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Macroeconomic Analysis and Positive Economic Impacts of Plug-in Hybrid Electric Vehicles

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Overview of Presentation

- Why PHEV technology should be pursued from a macroeconomic perspective
- Some details of the macro analysis framework for PHEV potential
- Exploring dynamic optimization, uncertainty analysis, and conclusions

We Consider PHEV to Be One of the Potential Technologies That Could Help Achieve Climate Stabilization in a Positive Economic Context

- In Stanford's Energy Modeling Forum 19 (EMF-19), on modeling CO_2 emissions reductions through technology strategies, we used PHEV as our major backstop technology and demonstrated the potential for a positive economic benefit to the economy. See, *Donald A. Hanson and John A. "Skip" Laitner, "An Integrated Analysis of Policies That Increase Investments in Advanced Energy-Efficient/Low-Carbon Technologies," Energy Economics, 2004, 26(4), pp. 739-55.*

- In the EMF-21 exercise on multigas mitigation and climate policy, we again included PHEV as a major emissions reduction strategy. See, *Donald A. Hanson and John A. "Skip" Laitner, "Technology Policy and World Greenhouse Gas Emissions in the AMIGA Modeling System," Francisco C. de la Chesnaye and John P. Weyant, eds., Special Issue on Multi-Greenhouse Gas Mitigation and Climate Policy, Energy Journal, 2006.*

- In this presentation, we will present some of the logic that underpins this more recent set of modeling results.

The DOE National Energy Technology Laboratory (NETL) Added a Second Goal of Improved Energy Security With PHEVs

- President Bush, February 2003:
  - Reduction of Petroleum Consumption
    - *11 million barrels per day, by 2040*
  - Reduction of Carbon Equivalent
    - *500 million metric tons per year, by 2040*
- See, Peter Balash, Donald Hanson, John Ruether, David Schmalzer, John Molburg, Dale Keairns, Kenneth Kern, Kathy Stirling, and John Marano, "Use of Hydrogen for the Light Duty Transportation Fleet: Technology and Economic Analysis: Comparative Energy Security and Environmental Implications of Chemical and Gaseous Hydrogen Economies," paper based on presentation to the US Association for Energy Economics, Denver, September, 2005.
- See also, "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options," EPRI, Palo Alto, CA: 2001. 1000349 (and subsequent updates).

There Have Been a Number of Recent Cautionary Studies

- See, for example, James Kliesch and Therese Langer, *Plug-In Hybrids: An Environmental and Economic Performance Outlook*, American Council for an Energy-Efficient Economy (ACEEE), Report T061, September 2006.

- There are important near/medium term obstacles
  - Battery performance and cost
  - Need to invest in power generation and grid

- This gives rise to uncertainly about the future amount of transportation fuels that can be economically displaced by PHEVs – see DOE Stochastic Energy Deployment System (SEDS) Model

- We see the technology outcomes as
  - Incremental improvements, or
  - Major successes,
  - But in any case having an important role for PHEVs

Opportunities: The Glass is Better than Half Full

- All power generation classes benefit from the increased electrical demand from PHEVs
- PHEV has a great attribute: High substitution elasticity regarding when to charge its batteries
- Under a carbon charge, or carbon emissions constraint, zero carbon sources are provided an opportunity to show their potential:
  - Renewable electricity (onshore and offshore wind, solar, geothermal, and other emerging technologies)
  - Carbon capture and sequestration
  - Nuclear
- Provides an advantage for wind which generates relatively more electricity off-peak.

Simulations of Grid System Impacts from PHEV Deployment Using the Argonne National Laboratory's AMIGA Modeling System

- Effects of carbon charge
- Effects of higher coal and gas prices
- General equilibrium, or feedback, effects on gas prices
- Resulting electricity price patterns
  - Provide a signal when it's economic to dispatch a unit or not
  - Provide the correct investment incentives for the amount and type of new capacity
- Though not considered here, there are also the productive benefits of alternative patterns of technology investments, the likely reductions in other energy prices resulting from lower resource demands, and other induced technological innovations.

Investment Criteria for Entry of New Power Facilities

- Total Revenue > Total Costs
- Revenue is based on electricity pricing schedule
- Costs include
  - Fuel costs
  - Carbon charges and emission allowance prices
  - Other operating costs
  - Capital outlays
- These depend on external prices and vary by technology
- Generation technology investments depend on the total load (energy) and its shape, both affected by PHEVs.

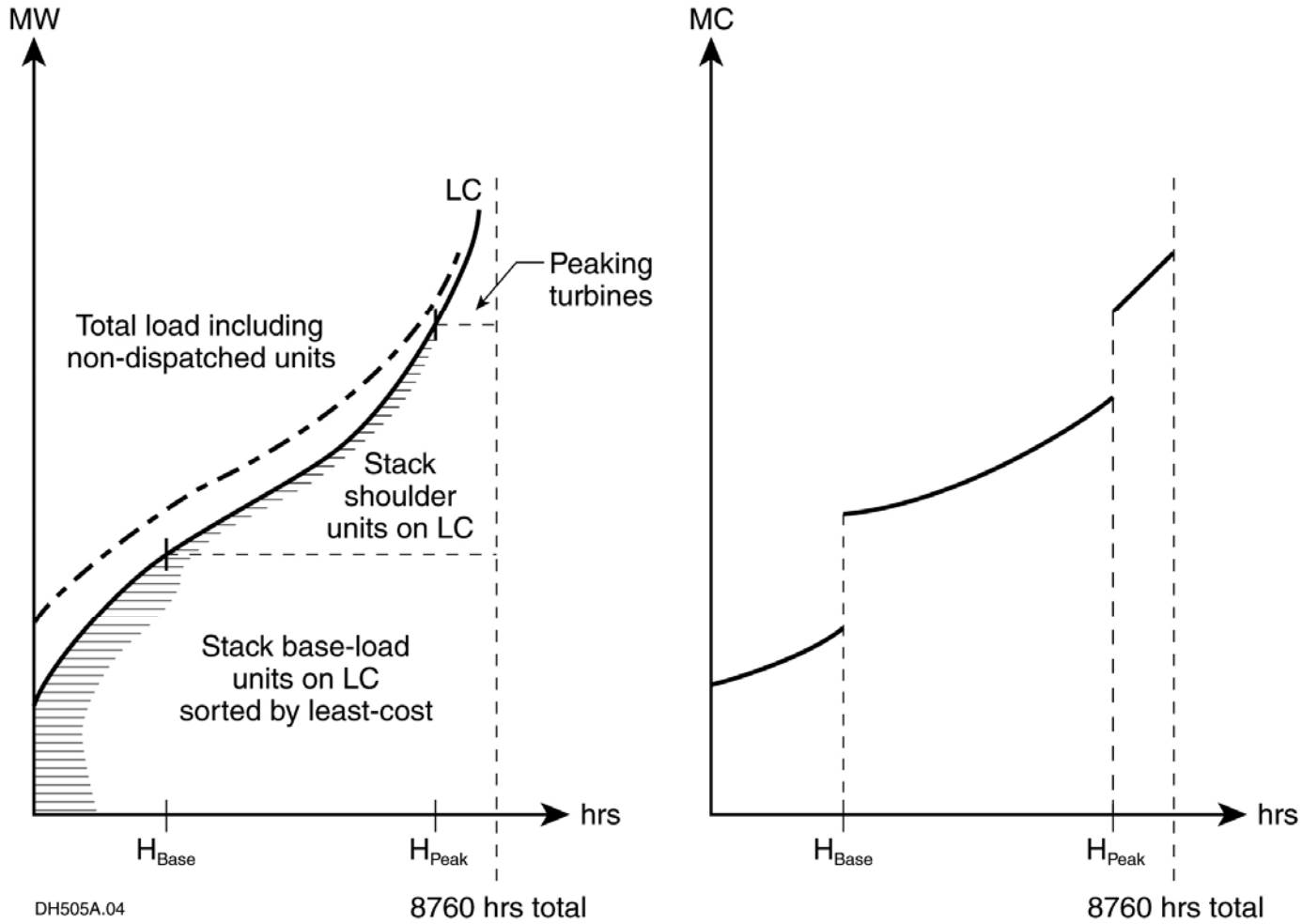
Developing Technologies Are Represented by S-Shaped Market Penetration Dynamic Equations

- Developing technologies for electricity generation are treated differently than mature technologies
  - e.g. wind, photovoltaic, solar thermal power, geothermal, biomass, and IGCC are considered to be developing technologies
- Represented as gradually gaining market share, $\boldsymbol{x_t}$, from a small initial value according to a logistic function:

$$x_{t+1} = x_t \cdot \left(1 + b \cdot \left(y\left(p\right) - x_t\right)\right)$$

  - ***b*** is a parameter related to the growth rate,
  - where ***y*** is a forecast of the eventual market share, and
  - the eventual market share is a function of ***p*** the price of electricity

Break Points Between Market Segments, Capacity Factors, and Marginal Costs Change Under Different Situations



Like Good Economists We Make the Assumption that PHEV Technology is Used Well – Not Poorly

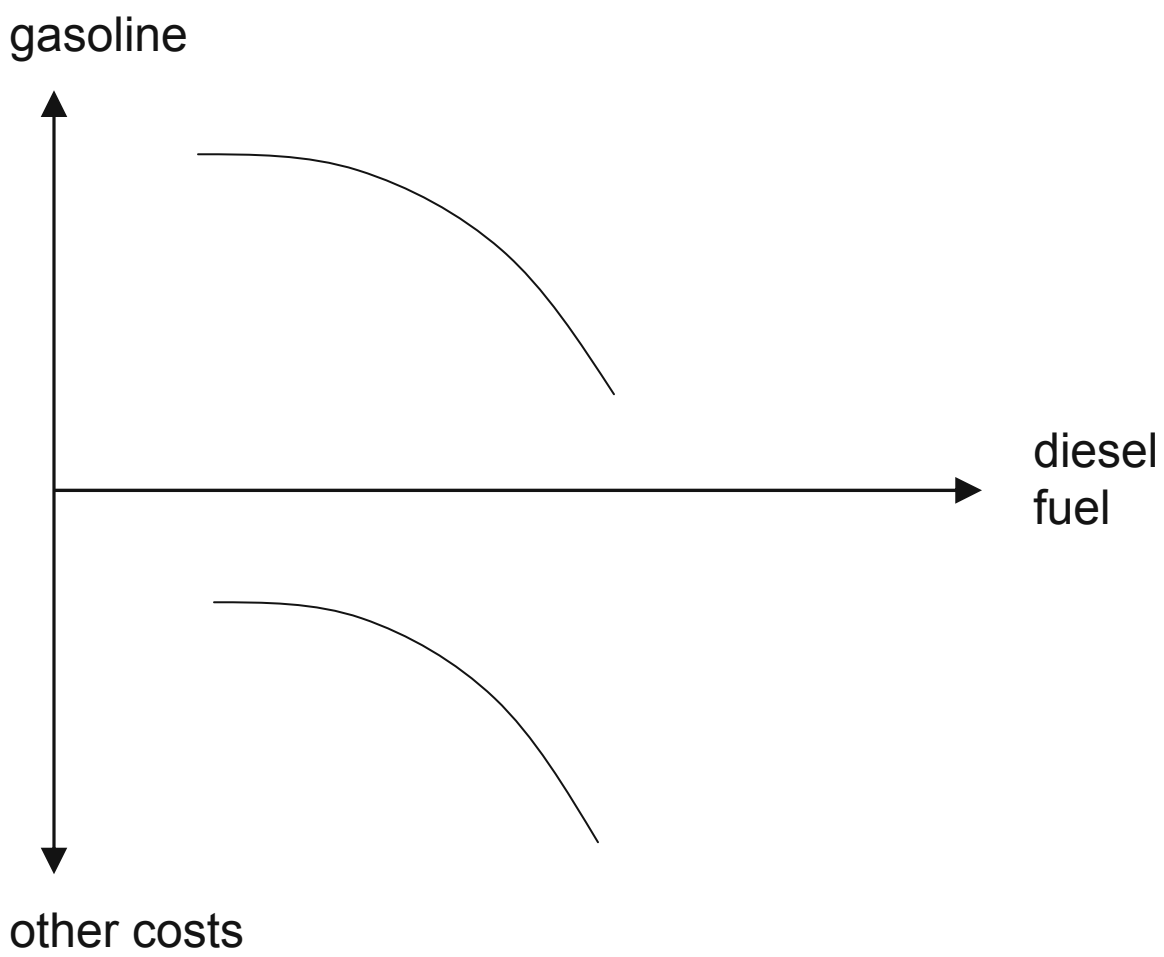
- We can analyze the effects of PHEV on the grid with ordinary electricity pricing, but the real benefits occur with time varying pricing
  - Real-time pricing or Time-of-Use pricing
  - Special incentives for PHEVs

- Optimal electricity pricing for PHEVs under dynamic optimization

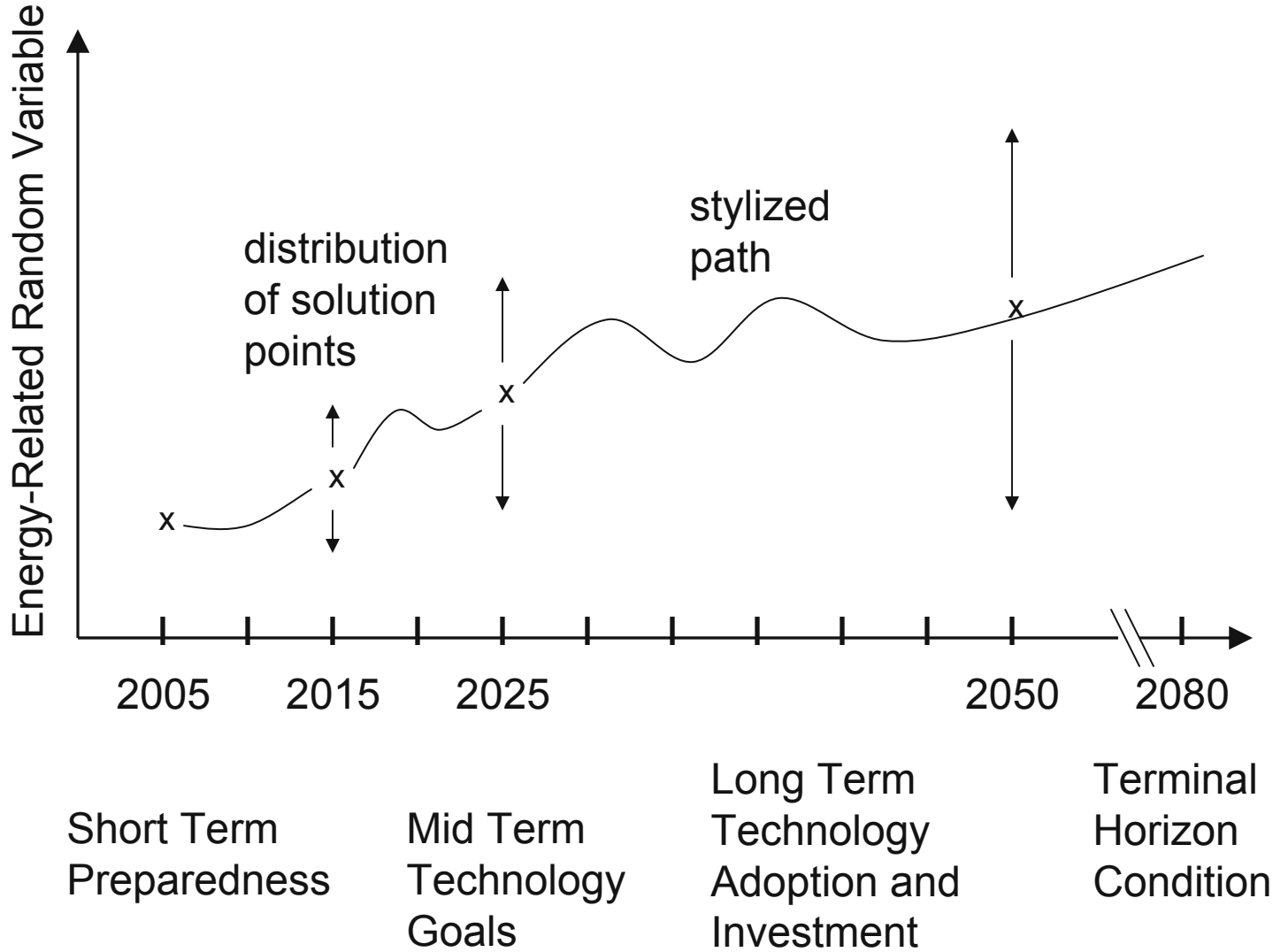
$$P_t^{elect} = MC_t^{elect} - \xi_t$$

where ξ reflects the marginal benefit of increasing the penetration of zero-carbon technologies. It is the shadow price on the state variable representing current period penetration of those zero-carbon technologies.

What Will the Other Fuel Be? Probably Gasoline. High Efficiency LDVs Will Already Lower Gasoline Use, Leaving What Diesel Fuel is Available for Jet Turbines and Freight



Uncertainty Analysis (e.g., SEDS) Reflects Upside and Downside Roles of the PHEV Technology



Conclusions

- The battery is a significant capital charge. But this source of power can be used in lieu of grid system capacity, if the PHEV buys off-peak power, and hence the PHEV need not pay much for electric capacity.
- The extent of application of the technology (i.e., how much power is ultimately drawn from the grid for PHEVs) will depend on where marginal costs (of batteries and power generation) start to rapidly rise.
- Nevertheless, we see an important energy security and climate mitigation role for this technology, and enabling R&D and infrastructure development should be pursued.
- More macro perspectives, such as the positive impact of more productive investment patterns embodied in the AMIGA model, can be helpful for considering long run technology diffusion.