Electrification

Opportunities for multiple win wins?!

PRESENTED TO

Rhode Island Power Sector Transformation Technical Meeting

PRESENTED BY

Jurgen Weiss

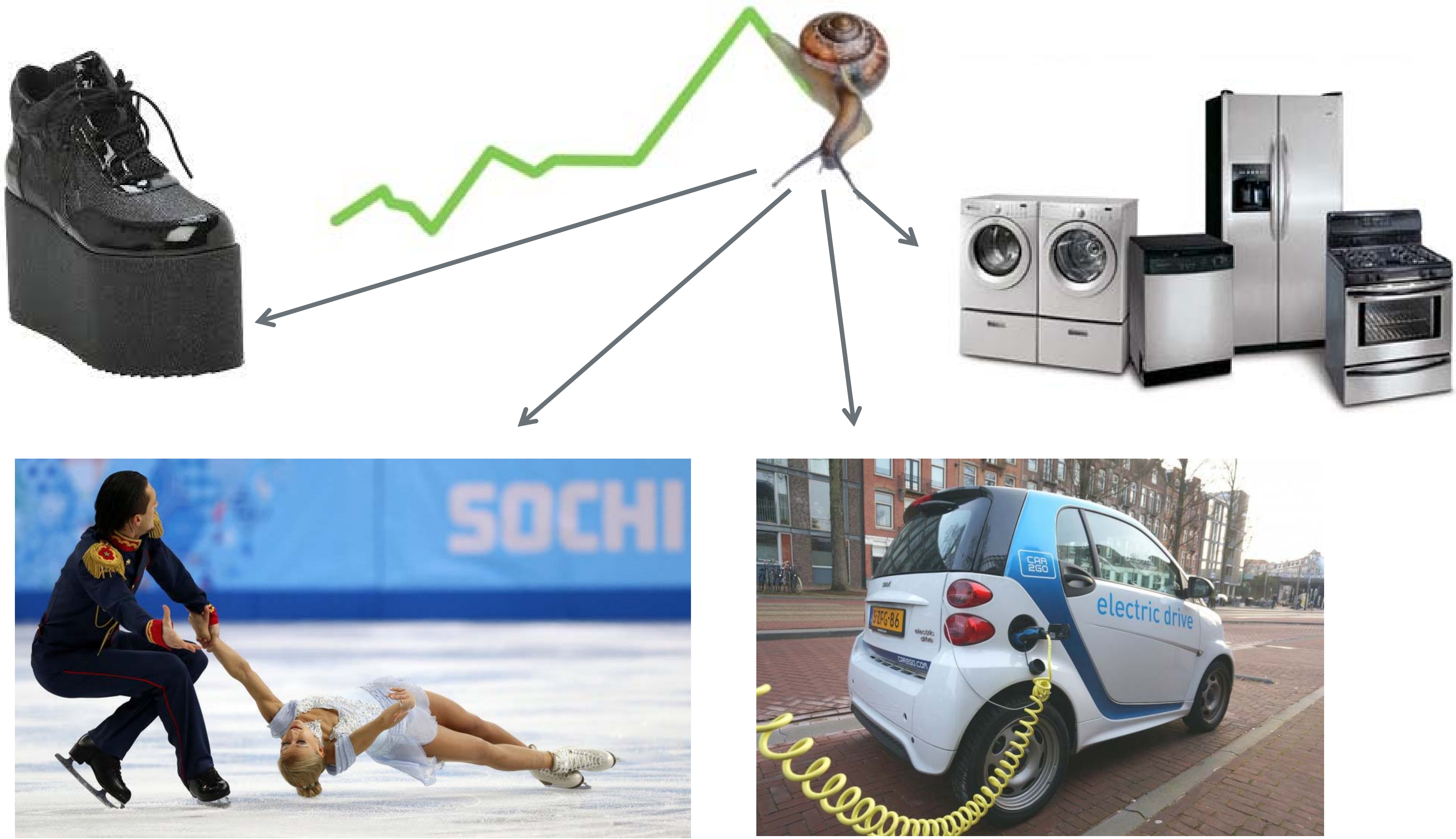
May 31, 2017

THE Brattle GROUP

Disclaimer

The views and opinions expressed in this presentation are strictly those of the Author and do not necessarily represent the views or opinions of Brattle or any of its other employees.

Quo Vadis Utility



The bottom line (in case I run out of time)

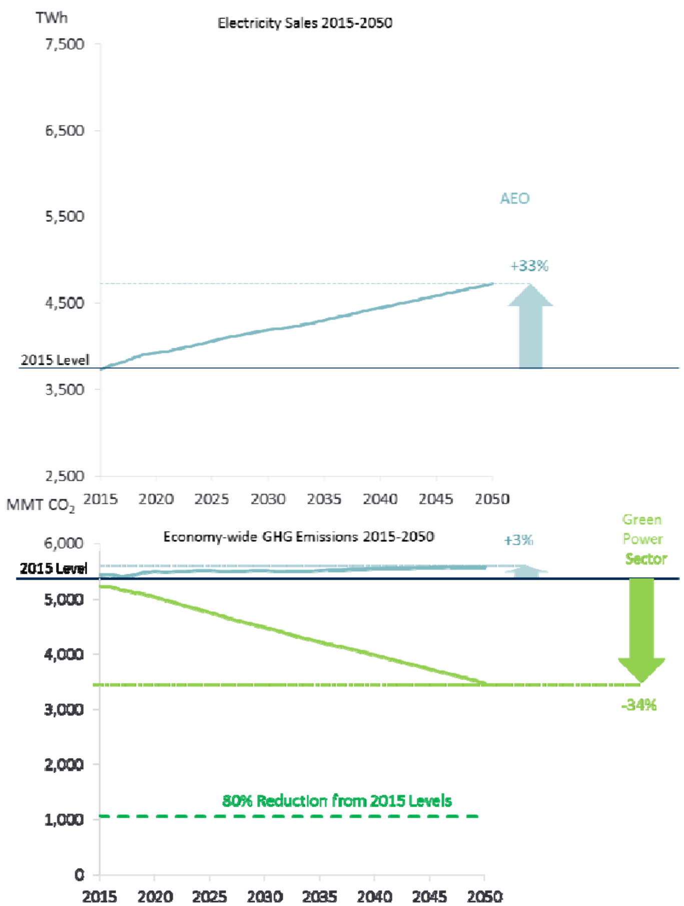
- **A less energy intensive economy, DER and EE are likely here to stay**
  - Absent a fundamental shift, the old utility business model is under threat
- **The death spiral seems pretty unlikely, but milder versions are possible**
  - Being able to invest in the infrastructure needed for more active consumers may be harder if the investment is spread over fewer kWhs
- **Many ideas for "new business models"**
  - Utilities as platform businesses – but what is the "killer app"?
  - Expansion into areas that are at least candidates for competition – ATT Redux?
- **Electrification is a topic whose time may have come**
  - Could lead to win/win: good for utilities, good for the environment
  - Important questions less about if, more about who/when/how
  - ***Acting early is likely important since many investments are in long-lived assets, regulatory changes are needed and slow, and absent fast-acting utilities the path of the transition could be very different***

Without electrification sales growth and economy-wide decarbonization will likely be slow

Without Electrification

U.S. Electricity Sales

Economy-Wide GHG Emissions



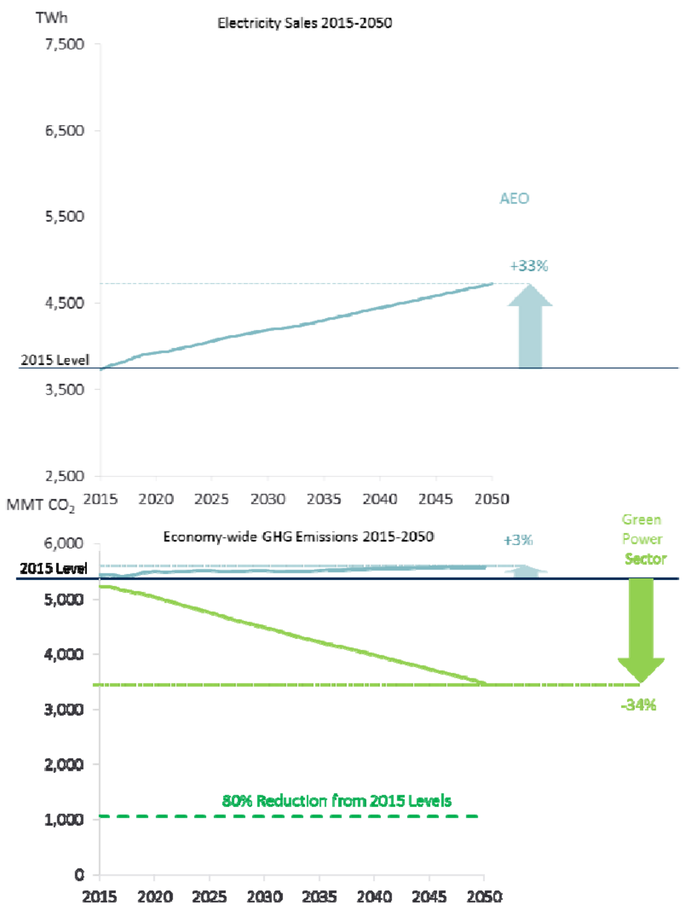
- Less than 1% annual utility sales growth through 2050
- Total sales would grow by a third by 2050 before considering impact of rooftop PV and other DER
- BAU emissions (economy wide) actually increase slightly
- Even a fully decarbonized electricity sector leads only to a 34% decline in GHG emissions
  - Very significant gap to 80% economy-wide GHG reduction goals (ultimate Paris target)

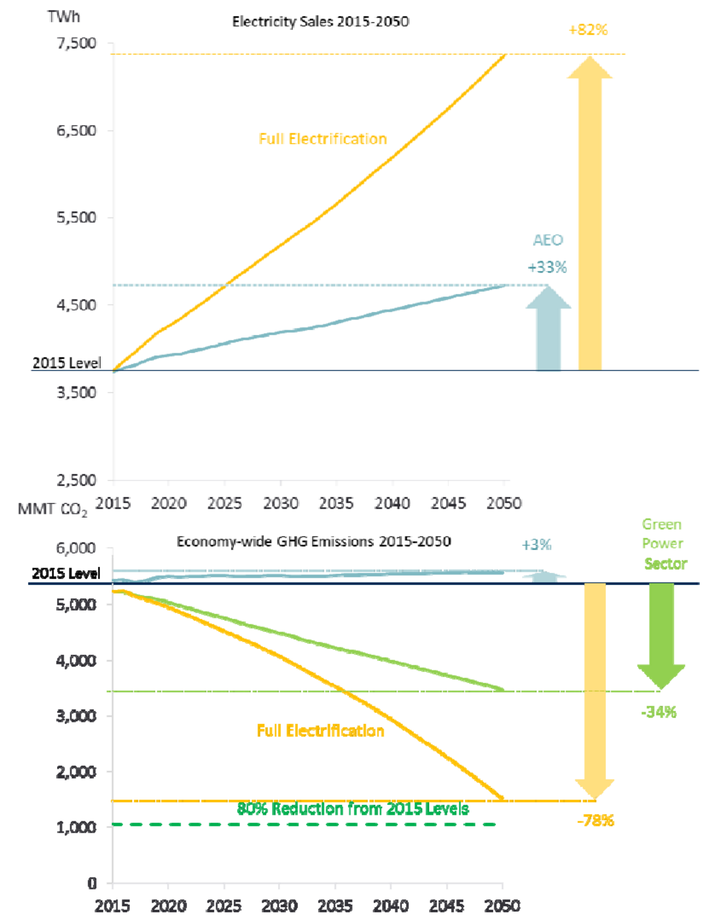
Electrification of transport and heating has the *potential* to significantly change the story

Without Electrification | **With Electrification (Technical Potential)**

U.S. Electricity Sales

Economy-Wide GHG Emissions

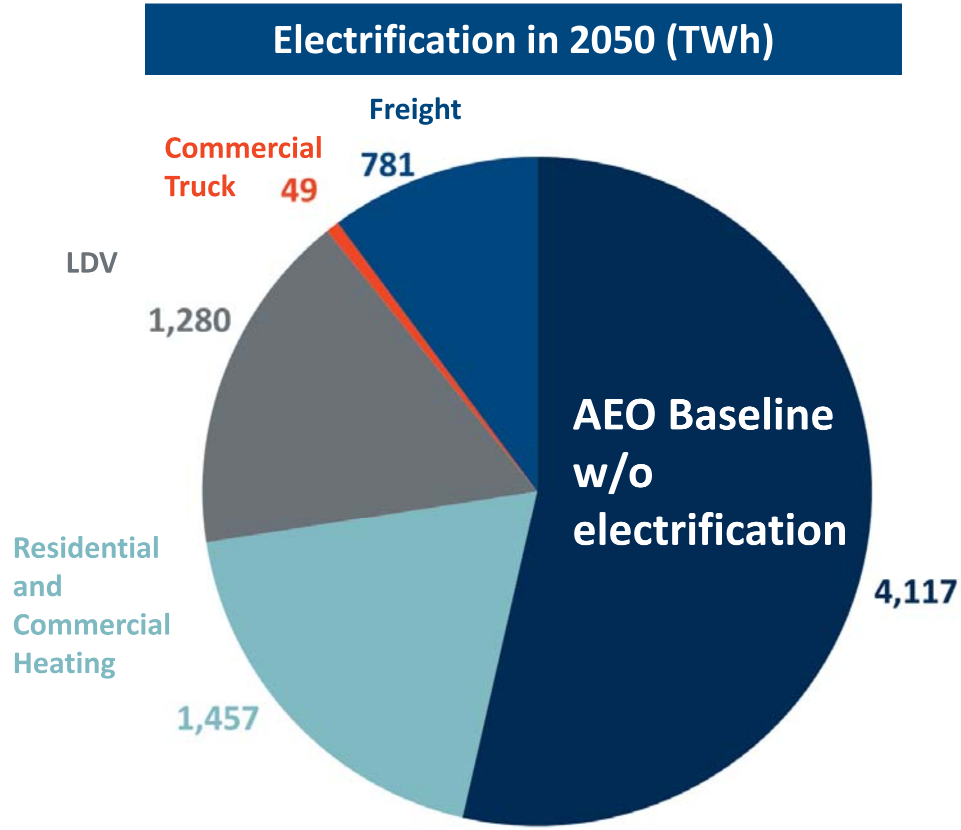




Several sectors could create significant additional demand

Total electrification could result in approximately 3,600 TWh more than the Baseline case

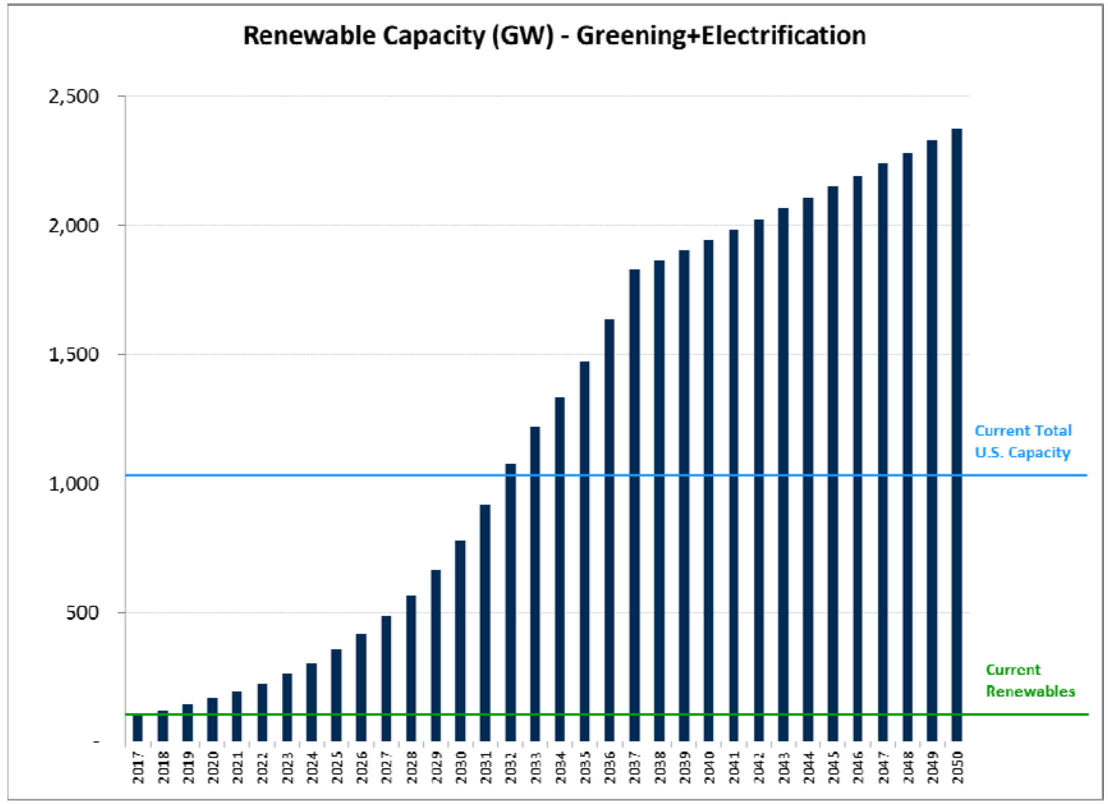
- 22% from Freight
- 36% from Light-duty vehicles
- 41% from residential and commercial heating



The rest of this presentation mostly focuses on LDVs since they represent the largest share of transport electrification potential and are subject to the most potential disruption.

Even moderate electrification means building significant new (clean) resources

- In 2016, US installed 23 GW of Renewable Capacity
- 20% electrification of transport would require over 100 GW of new wind and solar capacity
  - About equal to existing wind and solar capacity (126 GW as of 2016)
  - 4+ years at 2016 pace
- 100% electrification of everything would require over 1,200 GW of **incremental** renewable capacity
  - 50+ years at 2016 pace



- **In addition to "greening" the existing grid**
- **Likely means that a continued and scaled-up effort would be needed (~75-100 GW p.a.)**

When thinking about LDVs, most assume the 1960s transportation paradigm will continue…

Prevailing Electrification Paradigm

200 million homes

↓ Individual car ownership

300 million cars

↓ Daily commutes to/from work

12,500 VMT per car

↓

Slowly replaced by EVs, charged mostly at home, a bit at work (L1 or L2)

- **Home-focused charging pyramid**
- **Mostly overnight charging**
- **Beneficial charging**
- **Moderate incremental kWh**
- **Slow change**

...which ignores potentially important dynamics

Prevailing Electrification Paradigm

200 million homes

↓ Individual car ownership

300 million cars

↓ Daily commutes to/from work

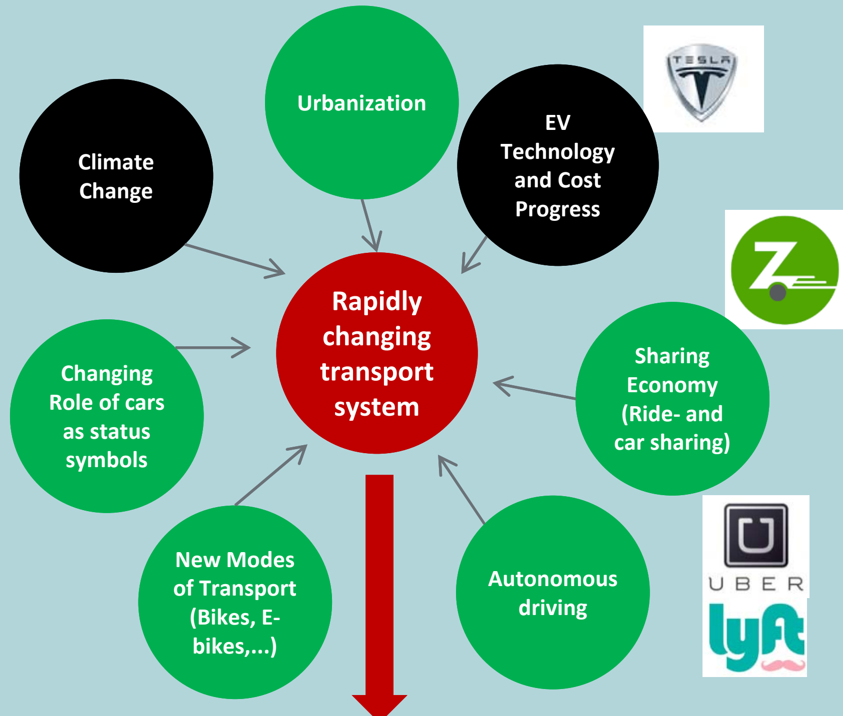
12,500 VMT per car

↓

Slowly replaced by EVs, charged mostly at home, a bit at work (L1 or L2)

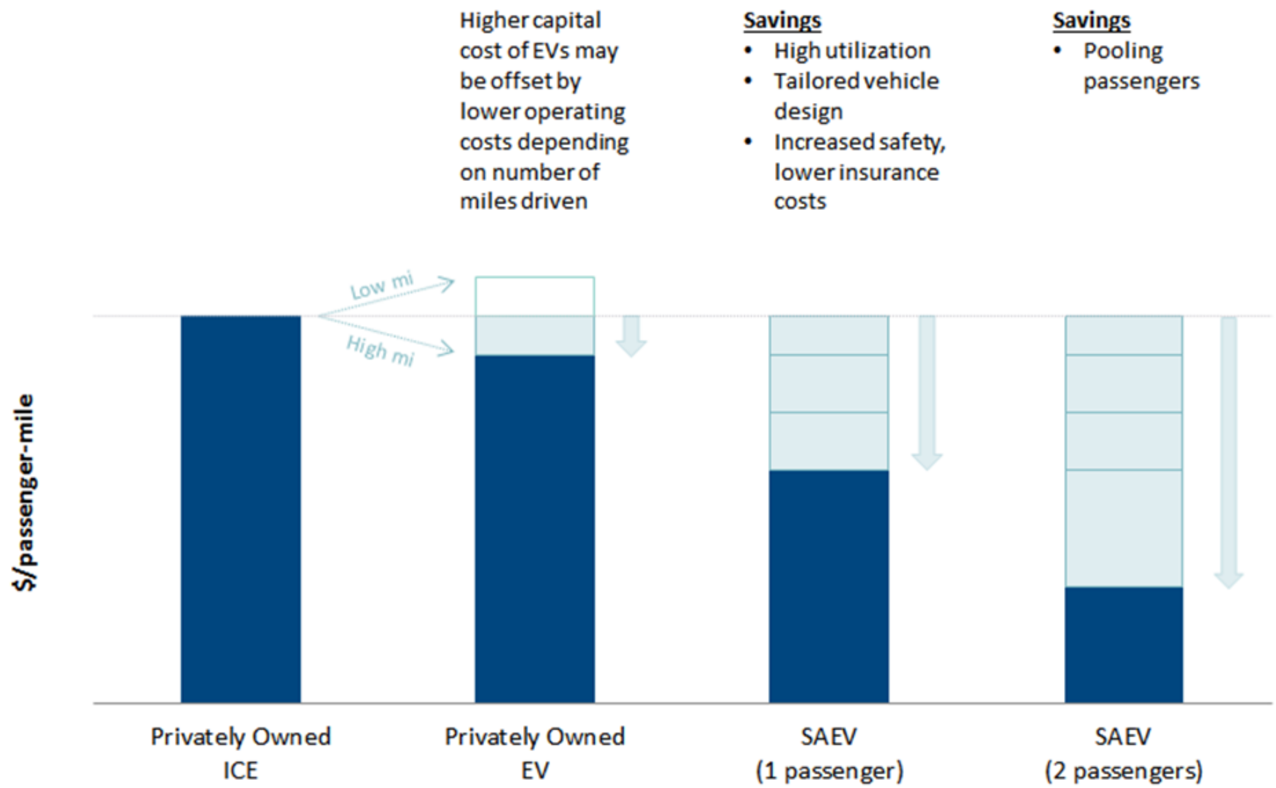
- Home-focused charging pyramid
- Mostly overnight charging
- Beneficial charging
- Moderate incremental kWh
- Slow change

Potential New Transportation Paradigm



- A smaller number of (highly utilized) vehicles meet a significant portion of transport demand
- Different charging needs with impact on grid and charging infrastructure
- Move from individual to fleet ownership may make electrification the logical choice

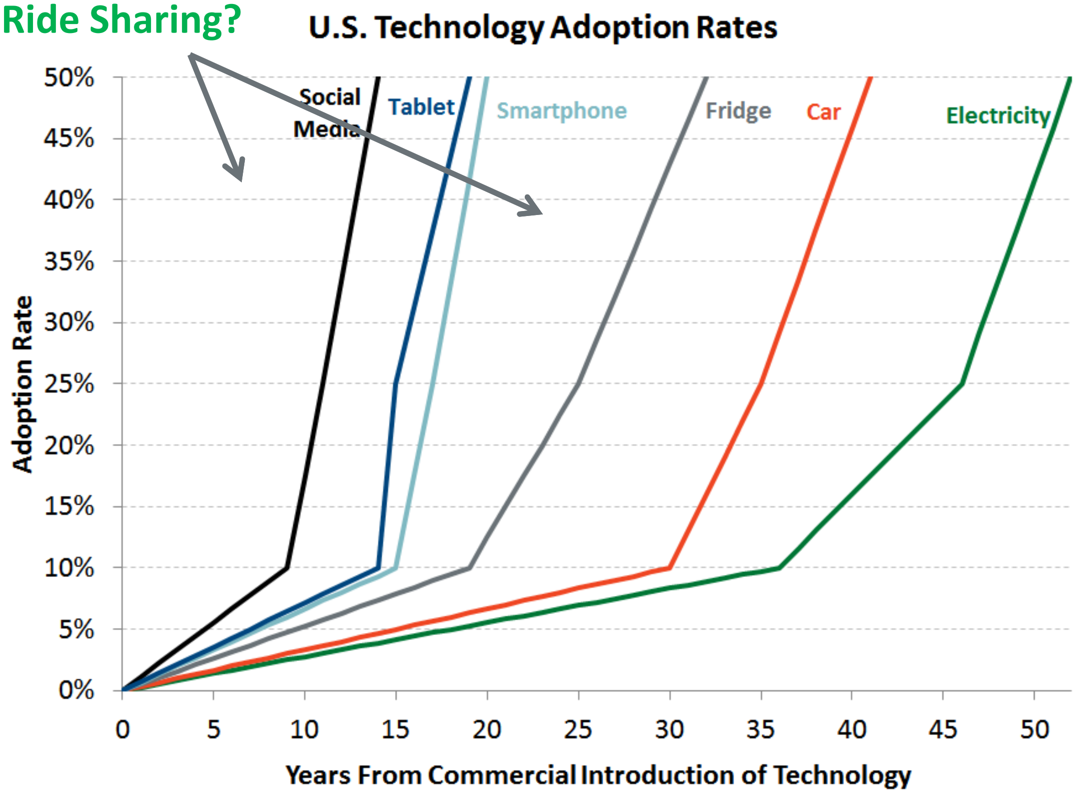
Individual economics of electrified transport improve with autonomy and even more with sharing



Important to understand why "sharing" (multiple riders in a same car) will occur more in the future than in the past

Due in part to digitalization, the transformation could happen very quickly and unexpectedly

Ride Hailing/ Ride Sharing?



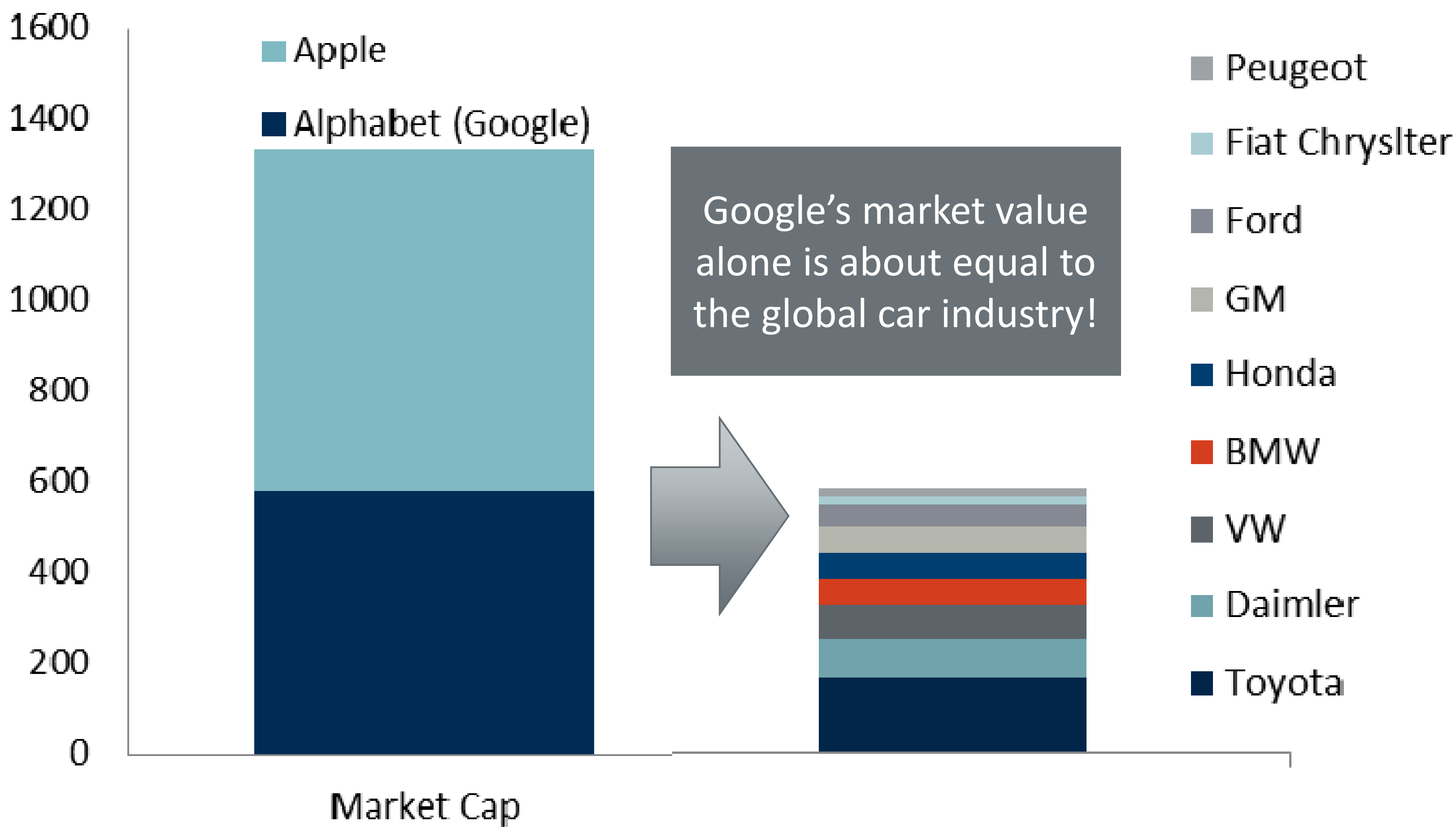
Sources: https://www.linkedin.com/pulse/part-2-megaproject-paradox-what-chances-barrel-oil-being-john-noonan and Brattle analysis

Uber was launched in 2010: In 2016, 15% of Americans have used a ride-sharing app – 29% of under 30 year-olds (Source: Pew Research Center)

PALO ALTO, Calif., Aug. 16, 2016 – **Ford** today announces its intent to have a high-volume, **fully autonomous** SAE level 4-capable vehicle in commercial operation in 2021 in a ride-hailing or ride-sharing service.

Bloomberg., Aug. 18, 2016 – **Starting later this month**, Uber will allow customers in downtown Pittsburgh to **summon self-driving cars** from their phones, crossing an important milestone that no automotive or technology company has yet achieved…Uber can use the data collected from its app, where human drivers and riders are logging roughly 100 million miles per day, to quickly improve its self-driving mapping and navigation systems.

The companies benefitting from disruption have the capital to disrupt



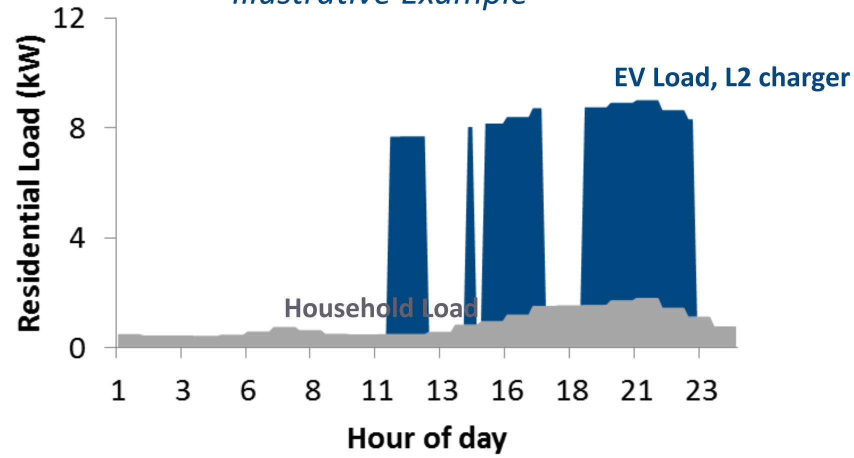
Sources: Yahoo Finance, Google Finance (March 2017)

Even "standard" (LD)EVs could have a big impact on peaks and infrastructure (hot spots)

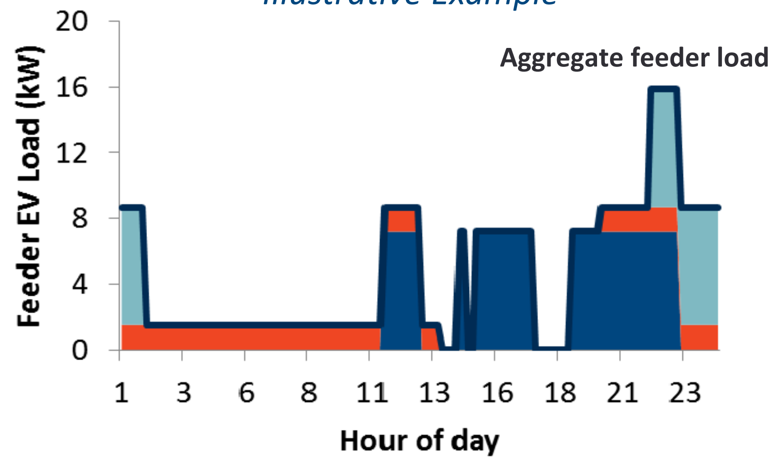
- Fast home charging would dramatically impact home load and peak, and potentially the bill (depending on rate design)

- Even a few EVs on a single feeder could significantly increase substation and transformer load with fast charging
  - Think Tesla clusters in Palo Alto

Effect of EV load on residential load profile
Illustrative Example



Effect of Adding 3 EVs to a Distribution Feeder
Illustrative Example

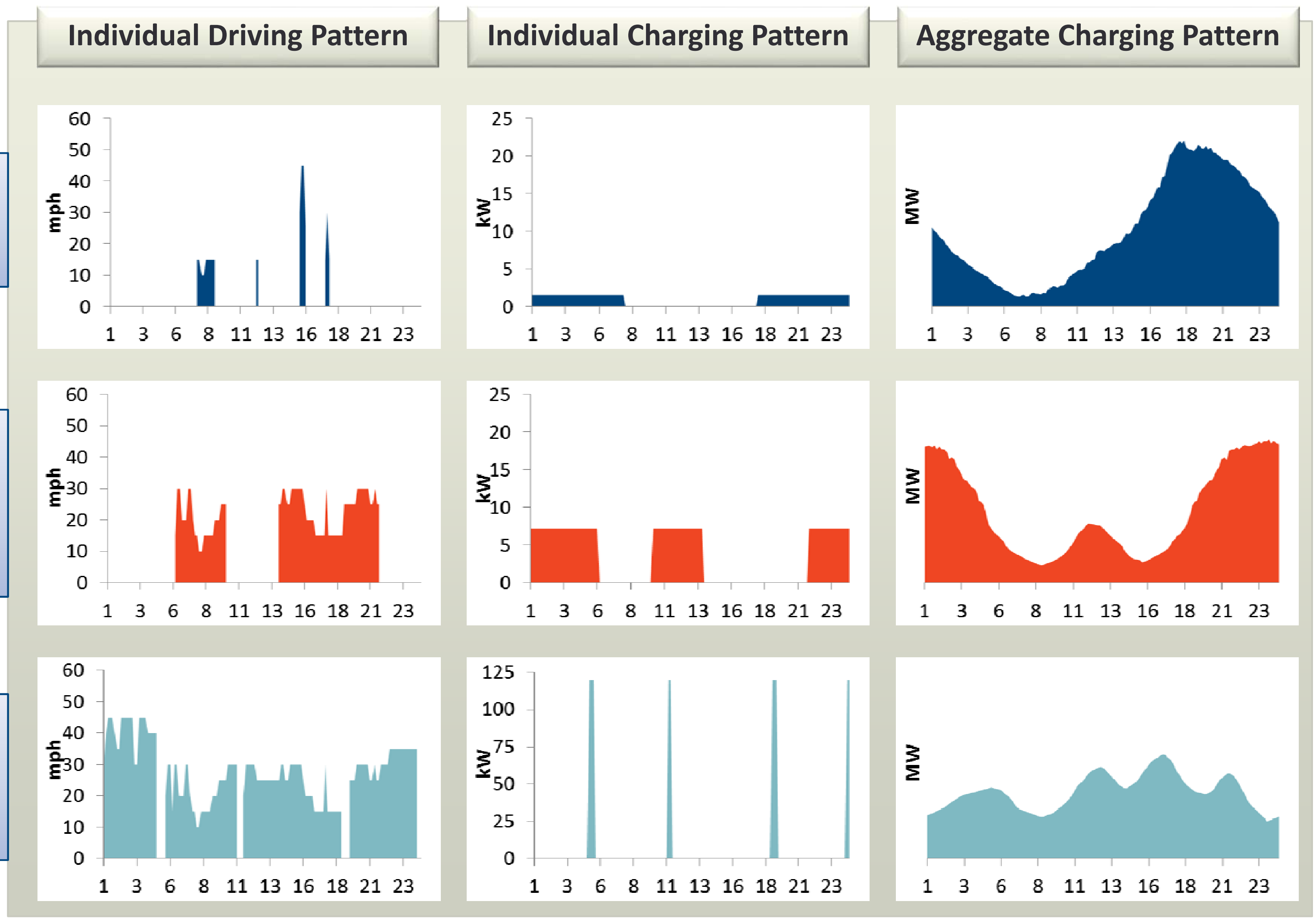


Different transportation paradigms likely mean different charging patterns with serious load shape implications

Scenario 1: Conventional Ownership

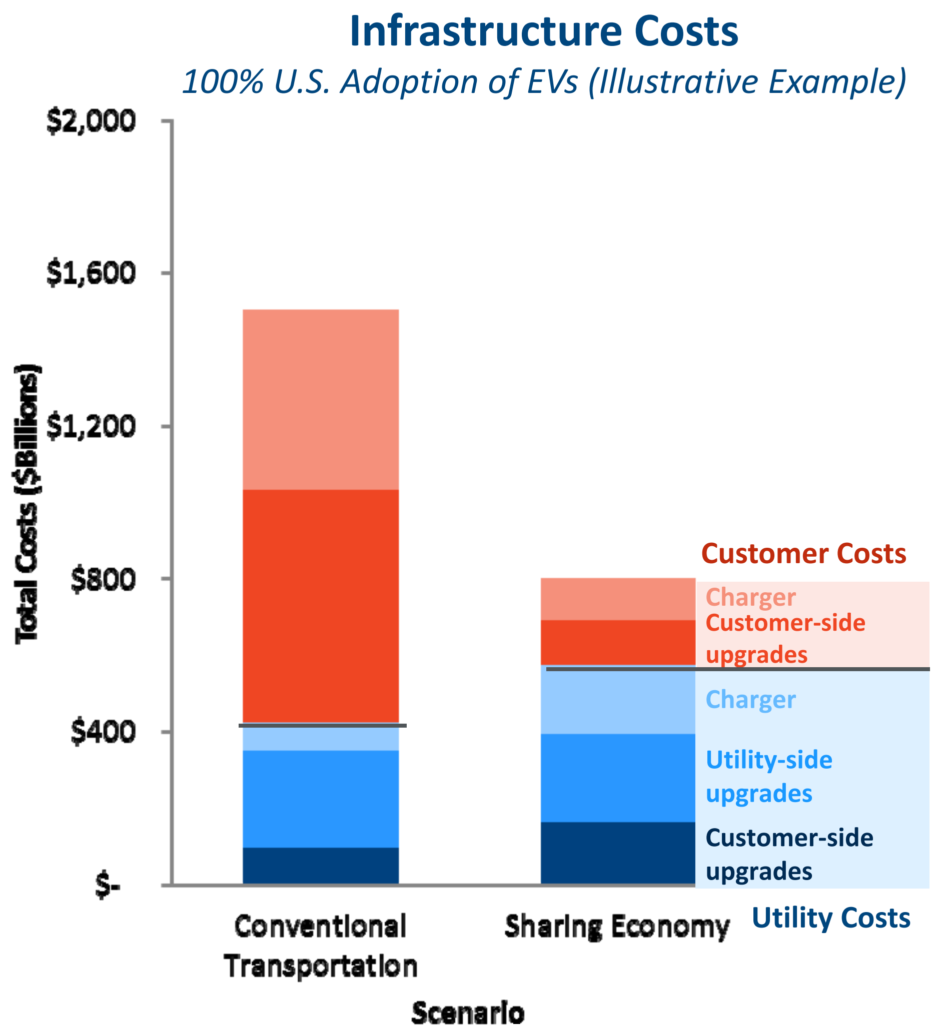
Scenario 2: Shared Ownership, Moderate Utilization, Centralized Charging

Scenario 3: Shared Ownership, High Utilization, Distributed Fast Charging



Infrastructure investment due to EVs could be large, but the utilities' share will depend in part on the transport "model"

- EVs require several types of significant investments
  - **Chargers**
  - **Customer-side upgrades:** panel, conduit, trenching
  - **Utility-side upgrades:** meter, transformers, substations, grid reinforcement
- The opportunity for utilities varies by scenario
  - Smaller role for utility in "standard" paradigm of home and work-place charging
  - Total investment under "urban SAEV" paradigm potentially smaller, but larger role for utilities

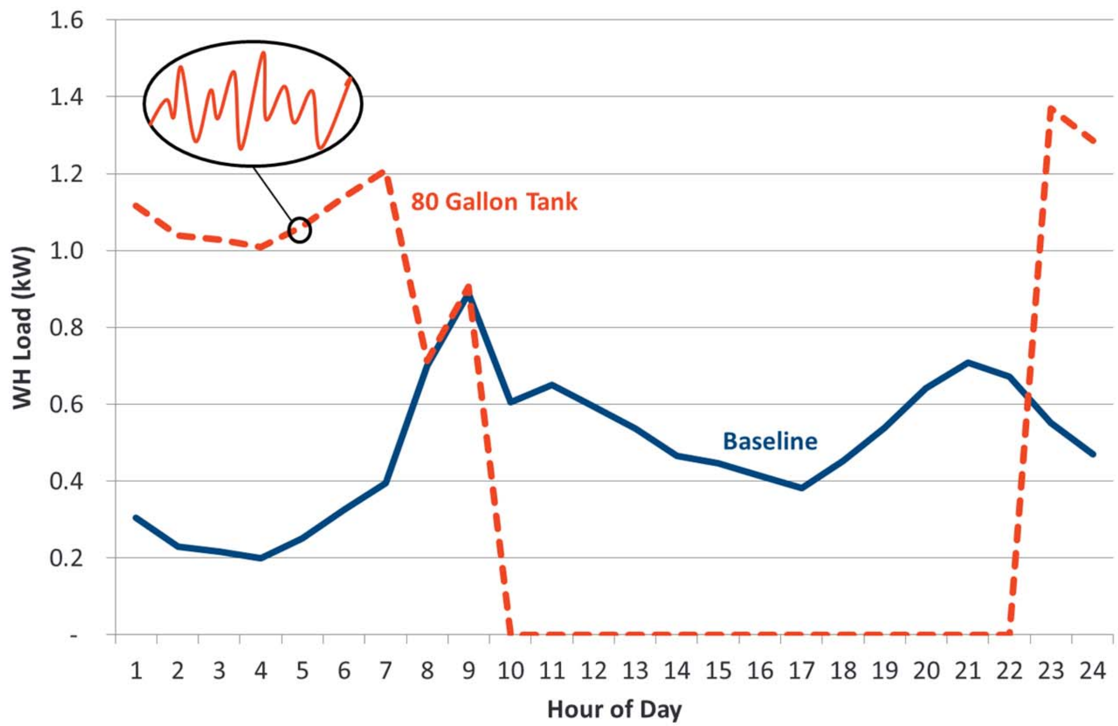


Thinking about LDVs is important, but important to think about other areas as well

- **LDVs represent single largest electrification opportunity**
  - But as just shown where LDVs go is very unclear
  - Also, EV purchasing and personal transport are complex choices driven by many factors other than economics
- **But fleets may represent a more near-term opportunity**
  - Personal LDVs may transition to fleets anyway (Uber, Zipcar) – see above
  - Fleet owners likely focus more on economics than other purchasing factors
    - The economic advantage of Evs with high utilization matter more
  - Fleets tend to be more local (school buses, municipal fleets, taxis, utility trucks, mass transit buses, ambulances, local delivery trucks, etc.)
    - Do not depend on long-distance charging infrastructure/range anxiety solution
  - Fleets may also more logical take-off points for AVs
    - Fleets of autonomous farm equipment, autonomous factory fork lifts, etc.
  - Fleets may also have more predictable/controllable charging and driving patterns
    - May be able to provide system services more readily

Electrification could also provide significant operational benefits: Example Water Heaters

Load profile of Grid-Integrated Water Heater



Source: Ryan Hledik, Judy Chang, and Roger Lueken, "The Hidden Battery: Opportunities in Electric Water Heating," prepared by The Brattle Group for NRECA, NRDC, and PLMA, January 2016.

An electric water heater providing load shifting and grid balancing services could provide up to $200/year in net benefits

Electrified appliances and vehicles could contribute significantly to RE Integration

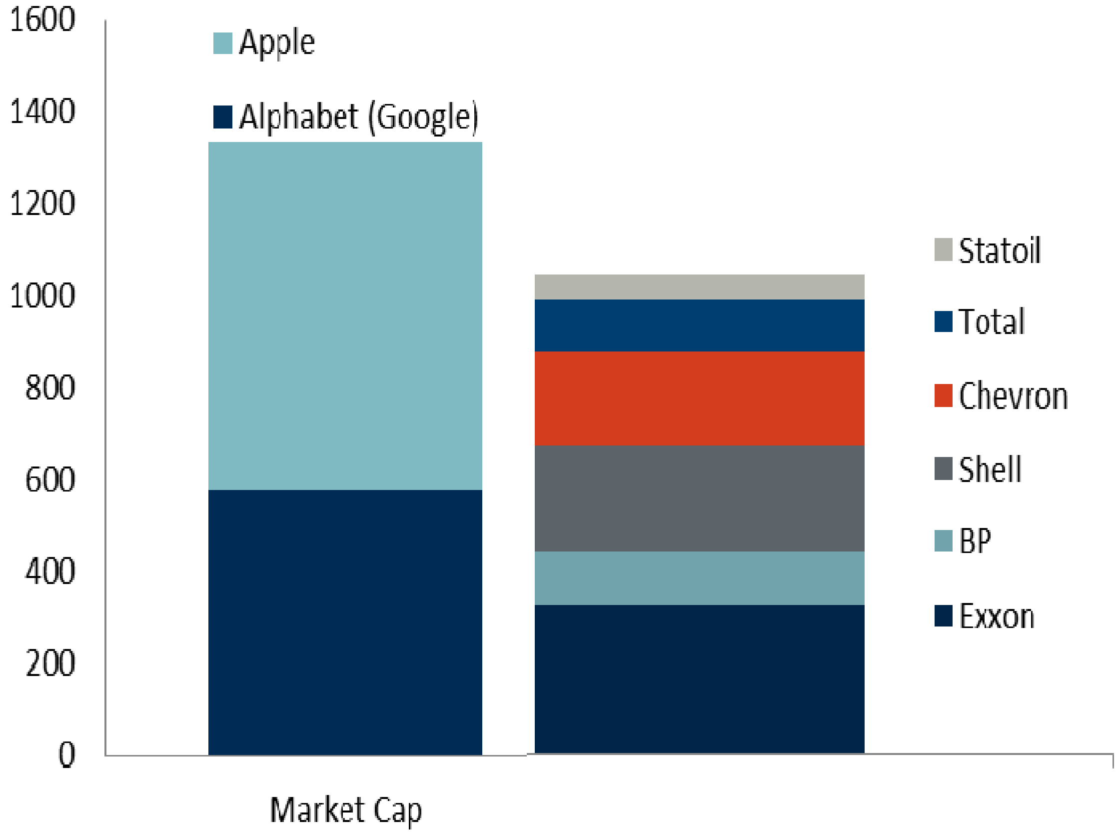
- 2016 PJM Total Frequency regulation market: 600MW
  - Can be provided by about 300,000 controllable electric water heaters
  - Roughly 2% penetration of such water heaters would be able to provide all frequency regulation for US power system
  - Even if frequency regulation increases due to RE, ample flexibility from such resources technially available.
- Assume average LDV battery size is 60kWh (current new models)
  - 1 million EVs (0.3% penetration) would represent 60 GWh of storage
  - Equivalent to 5-10 GW of Pumped Storage capacity
  - [keep going and improve]

Electrified appliances and vehicles could contribute significantly to RE Integration

- 2016 PJM Total Frequency regulation market: 600MW
  - Could be provided by about 300,000 controllable electric water heaters
  - Rough estimation: 2% penetration of such water heaters would be able to provide all frequency regulation for US power system
  - Even if frequency regulation increases due to RE, ample flexibility from such resources technially available.
- Assume average LDV battery size is 60kWh (new EV models)
  - 1 million EVs (~0.3% penetration) would represent 60 GWh of storage
  - Equivalent to 5-10 GW of Pumped Storage capacity (1-2 storage assumed)
- **Conclusion: Technical Potential** for storage and flexibility from electrified sectors is enormous – but how much can realistically be used is an important question to study

If you don't others likely will.

If electrification is an opportunity for utilities, it is a threat to oil and gas companies (and car manufacturers). They will fight for alternatives.



Sources: Yahoo Finance, Google Finance

Presenter Information

JURGEN WEISS
Principal | Boston/Rome
Jurgen.Weiss@brattle.com
+1.617.864.7900

Dr. Jurgen Weiss is an energy economist with 20 years of consulting experiences. He specializes in issues broadly motivated by climate change concerns, such as renewable energy, energy efficiency, energy storage, the interaction between electricity, gas and transportation, and carbon market design and the impact these changes have on existing assets, market structures, and long-term planning needs for electric utilities in North America, Europe, and the Middle East.

Dr. Weiss holds a B.A. from the European Partnership of Business Schools, an M.B.A. from Columbia University, and a Ph.D. in Business Economics from Harvard University.

Appendix

Understanding the potential and implications of electrification is an important first step

- Understand your own potential for electrification in various areas
  - LDVs
  - Other transport (fleets, agricultural equipment, public transit, school buses, HDVs, utility trucks, UPS, FedEx, etc.)
  - Electric water and space heating
- Stress-test the “standard” electrification paradigm (slow, based on current transportation patterns)
- Develop an understanding of the implications of alternative electrification pathways
  - Peak Load and total load impacts
  - Differences in infrastructure needs (nature and speed)
- Develop a strategic position
  - What is most desirable for you, your customers?
  - More electrification = more sales and perhaps more RAB

Electrification requires changes to the regulatory treatment of investments

- Electrification will increase electricity bills (through higher volume)
  - PUCs tend not to like utilities doing things tha increase customer bills
  - Need to convince PUCs and Legislators to expand the scope of what is possible (energy rather than electricity+gas "wallet")
- Early infrastructure investments also risk not having near term benefits in excess of costs and near term benefits can accrue to "the wrong" customers
  - Chicken and egg and cross-subsidy issues
- Electrification has benefits for society (GHG, less local air pollution from transport, less congestion, accidents, etc.), but those benefits are not typically part of regulatory tests
- "Standard electrification" often benefits the privileged
  - Need to develop programs with broader benefits
- Utilities need to develop solid arguments (and proposals) to allow regulators to approve investments in electrification.

Rate (re) design should keep in mind the incentive effects on EV adoption

- There is a huge debate about the future design of rates
  - Volumetric to multi-part rates
  - Role of demand charges, TOU rates etc.
- Changes of rate structures should consider the impact on electrification incentives, both positive and negative
  - Examples of “free charging” during certain hours to make EVs more attractive
  - A poorly designed demand charge could create very significant risk for fast charging by individual vehicles, even though fleet level charging may be relatively smooth (see SAEV slides above)
- Find the right balance between designing retail rates that are cost-reflective and also don’t create disincentives for electrification
  - Predictability may be particularly important in the early phase

"Smart" pilots may help overcome regulatory reluctance

- Many utilities propose investments in "pilot" infrastructure that is very close to what is/could be provided by the market
  - Rebates for L1 charging equipment
  - Deploying L1/L2 charging infrastructure
  - EV rebates
- Case for utility involvement is relatively weak (Amazon/Home Depot can provide chargers)
- Often benefits wealthier customers (the Tesla owners) at the expense of lower income groups – there are pilots that benefit broader groups
  - School bus fleets
  - Agricultural communities
  - Public transit
- Consider partnerships with other infrastructure providers (cities, etc.) to develop pilots with broader and immediate benefits
  - In cities, dedicated electric (autonomous) shuttle bus lanes through underserved corridors (using road-embedded induction chargers)
  - Electrified school bus fleets or electrified farm equipment for coops

Key Take Aways

- Electrification in general represents a new source of sales and could potentially be significant in terms of both sales and asset deployment
  - Transportation electrification is a completely new source of potential revenues, while heating may be at least partially displacing other utility sales/assets
- Transportation innovation largely unrelated to EVs or climate change is currently very active and fast paced, making a very different transportation system (at least in urban areas) at least possible – and quickly so.
- While the link between the new transportation paradigm and electrification is not automatic, it seems very plausible
- Rapid changes in the transportation sector could lead to more near term opportunities (sales, assets) and challenges (peak, T&D capacity)
- Better understanding the implications of altnerative future paths for the utility, its assets and its sales, seems critical for planning, strategic and regulatory reasons.

In dense/urban areas, there is potential for utility-city infrastructure partnerships

- SAEV model much more attractive in densely populated/urban areas
  - Bulk of ride and car sharing occurs there today
  - Possible to forego individual car ownership without significant loss of mobility convenience and with significant cost savings
- Technological constraints of urban SAEV fleets are rapidly being removed
- SAEVs likely will have much higher capacity factors
  - Idle time = opportunity cost and hence demand for much faster (and perhaps more concentrated) charging
  - Could lead to very significant incremental loads in urban areas, requiring upgrades to T&D infrastructure
  - High voltage charging infrastructure much closer to T&D assets than consumer electronics
- Natural role for utilities – in partnership with cities
  - Examples include dedicated SAEV lanes with embedded inductive charging, super high voltage fleet charging areas, etc.

In the longer term, utility electrification initiatives will intersect with many core activities

Rate reform	• Cost-based modifications to remove barriers to electrification • Rates to account for characteristics of new technologies
Infrastructure deployment	• Charging infrastructure analysis & planning • Programs to facilitate deployment and adoption
Regulatory outreach	• Quantifying and communicating benefits and challenges • Barriers assessment & policy options to overcome barriers
Program development	• Pilot programs and demonstration projects • Financial incentive programs to promote adoption
Resource planning	• Enhanced load (shape and growth) forecasting • Analysis of technology cost trajectories & adoption rates

In urban settings, we could have significant near term growth of transportation as a service

- Fully autonomous AVs likely before/around 2020
- Most likely early use off-public roads (campuses, office parks, factories) and use by fleet operators such as Uber/Lyft etc.
- Will have profound implications for urban infrastructure and the automobile industry
- For utilities, this could mean very different charging demands
  - Fast charging more evenly distributed throughout the day
    - Could require charging (and supporting distribution grid) infrastructure clearly in the domaine of the distribution utility (not Home Depot, not Chargepoint, etc.)
      - Examples: 200kW inductive charging stations, embedded in road infrastructure or at central locations
      - Would also require significant strenghtening of existing distribution system and potentiall lots of new wires.
  - Could also mean different shifts in overall load pattern (with energy and capacity implications)

The impact of rate design on EV attractiveness depends on (desired/actual) charging patterns

Annual EV Charging Cost per Traveler

Charging Profiles \ Rate Designs	Flat rate	TOU (3:1 ratio)	TOU (10:1 ratio)	Inclining block rate	Unconstrained demand charge	Peak period demand charge
Off Peak L1	$744	$510	$289	$971	$562	$550
On Peak L1	$744	$1,059	$1,356	$971	$639	$676
Post-Commute L2	$744	$886	$1,021	$971	$976	$1,155
Off Peak L2	$744	$510	$289	$971	$882	$550
On Peak L3	$744	$1,290	$1,807	$971	$1,335	$1,656
Autonomous Fleet	$744	$824	$899	$971	$639	$675

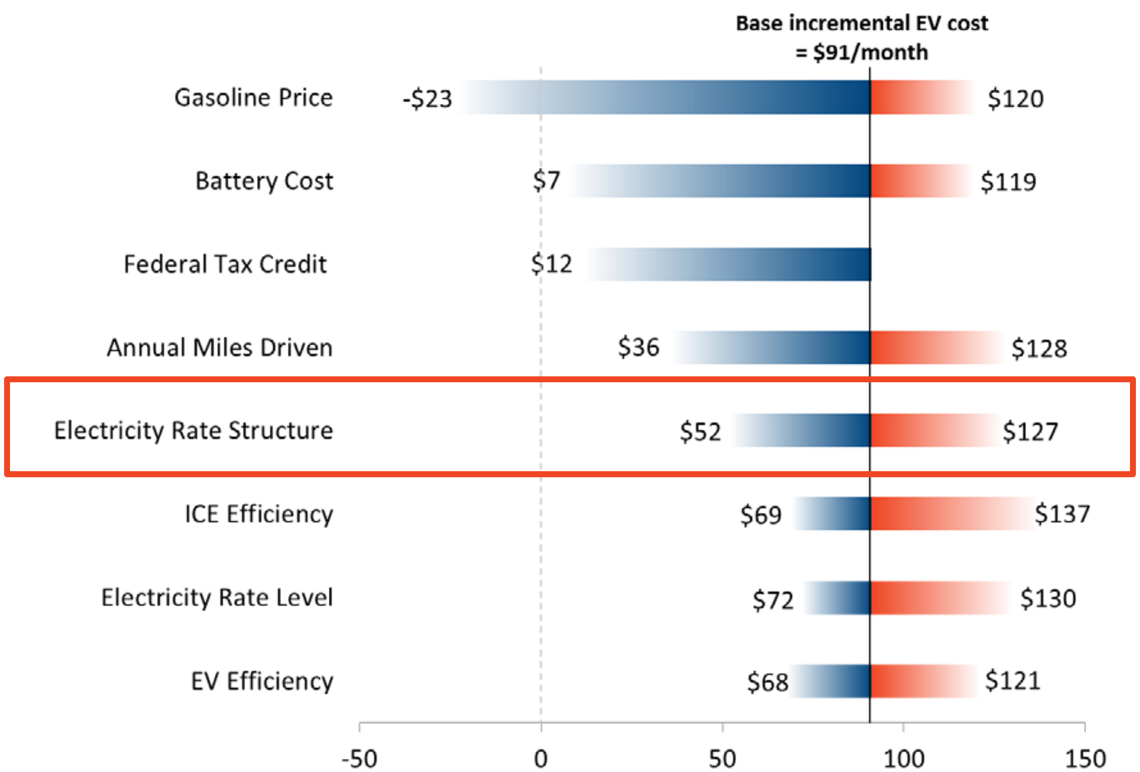
Comparable annual fuel cost of an ICE vehicle at $3/gal, 30 mpg is **$1,460**

Notes:
Rates and charging profiles are purely illustrative
Typical annual residential electricity bill is $1,140
Assumes constant vehicle miles traveled across all charging profiles
Each rate is applicable to whole home load, but figures shown are only incremental EV charging costs
Rates are revenue neutral for a class average residential customer

- TOU and demand charges incentivize off-peak charging but also introduce an element of financial risk for the EV owner
- It will be important to understand the extent to which customers are able and willing to respond to these price signals
- Technology that automates charging control will likely play a key role
- **Fleets with higher utilization likely favor frequent, fast charging and respond less to price signals because of higher opportunity cost of being idle/charging**

Rate design appears more likely to influence charging patterns than to impact EV adoption

Incremental Monthly Cost of EV Ownership Relative to ICE Vehicle (Illustrative)

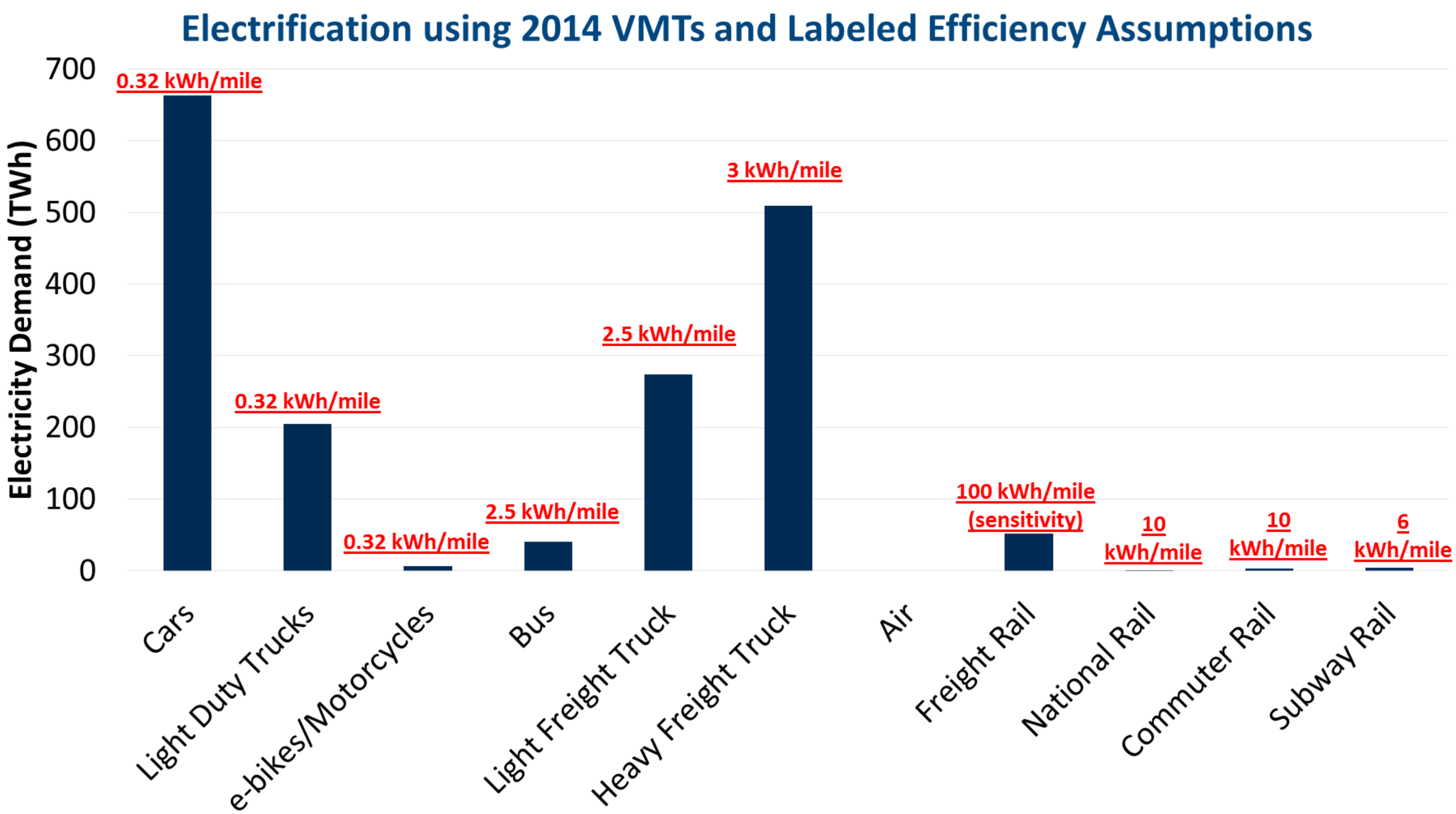


Notes:
Results are illustrative.
The "Base incremental EV costs" is a levelized value over the life of the vehicle (10 years, 150,000 miles) reflecting the higher costs of the battery and lower fuel costs.
Range shown is based on "high" and "low" assumptions for each key cost driver
See appendix for assumptions behind sensitivity analysis.

Comments

- Rate design appears to impact total EV ownership costs modestly relative to other cost drivers, though this is heavily dependent on charging patterns
- Additionally, there are significant non-economic drivers of vehicle adoption
- Thus, rate design may be a better tool for influencing the behavior of EV owners rather than being a primary consideration in the vehicle purchase decision
- Caveat: SAEV adoption could be hampered by some rate designs

Transport electrification alone could lead to significant additional sales for utilities

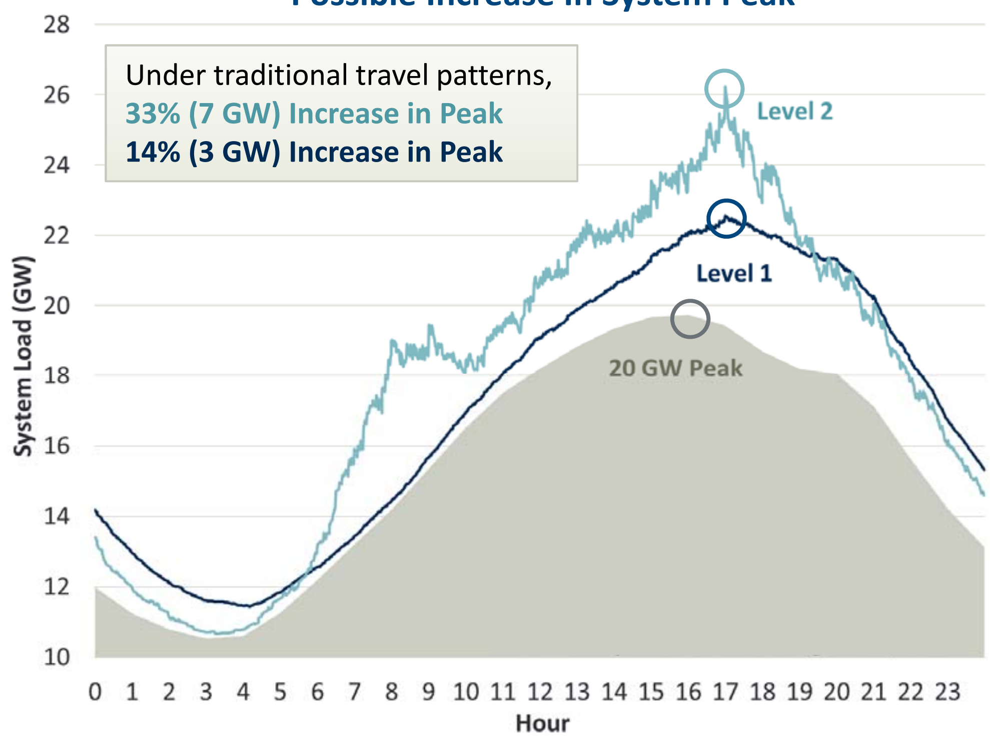


U.S wide Technical potential of 1,750 TWh based on 2014 VMT (compared to 3,764 TWh of electric sales in 2014 – assumes just swapping ICE cars and EVs

Widespread EV adoption could potentially worsen system peak issues rather than "fill in the valleys"

- A common assumption is that nighttime charging will improve system load factors
- But commuting data from large Midwestern city suggests full transport electrification could increase peak load by 3-7 GW
  - **Level 1:** Assumes charging occurs when customers return home from work, when system loads are still high
  - **Level 2:** Assumes charging occurs both when customers arrive at work and return home from work
- Even under current transport paradigm, the effect on system load depends on aggregate charging patterns and EV adoption rates
- Could be influenced by utilities through by rate design/incentives

Possible Increase In System Peak



Increase In Peak Demand Across EV Penetration Levels (MW)

	5%	10%	25%	50%	Max
Level 1, At Home	147	294	734	1,647	2,820 (80% electrified)
Level 2, At Home and At Work	230	461	1,540	3,391	6,498 (92% electrified)

Simulates the electrification of 100% of 2009 VMT for light duty vehicles, , excluding those vehicles with very long trips that cannot be served with electric vehicles (e.g .inter-city travel and very long commutes). Level 1 charging at home enables electrification of 80% of vehicles. Level 2 charging at home and at work enables electrification of 92% of vehicles. Assumes 90 miles of range on a 30 kWh battery.