Within-Day Recharge of Plug-In Hybrid Electric Vehicles:

Energy Impact of Public Charging Infrastructure

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Introduction

- Plug-in hybrid electric vehicle (PHEV)
  - partially substitute electricity for gasoline
  - a bridging technology towards battery electric vehicle (BEV)
- Public charging opportunities
  - provide PHEV drivers with more flexibility
  - further improve fuel economy
- This study is intended to
  - assess the effect of public charger availability in increasing PHEV's share of driving on electricity
  - capture within-day recharge behavior, considering real world travel activities

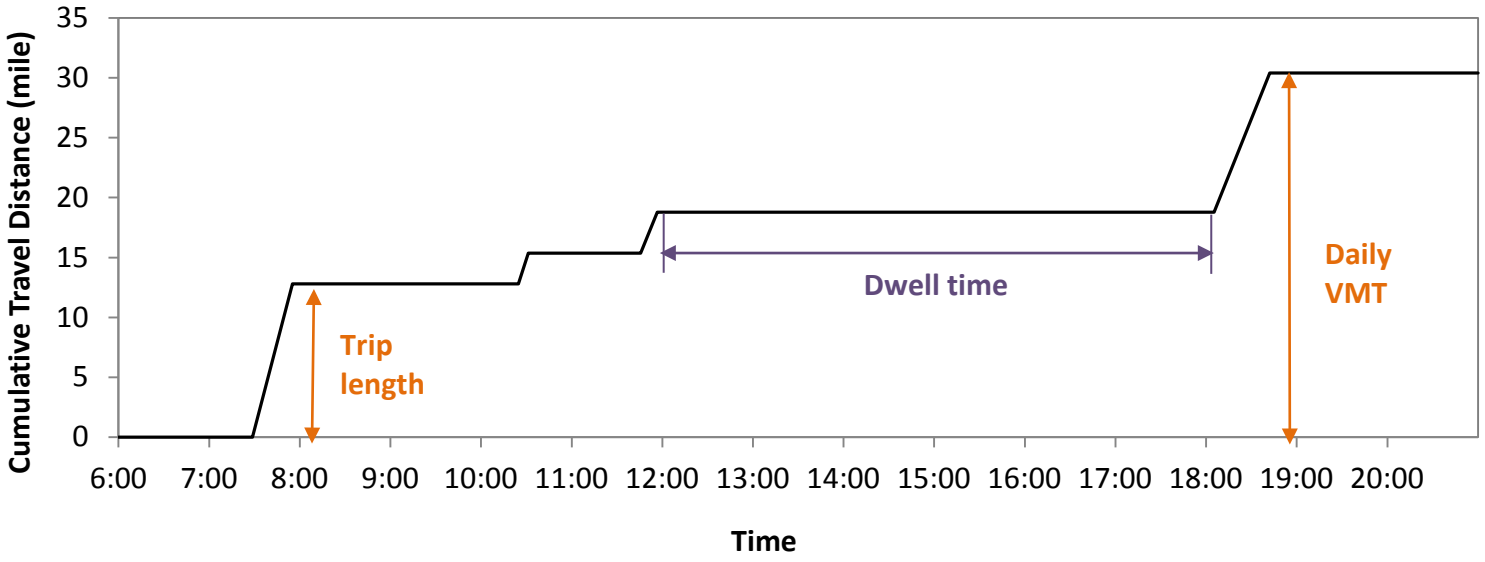
Background

- PHEV operates through a hybrid powertrain
  - Charge depleting (CD): battery as the major energy source
  - Charge sustaining (CS): engine as the major energy source
  - CD range: the distance that a PHEV can travel in CD mode, designated by PHEV-*[miles]*
- Charging infrastructure
  - Charging time and power, collectively, determine the amount of the electricity transferred to the battery

	Voltage	Ampere circuit	Charge power	Charging time (10kWh)
Level 1	120 volt	15 Amp	1.44 kW	7 hours
Level 2	240 volt	30 Amp	6 kW	1-2 hours
Level 3	480 volt	200 Amp	90 kW	Less than 10 minutes

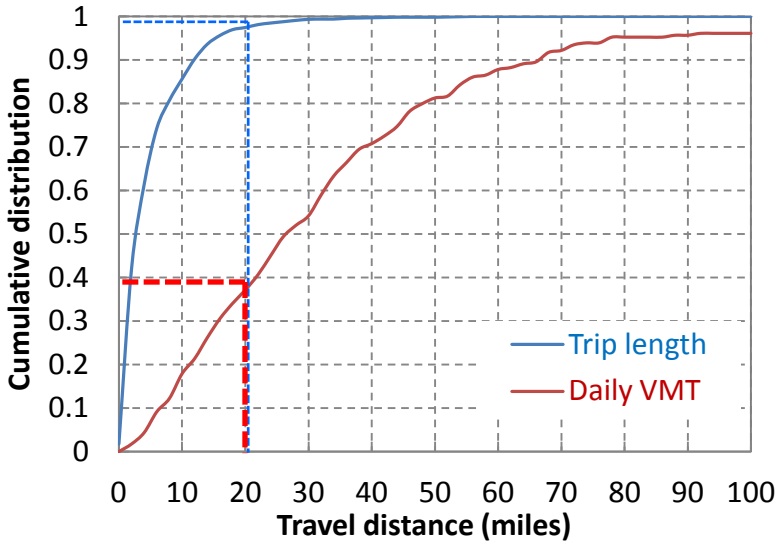
GPS Travel Data

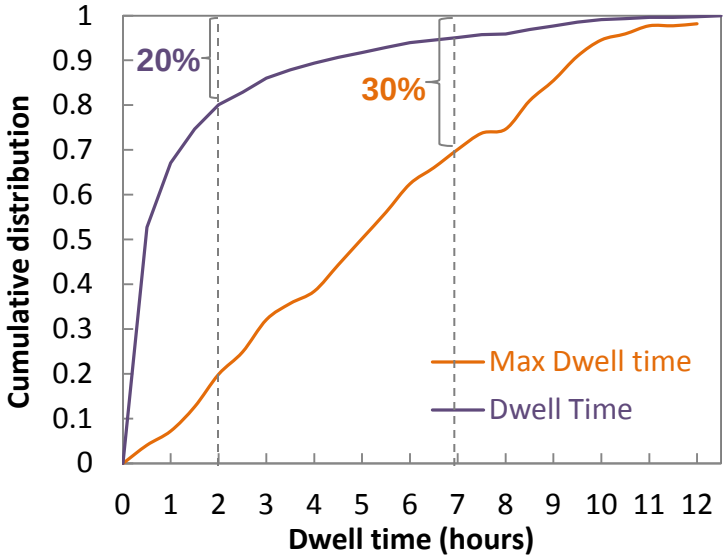
- Obtained from NREL's Transportation Secure Data Center
- Collected *continuously* using passive GPS tracking devices
- Household travel survey conducted in Austin, Texas, USA
  - One-day travel data of 229 vehicles
  - Travel distances of 1652 trips and the intermediate dwell times



GPS Travel Data: Travel Pattern

- Daily VMTs and trip lengths
  - determine vehicle's energy consumption
  - 40% of *daily VMT* are less than 20 miles
  - 97% of the *trips* are less than 20 miles
  - a *PHEV-20* can operate in CD mode more often if public charging is available





- Dwell time between two consecutive trips
  - limits the charging time
  - 20% of the stops last more than 2 hours (to fully charge a *PHEV-20* by a *Level 2* charger)
  - 30% of the vehicles are continuously parked for more than 7 hours (to fully charge a *PHEV-20* by a *Level 1* charger)

Methodology: Energy Consumption

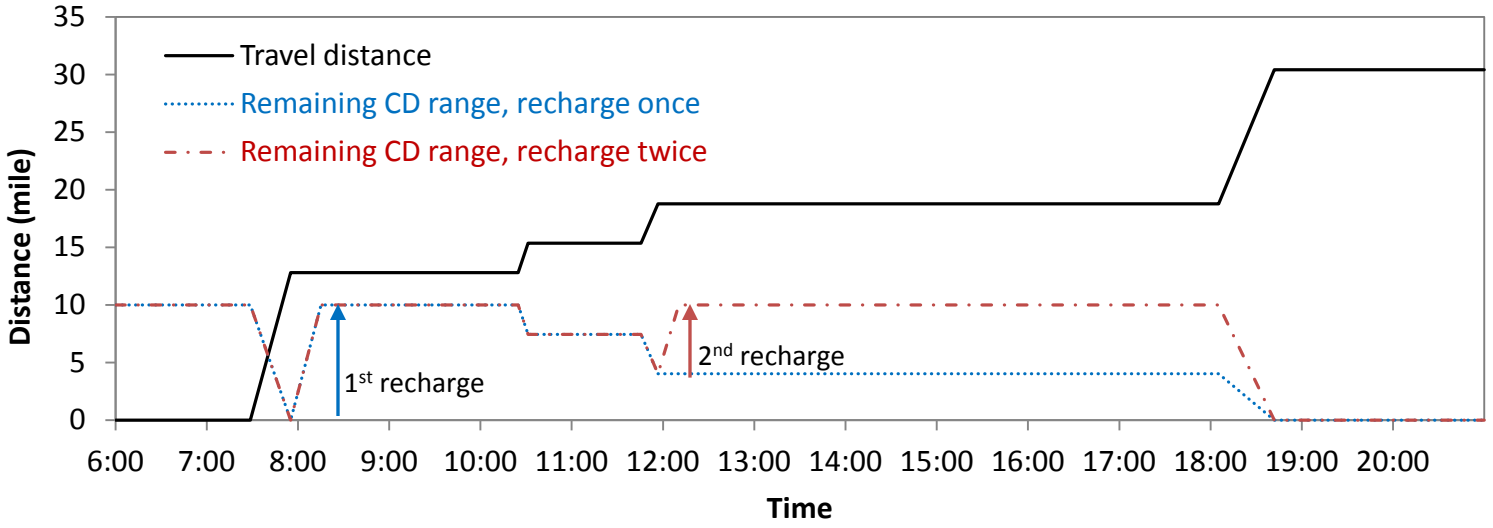
- Power split PHEV with blended-mode operation
- Operate in the CD mode until the CD range is exhausted
- Electricity consumption: $E_e = d_{cd} \times r_{cd,e}$
- Gasoline consumptions: $E_g = d_{cs} \times r_{cs,g} + d_{cd} \times r_{cd,g}$
- Energy cost: $E_e \times price_e + E_g \times price_g$

CD range (mile)	CD mode		CS mode
	Gasoline, $r_{cd,g}$ (gallon/mile)	Electricity, $r_{cd,e}$ (kWh/mile)	Gasoline, $r_{cs,g}$ (gallon/mile)
10	0.0095	0.1800	0.0237
20	0.0082	0.1975	0.0238
40	0.0057	0.2386	0.0244

Source: Automomie model developed by Argonne National Laboratory

Methodology: Within-Day Recharge

- Assumption: Recharging PHEV will not interfere with existing travel routines.
- The *remaining CD range* indicates the battery's state of charge.
- In the following example, the CD range of a PHEV-10 is extended by 10 miles if recharged once and 16 miles if recharged twice.

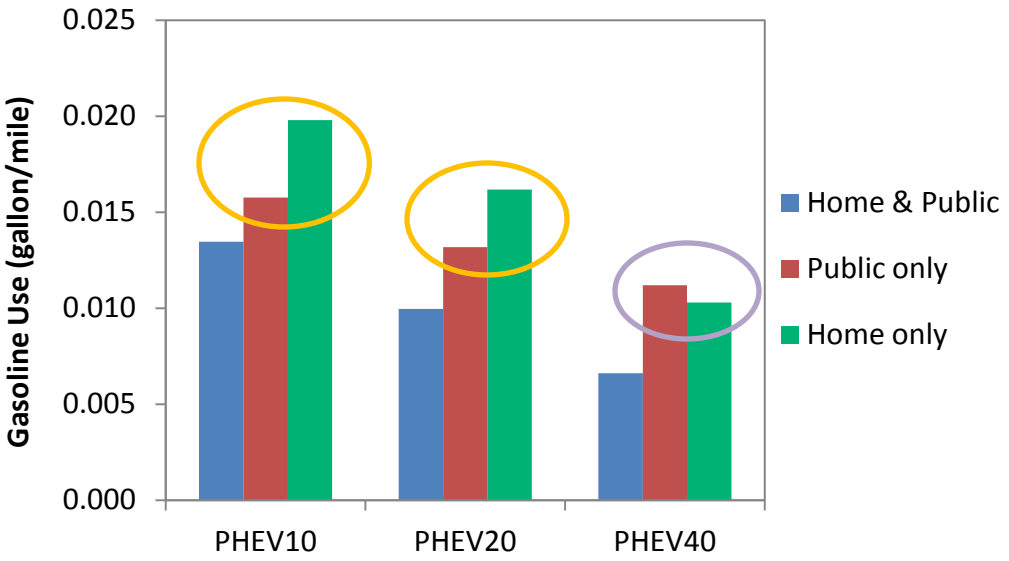


Methodology: Within-Day Recharge (cont'd)

- Charger network coverage
  - the probability that a charger is available at a certain stop
- User's decision on recharging
  - perceived benefit and cost associated with the recharge
    - *Benefit* includes gasoline cost savings, refueling burden relief etc.
    - *Cost* comprises electricity cost and the perceived recharge burden.
  - bounded rationality
    - driver will recharge when the benefit-cost ratio is greater than a bounded rationality threshold.
- Travel distances in CD and CS modes can be computed to estimate energy consumptions and cost.

Result: Home vs. Public Charging

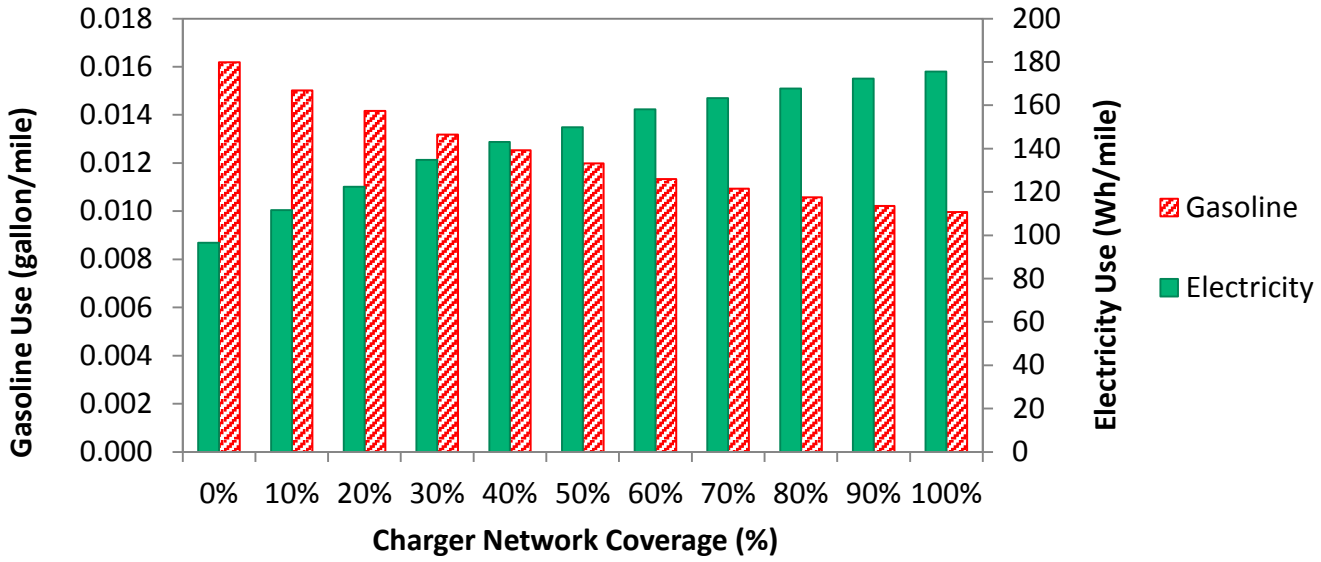
- Scenarios
  - Home & Public: charged at home and public charger available
  - Public only: no charger at home and public charger available
  - Home only: charged at home and no public charger



- PHEV-40 consumes less gasoline than PHEVs with smaller battery packs.
- For PHEV-10 and -20 (but not for PHEV-40), relying solely on public charging consumes less gasoline than home charging only.

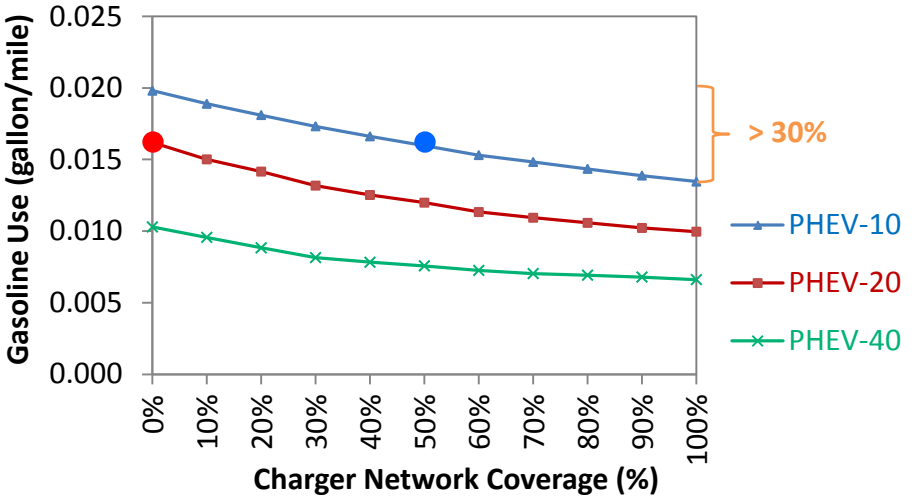
Result: Public Charger Network Coverage

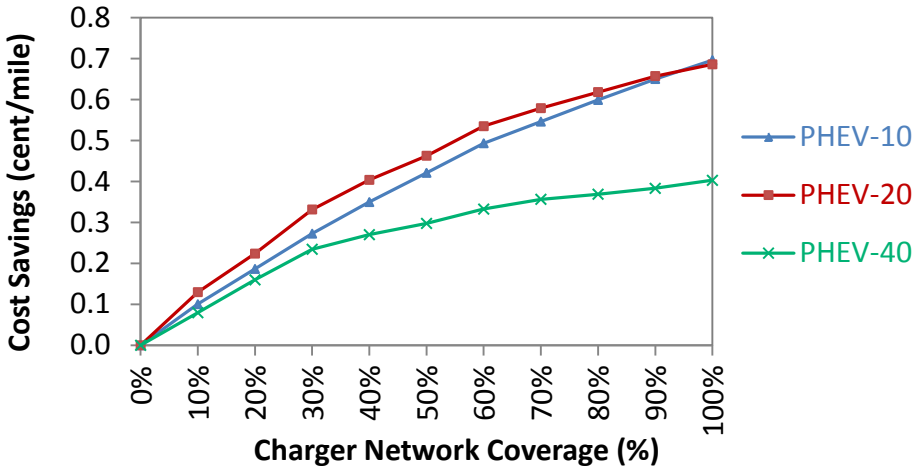
- Scenario: Assume a fleet of PHEV-20
  - All vehicles are fully charged when leaving home.
  - Public charger availability varies from 0 to 100%.
- Public charging opportunities encourage within-day recharge behavior.



Result: Public Charger Network Coverage

- Gasoline consumption:
  - Fully covered public charger network provides more than 30% reduction in gasoline use
  - PHEV-10 with 50% charger coverage consumes less gasoline than PHEV-20 (no public charger)
- Energy cost:
  - Electricity price: $0.11/kWh
  - Gas price: $2.55/gallon
  - Higher charger coverage results in more energy cost savings
  - Greater savings are observed for PHEV-10 and -20 than for -40.





Conclusions

- This study
  - estimates PHEV energy consumption based on GPS tracking data
  - considers within-day recharge, constrained by travel activities and charger availability

- Key findings
  - Providing public charging service reduces PHEV gasoline consumption and energy cost
  - Public charging offers greater benefits for PHEVs with a smaller battery pack (within-day recharges compensate battery capacity)

Thanks!
Q & A