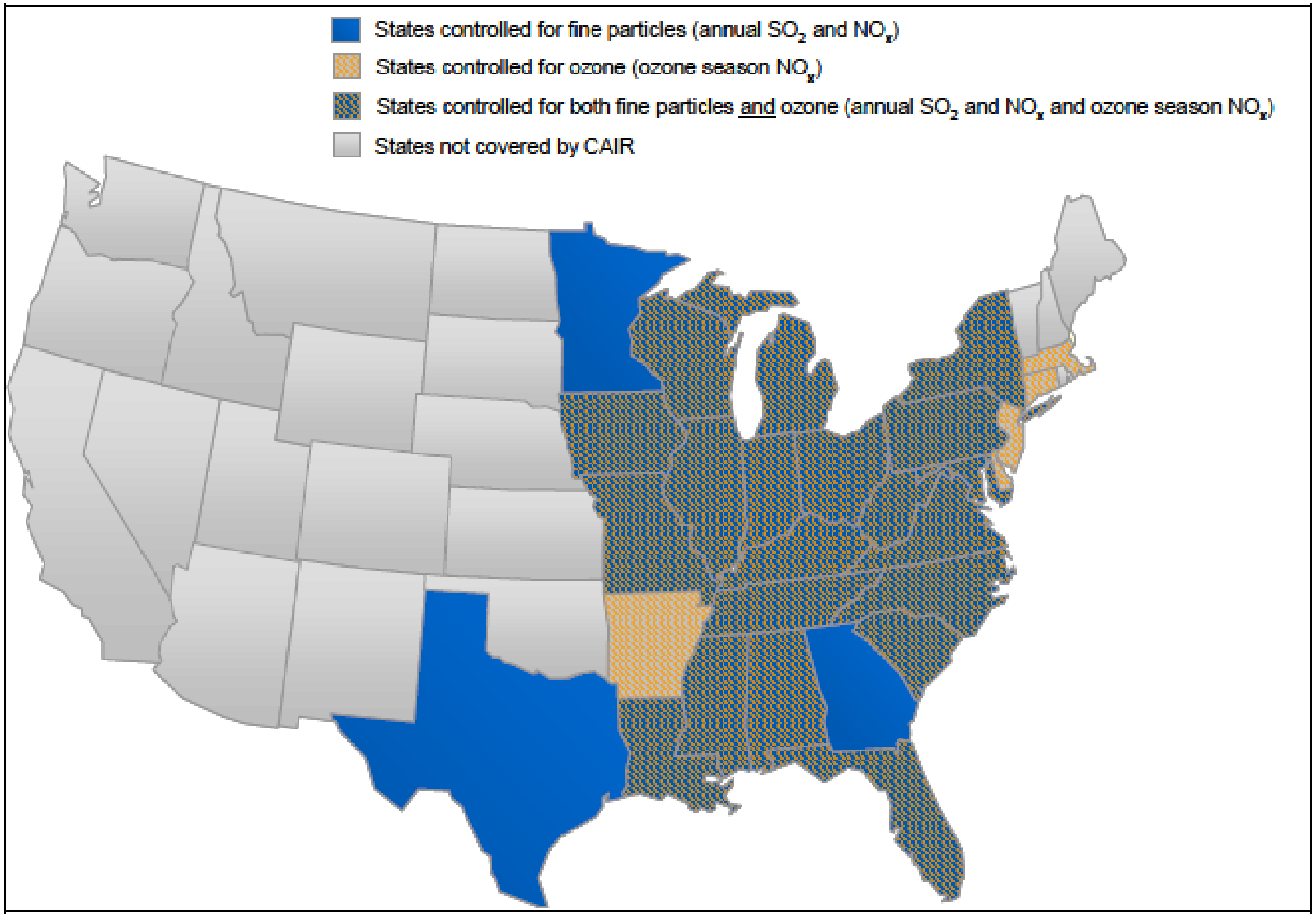
The Clean Air Interstate Rule (CAIR): *Preliminaries*

- Issued in 2005 to address air pollution that crosses state boundaries in the eastern U.S.
- Limits total SO_2 and NO_x emissions from electric generators
- SO_2 and NO_x annual caps (fine particulates)
  - SO_2 cap is implemented as a trade-in ratio, applied to Title IV acid rain caps
    - 2.00 in 2010
    - 2.86 in 2015
  - NO_x annual cap went into effect in 2009
- NOx seasonal cap (summer ozone)
  - Went into effect in 2009
- Banking
  - Provides flexibility to over-comply in current period to avoid steeper cuts later

Most of the CAIR states are under all three caps:
Preliminaries



SO_2 and NO_x Example (CAIR): *Preliminaries*

- In NEEM, coal generators emit SO_2 and NO_x
  - Existing pollution controls are modeled (FGD, SCR, SNCR)
  - NEEM can choose additional pollution control retrofits, based on economics
  - Annual SO_2 emissions from a unit depend on generation level, the coal(s) being burned (sulfur content), and pollution control efficiencies (existing/future)
  - Annual NO_x emissions from a unit depend on generation level, the unit's historical emissions factor (lbs/MMBtu; CEMS), and pollution control efficiencies (future)
- Gas-fired generators emits NO_x
  - Similar to coal generators: generation level, CEMS emissions factor
- NEEM ensures that annual (and seasonal) caps are met
  - Over-compliance for banking purposes allowed

SO_2 and NO_x Example (CAIR): *Preliminaries*

- In order to comply with emissions caps, NEEM optimizes the following alternatives for each coal unit (*SO_2 example*):
  - Reduce generation
  - Switch to lower-sulfur coal (switching to PRB entails capital and O&M cost adders and efficiency penalties)
  - Retrofit with FGD
  - Retire (to avoid fixed O&M) / replace capacity (to maintain reserve margin and meet energy demand)

SO_2 and NO_x Example (CAIR): *Set-up*

- Based on the CAIR policy's state coverage, we tie generators to the CAIR policy
  - We do this for CAIR SO_2, CAIR NO_x annual, and CAIR NO_x seasonal
- Assuming we are modeling a cap (and not a tax), we specify the caps (millions of tons over time)
  - For CAIR SO_2, this is implemented through the trade-in ratio (2.00 in 2010, and 2.86 in 2015)
- We specify whether banking is allowed, initial bank balances, etc.

Note: The Utility MACT may render SO_2 and NO_x policy less important, depending on the MACT requirements.

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SO_2 and NO_x Example (CAIR): *Results*

- The pollutant caps, if binding, will result in an emissions price trajectory
- The emissions prices affect the dispatch of emitting units (in the equilibrium solution)
  - A tighter SO_2 cap and therefore a higher price will – all else equal – result in less coal generation
  - Some units will retrofit
  - Tight caps can also lead to coal retirements
    - For example, a unit that cannot (currently) burn PRB might have SO_2 costs that are high enough that it significantly lowers the unit's capacity factor (so that it does not earn enough margin to cover its fixed costs)
    - For this particular unit, the cost of control (retrofitting / fuel-switching) may be high enough such that it is less expensive in present value terms to retire and build replacement capacity (e.g., combined-cycle)
    - Small units have poorer retrofit economics, so they tend to retire more easily
    - Fuel-switching involves a small amount of capital ($70/kW amortized over 10 years), a small amount of variable O&M ($0.50/MWh), and small heat rate / capacity penalties

SO_2 and NO_x Example (CAIR): *Questions and Discussion*

- Questions?
- Transport Rule
- Utility MACT

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Local RPS Example

Local RPS Example (New England RPS): *Preliminaries*

- Most of the New England states have binding RPS policies
  - These are typically percentage requirements over time
  - Not all sales covered (e.g., munis and coops often are exempt)
  - Alternative compliance payments provide cost-containment
- There may be multiple classes of renewables requirements
  - Class I (new, clean renewables)
  - Class II (e.g., renewables installed long ago; waste-to-energy)
  - Carve-outs and set-asides (e.g., solar carve-outs)

Local RPS Example (New England RPS): *Set-up*

- The relevant NEEM regions have to be tied to the New England RPS (for the purpose of defining which demand is covered)
  - For New England, there is only one NEEM region (NEISO)
  - We often model all the New England states' RPS policies as a single requirement with unlimited REC trading (plus solar carve out separately)
  - We typically only model the Class I and solar requirements (i.e., not waste-to-energy requirements or requirements on units that were built a long time ago to operate)
- We then tie existing and new units to the RPS (these are the units that can count toward the RPS)
  - New units outside of New England (in NYISO) can sell RECs into New England, thus we have some new wind units in NYISO that can be built for the New England RPS and others that can be built for the NYISO RPS
    - The sum of the two sets of NYISO builds cannot exceed specified NYISO wind capacity constraints
  - If only some of the existing units are eligible for the RPS, we can separate those that are eligible

Local RPS Example (New England RPS): *Set-up*

- We then specify the MWh requirements for the NEISO RPS that NEEM must attempt to meet
  - We assess the fraction of the load that is covered by the RPS
  - In MRN-NEEM, these requirements will scale with changes in demand
- As mentioned, we model solar carve-outs separately
- We also specify the safety-valve price (alternative compliance payment)

Local RPS Example (New England RPS): *Results*

- NEEM will either meet the RPS requirements or pay the alternative compliance payment
- NEEM reports RECs prices over time
  - REC prices cannot exceed the alternative compliance payment
  - Renewable units that contribute to the RPS receive REC revenue
  - In the absence of an alternative compliance payment, you can think of the present value of REC prices (going forward) as the compensation that is needed to build the marginal renewable unit in order to comply with the RPS
- NEEM reports the mix of renewable generation that is contributing to each RPS policy over time

Local RPS Example (New England RPS): *Questions and Discussion*

- Questions?
- Deliverability requirements from out-of-state resources vs. freely traded, unbundled RECs
  - It is difficult to model deliverability requirements
- Other frictions to trading RECs
  - If units in NEEM region A serve NEEM region B's RPS, it is possible to apply a transaction cost to NEEM region A
    - Such a unit in Region A would be dedicated to Region B
    - If region B has a high REC price trajectory, it may be economic to build the "penalized" capacity in Region A
  - In particular, we seek input on modeling the RECs trading that is facilitated under the Midwest Renewable Energy Tracking System (MRETS)
    - Illinois, Iowa, Minnesota, Montana, North Dakota, Ohio, South Dakota, and Wisconsin

Differentiating Remote Wind Resources Example

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Differentiating Remote Wind Resources: *Preliminaries*

- New wind units in NEEM generally have an average adder to represent transmission hookup, etc.
- We also generally assign one capacity factor (and shape) for new wind units within a single NEEM region
- For important wind regions, we can add more detail to capture:
  - Different capacity factor bins
  - Differential access to transmission

Differentiating Remote Wind Resources: *Set-up*

- Region A has a lot of wind potential and is geographically large
  - The high capacity factor resources (42%) are in the western portion of the region and not close to existing transmission
  - The eastern portion of the region has fewer resources, they are of lower quality (34% capacity factor), but they are close to existing transmission
- This situation could be modeled in the following manner:
  - Region A could have two new wind units
    - The 34% capacity factor wind would have lower capital cost (no additional high-voltage transmission needed)
    - The 42% capacity factor wind would have higher capital cost (additional high-voltage transmission needed)
    - Both units could have the same (relative) wind shapes, or different shapes

Differentiating Remote Wind Resources: *Results*

- NEEM will either build the 42% capacity factor wind, the 34% capacity factor wind, or both
- The result depends on the policy (e.g., federal RES), the policy stringency, and the economics of competing renewables (in other regions or other renewable technologies)
- If the 42% capacity factor wind is built, this would indicate that the high capacity factor is sufficient to warrant transmission expansion
  - Depending on the situation, the lower quality wind may or may not be exploited first

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Differentiating Remote Wind Resources: *Questions and Discussion*

- Questions?
- If remote wind resources have limited existing transmission access to load centers, there may be situations where it would make sense to split a NEEM region
  - Wind-rich vs. wind-poor, with a limited connection between them
  - Inside of the wind-rich region, you could have two wind units:
    - Low-capital cost vs. high-capital cost
    - The low-capital cost unit would represent high-quality wind that can currently be tapped without further transmission expansion
    - The high-capital cost unit would represent further transmission expansion

Other NEEM Questions?

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Purpose of NEEM

- NEEM is designed to model:
  - Decisions about the timing and mix of new generating capacity
  - Retirement and mothball decisions
  - Environmental compliance decisions for SO_2, NO_x, Hg, and CO_2, including pollution control retrofits and choice of emission controls for new units
  - Fuel choice in new units and fuel switching in existing units
  - Dispatch decisions based on load duration curves
  - Flow of power among regions by load block
  - Banking (for cap & trade policies)
- NEEM finds the least-cost compliance with emissions requirements and other regulations, which represents the likely outcome in competitive electricity markets
- NEEM can be used for policy analysis, investment analysis (often micro-view), or to inform other models (GE MAPS, MRN, gas model)

Types of Analysis that NEEM Perform

- Electricity price forecasts
- Unit-level analysis
- Plant or portfolio valuation
- Greenhouse gas scenario analysis (coupled w/ MRN)
- Assessment of transmission projects
- Evaluation of environmental policies (e.g., SO2 / NOx, Hg, RPS, etc.)

NEEM (stand-alone) is an LP optimization*

* Can be run as a QP (quadratic program) model, as is done with MRN-NEEM

- Linear programming involves an objective function and constraints on the choices/variables
- *NEEM's objective function is designed to minimize the present value cost of:
  - Building new capacity
  - Retirements
  - Environmental compliance
  - System dispatch

* Objective function includes: capital costs of new generators, refurbishment costs, fuel cost, ordinary VOM, ordinary FOM, retrofit capital costs, retrofit VOM, retrofit FOM, fuel-switching capital costs, fuel-switching VOM, fuel-switching FOM, environmental permit costs, transmission charges, costs of transporting / sequestering CO_2, mothballing costs

NEEM (stand-alone) is an LP optimization *(cont'd)*

- NEEM has perfect foresight
- Constraints in NEEM ensure:
  - Electricity demand is met
  - Reserve margin requirements are met
  - Environmental constraints are satisfied (e.g., SO_2 caps)
  - Unit operational limits and energy limits cannot be exceeded (e.g., maximum hydro output by season)
  - Limits on interregional power flows cannot be exceeded (i.e., transfer limits)
  - Unit maintenance requirements are met (i.e., PODs and forced outages)
  - RPS standards are met

Uses of NEEM

- Policymaking or policy-level analysis
  - Emissions policies
  - Transmission cost-benefit analysis
- Investment decisions
  - Mix and timing of new capacity additions
  - Retrofit decisions
  - Retirements
- To feed other models
  - GE MAPS (GE's Multi-Area Production Simulation model)
  - *MRN (MRN and NEEM exchange information within MRN-NEEM)
  - Gas model (GPCM)

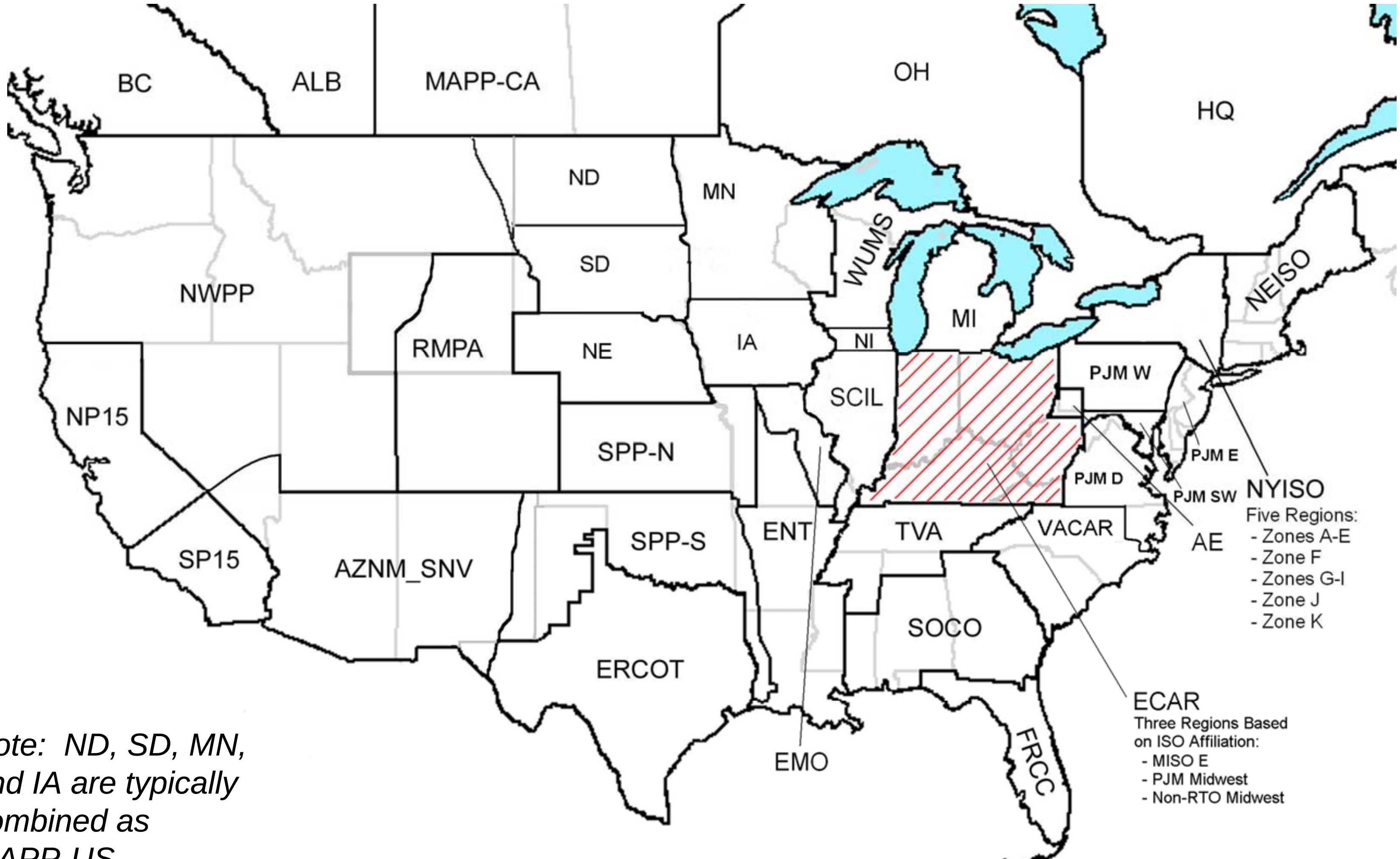
* MRN is the Multi-Region National macroeconomic model.

Geographic coverage of NEEM

- NEEM simulates the entire US electric power system and portions of the Canadian system
  - Fundamental geographical structure is determined by transmission interfaces – approx 40 regions/sub-regions
  - Additional geographic structure within regions to reflect environmental regulations, usually along state boundaries
  - Regions can be adjusted for project-specific requirements
  - Operates over a long time-horizon to allow for better long-term decision making

NEEM Transmission Regions

It is possible to change NEEM regions. To facilitate interpretation of model output, the regions should probably stay the same across futures.



Note: ND, SD, MN, and IA are typically combined as MAPP-US.

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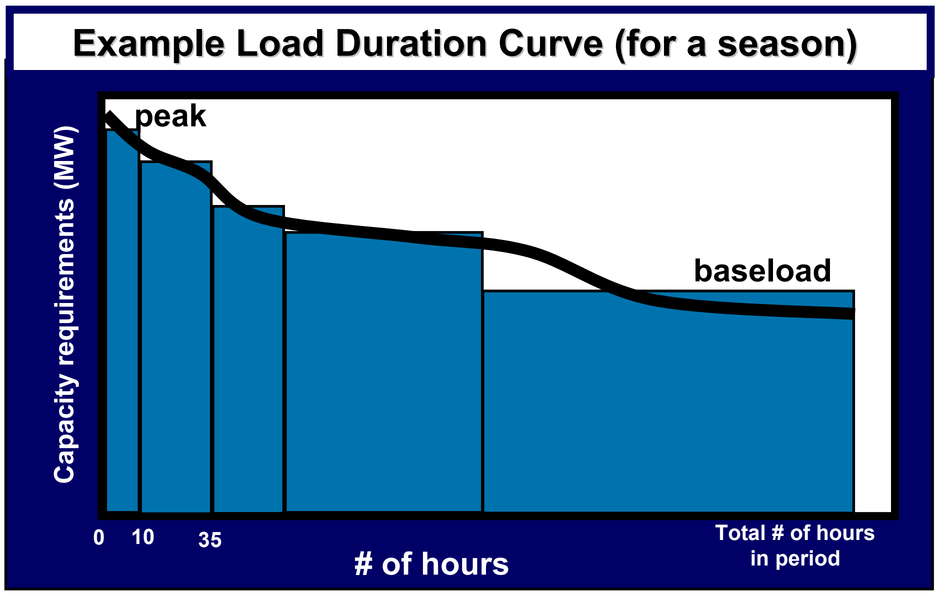
NEEM Inputs

Input Data

- Fuel prices (natural gas and oil prices, coal supply curves, *etc.*)
- Existing units (capacity, heat rates, emission rates, *etc.*)
- Forced actions (new builds, retrofits, retirements)
- New capacity options
- New capacity costs & characteristics
- Pollution control options (aka retrofits on existing units)
- Emissions & similar constraints
- Demand (MWh) and Max Demand (MW) (aka load)
- Transmission

Input Data – Demand

- Load represented as Load Duration Curve (LDC)
  - Load block duration measured in hours, not chronologically ordered
  - Typically 20 load blocks divided into 3 seasons
    - 10 blocks in the summer (May–Sept), 5 blocks in winter (Dec–Feb), 5 blocks in shoulder (Mar-Apr, Oct-Nov)
    - Demand in a load block = average hourly demand
    - Fewer hours in peak demand blocks, more in off-peak demand blocks
    - Can be altered
  - LDCs for future years based on 2006 load shapes adjusted for future peak and base energy demand



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Input Data – Max Demand

- Max Demand is just a number (MW) by region by year
- NEEM applies a reserve margin percentage to this in order to decide how much capacity needs to be online (by region by year)
  - Reserve Margin Regions can be multiple NEEM regions
  - The reserve margin has to be met within the Reserve Margin Region, providing flexibility among NEEM regions
  - Reserve Margin Regions can be overlapping such that a single unit's capacity can count towards two or more reserve margin requirements

Input Data – Existing units

- Aggregation (*necessary to reduce model size*)
  - Most units aggregated by region/type
  - Peakers and steam oil/gas also aggregated by size and heat rate
- Most coal plants are modeled at the unit (or same-station, sister-unit) level
  - Units smaller than < 100 MW are aggregated (grouping 1)
  - Units between 100 and 150 MW are aggregated (2)
  - Units between 150 and 200 MW are aggregated when almost indistinguishable from a modeling perspective (3)
- The coal aggregates have been split into those equipped with Flue Gas Desulphurization (FGD) retrofits and those without
- Units that are not in aggregates (> 200 MW) are called "named coal"
- Feasible alternative coal supply choices are modeled for each coal plant

Input Data - New capacity options

	Existing Units	New Units
Fossil Fuel	Oil and gas-fired Combustion Turnines (CT) Gas-fired combined cycle (CC) Oil and gas-fired steam units (STOG) Coal-fired steam units	Gas-fired CTs Gas-fired CCs Pulverized coal (AC) Integrated gasification CC (IGCC) IGCC with sequestration (SEQ)
Nuclear	Nuclear	Advanced Nuclear
Renewables	Wind Geothermal Photovoltaic Solar thermal Wood/Refuse Hydro-electric Pumped storage hydro	Wind (WT) Geothermal (GEO) Photovoltaic (PV) Solar thermal (ST) Biomass (BM) Landfill gas (LG)







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Input Data - New unit additions

- NEEM adds new units to meet load growth & maintain reserve margin
  - Can force in "known" new units (units under construction or in pre-operational "testing" phase)
  - NEEM has full menu of future units, both fossil fuel and renewable, with capital cost varying by region
  - Can specify renewable resources and potential along with RPS standards by region
  - Can limit type, location, quantity of new units built by region over time (cumulatively and/or annually)
- New unit builds – year, type, size, region – are an output of NEEM optimization
- Retirements are also a NEEM output, and occur when economically rational (e.g., fixed costs not covered on a present value basis)

Input Data - Pollution control options

- The model data includes existing and planned equipment for each unit, which determines the starting emission rates for each pollutant for each unit
- The model selects retrofit installations based upon economics, with the exception of planned retrofits
- Coal-fired units can also switch coal types by expending the necessary capital to retrofit the plant (not all coals can be costlessly switched to)
- The NEEM data file includes environmental retrofits for existing coal-fired units to reduce emissions of SO_2, NO_x, Hg, and CO_2

	Retrofit options
SO_2	Flue gas desulphurization (FGD)
NO_X	Selective catalytic reduction (SCR) Selective non-catalytic reduction (SNCR)
Hg	Activated carbon injection (ACI) ACI with a fabric filter
CO_2	Carbon capture and sequestration (SEQ)

Input Data - Emissions & similar constraints

- NEEM can model environmental limitations on SO_2, NO_x, Hg, and CO_2
- Forms of constraints include caps, emissions prices (taxes on emissions), required emission rates, and required emissions reductions (relative to inlet emissions)
  - These constraints or taxes can be applied nationally, regionally, by state, or even on particular units
- NEEM also models RPS/RES constraints

Input Data – Fuel Prices

- Coal Prices (*not an input – coal prices are an output*)
- Gas Prices
  - Very important: often determine on-peak electricity prices
  - Unlike coal prices, they are an input (in BAU)
  - In NEEM, they typically vary by region by season by year
    - There are “basis differentials” – this converts Henry Hub prices to region-specific prices
    - Gas prices can vary by unit within a region in NEEM, but we typically do not
- Fuel Oil Prices
  - Unlike coal prices, they are an input
  - In NEEM, they vary by region by year
    - Not by season

Input Data - Transmission

- Inter-regional transmission limitations are represented based on NERC transfer limits
- NEEM has the flexibility to allow for changes in transmission capacity over time
- Model assumes no transmission constraints within each NEEM region
- Transmission representation is “bubble-to-bubble”
- Model includes transmission costs for flows between NEEM regions
  - Explicit wheeling charges
  - Hurdle rates to reflect non-explicit costs of entering/exiting RTO systems

NEEM Outputs

Key Outputs

- Electric sector results (national and regional)
  - New capacity and retirements
  - Electricity prices (total and by component) by region, year & load block
  - Capacity prices
  - Environmental retrofits (type, timing)
  - Environmental allowance prices
  - Minemouth coal prices by coal type by year
  - Delivered coal prices by coal type by plant by year
  - Power flows between power pools by load block by year
  - REC prices (for RPS)
- Unit-level results
  - Generation and capacity factor
  - Emissions and emission rates
  - Fuel consumption
  - Energy and capacity revenues (and REC revenues for renewables, if applicable)
  - Costs (fuel, VOM, FOM, allowance costs, depreciation on incremental capital)

NEEM Outputs - Coal supply and costs

- NEEM determines minemouth prices for each coal type based on supply and demand for that coal
  - Coal supply varies by coal type and is a function of mine cost characteristics
- Coal supply curves only include data for the electric sector (non-electric sector use and exports are removed from the curves)
- Transportation costs for each plant are used to develop delivered coal prices (lowest cost transport mode reflected for each plant)
- Lifetime resource constraints / mine depletion




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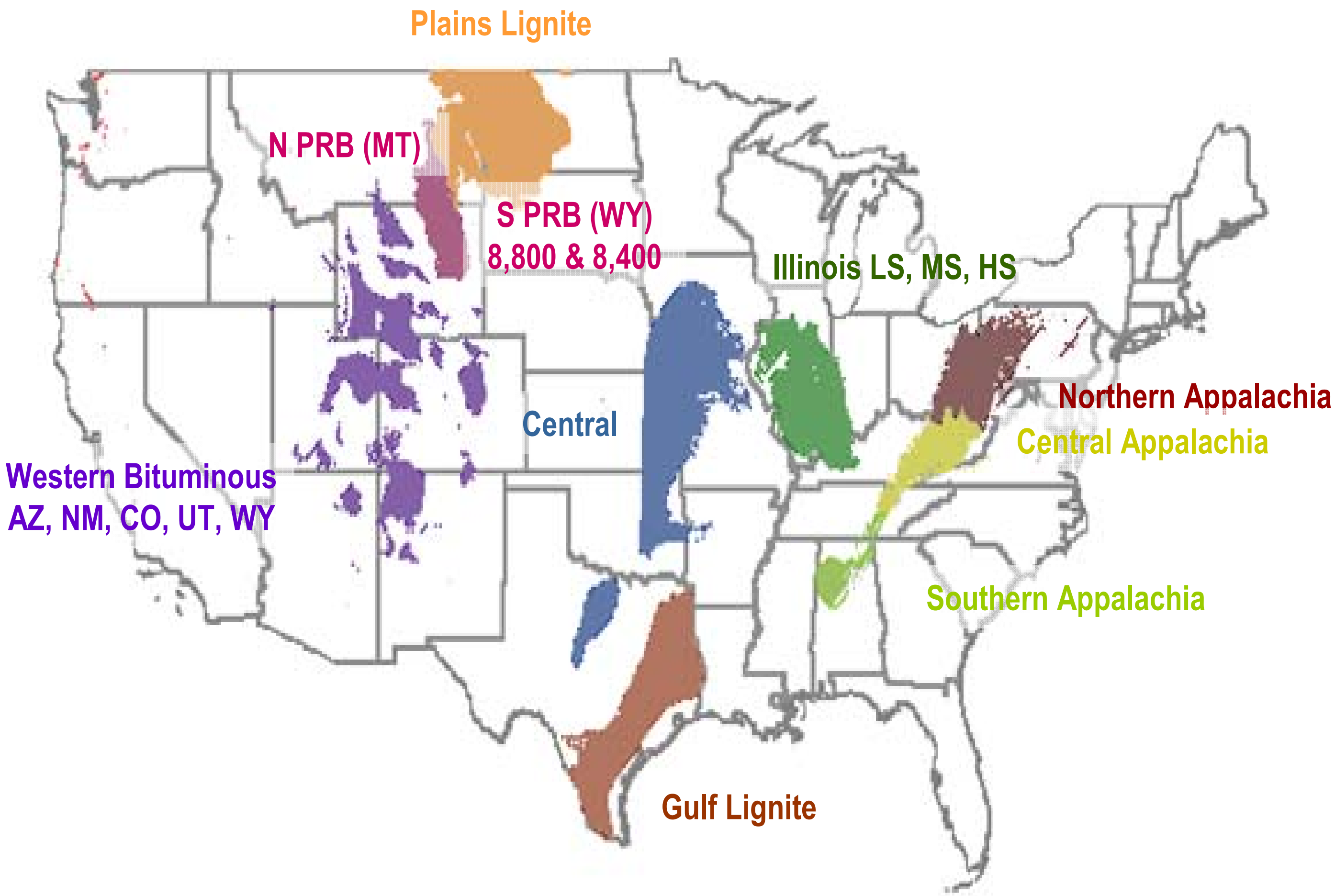
NEEM's coal-producing regions in the United States



Imports and Saskatchewan lignite not depicted. NEEM's solution results in mine-mouth coal prices for each region and coal type (e.g., high-sulfur, low Btu). The transport costs are inputs (by plant).

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