Optimal Policy for Plug-In Hybrid Electric Vehicles Adoption

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OUTLINE

- Problem Statement
- Methodology
- Results
- Conclusion & Future Work

Motivation

- Consumers' adoption of energy-efficient technologies
- Government's role
  - Rebates, tax credits, subsidies, loan guarantees,…
- Government's goals
  - Energy security and independence
  - Pollution prevention
  - Sustainability
- The challenge?
  - Solyndra, Beacon Power, Konarka,...

Motivation

- The proposal
  - Build a decision aid tool for policy makers
    - To further our understanding of the dynamics between consumers' adoption of energy-efficient technologies and government intervention efforts
    - To capture system-wide and local impacts of policies
  - An integrated energy-system model
- Why PHEVs?

Policies of Interest

- Market penetration target
  - Subsidy/Tax Break
  - Tax on conventional vehicle users
  - Penalties on manufacturers
    - CAFE Standards
    - California's ZEV Program

- GHG emissions reductions target
  - Carbon Tax
  - Cap and Trade

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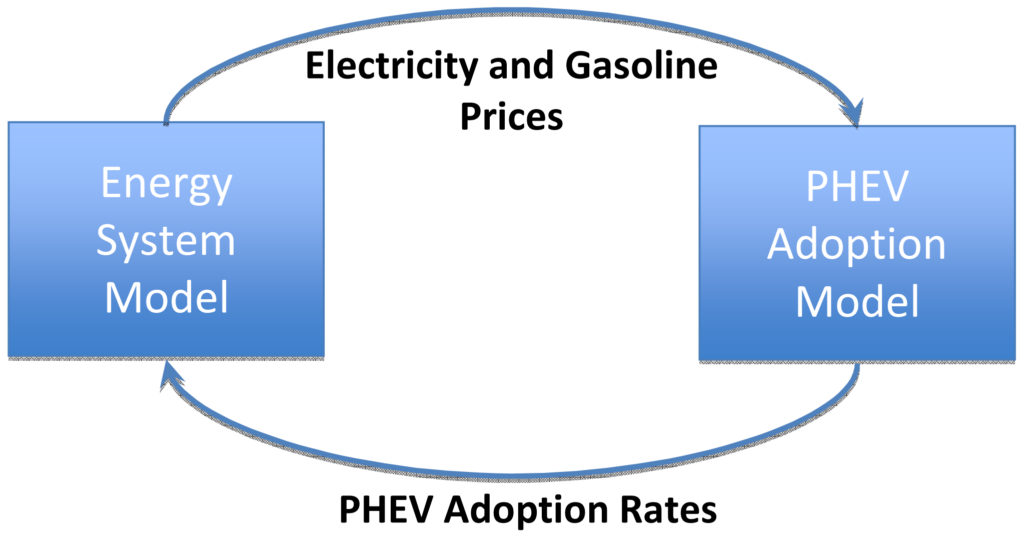
Integrated Energy System Model

- Integrate a PHEV adoption model with an energy system model to devise efficient energy-efficiency policies
  - Track impact of one sector on the others



  - Iterative approach

PHEV Adoption Model

- Based on discrete choice analysis
  - Traced back to the 70s [McFadden]
  - Models choices made by people among a finite set of alternatives
    - Choice behavior based on the attributes of the individual and alternatives
  - Calculates the probability that a person chooses a particular alternative
    - Based on utility theory
  - Has several variations based on:
    - Number of available alternatives
      - Binomial choice
      - Multinomial choice
    - Model specification
      - Logit
      - Probit

PHEV Adoption Model: Formulation

- Based on discrete choice analysis (Binary Logit model)

\# of Vehicles on the Road = # of Surviving Vehicles from Previous Period + New Purchases

$$x_{it+1} = \delta_{it} x_{it} + d_{it}(x_{it}, s_{it}) \;\; \forall\, i, t = 1, \dots, T-1 \qquad (1)$$

PHEV Demand = Market Size x PHEV Purchase Probability

$$d_{PHEV_t}\left(x_{CV_t}, x_{PHEV_t}, s_{PHEV_t}\right) = M_t \left[\frac{1}{1+e^{a_D \Delta TOC - b_D \log\left(\frac{x_{PHEV\,t}}{x_{CV\,t}}\right) + c_D}} \right] \;\; \forall\, t \qquad (2)$$

Word-of-mouth

Total Vehicle Ownership Cost = Purchase Price + O&M Cost – Government Subsidy

$$TOC_{it}(s_{it}) = P_{it} + OM_{it} - s_{it} \;\; \forall\, i, t$$

$$P_{PHEV_t} = P_{PHEV_1}\Big(\sum_{k=1}^{t-1} d_{PHEV_k}\Big)^{-b_L} \qquad \forall\, t = 2, \dots, T \qquad (3)$$

Elasticity of price with regard to demand

$$x_{it}, s_{it} \geq 0 \quad \forall\, i, t$$

PHEV Adoption Model: Parameter Estimation

- Challenges and assumptions
  - Limited history of annual sales data for PHEVs
    - Use hybrid vehicle history for parameter estimation
  - Classify available vehicles into two categories
    - Conventional vehicles and PHEVs

- Data sources
  - Market size, vehicle purchase price, efficiency and stock
    - EIA's Annual Energy Outlook reports
  - Annual miles driven, vehicle retirement rates and maintenance costs
    - DOE's Transportation Energy Databook and Quality Metrics report

Government's Optimal Subsidy Problem

- Cost minimization approach

Model

Minimize Total Subsidy Cost
(Subsidy per Vehicle x Number of Vehicles Demanded)

$$\min TSC(x_{it}, s_{it}) = \sum_{i=1}^{2} \sum_{t=1}^{T} r^{t-1} s_{it} d_{it}(x_{it}, s_{it})$$

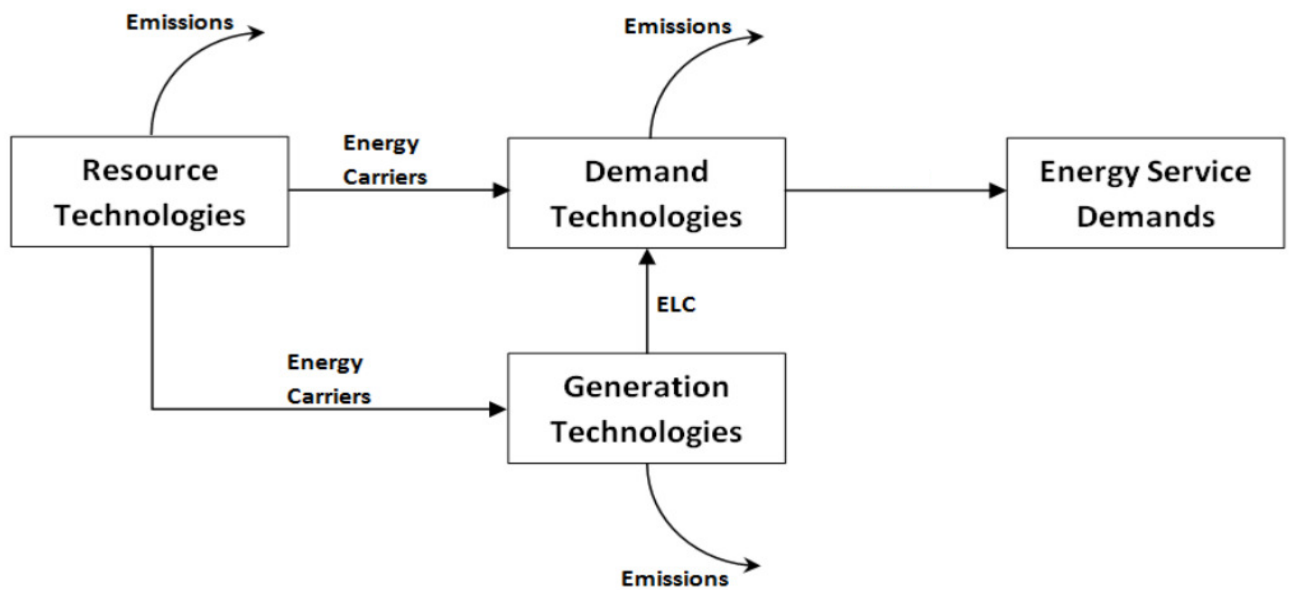
s. t.

$$Target\ Percentage\ of\ PHEVs\ Constraint$$

$$Logit\ Model\ Constraints$$

Energy System Model

- Based on EPA's National MARKAL Model
  - Bottom-up energy system model
  - Detailed technology representation and multiple sectors
  - Demand driven, multiperiod, linear programming optimization model
  - Least-cost path to user-provided demands and imposed policies
  - Can reflect pollutant emissions
  - Reference Energy System (RES)



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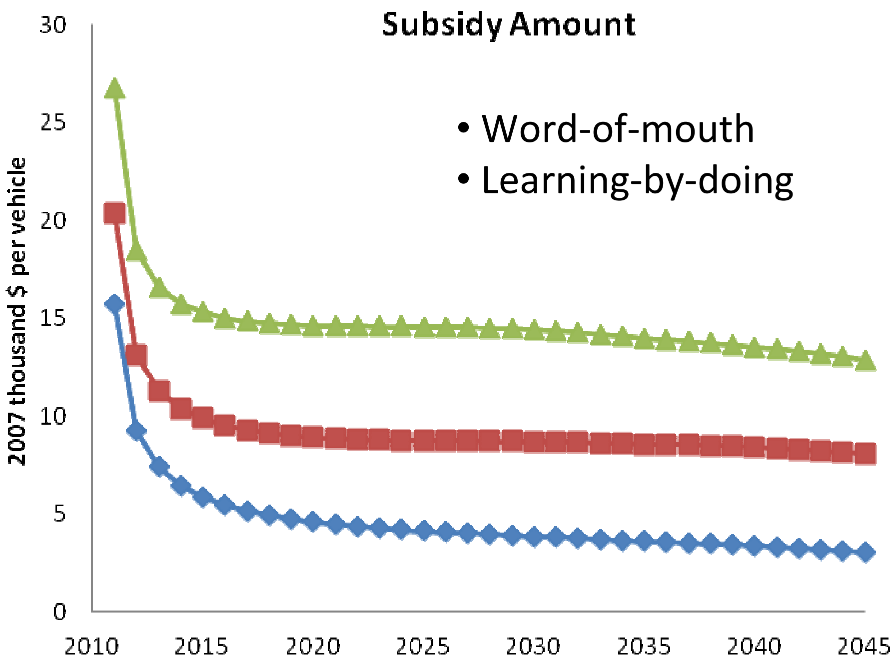
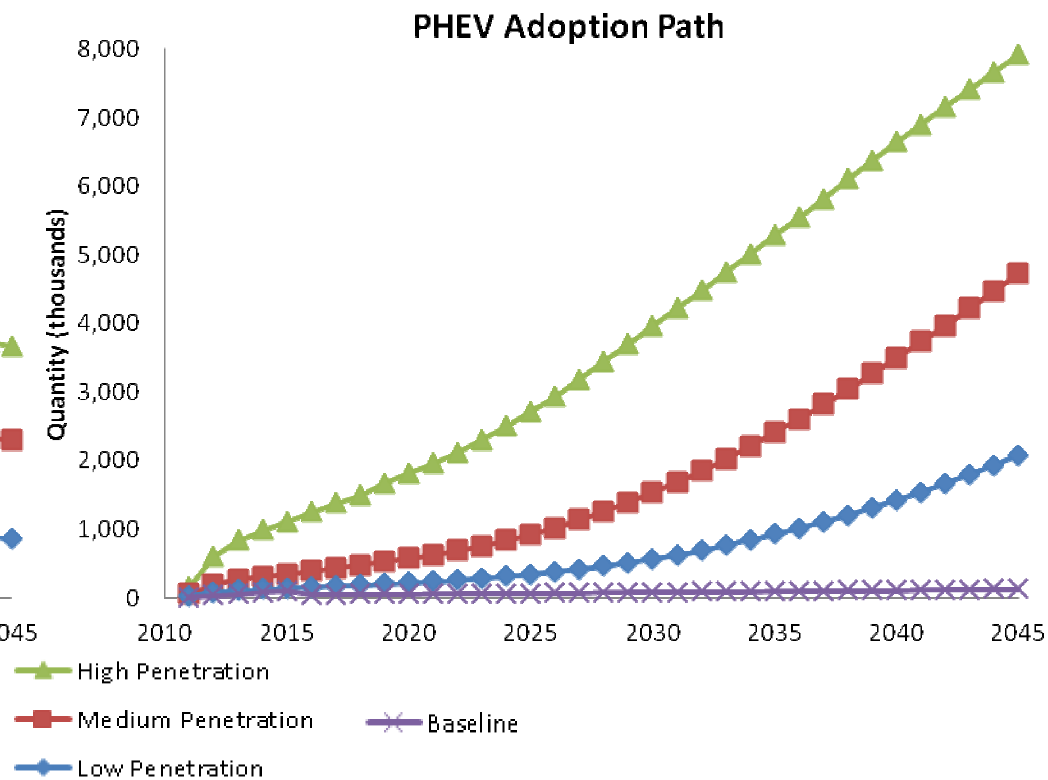
PHEV Adoption Model Results

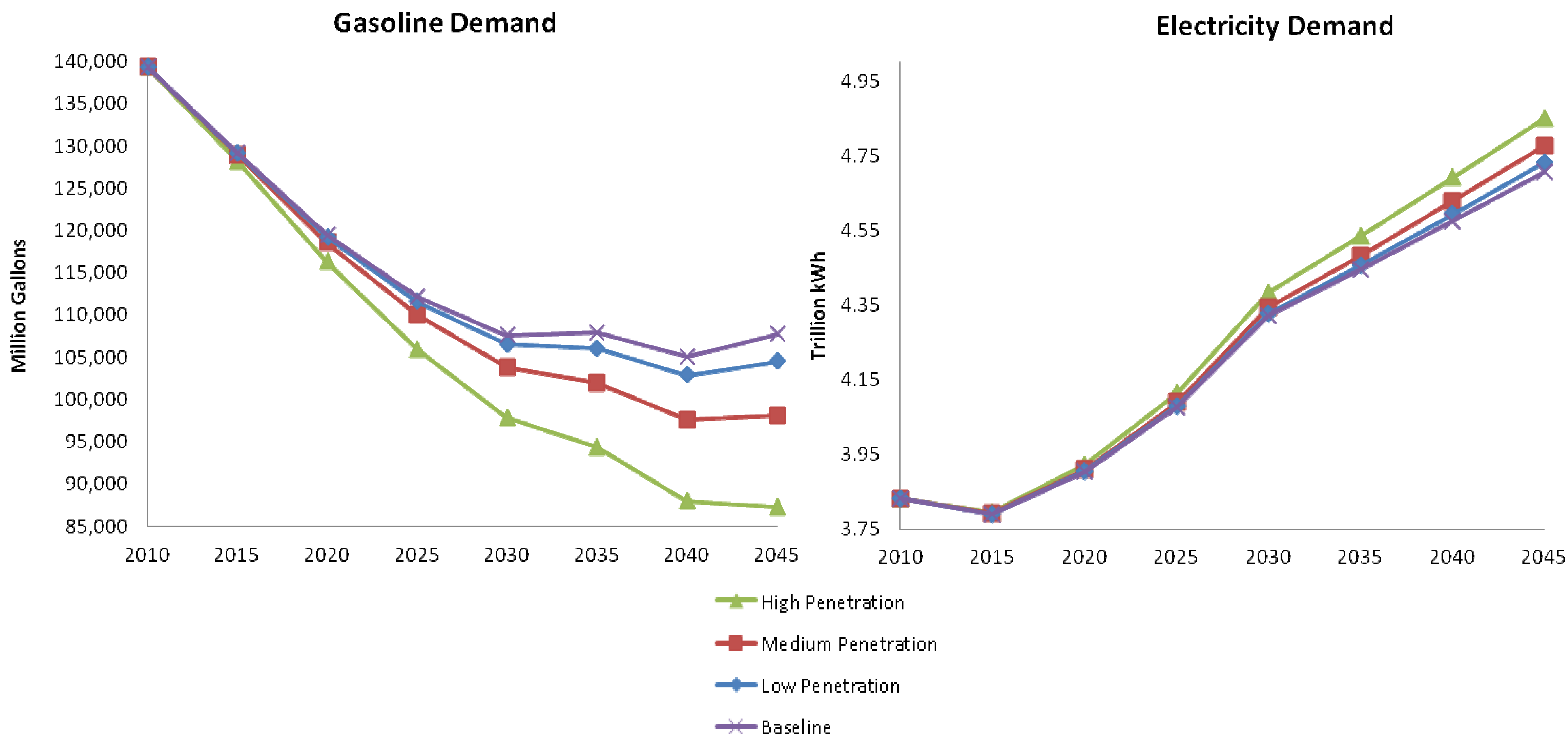
- Three scenarios based on PHEV market share by 2045:
  - High Penetration: 50% PHEV share
  - Medium Penetration: 25% PHEV share
  - Low Penetration: 10% PHEV share





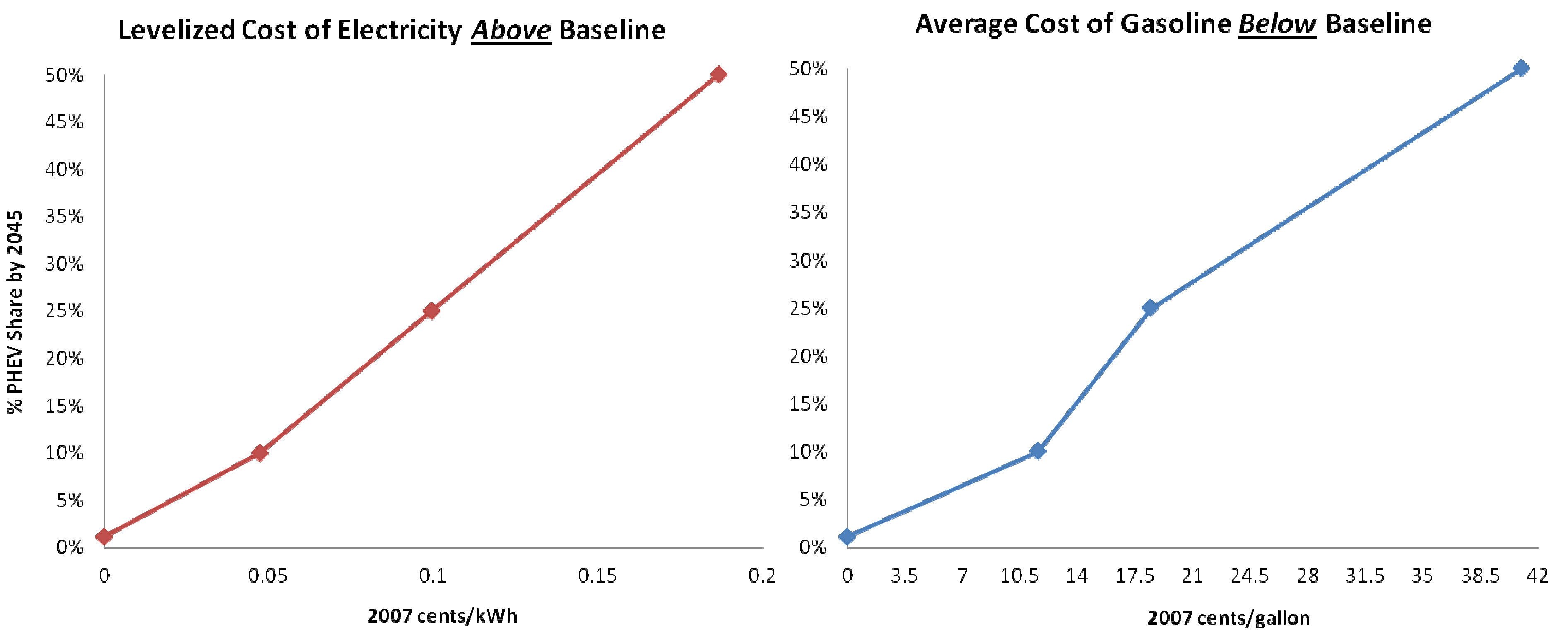
Integrated Energy System Model Results

- Gasoline and electricity demand
  - Convergence achieved after 4 iterations



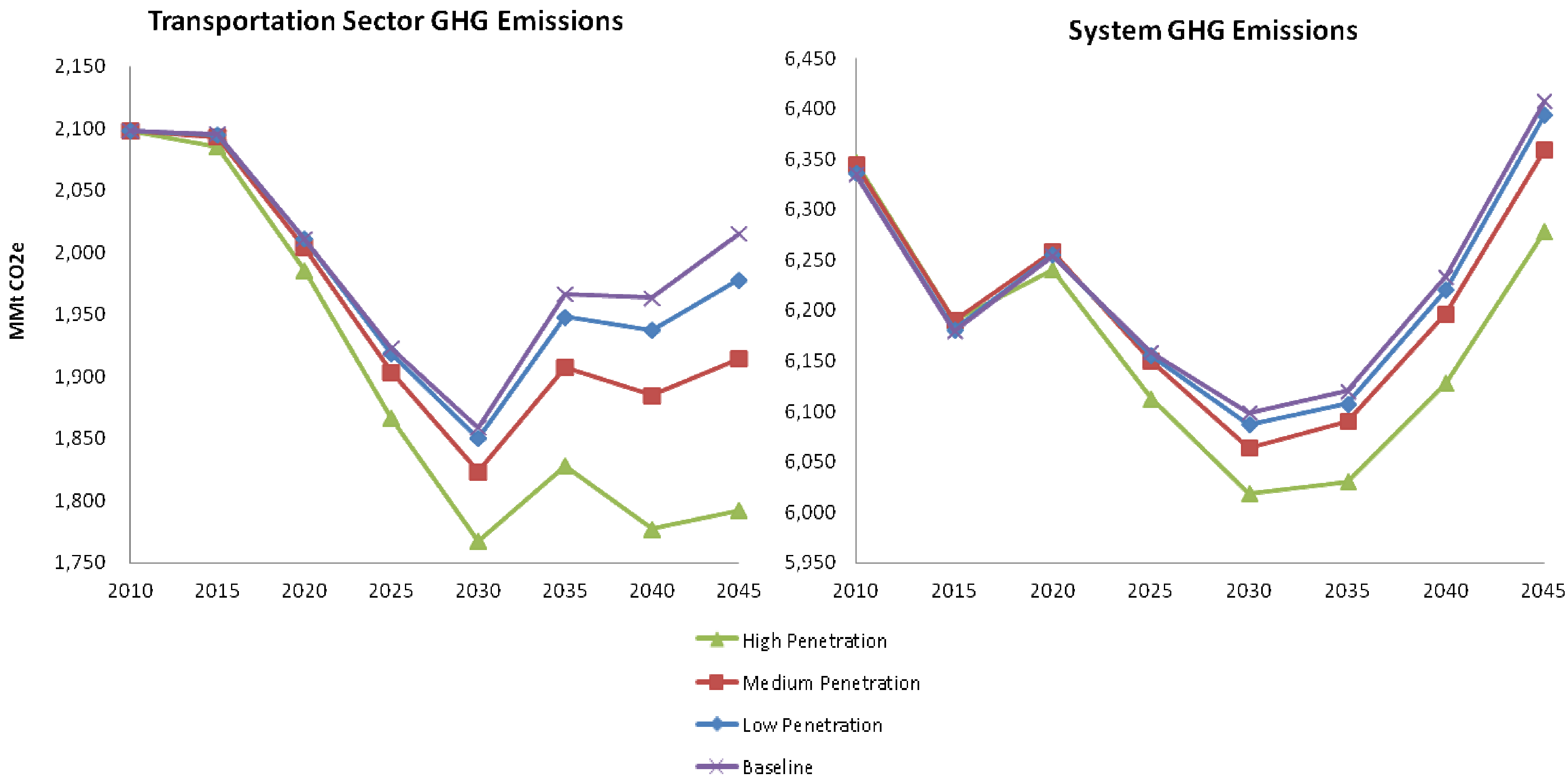
Integrated Energy System Model Results

- Electricity and gasoline prices



Integrated Energy System Model Results

- GHG Emissions



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Conclusion

- PHEVs are not economical without subsidies
- Government should not give out the subsidies all up-front
- Minimal impact on *electricity prices*
- Bigger impact on *gasoline prices*
- System GHG emissions heavily dependent on generation mix

Future Work

- Impact of PHEV charging behavior
- State-level policy impact
- Improve the consumer choice model
  - Number of vehicle categories considered

Thank you!

Integrated Energy System Model

- Convergence metric
  - Similar to the metric used in EIA's NEMS model
    - Qualitative metric, based on a 4-point grading scale
    - Compares deviations of convergence variables at each iteration with deviations from the previous iteration (as a percentage)
    - A grade point average (GPA) is given to each convergence variable based on the following grading metric

Score (% basis)	Grade on 4-pt scale	Letter grade
0.05 or less	4.0	A
0.20	3.0	B
0.50	2.0	C
1.00	1.0	D
1.50 or more	0.01	F

    - Continue iterations until either a pre-specified number of iterations or inter-cycle convergence objective is met