Electric Vehicle Transportation Center

EV Market and Technology Workshop

October 20th, 2015
Florida Solar Energy Center, Cocoa, FL


Paul Brooker


Nan Qin


John Smart

Disclaimer

Illustrations, charts, and graphs obtained from outside sources are given credit on the slide in which they are used. If you wish to use graphs that were created originally for this workshop, please give the proper acknowledgement to EVTC 2015 Electric Vehicle Market and Technology Workshop.

Contributing Institutions

Florida Solar Energy Center

- Building energy efficiency
- Electric vehicles
- Solar PV
- Solar water heating
- Alternative energy
- Education and workforce training

Idaho National Lab

- Nuclear fuels and systems
- Space power systems
- Advanced transportation
- Clean energy integration
- Infrastructure protection
- Defense systems

EVTC Overview

- U.S. DOT Grant
- University of Central Florida
  - **Florida Solar Energy Center**
  - Civil, Environmental and Construction Engineering
  - Center for Advanced Transportation Systems Simulation
  - Electrical Engineering and Computer Science
- University of Hawaii
  - Hawaii Natural Energy Institute
- Tuskegee University

Research & Development Projects

Policies
- Prediction of EV Penetration
- Impact of EV Penetration on Gas Taxes
- Develop EV Workforce Needs

Data Gathering
- Assess SunGuide and STEWARD databases

EV Site Data and Analysis
- EV/Grid Experiments

Standards
- Charging Station
- Plug Connector

Sub-Systems
- EV Assessment
- Fuel Cell Technologies
- Battery Technologies

Specialized EV Applications
- Fleet and Rental
- Florida Turnpike

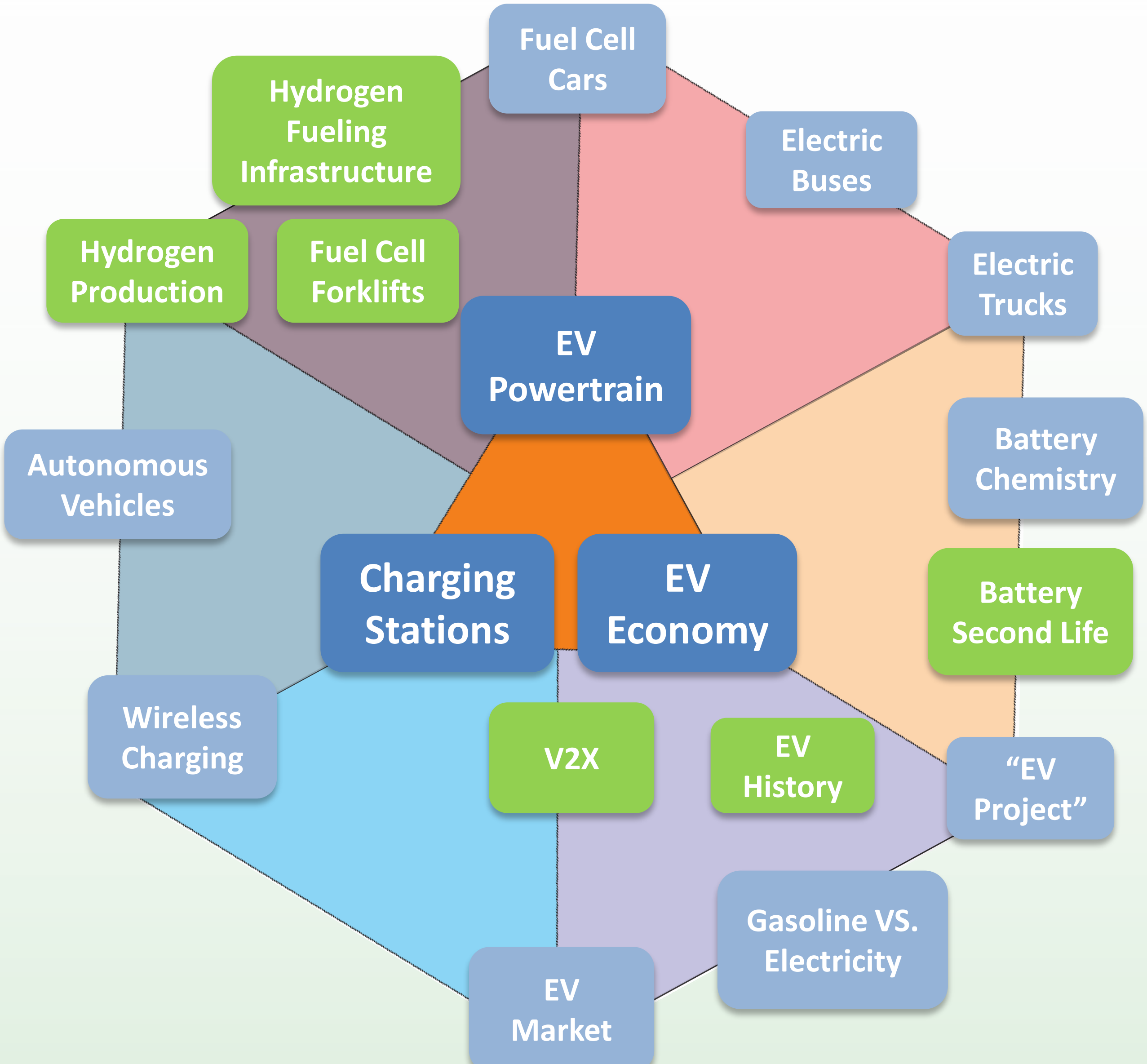
Large Scale Socio-Economic Implications
- Model development
- Infrastructure requirements

Large Scale Techno-Economic Systems Analysis
- Model development
- Impact of EV on electric grid

Agenda

- EV Overview
  - Market
  - Technology
  - Non-consumer applications
- Break
- Real world applications
  - National studies of real EV usage
- "EV Ecosystems"
- Conclusions

Workshop Goals



Electric vehicles: History

Ancient History of Electric Vehicles

- Invented in 1890's
  - Ferdinand Porsche and Henry Ford worked on EVs
  - Edison tried making better batteries
- Several factors led to the demise of the EV
  - Cheap oil in Texas
  - Mass-produced Model-T
  - The electric starter
  - Poor electricity in rural areas

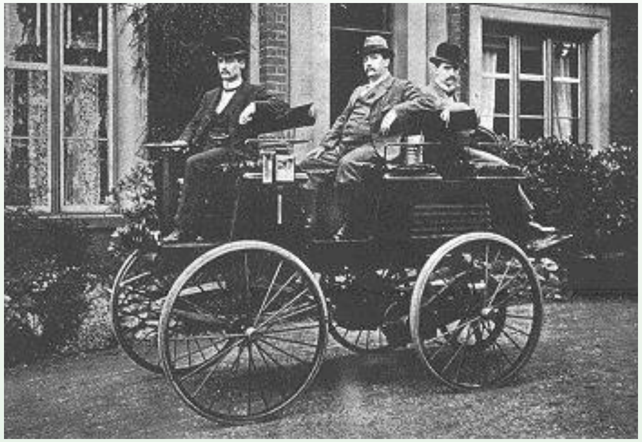


Photo courtesy of Wikimedia Commons

Near History of Electric Vehicles

- Fast-forward to 1960-70's
  - Oil embargo increased interest in domestic energy
  - EVs only had 40 mile range and 45mph top speed
- Citicars become popular
  - 2000 vehicles sold (6^{th} largest US automaker)
- By 1990, interest in EVs had waned again
  - Gasoline was abundant and cheap

Photo courtesy of Austin EV, Wikimedia Commons

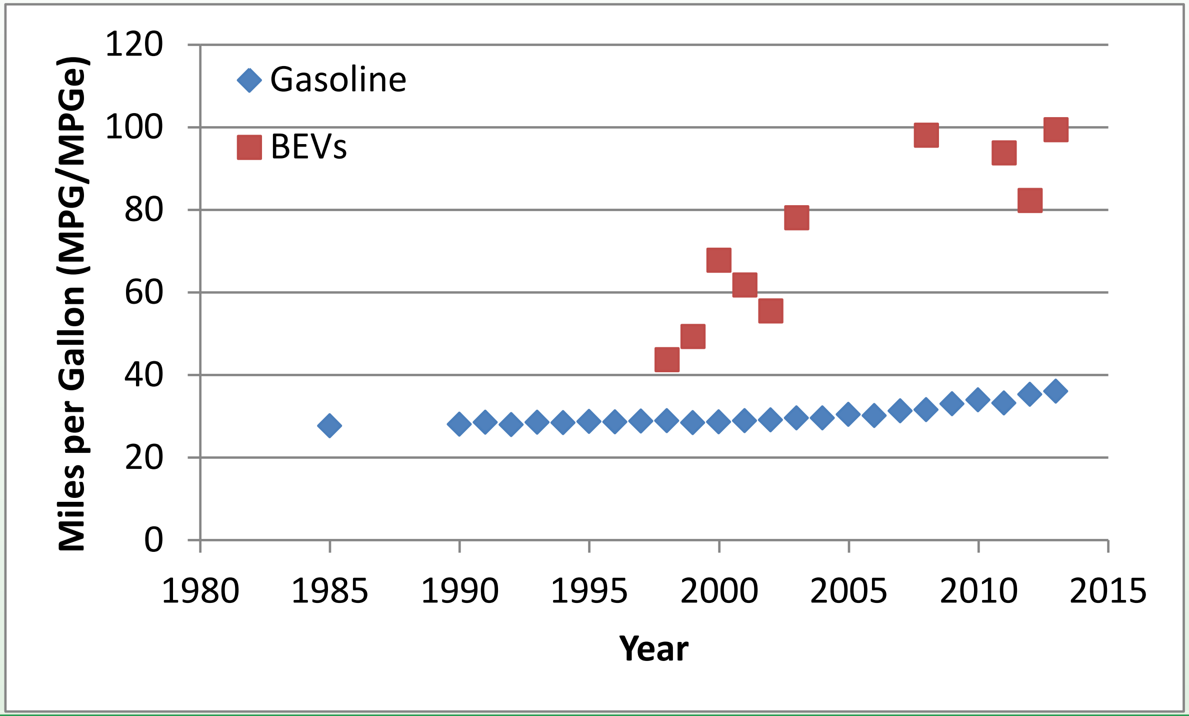
Recent Past of Electric Vehicles

- Concern for the environment promotes Evs in 2000's
- GM produced the EV-1
  - 80 mile range, 0-50 mph in 7 seconds
  - High costs ended production in 2001
- Toyota Prius changes the game
  - Hybrid vehicle rapidly becomes popular
  - Creates a market with staying power

Photos courtesy of Wikimedia Commons

Advantages of Electric over Gasoline

- Improved energy efficiency
  - Gasoline = 17-21% efficient
  - Electric = 59%-62% efficient

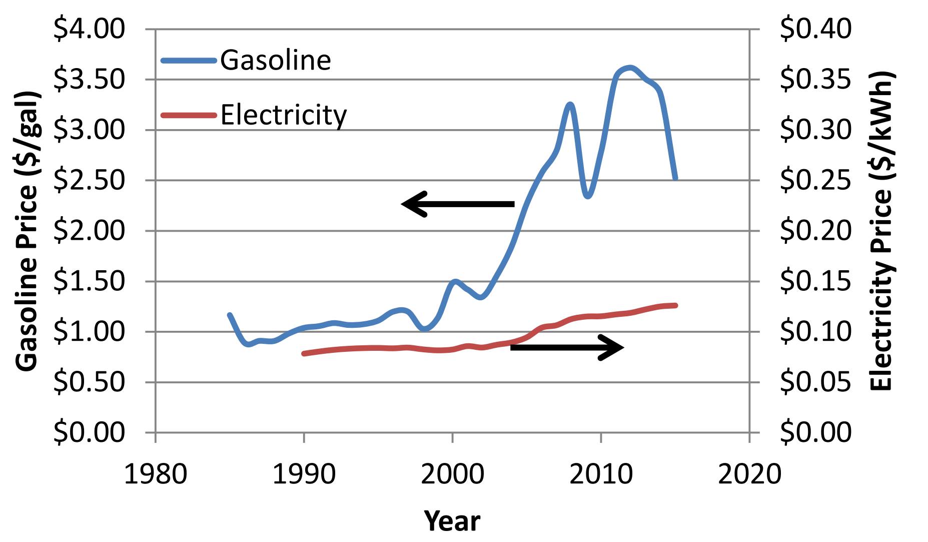


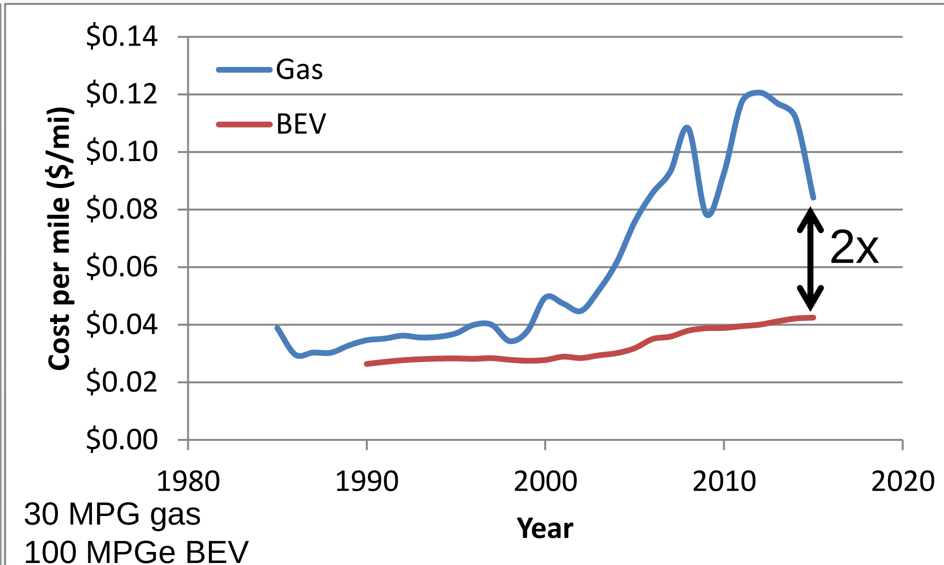
www.fueleconomy.gov

http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_23.html

Advantages of Electric over Gasoline

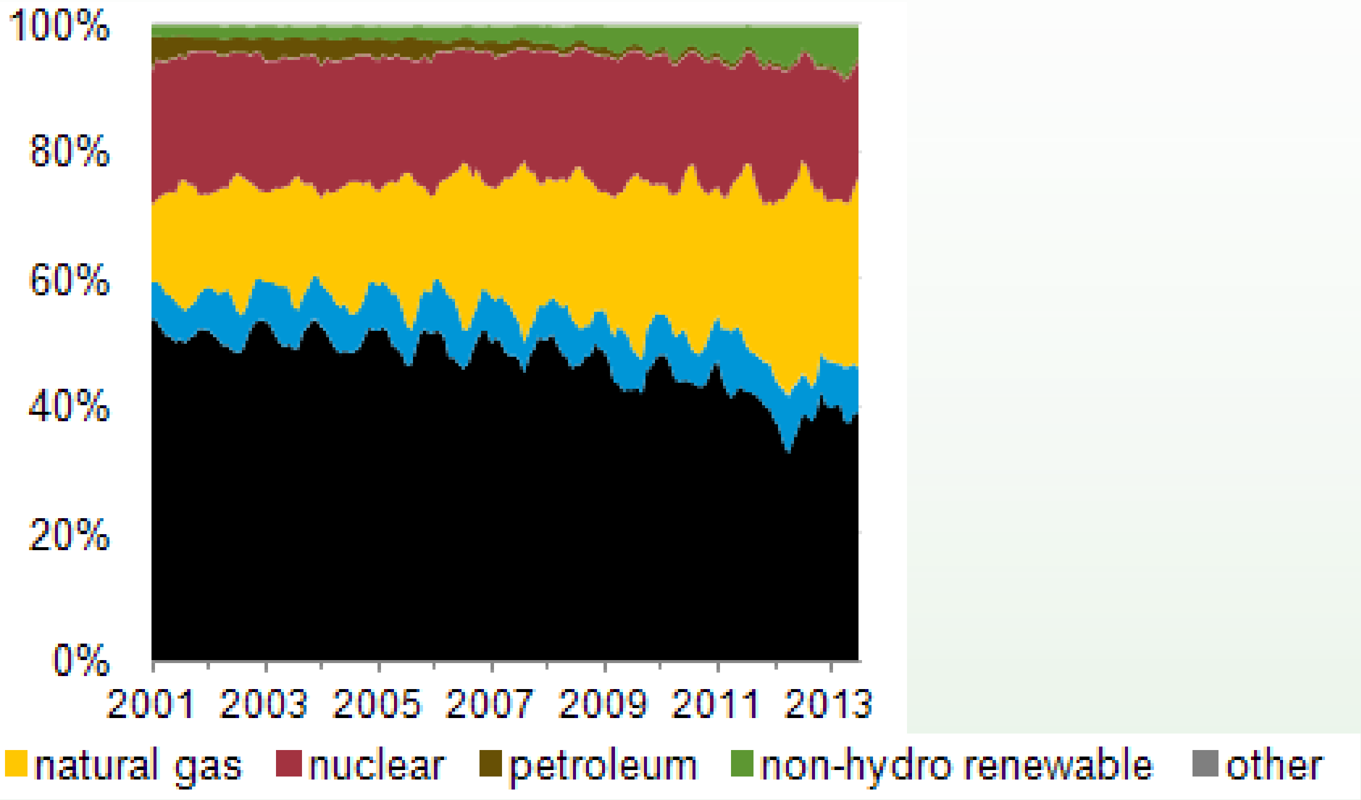
- Cheaper operating costs
  - Different energy sources lead to different variations
  - Efficiency of engine impacts operating costs





US Electricity Mix

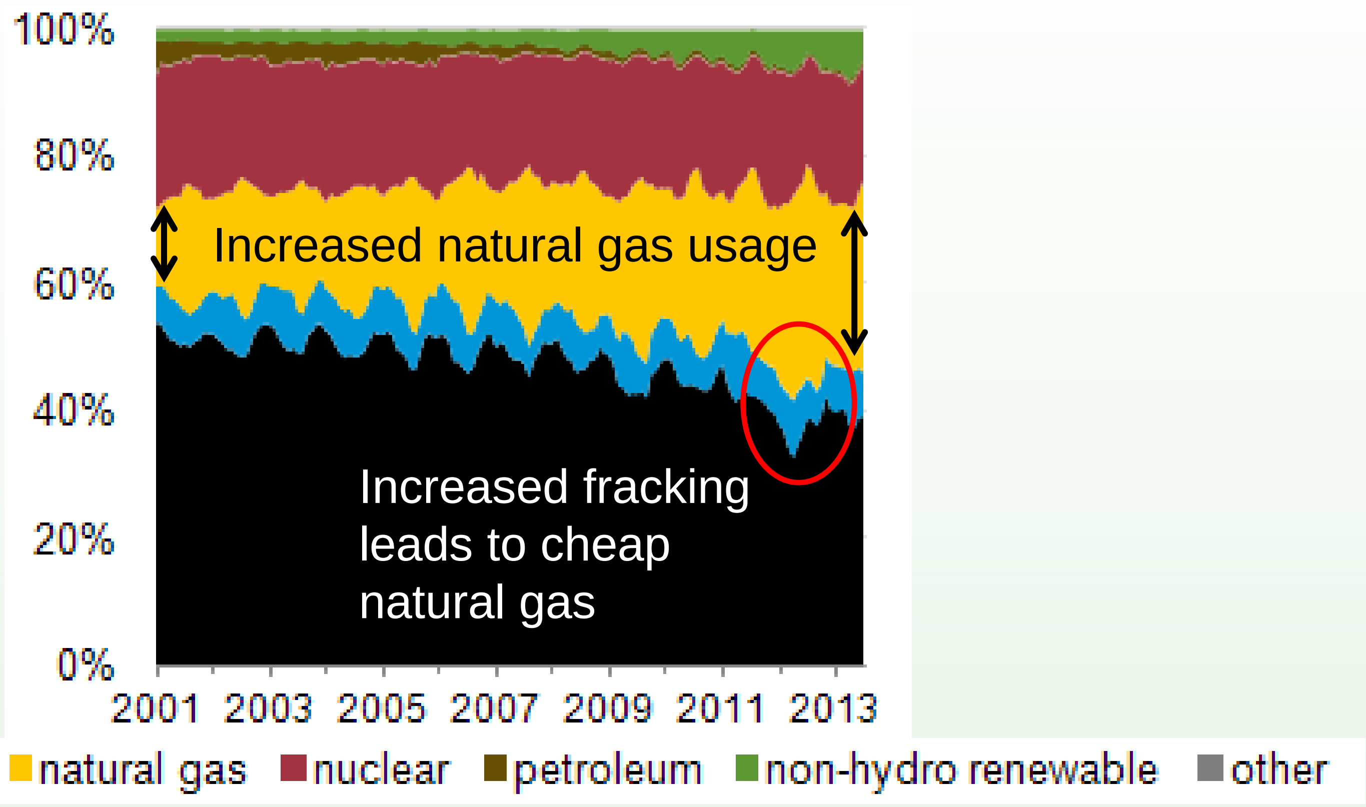
Fuel shares of total electricity generation in the lower 48 states



http://www.eia.gov/todayinenergy/detail.cfm?id=13731

US Electricity Mix

Fuel shares of total electricity generation in the lower 48 states



http://www.eia.gov/todayinenergy/detail.cfm?id=13731

Advantages of Electric over Gasoline

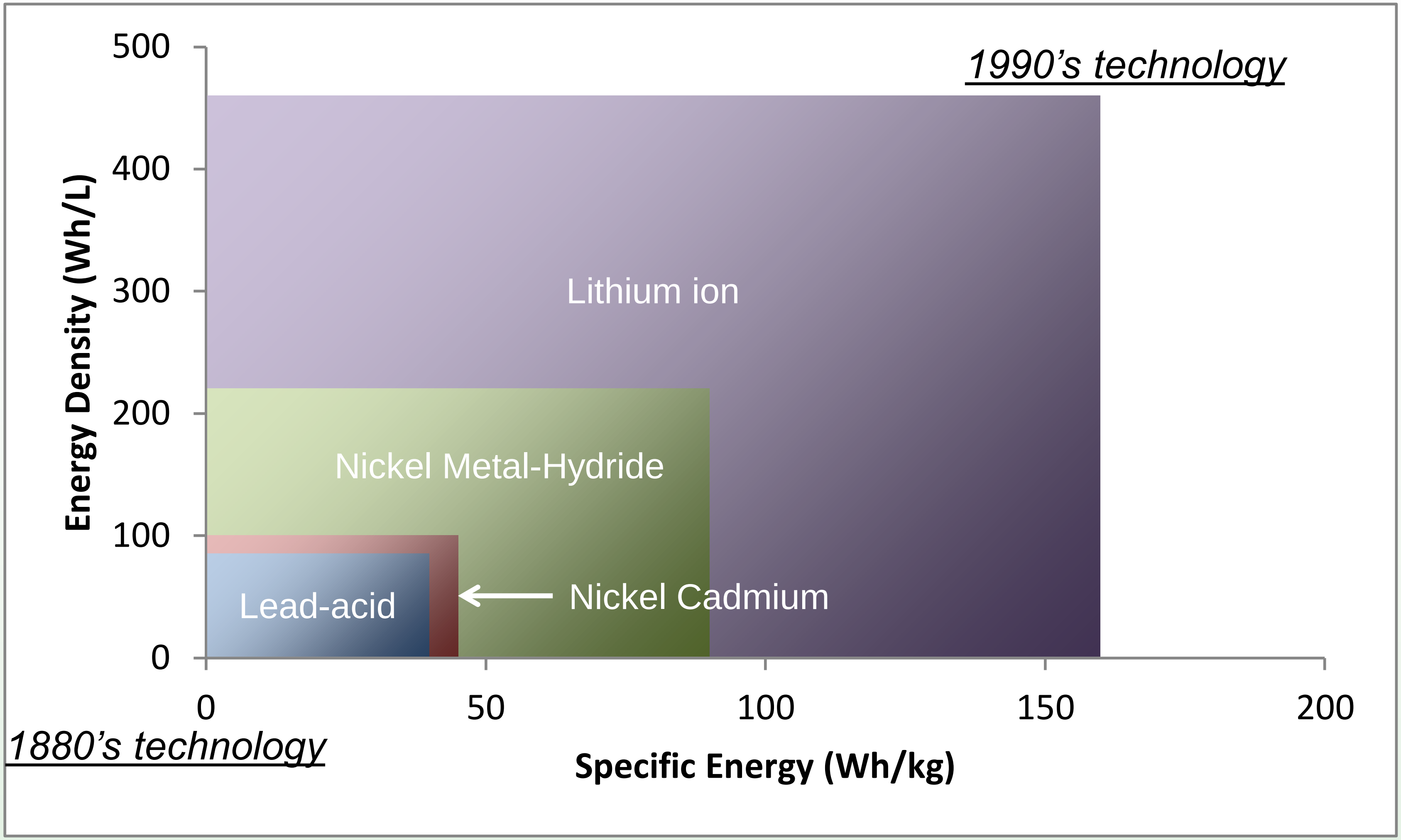
- Lower emissions
  - None at tailpipe
  - Could be some at the source (e.g. coal vs. solar)
  - VW emissions test “cheating” scandal
- More power = FUN!
  - E.g. Tesla’s “insane” mode = 691 hp

Why Not More EVs in Market?

- 1900's – No go…
  - Low range, no infrastructure, cheap oil
- 1970's – No go…
  - Low range, no infrastructure, cheap oil
- 1990's – Moderate success!
  - Low range, no infrastructure, high manufacturing costs (a.k.a. cheap oil)

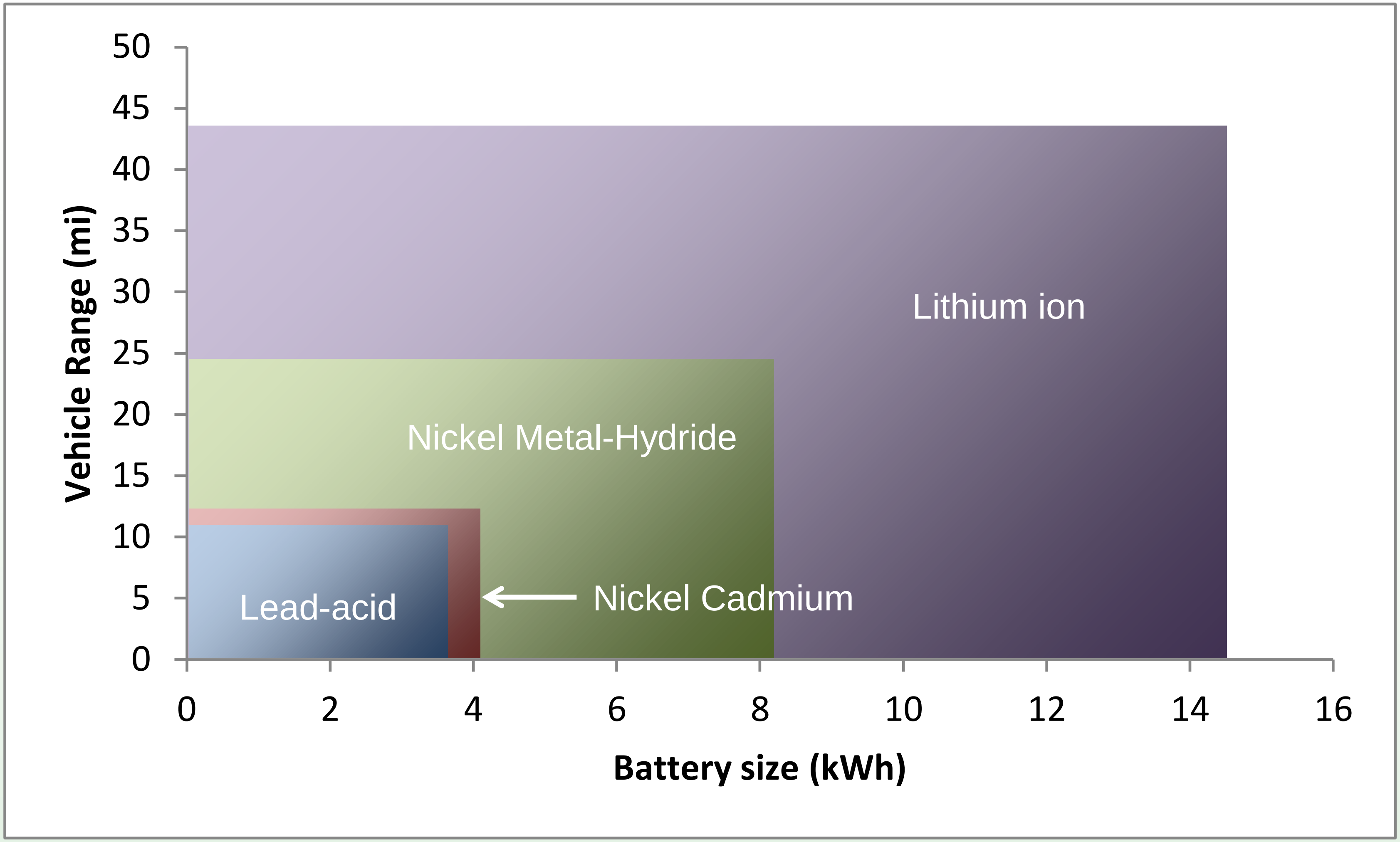
<u>What's different about today???</u>

Invention of Better Batteries



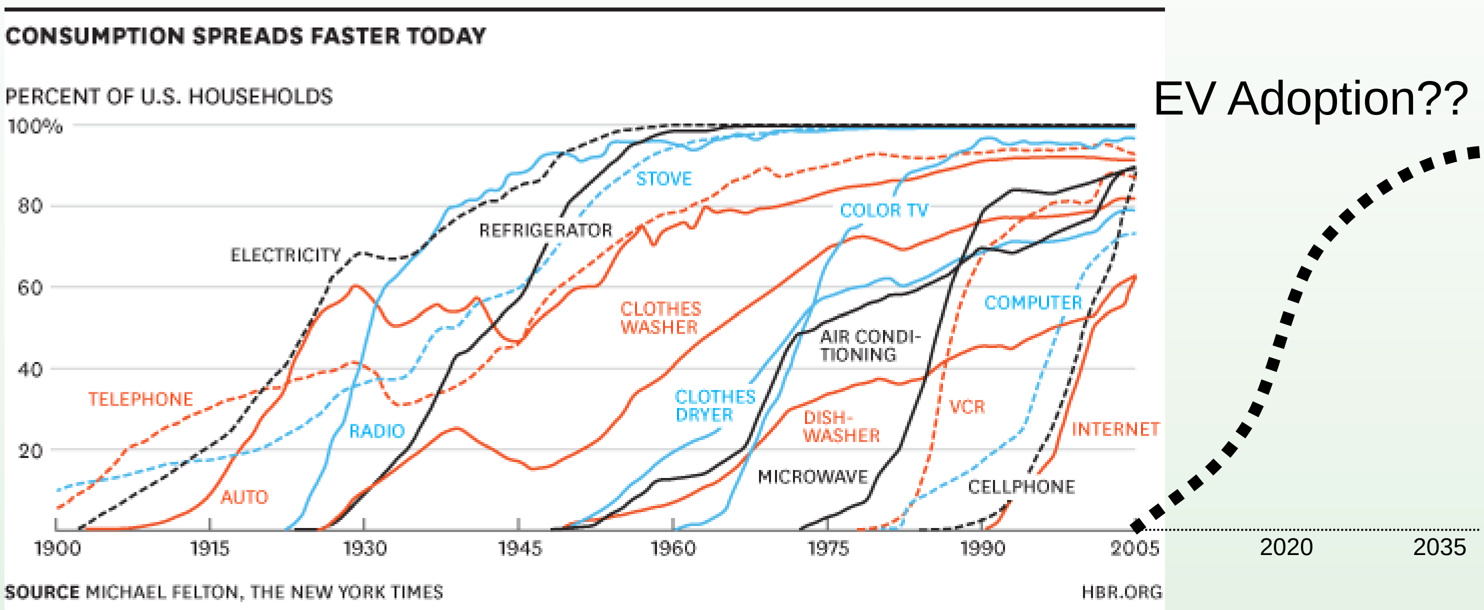
Battery Size vs. Vehicle Range

Assume 200 lb battery and 3 mi/kWh vehicle efficiency, based on theoretical energy density



Infrastructure Improvements

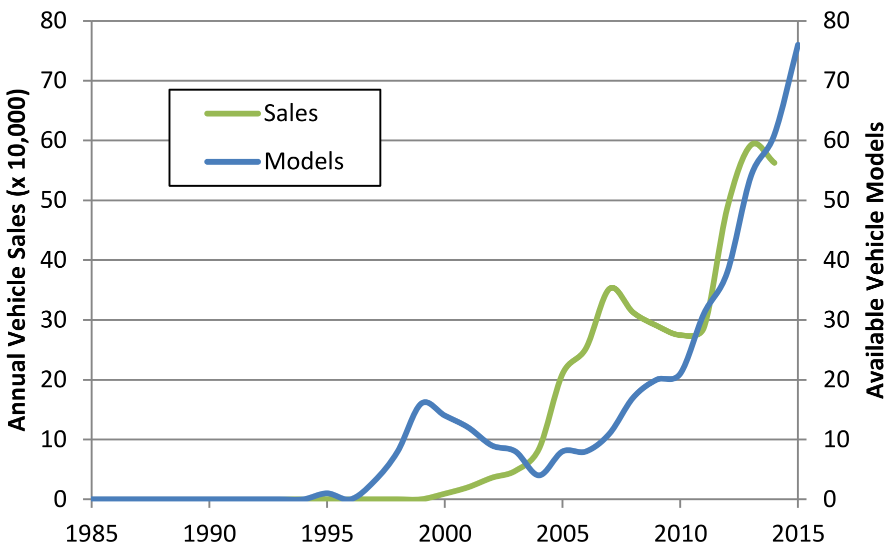
- In early 1900’s, <10% of households had electricity
- Refueling EVs was more difficult than gas

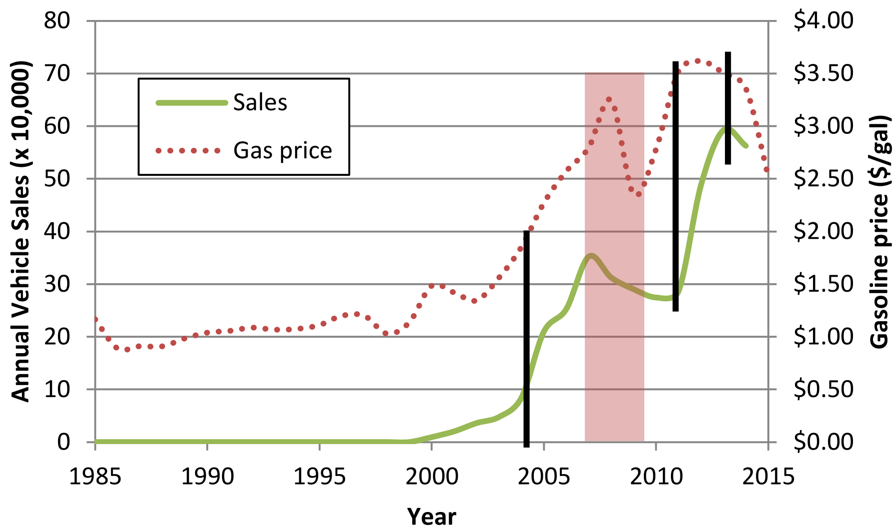


https://hbr.org/2013/11/the-pace-of-technology-adoption-is-speeding-up/

Electric Vehicle Sales

- An increasing number of models since 2005
  - Many models in late 1990's didn't succeed
- Steady sales increase since 2005
  - Gas prices have significant impact

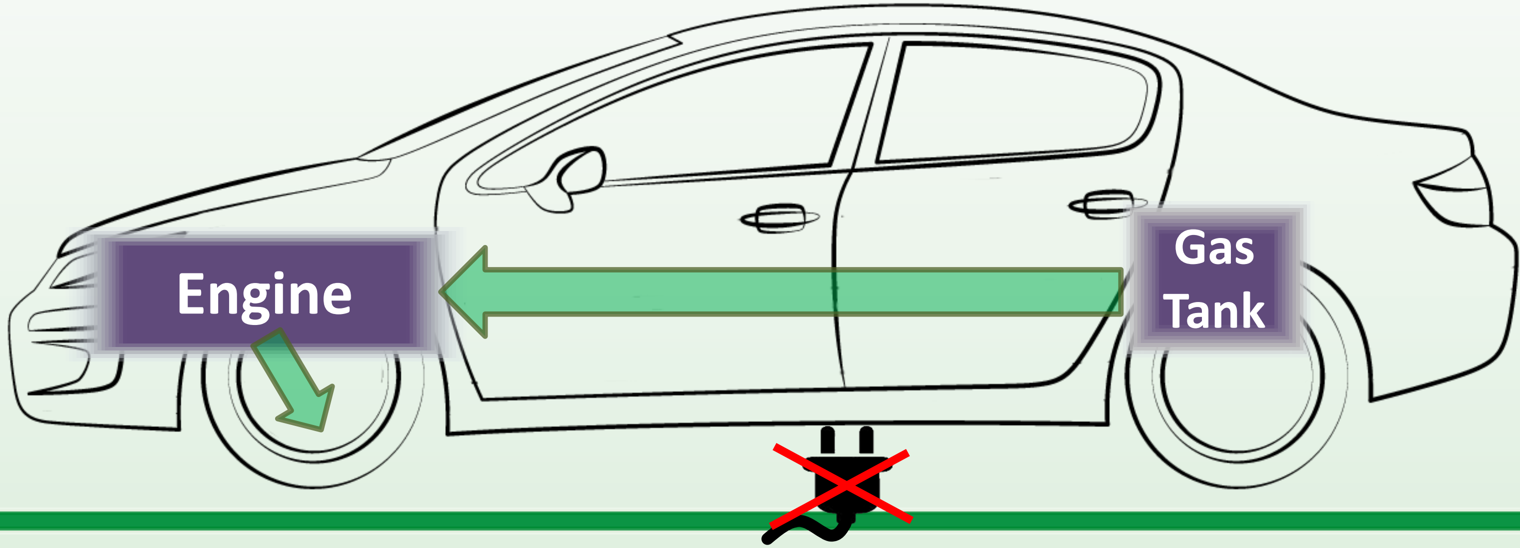




Electric vehicles today

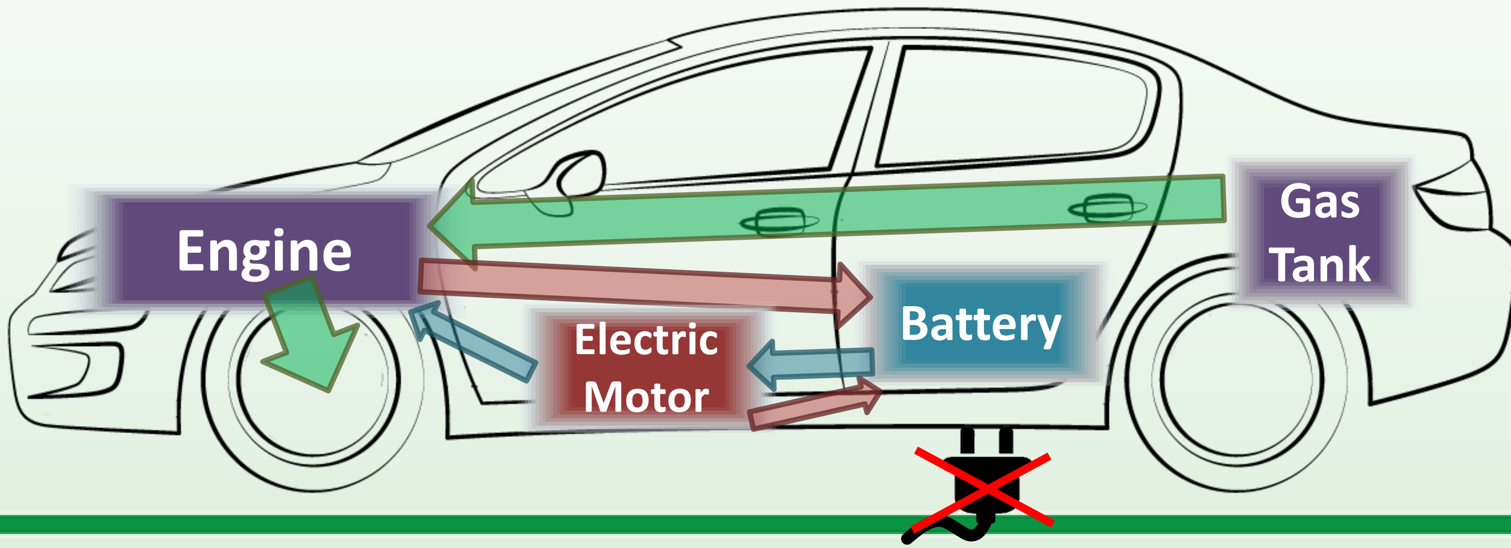
Powertrain Types

- Conventional Vehicles – 25-30 MPG
  - E.g. Toyota Camry, Honda Accord
  - Gasoline engine
  - No way to import/export electricity



Powertrain Types

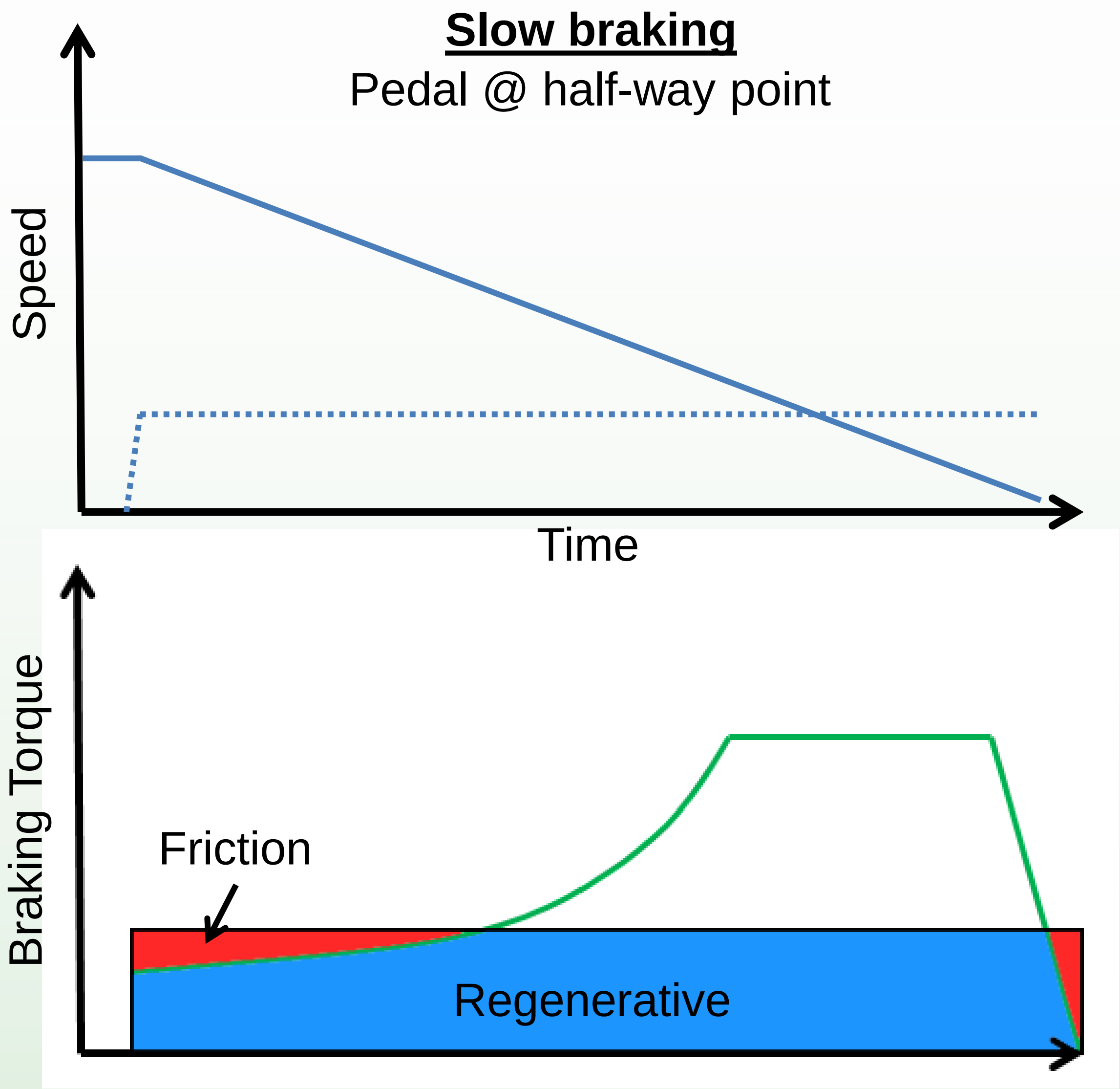
- Hybrid Vehicles – 50 MPG
  - E.g. Toyota Prius, Honda Accord Hybrid
  - Small battery, used for engine assists periodically
  - No way to import/export electricity

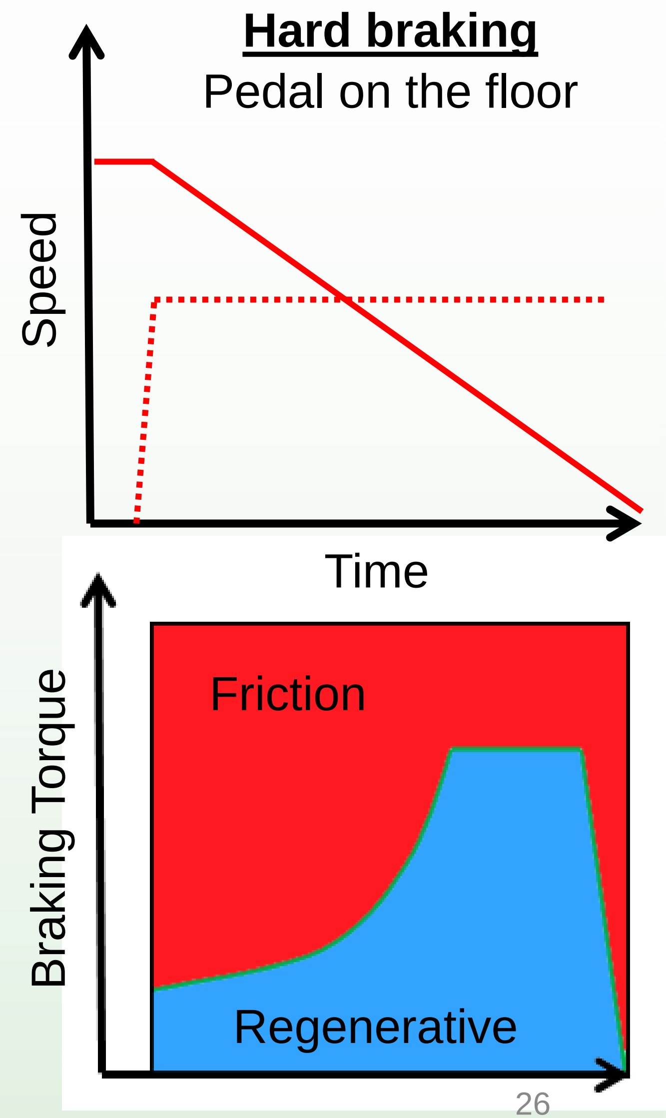


Regenerative Braking

- Recapture kinetic energy and store in battery
  - Efficiency: 30-40%, depending on speed and SOC
- Utilizes AC motor to produce back-EMF
- Advantages
  - Improved fuel economy
  - Reduced brake wear
  - Reduced engine wear

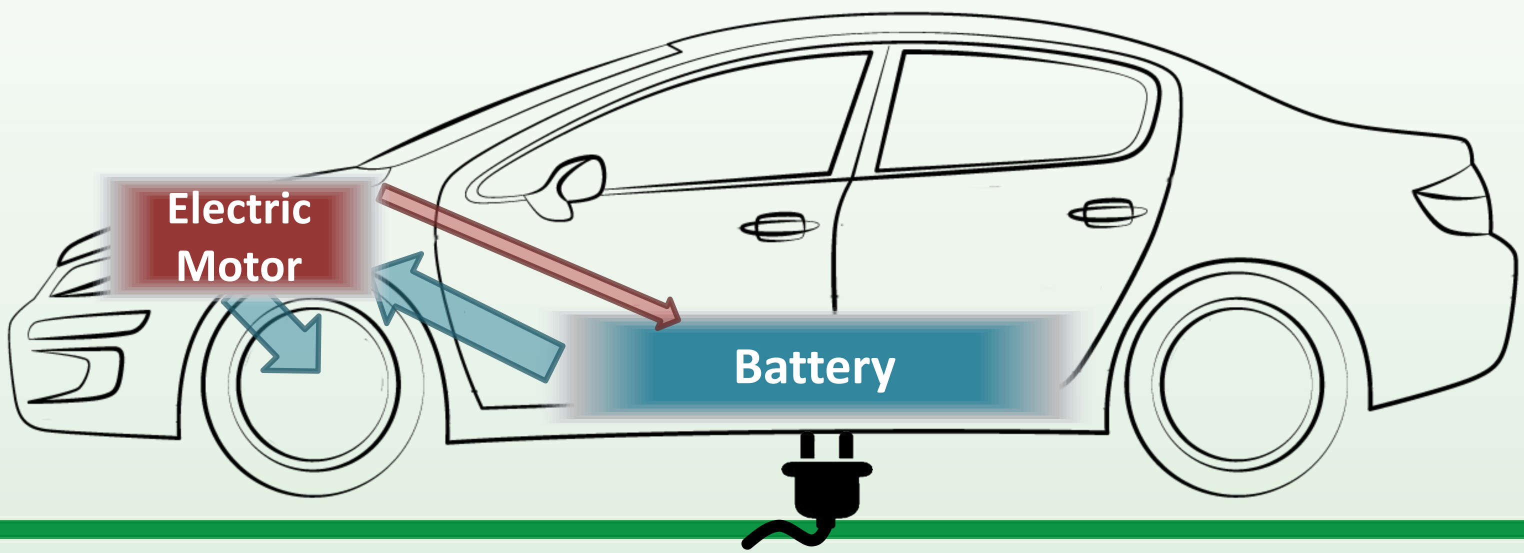
Braking Style vs. Efficiency





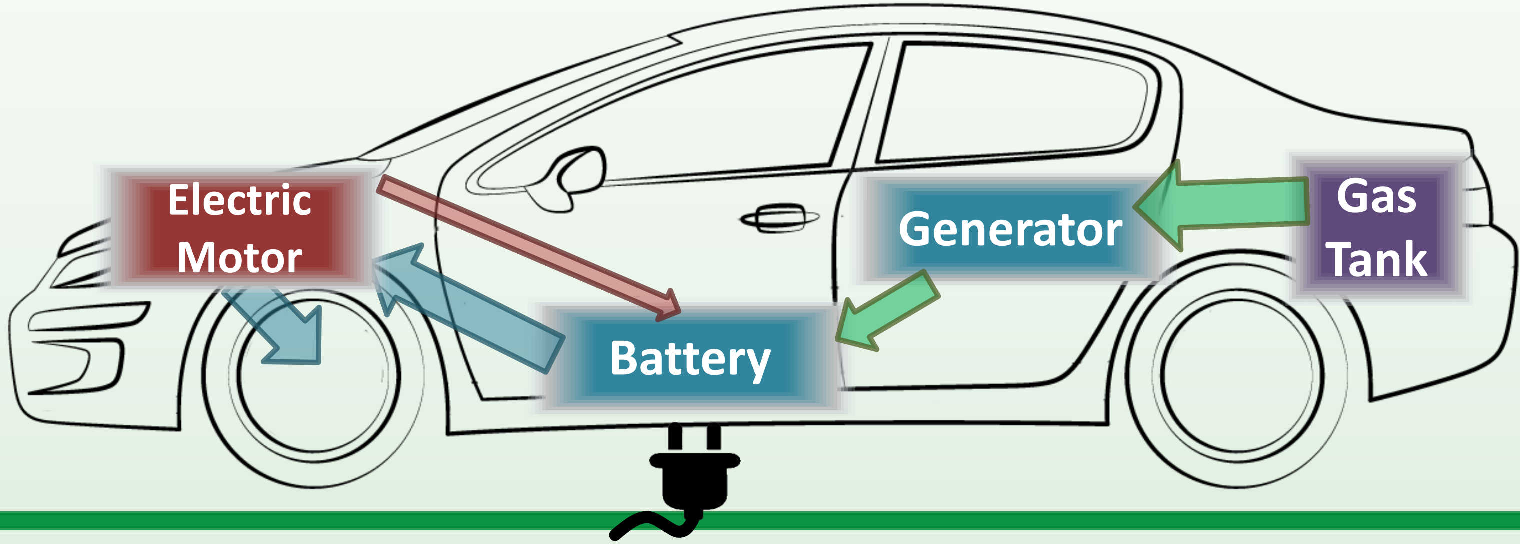
Powertrain Types

- Battery Electric Vehicle (BEV) – 95-112 MPGe
  - E.g. Nissan Leaf, Tesla
  - Large battery (24-85 kWh) = *ENERGY*
  - High power (100-250 kW, 130-335 hp) = *POWER*



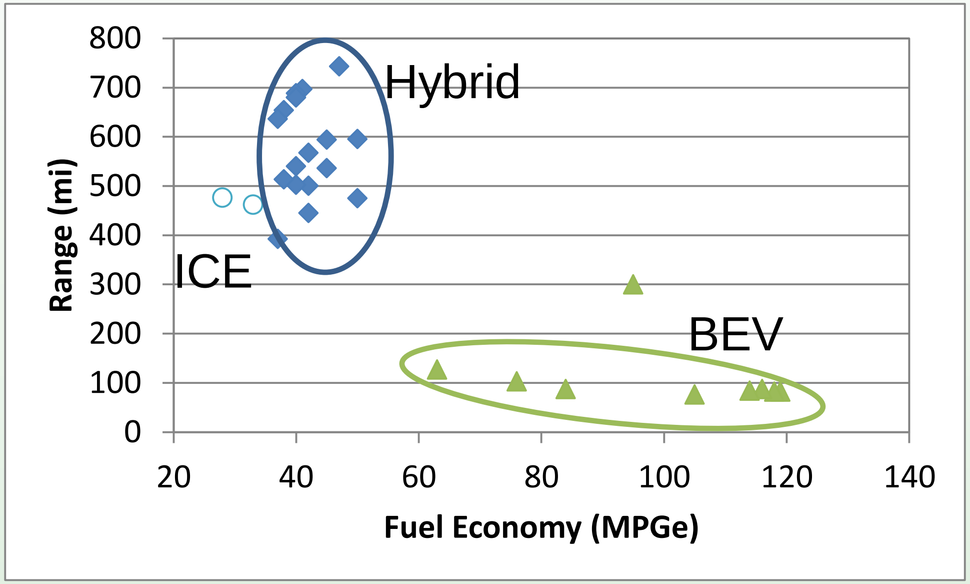
Powertrain Types

- Plug-in Hybrid Electric Vehicle (PHEV) – 38/92 MPGe
  - Fuel economy depends on trip length
  - Battery and on-board generator
  - E.g. Plug-in Prius (PHEV-11), Chevy Volt (PHEV-38)



Impact of Range on Fuel Economy

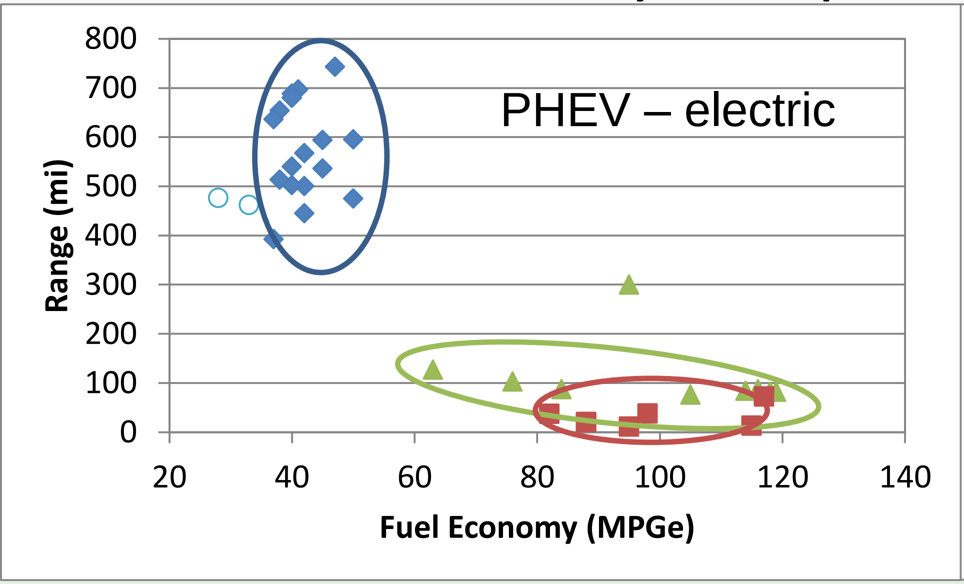
- BEV give higher economy, but lower range
  – Electric conversion efficiency >90%
  – ICE conversion efficiency ~30%
- Constant fuel economy for a given trip length

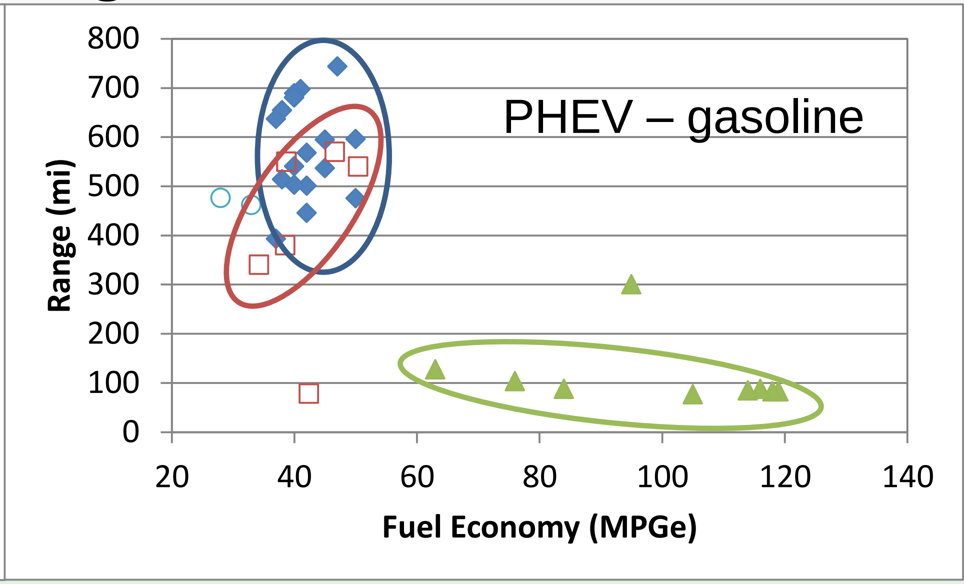


Data from www.afdc.energy.gov

Impact of Range on Fuel Economy

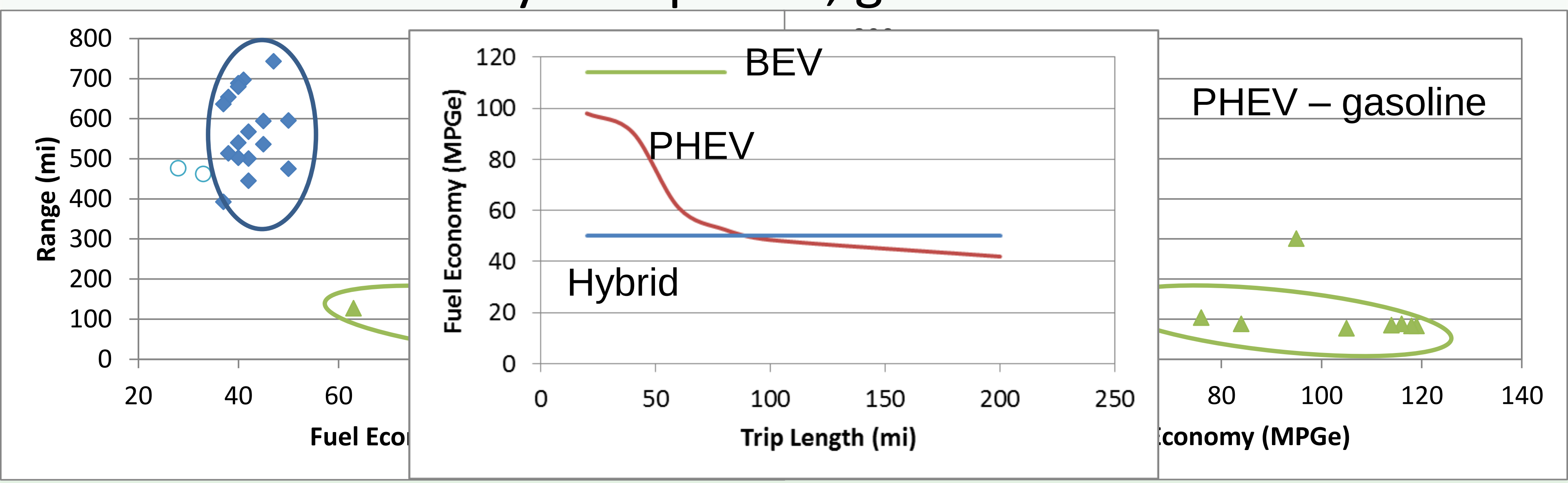
- PHEVs operate some distance on electric
  - Small range (11-40mi) on battery only
- Fuel economy changes with trip length
  - After battery is depleted, gasoline kicks in





Impact of Range on Fuel Economy

- PHEVs operate some distance on electric
  - Small range (11-40mi) on battery only
- Fuel economy changes with trip length
  - After battery is depleted, gasoline kicks in

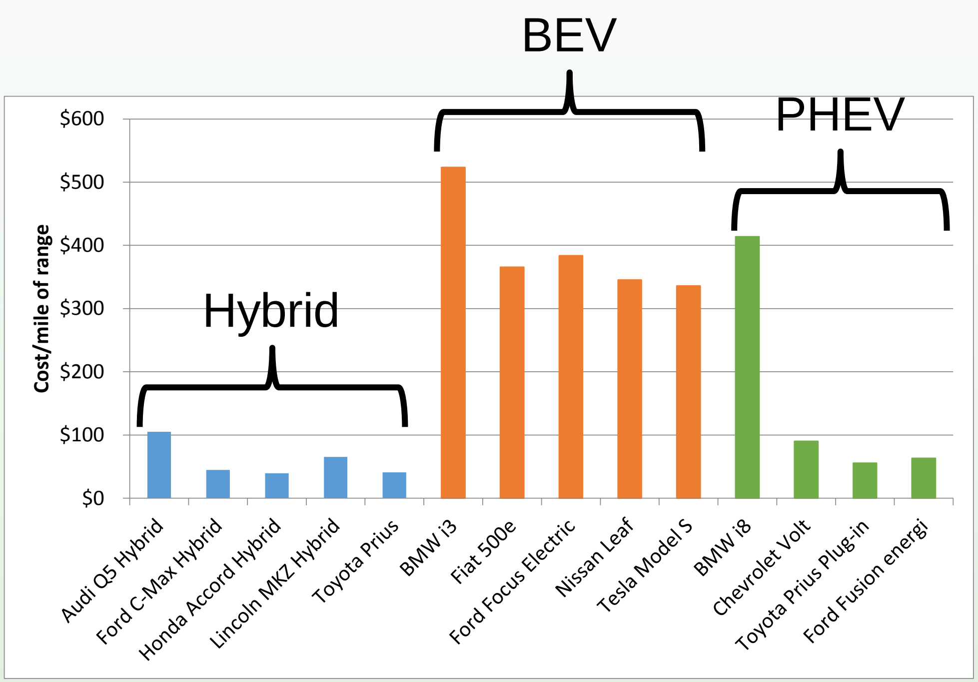


Hybrid Vehicles HVs	Battery Electric Vehicles BEVs	Plug-in Hybrid Electric Vehicles PHEVs
27 to 70 MPG	84 to 124 MPGe	17-50 MPG (gas) 18-117 MPGe (battery)
Audi Q5 Hybrid BMW ActiveHybrid 3, 5, and 7L Buick Lacrosse Buick Regal Ford C-Max Hybrid Ford Fusion Hybrid Honda CR-Z Honda Civic Hybrid Honda Accord Hyundai Sonata Hybrid Infiniti Q50, Q70, QX60 Hybrids Kia Optima Hybrid Lexus CT, ES, LS, NX, RX Lincoln MKZ Hybrid Mercedes E 400 Hybrid Nissan Pathfinder Hybrid Subaru XV Crosstrek Hybrid <u>Toyota Prius</u> Toyota Avalon Hybrid Toyota Highlander Hybrid VW Jetta Hybrid VW Touareg Hybrid	<u>BMW i3</u> Chevrolet Spark EV Fiat 500e Ford Focus Electric Kia Soul Electric Mercedes B-Class Electric Mercedes Smart fortwo Electric Nissan Leaf Tesla Model S Tesla Model X Volkswagen e-Golf	<u>BMW i3-REX</u> BMW i8 Cadillac ELR Chevrolet Volt Ford C-Max Energi Ford Fusion Energi McLaren P1 Porsche 918 Spyder Porsche Cayenne S e-Hybrid Via Motors VTrux Toyota Prius Plug-In

Underlined vehicles are most efficient
Data from www.fueleconomy.gov

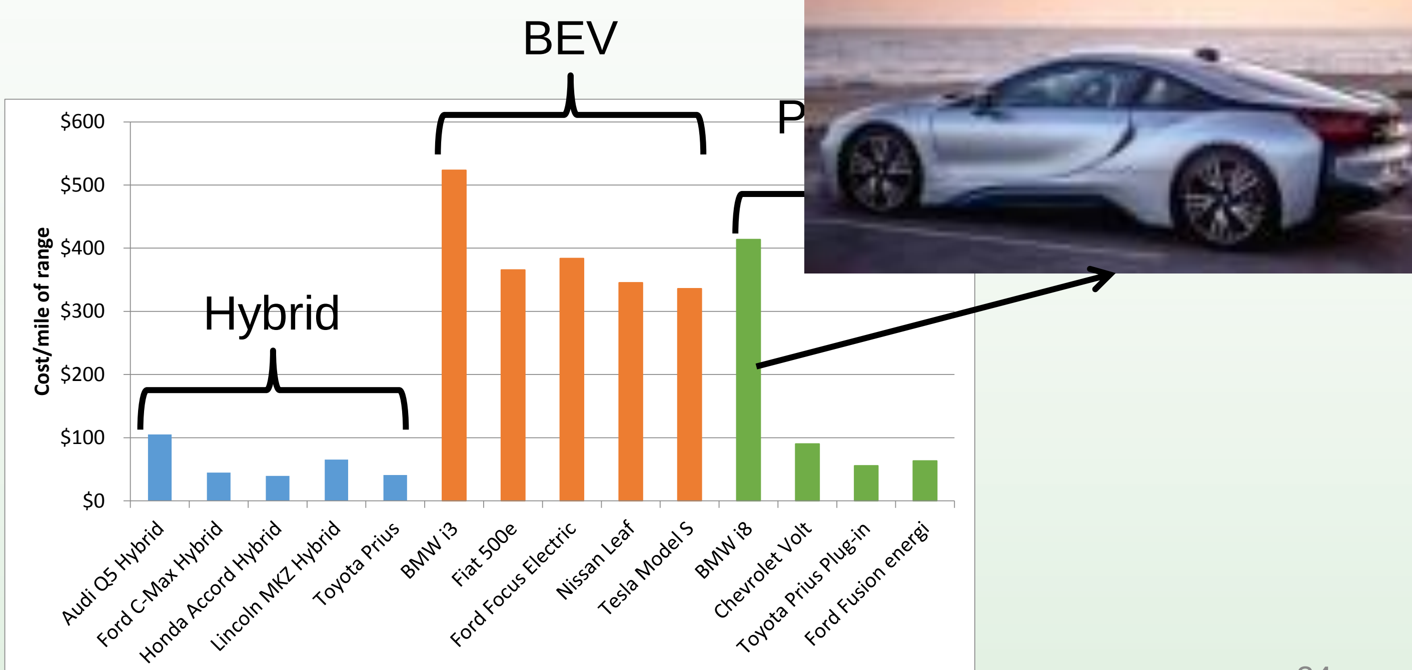
Cost Per Mile of Range

- MSRP divided by range of vehicle
  - BEVs cost more per mile of range
  - Lower fueling costs could help mitigate this effect



Cost Per Mile of Range

- MSRP divided by range of vehicle
  – BEVs cost more per mile of range
  – Lower fueling costs could help mitigate this effect



Fueling electric vehicles

Charging Stations (EVSE)

- Batteries are DC devices
  - Always requires DC at the terminals to recharge
- Two broad categories of chargers
  - AC chargers: rely on on-board AC-DC converters
  - DC chargers: utilize off-board AC-DC converters

120V AC

L1

240V AC

L2

DC Fast charger

DCFC

Charging Stations: AC

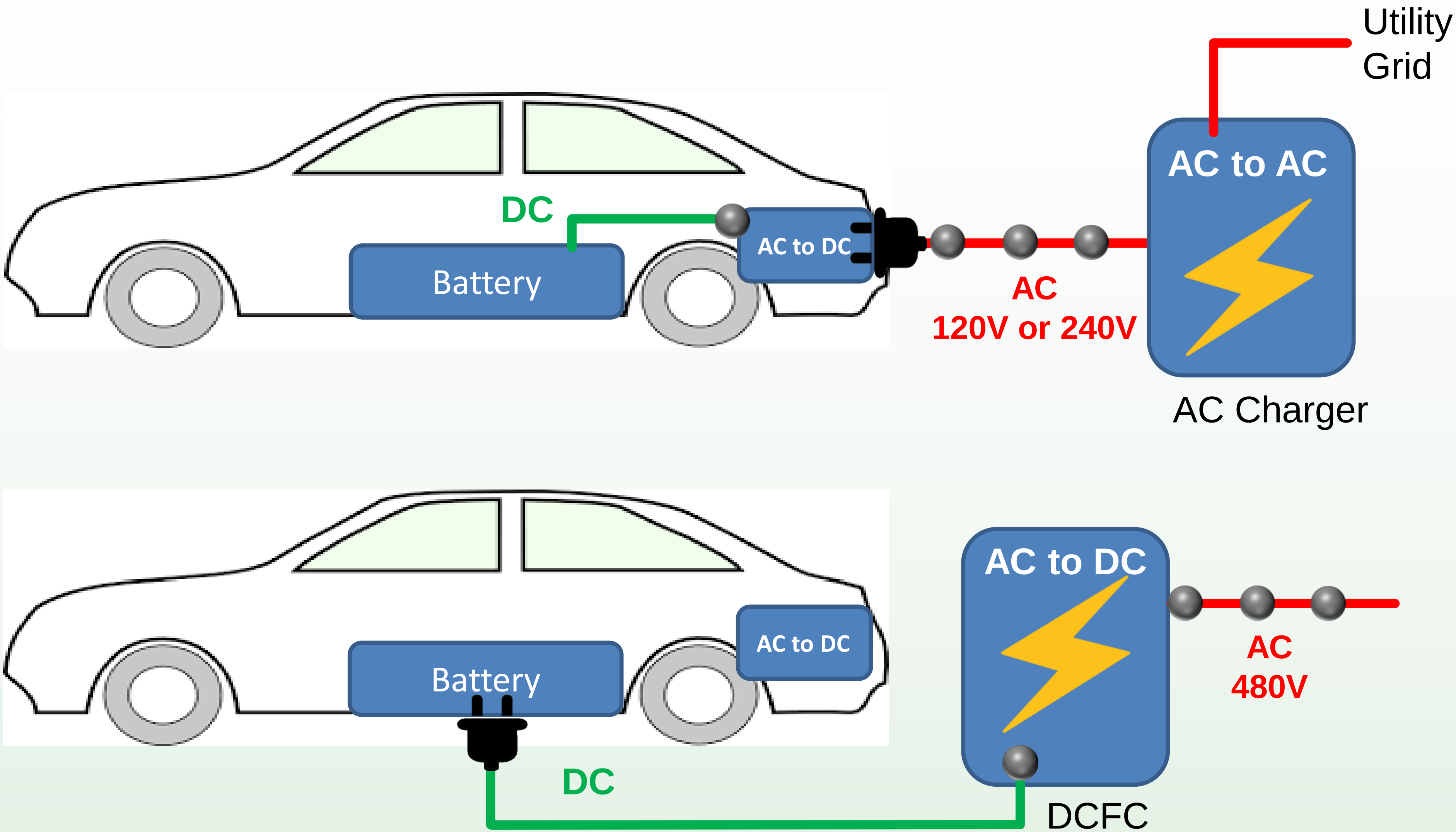
- Purpose: to deliver AC to the vehicle
- SAE J1772 Standard specifies three levels
  - Level 1: 0-2 kW (16A @ 120VAC)
  - Level 2: 2-20 kW (28A @ 240VAC)
  - *Level 3: 20-100 kW (416A @ 240VAC)*
- The on-board AC-DC converter is limiting
  - Typically 3.3 or 6.6 kW (13-26 mi/hr of charge*)

* depends on the efficiency of the vehicle

Charging Stations: DC

- Purpose: Convert AC into DC and deliver directly to the battery
- SAE J1772 Standard specifies three levels
  - Level 1: 0-32 kW (70A @ 480VAC)
  - *Level 2: 32-80 kW (170A @ 480VAC)*
  - Level 3: 80-160 kW (260A @ 480VAC)
- Power limited by off board charger and battery sizes

AC and DC Chargers

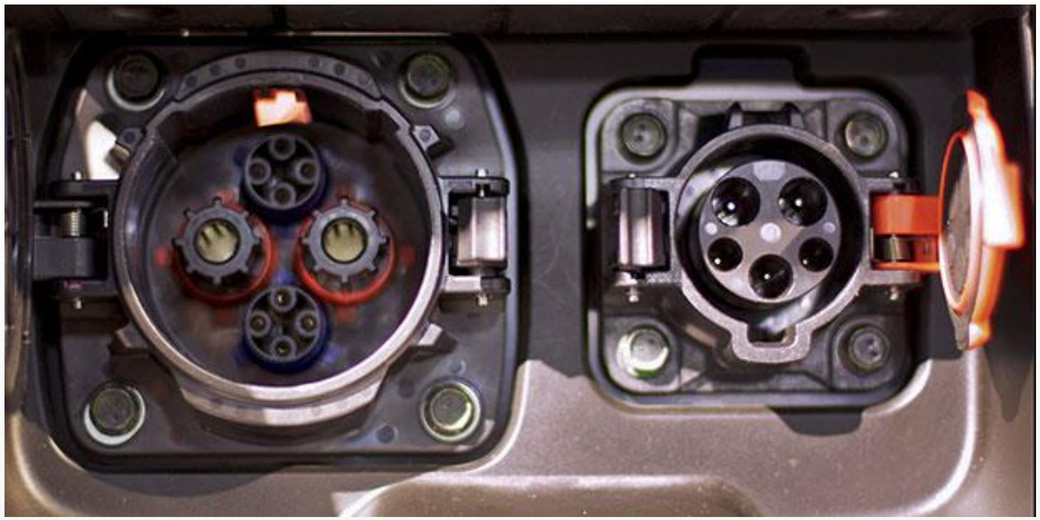


Charging Ports

DCFC port

L1/L2 AC port

Mynissanleaf.com



http://www.plugincars.com/electric-vehicle-charging-basics-125792.html

Wikipedia

DCFC and L2

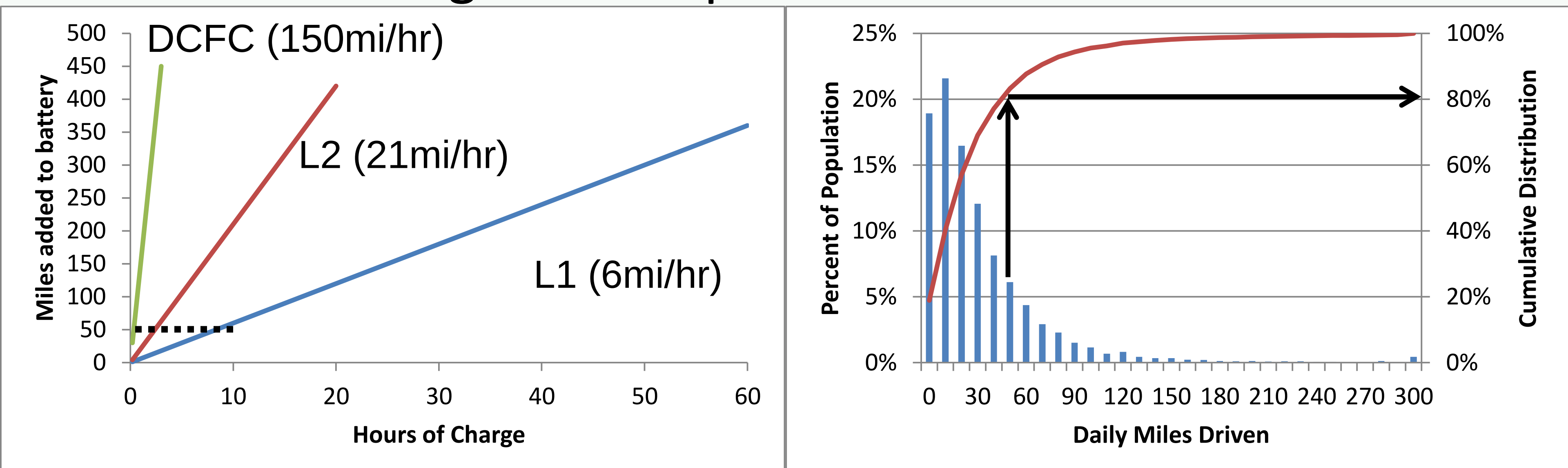
http://articles.sae.org/11484/

240V “Dryer” plug

120V plug

Miles/hr-Charge vs. Miles/Day

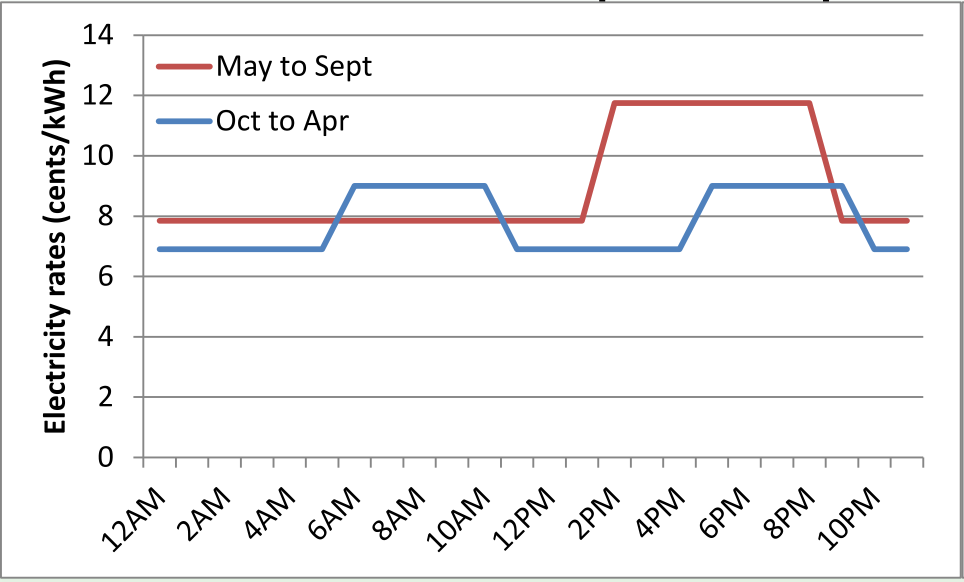
- Amount of time for recharge depends on charger type and miles "consumed"
- Most driving habits "consume" < 50 miles/day
  - L1 overnight is adequate for most users

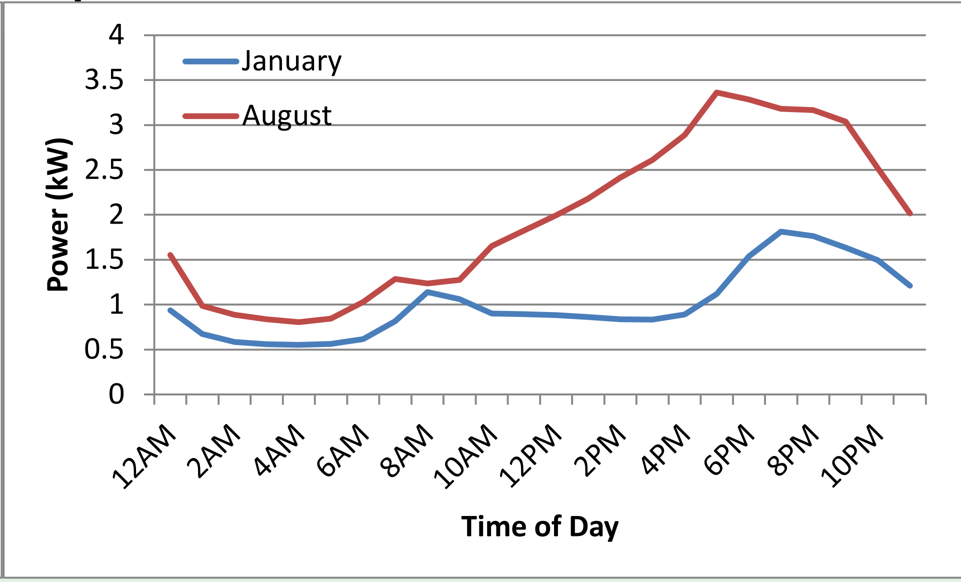


R.P. Brooker and N.Qin. Identification of potential locations of electric vehicle supply equipment. Journal of Power Sources 299 (2015) 76-84

Comments about EVSE Operation

- Residential – “Time of Use” Rates
  - – Increased rates at different times of day
- Due to cyclic energy demand at homes
  - – Inefficient peaker power plants come online

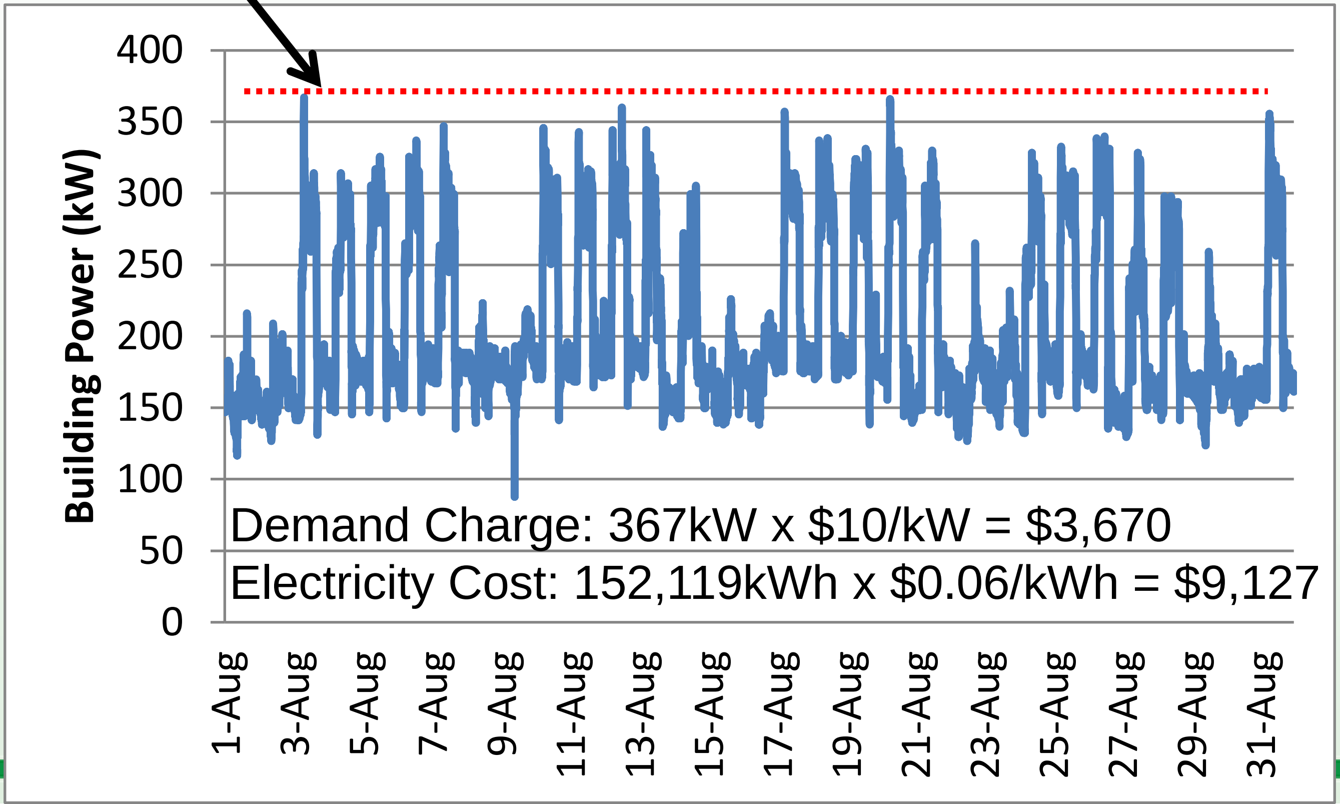




Comments about EVSE Operation

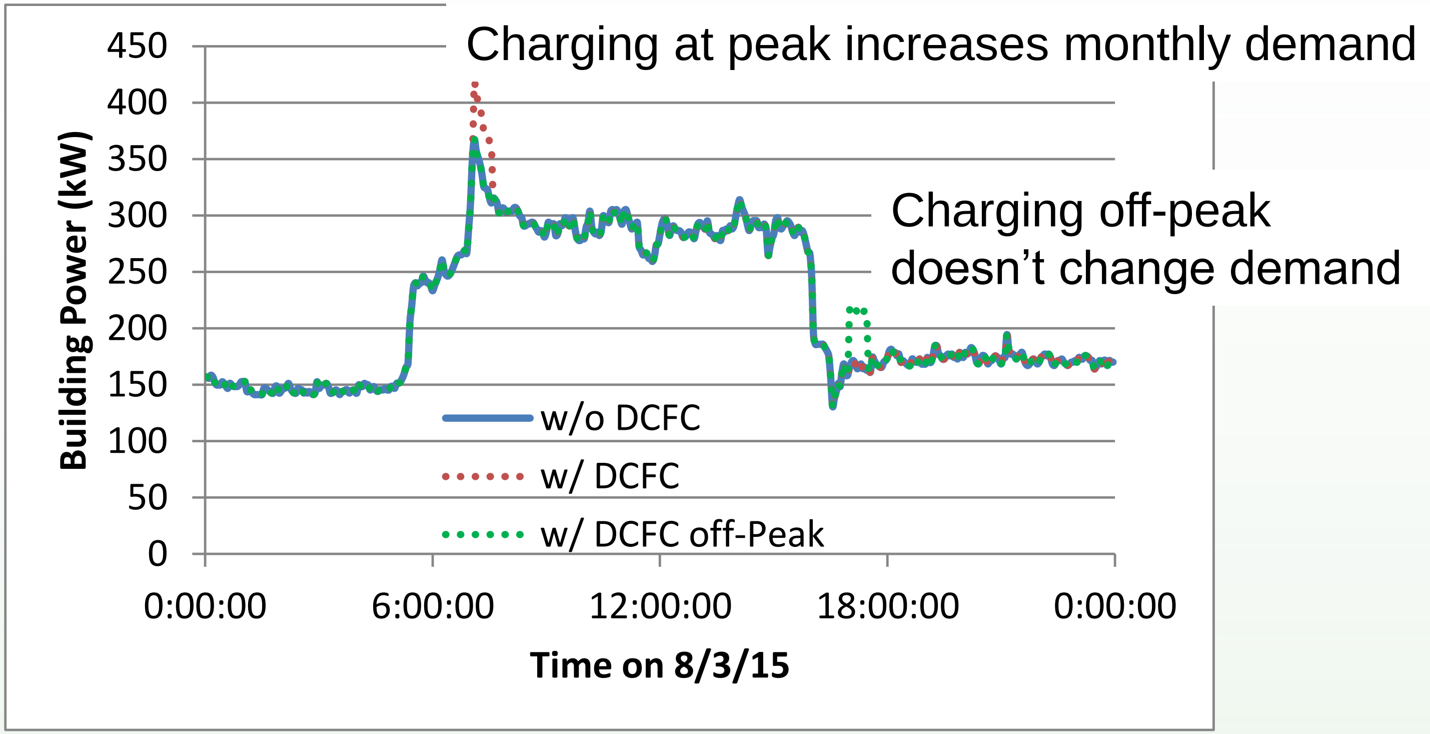
- Commercial – Demand Charges
  - Monthly costs associated with *power* at the site

Highest Power = 367 kW on 8/3/15



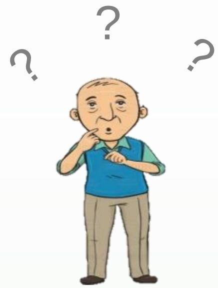
Building power demand on 8/3/15 contributed to 29% of electricity bill

Impact of DCFC on Demand Charges



	Demand Charges	Electricity Costs	% Demand Charge
w/o DCFC	$3,672	$9,127	29%
w/ DCFC	**$4,172**	$9,128	**32%**
w/ DCFC off-Peak	$3,672	$9,128	29%

Lithium-ion Batteries



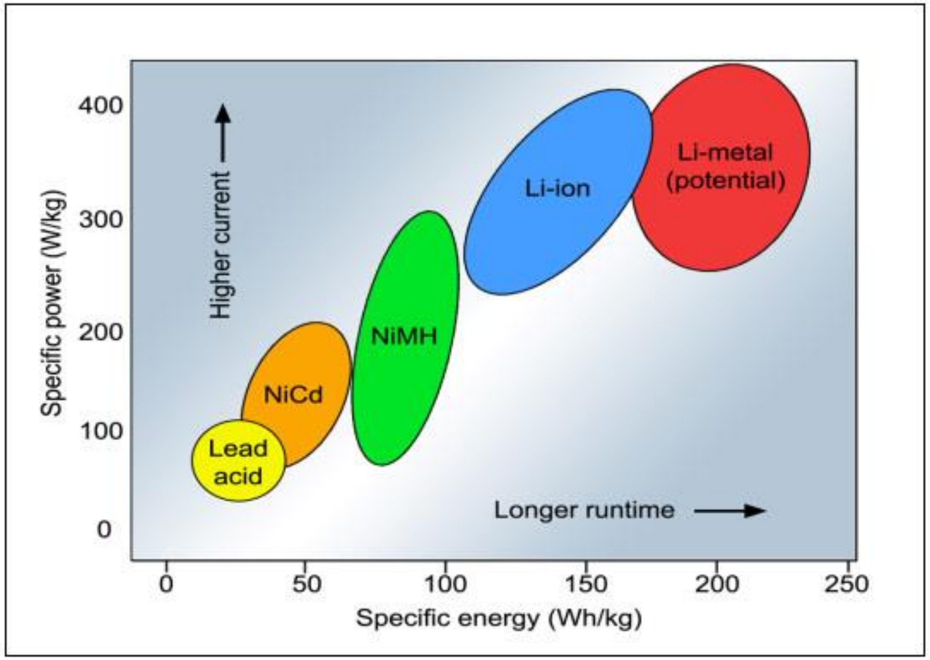
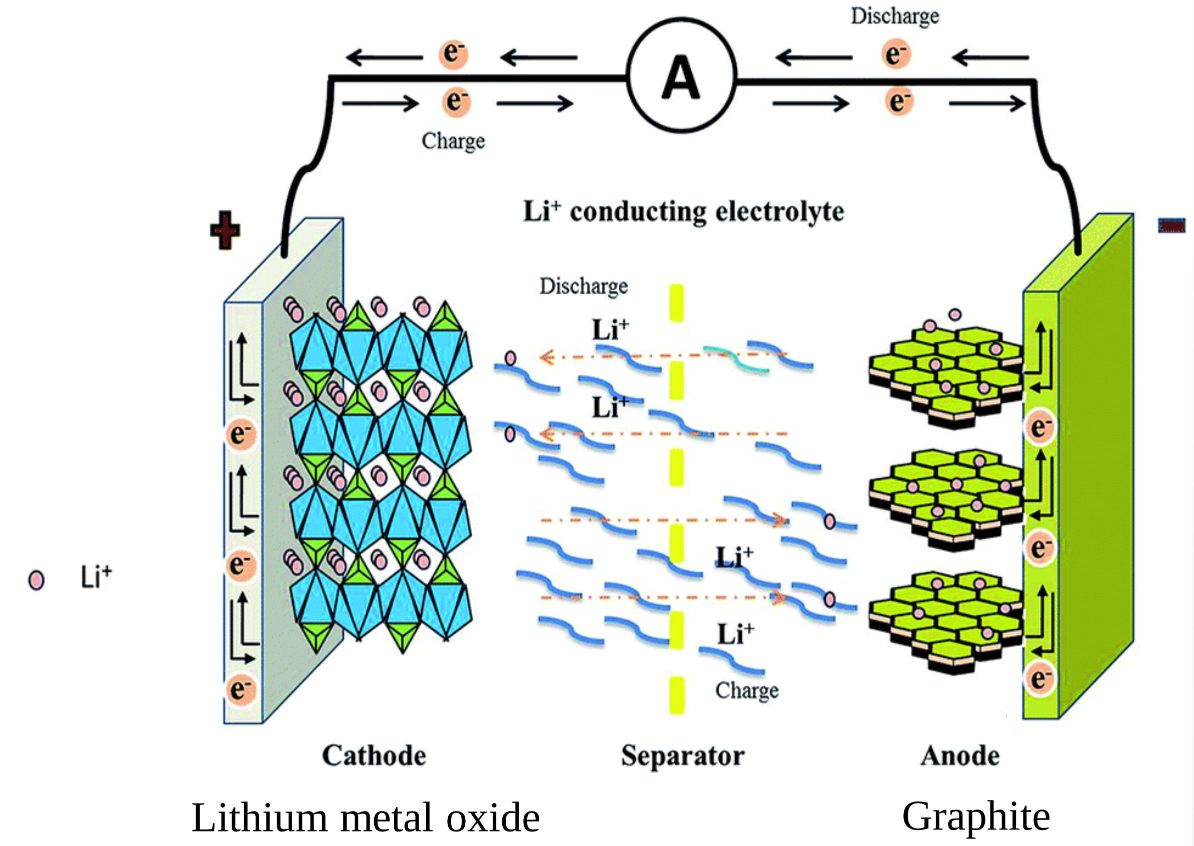


Image downloaded from manufacturer website
http://batteryuniversity.com/learn/article/global_battery_markets

Lithium-ion Battery Mechanism



$$LiC_6 \rightarrow Li^+ + e^- + C_6$$

Discharge

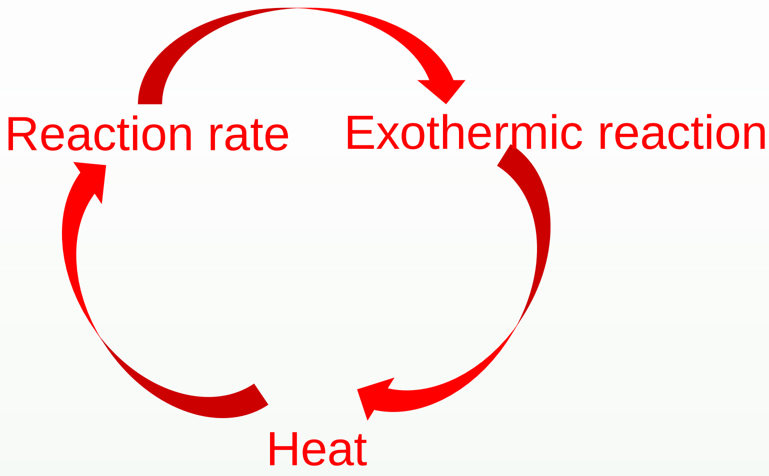
H. Lee, et. Al., A review of recent developments in membrane separators for rechargeable lithium-ion batteries, Energy & Environmental Science, 2014, 7, 3857-3886

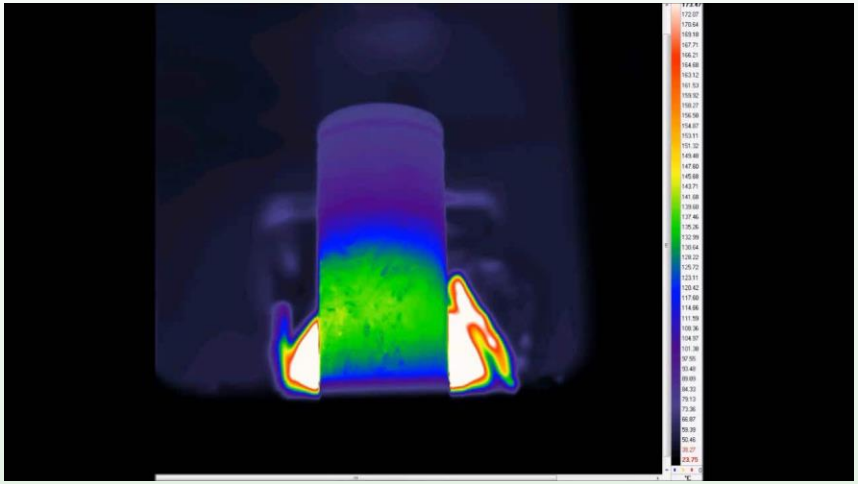
Types of lithium-ion Battery

Type	Chemical Composition	Acronym
Lithium cobalt oxide	$LiCoO_2$	LCO
Lithium manganese oxide	$LiMn_2O_4$	LMO
Lithium nickel manganese cobalt oxide	$LiNiMnCoO_2$	NMC
Lithium iron phosphate	$LiFePO_4$	LFP
Lithium nickel cobalt aluminum oxide	$LiNiCoAlO_2$	NCA
Lithium titanate	$Li_4Ti_5O_{12}$	LTO

Thermal runaway (safety)
C-rate (discharging and charging rate)
Specific Energy
Specific power

Thermal Runaway

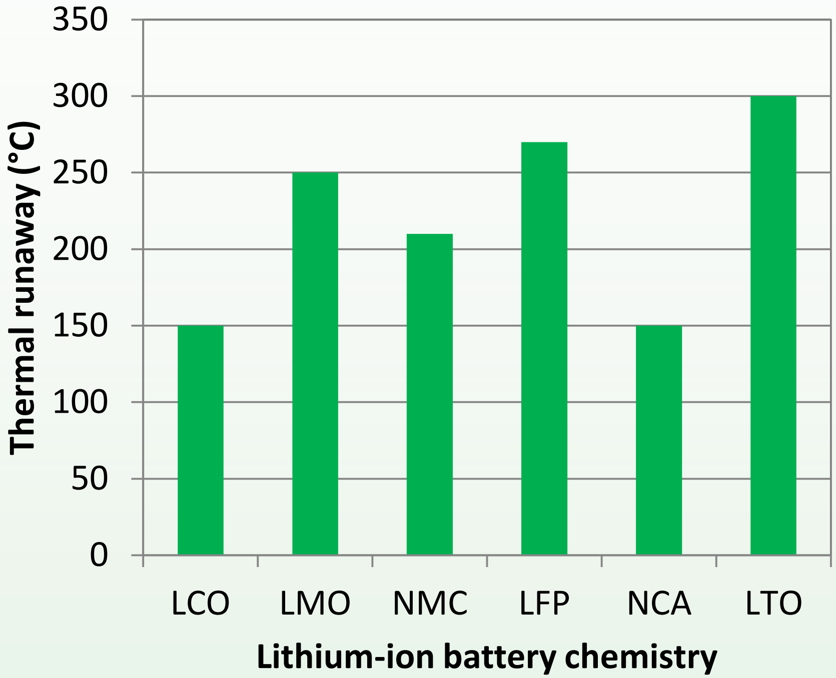




http://www.nature.com/ncomms/2015/150428/ncomms7924/full/ncomms7924.html

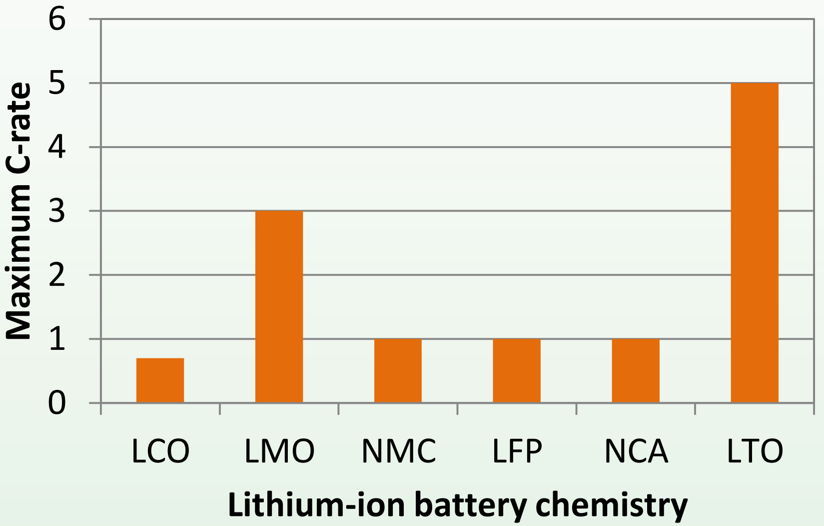
Safety of Lithium-ion batteries

The higher the thermal runaway temperature, the safer the battery



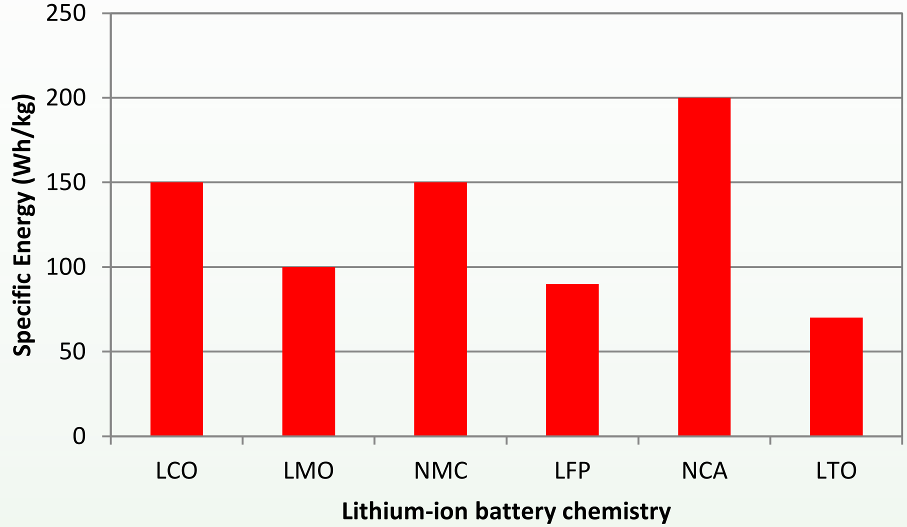
What is C-rate

- C-rate is a measure that governs at what current a battery is charged and discharged.
- E.g. for a 1,000 mAh battery:
  - 0.5C=500mA/hour
  - 1C=1000mA/hour
  - 2C=2000mA/hour
  - 5C=5000mA/hour



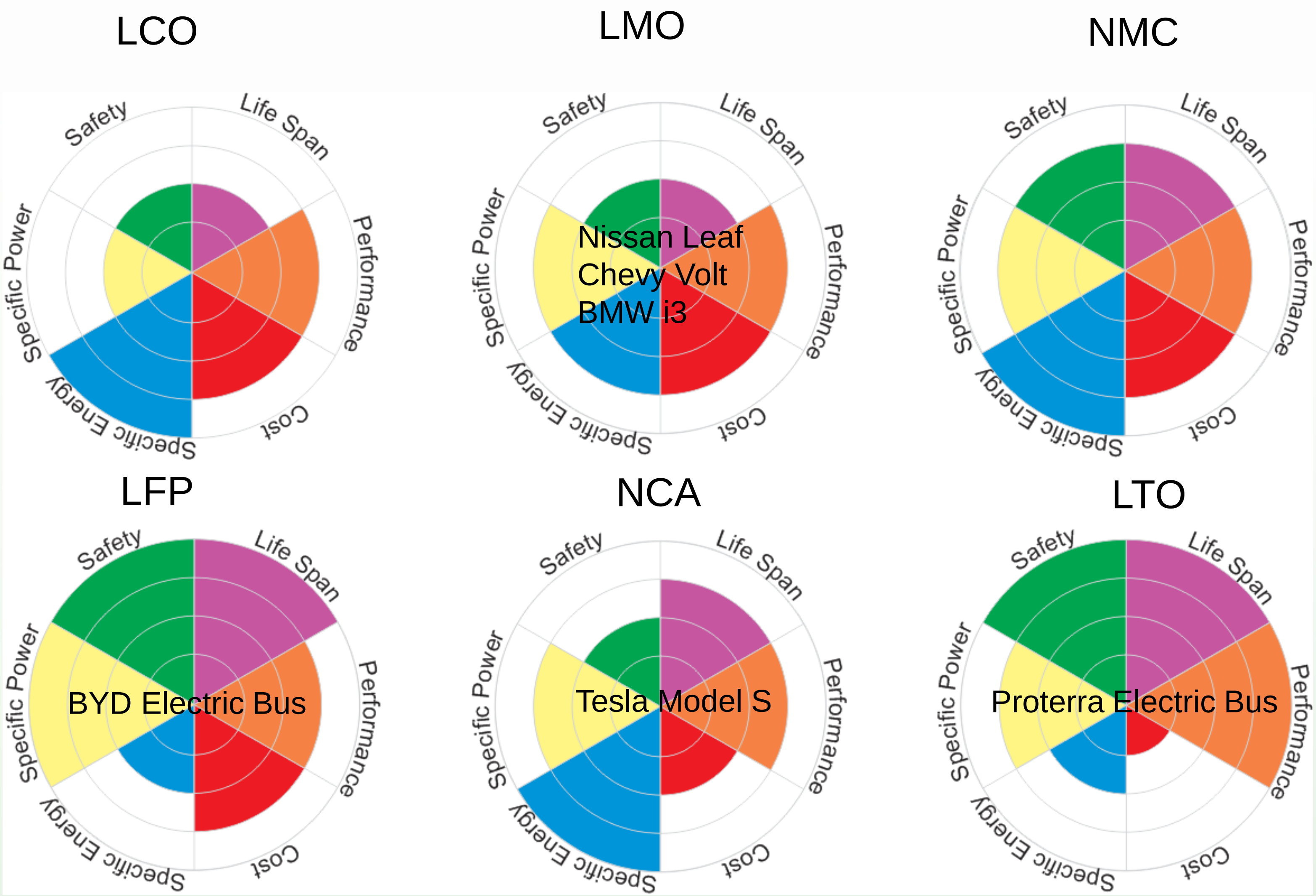
Specific Energy and Specific Power

- Specific Energy: Energy per unit mass.



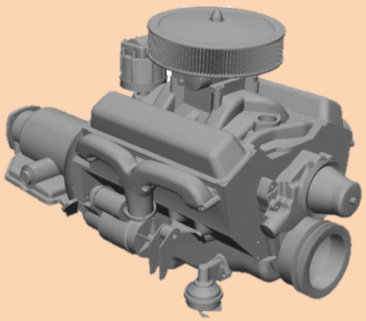
- Specific Power: Power per unit mass.
  - Specific power is depending on the specific energy and maximum C-rate.

Lithium-ion Battery Comparison

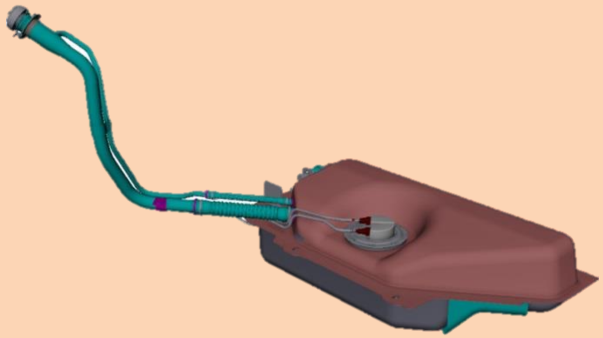


Dilemma for Lithium Battery as an EV Energy Source

Conventional Vehicles

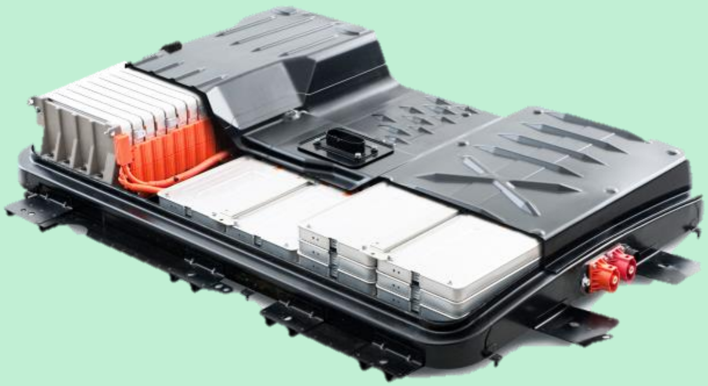


Engine determines power



Gas tank size determines energy (range)

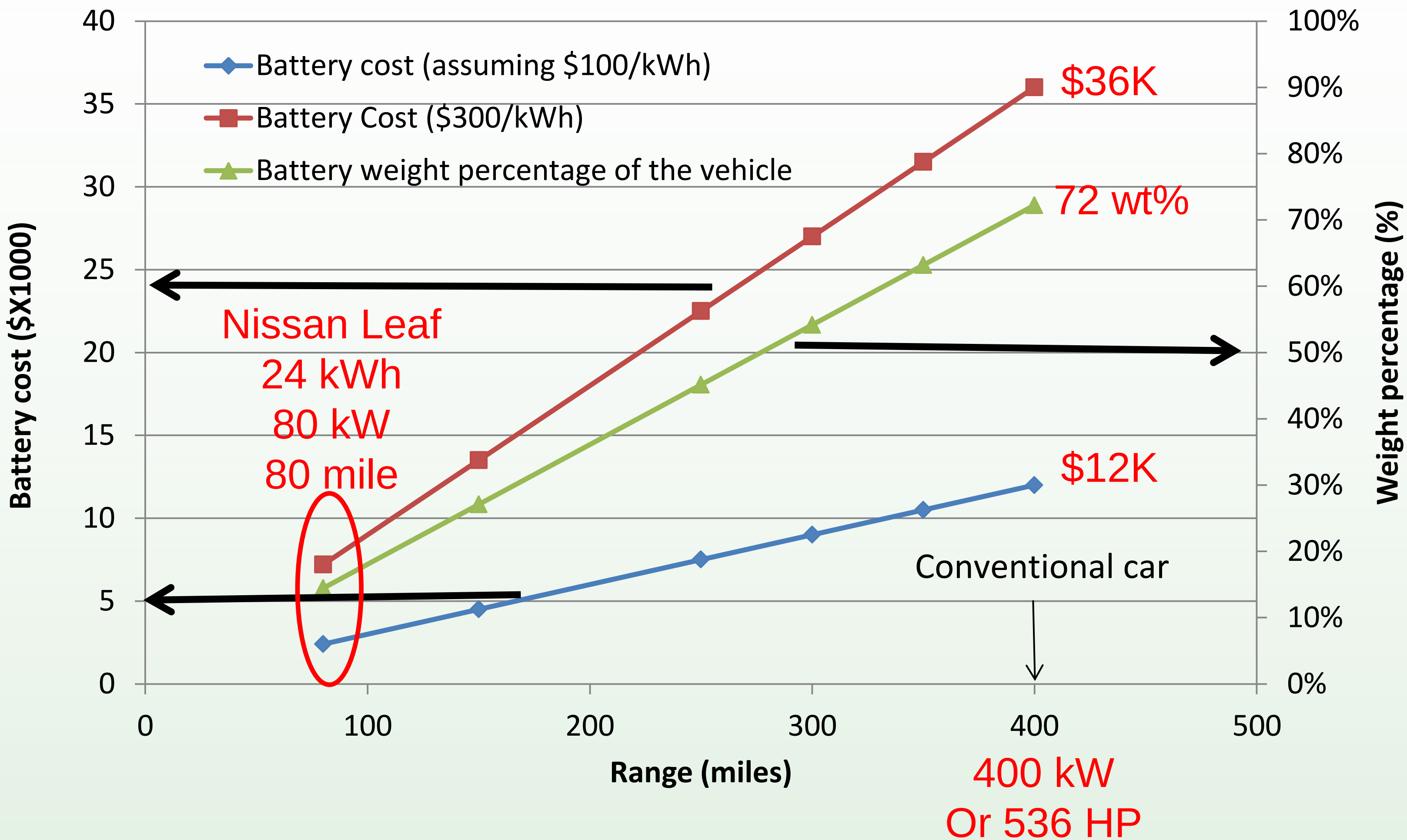
Electric Vehicles

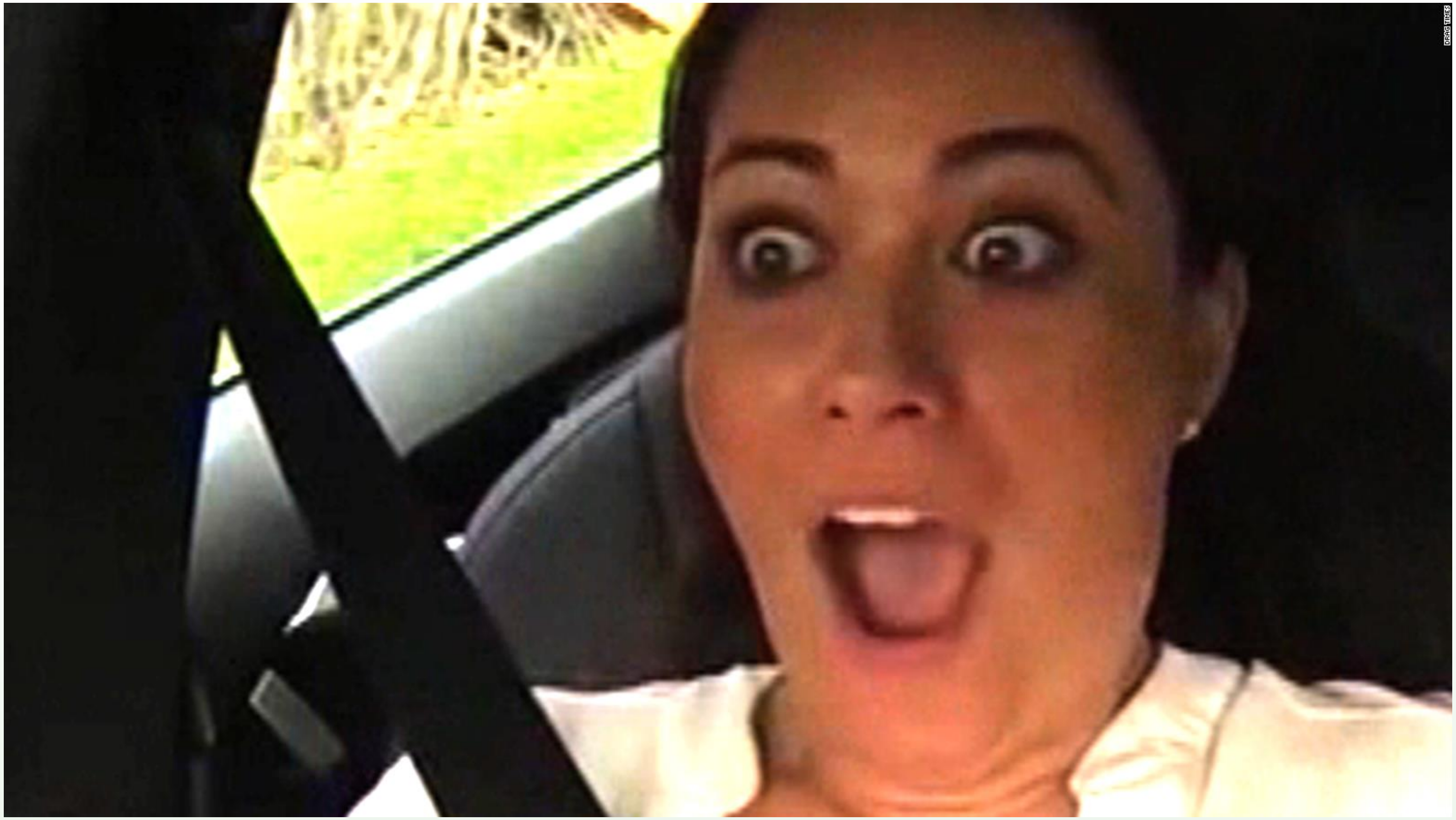


Battery determines both range and power

http://www.nissan-global.com/EN/TECHNOLOGY/MAGAZINE/ev_battery.html

Challenge for Lithium Battery as an EV Energy Source





Specific Energy and Energy Density

Material	Specific Energy (MJ/kg)	Energy Density (MJ/L)
Hydrogen	142	5.6 (compressed at 700 bar)
Natural Gas	55.5	0.0364
Diesel	48	35.8
Gasoline	44.4	32.4
Ethanol	26.4	20.9
Methanol	19.7	15.6
Lithium-ion battery	0.36-0.875	0.9-2.63
Lead-acid battery	0.17	0.56

Hydrogen fuel cell vehicles (FCEV)

Range= 300 plus miles

Refueling time <5 min

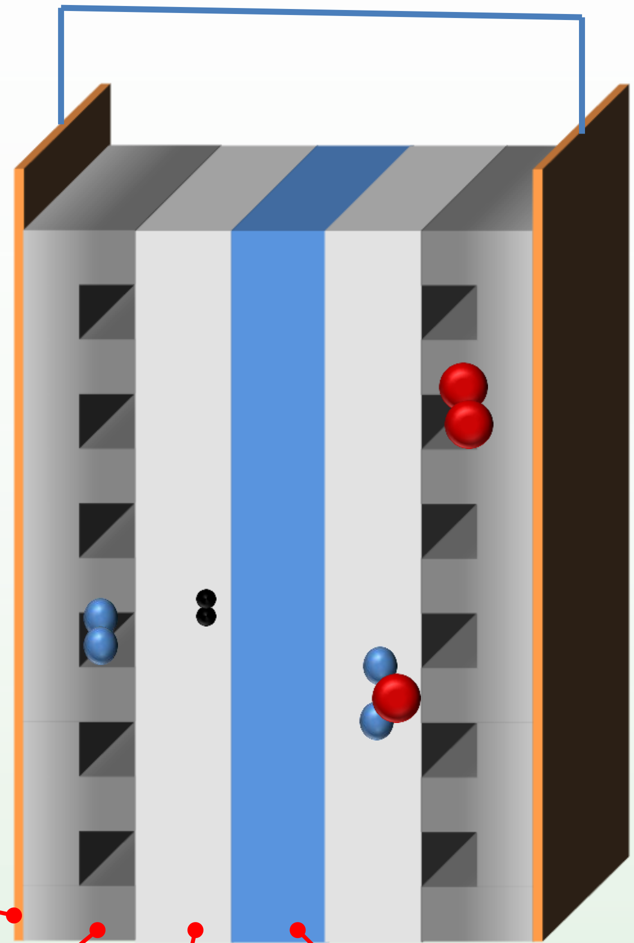
Proton Exchange Fuel Cell Mechanism

Anode
Fuel
Oxidation

$H_2 \rightarrow 2H^+ + 2e^-$

Cathode
Oxidant
Reduction

$^1/_2\, O_2 + 2H^+ + 2e^- \rightarrow H_2O$

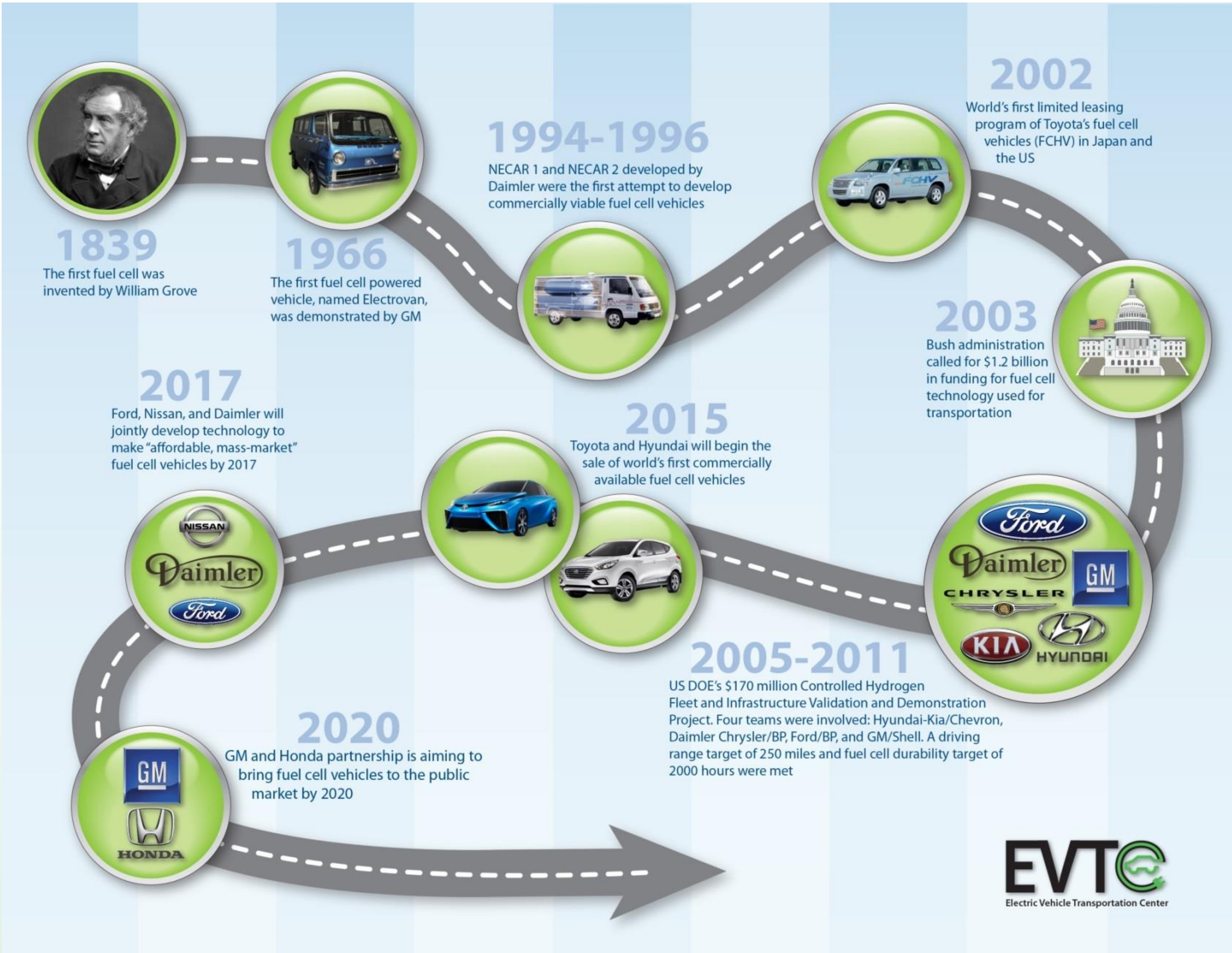


Total Reaction:

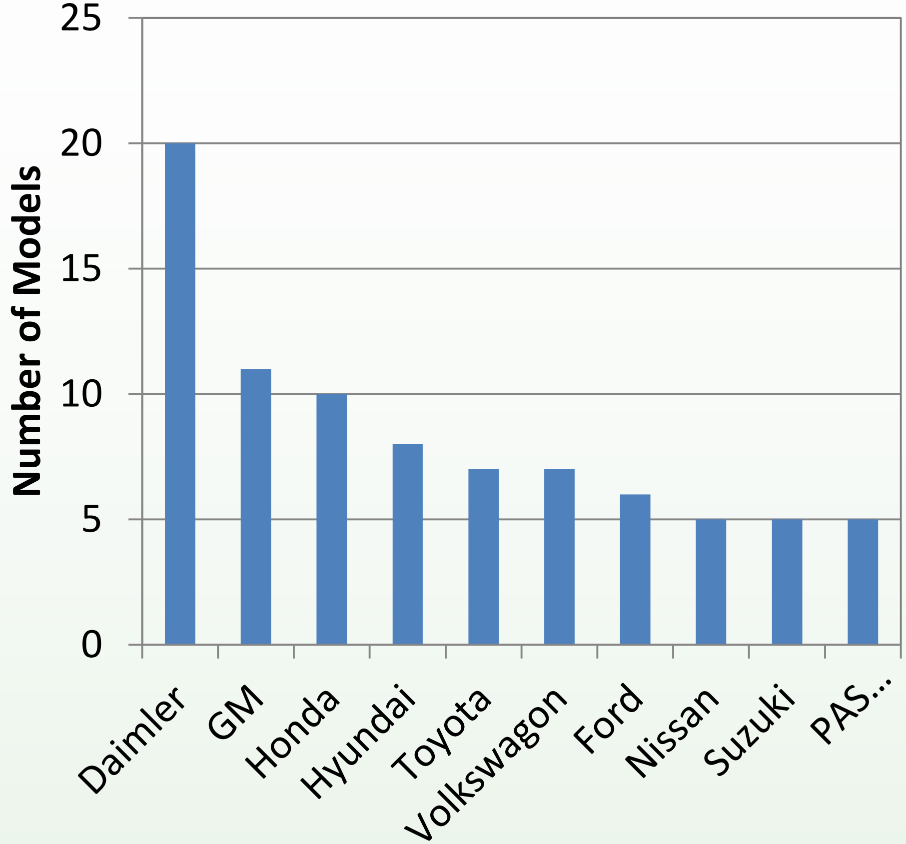
$H_2 + O_2 \rightarrow H_2O + heat$

57

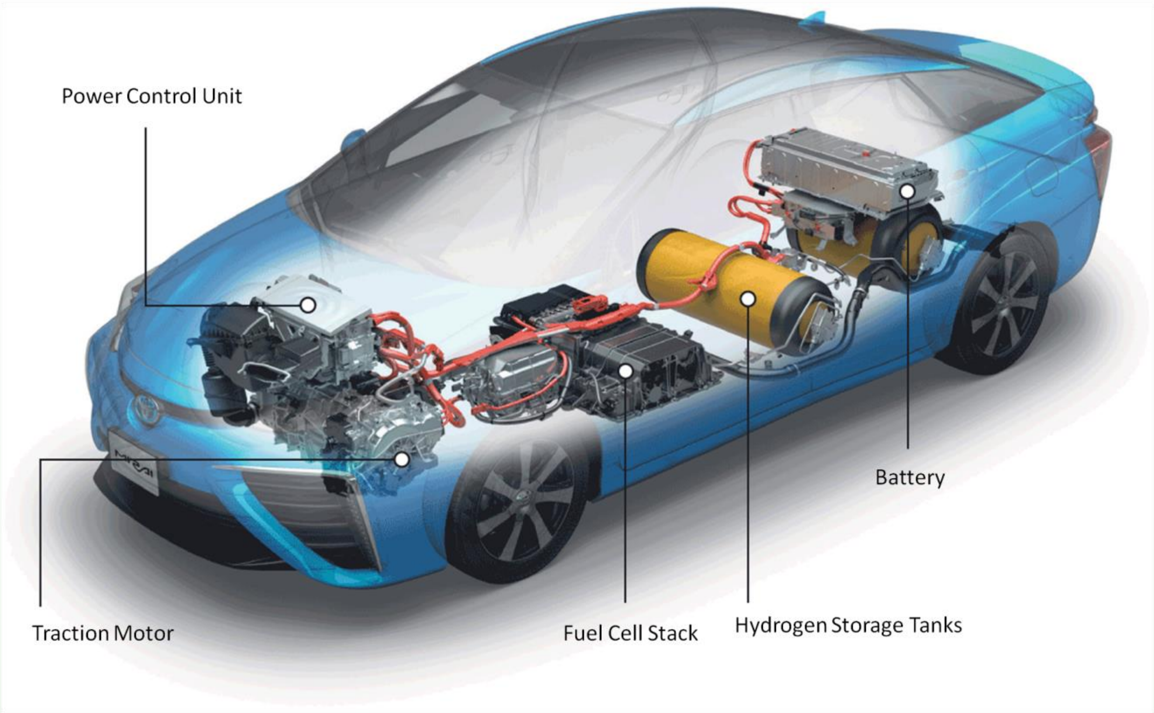
FCEV History



Automakers with the Most FCEV Models



FCEV Powertrain



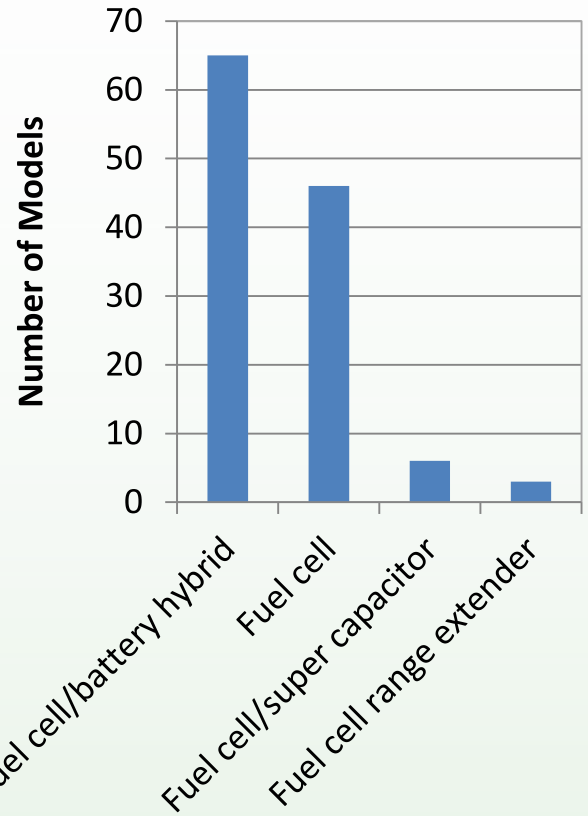
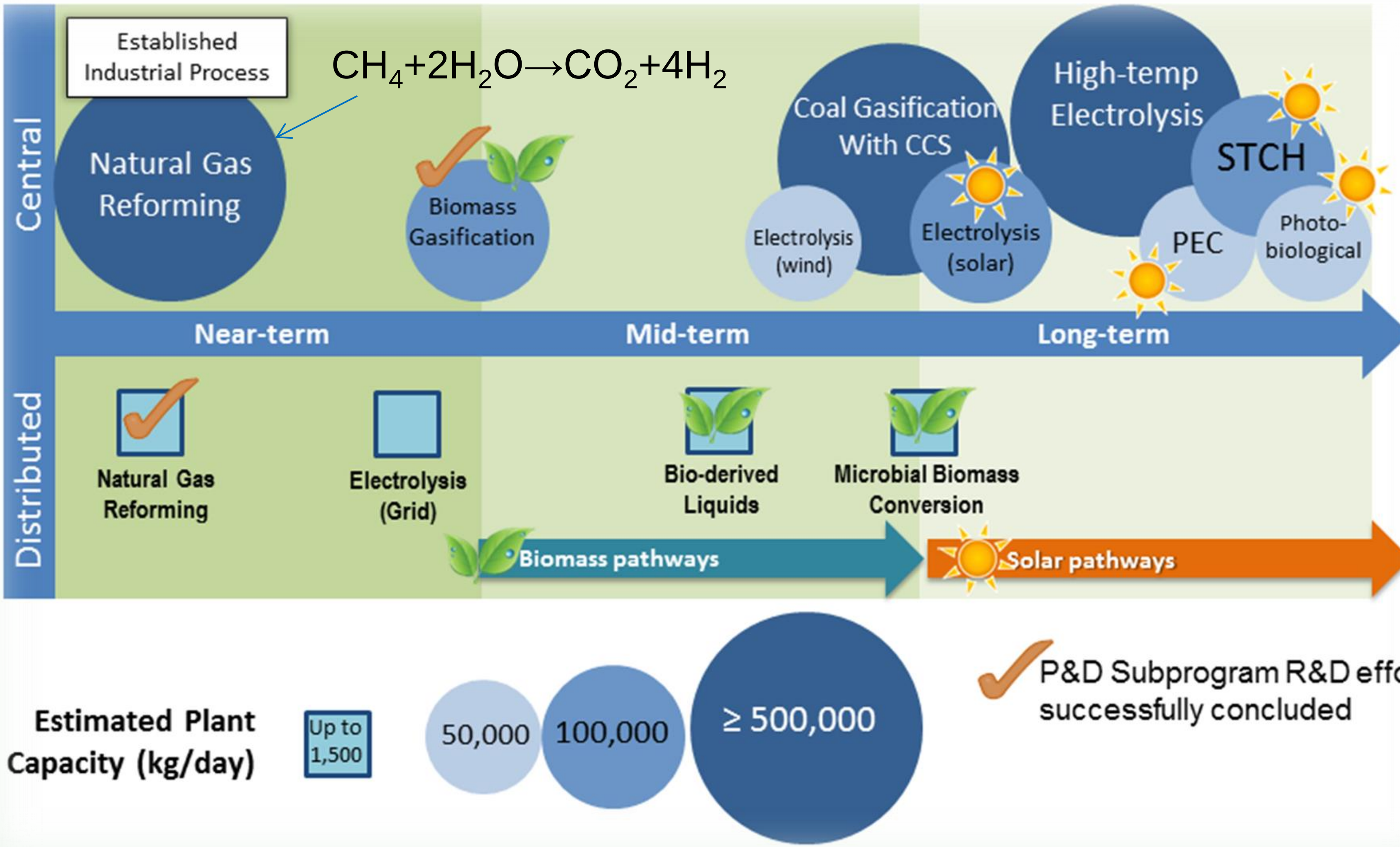


Image downloaded from manufacturer's' website Oct 2015

Hydrogen Production



http://energy.gov/eere/fuelcells/hydrogen-production

Hydrogen Storage

DOE Target for 2015:
5.5 wt%
40 g/L

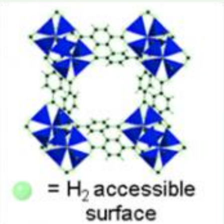
Physical-based

- Compressed Gas
- Cold/Cryo Compressed
- Liquid H_2

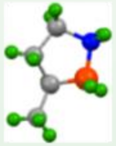
350 bars
700 bars

Material-based

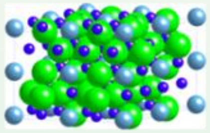
- Adsorbent — Ex. MOF-5



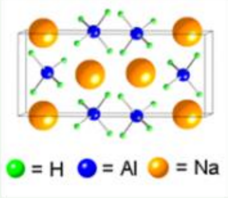
- Liquid organic — Ex. BN-methyl cyclopentane



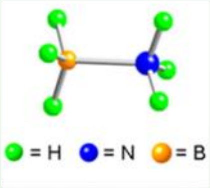
- Interstitial hydride — Ex. $LaNi_5H_6$



- Complex hydride — Ex. $NaAlH_4$



- Chemical hydrogen — Ex. NH_3BH_3

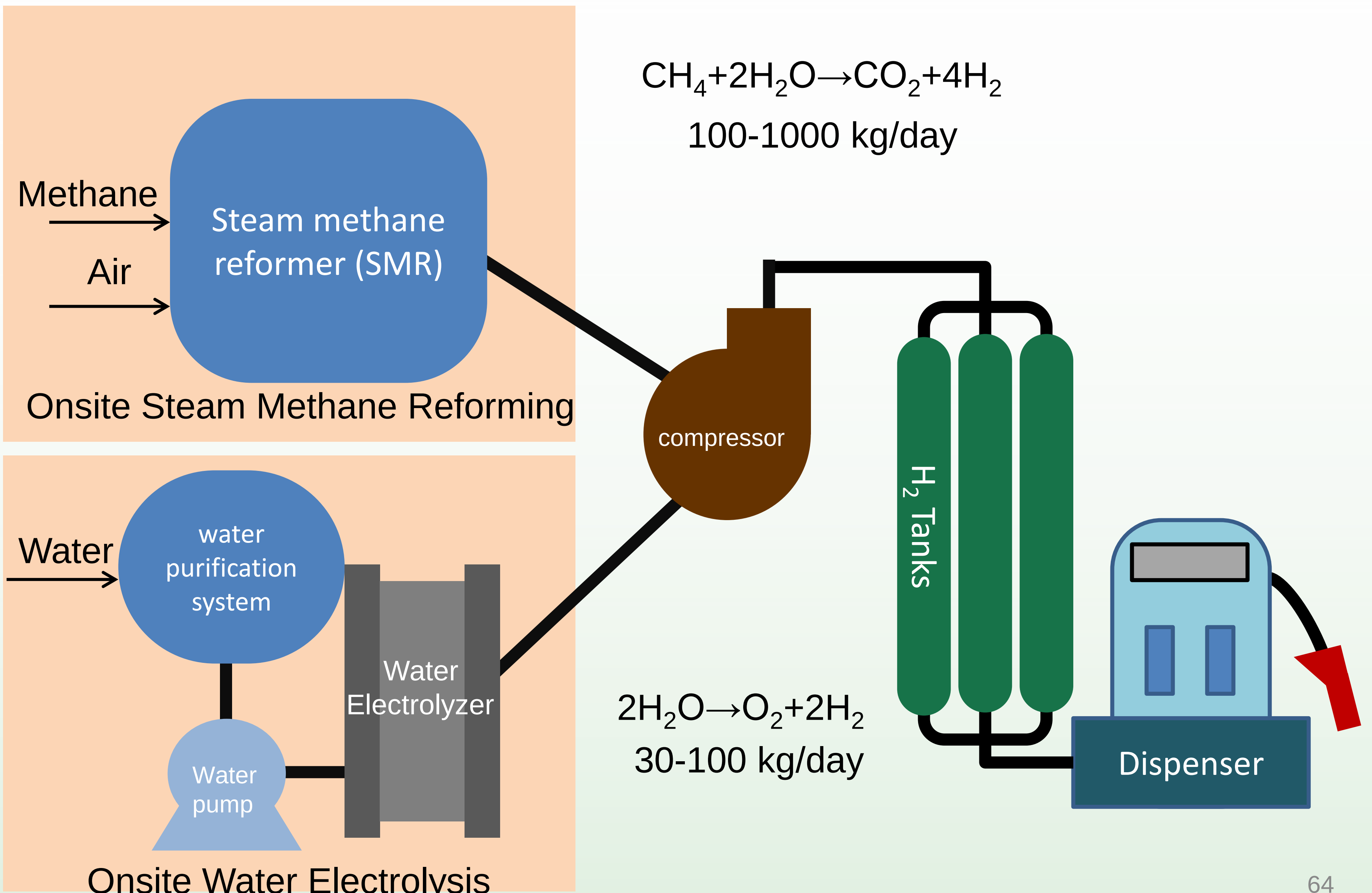


http://energy.gov/eere/fuelcells/hydrogen-storage

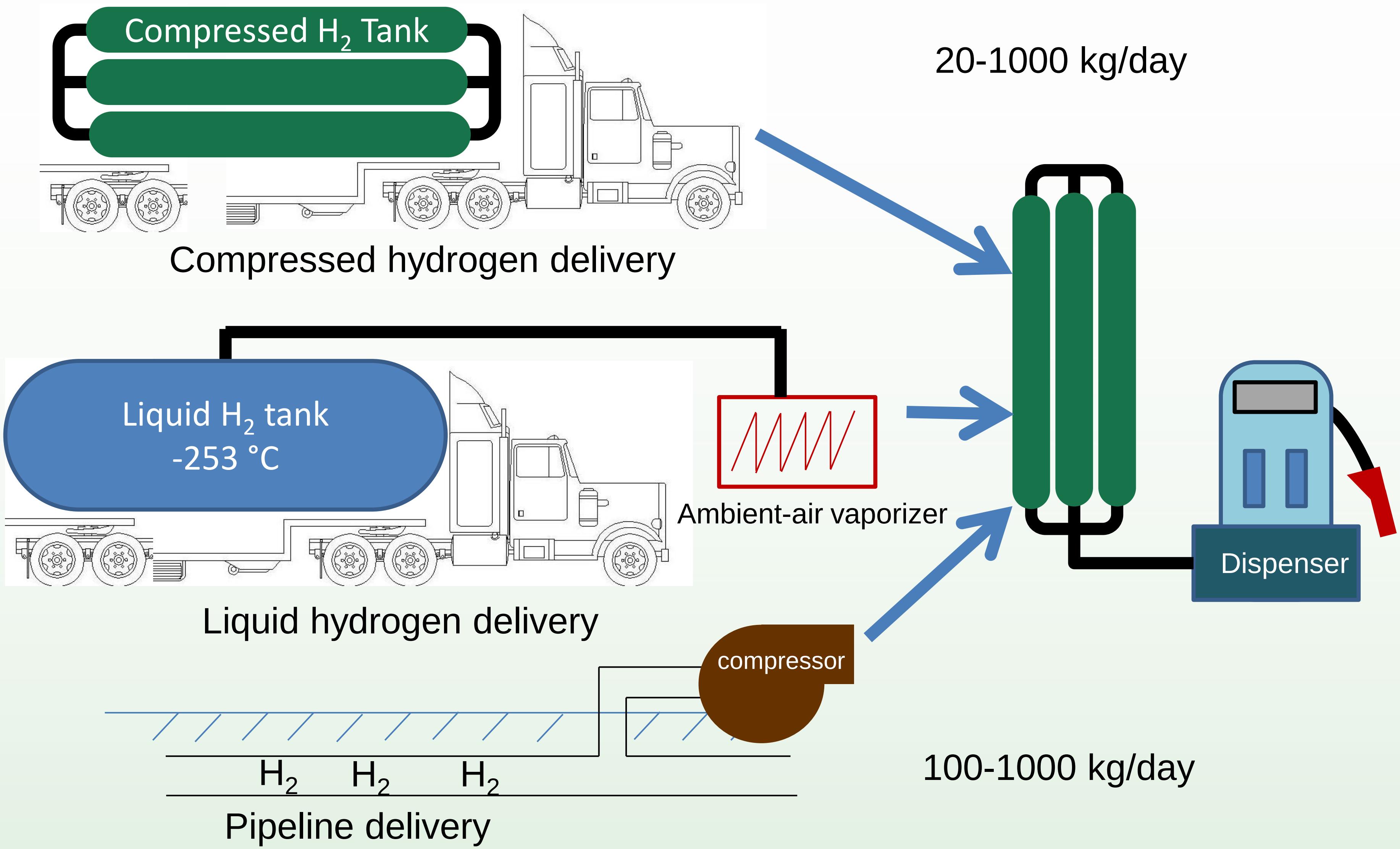
Hydrogen Fueling Infrastructures

- Onsite Steam Methane Reforming
- Onsite Electrolysis of Water
- Liquid or Gaseous Hydrogen Delivery
- Pipeline Delivery
- Mobile Refueling

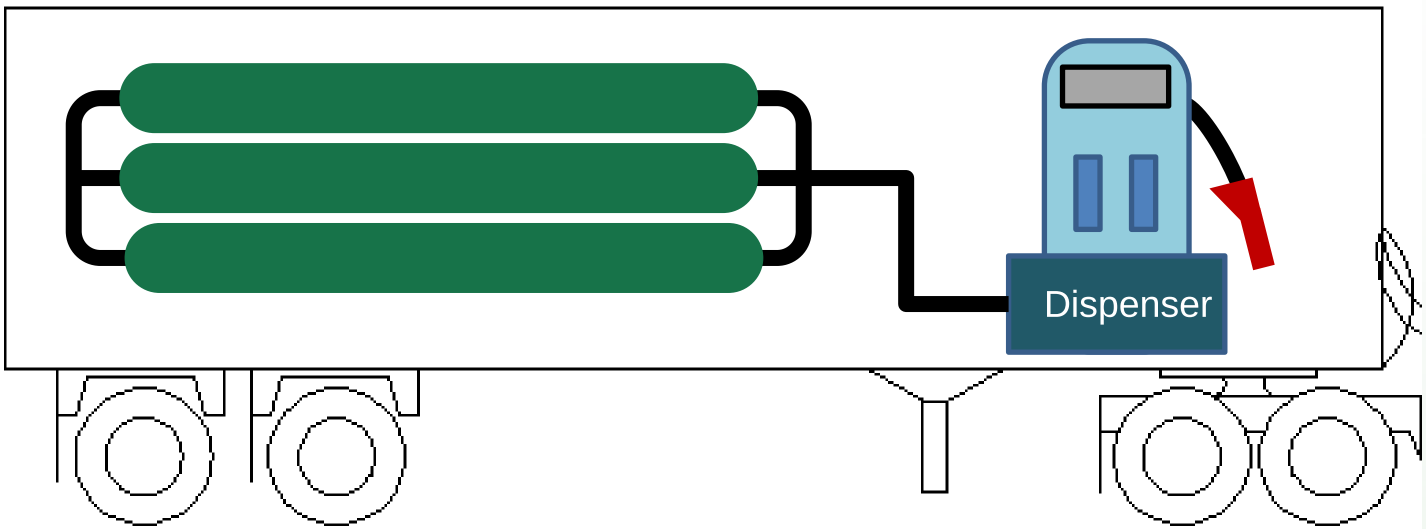
Onsite Methods



Delivery Methods



Mobile Methods

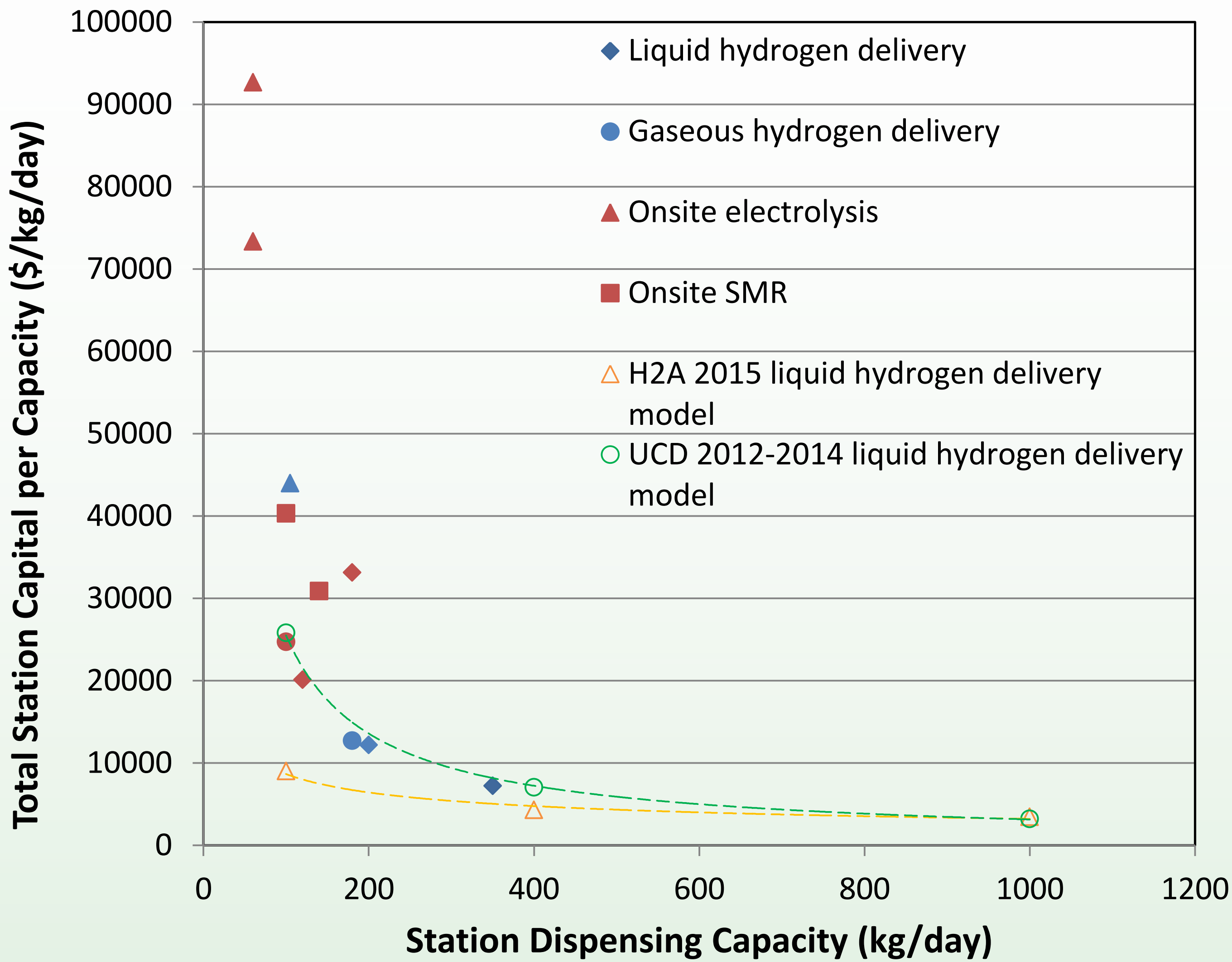


10-60 kg/day

Fueling Station Cost (CA)

Hydrogen Stations	Station Capacity (kg/day)	Total Capital ($M)
onsite electrolysis (Emeryville)	60	5.56
LH_2 Delivery (Askland)	180	5.96
Onsite SMR (UCLA)	140	4.32
GH_2 Truck (Harbor city)	100	2.47
LH_2 Delivery (SFO)	120	2.41
GH_2 truck (APCI, 2Stns)	180	2.29
LH_2 truck (Linde, 3 Stns.)	350	2.52
LH_2 truck (Air Lquide, 1 Stn.)	200	2.43
Onsite Electrolysis (H_2 Frontier)	105	4.62

Fueling Station Cost Predictions



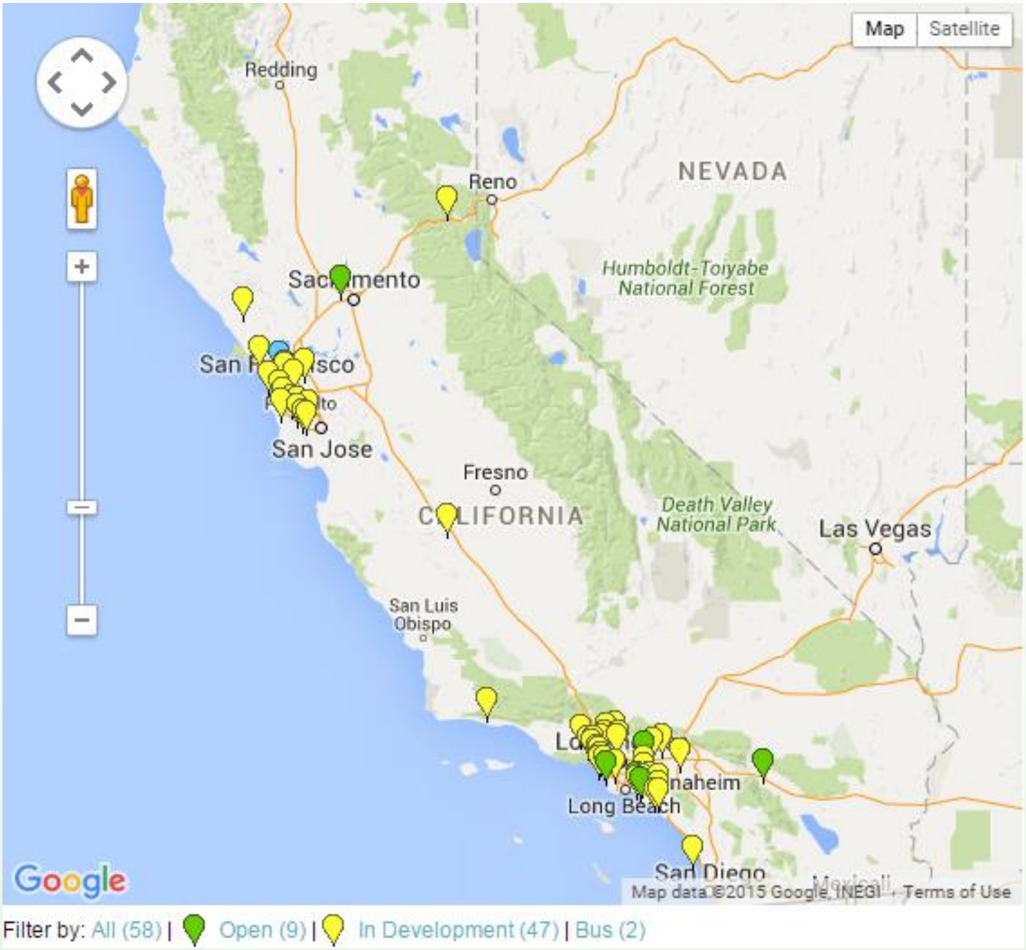
N. Qin et. Al. Hydrogen fueling stations infrastructure, EVTC report EVTC-RR-02-14.

Hydrogen Fueling Stations Rollout Strategy

- "Hydrogen Highway"
  - Every 20 miles along highways in California
- Based on population density
- "Clustering" strategies

J. Ogden and M. Nicholas, "Analysis of a "cluster" strategy for introducing hydrogen vehicles in southern California," *Energy Policy,* vol. 39, pp. 1923-1938, 2011.

Current and Near Future Hydrogen Stations in the US



http://www.cafcp.org/stationmap

Non-Consumer Applications of EVs

- Electric Trucks
- Fuel Cell Forklifts
- Electric Buses

Trucks Electrification

- Hybrid-electric trucks--Prius
- Battery electric trucks--Leaf
- Plug-in hybrid electric trucks--Prius Plug-in
- Fuel cell electric trucks—Mirai
- Electric truck with a range extender-- Volt

VIA Motor Truck

  - 120 kilowatts of power
  - 44-mile all-electric range
  - 400 miles full range

Image downloaded from manufacturer's' website Oct 2015

Trucks Electrification

- Auxiliary Power Units
  - US EPA estimates that a truck uses up to 1400 gallons of diesel per year just in idling.
- Power Take-off (PTO)

120 kilowatts of power

40-mile all-electric range

Pacific Gas and Electric Company (PG&E) electric bucket truck

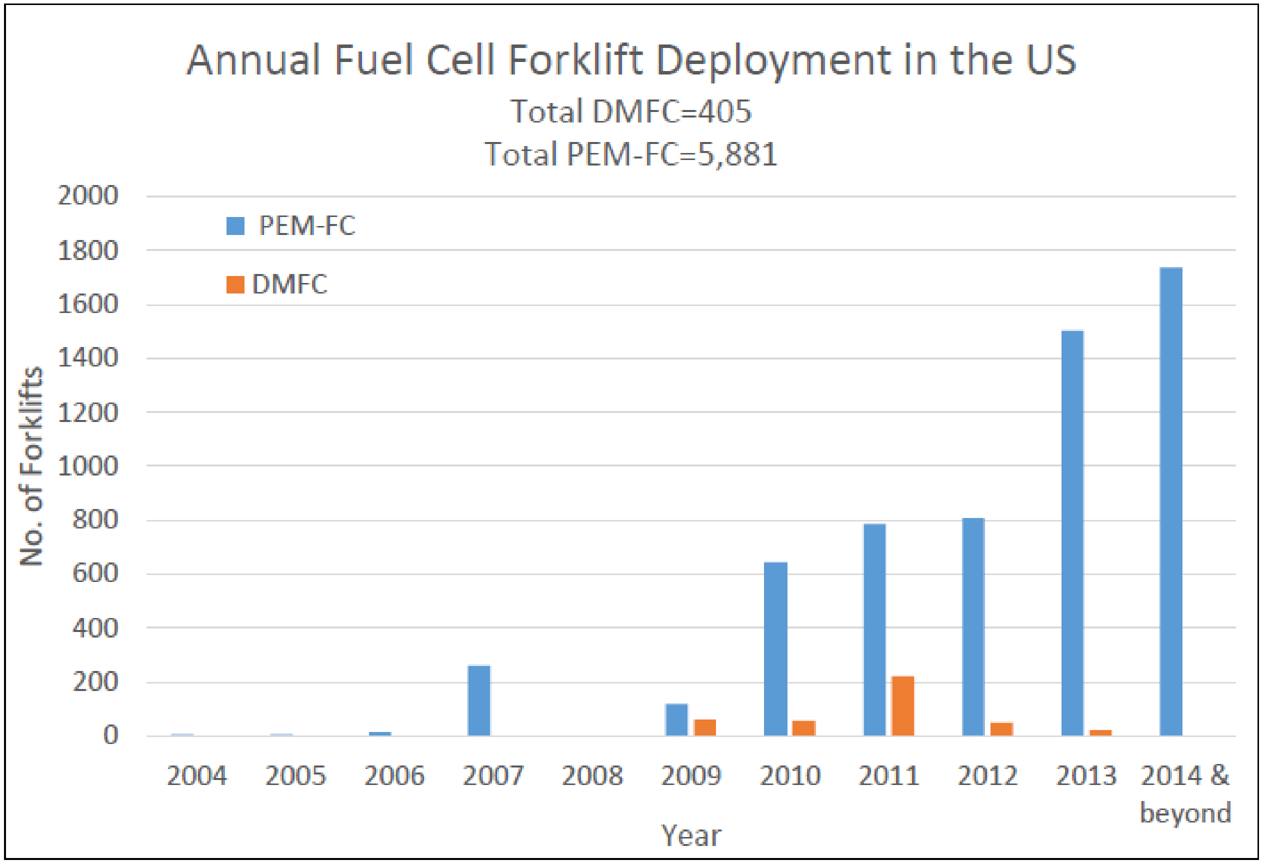
Image downloaded from manufacturer's' website Oct 2015

Fuel Cell Forklifts

- Can operate for more than 12 hours without performance degradation.
- Can be refueled in a couple of minutes.
- Can sustain cold temperature operation.

Image downloaded from manufacturer's' website Oct 2015

Fuel Cell Forklifts

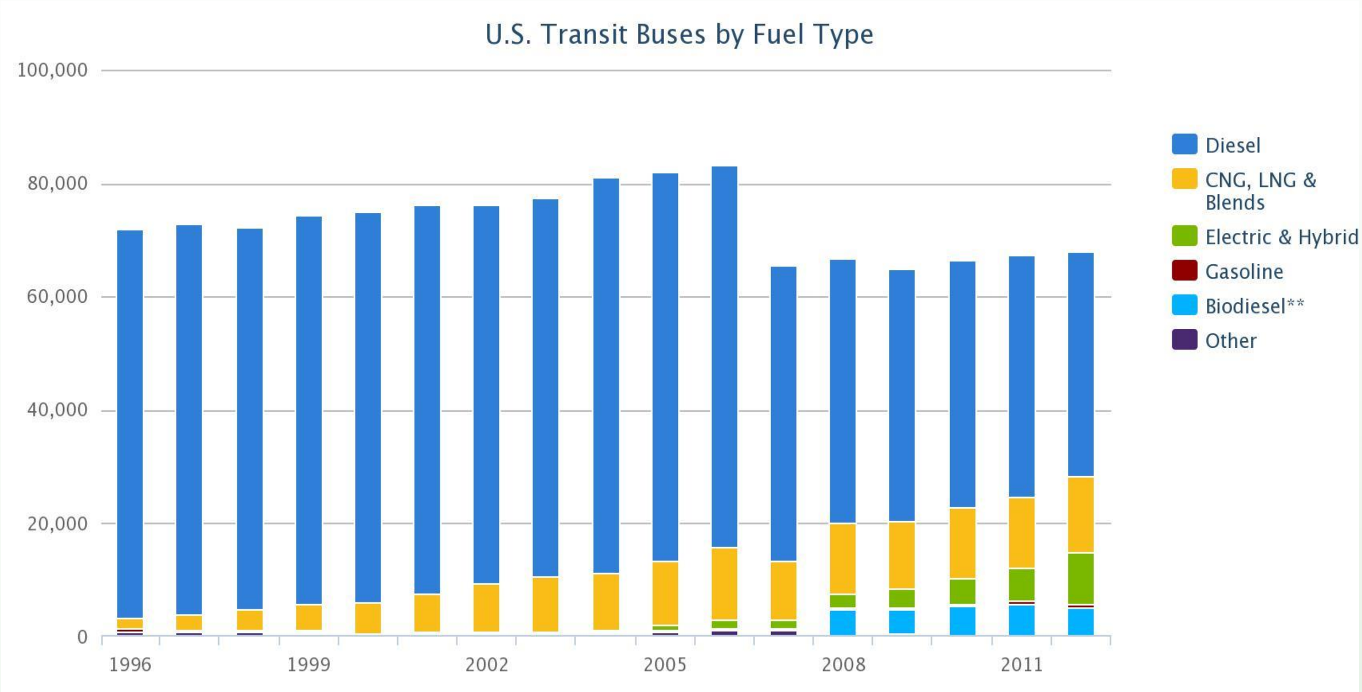


A. Mayyas, Fuel cell forlift deployment in the U.S.

Electric Transit Buses

DIESEL BUS **COMPRESSED NATURAL GAS (CNG) BUS**

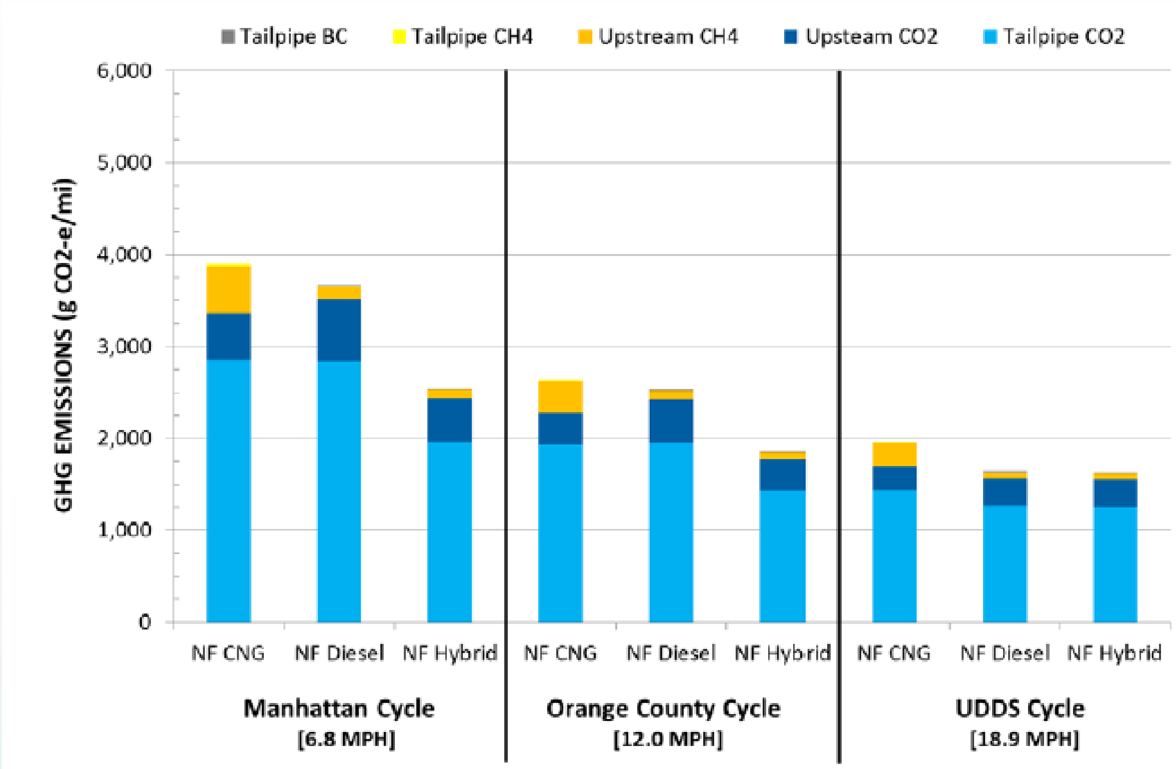
BIODIESEL BUS **HYBRID BUS** **BATTERY ELECTRIC BUS**



http://www.afdc.energy.gov/data/

Greenhouse Gas Emission of Alternative Bus Types

Estimated long term wells-to-wheels GHG emission for New Flyer buses

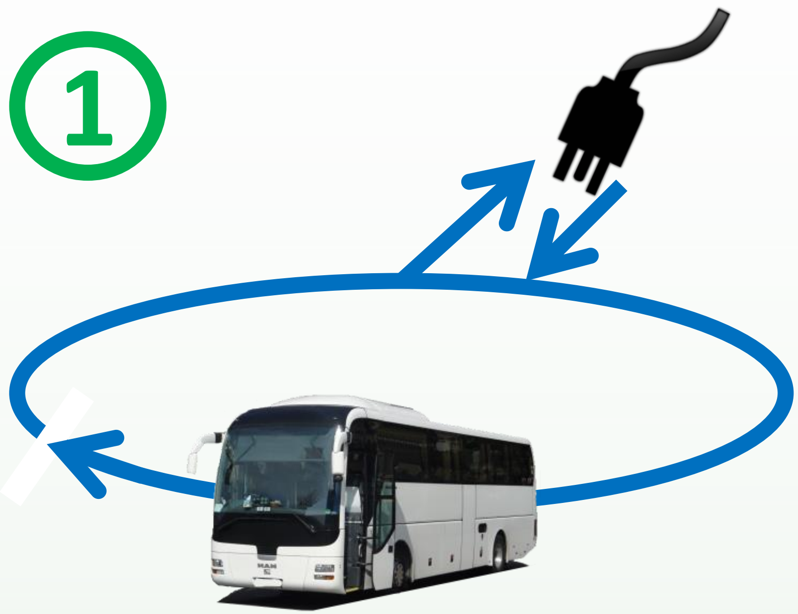


Altoona Bus Research & Testing Center

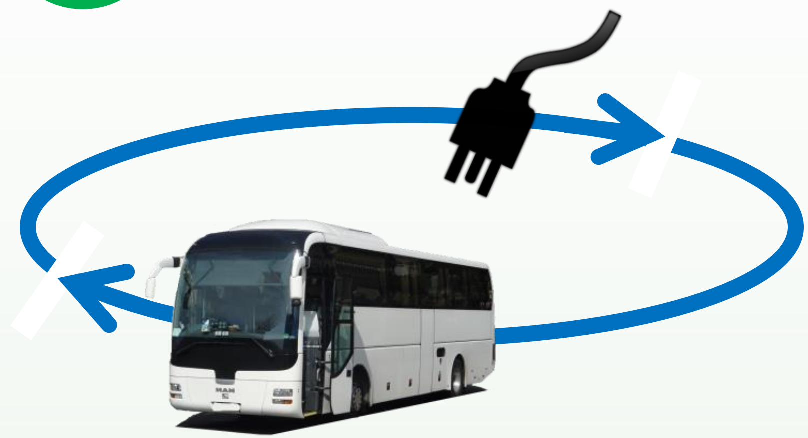
http://mjbradley.com/sites/default/files/CNG%20Diesel%20Hybrid%20Comparison%20FINAL%2005nov13.pdf

Types of Electric Buses

①



②



Lithium iron phosphate	Battery type	Lithium titanate
~300 kWh	Battery size	55-72 kWh
~150 miles	Range	~30 miles
Off route charging	Charging Type	In route charging
~ 5 hours	Charging time	<10 minutes

Tallahassee Electric Bus Program

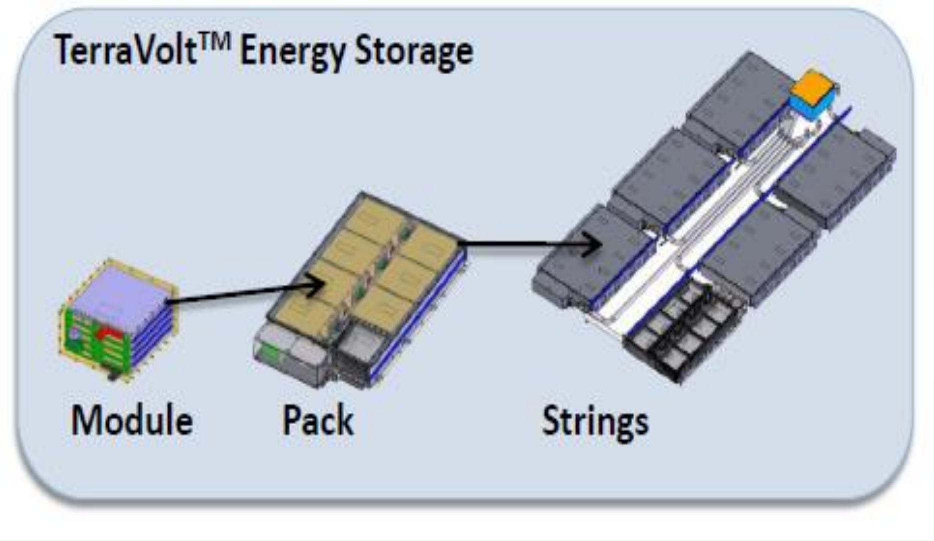
Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program

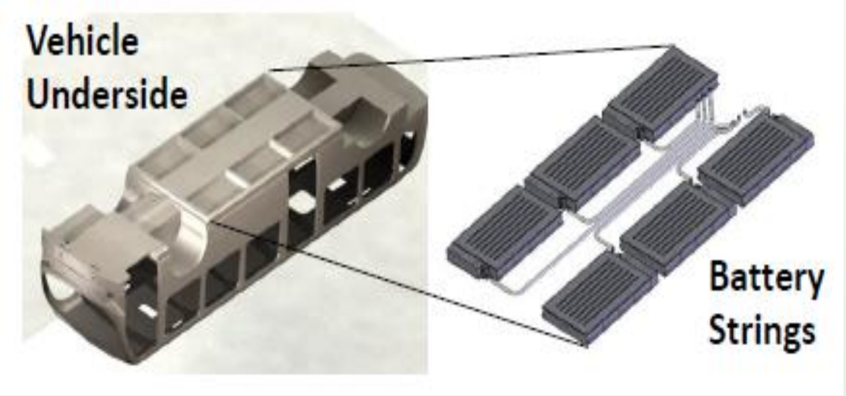
$4,900,000 for the buses,
$1,165,000 for infrastructure
$52,000 for vehicle introduction
$349,003 for program management

$ 950K-1.1 M

Technical Specifications

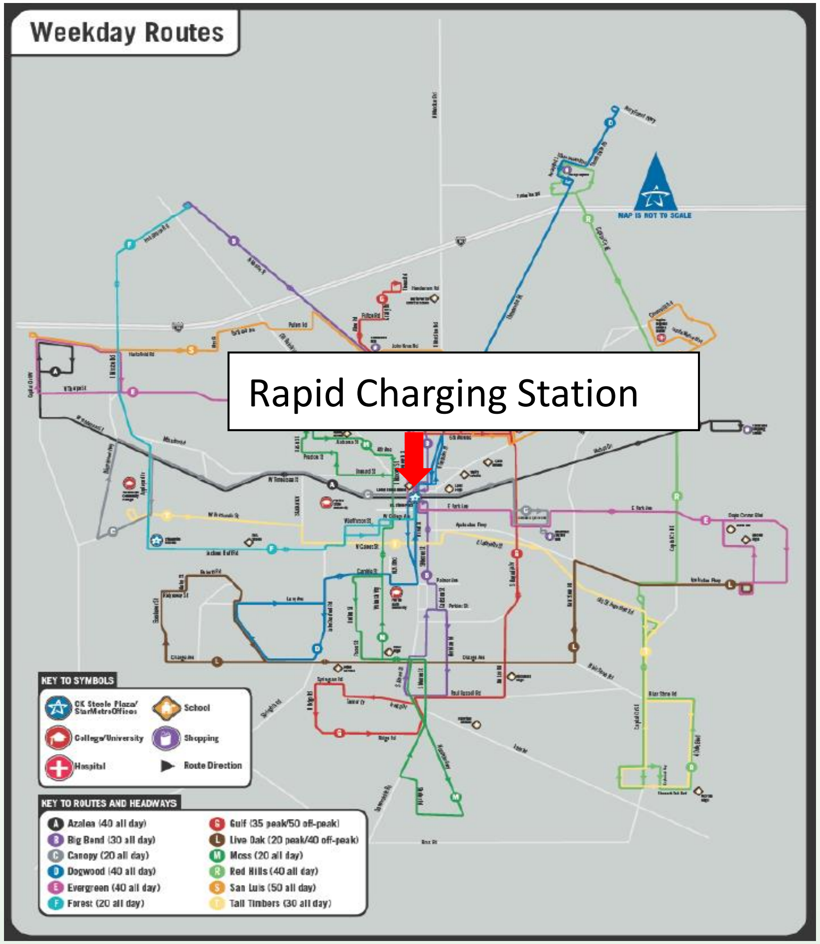
Design Element	Description
Body construction	Resin laminate fiber glass reinforced (composite)
Motor Power	150 kW (200 HP) peak power
Battery	**Lithium titanate battery 72 kWh**
Curb Weight	27250 lbp
Acceleration	60 seconds (0-60mph)
Passenger Capacity	62
Top Speed	55 MPH





Images obtained from Proterra

Bus Charging Infrastructure

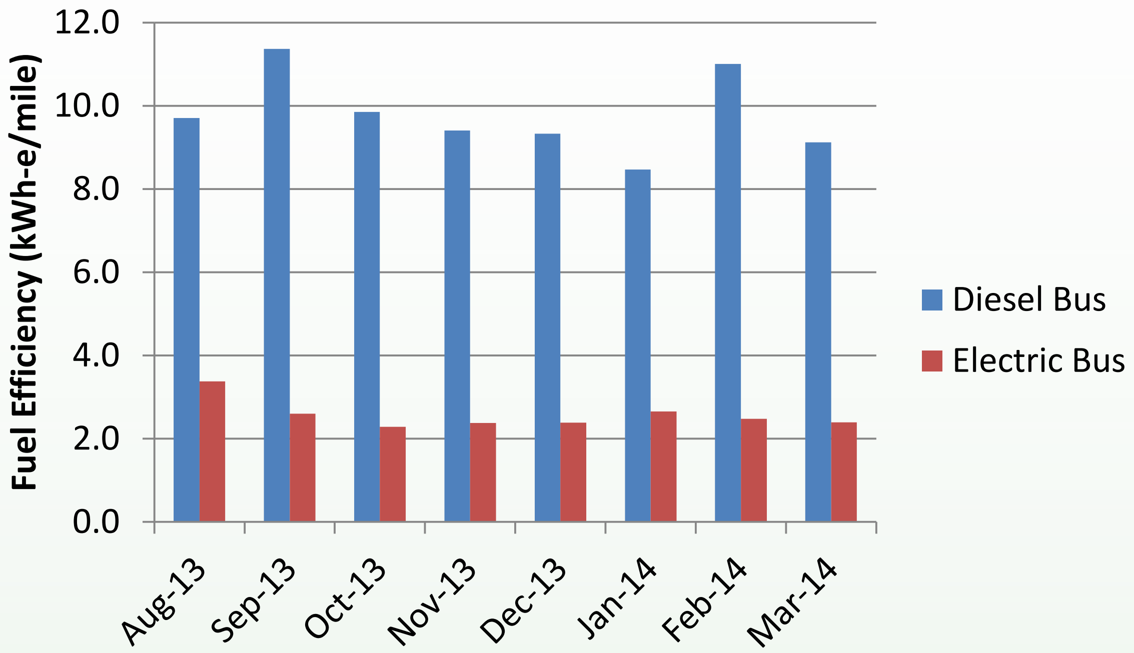


FastFill™ rapid charging station, 500 kW DC
Charge bus battery 10-95% in <10 min

Fuel Efficiency Comparison

Baseline buses:
Five 2010 Diesel bus

1 gallon diesel = 37.3 kWh



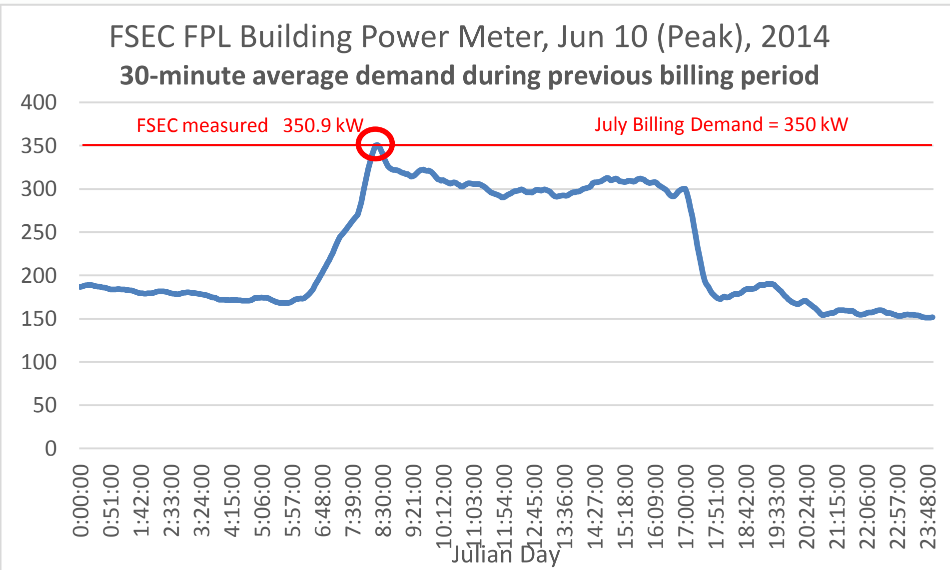
	Electric Bus	Diesel Bus
Efficiency (kWh/mile)	2.5	9.7
Cost per Mile ($)	0.7	0.9

300% better

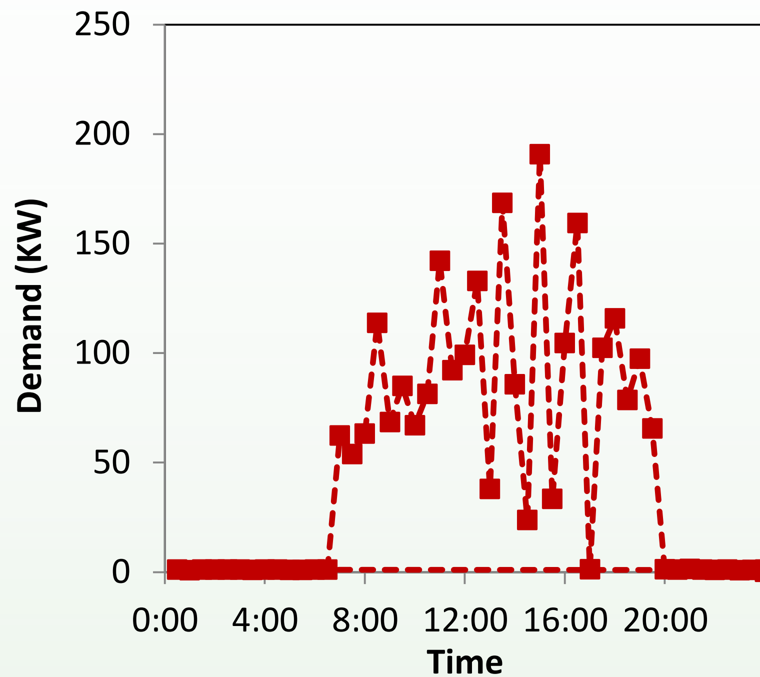
30% better

Demand Charge with Bus Charging

Energy Consumption (kWh) x Base Price (6₵/kWh)+Peak Demand (kW) x $12.72/kW

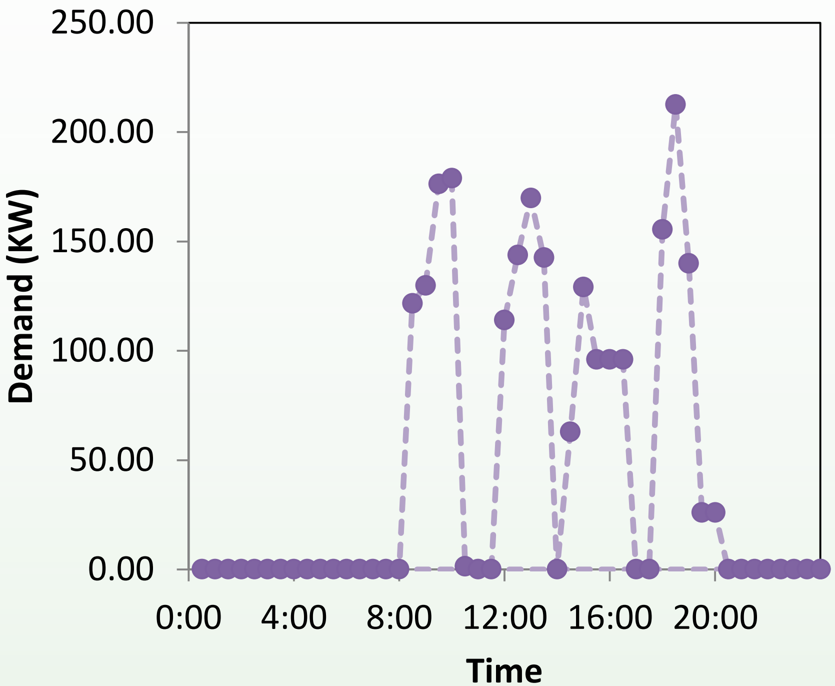


Demand Profile of the peak demand day of Florida Solar Energy Center-June 2014

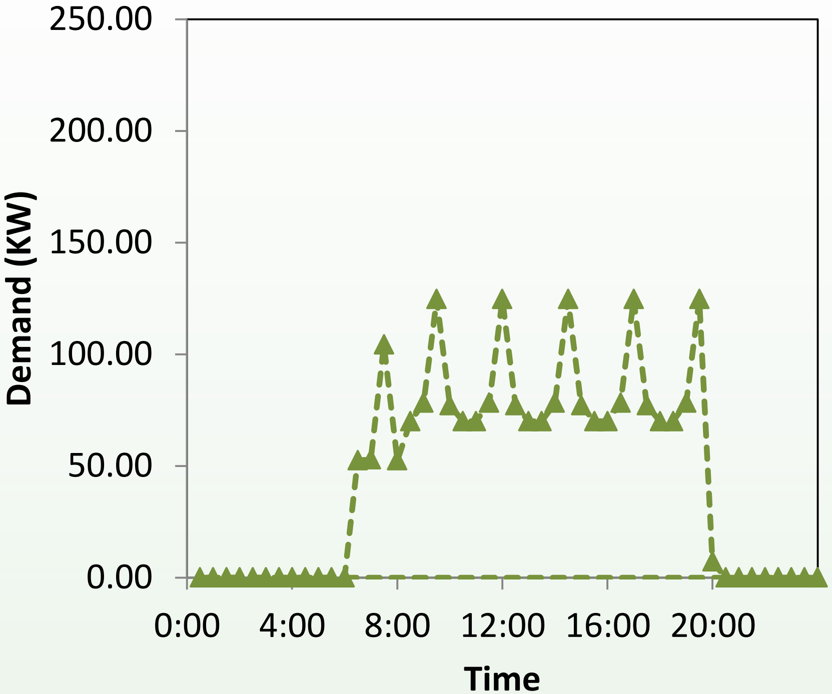


$0.06/kWh ⟶ $0.28/kWh

Shaving Peak Demand Via Optimizing Charging Behavior



Demand profile before optimization



Demand profile after optimization

Total Cost of Ownership

TCO=Initial price+ Fuel cost + Maintenance cost

	Purchase price ($)	Fuel Cost ($)	Maintenance Cost ($)	TCO ($)
Diesel Bus	450k	432k	211k	1,093 k
Electric Bus	950k	336k	141k	1,427 k
Electric Bus*	800k	140k	141k	1,057 k

All calculation assumes 40,000 miles/year and 12 years services

Electric Bus* calculation used optimized electricity cost.

Real World Applications

- Slides 87 to 116 were presented by John Smart from Idaho National Lab, showing results from the EV Project

Plugged In: How Americans Charge Their Electric Vehicles

Findings from the largest plug-in electric vehicle infrastructure demonstration in the world

www.inl.gov

Idaho National Laboratory

INL/MIS-15-35584

Idaho National Laboratory

- U.S. Department of Energy (DOE) federal laboratory
- 890 square mile site with 4,000 staff
- Support DOE's strategic goal
  - Increase U.S. energy security and reduce the nation's dependence on foreign oil
- Multi-program DOE laboratory
  - Nuclear Energy
  - Renewables and Hybrid Energy Systems
  - Advanced Vehicles, Batteries, Fuels, and Infrastructure
  - Unmanned Aerial Systems and Autonomous Vehicles
  - Cyber Security

Questions to Be Answered

Widespread adoption of plug-in electric vehicles (PEVs) has the potential to significantly reduce our nation's transportation petroleum consumption and greenhouse gas emissions.

Barriers to PEV adoption remain, however.

What kind of charging infrastructure is needed?

Where will PEV drivers plug in? How often?

Building the Laboratory

To answer these questions, the U.S. Department of Energy launched The EV Project and ChargePoint America to install charging infrastructure and study its use

These two projects combined represented the largest PEV charging infrastructure demo in the world

Participants agreed to allow data collection from vehicles and charging stations.

INL's role was to collect data and study user behavior

THREE	Years
8,300	EVs
22	Regions in the U.S.
125 Million	Miles of driving
6	Primary project partners
6	Million charging events
17,000	Residential and commercial charging stations

Project Partners

blink

NISSAN

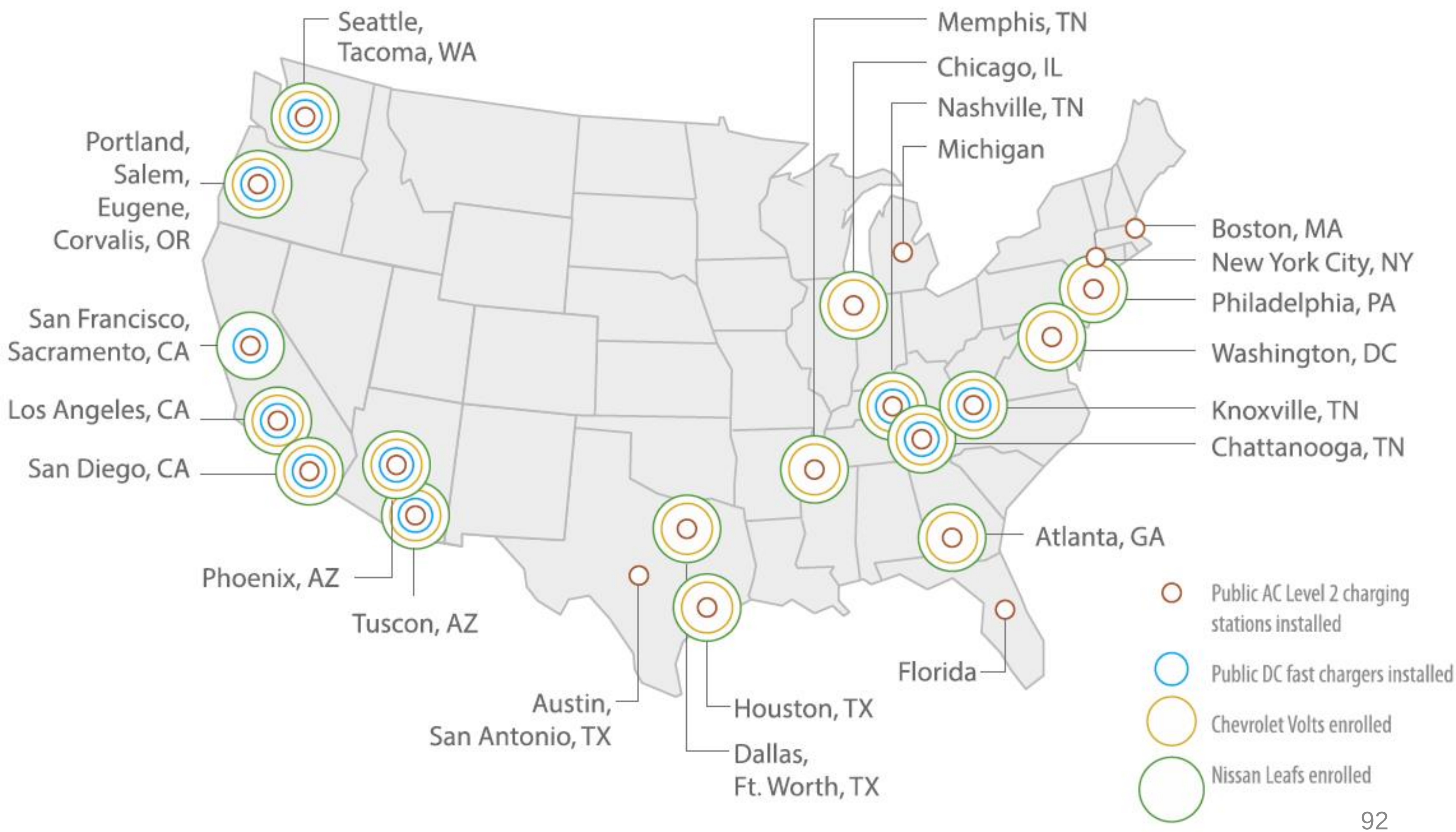
GM

OnStar

chargepoint

CAR2GO

Project Areas



The Question

With gas stations on seemingly every block, should we expect a similarly ubiquitous charging network is needed to refuel PEVs?

PEV charging is different – vehicles can be charged where they are parked

AC Level 2 and DC fast chargers were installed at residences, workplaces, stores, restaurants, airports, and other locations

Photo courtesy of ChargePoint

What Have We Learned?

Despite extensive public charging networks in most areas, the majority of charging was done at home

About half of participants charged almost exclusively at home

Of those who charged away from home, the vast majority favored 3 or fewer away-from-home charging locations

What Have We Learned?

This does not mean that public charging stations are not needed or desirable

DC fast chargers were popular to support both local and long-distance driving

What Have We Learned?

This does not mean that public charging stations are not needed or desirable

A relatively small number of AC Level 2 charging sites saw consistently high use

What is it about these sites that make them popular?

Photo courtesy of ChargePoint

What Have We Learned?

Public Level 2 charging stations installed where vehicles were typically parked for long periods of time were among the most highly used

- Shopping malls
- Airports and commuter parking lots
- Downtown parking lots and garages with easy access to multiple venues

Exact factors that determine what makes a public charging station popular are community-specific… and more research is needed

Nevertheless, it is clear that…

To support PEV driving, charging infrastructure should be focused at home, workplaces, and in public “hot spots” where demand for Level 2 or DC fast charging stations is high

Exceptions

Organizations may want to install charging stations regardless of how much they are used

- Attract a certain customer demographic
- Project a “green” image
- Encourage PEV adoption

(This project did not study effectiveness of charging infrastructure in meeting these goals)

DC fast chargers along travel corridors were found to effectively enable long-distance range extension for battery electric vehicles

Infrastructure is needed to serve PEV customers without access to charging at home

Areas of Analysis

- PEV driving patterns and charging preferences
- Away-from-home charging for range extension
- Workplace charging
- Public charging station use
- Charging at home
- Charging infrastructure installation costs

What have we learned about PEV driving patterns and charging preferences?

Volt drivers averaged only 6% fewer EV miles per year than Leaf drivers, despite having less than half as much battery energy storage capacity.

	Leaf	Volt	National Average[1]
Average annual vehicle miles traveled	9,697	12,238	11,346
Average annual electric vehicle miles traveled	9,697	9,112	–

[1] *Office of Highway Policy Information, Federal Highway Administration, "Highway Statistics 2013-Table VM-1," January, 2015, www.fhwa.dot.gov/policyinformation/statistics/2013/vm1.cfm*

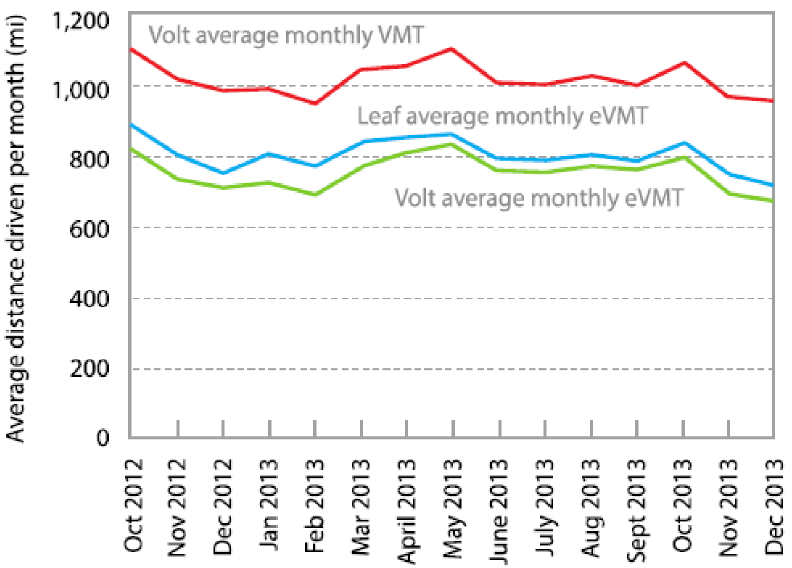
What have we learned about PEV driving patterns and charging preferences?

Volt drivers tended to fully deplete their battery packs prior to recharging, whereas Leaf drivers favored recharging with significant charge left in their batteries (as expected for EREV vs. BEV)

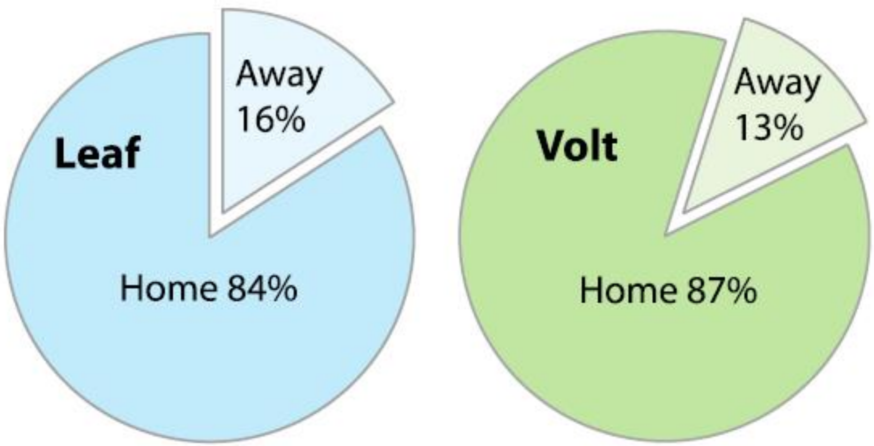
Volt drivers charged more frequently

- Volt: 1.5 charges per day
- Leaf: 1.1 charges per day

Trend was consistent, with some seasonal variation

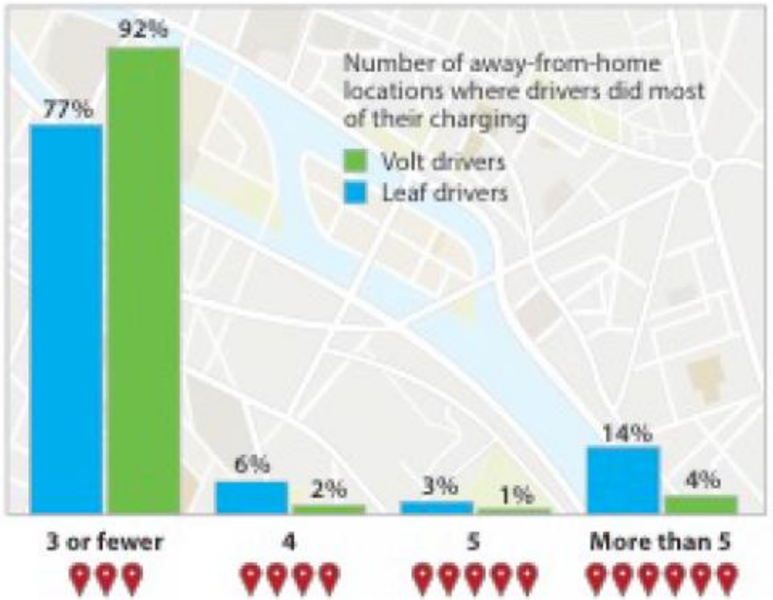


Preference for charging frequency and location



Leaf and Volt drivers performed most of their driving at home

92% of Volt drivers and 77% of Leaf drivers did most (at least 80%) of their away-from-home charging at 3 or fewer locations



Preference for charging equipment

Volts and Leafs come with an AC Level 1 cordset

All Leafs in the project were DC-fast-charge capable (CHAdeMO)

Participants could charge wherever they wanted

What have we learned about away-from-home charging for range extension?

PEV drivers who plugged in away from home tended to drive more EV miles

72% increase

Tendency to charge away from home:	Never	Sometimes[2]	Frequently[3]	Most of the time[4]
Leaf average daily driving distance (mi)	25	31	43	32
Volt average daily driving distance in EV mode (mi)	25	29	40	26

[2]>0 to 30% of all charging events *[3]>30 to 60% of all charging events* *[4]>60% of all charging events*

What have we learned about away-from-home charging for range extension?

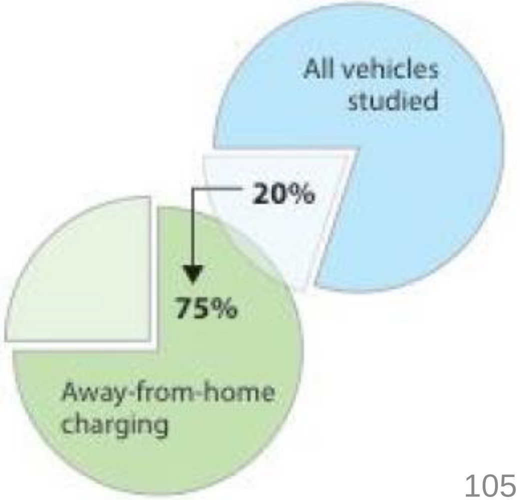
However, most drivers did not charge away from home frequently

Tendency to charge away from home:	Never	Sometimes[2]	Frequently[3]	Most of the time[4]
Percent of Leafs	13%	69%	14%	4%
Percent of Volts	5%	81%	13%	1%

[2]>0 to 30% of all charging events [3]>30 to 60% of all charging events [4]>60% of all charging events

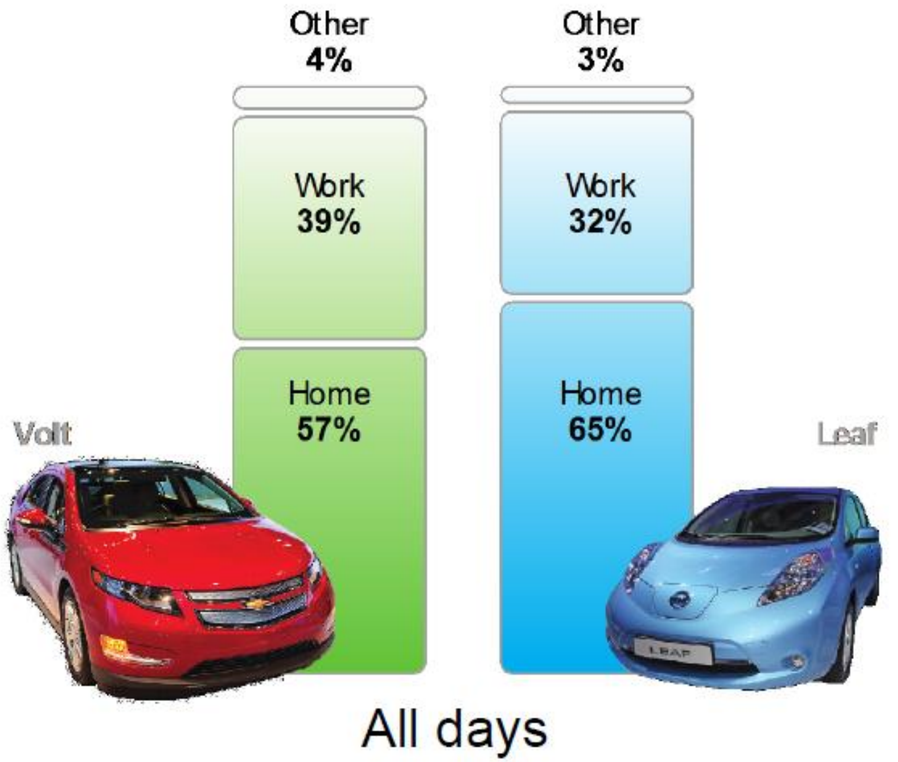
Overall, 20% of the vehicles studied were responsible for 75% of the away-from-home charging

Much of this can be attributed to workplace charging



What have we learned about workplace charging?

98% Of charging events were performed at home and work on work days.



Range extension from workplace charging

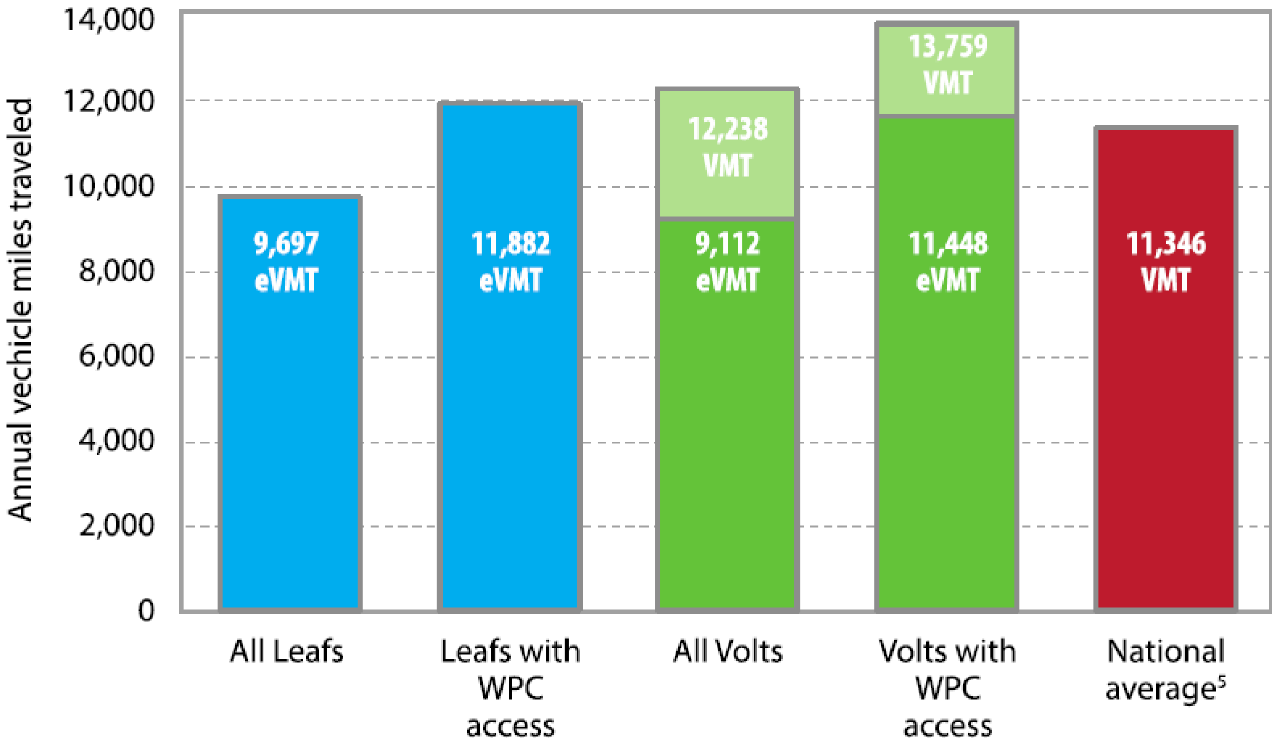
6% of drivers drove a Leaf to work even though they could not make it back home unless they charged at work

8% of Leaf drivers could complete their direct commute without charging at work, but their routine on most days required them to drive additional distance, which necessitated charging at work in order to make it home

40% of Leaf drivers relied on workplace charging on at least one day a month to complete their daily commutes

Range extension from workplace charging

Leaf and Volt drivers with known workplace charging averaged 23% and 26% higher annual EV miles traveled than the overall groups of vehicles in the project, respectively



[5] *Office of Highway Policy Information, Federal Highway Administration, "Highway Statistics 2013-Table VM-1," January, 2015, www.fhwa.dot.gov/policyinformation/statistics/2013/vm1.cfm*

Workplace Charging as a Substitute for Home Charging

About 30% of drivers only charged at work on most days

This shows that workplace charging could make PEVs viable for people without access to home charging

Photo courtesy of Facebook

Idaho National Laboratory

What have we learned about public charging station use?

Level 2 charging station usage (excluding workplace charging) was low overall

Median of 1.4 charges per week

75% of 2,400 sites nationwide averaged 4 or fewer charges per week

However, well designed sites at retail stores, especially shopping malls, and parking lots and garages serving multiple venues demonstrated potential to support 7 – 11 charges per day

What have we learned about public charging station use?

DC fast chargers were used much more frequently than most public Level 2 stations

Median of 7.2 charges per week

25% of DCFC's averaged >15 charges per week

The highest site saw 70 charges per week

The most highly utilized DC fast chargers tended to be located close to interstate highway exits.

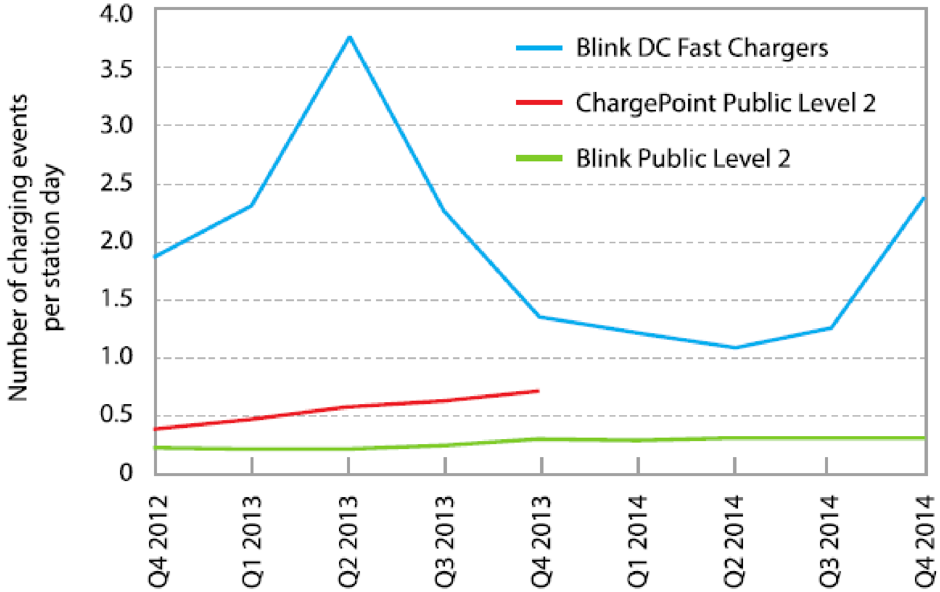
Public charging station usage varied by region, with higher usage in areas with higher PEV sales

However, highly utilized public charging sites were found in most regions, proving that utilization is dependent on local factors

How did public usage change over time?

Blink DC fast chargers were initially free and usage increased quickly

Usage dropped dramatically when the Blink Network instituted fees in summer 2013



19.5 The average number of minutes in a Blink DC fast charger session prior to the onset of fees.

After the onset of per-session fees, the average time spent charging increased by 20%

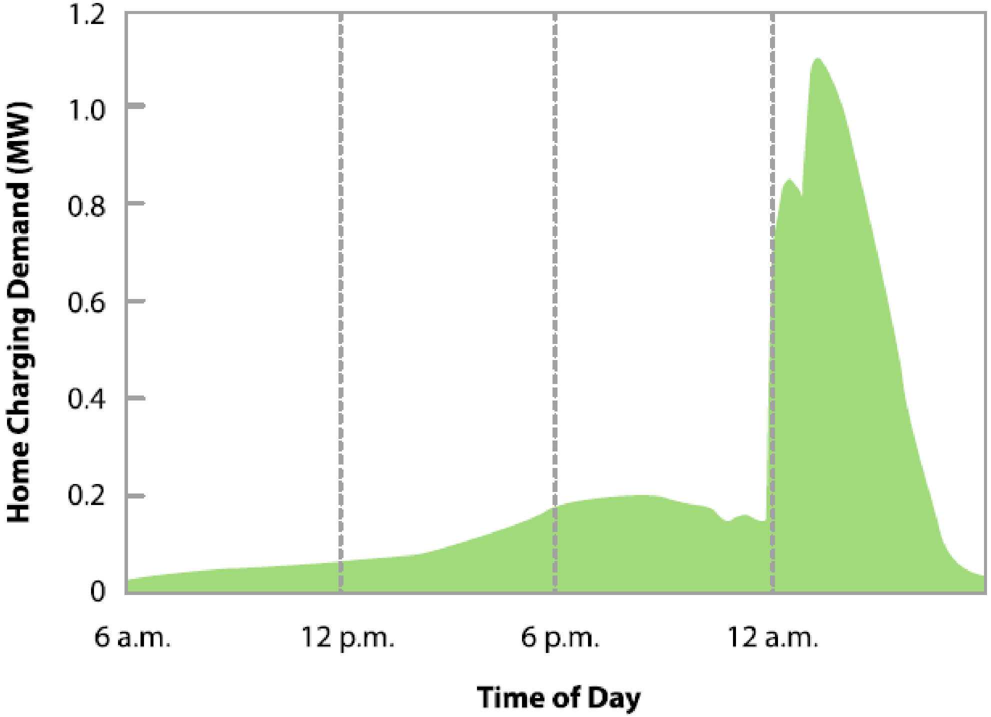
What have we learned about charging at home?

The vehicles never needed more than 5 hours to fully charge at home using the Level 2 charging units, and usually only took 1 to 3 hours to charge completely

This means that even though most vehicles were plugged in by 10 p.m., overnight charging at home typically could be delayed until the early morning hours when overall demand on the electric grid is lowest

What have we learned about charging at home?

PEV owners in the project in areas where time-of-use rates were offered showed a willingness to delay charging at home until off-peak periods



In San Diego, where the cheapest time to charge was midnight to 5 a.m., most PEV owners programmed their charging to start at midnight or 1 a.m.

What have we learned about charging station installation costs?

RESIDENTIAL LEVEL 2 AVERAGE INSTALLATION

$150 — $1,354 — >$8000

WORKPLACE LEVEL 2 AVERAGE INSTALLATION

$600 — $2,223 — $12,660

PUBLIC LEVEL 2 AVERAGE INSTALLATION

$3,108

BLINK DC FAST CHARGER AVERAGE INSTALLATION

$8,500 — $22,626 — >$50,000

For more information about The EV Project and ChargePoint America, visit **avt.inl.gov/evproject** and **avt.inl.gov/chargepoint**

john.smart@inl.gov **at.inl.gov**

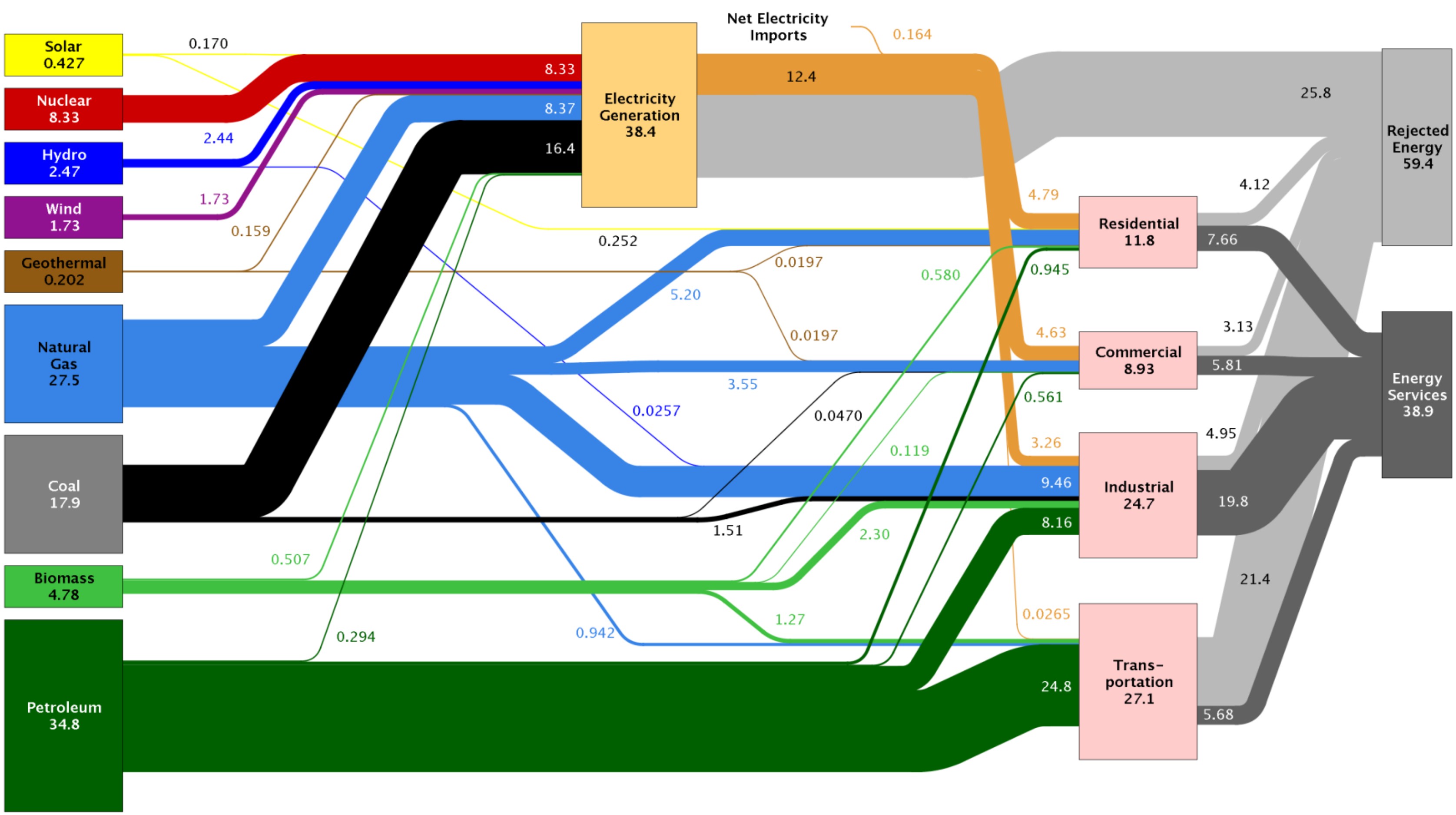
VEHICLE-TO-“X” APPLICATIONS

View of the Energy Landscape

- We use energy in everything we do
  - For our appliances, we call it “electricity”
  - For our heat, we call it “natural gas”
  - For our cars, we call it “gasoline”

Estimated U.S. Energy Use in 2014: ~98.3 Quads

Lawrence Livermore National Laboratory

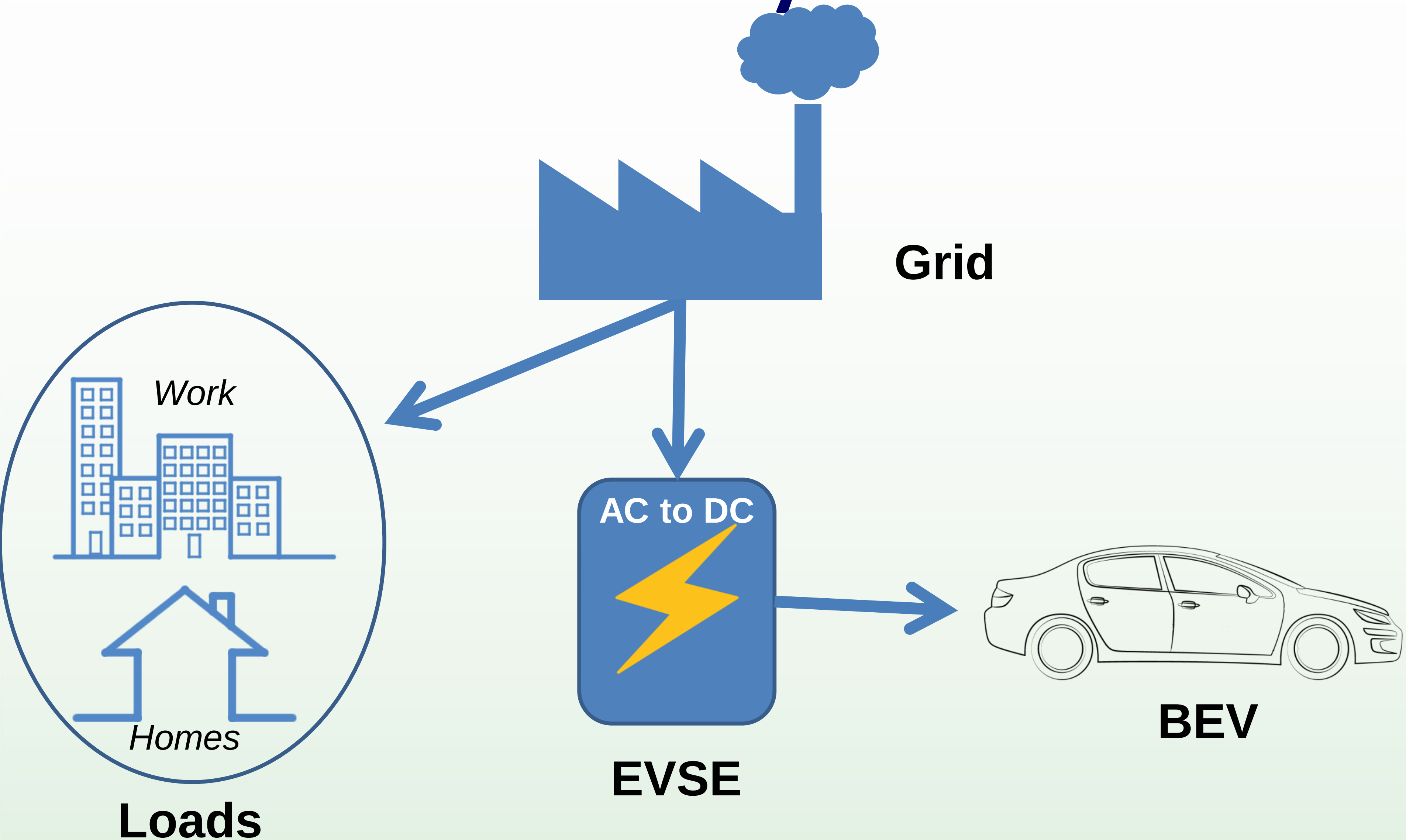


Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Image credit: Lawrence Livermore National Laboratory and Department of Energy

https://flowcharts.llnl.gov/commodities/energy

Current System

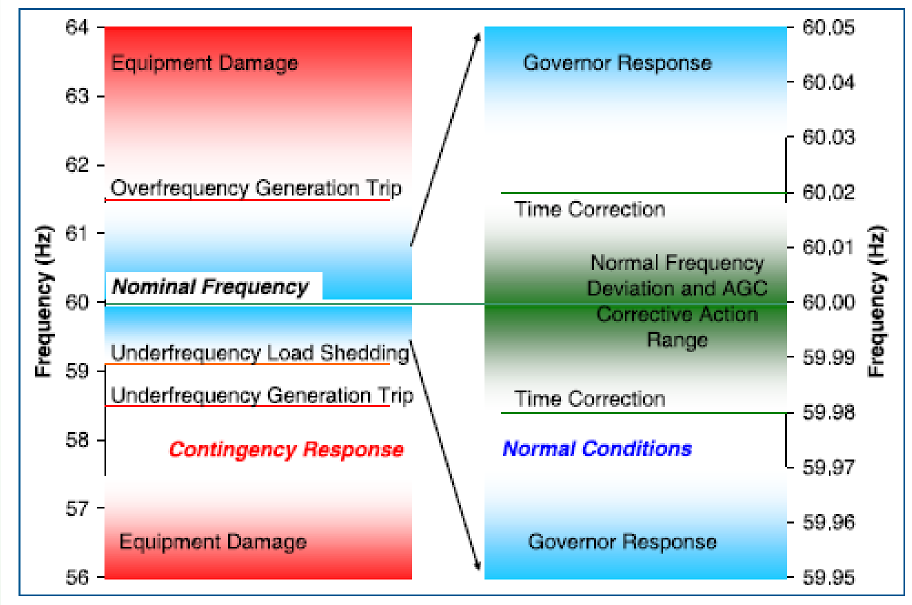


Challenges with Current System

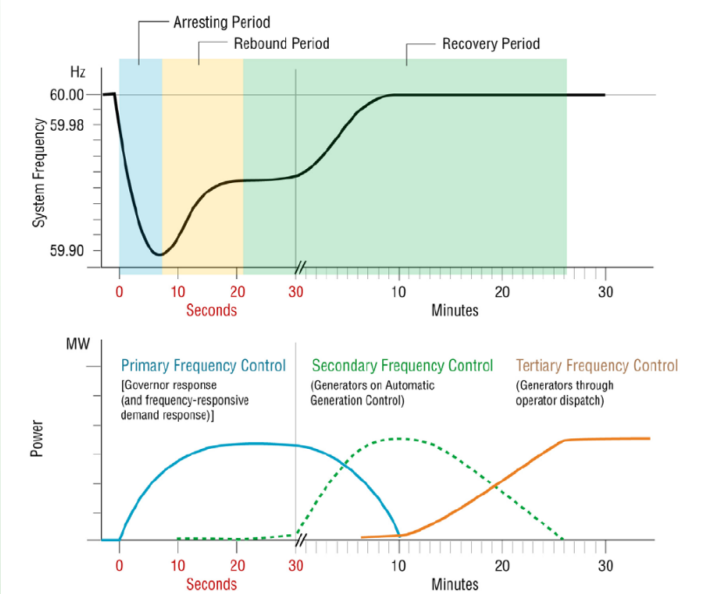
- "Just-in-time" electricity generation and consumption
  - Need to match production with load exactly
  - Maintain frequency at 60Hz (+/- 0.02 Hz)
- High costs with peaker power plants
  - Inefficient, "spinning reserves"
- Curtailment with high renewable penetration

Frequency Regulation

- Increased load = decreased frequency
  - Must increase generation/decrease load
- Generation and demand are matched exactly



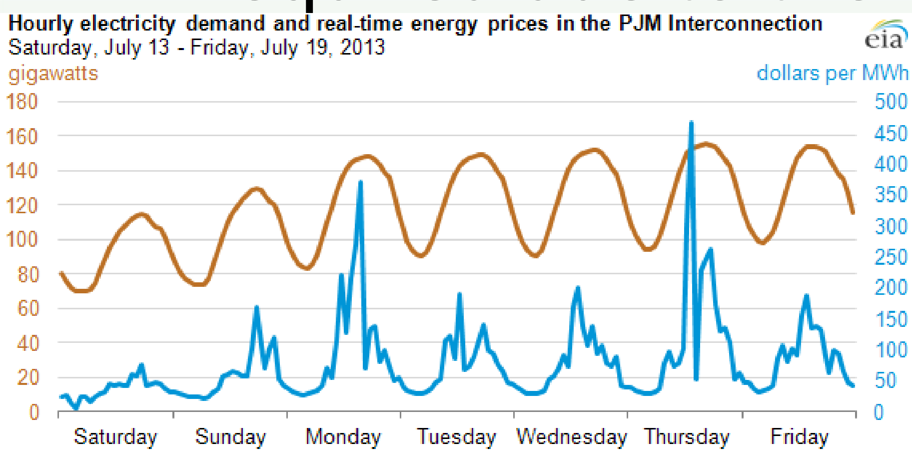
U.S.-Canada Power System Outage Task Force. Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations. April 2004.



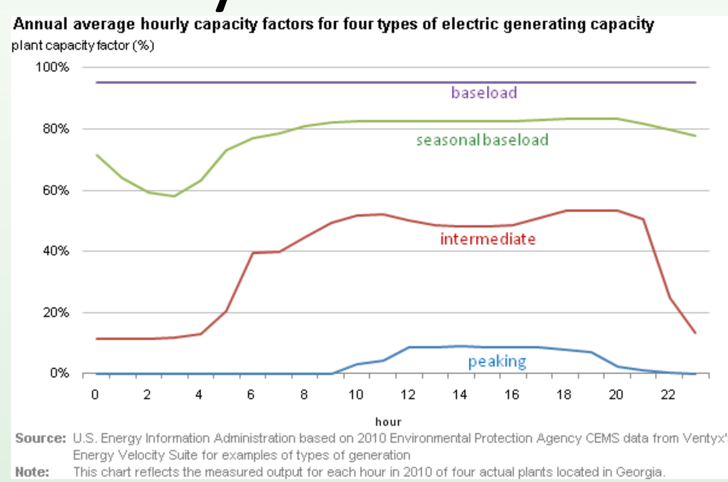
J.H. Eto et al., "Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation" December 2010. LBNL-4142E

Types of Power Plants

- Baseload plants operate nearly continuously
- Peaker plants operate ~10% of the time
- Costs are nearly double for peakers
  - $0.07-0.08/kWh vs. $0.14-$0.15/kWh
- Required due to the variability of demand



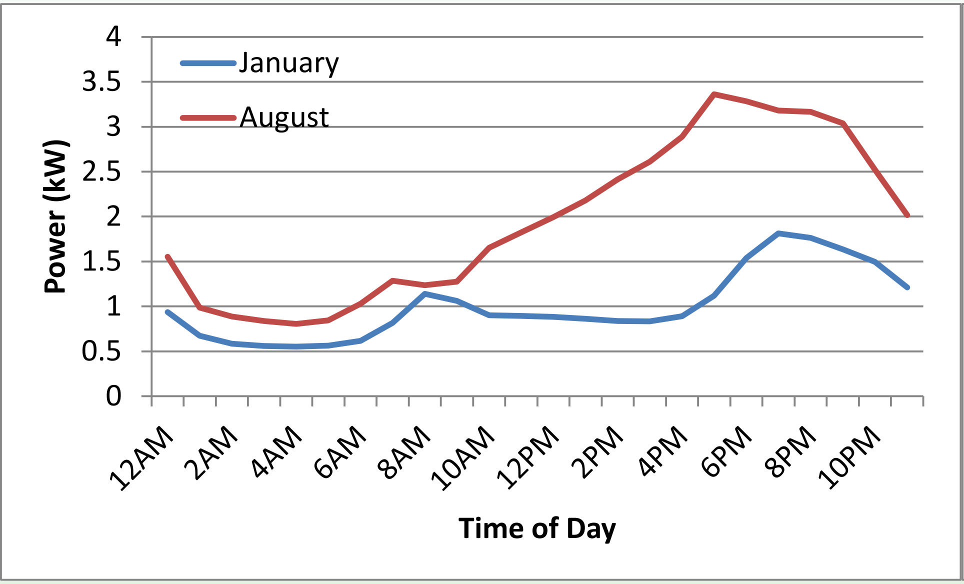
http://www.eia.gov/todayinenergy/detail.cfm?id=12711

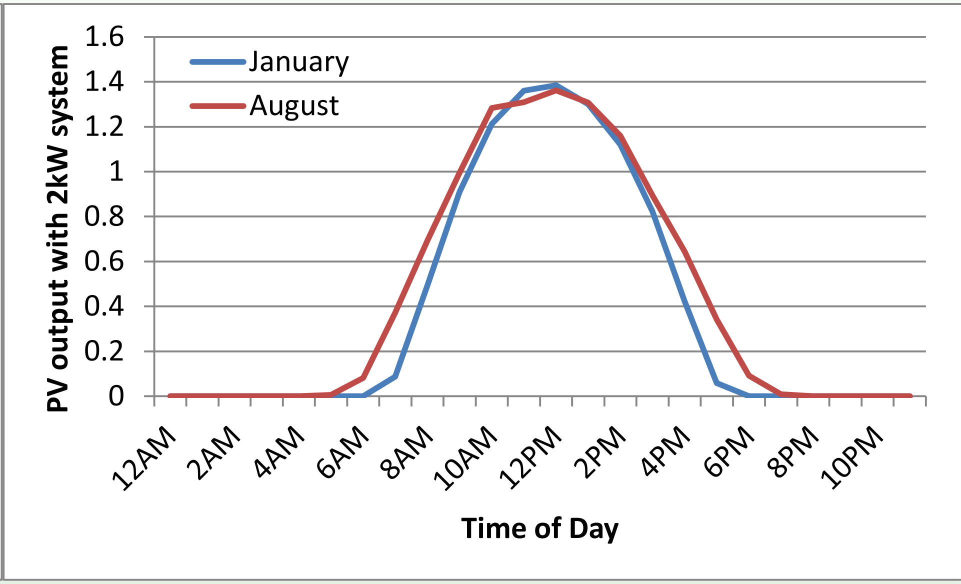


http://www.eia.gov/todayinenergy/detail.cfm?id=1710

“Duck Curve”

- Electricity demand does not match up with renewable production
  - Daily variation in wind and solar
  - Seasonal variations complicate planning
- Data from Tuscon, AZ home and 2kW PV models



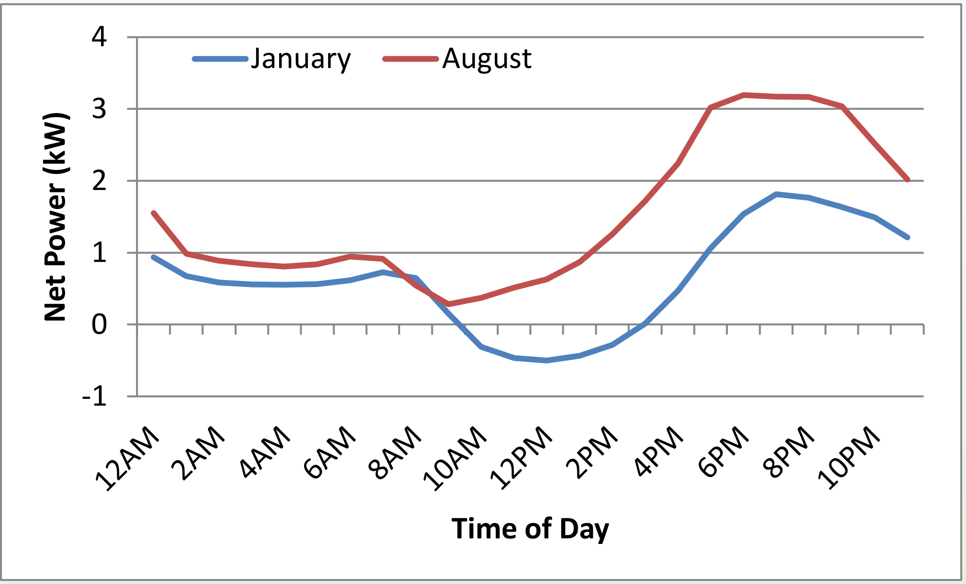


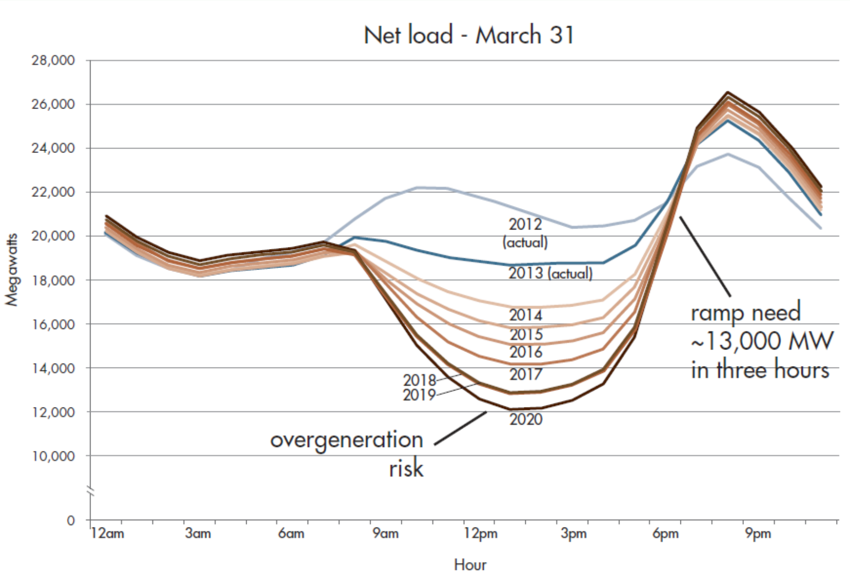
http://en.openei.org/datasets/files/961/pub/

http://pvwatts.nrel.gov/pvwatts.php

"Duck Curve"

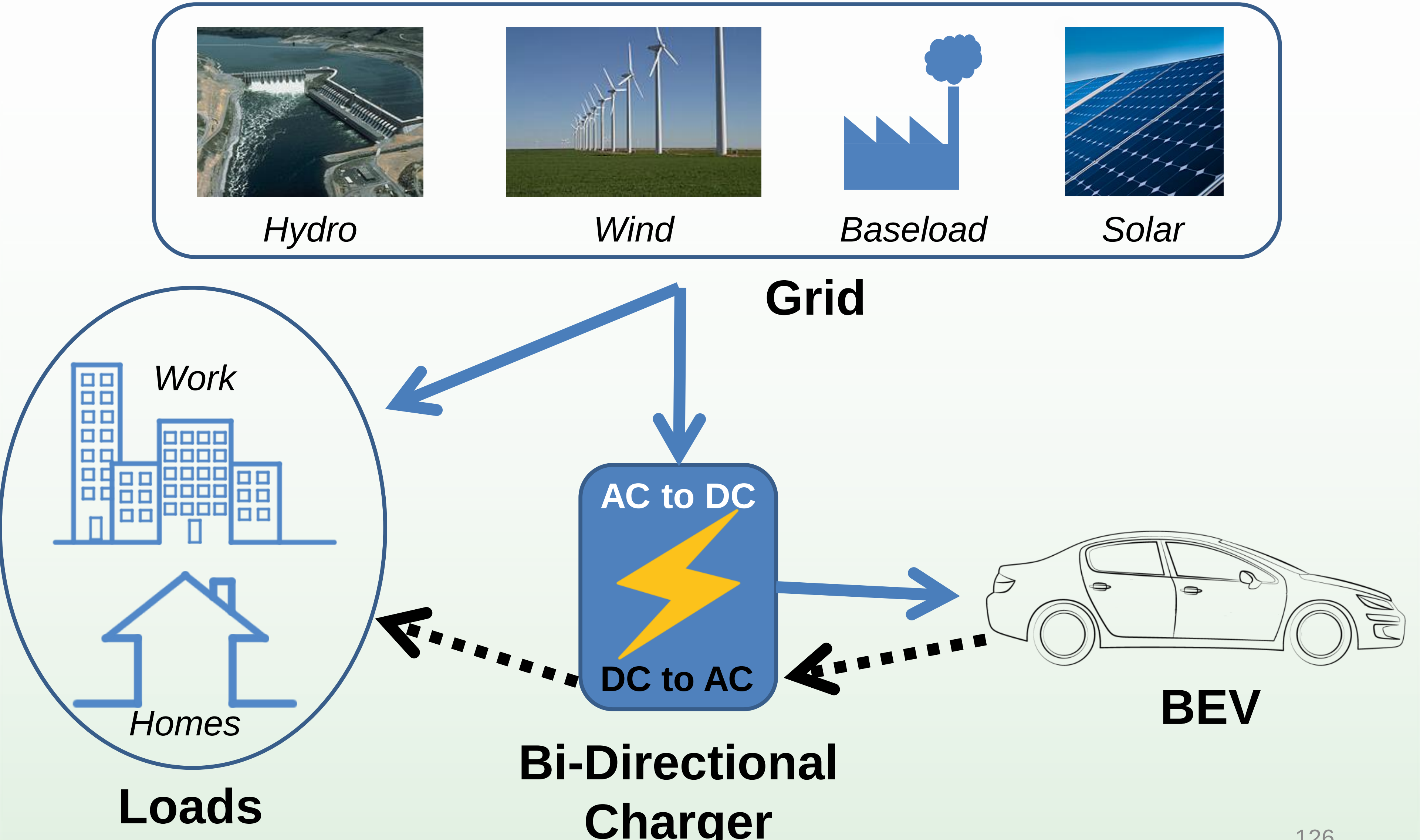
- Can meet building energy demand with 2kW
  - Winter months = "overgeneration"
- California has predicted high PV penetration statewide could lead to risks



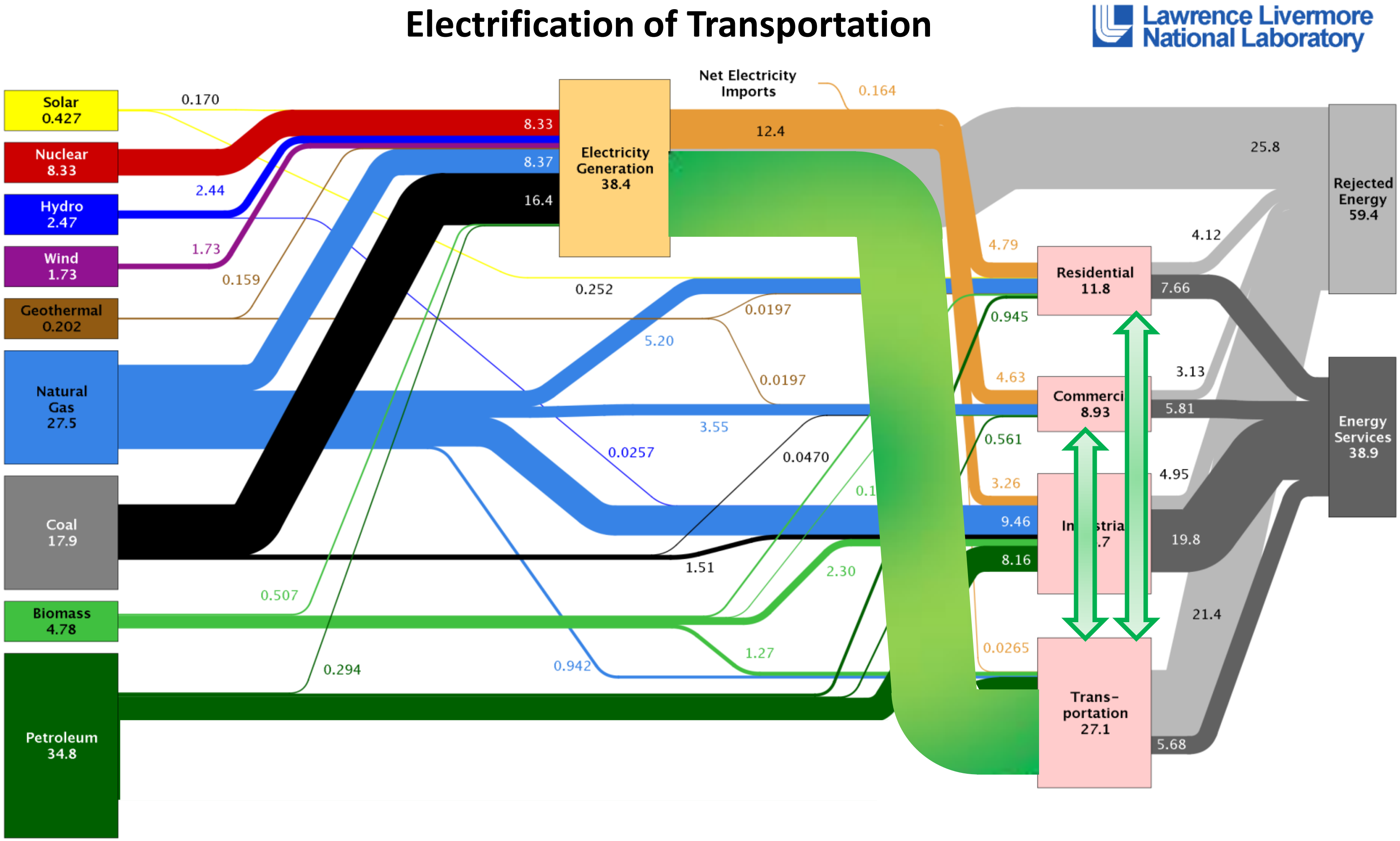


California Independent System Operator, "What the duck curve tells us about managing a green grid". CommPR/HS/10.2013

V2X System


Hydro
Wind
Baseload
Solar
Grid
Work
Homes
Loads
AC to DC
DC to AC
Bi-Directional Charger
BEV

Electrification of Transportation



Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

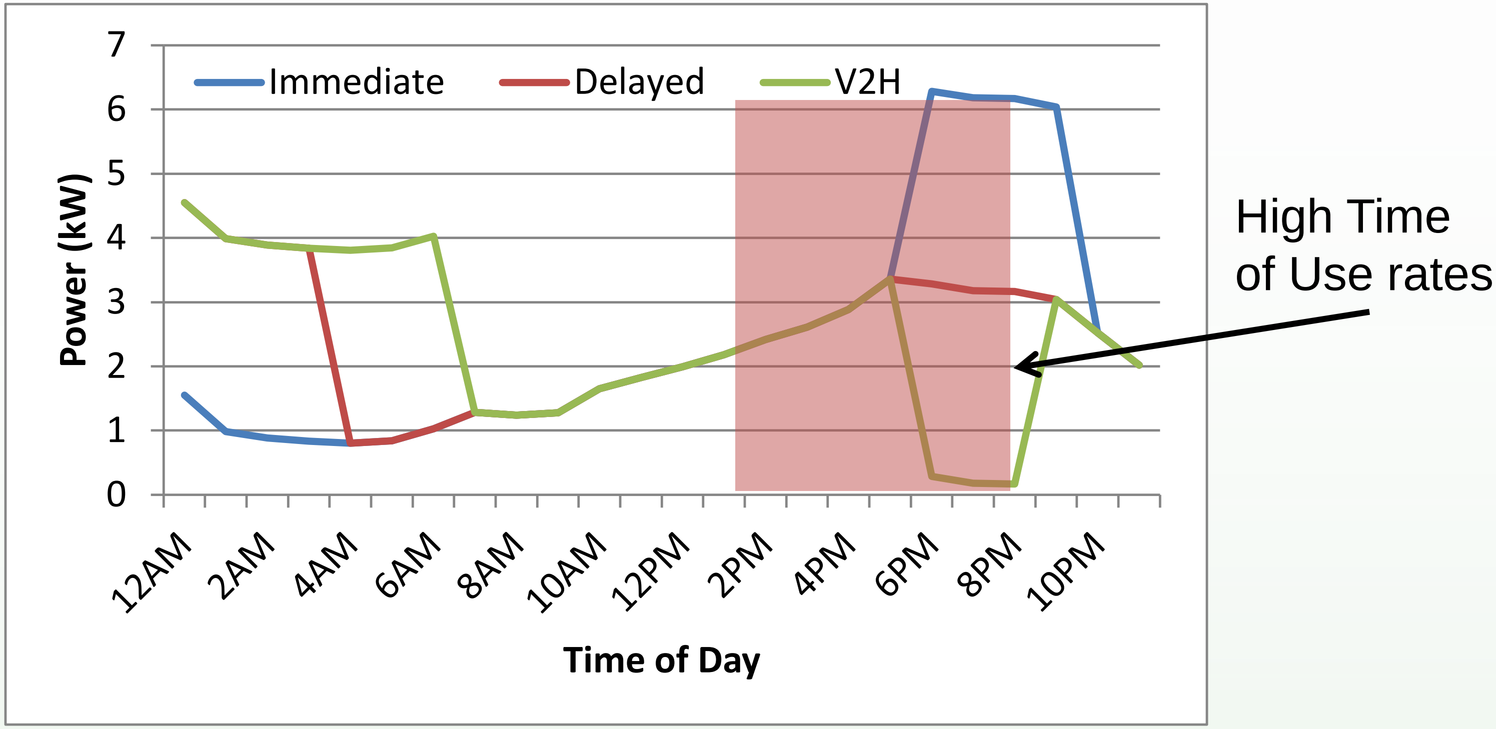
Benefits of V2X System

- Vehicle-to-home (V2H): single, 3-5 kW
  - TOU cost reductions
  - Backup power
- Vehicle-to-grid (V2G): multiple, 10-30 kW
  - Improved frequency response
  - Reduce peaker plant usage
- Vehicle-to-building (V2B): multiple, 10-30 kW
  - Micro-grid backup
  - Demand charge reductions

V2H: Modeled Case Study

- NHTS data shows vehicles leave at 7am, return at 6pm
- Upon return, BEVs will have traveled ~40 miles
  - For this model, assume Nissan Leaf, 80 mi range
- Must recharge vehicle before the following day
  - Three scenarios: Immediate, Delayed, V2H
  - Time of Use (TOU) rates in effect

TOU and Charging Profiles



- Same energy required for BEV recharge
  - Delaying until midnight shifts charge time
  - Adding V2H reduces demand during high rates

TOU and V2H

- Adding EV increases electricity costs
  - Offset by no gasoline costs
- V2H saves $50/month for BEV owners
  - Improves cost-margins vs. gasoline savings only

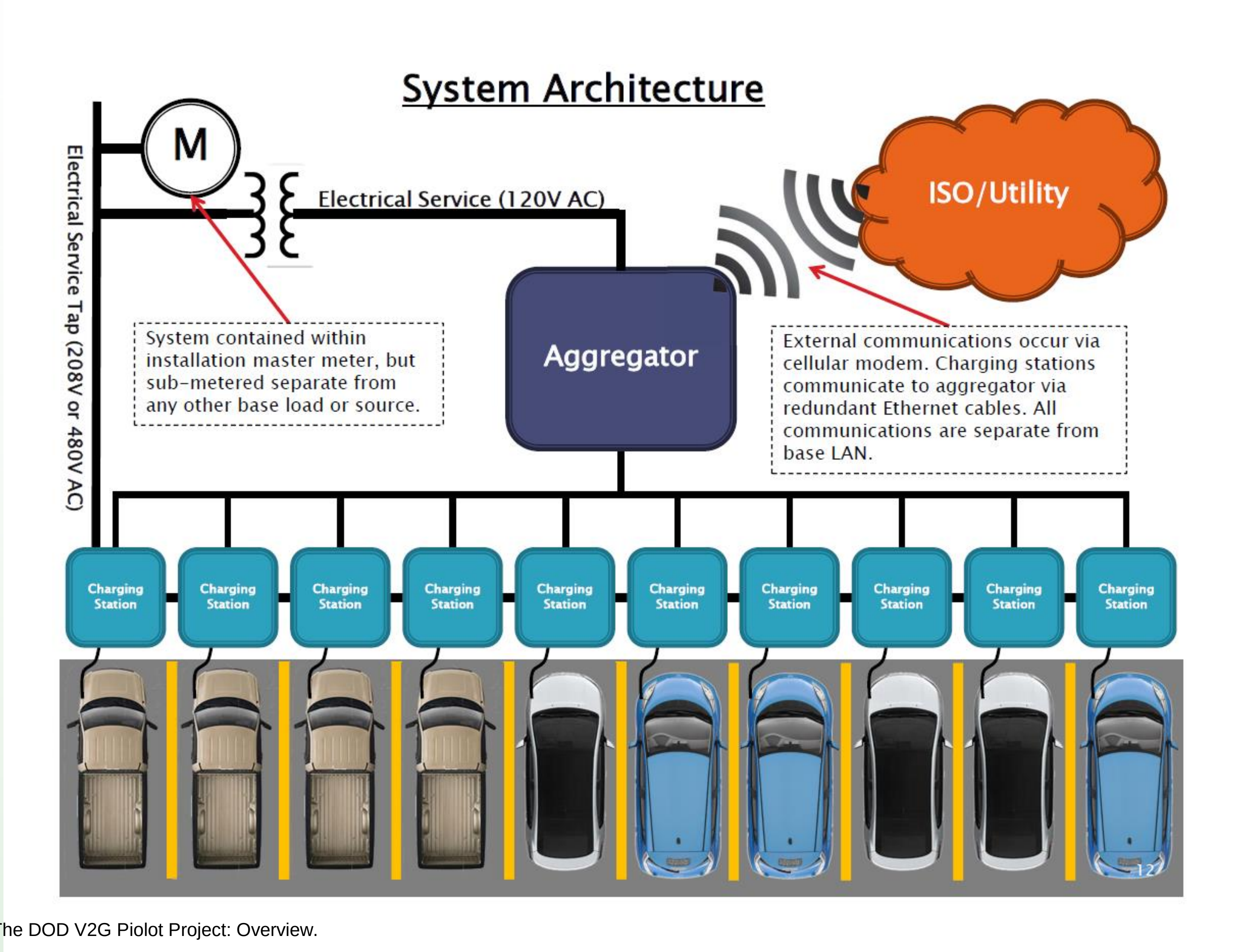
	Monthly Electricity Costs	Gasoline Costs	Total
No BEV	*$135*	*$65**	*$200*
Immediate Charging	$175	$0	$175
Delayed Charging	$160	$0	$160
V2H	$150	$0	$150

* 1000 miles per month, 30 MPG vehicle, $2.00/gal gasoline

Backup Power and V2H

- Model home requires 46kWh/day in Aug
  - Nissan Leaf has 24kWh
  - Tesla Model S has up to 85kWh
- A single BEV may not meet energy needs
  - Super Storm Sandy left some people without power for nearly 3 weeks
- Reduce home electricity during outage

V2G: DOD Pilot Project



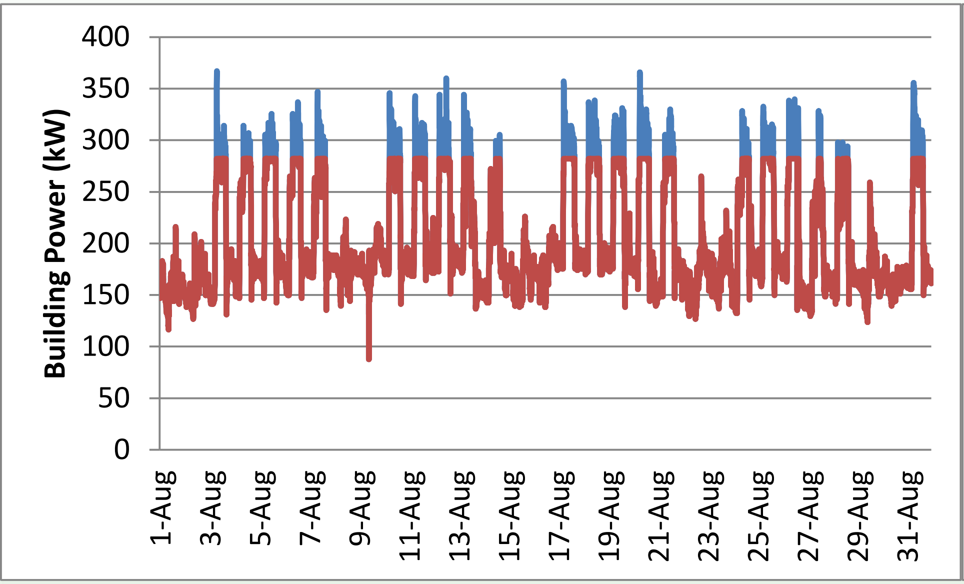
Camron Gorguinpour. The DOD V2G Piolot Project: Overview.

V2G Benefits

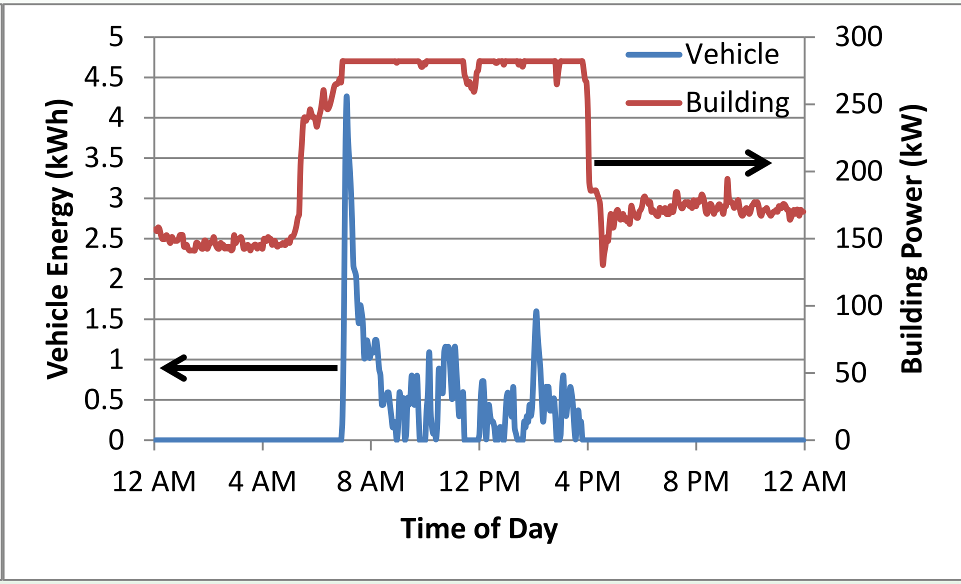
- Reduce the cost of leasing the vehicle through participating in grid frequency regulation markets
  – Southern CA market could save $209/month/car
- Additional savings could be realized
  – Participate in “spinning reserves” markets
  – Increased price of natural gas

V2B: FSEC Model

- Reduce demand charges
  - Need to recharge vehicles before COB
  - Need multiple vehicles



85 kW reduction in demand = $850 saved



Vehicles provide 109 kWh
FSEC has >120 kWh in “gaps”

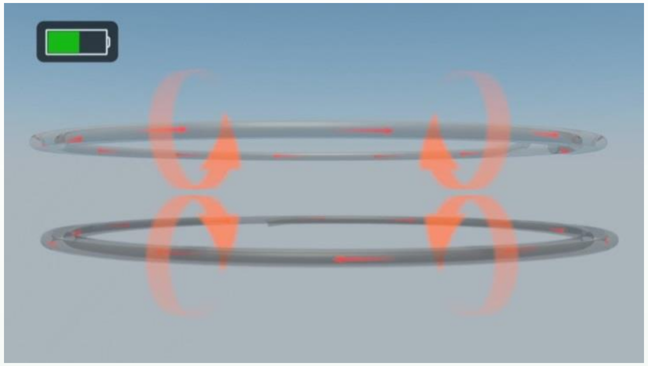
V2X Summary

- Significant reductions in operating costs
  - Frequency regulation limited to select markets
  - TOU savings possible with correct strategy
  - Demand charge reduction very likely
- Need to identify infrastructure
  - DC to AC converters required for most applications
  - May not be needed everywhere
- Impact on battery lifetime unknown
  - EVTC is currently researching

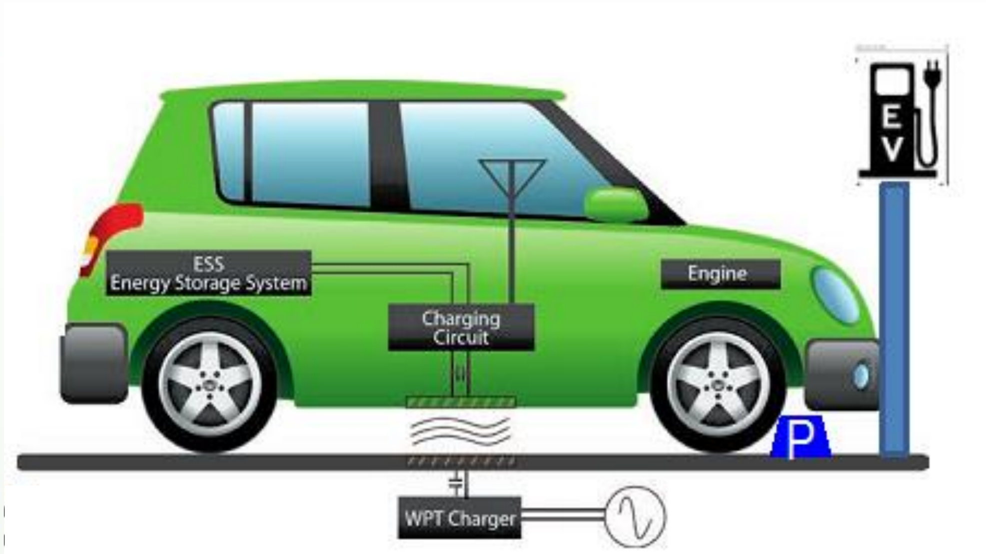
Other Emerging Technologies

- Wireless charging
- Autonomous vehicles.

Wireless charging



Faraday induction

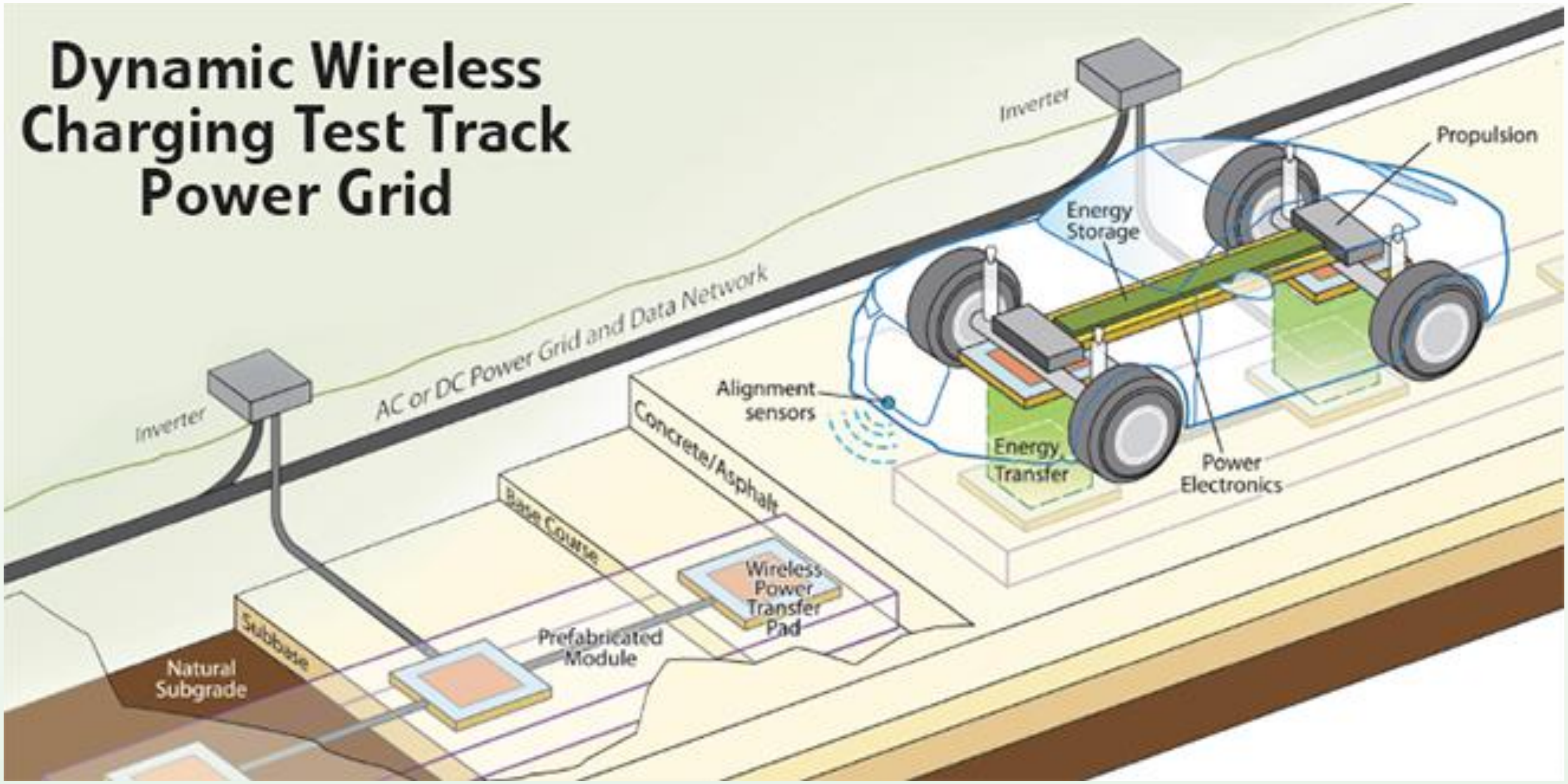


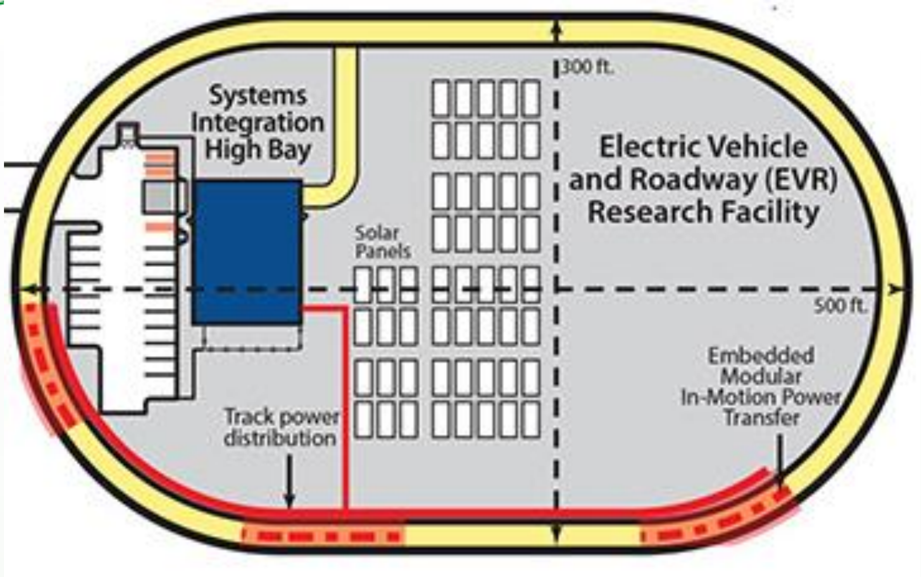
Convenient
Up to 90% efficiency
Non-radiative power transfer
Current power rating: 3.3 kW

High cost
Sensitive to alignment
Large size
The secondary coil needs to be installed

Images obtained from Oakridge National Lab

Dynamic Wireless Charging





Utah State University Electric Vehicle and Roadway research facility

Highways England

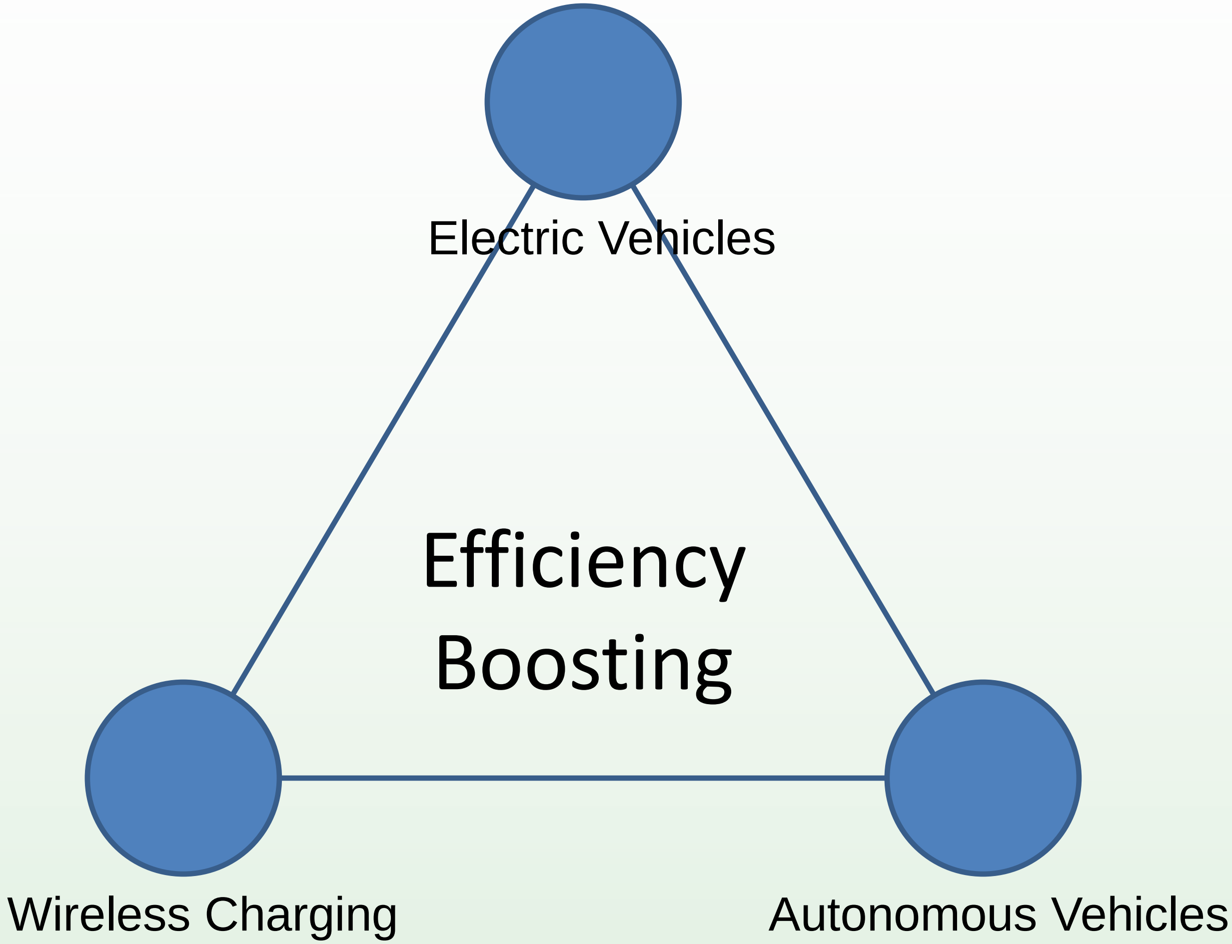
Autonomous Vehicles

Autonomous Vehicle Technology

- Radar
- Lidar
- GPS
- Computer vision

Level 0: The driver has full controls.
Level 1: Individual vehicle controls are automated.
Level 2: At least two controls can be automated in unison.
Level 3: The driver can fully cede control of all safety-critical functions in certain conditions.
Level 4: The vehicle performs all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time. (self-driving cars)

Autonomous Vehicles and EVs



Electric Vehicle Ecosystem

- What do we mean by “Ecosystem”

143

Business strategy variant	Charging infrastructure sphere	OEM sphere	Utility sphere	Customer sphere	Risk/Reward assessment	
					Risk	Reward
The builder	A supplier of charging infrastructure hardware.				↗	→
The maintenance-installer	Installation and maintenance services to charging network owners.				→	↗
The broker-operator	A manager of the charging infrastructure on behalf of potential network owners.				↗	↗
The gridmaster	An agent that integrates smart grid solution for utilities with charging infrastructure management.				↗	↗
The guardian	A provider of services ranging from charging infrastructure management to supporting EV manufacturers as well as customers (fleets and individuals).				↑	↗

↑ Very high / Excellent ↗ High / Good → Medium / Satisfactory ↘ Low / Poor ↓ Very low / Very poor

EVTC UCF

The ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. --DOE

Thank You!

For more information about EVTC, please visit http://evtc.fsec.ucf.edu/

nqin@fsec.ucf.edu PBrooker@fsec.ucf.edu