ECE 398GG – ELECTRICAL VEHICLES

3a. Key Considerations in EV Design and Operations

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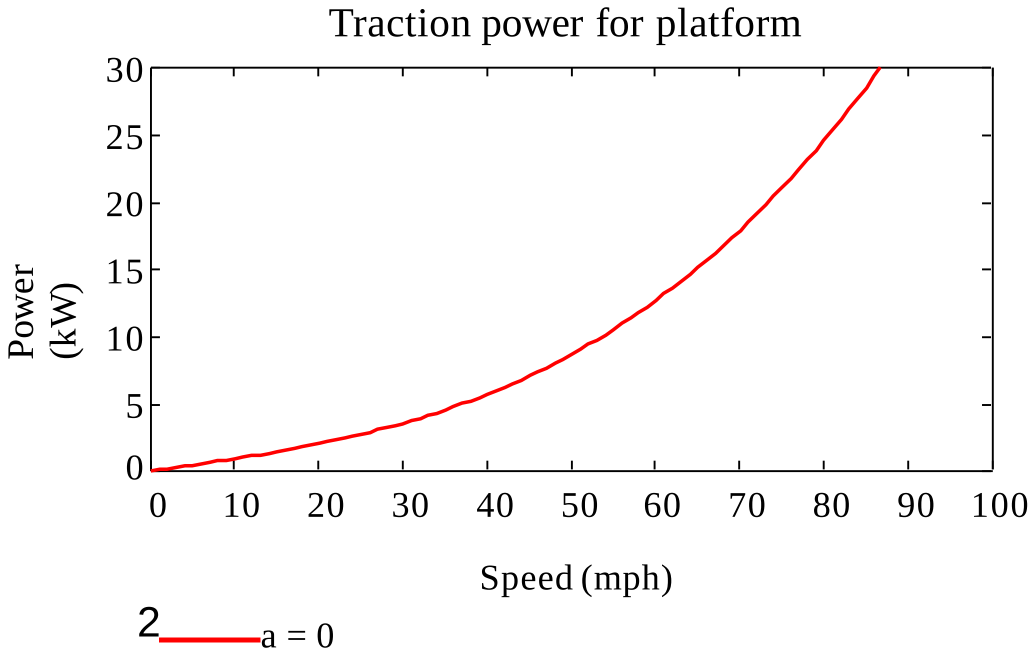
Reminder, Traction Force, Power

$$f_{traction} = mg\sin\theta + mgR_t + \frac{1}{2}\rho C_d A_f v^2 + m_{eq} a$$

- Power = f × v, but add in some overhead

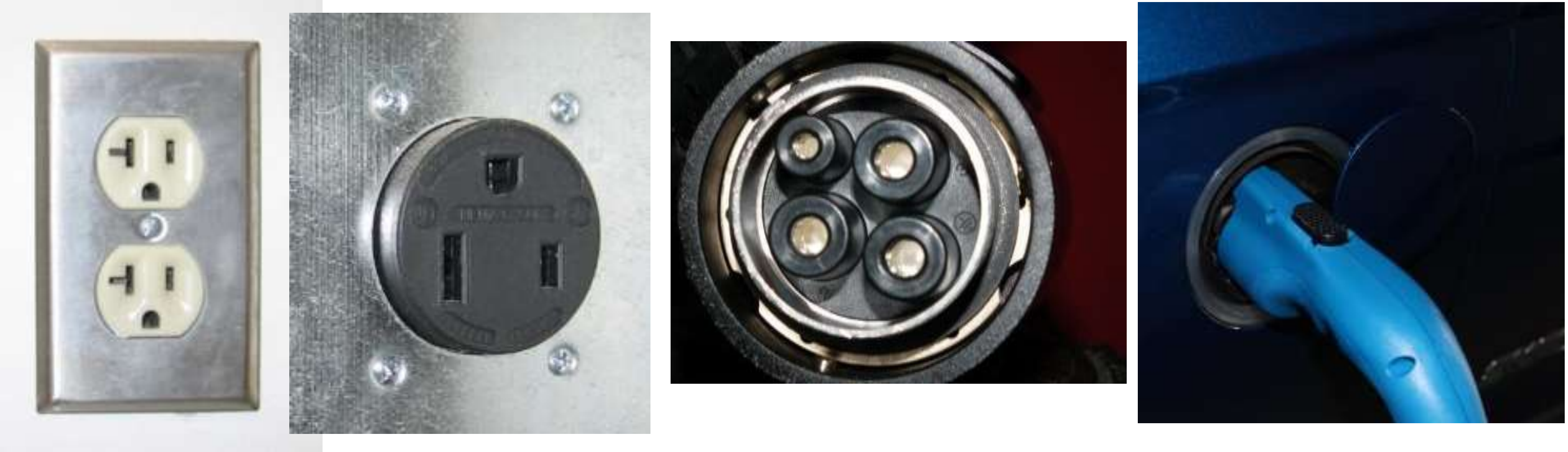


Rate and power needs

- *Rate* is a problem.
- Example: refill a gas tank with 15 gal in 5 min.
- The energy rate is that of a huge office building (6.7 MW).
- It is costly and problematic to fill batteries quickly.

Electric Charger Levels

- Level 1 – convenience outlet, 0 to 3.8 kW (typical 1.4 kW).
- Level 2 – dedicated charge point, 4 to 17 kW (typical 6 kW).
- Level 3 – fast charging, 25 kW and up (typical 50 kW).
  - Some are direct dc chargers.
  - Special charge points, not usual at homes or small businesses.



Electric Charger Levels

- Tesla Motors introduced the idea of thinking of these in terms of “miles per hour” (of useful charge).
- Level 1 – about 6 to 10 mph.
- Level 2 – about 25 to 60 mph.
- Level 3 – up to 500 mph.

Charge times

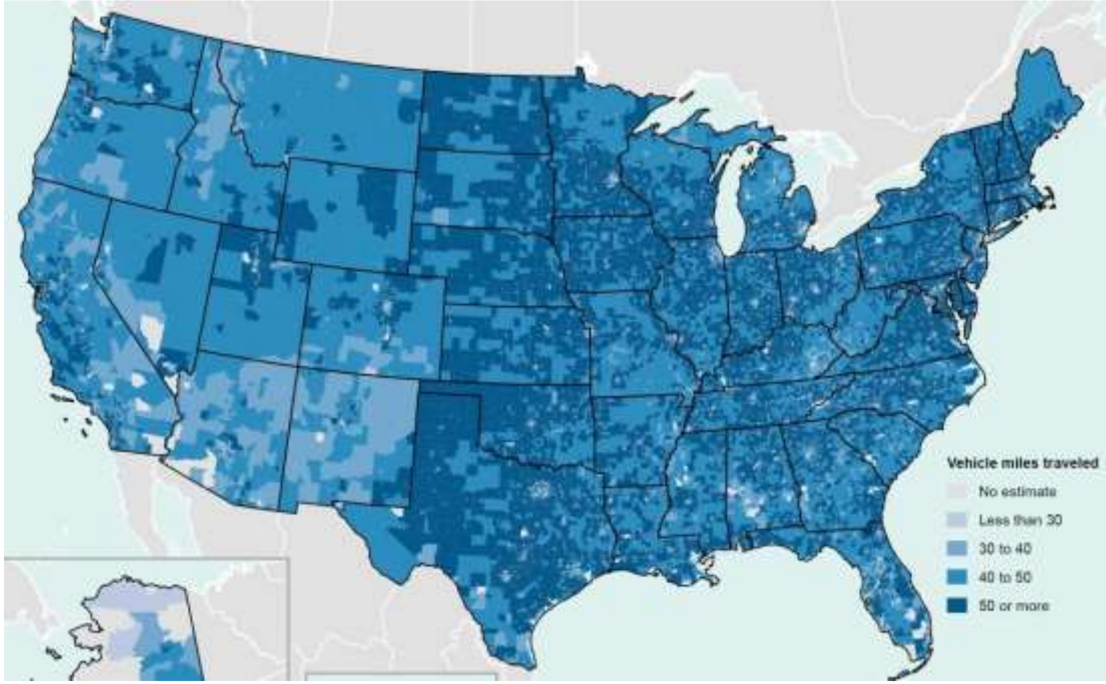
- This can result in a lot of confusion.
- Passenger cars are parked more than 80% of the time.
- You don’t park connected to a gas pump, but you *can* park connected to an electric outlet.
- 8 pm to 6 am: 10 hrs
  - – Level 1 – 60 to 100 miles.
  - – Level 2 – 250 to 600 miles.
  - – Level 3 – not for overnight connection.
- I will not have this time in a long-distance trip, but likely for daily driving.

Usage

- There is a temptation to map EVs onto fuel vehicles.

But, consider:

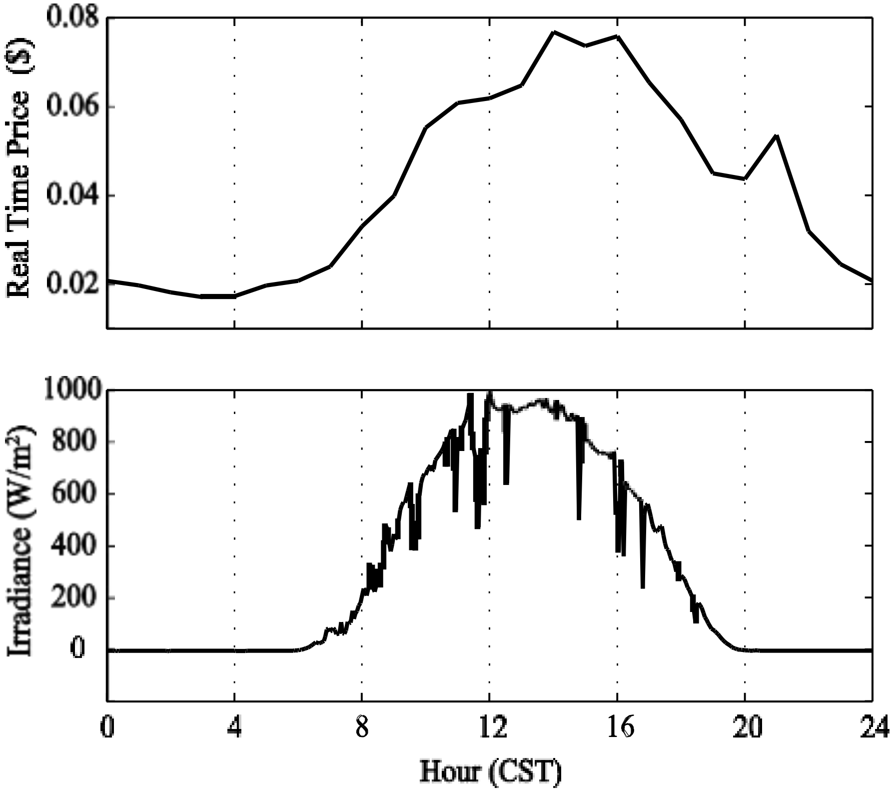
- U.S. daily car travel average is 29 mi.
- 95% of U.S. daily trips are below 31 mi.



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
http://nhts.ornl.gov/vehicle-trips

Incentive for long-term outlet connection

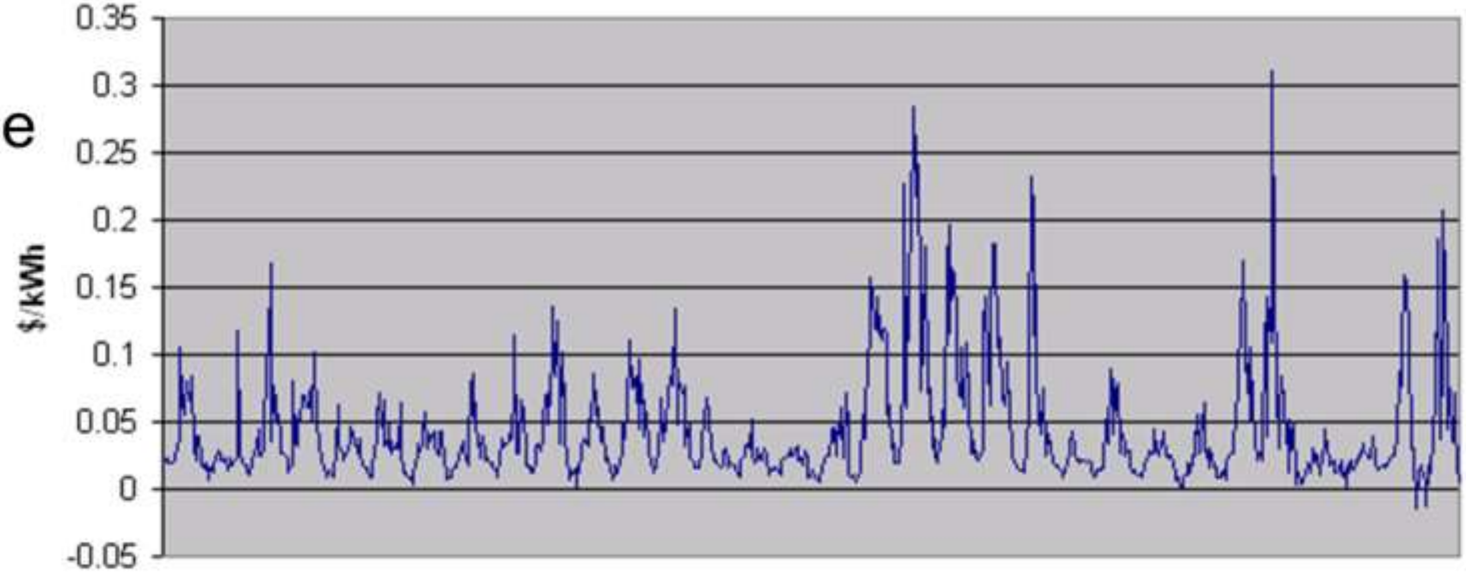
- Electricity is usually much cheaper at night than during the day. Likely 4x difference.
- If a vehicle can be programmed or controlled, it can choose to charge for the cheapest energy.
- Or sell timing flexibility back to the grid for a discount.



What does this mean?

- "It takes a long time to charge an electric vehicle."
  - – It takes a long *connection* time, but this is not the same as *driver* time.
- Rate matters in at least three major situations:
  1. Vehicles that park only a limited portion of time (trucking, taxi service, public transport, delivery, …).
  2. When I want to take a long trip.
  3. *When I have no access to an outlet.*

Retail real-time price, one month, Spring 2007



A quick economic check

- Take gasoline at $3.60/gallon, and a car that achieves 30 miles/gallon.
- Energy cost is $0.12/mile, and usage is about 1240 Wh/mi.
- Now take electricity at full retail $0.12/kW-h, and a car that consumes 250 W-h/mile.
- Energy cost is $0.03/mile.
- Much cheaper with night charging.

This plug-in hybrid gives a choice.

electrek.co (2/18/20)

Rate plan: $2/hr

Some points

- At a night rate of $0.04/kW-h, cost becomes $0.01/mile.
- Substantial incentive for the customer.
- Even at full retail electricity price, the energy is much cheaper than gasoline. But some folks are trying to cash in anyway.
- Still the issue of range and long-range driving.

guardian.co.uk

Examples

- 2020 Nissan Leaf with 40 kWh battery pack.
- Data from the manufacturer, www.nissannews.com
- 6.6 kW charger on board – direct plug into 120 V or 240 V outlet.
- Drag and frontal area can be hard to find. Car and Driver reported 24.5 ft^2 (2.28 m^2) for the 2012 leaf in the June 6, 2014 issue. Nissan reports Cd = 0.28 for the 2020 model.
- Unloaded weight is 3540 lb (1606 kg), and fully loaded gross weight rating is 4750 lb (2156 kg).
- Let’s load it to 1800 kg and see what it needs!

Examples

- By the way, a more recent *Car and Driver* issue tells us the car can do 0 to 60 mph in 6.8 s.
- 60 mph → 26.8 m/s.
- 26.8 m/s in 6.8 s is 3.94 m/s^2, or 0.4g.
- The same test showed that the car could pull 0.76g in a tight turn before sliding. This gives us the tire friction coefficient, but only on their test pavement.

Examples

- 70 mph cruise, flat: Traction force 516 N, power 16.1 kW.
- 100 mph, flat: Traction force 905 N, power 40.5 kW.
- 0.3g acceleration, flat, 30 mph: Force 5850 N, power 78.5 kW.
- 0.4 g acceleration, flat, 60 mph: Force 7936 N, power 213 kW.
- Nissan reports a motor rating of 110 kW.
- 35 mph cruise, flat: 235 N, 3.67 kW.
- 5% grade at 72 mph: 1420 N, 45.7 kW.

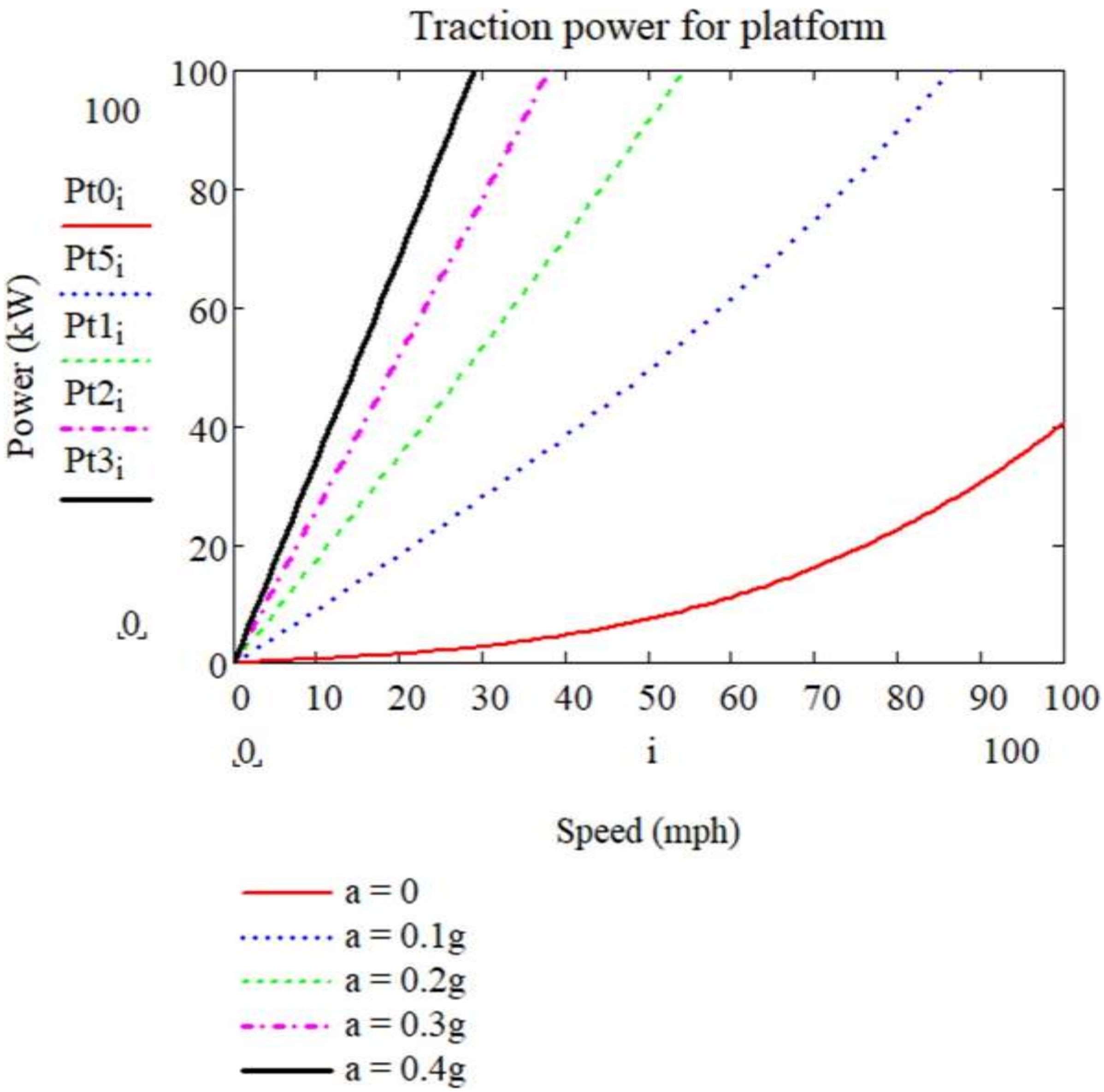
Examples

- What energy?
- 70 mph cruise, 90% drivetrain efficiency, plus 1 kW hotel load, for example:
- 16.1 kW/0.9 + 1 kW = 18.9 kW input, so 18.9 kWh/h, equal to 270 Wh/mile.
- Range based on using 80% of storage is 119 miles.
- “EPA range” is 149 miles, but this is for a combined city and highway test, not cruise at speed.
- 75 mph cruise, 19.1 kW traction, 22.3 kW input, 297 Wh/mile.
- Range based on using 80% of storage is 108 miles.
- 45 mph cruise, 170 Wh/mile, 189 miles of range.

Examples

- Move up a 30% grade: 5440 N (at zero speed)
- From experience, power to provide 2.5 m/s^2 at 50 mph should be representative of top end power needs.
- Here that gives 112 kW (same as motor rated power!).
- Maximum speed, flat, 110 kW: 143.5 mph.
  - This defines “top speed” for a vehicle – continuous rating, maximum speed.
- Looks like this vehicle runs at 200% rated power for a few seconds to achieve its 6.8 s time.

Examples


Traction power for platform
Power (kW)
100
Pt0_i
Pt5_i
Pt1_i
Pt2_i
Pt3_i
0
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
0
i
100
Speed (mph)
a = 0
a = 0.1g
a = 0.2g
a = 0.3g
a = 0.4g

Examples

- Typical Class 8 tractor-trailer with cab fairing
- Data from NASAAmes and others.
- Frontal area 9.89 m^2, Cd 0.60, tire resistance 0.007.
- Load to 60000 lb.

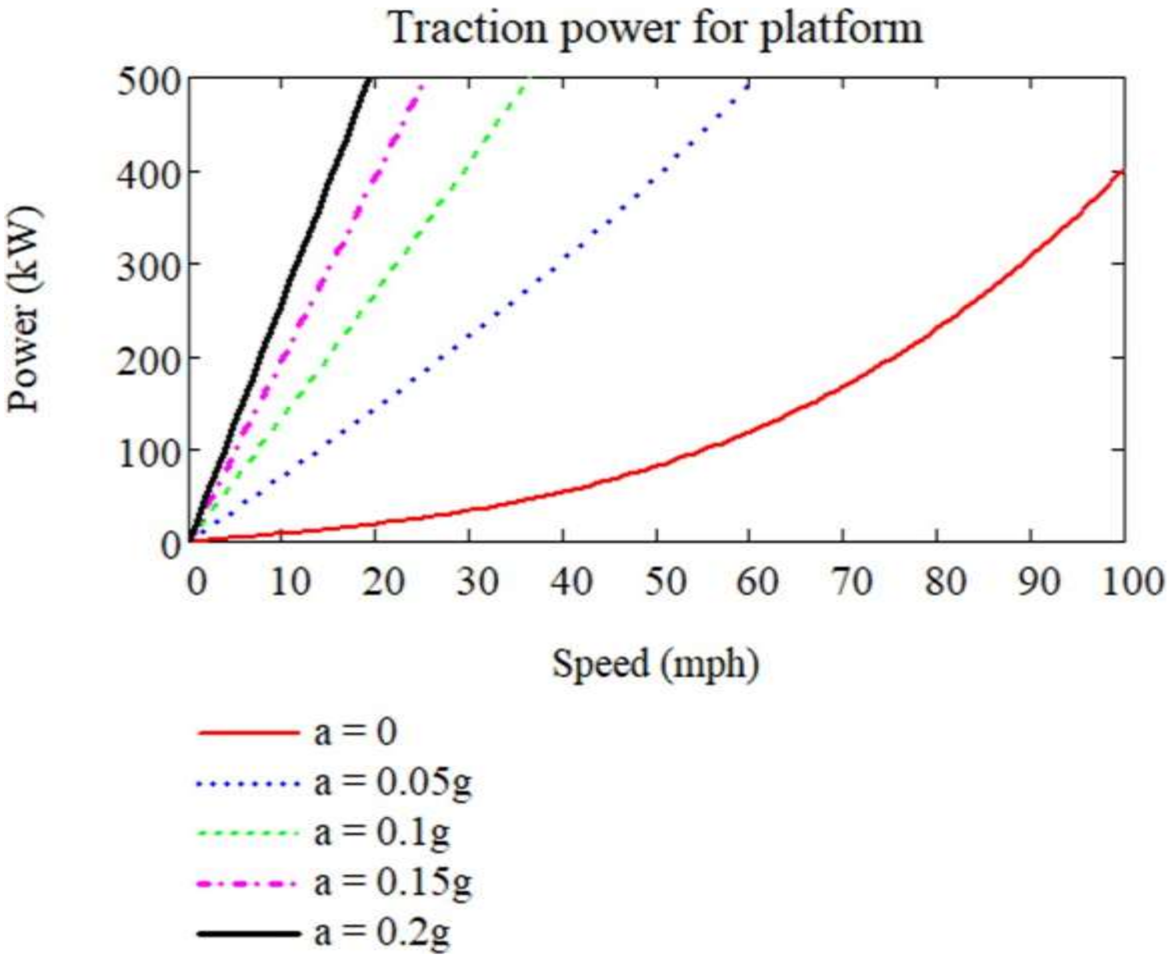
Examples

- 70 mph cruise, flat: Traction force 5356 N, power 168 kW.
- 100 mph, flat: Power 402 kW.
- 0.3g acceleration, flat, 30 mph: Force 86.3 kN, power 1.16 MW.
- 0.1 g acceleration, flat, 60 mph: Force 32.4 kN, power 868 kW.
- 5% grade at 72 mph: 18.9 kN, 608 kW.

Examples

- What energy?
- 70 mph cruise, 90% drivetrain efficiency, plus 1 kW hotel load, for example:
- 168 kW/0.9 + 1 kW = 187 kW input, so 18.9 kWh/h, equal to 2675 Wh/mile.
- 75 mph cruise, 197 kW traction, 220 kW input, 2930 Wh/mile.
- About 10x compared to passenger car.
- Implies 10x for storage needs!

Examples

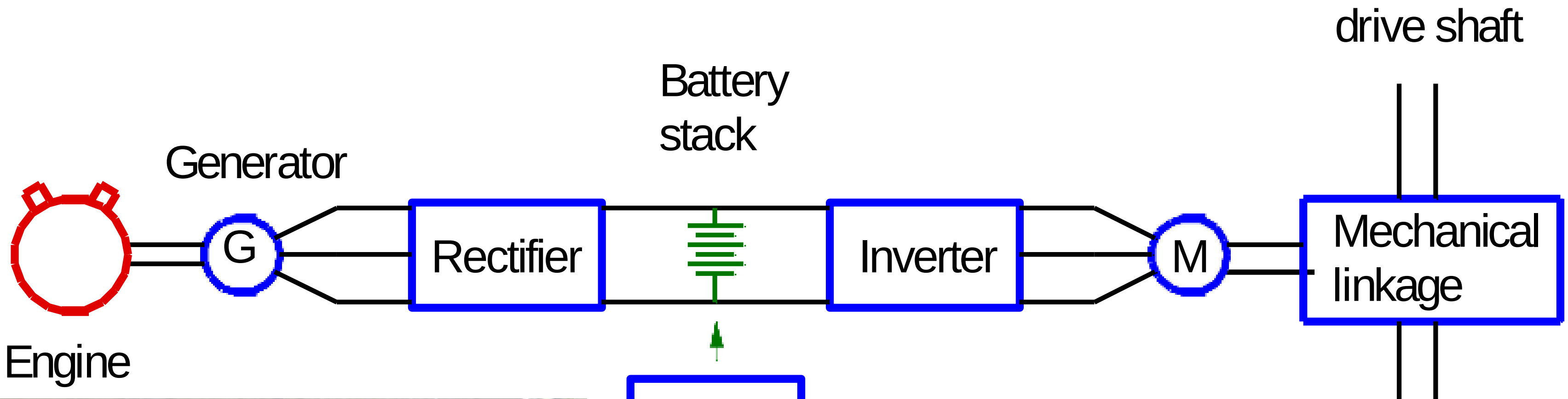

Traction power for platform
Power (kW)
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
Speed (mph)
a = 0
a = 0.05g
a = 0.1g
a = 0.15g
a = 0.2g

Energy

- Could we store 700 kWh on board a truck?
  - Diesel at 45000 kJ/kg. If we convert 30% of it, a truck can easily store 300 kg of fuel and has about 4 GJ, or 1125 kWh of useful energy stored up.
  - For Li-ion batteries, at a (future) 1000 kJ/kg, 700 kWh is 2.52 GJ, requiring 2520 kg of batteries (5500 lb).
  - This is not impossible (about 10% of the loaded mass), but it is a future development.

Baseline Architecture

- Generic architecture for a “series” hybrid electric vehicle.
- This means the energy comes together at an electrical bus.



drive shaft

Battery stack

Generator

G

Rectifier

Inverter

M

Mechanical linkage

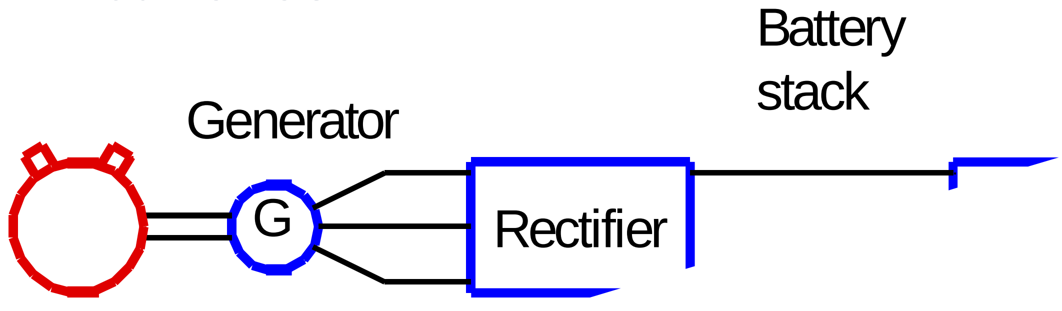
Engine

Charger

Baseline Architecture

- Example: Diesel-electric train. Same (with ac motors) but no batteries.

drive sha



Battery stack

Generator

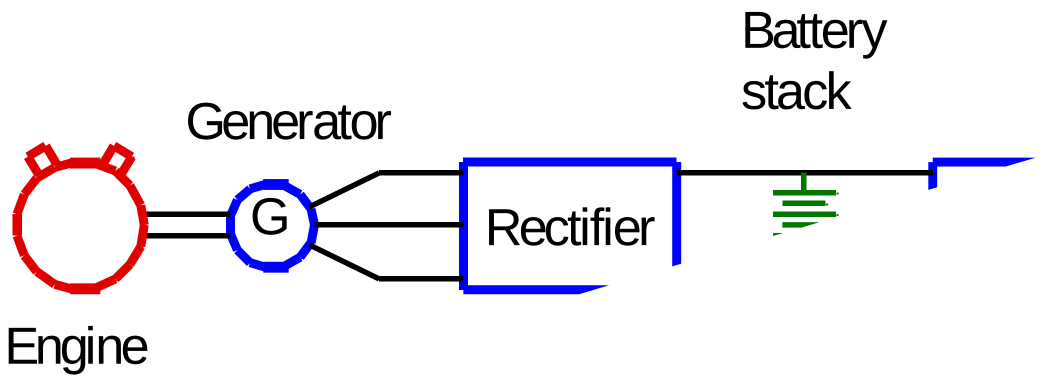
G

Rectifier

Engine

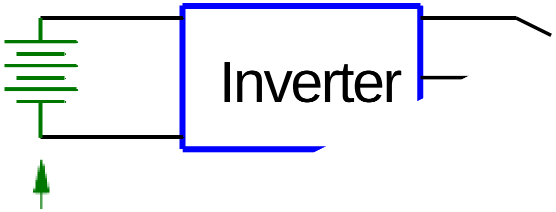
Baseline architecture

- Typical for plug-in hybrid.



Battery electric vehicle

- Pure EV, larger battery, typically an on-board charger.



drive shaf

Battery
stack

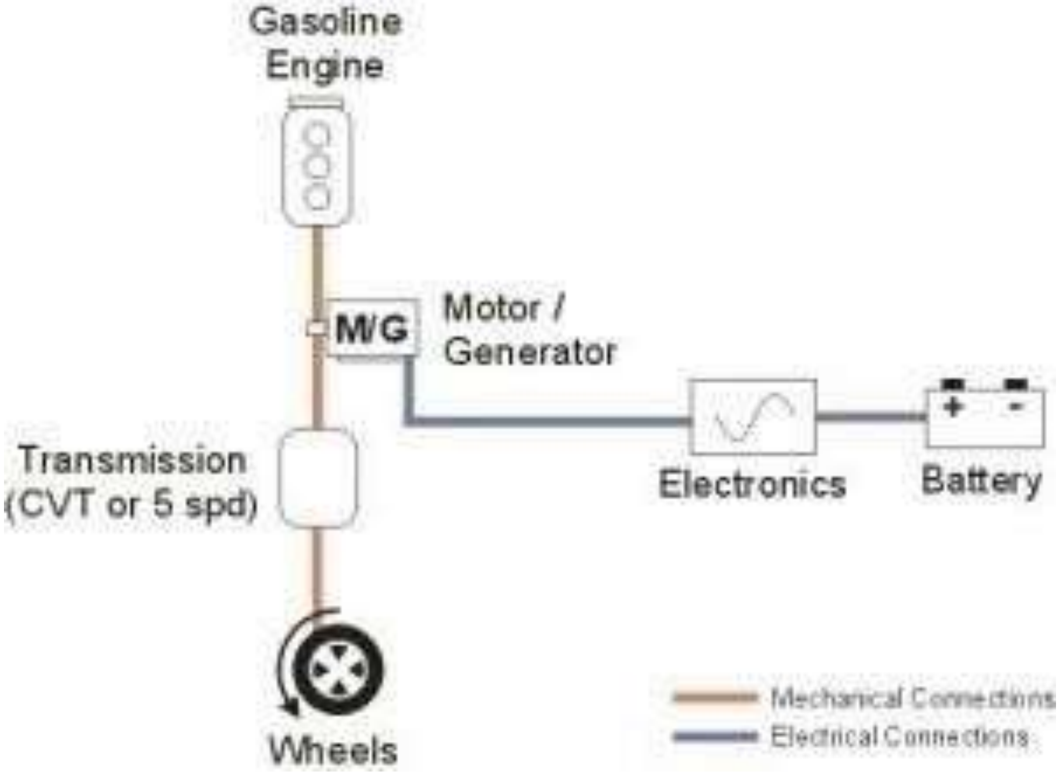
Inverter

Char

Other hybrid electric vehicles

- Parallel hybrid: energy is assembled mechanically.

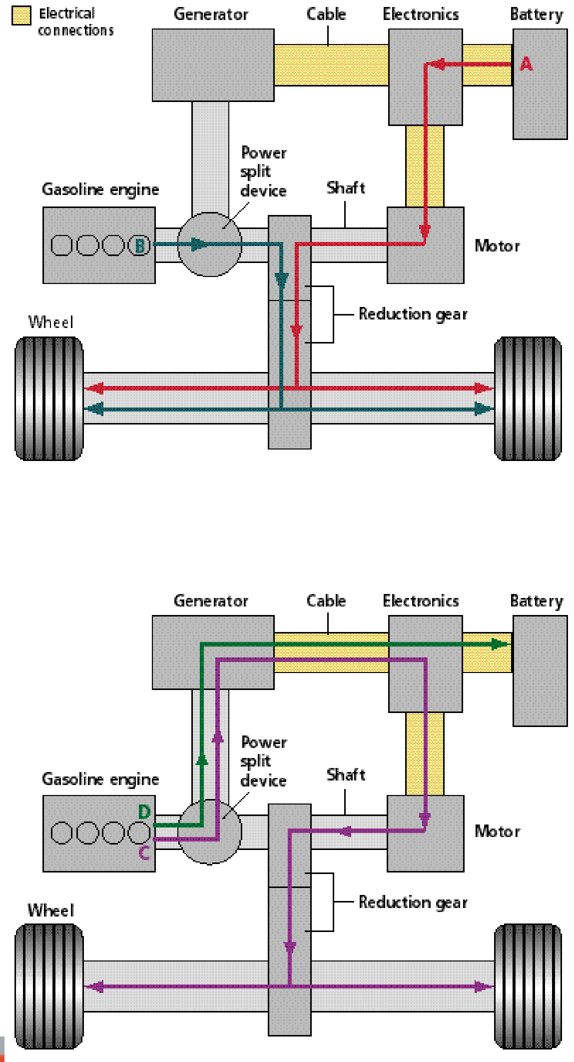
Source: Mechanical Engineering Magazine online, April 2002.

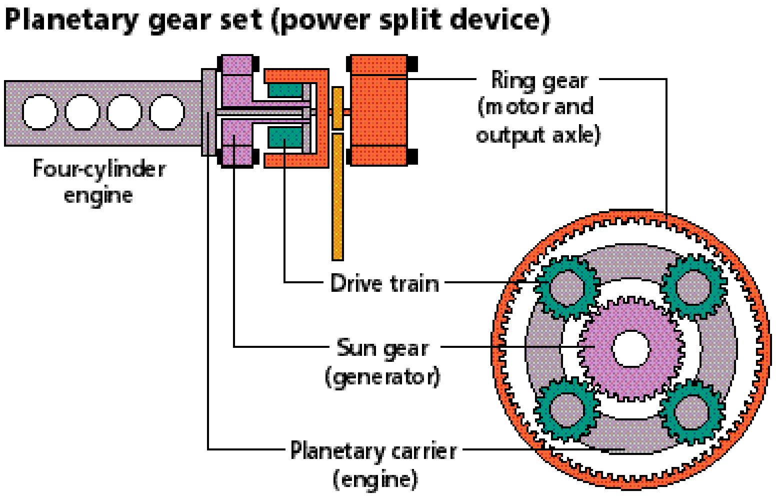


Credit: Honda

Other hybrids

- “Dual” hybrids are parallel designs with some series modes.
- A “mild” parallel hybrid uses a small electric motor to recover braking energy and allow easy engine start and stop.





Source: Toyota

Basic battery issues

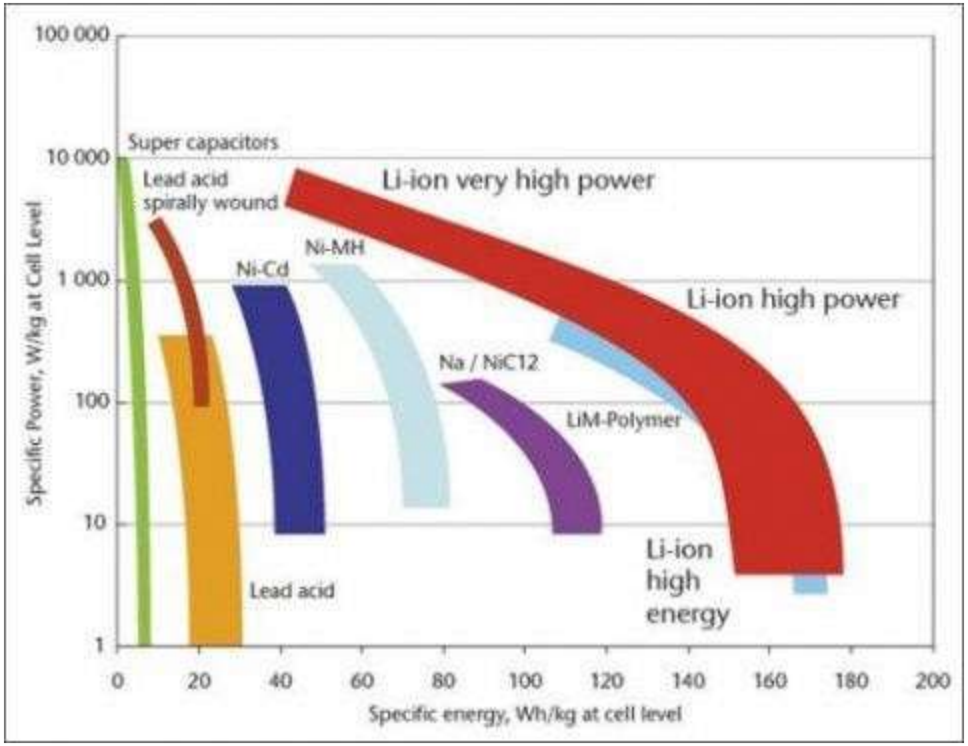
- More in depth later, but here are things to recognize:
  - Most rechargeable battery types should not be pushed to use 100% of their capacity. Extreme usage diminishes their reversibility and cuts life.
  - We try to monitor *state of charge* (SOC), really a measure of energy content.
- Battery energy capacity is usually measured in amp-hours (this is units of electric charge). We need to know voltage to determine watt-hours (units of energy).
- Batteries have rate limits. Often these are related to the *capacity rate*, *C*. This is the “nominal one hour rate.”

Basic battery power capability

- Example: for a battery with 2 A-h capacity, the C rate is 2 A.
- In an ideal world, a battery could supply a load at the C rate for one hour, at the $C/10$ rate for 10 hours, at the $10C$ rate for 0.1 h = 6 min, and so on.
- There must be internal I^2R loss, so this simplicity is impossible.
- There are also diffusion rate limits and side reactions. To learn more, look up “Peukert’s Law,” which provides simplified empirical ways to look at this.

Basic battery power capability

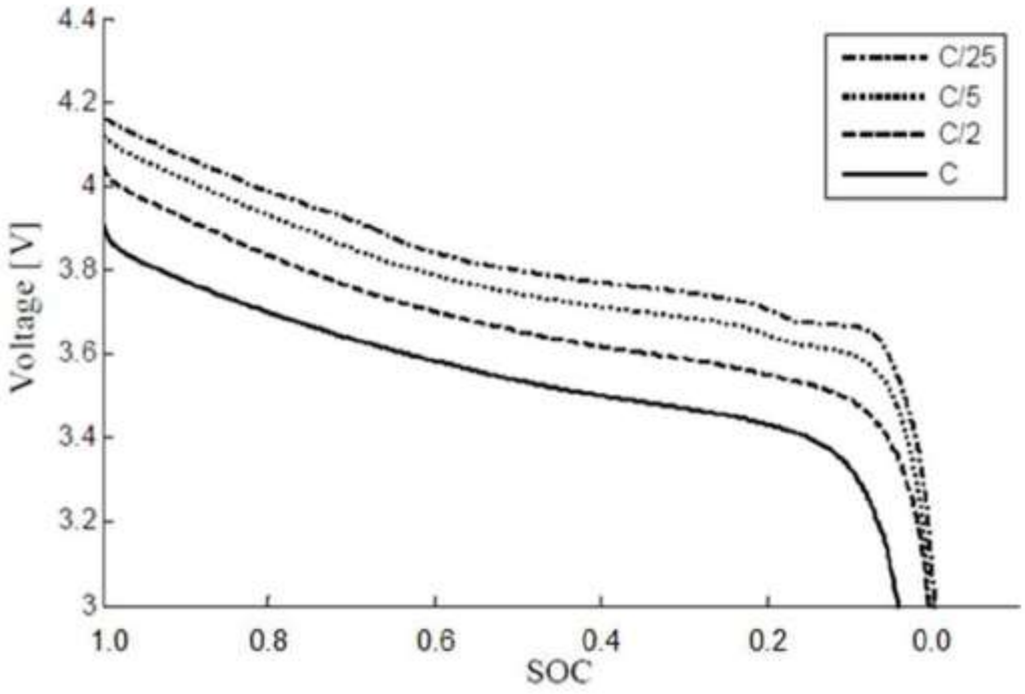
- Important tradeoff between “energy cells” optimized for capacity, and “power cells” optimized for rate.



Fact sheet #607, DOE Vehicle Technologies Office

Basic battery power capability

- Measured voltage vs. SOC for a typical lithium-ion cell.
- This is an energy cell. It has a working rate limit of 2C.



Rate issues

- The charge rate can also be used as an “energy rate.”
- For example, a 40 kWh battery pack has a *C* rate of 40 kW.
- A Nissan Leaf with a 40 kWh pack will need to operate at 3*C* to deliver its motor rating of 110 kW.
- Notice how limiting this can be: A smaller battery pack decreases available energy AND limits available power.
- Megawatt power scales (such as for trucks) imply megawatt-hour battery capacity scales. Very heavy.

Rate issues

- Lithium-ion cells are “happier” with rates of $C/3$ and less.
- Notice that this links to battery recharge: Anything faster than a 3 hour charge can be stressful.
- Some designers consider *hybrid storage*, with ultracapacitors to provide power capability and batteries for energy capability.
- This is not cost effective yet for conventional transportation.

- We find a broad design attribute: *All things in moderation.*