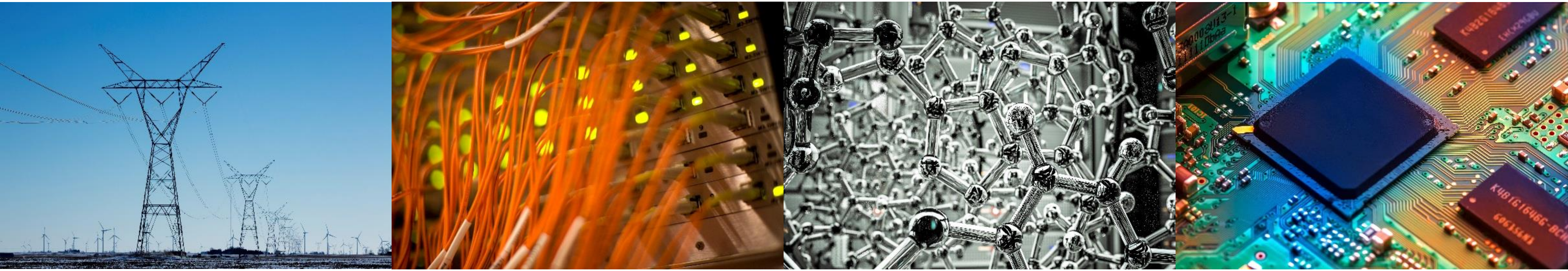
The Future of Electric Cars: How do we charge them up? Do they really bring benefits?



ILLINOIS
Electrical & Computer Engineering
GRAINGER COLLEGE OF ENGINEERING

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Professor Emeritus
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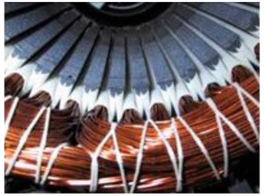
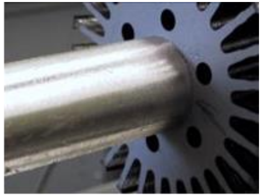
- Grainger Center for Electric Machinery and Electromechanics at the University of Illinois
- Zhejiang University/University of Illinois Institute

Some results are based on survey information and charging operating history at the University of Illinois at Urbana-Champaign.

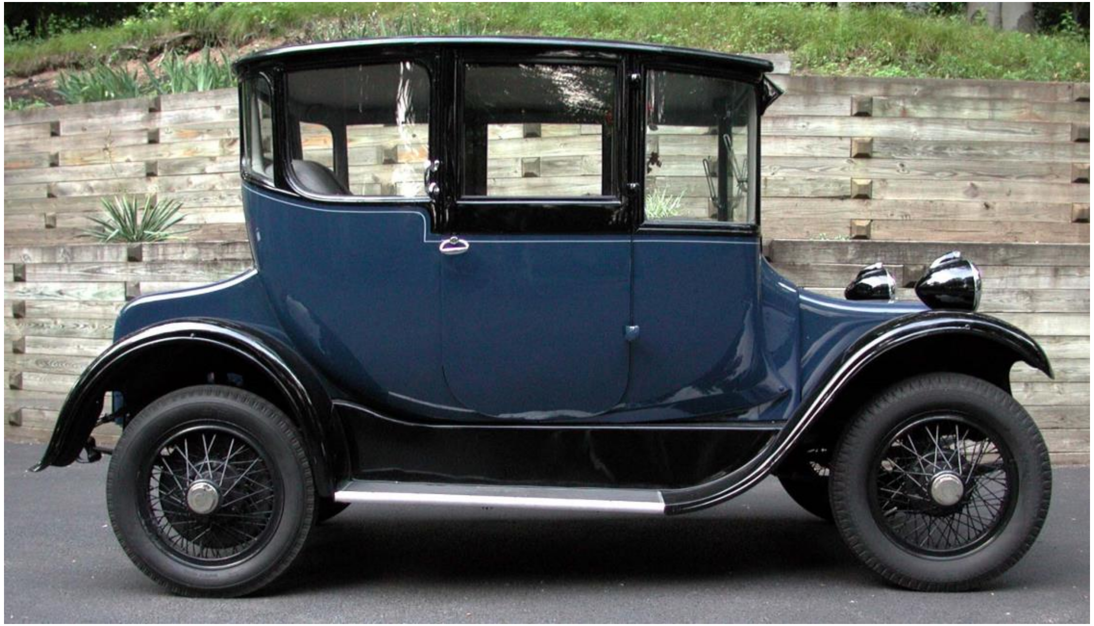


- Opportunities for operation, control, autonomy
- Extreme performance
- Energy reduction and energy flexibility
- Operating cost reduction
- Emissions reduction

Why electric (and hybrid) vehicles?

- Capability today finally pushes out the “leading edge” from more than 100 years ago.
- This 1914 Detroit Electric car was a high-performance vehicle at the time.



Courtesy I. Pitel

It took a long time to catch up

- Limited range. Where can I charge up?
- Battery performance, cost, and life.
- Refueling time.
- Other stuff people hate.
  - Cargo limits
  - Heavy cars
  - Energy for comfort

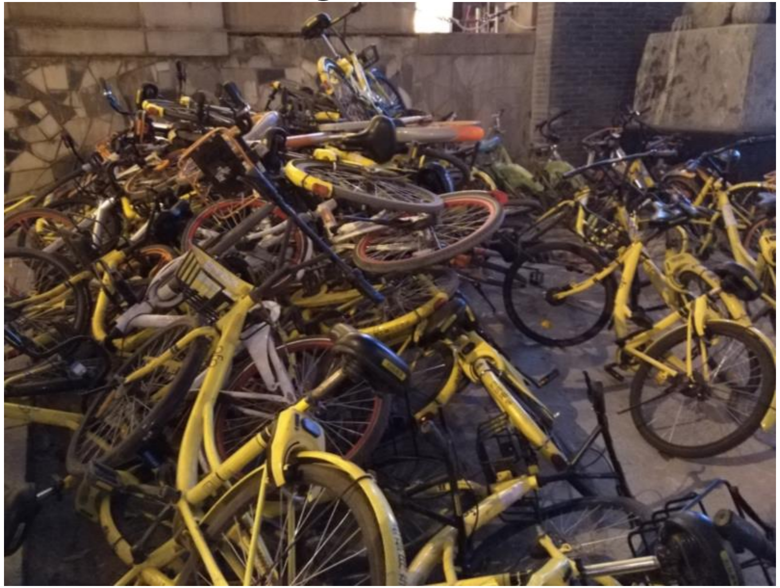
Why not? What are the problems?

“An electric car will need to match everything we can do with a conventional (fueled) car.”

-- *Differentiation is common in transportation markets.*

“People will not buy a car just for commuting.”

-- *Actually, this is not unusual.*



“Fast charging is a must.”

-- *This needs more thought.*

“Range is everything.”

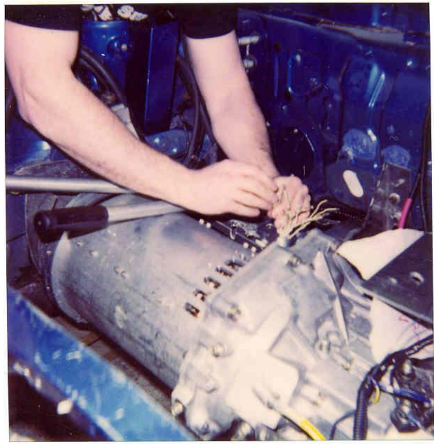
…

- Electric cars are fast. This opens opportunities for operation and control.
- Electric transportation is a potential beneficial partner for the electricity grid.
- **Data** on actual vehicle use are essential.
- The biggest electric vehicles are trains.

i.imgur.com

- Change torque 100 times per second.
- Modest-sized motor can change ±100 N-m (±75 ft-lbs) in 10 ms with control.
- These are commodity industrial motors, not special purpose devices.

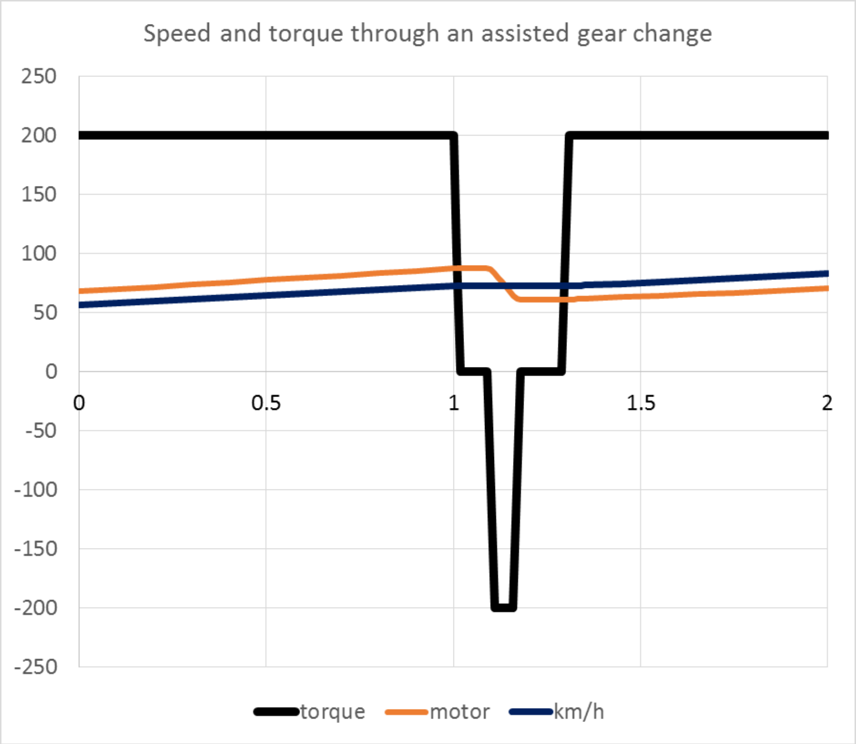
Air-cooled motor



Fast dynamics

- Active suspensions: electric motors can move a wheel assembly extremely fast.
- Similar application: aircraft control surfaces.

- Active gearbox shifting: a motor can drop torque, sync to a new speed, and reapply torque, all faster than a driver can move the shift lever.
- No clutch, no operating limits on gear ratios.



- This hybrid-electric loader gains a lot of performance through rapid energy flow reconfiguration.

Deere.com

Hybrid and electric aircraft are emerging

- Large fuel and emissions reductions.
- High impact on airport infrastructure and loads.
- Enormous emerging energy opportunity.

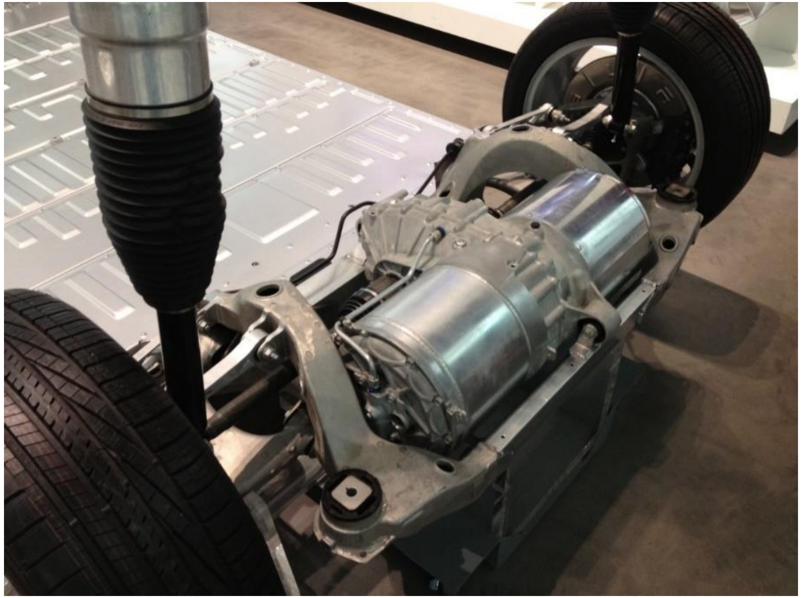
Hinetics.com

NASA N3-X turboelectric concept platform.

www.nasa.gov

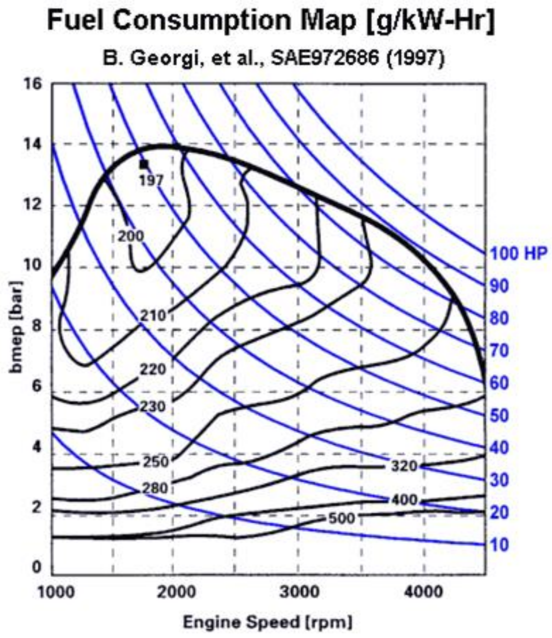
Aircraft electrification is changing rapidly

- When multiple motors are used, independent two-wheel and four-wheel dynamic control can be available.
- Aircraft-style collision avoidance paths.
- Dynamic crush-zone reconfiguration.



evtv.me, Tesla transaxle

- In a hybrid car, one strategy is to use dynamic reconfiguration to get the best fuel economy.



- People value personal mobility.
- How do we enable *mobility for everyone*?
- Electric transportation and smart vehicles transportation must answer fundamental needs, not just match existing thinking.

Pullman Car Company was once one of the world's largest corporations.

What about personal mobility?

- How can electric and intelligent transportation help get a kindergartner to a doctor?
- Support a non-polluting autorickshaw in Bangkok?
- Relieve traffic congestion in Mumbai?
- Deliver fresh food around the world?

campusghanta.com

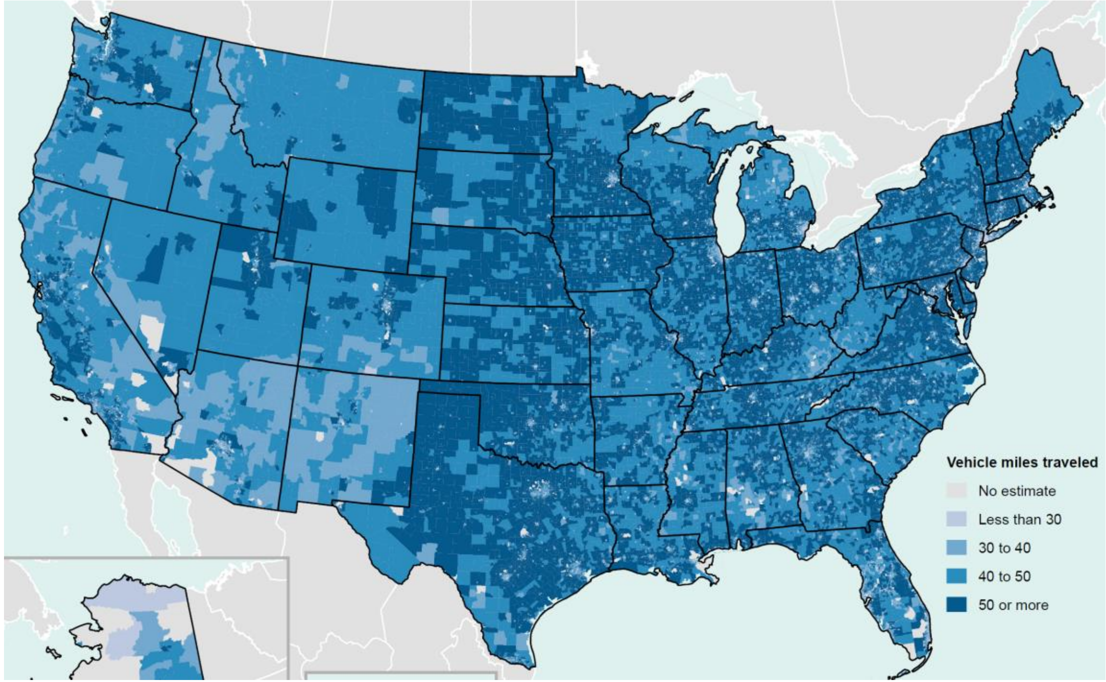
What does “personal mobility” mean?

- Charging infrastructure is a big barrier for plug-in vehicles.
- A mix of issues:
  - *Safety and safety perception*
  - *Charge rate*
  - ***Should we emulate fueled vehicles?***
- Conventional outlets meet most of the needs in many locations.
- Can we just use regular outlets? It is a lot cheaper.

Courtesy of Alicia Tomaszewski

- Owners of EVs and PHEVs typically do not use their cars just like gas vehicles.
- They want simplicity and convenience.

- U.S. daily car travel average is 29 miles[1].
- Less than 5% of trips exceed 31 miles[2].



[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

Need actual usage data

- The usual view: only a few EV charging points exist (less than 80,000 in the US, for instance).
- But: hundreds of millions of electrical outlets provide ready access to energy.

- *Use conventional outlets.*
- This does not meet needs for long-distance driving, but that is taken here as a separate issue.

How much infrastructure do we have?

- Low-level V2I (vehicle-to-infrastructure) interfaces.
- Vehicle communicates for billing and grid interfacing.
- Vehicle uses its onboard charger for active safety management.
- The communication needs are low, e.g. one message per hour each way.

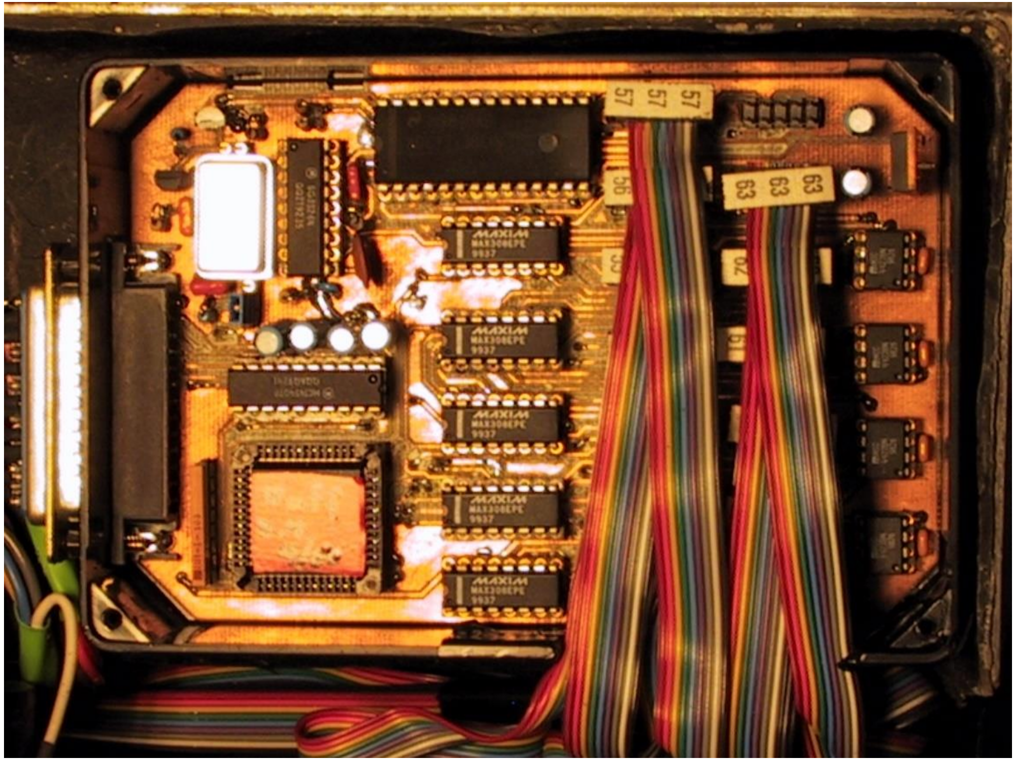
Safety can be an issue of perception, even though emerging codes address concerns.

Some of these block heaters are rated to 1500 W.

An EV owner sees a forest of charge points.

Regina.ctvnews.ca

Software safety and failsafe electronics are a critical and very difficult challenge.



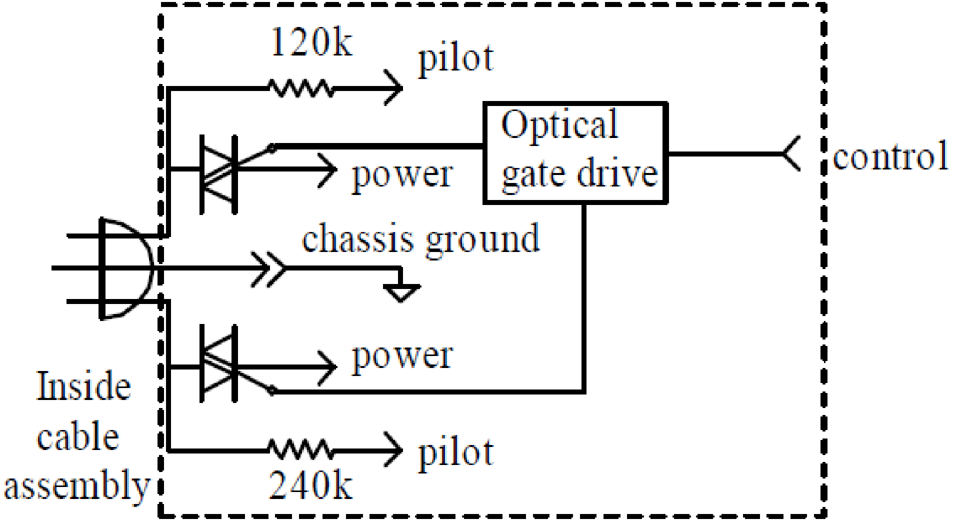
How do we know that a software bug will not cause harm?

How can we test electronics enough to keep all failure modes safe?

Power electronics for in-vehicle chargers can support protection:

- Handshaking
- Watch for ground faults
- Current limits
- Safety lockouts
- Monitor moisture and wet environments
- Delay or coordinate charging times.
- …

- This little circuit supports a lot of safety features.
- It measures the input voltage before starting a charge process.
- It implements requirements for “electric vehicle supply equipment” (EVSE).
- It measures ground current.



Consider these

- Basic outlet, 120 V at 12 A (or 16 A).
- Tool outlet, 220V at 12 A.

These exist in most of the world as conventional electrical outlets.

US, Canada

China (but accepts EU, Australia, US, British plugs).

What about basic outlets?

Basic outlets

Well designed EV uses less than 250 Wh per mile (160 Wh/km) in city operation

Basic outlet – 1.4 kW, about 8 km/h, 5 mph

Seems like not very much, but a car is parked many hours a day, and 60 km (38 miles) one way is plausible.

Tool outlet– 2.6 kW, about 16 km/h, 10 mph

Twice as far.

R. Bruninga, “Overlooking L1 charging at work in the rush for public charging speed,” in *Proc. IEEE Int’l. Electric Vehicle Conf.*, 2012.

What about higher levels?

Dedicated charge point (typically 6 to 7 kW)
This is about 40 km per hour, 25 mph
Not sufficient for distance driving
Not necessary for most commuting

Fast charging:
the alternative that supports distance driving – separate issue, and yes we need them.

tesla.com

Many infrastructure projects address dedicated charge points

Expensive charging stations

Instead

A 220 V, 12 A outlet supports a one-way commute of 100 km with less than 8 hours of charge time.

Even less relevance for plug-in hybrids

A plug-in hybrid with 60 km range can charge during a work day from a basic outlet.

Illinois campus experience: Charge point usage 8 hr/month, outlets daily

Remember the data? More than 95% of U.S. car trips are less than 31 miles.

Courtesy of R. Fritz

Actual usage is covered by basic outlets.

Usage cases

1. Extended connection time. Enough time for charge, plus flexibility.
2. Defined time. No extra time for flexibility.
3. True “opportunity charging.”
4. Non-routine locations (hotel, shopping mall, relative’s home, etc.).

At an average cost of $0.12 per kWh, a basic outlet delivers $0.17 of energy value per hour. (Price late at night could be half.)

“It takes a long time to charge an EV from an outlet.”

-- The *connection* time is long.
-- The driver’s time is a different story!

Owners of plug-in hybrids seem to hate gas stations.

The U.S. Census Bureau estimates 111,000 gasoline stations in the U.S. as of 2016[1].

Nearly *all* fuel is distributed from these locations.

-- 95% fossil fuel

-- 5% biofuel

[1]http://www.statista.com/statistics/525107/number-of-gasoline-stations-in-the-united-states/

Fuel vehicles convert ~20% of fuel energy to wheel power

-- Refinery is ~85% efficient

-- Overall no better than ~17% “well to wheels”

EVs convert ~80% of input electricity to wheel power

-- Combined cycle plant is ~56% efficient

-- Overall >40% “well to wheels”

-- *And* there are other sources

http://www2.daimler.com/sustainability/optiresource/pages/pagMainSelection.html

The case for flexibility

Long connection time, limited need

Sell flexibility to the grid

Charge is delivered per a contract, but at times and rates that meet grid needs.

Charge to get lowest cost OR
Charge to get low stress on the power grid OR
Charge as slowly as possible, but meeting the energy target OR …

The box creates a special signal to “fool” the standard.

Flexibility is a big advantage

Plug in and charge

Energy cost: retail or maybe a premium
But a store might offer free connections.
The vehicle manages billing services, and pays for energy unless the facility owner allows otherwise.

Notice two *outlet* database possibilities:
1. "Bill to" information.
2. Outlet capacity information.

This EV cable interface supports 120 V or 240 V.

Should a business give away 25¢/hr of energy?

Vehicles:

Measuring and metering

The vehicle tracks usage and communicates billing

Infrequent data unless extra services are being sold.

Secured within the vehicle.

Safety and handshaking

The vehicle will not activate charging unless everything checks out

Test for safety ground, for valid connection, for who will pay.

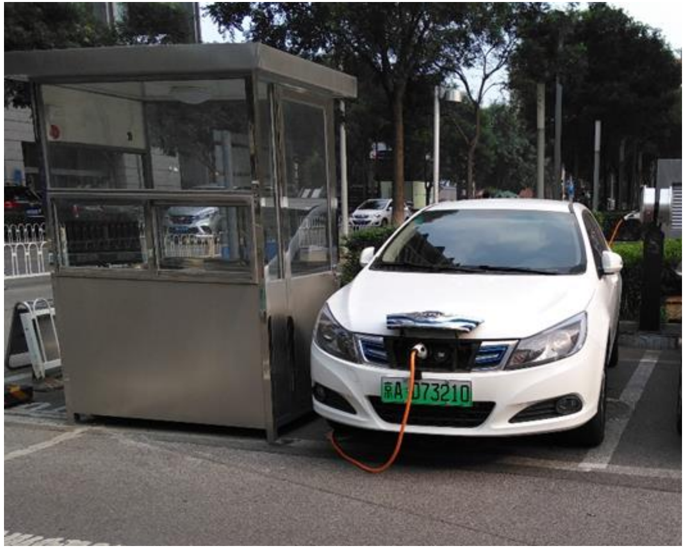
What changes in the car?

Infrastructure:

Provisioning

Outlet is unintelligent, but could be entered into a database that lists capacity and payer.

Parking provider installs outlets.



Utility

Pricing signals, updated "user pays" energy billing.

Aggregator could manage a "parked fleet:" flexible timing, pricing schedules, grid services.

Less than 10% of charging energy is likely to be at high rate.

Fast charging energy will carry a large premium
But still cheaper than fuel.

Interstate highway rest areas, or in the vicinity of exits
Tesla is building up in these places.

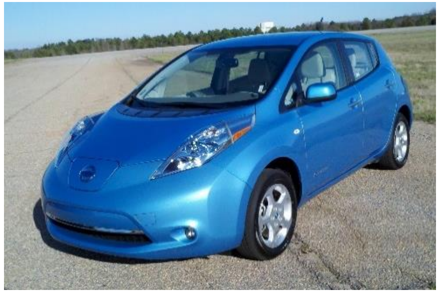
teslamotorsclub.com

Roadways?
Wireless roadways? Mainly on rural interstate highways? Sliding contacts instead?

Battery swaps?

- EVs come with enormous benefits in terms of energy, performance, and mobility.
- About 95% of EV commuting needs can be supported by charging from basic outlets.
- Easy in new construction.
- Not hard to add to existing garages
- Possible for surface and street spaces.
- The vehicle can manage safety, billing, measurement, and other attributes.

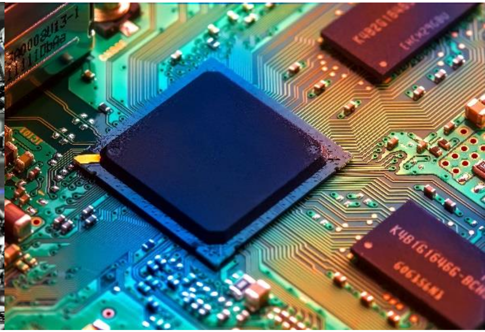
Courtesy of R. Fritz



Now for questions and challenges!

THANK YOU!



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