Managing the Seams Between Electromobility and Power Systems

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The following are our my views and not necessarily those of the Electricity Advisory Committee or the U.S. Department of Energy.

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Mea Culpa

- I'm from the U.S.
- . . . so I'll tell a U.S.-centric story
- Let's say that there is value in this to a European audience (*i.e.*, learn from our successes and failures)

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Opportunities of Electromobility

- Fuel security/hedging
- Sustainable and environmentally benign transportation
- Demand-side flexibility for power systems
- Electricity-supply resilience

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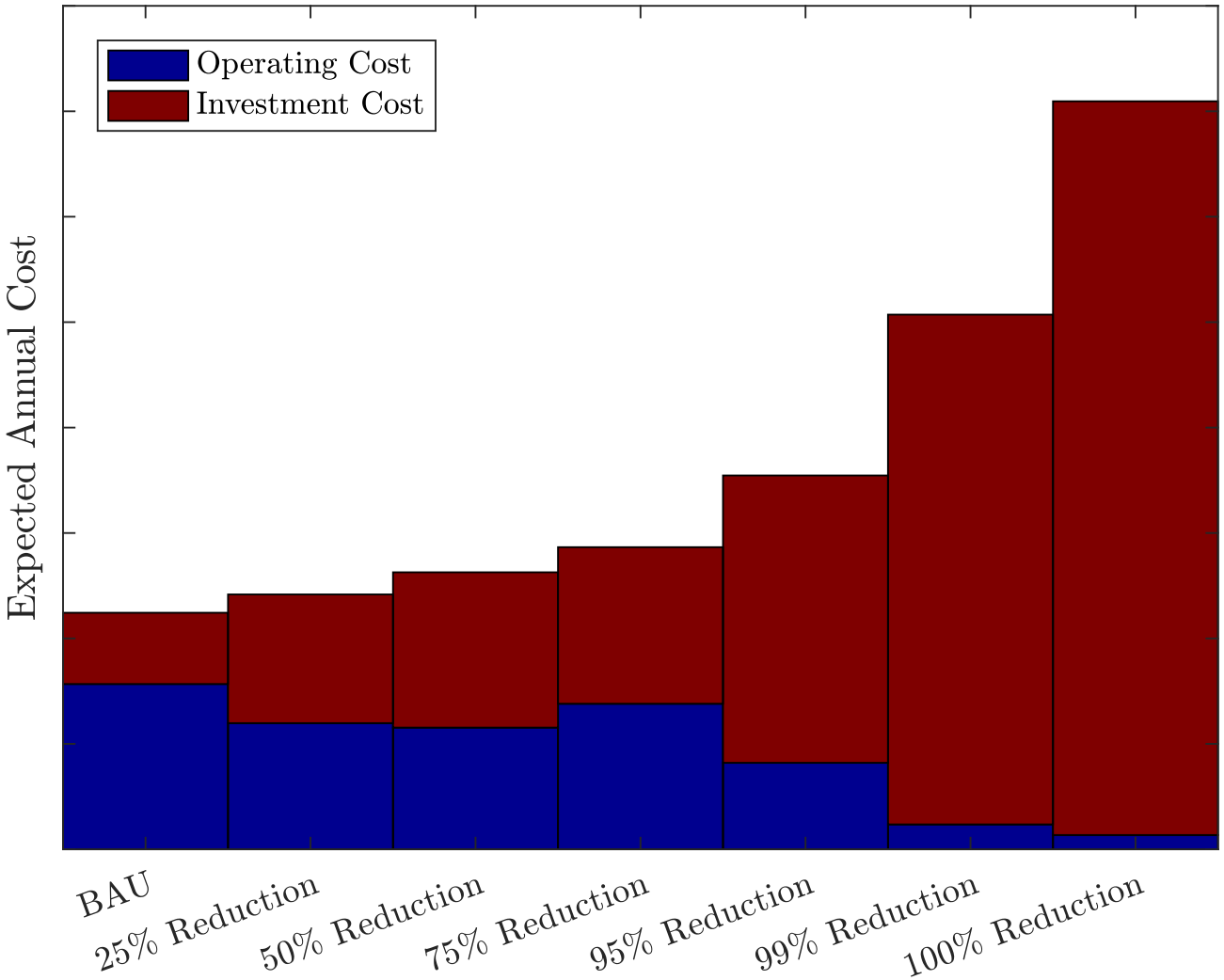
Virtuous Flexibility Cycle



http://dx.doi.org/10.1016/j.eneco.2019.07.017

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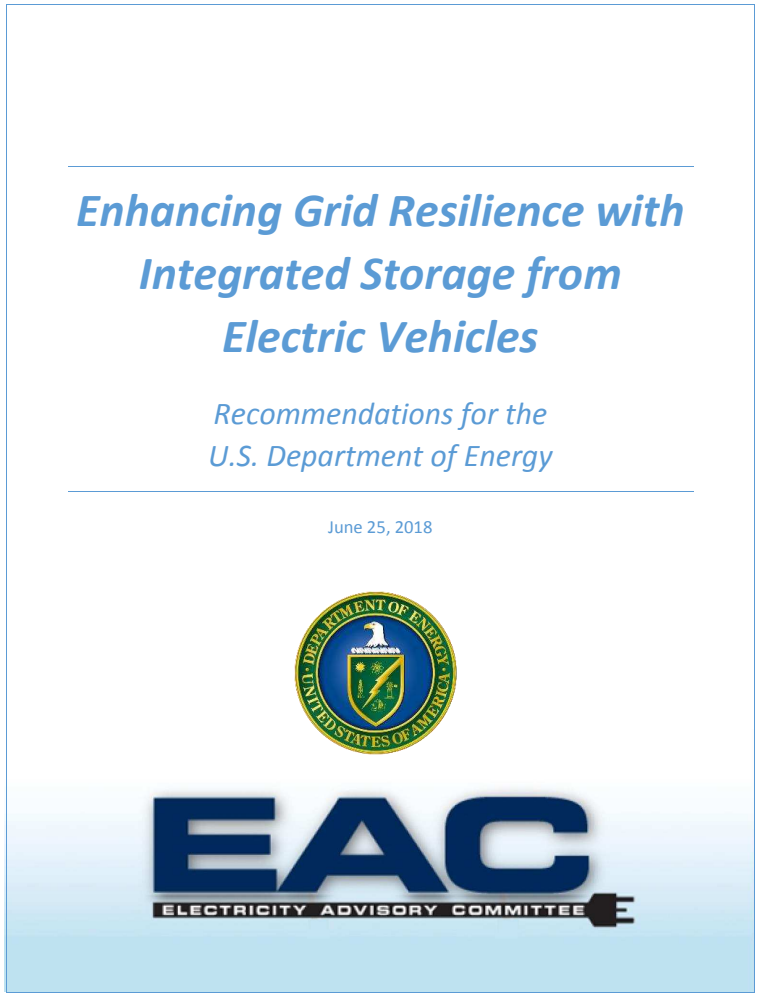
Supply Resilience



https://www.energy.gov/sites/prod/files/2018/06/f53/EAC_Enhancing%20Grid%20Resilience%20with%20Integrated%20Storage%20from%20EVs%20%28June%202018%29.pdf

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Supply Resilience

Recommendations

Natural and man-made disasters threaten the electric grid's ability to deliver reliable, high-quality power. . . The emerging market of electric vehicles (EVs) presents a new opportunity to improve the grid.

Recommendation #1: *The DOE should increase support for research to create and harmonize standards needed for EVs to integrate with the grid and participate in the market, particularly with respect to bilateral exchanges.*

Recommendation #2: *The DOE should increase support for research to evaluate the range of possibilities for using EVs for grid services, effects at both the distribution and transmission level, mitigation techniques to avoid negative grid impacts, and impacts of bidirectional charging on the lifetime of EV batteries when used within such systems.*

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Supply Resilience

Recommendations

Recommendation #3: *The DOE should commence a comprehensive economic study that analyzes US EV penetration scenarios, grid impacts and investment requirements to provide charging infrastructure and generation requirements.*

Recommendation #4: *The DOE should increase support for research on the range of business models for EV charging infrastructure, policies that create barriers or incentives to each, and provide materials to guide state decision making for ownership, control and rate-basing methodology given the objective of increased reliability and resilience.*

Recommendation #5: *The DOE should fund additional V2G pilot projects to better understand these challenges, public acceptance, the costs and benefits to vehicle owners, and best practices to best optimize the outcome of electric transportation and grid infrastructure development.*

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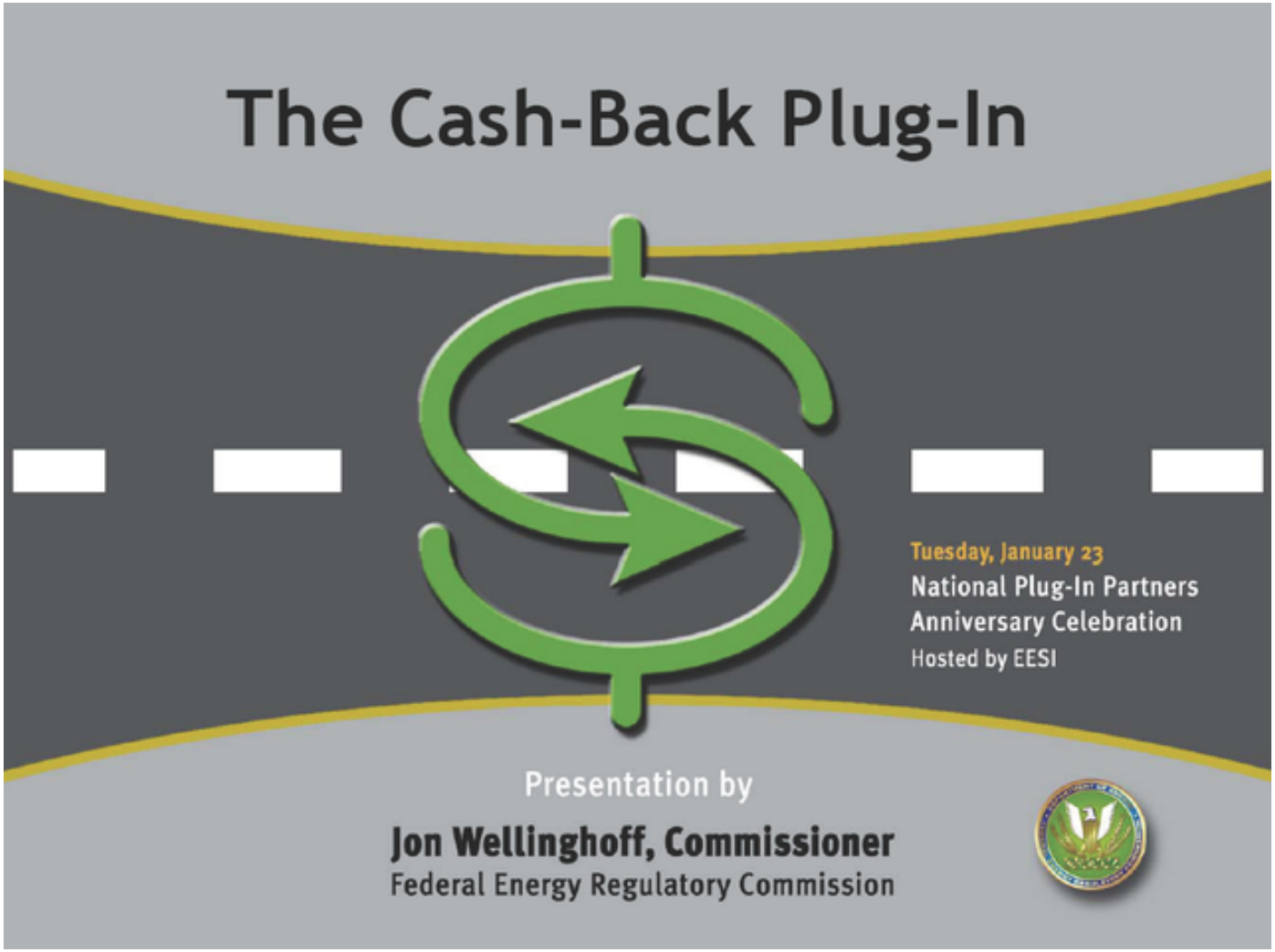
Wasn't This Supposed To Happen Already?

A View From 2007



https://www.greencarcongress.com/2007/01/opinion_introdu.html

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What Happened?

- Fuel prices
- Charging infrastructure
- Charging management
- Tariff/market design
- OEMs/battery warranties

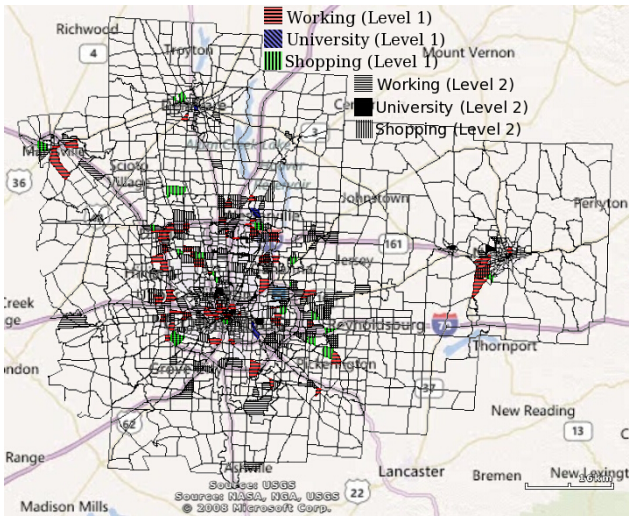
Fuel Prices

- Financial downturn of 2007/2008
- Hydraulic fracturing
- Real decrease in Federal gasoline tax since 1993
- Public-policy questions:
  1. Is volume of fuel consumption reflective of cost-causation for funding transportation-infrastructure construction and maintenance?
  2. Does a fuel tax reflect externalities of fuel use (*e.g.*, environmental, geopolitical, and defense)?

Charging Infrastructure

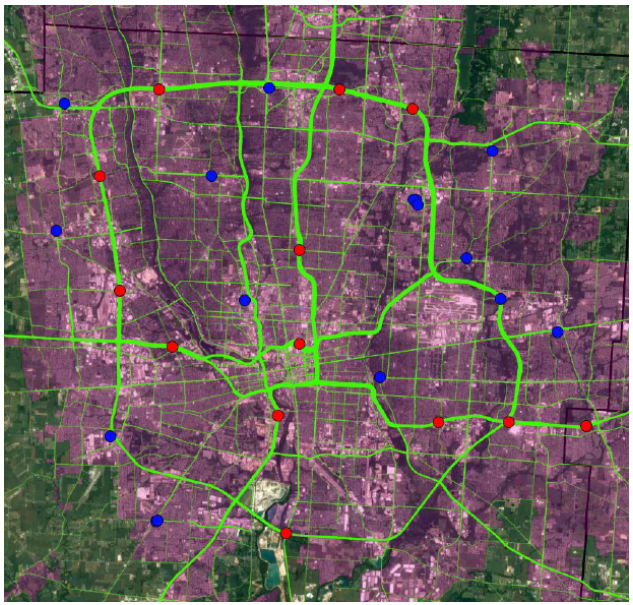
Many Central-Planning Exercises

- Flow-catching
- Set-covering



http://dx.doi.org/10.1016/j.trd.2013.02.014

- Simulation/optimization
- Heuristics



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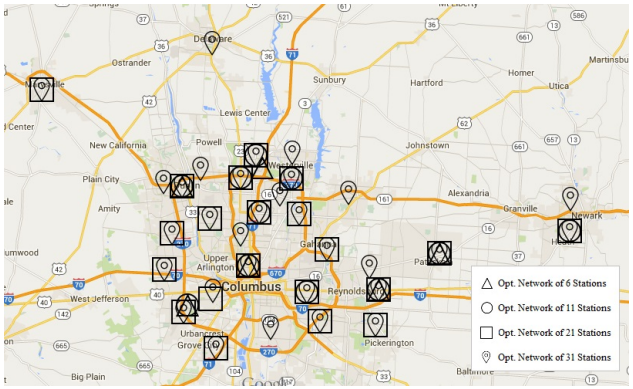

http://dx.doi.org/10.1016/j.trd.2017.04.035

- Technically sophisticated but. . . we don't do much central planning

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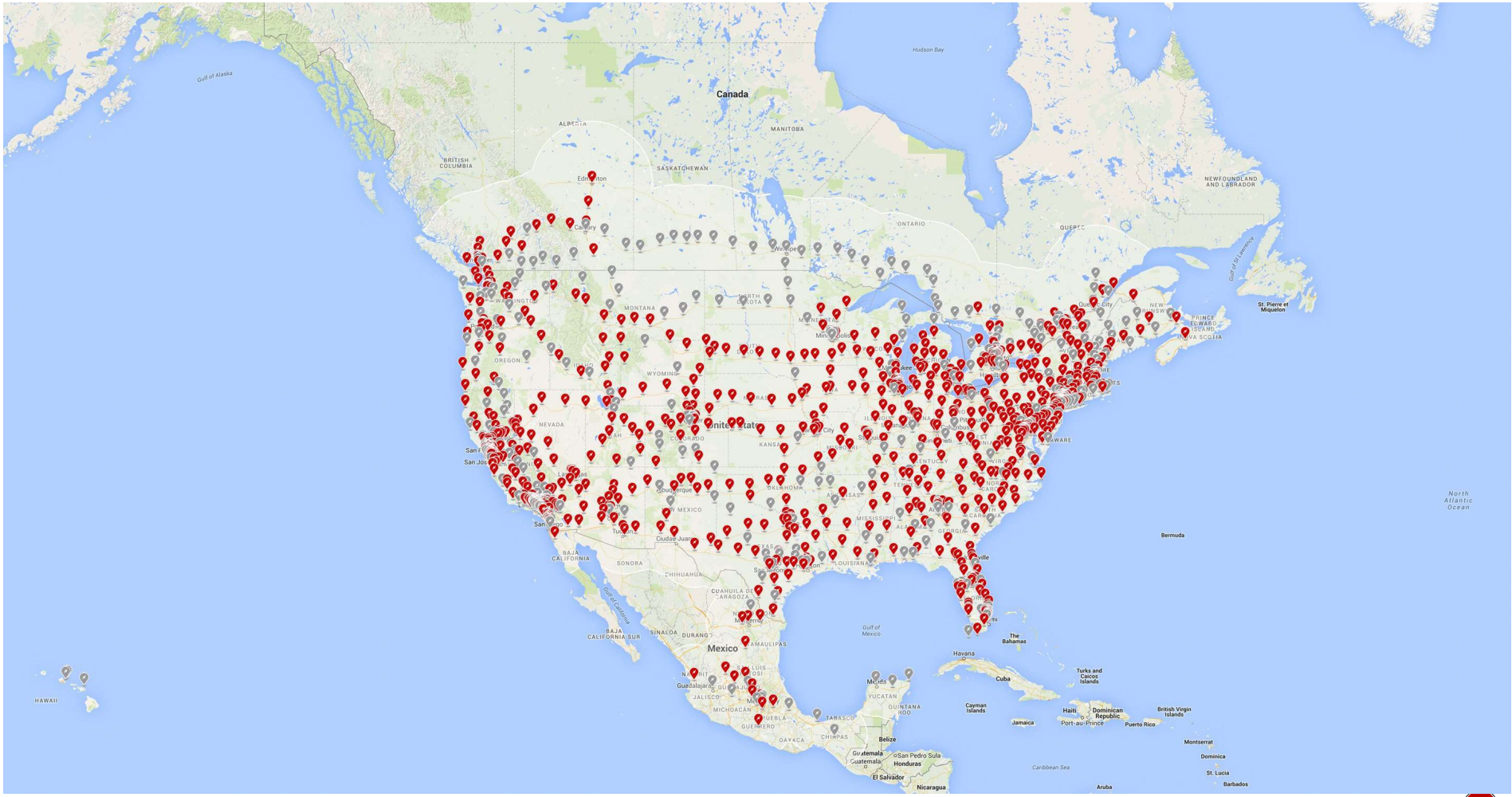
Tesla Model



https://www.tesla.com/supercharger

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Other Models

- Car sharing programs (*e.g.*, ReachNow, Maven, and car2go)
  - Many have ceased operation or are pilots only
  - Urban regional networks only
- Poor attempts at central planning (*e.g.*, ratepayer-funded subsidies for ~~Tesla owners~~ millionaires to get in-home charging stations)

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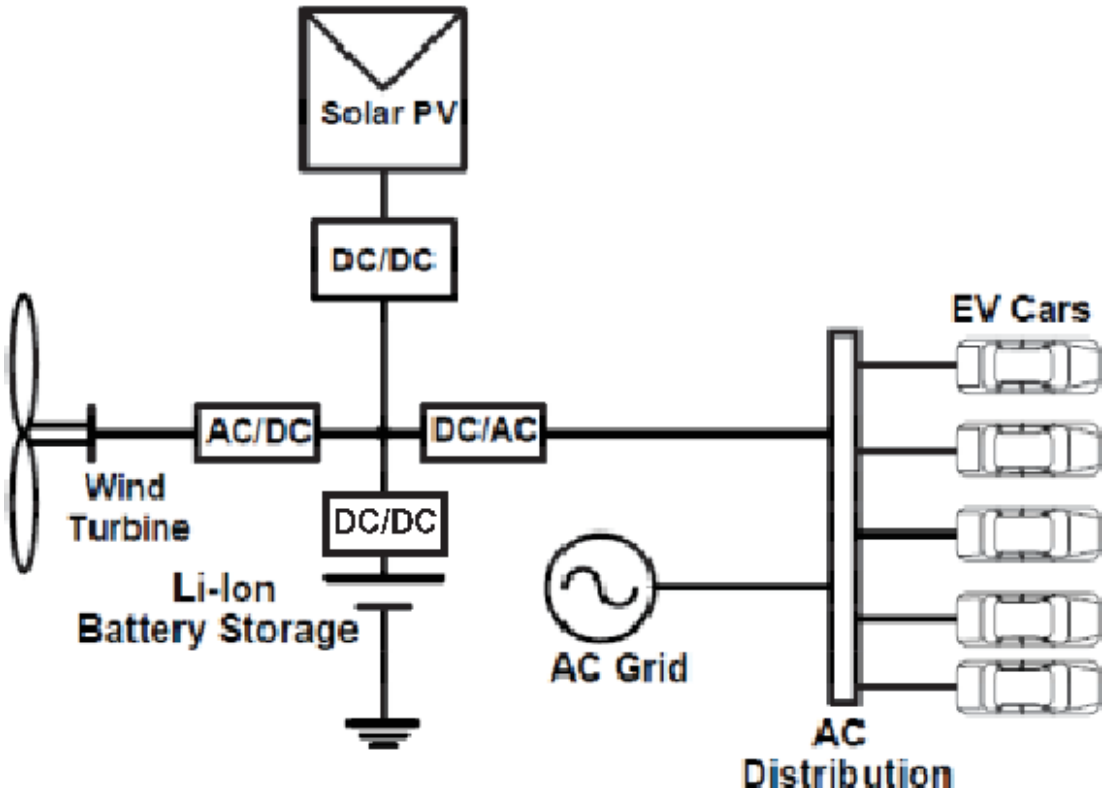
Station Design

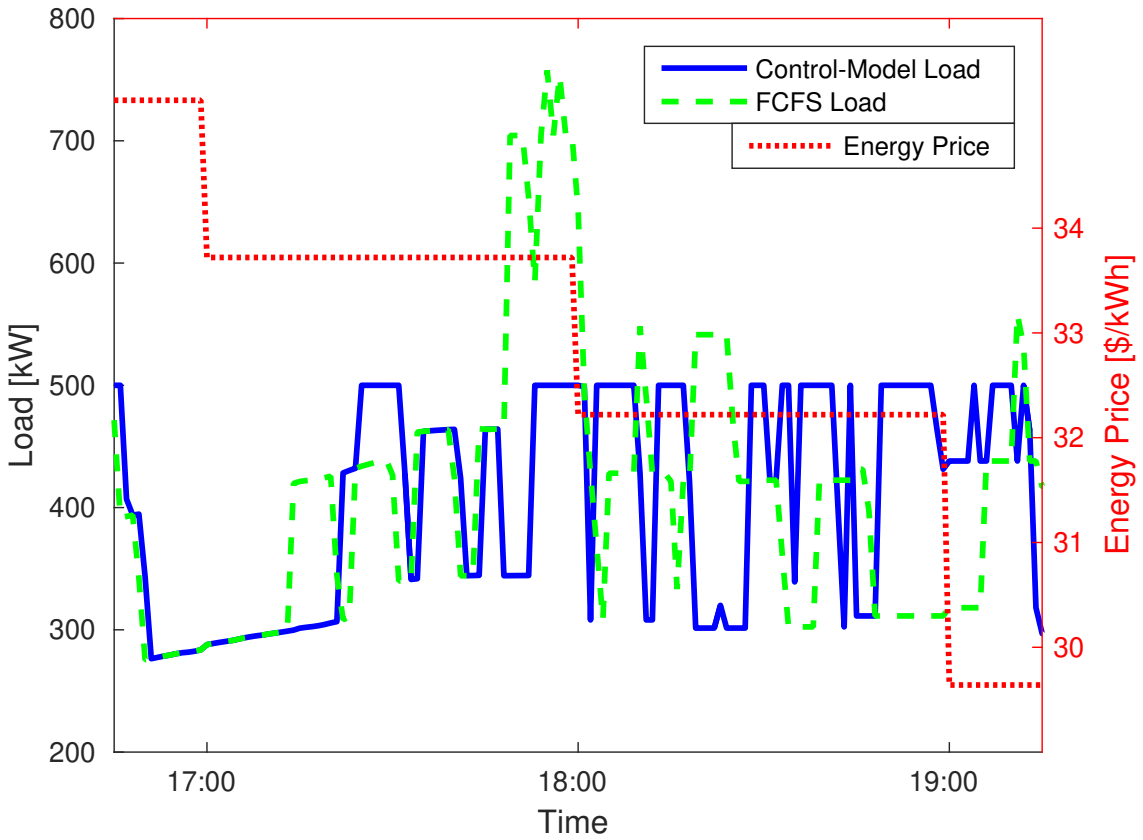


http://doi.org/10.1109/icrera.2013.6749937

- Flavor of the month: Optimizing these designs
- Possible resilience/reliability argument (*cf.* California wildfires), but wouldn't vegetation/deferred-maintenance management be cheaper?
- Economic rationale likely reflects poor retail-tariff designs

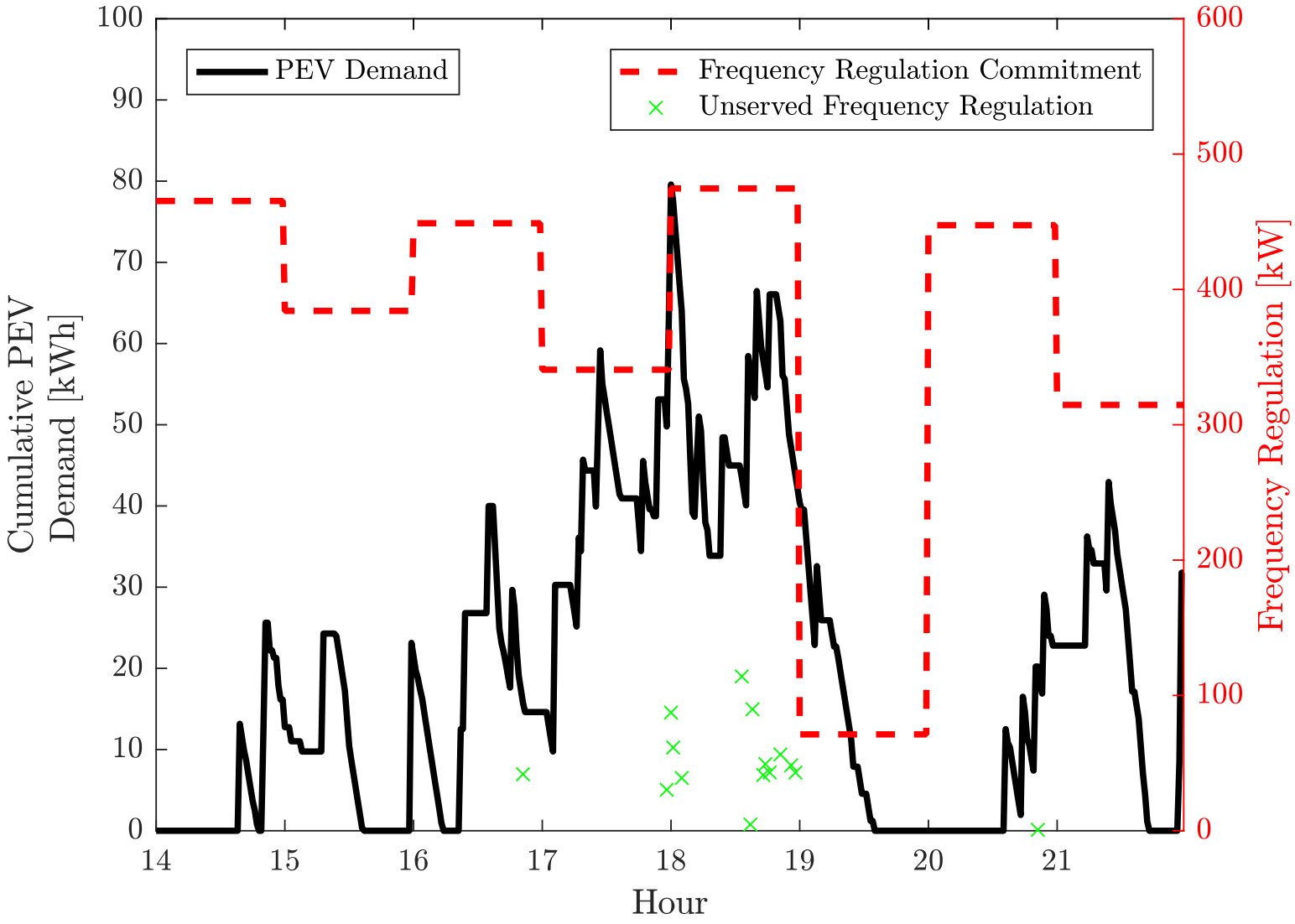
Charging Management

- Energy-cost management
- Distribution-infrastructure constraints



http://dx.doi.org/10.1016/j.trb.2017.05.002

More Sophisticated. . .



https://doi.org/10.1016/j.trd.2018.12.005

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Market and Tariff Design

All of This Untapped Potential

- Wholesale markets are non-existent or provide limited opportunities for behind-the-meter assets
- Fractured retail-competition landscape
- Significant challenges for aggregators
- No competitive distribution-level markets (*contra*: regulatory grab by some utilities)
- Inefficient tariff design (*cf*. almost every study showing good economics of distributed renewables co-located with a charging station)

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FERC Action

- Originally, Order 841 supposed to address wholesale-market participation for distributed energy resources
- In the end, FERC deferred most of this to a future order
- Recent litigation:
  - Can FERC regulate distributed energy and behind-the-meter resources or should they be state-jurisdictional?
  - This may well end up before the Supreme Court in the next few years

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Even If We Get Market Participation

- Wholesale prices signal value/cost of transmission-level services/usage only
- Retail-level rates mix fixed and variable costs (*cf*. issues with net-energy metering in California, Arizona, *etc*.)
- . . . some retail-price designs are atrociously bad (*e.g*., tiered rates in California)
- . . . some require submetering
- *De minimis* we should use time-of-use or real-time pricing tariffs (which exist in very few places)
- If based on transmission-level locational marginal prices, they provide signals for when and where in the transmission network vehicles should be charged
- Even with that. . . distribution-level costs (*e.g*., power factor, voltage, harmonics, and power quality) are hidden/socialized in retail rates

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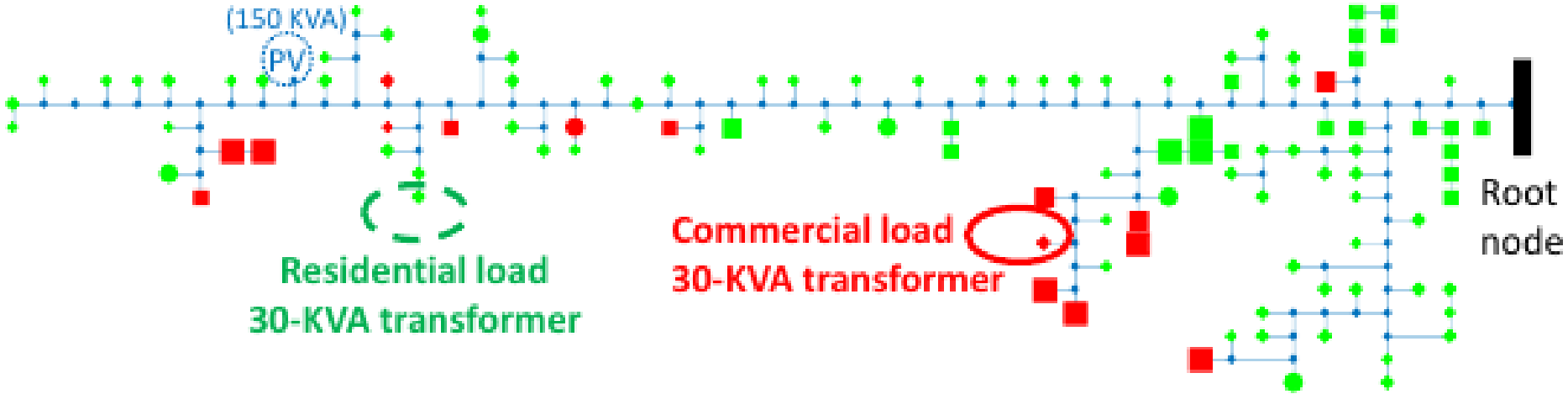
Distributed Locational Marginal Prices

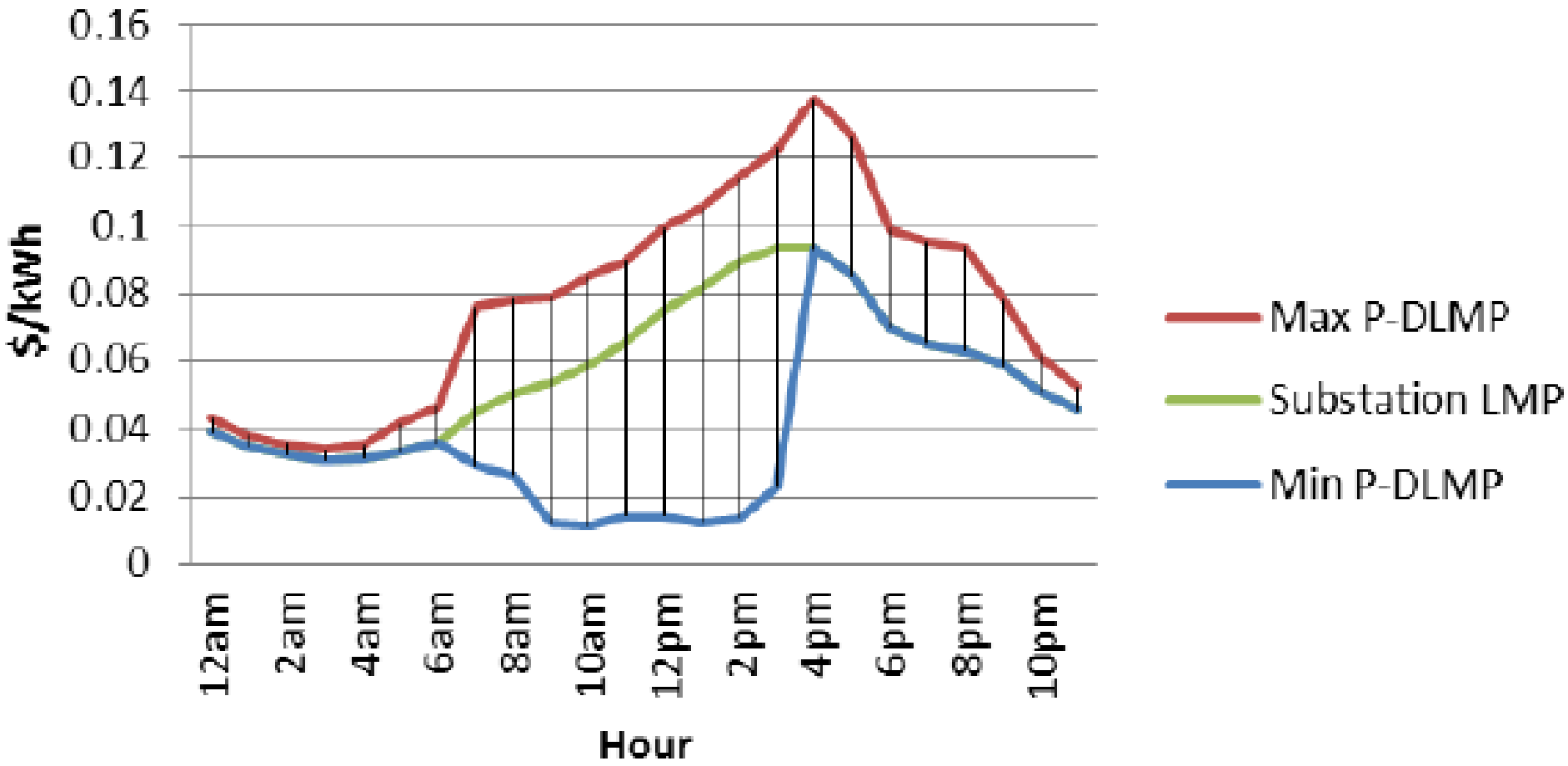
- **Basic Concept:** model real and reactive power at the distribution level
- Produce temporally and spatially granular price information for real and reactive power at the distribution level



https://arxiv.org/abs/1906.01572

Example DLMPs

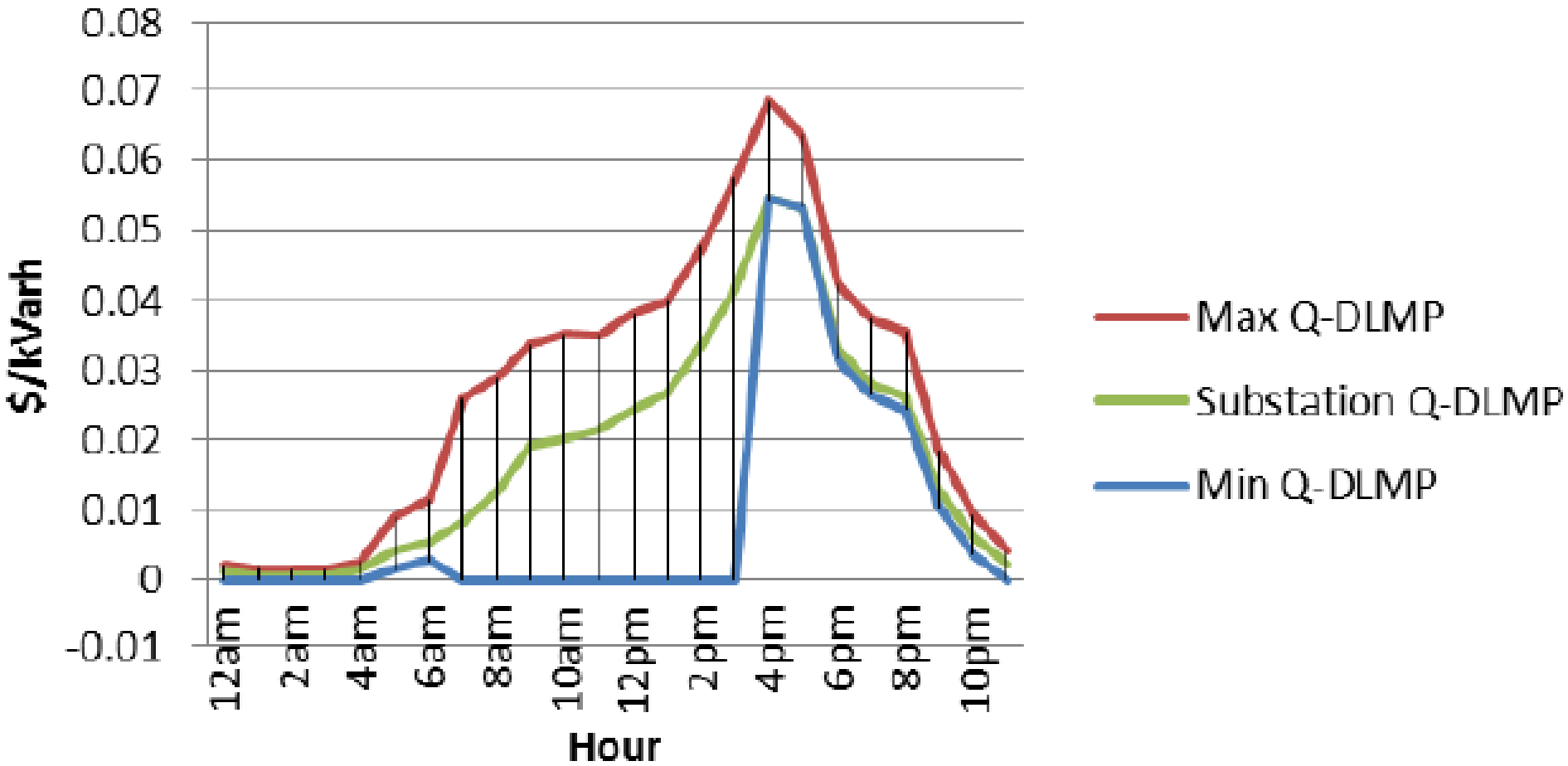
Real Power



https://www.energy.gov/sites/prod/files/2016/04/f30/DER%20Panel%20-%20Michael%20Caramanis%2C%20Boston%20University.pdf

Example DLMPs

Reactive Power



https://www.energy.gov/sites/prod/files/2016/04/f30/DER%20Panel%20-%20Michael%20Caramanis%2C%20Boston%20University.pdf

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What Does DLMP Allow?

- Prices that signal when and where in the distribution network vehicles should be charged
  - More specifically, prices reflect scarcity of transmission and distribution capacity
  - Stronger signals for *all* consumption and production, not only vehicle-related
- Financial incentives for inverters that can provide distribution-level support (*e.g.*, power factor, voltage, and harmonics), which are not free
- Outperforms heuristics (*e.g.*, staggered starts or delaying until middle of the night)

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Some Implementation Details

- DLMP is computationally expensive (*i.e.*, a much more complicated network model is needed)
- Distributed algorithms (*e.g.*, asynchronous ADMM) are shown to be computationally tractable
- Would need to adopt a DSO regulatory construct or have well regulated T&D utilities serve this role
- More temporally and spatially granular pricing means new sources of risk for consumers and producers, requiring hedging instruments (*e.g.*, DFTRs)

Summarizing

Where To Go From Here?

- Liquid-fuel pricing needs to be improved, as conventional vehicles are the entrenched incumbent that electric vehicles compete against
- Economics and 'chicken-and-egg' problem of charging infrastructure need to be addressed
- Charging-management algorithms need to be demonstrated using computational platforms that can be deployed at-scale
- Market designs need to address participation of behind-the-meter resources
- Retail tariff design needs to signal/value what electric vehicles are capable of (DLMP is a good long-term aspirational goal, but there is other 'low-hanging fruit' to pursue first)

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Thank you!

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