Haiku
the RFF electricity market model

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Resources for the Future (RFF)

January 11, 2011

Carnegie Mellon - EPP

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Outline

- Haiku
  - Overview
  - Supply
  - Demand
  - Current Baseline Scenario
- Model Development
- Recent Applications
  - Allowance allocation under cap-and-trade
  - Comparison of federal policies for renewables
  - Supply curves for conserved electricity

Introduction to Haiku

- electricity sector simulation of contiguous U.S.
  - supply side investment, retirement, and system operation
  - price responsive dynamic demand side
- emphasis on
  - airborne emissions and policies for abatement
  - electricity market regulatory institutions
- calibration to observed data and EIA projections

Haiku Overview

Data

- existing generators
  - capacity, heat rate, pollution controls, emissions rate, O&M costs, outage rates
- planned capacity expansion
- transmission grid capability
- fuels and resources supply
- electricity prices & consumption

User Inputs

- air pollution policies
  - allowances cap-and-trade: annual issuance, banking, seasons, offsets, rest-of-economy, safety valve
  - emissions tax, MACT for Hg
  - compliance regions & technologies
  - revenue allocation: producers (grandfathering, updating), consumers (LDCs, DCI), government
- renewables policies
  - portfolio standard, production/investment tax credit
- electricity market policies
  - cost-of-service vs. competitive pricing, time-of-use pricing, electricity tax, end-use efficiency investment
- assumptions
  - new capacity costs and performance, learning, transmission expansion, cost of capital

Haiku

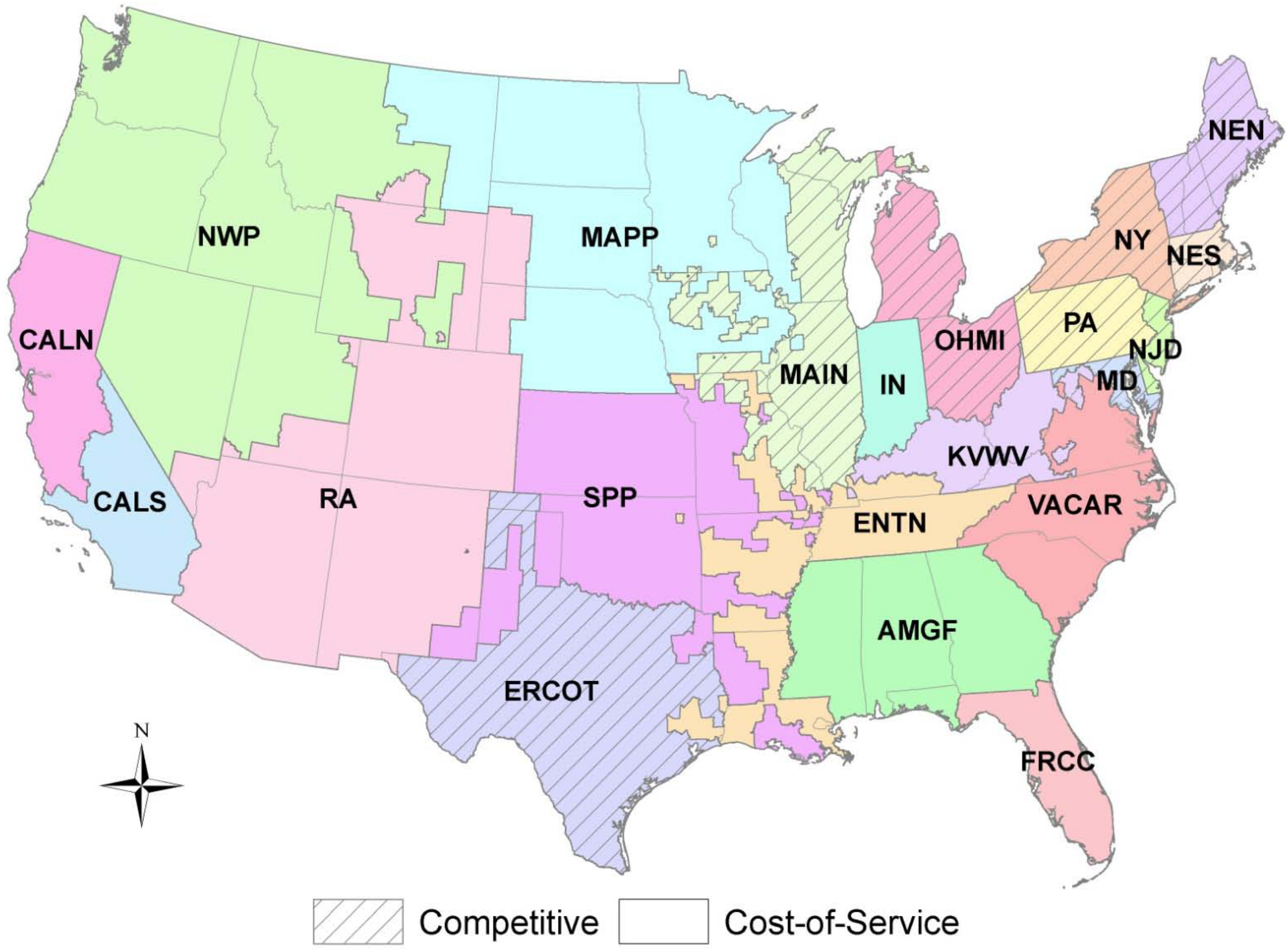
Model Outputs

- electricity prices & consumption
- savings from end-use efficiency
- generation capacity
- electricity generation and reserve
- fuel prices & consumption
- interregional electricity trade
- pollution controls capacity
- emissions (NO_x, SO_2, CO_2, mercury)
- allowance & REC prices
- domestic & international CO_2 offsets
- producer surplus

Time, Space, & Technology

- Time
  - Simulation to 2035
  - 1 yr = 3 seasons * 4 times of day per season = 12 time blocks
- 21 Regions of Contiguous U.S.
  - Energy balance in each region
  - Regions connected by transmission grid
  - Market regulatory structure: cost-of-service / competitive
- Model Plants
  - Groups of electricity generators with technological similarities
  - Pre-existing generators, planned & endogenous construction

Haiku Market Regions



Model Plants

Existing	New
Steam : Coal[1]	Steam : Coal[6]
Steam : Natural Gas[2]	Steam : Geothermal
Steam : Oil	Steam : Nuclear
Steam : Nuclear	IGCC : Coal w/ CCS
Steam : Biomass	IGCC : Biomass[7]
Steam : Geothermal	Combined Cycle : Natural Gas[8]
Steam : MSW	Combustion Turbine : Natural Gas[8]
Combined Cycle : Natural Gas	Wind[9]
Combustion Turbine : Natural Gas[3]	CSP w/ 6 hrs storage
Combustion Turbine : Oil[3]	IC Engine : LFG
IC Engine[4]	
Hydro[5]	
Wind	
Solar	

1. 16 MPs vary by the types of pollution control installed and location in coal market module regions.
2. 3 MPs vary by heat rate and the presence/absence of SCR for NO_x.
3. 2 MPs vary by size.
4. 3 MPs vary by LFG, natural gas, and oil fuel types.
5. 2 MPs vary by conventional and pumped storage technologies.
6. 3 MPs vary by location in coal market module regions.
7. 4 MPs vary by open and closed loop and by the choice for investment or production tax credit.
8. 2 MPs vary by conventional and advanced technologies.
9. 2 MPs vary by onshore or offshore.

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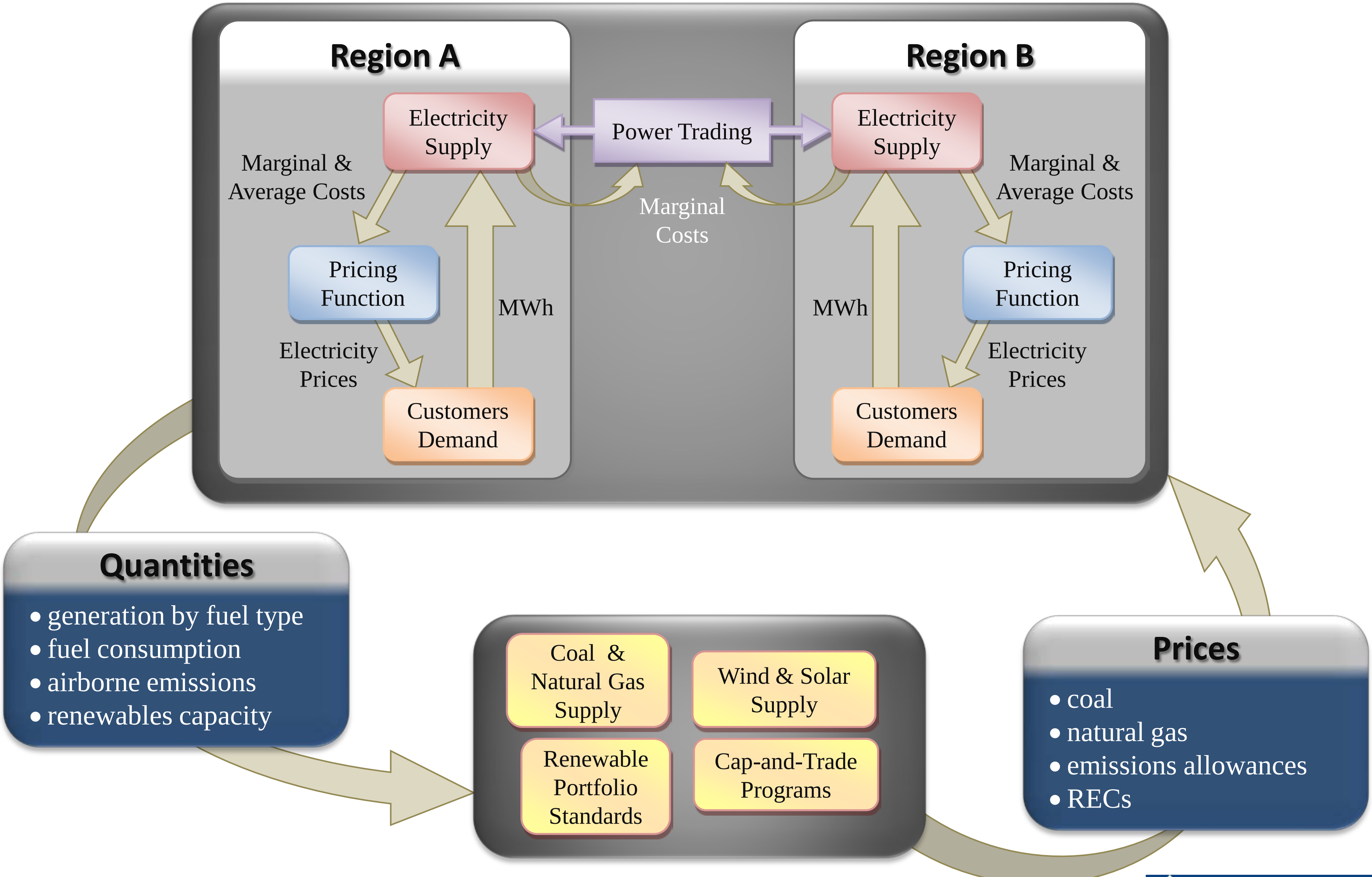
Markets Equilibrium: Electricity, Fuel, Other



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Electricity Supply

- System Operation
  - minimize short-run generation cost
  - reserve services
    - minimize going-forward cost
    - single market for reserve services with steam capacity constrained
- Generation Capacity Retirement/Investment
  - sequential and irreversible to minimize long-run total cost
  - model plants (MPs) can retire/invest in each simulation year based on going-forward profits (GFP) of last MW at each MP
  - existing MPs retire at year y if $GFP_y<0$ and $NPV(GFP_{t>y})<0$
  - new MPs invest at year y if $GFP_y>0$ and $NPV(GFP_{t>y})>0$

Electricity Supply (2)

- Air Pollution Abatement Technologies
  - SCR, FGD (wet & dry), ACI
  - minimize long-run total cost including allowance/tax cost
  - simultaneous solution over NO_x, SO_2, mercury
- Other Functions
  - wind capacity not dispatchable
  - hydro capacity partially dispatchable
  - scheduled outages allocated to low marginal cost seasons
  - forced outages reduce capacity in all time blocks
  - limited biomass cofiring at coal boilers

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Electricity Demand

- 3 customer classes: residential, commercial, industrial
- 2 stage demand system
  - seasonal demand depends on partial adjustment
  - time block allocation depends on CES function
- Partial Adjustment
  - simplified version takes the form: $Q_t = AQ_{t-1}^{\theta_1} Q_{t-12}^{\theta_{12}} P_t^{\varepsilon} X_t^{\beta}$
  - parameters are econometrically derived
    - θ_1 and θ_{12} are adjustment coefficients, ε is short-run price elasticity
    - X are covariates including weather, daylight, income, GSP
    - A is a benchmarking constant derived using EIA projections
  - dynamics proxy for end-use capital efficiency investment

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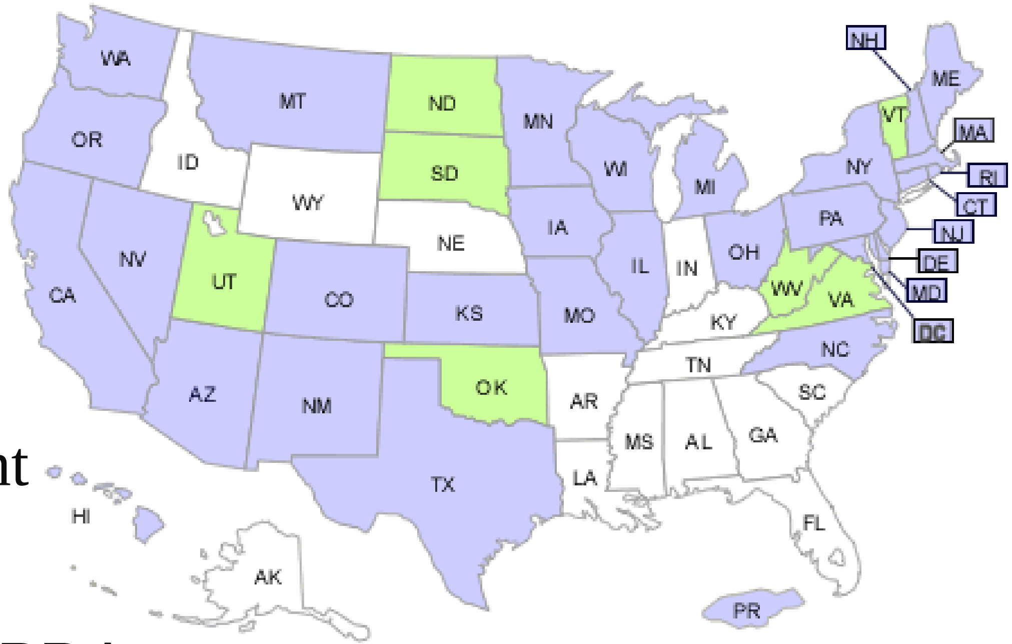
Baseline (BL) Scenario

- AEO 2010 calibration
- State RPS in 29 states + DC
  - characterized by level, timing, basis, coverage, technologies, interstate REC trading, alternative compliance payment



- Tax Credits for Renewables
  - 6 state programs and federal ARRA
  - ARRA allows choice between production or investment credit
- Environmental regulations
  - Title IV of 1990 CAAA for SO_2, CAIR for SO_2 and NO_x, RGGI, state Hg MACT

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Recent Applications of Haiku

- AB32 in California & the Western Climate Initiative
  - effects on CA and western electricity markets of AB32 & WCI
- RGGI in Maryland
  - effects on MD electricity markets of joining RGGI
  - effects of MD use of RGGI auction revenues for demand efficiency
- Climate Change & Ozone
  - effects of warmer climate on ozone concentrations
  - Haiku linked with OUTEC & CMAQ (run at JHU)
- Incentives for investment in CCS
  - linked with stochastic dynamic program
- Emissions Allowance Allocation
  - effects on power plant profitability and consumers
- Renewables and Efficiency Policies
  - federal renewable policy design and policy interactions
  - supply curves for conserved electricity

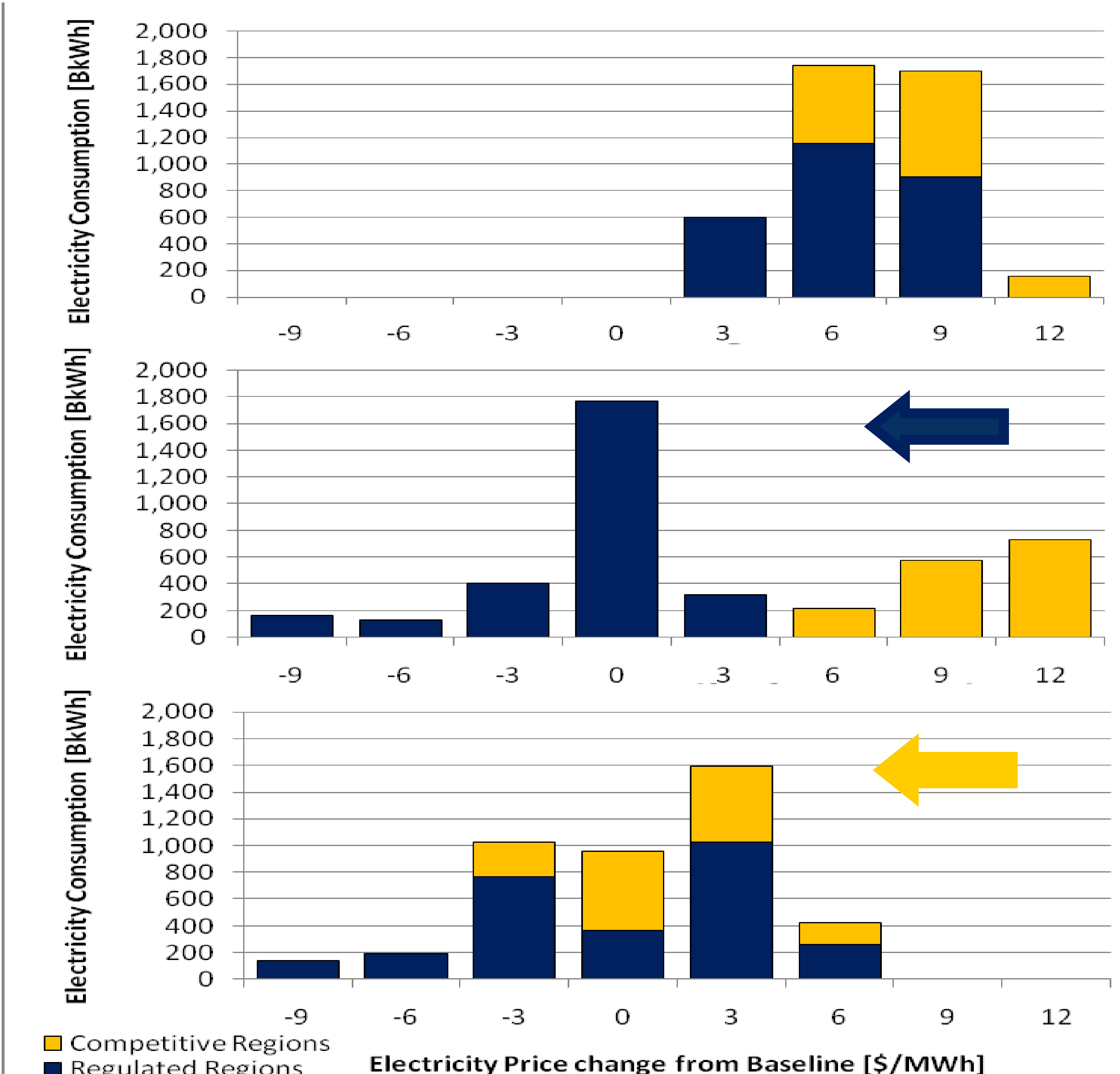
Model Development

- Heat rate standard as GHG regulation under CAA
  - Flexible vs. Inflexible
  - Include biomass cofiring as efficiency enhancement
- Water consumption and withdrawals
  - assuming no change in cooling systems at power plants
- End-use efficiency integration into RPS
- Retrofit CCS

Electricity Regulation and Price Effects of Federal Climate Policy

- Restructuring in 15 states, roughly 1/3 of national sales
- Electricity regulation and allowance allocation determine how climate policy affects electricity prices.
  - Allowance auction will raise electricity prices nationwide.
  - Grandfathering to producers will benefit *consumers* in regulated regions and *producers* in competitive regions.
  - Free allocation to distribution companies would restore symmetry to the benefit of all consumers.
- This observation is at odds with some intuition about cap-and-trade and it proved to be quite important in debates over federal and regional climate policy design.

Electricity Price Effects of Allowance Allocation



Auction

Efficiency Advantage
Lowest Social Cost
but Higher Prices

Free Allocation to Generators

Reduces Price only in Regulated Regions

Free Allocation to Consumers (LDCs)

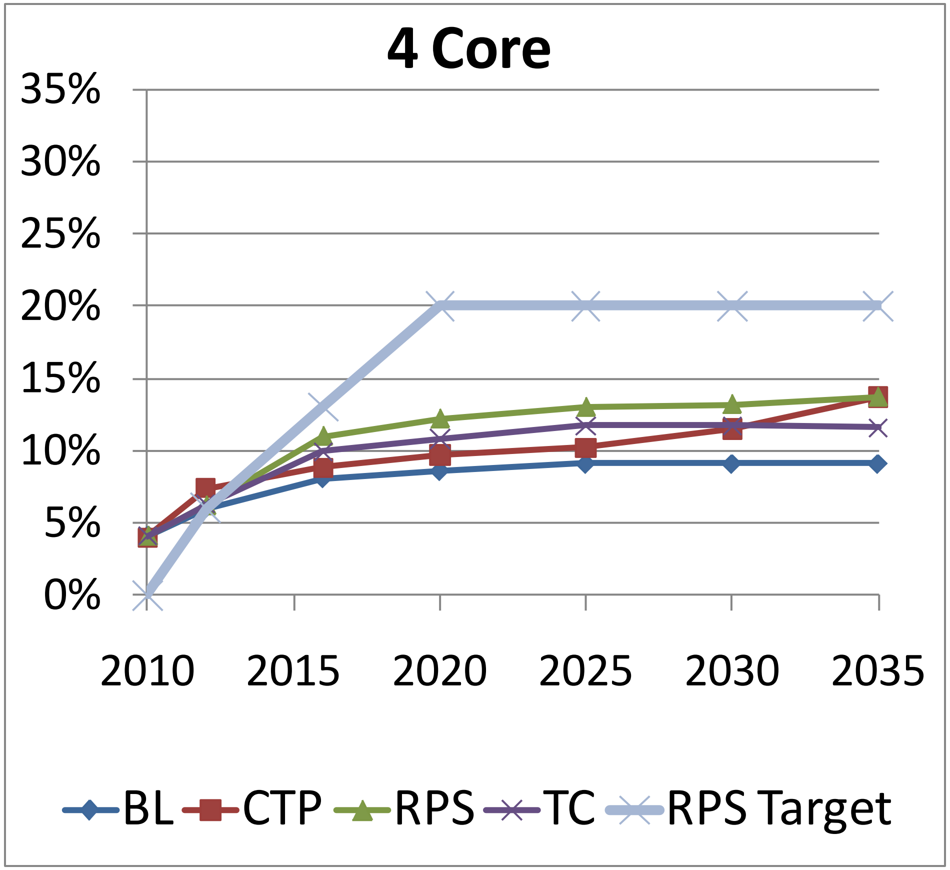
…But, Allowance Price Increases **by 12-15%** With Subsidy to Elec. Consumption

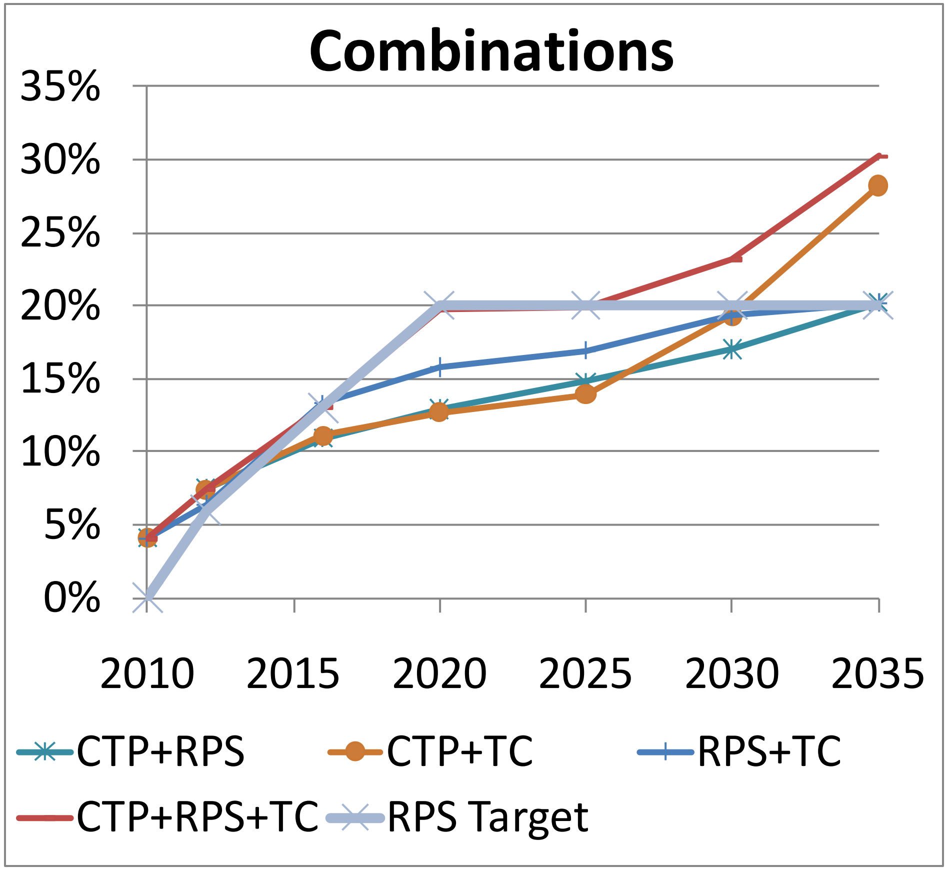
Federal Policies for Renewables

- BL + 3 policies are 4 core scenarios
  - CTP = *C*ap-and-*T*rade *P*rogram on CO_2 based on H.R. 2454
    - economy-wide coverage, banking, offsets, assume no revenue recycling
  - RPS = *R*enewable *P*ortfolio *S*tandard based on H.R. 2454
    - 20% by 2020 and thereafter, $25/MWh ACP, no EE
  - TC = *T*ax *C*redits based on ARRA extended through 2035

- Core & combinations are eight scenarios
  - Core 4: BL, CTP, RPS, TC
  - Combos: CTP+RPS, CTP+TC, RPS+TC, CTP+RPS+TC

Renewables Penetration (% of generation)

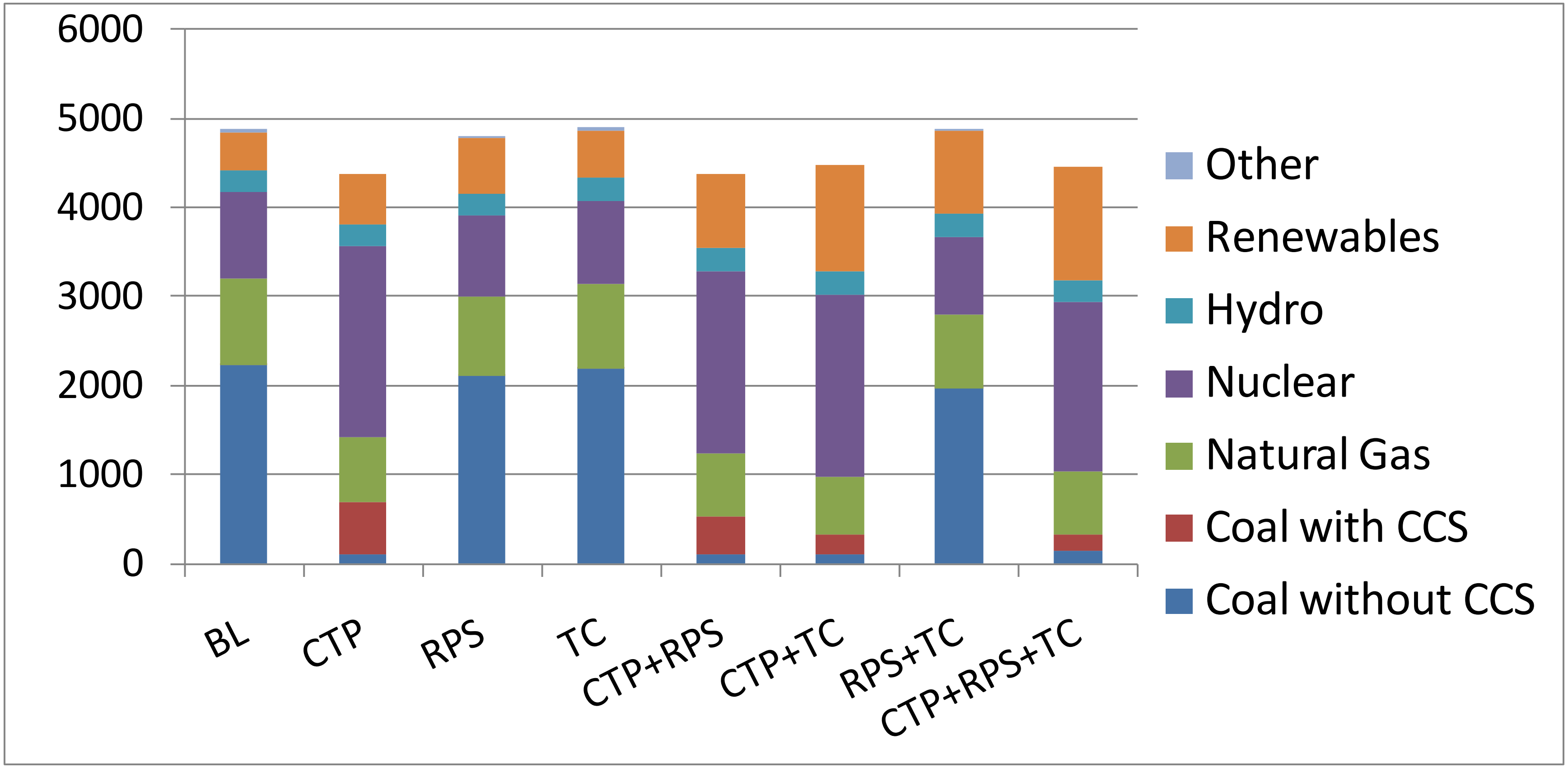




- Ranking: RPS, TC, CTP (until 2035)
- RPS is below target because ACP binds after 2012, so CTP and/or TC addition to RPS can lead to renewables expansion.

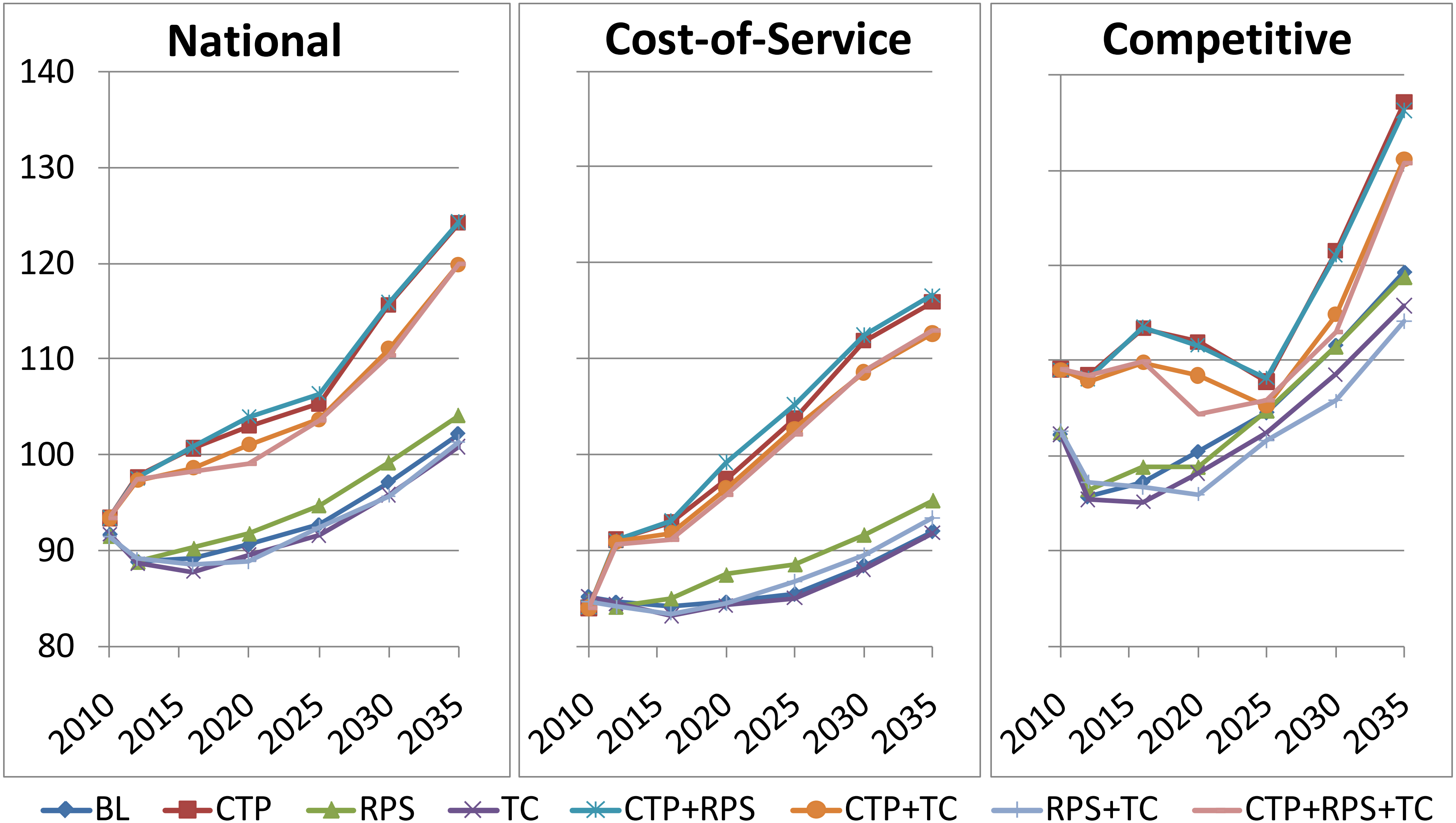
- ACP binding for CTP+RPS and RPS+TC until 2035.
- ACP non-binding for CTP+RPS+TC through 2025, then RPS non-binding thereafter.

Generation Mix in 2035 (TWh)



- CTP has much greater effect on generation mix than RPS or TC.
  - CTP brings in nuclear, displacing gas and especially coal.
  - RPS and TC bring in renewables, displacing a little of everything.
  - CCS comes in only under CTP scenarios.

Electricity Prices ($/MWh)



- CTP: large +Δ
- TC: -Δ
- RPS: no Δ or +Δ

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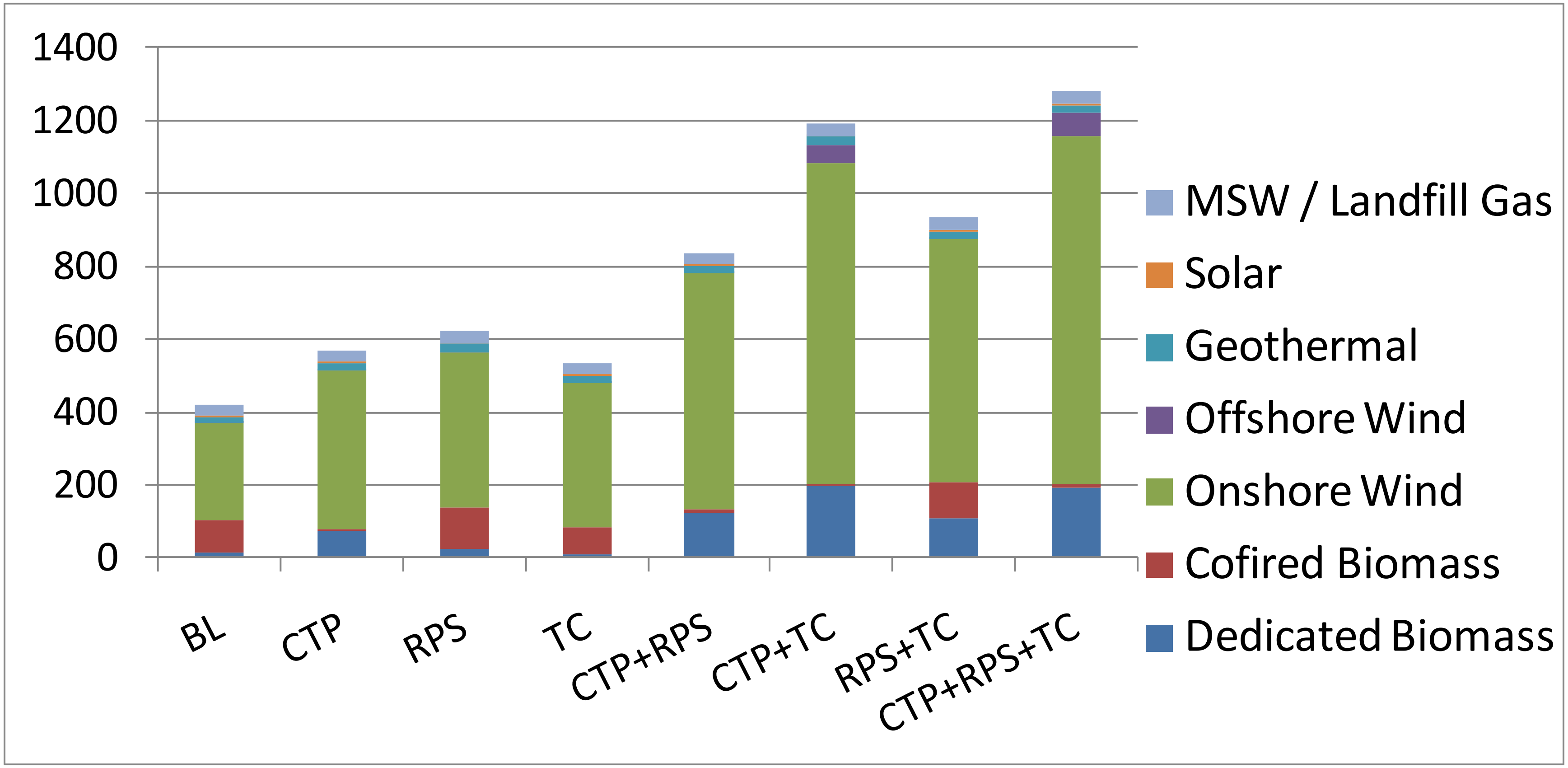
Renewables Generation in 2035 (TWh)



- Onshore wind dominates, biomass is second, others small.
- CTP drives trade-off between dedicated and cofired biomass.
- The whole is greater than the sum of the parts.
  - Each policy shrinks the cost gap between renewables and other technologies, so combinations are super-additive.

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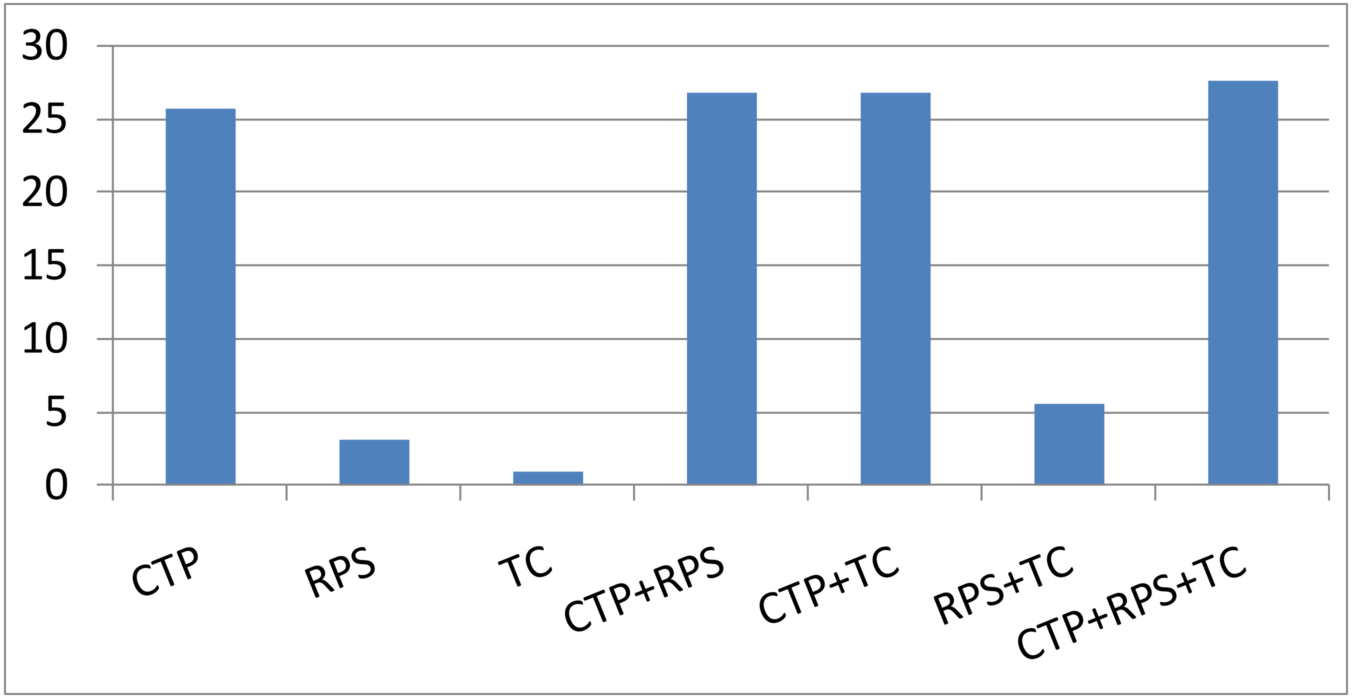
Cumulative CO_2 Emissions Reductions (B tons)



- CTP dominates, RPS second, TC third.
- RPS+TC > RPS since ACP binds under RPS.
- These are electricity sector reductions only. The addition of TC and/or RPS to CTP shifts reductions to the electricity sector from the rest of the economy due to lower allowance prices.

Policy Evaluation: Cost-effectiveness of Emissions Reductions

	NPV Total Cost B$	NPV Consumption TWh	NPV TC / NPV Cons $/MWh	Emissions Reductions Btons	Cost-effectiveness $/MWh/Btons
BL	3,647.7	46,368	78.67	-	-
CTP	3,700.3	43,964	84.17	58.1	0.0947
RPS	3,645.7	46,093	79.10	3.1	0.1360
TC	3,677.1	46,548	79.00	0.9	0.3651
CTP+RPS	3,695.7	43,899	84.19	58.1	0.0949
CTP+TC	3,738.9	44,251	84.49	58.1	0.1003
RPS+TC	3,722.4	46,557	79.95	5.6	0.2314
CTP+RPS+TC	3,779.4	44,402	85.12	58.2	0.1107

- Single-policy ranking: CTP, RPS, TC.
  - RPS is inferior to CTP because it fails to distinguish among non-renewables.
  - TC is inferior to RPS because it subsidizes production, which increases demand.
- Cost-effectiveness of combinations follows from single policies.
  - e.g., cost-effectiveness of CTP+RPS is between that of CTP and RPS.
- Policy objectives other than cost-effectiveness may pertain, like employment and energy security.

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Renewables Policies Conclusions

- CTP dominates other policies in terms of emissions reductions, electricity price effects, and cost-effectiveness.
- Renewables expansion is greatest under RPS, then TC, then CTP. Wind is the dominant renewable resource.
- Policy combinations are super-additive in terms of renewables expansion since each policy individually closes the cost gap between renewables and other technologies.
- ACP is an important design element of RPS that can yield much less renewable expansion than the target levels, but leave room for policy combinations to yield additional expansion.

Demand Conservation Incentive (DCI)

- Market clearing subsidy price, D_t, satisfies…

$$\frac{F_t(1-A)}{D_t} = KQ_t\left[1-\left(1+\frac{D_t}{P_t}\right)^{\varepsilon}\right]$$

consumption reductions
bought by EE program on LHS
provided by consumers on RHS

F_t=funding ($) in year t
A=administrative cost (%)
D_t=DCI price ($/MWh) in year t
K=calibrator
Q_t=electricity consumption (MWh) in year t
P_t=electricity price ($/MWh)in year t
ε=short-run price elasticity

- RHS is derived from simplified version of demand functions.
- DCI price is per unit of year-one reductions. Lagged reductions follow from adjustment parameters in demand functions.
- To be exact, Q_t is counterfactual electricity consumption.

DCI Calibration

- Captures program implementation inefficiencies.
- Calibrate to Arimura et al (2009) who found that the average utility during 1995-2006 would have realized 1.1% electricity savings at an average cost of $30/MWh for spending of $8/customer on EE programs.
- Alternative calibration: 2.2% savings
  - Suppose that…
    - consumer receptiveness to EE inducements improve
    - Arimura et al underestimated savings
  - … then assume double electricity savings = 2.2%.

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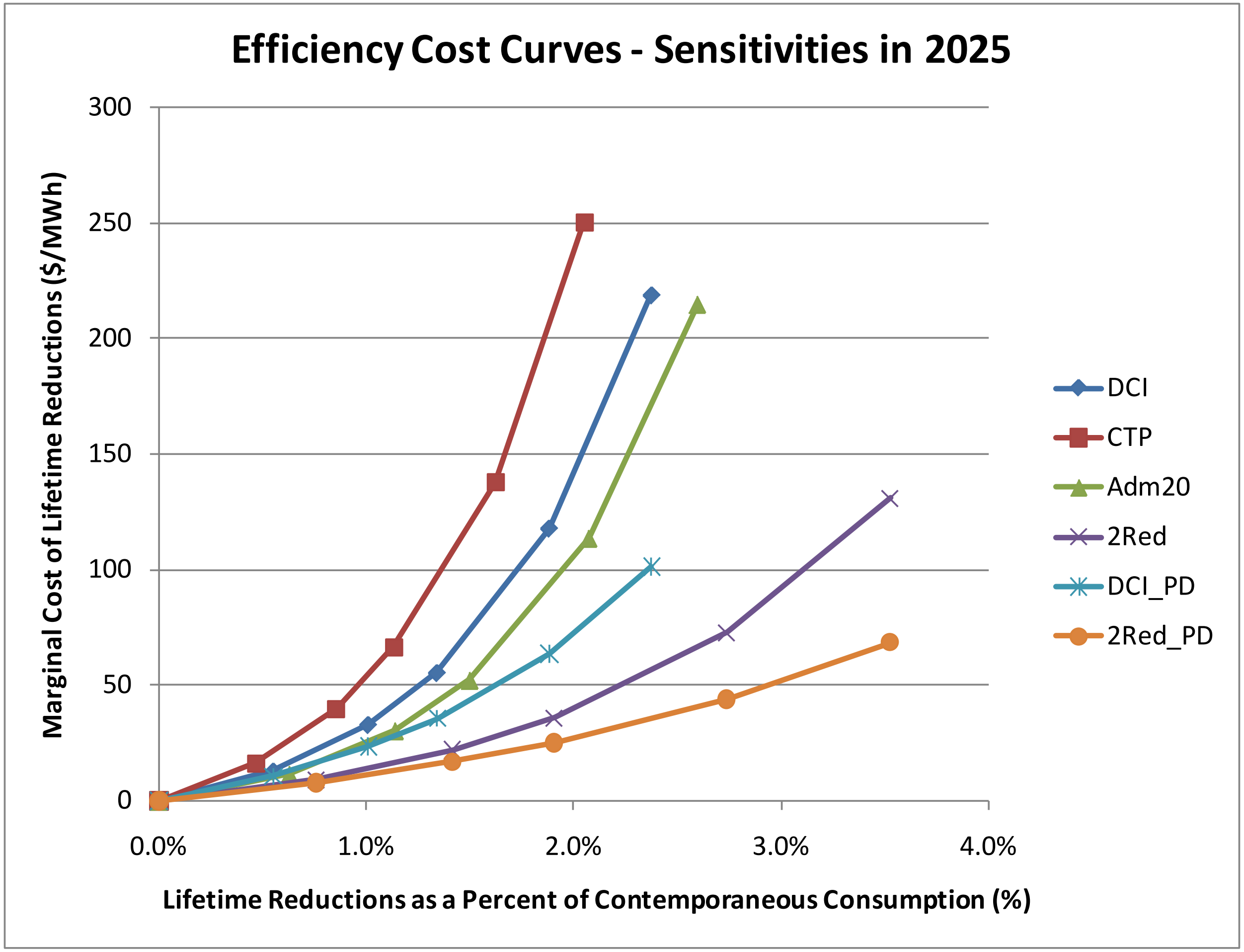
EE Supply Curves and RPS Integration



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