Battery Electric Vehicles
Economic and Environmental Benefits
And Enjoyment!
L. David Roper
ROPERLD@VT.EDU

ICEV = Internal Combustion Engine Vehicle (e.g., Honda Civic)
HEV = Hybrid Electric Vehicle (e.g., Toyota Prius)
PHEV = Plug-in Hybrid Electric Vehicle (e.g., Prius Prime)
BEV = Battery Electric Vehicle (e.g., Tesla Model 3)
EV = PHEV or BEV

kWh = battery energy, kW = battery charging power
SOC = State Of Charge (0%-100%)

Burning 1-gallon gasoline = 33.7 kWh

tinyurl.com/BEVs2019
My Two PHEVs & Five BEVs

2005 Prius converted to PHEV  2006 HiHy converted to PHEV  2007 Chinese Pickup lead-acid BEV

2012 Nissan LEAF 73 miles  2015 Nissan LEAV 84 miles

2017 Chevrolet Bolt EV 238 miles  Tesla Model 3 Long Range RWD 310-miles
Talk Outline

- Environmental reasons to drive battery-electric vehicles (BEVs).
- Economic reasons to drive BEVs.
- Comparison to internal-combustion-engine vehicles (ICEVs).
- Details about BEVs.
- Enjoyment of driving BEVs.
- Renewable energy to charge BEVs.
- Current long-range BEVs.
- Medium-range BEVs for local driving.
- BEV pickup trucks.
- Large BEV trucks and buses, including school buses.
- Charging BEVs.
- Long trips in BEVs.
- Plug-in hybrid vehicles (PHEVs).
- Future of cars.
- Appendix: Near-future long-range BEVs.
El Niño increases global warming & La Niña decreases global warming.

2016 was the hottest year on record!
As was 2015, 2014, 2010 and 2005!

Global warming could be decreased by making the air dirty again!

Peak in UK coal extraction

Air-pollution cooling & La Niña

US Clean-Air Act 1963

UK Clean-Air Act 1956

Temperature vs baseline (°C)

1880 1900 1920 1940 1960 1980 2000 2020

NASA 1951-1980 base

1.8°F
Environmental Aspect of BEVs

• Advantages
  – Reduction in carbon-dioxide emissions compared to ICEVs even with coal electricity
  – Much lower operating and maintenance costs reduce environmental footprint compared to ICEVs.
  – Reduction in local pollutants
  – Refuel (charge) at home, best using solar energy
  – Low noise pollution

• Disadvantages
  – Motors have some rare-earth and critical metals.
  – More carbon-dioxide emitted in manufacture than ICEVs.
  – Tires can wear out slightly quicker than for ICEVs.
Energy-Usage Efficiency

Taxis are almost 4 times more than transit buses!
Causes of Global Warming
Too many people is basic cause!

We need renewable electrical energy & electric cars!
Electric Vehicles vs Gasoline Vehicles

**GHG Emissions**

Minimum MPG for ICEV to match BEV GHG emissions.

- 2018 US ICEV average = 22 MPG
- Toyota Prius Eco = 56 MPG

2018 data: ICEV = 88 MPG
2015 data: ICEV = 68 MPG

Union of Concerned Scientists studies.

65 mpg ICEV for Tesla Model 3.
Well to Wheel Greenhouse Gas Emissions Comparison

- **Vehicle use (exhaust)**
- **Other vehicle (HFC, N2O, CH4)**
- **Fuel cycle**

<table>
<thead>
<tr>
<th>Year</th>
<th>GHG emissions (g/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline (2010)</td>
<td>500</td>
</tr>
<tr>
<td>Gasoline (2020)</td>
<td>400</td>
</tr>
<tr>
<td>Gasoline (2025)</td>
<td>300</td>
</tr>
<tr>
<td>Plug-in hybrid (PHEV20)</td>
<td>200</td>
</tr>
<tr>
<td>Fuel cell vehicle</td>
<td>100</td>
</tr>
<tr>
<td>Electric vehicle</td>
<td>50</td>
</tr>
</tbody>
</table>
Car Carbon Dioxide Emissions

• Burning 1 gallon gasoline (6.3 lbs) creates 20 lbs CO$_2$.
• The average gasoline car emits about 6 tons of CO$_2$ per year.
• Per year U.S. gasoline cars spew about 1,600,000,000 tons of CO$_2$ into the atmosphere.
• Tesla BEVs have saved about 3,600,000 tons of CO$_2$ spewed into the atmosphere.
In 2015 385,000 people died prematurely due to vehicle exhausts. 47% were due to diesel exhausts. Health costs estimated as $1 trillion.
Government ICEV Restrictions

• Countries will ban sales or registrations of ICEVs
  – 2025: Norway
  – 2030: Denmark, Iceland, Israel, Netherlands, Slovenia, Sweden
  – 2035: United Kingdom
  – 2040: France, Sri Lanka

• 23 cities/states will ban driving ICEVs
  – 2025: Mexico City, Paris, Madrid, Rome, Athens
  – 2030: Los Angeles, Seattle, Vancouver Canada, London
  – 2030: British Columbia Canada
  – 2050: CA, CT, MD, MA, NY, OR, RI, VT & Quebec
Average BEV vs Average ICEV Fuel Cost

1 gallon releases 33.7 kWh energy when burned.

- 2018 US average ICEV MPG = 22 = 0.653 miles/kWh
- 2018 average BEV MPGe = 102 = 3.03 miles/kWh
  - Tesla Model 3 SR+ = 141 MPGe = 4.18 miles/kWh
- 2019 US average $/gallon = $2.49
- 2018 US average $/kWh = $0.125
- ICEV $/mile = $2.49/22 = $0.113/mile
- BEV $/mile = $0.125/3.03 = $0.0413/mile
  - TM3SR+ $/mile = $0.125/4.18 = $0.0299/mile
- ICEV/BEV Cost = 2.74, ICEV/TM3-SR+ Cost = 3.77
- Electricity price is more stable than gasoline price.
Most Efficient BEV vs Most Efficient HEV

Tesla Standard Range+ vs Prius Eco Fuel Cost

• Toyota Prius Eco (HEV) MPG = 56 = 1.66 mi/kWh
• Tesla SR+ (BEV) MPGe = 141 = 4.18 miles/kWh
• **Efficiency Ratio = 2.51**
• 2019 US average $/gallon = $2.49 (= $0.0739/kWh)
• 2018 US average $/kWh = $0.125 (= $4.21/gallon)
• HEV $/mile = $2.49/56 = **$0.0445 per mile**
• BEV $/mile = $0.125/4.18 = **$0.0299 per mile**
• **Cost Ratio = 1.49**
• Electricity price is more stable than gasoline price.
$1.75 to $4 in 8 years!
Highly variable!

Note: Regular gasoline price is the retail price including taxes for all formulations of regular grade gasoline. Crude oil price is composite refiner acquisition cost of crude oil. Source: U.S. Energy Information Administration, Petroleum Marketing Monthly, May 2019
Considering inflation $0.13/kWh in 2015 is equivalent to $0.106/kWh in 2005.

Almost constant including inflation!

$0.10 to $0.11 in 10 years.
BEV vs ICEV Fuel Cost Range

Annual Fuel Cost Ranges by Technology Type, MY 2019

- **All-electric Vehicles**
  - BEV
  - PHEV

- **Plug-in Hybrid Electric Vehicles**
  - $500 to $900

- **Hybrid Electric Vehicles**
  - $600 to $1,950

- **Gasoline Vehicles**
  - $650 to $2,500

- **Diesel Vehicles**
  - $1,150 to $2,250
  - Diesel Vehicles

- **ICEV**
  - $1,000 to $4,100
ICEV vs BEV Needed Maintenance

ICEV maintenance **NOT** needed for a BEV
- Mechanical brakes (used constantly)
- Oil and oil-filter regular changes
- Transmission fluid changes
- Mufflers and tail pipes
- Catalytic converters
- Belts
- Spark plugs
- Many engine moving parts to wear out

• BEV maintenance
  - Mechanical brakes are **used only in emergencies and at low speed**. Otherwise **electricity regeneration** slows or stops a BEV.
  - Electric motors usually run 24/7 for many years without maintenance or repairs.
  - Rotate tires at 10,000-miles intervals.
  - Battery/electronics coolant change at 50,000 miles.
  - Solid-state electronics are very reliable.
Questions about BEVs

• Q: What do you do when you run out of electricity?
• A: What do you do when you run out of gasoline? You don’t, because you watch the fuel gauge. You fill it up when needed.
• Q: Do you have “range anxiety” when you drive?
• A: No, because I plan my trip.
• Q: What do you do when you go up a steep hill?
• A: You step on the accelerator and pass the gasoline cars.
• Q: Is a charged battery dangerous?
• A: Not nearly as dangerous as a tank of gasoline!
“Driving an Escalade to buy groceries is like hanging a picture with a sledge hammer!”

A 100-miles range BEV is sufficient for most commutes to and from work.
EV Buying Experience

• Sales persons are often poorly informed about plug-ins features and technology.
• Sales persons are often poorly informed about different available charging possibilities.
• Customers are often poorly informed about plug-in features, technology and charging.
• Dealers do not like the fact that it takes longer to inform customers about plug-ins than ICEVs.
• Dealers do not like low maintenance costs for BEVs.
• **For the above reasons Tesla decided to not sell their BEVs through dealers.**
What about BEV Batteries?

- BEV batteries are guaranteed for defects for 8 years and 100,000 miles. (Tesla Model 3 Long Range for 120,000 miles)
- Lithium-ion batteries lose capacity with time.
- Tesla Model 3 has a 70% degradation warranty within 8 years. Most will degrade much less than that depending on how they are driven and charged. **Projected lifetime (70% capacity) = 300,000-400,000 miles.**
- New batteries that will last longer and cost less are being developed. **Tesla states next battery will last 1-million miles and will be available soon!**
Battery Reuse and Recycling

• When capacity down to about 70% BEV batteries can be used to store solar and wind energy and to store energy during time-of-day (TOD) low rates to be used during TOD high rates.

• When reused BEV batteries are down to about 20% they can be recycled.

• Toxco Inc. awarded $9.5-million DOE grant to recycle lithium batteries.
Lithium-Ion Battery Components

Note that Lithium (Li) is a small fraction. The main abundance problems are for Cobalt (Co) and Nickel (Ni). Tesla plans to eliminate Cobalt in Lithium-Ion batteries.
Other battery chemistries are possible; e.g. solid state, the “Holy Grail”.

Source: BloombergNEF
Enjoyment!

• Very quiet. (New regulations require sound below 19 mph.)
• High acceleration! (See next slide.)
• Most battery charging overnight at home.
  – No fumes or bad weather when charging.
• Much free < 10-kW public charging.
• Low center of gravity enhances safety and performance (heavy battery underneath).
• One-pedal driving = foot off pedal stops BEV.
0-30 mph Acceleration is a BIG DEAL!

- High torque at low speed! Triple acceleration same efficiency as for ICEV.
- Can get to the next traffic light far ahead of ICEV cars with no roar.
- Can maneuver much better in tight traffic.
Highest 2 data points are projections for 2019 & 2020. The area under the red curve includes existing fields, discoveries and estimated as-yet-undiscovered fields.

Assumes a symmetric peak; asymmetric peak would be lower, later and extend further.
Current crude-oil price = $55-$60/barrel.

A recent study shows that crude-oil price **must be no higher than $10/barrel** for ICEVs to match the operating cost of BEVs fueled by solar and wind energy!
Assumes 3 times estimated reserves!

Assumes a symmetric peak; asymmetric peak would be lower, later and extend further.

Do not plan to power future vehicles with natural gas!
“Renewables” are Passing Coal for U.S. Electricity Generation

Renewables = hydropower, wind, solar, geothermal and biomass.
(Note it includes hydropower, which is arguably not renewable.)
Solar/Wind/Biomass are Passing Coal for U.S. Electricity Generation

Renewables = wind, solar, and biomass, not including hydropower.

Natural-gas curve will bend downward because U.S. extraction will peak soon.

Renewables dominate by 2030!
Are You Convinced of the Necessity and Desirability to **Drive BEVs**?

- What BEVs are available or will be available soon?
- How do they compare?
- Buying price minus tax credits?
- Range (miles/full-charge)?
- Operating price (efficiency: MPGe)?
- Safety?
- Reliability?
- Attractive design?
- Performance (0-60 mph seconds)?
### Tesla Model 3

#### Standard Range *
- EPA Range: 220 miles
- MPGe: 131 miles
- Price: $35,900

#### Standard Range Plus
- EPA Range: 250 miles
- MPGe: 141 miles
- Price: $39,990

#### Long Range *
- EPA Range: 330 miles
- MPGe: 130 miles
- Price: $45,900

#### AWD
- EPA Range: 322 miles
- MPGe: 121 miles
- Price: $48,490

#### Performance (AWD)
- EPA Range: 322 miles
- MPGe: 121 miles
- Price: $56,990

**Autopilot software is included in all 5 versions. Order online. * = phone order. If leased, returned to Tesla.**

**US 2018 average price of a light vehicle was $37,577.**

**Federal tax credit = $1875 until 31 Dec 2019.**

**Average gasoline car in 2018: 25 MPG**

---

*Consumer Reports: Tesla Model 3 is “most satisfying” car, more than Porsche or Corvette.*
Tesla Model 3 Dashboard

Tesla BEVs have regular software updates, about one per month, to add new features and fix problems. My TM3LR-RWD had 24 updates in first 20 months. It now has many features it did not have originally.

All car controls are on the 15” screen or on the steering wheel and steering column. Adaptive cruise control is simplest. Cabin air flow is across entire dashboard. Excellent navigation including Superchargers and Destination Chargers.
What is **Tesla Autopilot**?

- Requires slight torque on steering wheel.
- 8 cameras, 12 ultrasound sensors & forward radar
- Automatically brakes as leading car slows.
  - Also, occurs with adaptive cruise control (TAAC).
- Stays between lane lines; changes lanes after turn-signal activation.
- Makes driving on long trips less tiring since attention can be concentrated on nearby traffic instead of lanes, acceleration and braking.
- **Full Self Driving** (FSD, extra cost)
  - Auto Lane Change, Autopark, Summon, Smart Summon
  - Automatically turns onto ramps when navigating trips.
- **Future**: respond to stop lights/signs, auto city driving.
Chevrolet Bolt EV

Range: 259 miles  MPGe: 119  Price: $36,620

US 2018 average price of a light vehicle was $37,577.

Federal tax credit = $1875 until 31 Mar 2020.

There are two trims in order of increasing cost: LT & Premium.
Chevrolet Bolt EV Dashboard

GM OnStar, Apple CarPlay or Android Auto for Navigation
Nissan LEAF II e-Plus

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEAF</td>
<td>150</td>
<td>112</td>
<td>$31,600</td>
</tr>
<tr>
<td>LEAF ePlus</td>
<td>226</td>
<td>108</td>
<td>$38,200</td>
</tr>
</tbody>
</table>

Federal tax credit = $7500.

US 2018 average price of a light vehicle was $37,577.

These two models have 3 variants in order of increasing cost: S, SV, & SL.
Hyundai Kona Electric

Range: 258 miles  MPGe: 120  Price: $36,450

US 2018 average price of a light vehicle was $37,577.
Hyundai Ioniq Electric

Range: 170 miles    MPGe: 133    Price: $30,315

US 2018 average price of a light vehicle was $37,577.
Kia Niro Electric

Range: 239 miles  MPGe: 112  Price: $39,495

US 2018 average price of a light vehicle was $37,577.
Kia Soul Electric

Range: 243 miles  MPGe: 114  Price: $33,950
<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Range (AWD)</td>
<td>390</td>
<td>111</td>
<td>$79,990</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>348</td>
<td>104</td>
<td>$99,990</td>
</tr>
</tbody>
</table>

Autopilot software included in both versions. Order online. Free Supercharging!
## Tesla Model X AWD SUV

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Range (AWD)</td>
<td>351</td>
<td>96</td>
<td>$84,990</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>305</td>
<td>90</td>
<td>$104,990</td>
</tr>
</tbody>
</table>

**Autopilot software included in both versions. Order online. Free Supercharging!**
# Jaguar i-Pace AWD

<table>
<thead>
<tr>
<th>Price</th>
<th>Range</th>
<th>MPGe</th>
<th>0-60</th>
</tr>
</thead>
<tbody>
<tr>
<td>$69.500</td>
<td>253</td>
<td>76</td>
<td>4.5</td>
</tr>
</tbody>
</table>
# Audi e-Tron AWD

<table>
<thead>
<tr>
<th>Model</th>
<th>Price</th>
<th>Range</th>
<th>MPGe</th>
<th>0-60</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>$56,100</td>
<td>186</td>
<td>97</td>
<td>6.8</td>
</tr>
<tr>
<td>55</td>
<td>$74,800</td>
<td>242</td>
<td>94</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Tesla Model 3 Drive Train

AWD (Dual Motor) has another motor in front.
What About Depreciation?

• Almost all BEVs besides Tesla’s have about twice the annual depreciation as similar ICEVs.

• Great opportunity to buy used BEVs!

Annual U.S. comparison of (Chevy Bolt EV, Hyundai Ionic EV, Kia Soul EV, Nissan LEAF, VW e-Golf) versus (Chevy Cruze, Honda Civic, Hyundai Elantra, Nissan Sentra, Toyota Corolla).

<table>
<thead>
<tr>
<th></th>
<th>EV</th>
<th>ICE</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>546</td>
<td>1,255</td>
<td>709</td>
</tr>
<tr>
<td>Maintenance/repair/tires:</td>
<td>949</td>
<td>1,279</td>
<td>330</td>
</tr>
<tr>
<td>Insurance</td>
<td>1,214</td>
<td>1,328</td>
<td>114</td>
</tr>
<tr>
<td>License/registration/taxes:</td>
<td>-579</td>
<td>466</td>
<td>1,045</td>
</tr>
<tr>
<td>Depreciation</td>
<td>4,806</td>
<td>2,240</td>
<td>-2,566</td>
</tr>
<tr>
<td>Finance</td>
<td>768</td>
<td>546</td>
<td>-222</td>
</tr>
<tr>
<td>Total per year</td>
<td>7,704</td>
<td>7,114</td>
<td>-590</td>
</tr>
</tbody>
</table>

Kelly Blue Book: TM3 estimated value = 69% @3 years & 49% @ 5 years

Tesla Model 3 has caused the ICEV premium sedans to depreciate more than before.
Used to find a NHTSA Star rating (1-5) for a specific car.

4th quarter 2019 accident rates:
- All U.S. cars: 1/479,000 miles
- Tesla without Autopilot: 1/2.10 million miles
- Tesla with Autopilot: 1/3.07 million miles

2012-2019 vehicle fires:
- All U.S. cars: 1/19 million miles
- Tesla BEVs: 1/175 million miles
Tesla Model 3 has taken over the premium-sedans market in the U.S. and is beginning to do so in Europe.
BEV Supercar: **Porsche Taycan**

Available now

<table>
<thead>
<tr>
<th>Model</th>
<th>Range (mi)</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4S</strong></td>
<td>226-257</td>
<td>96-92</td>
<td>$103,800</td>
</tr>
<tr>
<td><strong>Turbo</strong></td>
<td>201</td>
<td>69</td>
<td>$150,900</td>
</tr>
<tr>
<td><strong>Turbo S</strong></td>
<td>192</td>
<td>68</td>
<td>$185,000</td>
</tr>
</tbody>
</table>

https://electrek.co/2019/12/11/porsche-taycan-turbo-201-mile-epa-range/
Probably range is more important than efficiency.
Tesla Model Y SUV

Built on Model 3 skateboard.

<table>
<thead>
<tr>
<th>Model</th>
<th>Range (mi)</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR RWD</td>
<td>300</td>
<td>137</td>
<td>$48,000</td>
</tr>
<tr>
<td>LR AWD</td>
<td>315</td>
<td>121</td>
<td>$52,990</td>
</tr>
<tr>
<td>Perform</td>
<td>315</td>
<td>121</td>
<td>$60,990</td>
</tr>
</tbody>
</table>

Available mid-2020
Volkswagen BEV Plans

ID.3  ID. Buzz  ID. Crozz

ID. Vizzion  ID. Beach Buggy
Volkswagen ID.Crozz (ID.4)

<table>
<thead>
<tr>
<th>Model</th>
<th>Range (mi)</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID.Crozz</td>
<td>310</td>
<td>?</td>
<td>₹?</td>
</tr>
</tbody>
</table>

Available 2021
# Ford Mustang Mach-E

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range (miles)</th>
<th>Efficiency (MPGe)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Range RWD</td>
<td>230</td>
<td>102</td>
<td>$39,000</td>
</tr>
<tr>
<td>Long Range RWD</td>
<td>300</td>
<td>102</td>
<td>$48,000</td>
</tr>
<tr>
<td>Long Range AWD</td>
<td>280</td>
<td>96</td>
<td>$52,000</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>280</td>
<td>96</td>
<td>$61,000</td>
</tr>
</tbody>
</table>

Federal tax credit = $7500

Available in early 2021.

Average gasoline car in 2018: 25 MPG

US 2018 average price of a light vehicle was $37,577.
### Ford Mustang Mach-E Dash

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range (miles)</th>
<th>Efficiency (MPGe)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Range RWD</td>
<td>230</td>
<td>102</td>
<td>$39,000</td>
</tr>
<tr>
<td>Long Range RWD</td>
<td>300</td>
<td>102</td>
<td>$48,000</td>
</tr>
<tr>
<td>Long Range AWD</td>
<td>280</td>
<td>96</td>
<td>$52,000</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>280</td>
<td>96</td>
<td>$61,000</td>
</tr>
</tbody>
</table>

Federal tax credit = $7500.

Average gasoline car in 2018: 25 MPG

US 2018 average price of a light vehicle was $37,577.
BEV Mini-Compacts

**Smart ForTwo Electric Drive**
- 68 miles
- 75 mph

**Chevrolet Spark EV**
- 82 miles
- 89 mph
- $24,550

**Mini Cooper SE Electric**
- 110 miles
- $29,900

**Fiat 500e**
- ~125 miles
- $?

**Honda-E**
- 137 miles?

**Price:**
- $13,095
Electric Pickup Trucks

- Rivian electric pickup and SUV (rivian.com).
- Tesla Cybertruck
- Ford F150 electric promised.
- Many Electric trucks promised
- Top 10 future electric pickup trucks
## Tesla Cybertruck

<table>
<thead>
<tr>
<th>Type</th>
<th>Range (Miles)</th>
<th>0-60 mph</th>
<th>Storage (ft^3)</th>
<th>Towing (lbs)</th>
<th>Clearance (in)</th>
<th>Price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM RWD</td>
<td>250</td>
<td>6.5</td>
<td>100</td>
<td>7,500</td>
<td>16</td>
<td>$39,900</td>
</tr>
<tr>
<td>DM AWD</td>
<td>300</td>
<td>4.5</td>
<td>100</td>
<td>10,000</td>
<td>16</td>
<td>$49,900</td>
</tr>
<tr>
<td>TM AWD</td>
<td>500</td>
<td>2.9</td>
<td>100</td>
<td>14,000</td>
<td>16</td>
<td>$69,900</td>
</tr>
</tbody>
</table>
Tesla Cybertruck
Cybertruck tooling cost
Aerodynamics of Pickup Trucks

Tesla Cybertruck Tops Ram 1500, Ford F-150 Raptor In Aerodynamics

The calculation does not include the wheels.

Drag coeff. = 0.39 at 60 mph.

Drag coeff. = 0.56 at 60 mph.

Drag coeff. = 0.59 at 60 mph.

Vortices increase drag!
Large Electric Trucks

- **Tesla Semi**
  - 300-500 mi, $150k-180k
  - 67 MPGe vs 6.5 MPG for an average diesel semi truck.

- **Nikoli Semi**
  - 500-750 mi, fuel cell

- **Volvo Semi**

- **Daimler Semi**

- **e-Garbage trucks**

- **Autonomous Trucks**
  - **Volvo Vera**
Electric Buses

• About 650 e-buses on US roads at end of 2019, more than double 2018.
• Hundreds of thousands of e-buses in China.
• California replacing 200 polluting diesel school buses by e-buses.
• 50 e-school-buses in Virginia by end of 2020.
e-Vans
ZEV States in U.S.

• 2013: **Multi-state ZEV Task Force** formed: California, Connecticut, Maryland, New York, Oregon, Rhode Island & Vermont.
• 2018: Maine, Massachusetts & New Jersey joined the ZEV Task Force.
• 2019: Colorado joined the ZEV Task Force
• Delaware, District of Columbia, Pennsylvania & Washington follow the California LEV standards.
Battery Capacity Loss vs Charging Speed

- Estimate a BEV uses ¼ of battery charge (cycle) per day.
- 1000 cycles > 4000 days = 11 years
- > 150,000 miles
- Current Tesla battery < 500,000 miles to 70% capacity.
- New Tesla battery < 1,000,000 miles to 70% capacity.
BEV Charging Terms

• Battery energy is in **kilowatt-hours (kWh)**
  – Burning 1 gallon of gasoline = 33.7 kWh
  – E.g., Tesla Model 3 LR (TM3LR) has a 78-kWh battery

• Charging power is in **kilowatts (kW)**
  – Chargers start at peak power, then decrease power.
  – Typical garage charger provides **7.2 kW peak power**.
    • E.g., charging TM3LR: \((75\text{-kWh}/7.2\text{-kW})/85\%\) = 12 hours
  – Tesla V2 Supercharger (150 kW) charges TM3LR = 35 min
  – Tesla V3 Supercharger (250 kW) charges TM3LR = 21 min
Charging BEVs

- **Level-1:** 120-volts AC, **1.12-kW**, for all EVs (Everywhere!) *(SAE-J1772 portable charging station that comes with an EV)*

- **Level-2:** 240-volts AC, **3.3-kW** to **19-kW charging station** with SAE-J1772 plug, for all BEVs & PHEVs *(Your parking space, Kroger, InnVT, Campus Automotive)*

- **Level-3:** 480-volts DC, **35-kW - 350-kW**, only for BEVs *(Blacksburg Town Hall 40-kW)*
  - **CHAdeMO** standard *(Asian)* *(maximum **150-kW in 2017**)*
  - **SAE CCS** standard *(USA & Europe)* *(Level-2/3 one plug)*

Most charging occurs at home in a garage, driveway or parking space.
Charging BEVs

• SAE-J1772 cord that comes with an EV can have a pigtail that allows level-2 charging with a standard 240-volts outlet or 120-volts outlet.
• An adaptor is available to allow Teslas to charge at level-2 SAE-J1772 charging stations.
• 250-350 kW charging stations are being installed.
• Tesla Wall Connector: 240-volts AC, 11.5-kW for Tesla BEVs.
• Tesla Superchargers: 480-volts DC, 125-150-kW only for Tesla BEVs (Version 3 now being installed for 250-kW 77 installed or under construction)
Charging

• Most charging takes place overnight at home.
• Tesla has by far the most fast (Superchargers) and overnight charging stations at hotels for long trips.
• Electrify America is quickly building fast charging stations for all BEVs. (I-81 Exit 155 and Wytheville)
• Plugshare.com is the best web page for finding charging stations.
• ABetterRoutePlanner.com is an excellent program for planning BEV trips.
• Tesla has excellent navigation showing where Superchargers are and how long to charge there. – Shows number of charging stalls available at next SC.
Charging BEVs

• Most charging occurs at home in a garage, driveway or parking space. For me ~95% of time.
• Charging at work doubles the range.
• I charge my Tesla Model 3LR when it gets below 30% up to about 75% (about once a week), unless there will be a long trip the next day.
• Never fully charge at intermediate charging stops.
• I like to have ~20% SOC left when I get to a destination.
• ICE’d! Leave firm polite note on windshield of ICEV.
• Road-charging etiquette
  – Charge only when necessary.
  – Charge up and move on.
  – Don’t unplug a charging car.
  – Leave note asking charging car to plug yours in.
  – Neatly wind the cable on its holder after charging.
Tesla Supercharger in Carlisle PA
Largest has 50 stalls in Shanghai China!
Plans to finally have all Superchargers on solar energy with battery backup.
Charging Times for Fast Chargers

Charging starts off fast and decreases slowly at first and then decreases faster toward the end.

Charging from 10% to 80% is quick and typically provides ample range to travel between most Superchargers. Charging from 80% to 100% doubles the charge time because the car must reduce current to top off cells. Actual charge times may vary.
Charging starts off fast and decreases slowly at first and then decreases faster toward the end.

Average power = 85% of maximum power for battery fillup.
How Fast Do BEVs Charge

• Terms: $\text{kWh} =$ battery energy, $\text{kW} =$ energy/hour

• Tesla BEVs:
  – Model 3 SR+: 250 miles, 54 kWh, 170 kW
  – Model 3 LR: 325 miles, 75 kWh, 250 kW
  – Model S: 373 miles, 100 kWh, 200 kW
  – Model X: 328 miles, 100 kWh, 200 kW

• Chevrolet Bolt EV: 259 miles, 66 kWh, 50 kW

• Nissan LEAF II: 226 miles, 62 kWh, 44 kW

• Jaguar i-Pace: 234 miles, 90 kWh, 100 kW

• Audi e-tron: 242 miles, 95 kWh, 150 kW

• Porsche Taycan: 257 miles, 93 kWh, 270 kW

• Ford Mach-E: ~300 miles, 99 kWh, 150 kW

Average power = 85% of maximum power for battery fillup.
120-kW V2s are being upgraded to 150-kW, so first two bars will be decreased by 1/4th.
I have used several of them.
Orange = 480-volts DC fast chargers
Green = 240-volts AC chargers
Plugshare.com

I recommend installing level-2 240-volts charging stations at Sweet Springs, Union, Rainelle & Hillsboro WV.
Tesla Superchargers

Twenties 250-kW Stations completed across Canada in late 2019.

About 750 stations, average 6 stalls. Building about 1/day. 67 under construction 57 permitted.

On I-81: Salem VA, Bristol TN, Wytheville, Lexington, Staunton, Mt. Jackson, Strasburg, Martinsburg WV Hagerstown MD Soon: Lynchburg on US-460

Roper home charger: 9.6 –kW; Tesla Superchargers: 150-kW being updated to 250-kW. The Lynchburg Supercharger will have 250-kW capability!
A Tesla Supercharger is being built in Farmville VA that will allow direct Tesla travel between Blacksburg/Roanoke and Richmond on US-460 and direct travel between Charlottesville and northern North Carolina on US-15.
How to Drive a Tesla Long Distance

• Charge to near 100% at home.
• Use Tesla Navigation on the car screen.
• Charge at screen-indicated Superchargers or more often to the amount desired to get to the next Supercharger on the route.
• Choose a hotel with a charging station for overnight sleep to charge near 100% for the next day. (Most good hotels have charging stations, usually provided by Tesla. Use plugshare.com to find them.
• With charging stations provided by Electrify America, EVGO and other companies, similar long trips may be possible for other long-range BEVs in a few years.
Tesla Model 3 trip from Blacksburg VA to Fort Worth TX

TM3 wants 5 Supercharging stops over 1126 miles, 1 is overnight at Memphis; I need 3 stops/day over 2 days. Charge to 100% at Memphis hotel at night.
Tesla Supercharger Rates ($/kWh)

I pay APCO about $0.11/kWh in our garage.
Tesla Destination Chargers

At hotels, parks, businesses, multi-family complexes and workplaces. Usually there is no fee to use Destination Chargers.
Electrify America Fast-Chargers Plan

Two near Blacksburg: I-81 exit 156 near Fincastle and Wytheville at a Sheetz Station. One is under construction at a Sheetz station on Peters Creek Road.
Electrify America Chargers

Two near Blacksburg:
I-81 exit 156 near Fincastle,
Wytheville Sheetz Station
None for WV!

Total = 450 stations, average of 6 stalls
Cycle 2 investments will be made in 18 metropolitan areas across the country.
Petro-Canada Fast Charging Net

Fifty sites with CHAdeMO and CCS rated up to 200-kW.
Other U.S. Charging Networks

- **Blink** ~1680 sites
- **Chargepoint** ~6083 sites
- **EVgo** ~774 sites
  - EVgo is starting to **add a 50-kW Tesla connector at its sites**.
- **Greenlots** ~392 sites (subsidiary of Shell)
- **Semaconnect** ~1166 sites
- **Webasto** ~164 sites

Many < 10-kW chargers have no fee to use.
With a $450 adapter Teslas can use CHAdeMO stations as well as Superchargers, for a total of 2,818 locations and 10,124 charging stations!
Very soon CCS standard will quickly grow more than the CHAdeMO standard.
APCo TOD Rate for EV Charging

- Night-time lower rates for EV charging will save $0.032/kWh.
- Extra meter required for EV charging.
- One bill will combine residential and car charging.
Fuel in the Middle of “Nowhere”?  

• Here is an estimate of 5-billion 120-V electrical outlets in the US: How many electrical outlets exist in the United States?  
• Here is a survey of 186,000 gasoline stations in the US: How many gas stations are there in the U.S?
Plug-In Hybrids (PHEV)

- **Toyota Prius Prime**: 25 miles EV @ **133 MPGe**
- **Toyota RAV4 Prime**: 39 miles EV @ 90 MPGe, **AWD**
- **Mitsubishi Outlander**: 22 miles EV @ 74 MPGe, **AWD**
- **Honda Clarity**: 47 miles EV @ 110 MPGe
- **Chrysler Pacifica**: 33 miles EV @ 82 MPGe, van
- **BMW Rex**: 97 miles EV, 111 MPGe, **2.4-gal. gas tank**
- **Ford Fusion PHEV**: 21 miles EV @ 103 MPGe
- **Hyundai Ioniq PHEV**: 29 miles EV @ 119 MPGe
- **Kia Niro PHEV**: 28 miles EV @ 105 MPGe
- Several more expensive (Cadillac, Porsche, Volvo, etc.)
Exponential growth! EVs = PHEVs & BEVs
If this analysis is approximately correct, about half of the cars in the world will be electric by about year 2035 and almost all cars will be electric by 2100. Probably by 2100 almost all electric cars will be BEVs with few PHEVs.
Why Not Fuel-Cell Cars?

- They are very complicated:
  - Requires a lithium-ion or NiMH battery similar to a PHEV!
  - Hydrogen fuel is not easy to obtain. Most is made from methane and water, which produces carbon dioxide with the hydrogen! Should be made by solar!
  - Better for heavy-duty vehicles, such as trucks.
Why Not Solar Cars?

• **Lightyear One**
  – Extremely efficient: 253 MPGe (?)
  – 450-miles range (?)
  – Aluminum and carbon fiber body for low weight
  – 1-kW high-efficiency solar panels

• **Sion (Sono Motors)**
  – Totally covered with solar panels
  – 140 miles range
  – 118 MPGe
Conclusion

• If disasters due to global warming are to be mitigated we must reduce carbon emissions!

• All must do their part with their influence and wealth beyond necessities:
  – Install solar energy on homes and businesses.
  – Use low-carbon public transport or drive electric cars.
  – Consume food and materials that involve low carbon emissions.
  – Invest only in companies that are committed to reducing carbon emissions.
  – Vote for politicians that will institute mitigation programs.
Appendix: Future BEVs
Volvo Polestar 2

<table>
<thead>
<tr>
<th>Range (mi)</th>
<th>0-60 mph (s)</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>275</td>
<td>4.5</td>
<td>119</td>
<td>$63,000</td>
</tr>
</tbody>
</table>

Available 2020
### Volvo XC40 Recharge

<table>
<thead>
<tr>
<th>Range (mi)</th>
<th>0-60 mph (s)</th>
<th>MPGe</th>
<th>Price</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>221</td>
<td>4.8</td>
<td>96</td>
<td>$55,000</td>
<td>AWD</td>
</tr>
</tbody>
</table>

Available 2021
BMW iX3

<table>
<thead>
<tr>
<th>Range (mi)</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>223</td>
<td>100</td>
<td>$?</td>
</tr>
</tbody>
</table>

Available 2020
Mercedes-Benz EQC

Available 2021

<table>
<thead>
<tr>
<th>Range (mi)</th>
<th>0-60 mph (s)</th>
<th>MPGe</th>
<th>Price</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>5.1</td>
<td>88</td>
<td>$67,900</td>
<td>AWD</td>
</tr>
</tbody>
</table>
BEV Supercars: **Tesla Roadster 2**

<table>
<thead>
<tr>
<th>Range (mi)</th>
<th>0-60 mph (s)</th>
<th>Top Speed (mph)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>620</td>
<td>1.9</td>
<td>250</td>
<td>$250,000</td>
</tr>
</tbody>
</table>

Available 2021
References to Follow EV Future

- Insideevs.com
- Electrek.co
- Cleantechnica.com (also renewable energy)
- Teslarati.com (also SpaceX)
- pluginamerica.org
- plugstar.com
- greencarreports.com (also HEVs)