UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Memorials to N. Holonyak, P. Sauer, and W. Wulf, and commemoration of the 75th anniversary of the transistor.

Steps toward modern electric transport and the growing electronics revolution.

National Academy of Engineering Regional Meeting

April 4, 2023

Steps toward modern electric transport and the growing electronics revolution.

P. T. Krein
NSF Power Optimization of Electro-Thermal Systems (POETS)
Engineering Research Center and
Grainger Center for Electric Machinery and Electromechanics

Mobility for Everyone

Personal mobility and transportation are global aspirations.
How can electrification enable nearly unlimited mobility for people and goods?
It must be effective and fully sustainable.
Mobility is not limited to vehicles.

Quicknmobile.com

Army.mil, Army News Service

Keeping Eyes on the End Goal

We expect electrification to help enable universal mobility

How can smart transportation enable a blind person to drive?
Get a child or person with a disability to the doctor?
Relieve traffic congestion in dense urban environments?
Deliver fresh food around the world at minimum economic and environmental cost?

Insideevs.com 1/26/2023

campusghanta.com

People seem to overestimate costs of major transitions – and underestimate benefits

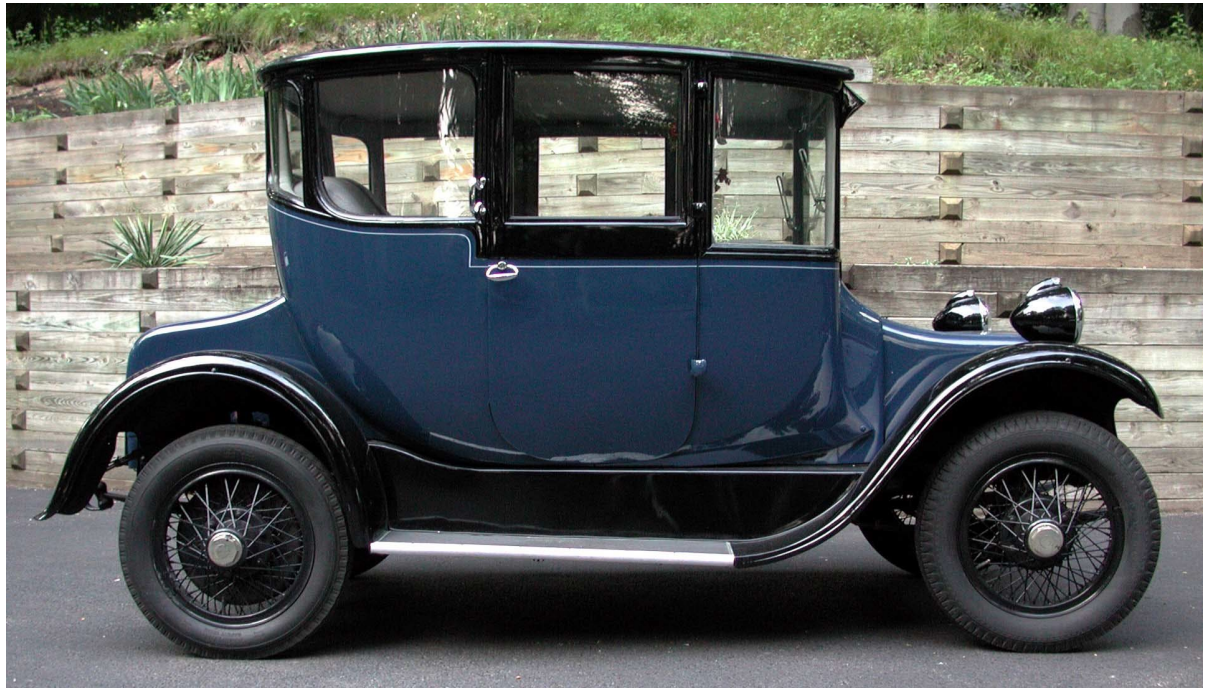
New York pollution impact

Manhattan skyline, May 1973: Chester Higgins, National Archives

Manhattan skyline, April 2021: wherearethosemorgans.com

Only in recent years have electric vehicles caught up with the past

This 1914 Detroit Electric was a high-performance car of its day



Courtesy I. Pitel

Tesla Model S

Why electric (and hybrid) vehicles?

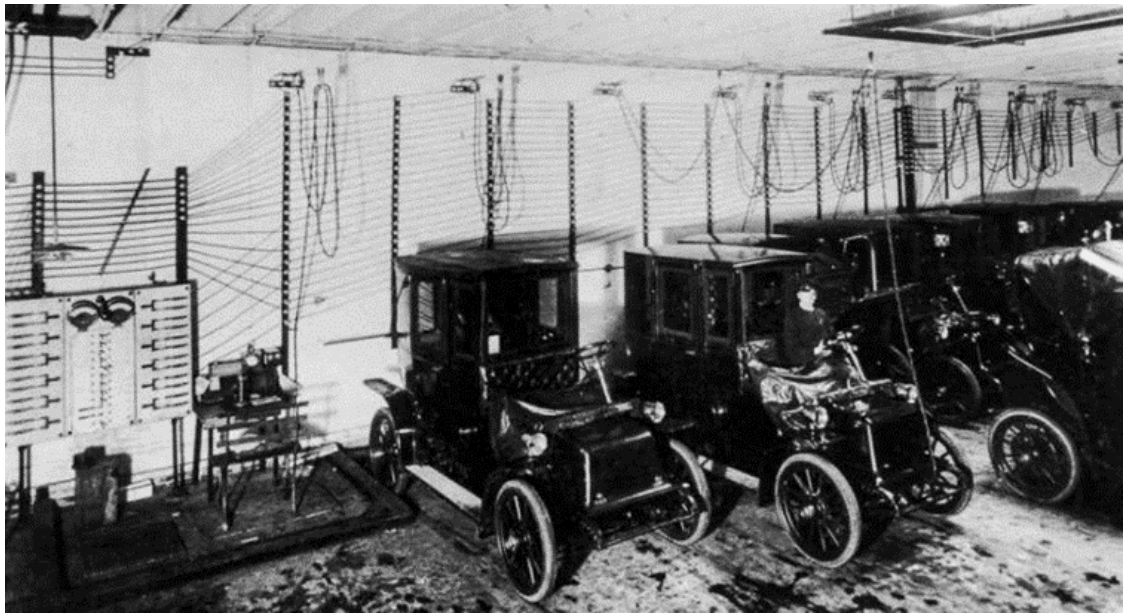
- **Energy reduction and energy flexibility**
- **Emissions reduction, including carbon**
- **Opportunities for operation, control, autonomy**

These come with lower operating costs and high performance

Key fallacy

"An electric car will need to match everything we can do with a conventional [fueled] car."

-- Fallacy because differentiation is common in transportation markets: no baseline
-- So far, EV owners do not use cars as they do fueled cars



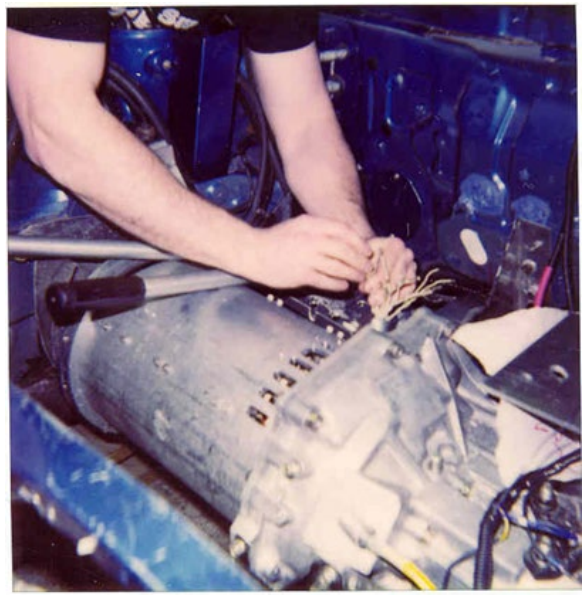
http://easyway.site (Schenectady Museum of Innovation and Science)

Early EVs were treated to emulate horses!
This horse stable has been repurposed for EV charging.

Extreme performance is readily available

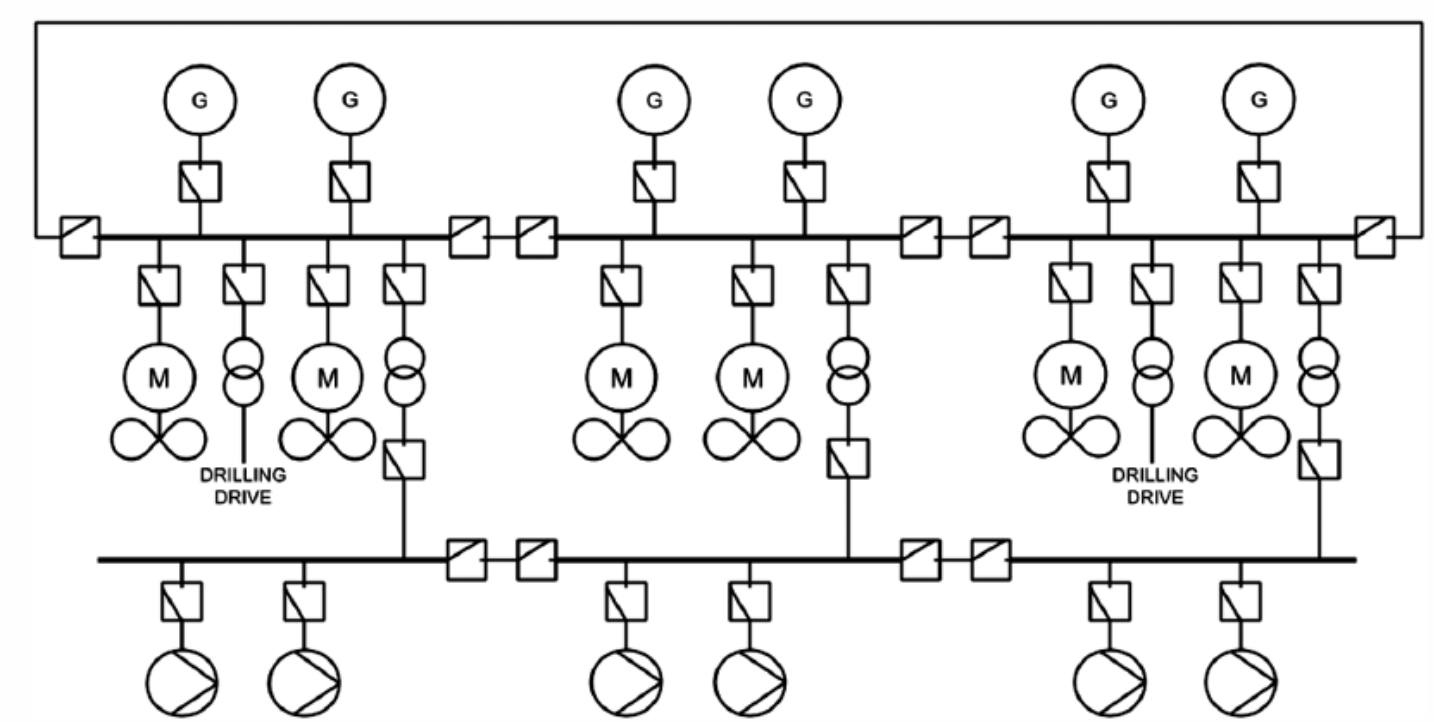
Quick motor response.
Fast power reconfiguration.
New kinds of performance capabilities.

This commodity motor can change torque ±100% as quickly as 100 times each second.



The switching transistors in an electric ship can direct energy as needed

Similar methods apply to many large mobile systems.



T. Johansen, T. Bo, E. Mathiesen, A. Veksler, A. Sorensen, “Dynamic positioning system as dynamic energy storage on diesel-electric ships,” *IEEE Trans. Power Syst.*, 2014.

Dynamic power control example

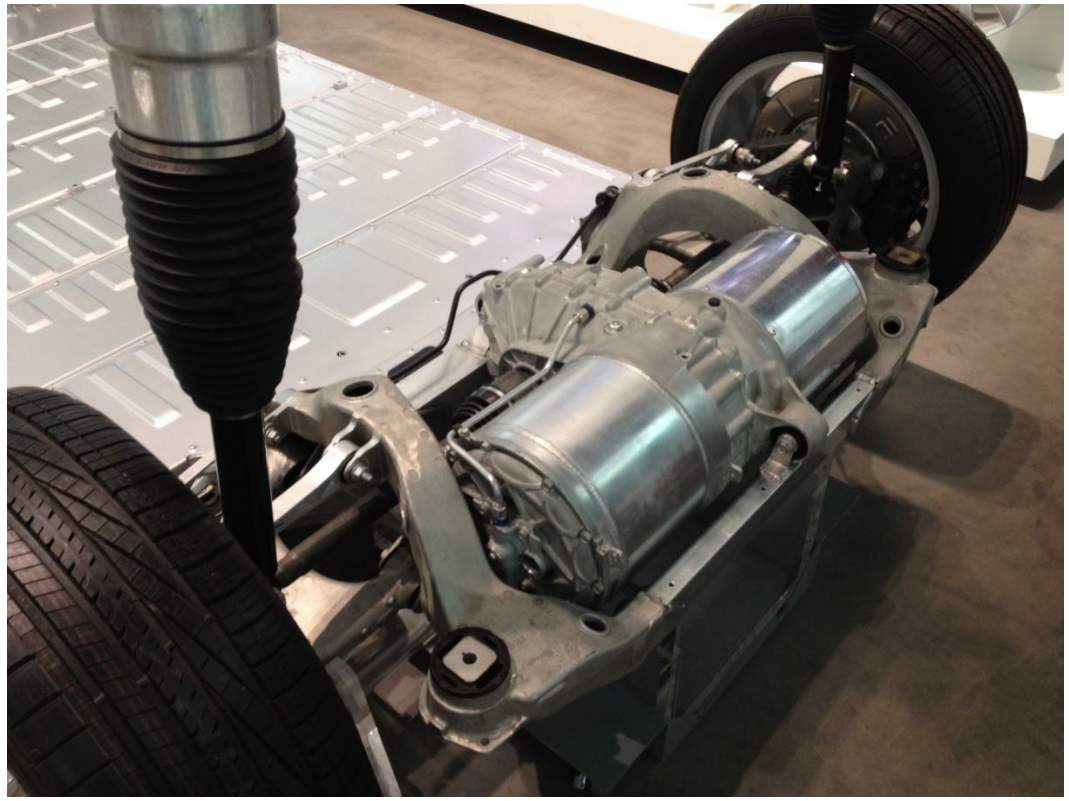
This hybrid-electric loader gains substantial performance benefits from fast power reconfiguration.

Deere.com

Collision avoidance and occupant protection.

If there are multiple motors, automated vehicle control can consider active collision avoidance.

Other actuators can reconfigure crush zones and manage occupant safety.



evtv.me, Tesla transaxle

Fully electric aircraft were not plausible only five years ago.

The Boeing 787 moves well down the “more electric aircraft” pathway.

Concepts to test platforms

Nasa.gov, N3-X turboelectric concept platform.

NASA electric X-57 Maxwell aircraft. NASA Photo/Lauren Hughes

Hinetics.com

What about charging infrastructure?

Charging infrastructure is a big barrier for plug-in vehicles.
Should we emulate fueled vehicles?

Safety and safety perception
Charge rates vs. connection and driver time

Can we just use regular outlets (for passenger cars)?

Cheap: retail electricity or less.

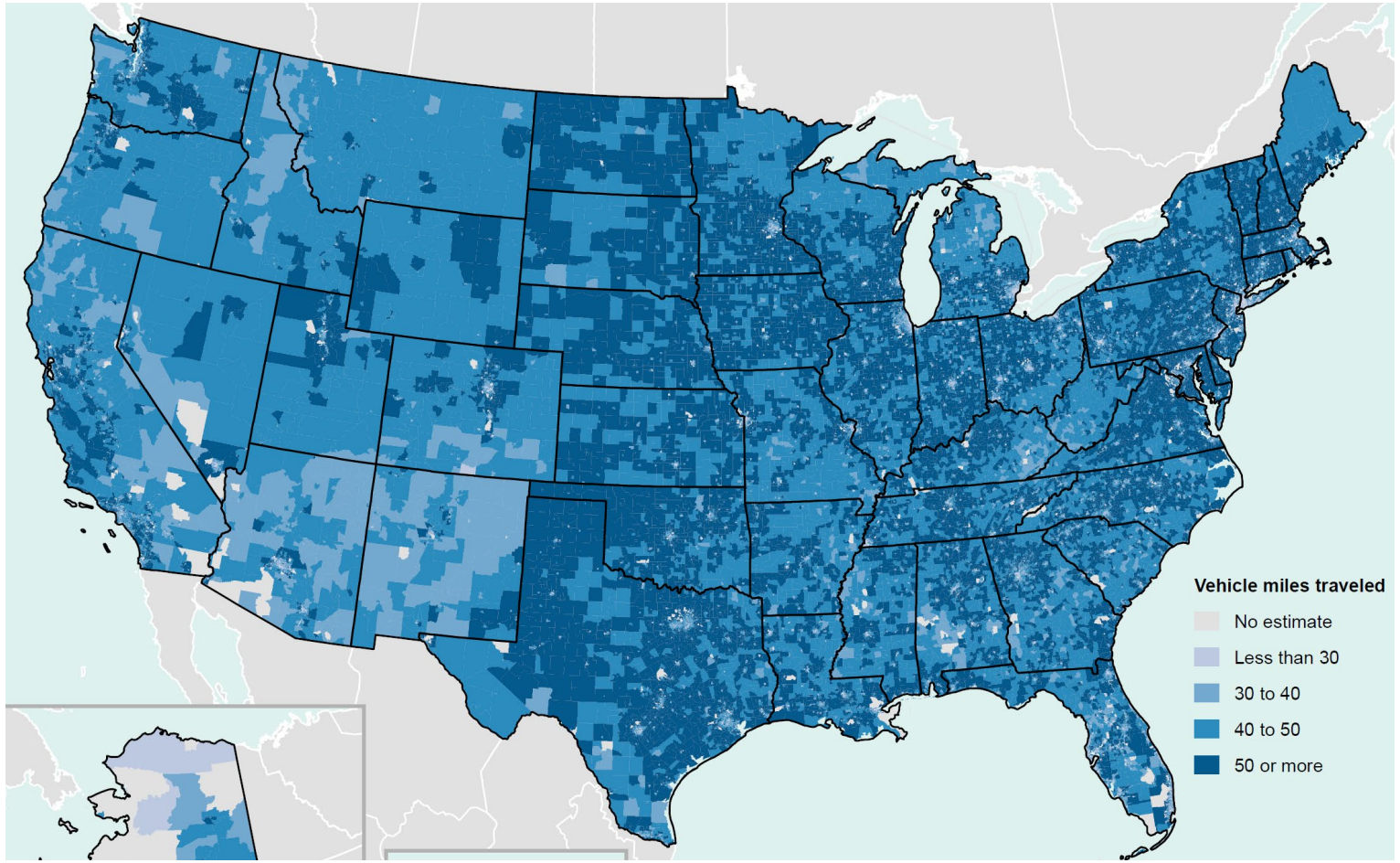
Courtesy of Alicia Tomaszewski

Actual usage data tends to alter the perception

U.S. daily car travel average is 29 miles.

Less than 5% of trips exceed 31 miles.

EV drivers seek out simplicity and convenience.



[1]Bureau of Transportation Statistics, updated May 2017.
http://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/surveys/224066/vmtmap.pdf
[2]http://nhts.ornl.gov/vehicle-trips

How much infrastructure do we have? Do we need?

Usual view: Only a few places to charge (Whitehouse.gov reports 130,000 nationwide)

Instead, hundreds of millions of conventional receptacles can provide ready energy access.

This is not the right approach for long-distance driving, but simple outlets at home and work can support 95% of daily trips.

Some interesting conventional adaptations

In some places, infrastructure exists for adaptation

Block heater receptacles in Saskatchewan can become a forest of low-cost EV charge points.

Regina.ctvnews.ca, used by permission

Entrepreneurs in Finland are repurposing block heater receptacles to provide 1 million EV charge points in a nation with 3 million cars

www.inisideevs.com

Basic receptacles as infrastructure

Can a simple 120 V receptacle really support EVs?

-- Typical recharge rate is only about 5 miles per hour.
-- But passenger cars are parked many hours a day.
-- Support for 95% of daily trips is straightforward.

A tool outlet or international outlet is twice as fast.

What about faster charging?

Typical dedicated “Level 2” charging

Charge rate can be 25 miles per hour.
-- Still too slow for long distances.
-- For 95% of daily trips, not much benefit.

Campus survey:
Typical usage 8 hrs per month

Electrek.co, 2/18/2020

Expensive: Charger pricing must add a large premium above energy cost to cover installation and maintenance.

Fast charging is vital for trucks and long distance

Fast charging is essential, but is expected to deliver only a modest fraction of transportation energy

The pricing, in energy terms, might approach fuel energy prices

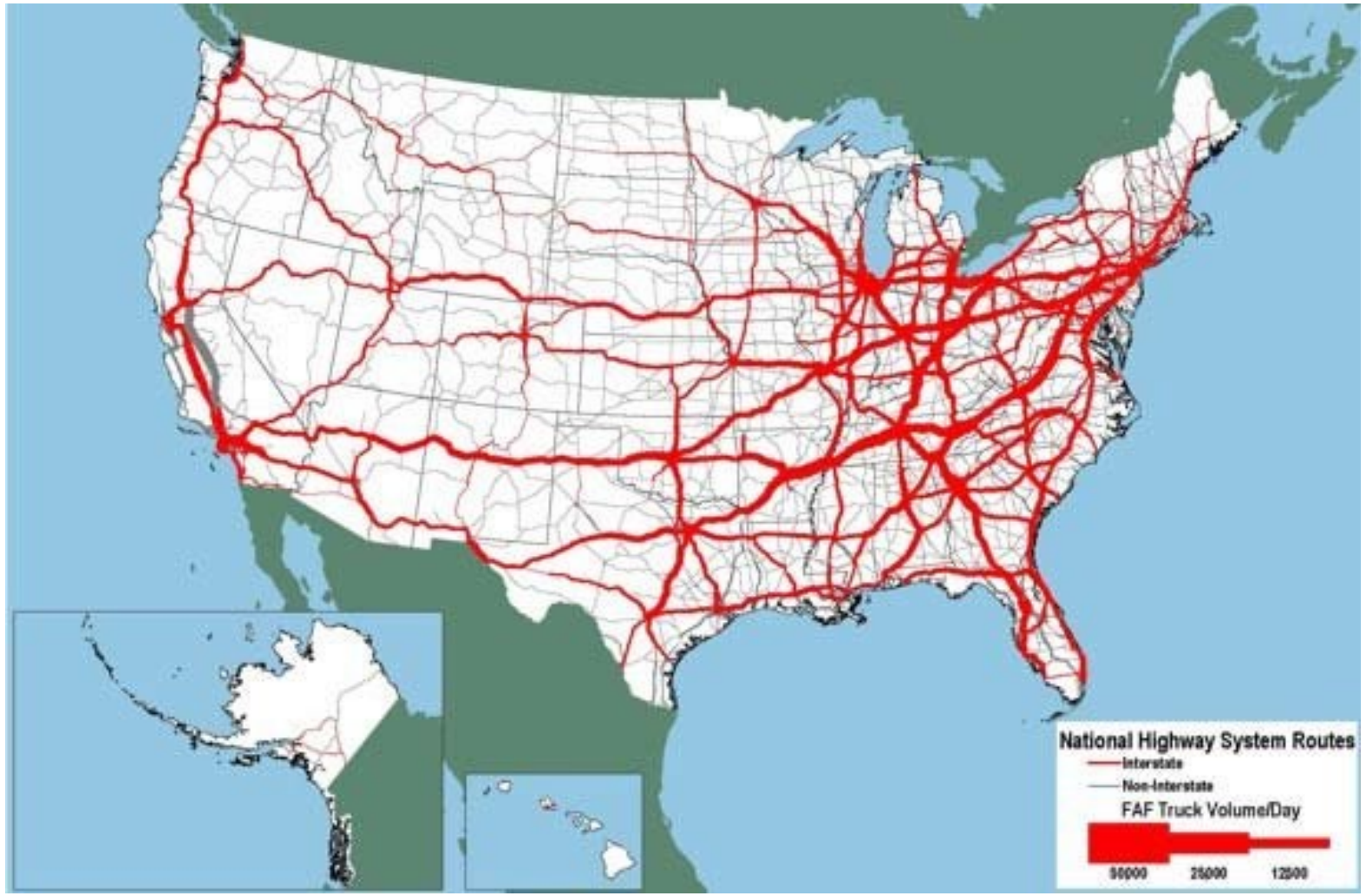
www.loves.com

Location planning is important for fast charging

Truck volumes on U.S. highways, 2017

This map provides insights about locating fast charging.

It also suggests possible plans for *highway* electrification.



US Department of Transportation

Basic scenarios in a small Midwest town

-- Employees, residents park several hours per day.
-- Visitors seek to shop and dine, parking only a few hours.
-- Short visit, dine or run errand, park about an hour.

Basic receptacles address employees and residents, lowest cost solution.

Parking meters and lampposts are an infrastructure opportunity.

Level 2 charging is nice for shorter visits. Compare energy cost to parking cost. *Energy overpricing is typical today.*

A future orientation

We know where we need to be, well before 2040

-- Receptacles easily available at home, at work, while shopping.
-- Fast charge infrastructure in strategic locations to support long distances.
-- Communications, billing, coordination to make this work.

Work backwards to 2023 and accomplish this

-- Communications.
-- Safety.
-- Reliability.
-- Easy access!

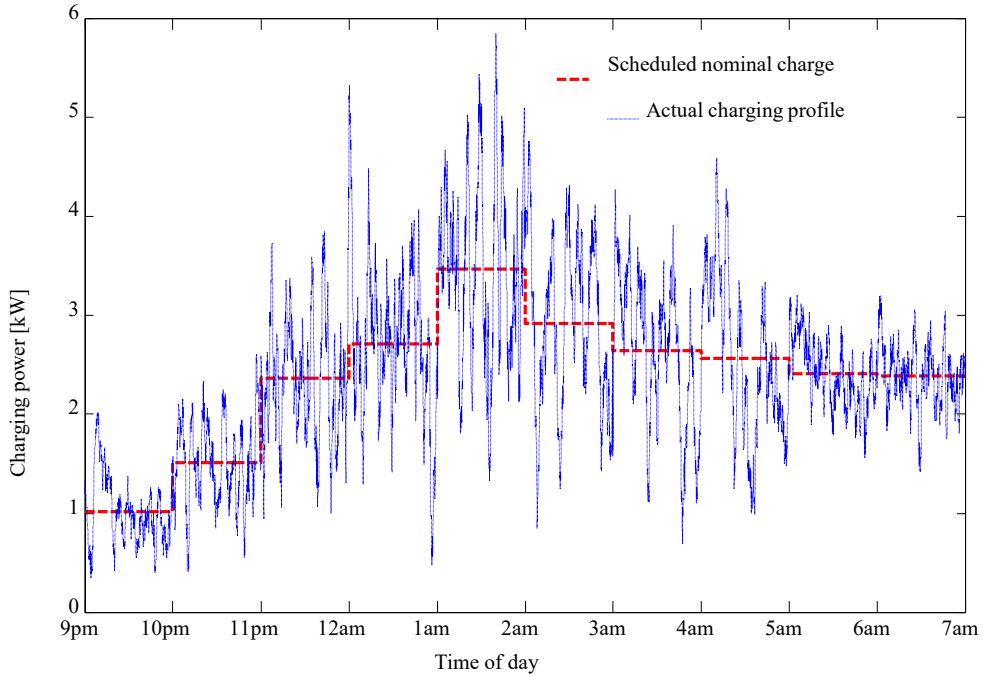
Courtesy of Yi Zhang

A connected car is a flexible car

This pair of plots compares two flexibility scenarios:

1. (Dashed line) Car controls low-cost charge.
- **a) Target time and amount of energy.**
- **b) Car downloads hour-by-hour prices.**
- **c) Minimize retail energy cost subject to limits.**

2. (Thin line) Grid operator controls low-cost charge.
- **a) Target time and amount of energy.**
- **b) Grid makes adjustments every few seconds for dynamic regulation services.**
- **c) Additional energy discount to car owner.**



M. A. Fasugba and P. T. Krein, "Cost benefits and vehicle-to-grid regulation services of unidirectional charging of electric vehicles," in *Proc. IEEE ECCE*, 2011, pp. 827-834.

Self-driving transport is possible, in the long term

Electrification and extensive sensing and control electronics start with
-- Much better energy results,
-- Much better pollution and carbon results,
-- Augmented safety systems.

Possibilities for ubiquitous energy access

www.caranddriver.com

www.exp.com

Some end points

95% of daily passenger vehicle trips can be supported from basic receptacles

Trucking is different, and needs to be addressed with location strategies.

Vast expansion of receptacle access in places where people live and work can support rapid scale-up of passenger car electrification.

Today and tomorrow, we will hear more elaboration on underlying mobility electrification challenges.

Please take advantage of the poster session during break times.

Thank you to the interdisciplinary MARTEC team at Illinois, and colleagues at Ohio State, Wisconsin, Michigan, Purdue, and others

Thank you to POETS and ICT for sponsorship, and the Grainger Lecture Series, Kent Seminar Series in Transportation, and MRL Distinguished Lecture Series for funding.

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