Battery Electric Vehicles
Economic and Environmental Benefits
And Enjoyment!

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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

tinyurl.com/BEVs2019
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!

El Niño
La Niña

1.8°F
50-year smoothing

Peak in UK coal extraction
Air-pollution cooling & La Niña

US Clean-Air Act 1963
UK Clean-Air Act 1956

NASA
1951-1980 base
Environmental Aspect of BEVs

• Advantages
  – Much lower operating and maintenance costs reduce environmental footprint compared to ICEVs.
  – Reduction in pollutants
  – Refuel (charge) at home and using renewable energy
  – Reduction in carbon-dioxide emissions
  – Low noise pollution

• Disadvantages
  – Motors have some rare-earth and critical metals.
  – More carbon-dioxide emitted in manufacture than ICEV.
  – Tires can wear out slightly quicker than for ICEVs.
High-Speed Train Routes in China (**155-217 mph!**)

Railway map of People's Republic of China
Colored lines showing CRH and other high speed rail services
Last update: 2018-01-15

18,000 miles in 2018!
Plans for 24,000
Passenger rail in United States

Planned High-Speed Rail in U.S.

Legend
- 160 mph (257 km/h)
- 125 mph (201 km/h)
- 110 mph (177 km/h)
- < 110 mph (< 177 km/h)
- Planned/Under construction
- Indefinitely suspended
Causes of Global Warming
Too many people is basic cause!

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

GHG Emissions

Union of Concerned Scientists studies.

Electric Vehicles

- Tesla Model 3: 65 mpg ICEV
- Toyota Prius Eco: 56 MPG

Gasoline Vehicles

- 2018 US ICEV average: 22 MPG
- 2018 US ICEV average: 80 MPG
- 2015 data: ICEV = 68 MPG

Note: The MPG (miles per gallon) value listed for each region is the combined city/highway driving only. 31+ MPG: Good, 41+ MPG: Better, 51+ MPG: Best. The 60 MPG US average is a sales-weighted average based on where EVs were sold in 2011-2017.
Well to Wheel Greenhouse Gas Emissions Comparison

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

<table>
<thead>
<tr>
<th>Year/Type</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>
Well to Wheel Smog-Forming Pollution Emissions Comparison [NOx + ROG]

ROG = Reactive Organic gases

- Vehicle use (exhaust)
- Vehicle use (evap)
- Fuel cycle

<table>
<thead>
<tr>
<th>Type</th>
<th>2010 (Gasoline)</th>
<th>2020 (Gasoline)</th>
<th>2025 (Gasoline)</th>
<th>Plug-in hybrid (PHEV20)</th>
<th>Fuel cell vehicle</th>
<th>Electric vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROG + NOx emissions</td>
<td>0.35</td>
<td>0.25</td>
<td>0.20</td>
<td>0.15</td>
<td>0.10</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Average BEV vs Average ICEV Fuel Cost

1 gallon = 33.7 kWh

• 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
• TM3 $/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.
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.
Considering inflation $0.13/kWh in 2015 is equivalent to $0.106/kWh in 2005.
BEV vs ICEV Fuel Cost

Annual Fuel Cost Ranges by Technology Type, MY 2019

- BEV: $500 - $900
- PHEV: $600 - $1,950
- HEV: $650 - $2,500
- ICEV: $1,000 - $4,100
- DICEV: $1,150 - $2,250
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)
- ICEV $/mile = $2.49/56 = **$0.0445** per mile
- BEV $/mile = $0.125/4.18 = **$0.0299** per mile
- **Cost Ratio = 1.49**
  - About ½ of average BEV vs average ICEV
0-30 mph Acceleration is a BIG DEAL!

- High torque at low speed! Triple acceleration same efficiency as for ICE.
- Can get to the next traffic light far ahead of ICE cars with no roar.
- Can maneuver much better in tight traffic.
Why BEVs Have Only One Gear

• Electric motors have high maximum RPM (Chevy Bolt EV: 8,810 RPM)

• Electric motors have high efficiency over a broad RPM range.

• Electric motors produce high torque at low RPM.

• Some expensive BEVs have 2 gears.
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!’
EV Buying Experience

• Dealers are often poorly informed about plug-ins features and technology.
• Dealers are often poorly informed about different available charging possibilities.
• Customers are often poorly informed about plug-ins features and technology and charging.
• Dealers do not like the fact that it takes longer to inform customers about plug-ins than ICEs.
• Dealers do not like low maintenance costs for BEVs.
• For the above reasons Tesla decided to not sell their cars 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!*
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.
Battery Reuse and Recycling

• When capacity down to about 70% they 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 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

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.
Abundance is not the only issue. Ease of extraction and refining ores is also an issue. In turns out that Lithium is not the main availability issue; Nickel (NI), Cobalt (CO) and Copper (Cu) are the main availability issues.
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 can run 24/7 for many years without maintenance or repairs.
  - Rotate tires at 10,000-miles intervals.
  - Battery/electronics coolant changed at 50,000 miles.
  - Solid-state electronics are very reliable.
Enjoysnt!

• Very quiet.
• High acceleration!
• 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.
2019 U.S. Survey about Electric Cars

• 31% would consider getting an EV now.
• 27% would consider getting an EV in the Future.
• 5% are definitely planning to get an EV for their next vehicle. (2.5 times as many who got an EV in 2018.)
• 72% say automakers should provide more kinds of EVs.
• 73% say EVs will reduce oil use.
• 72% say EVs will reduce pollution.
• 65% say EVs will save money on fuel and maintenance for drivers.
Global Temperature Relative to 1880-1920 Average.
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.
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!
Renewables are Passing Coal for U.S. Electricity Generation

Renewables = hydroelectric, wind, solar, geothermal and biomass. (Note it includes hydroelectric, 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 bends downward because U.S. extraction is peaking.

Renewables dominate by 2030!
Assumes 3 times estimated reserves!

Do not plan to power future vehicles with natural gas!
Are You Convinced of the Necessity and Desirability to Drive BEVs?

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

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range</th>
<th>MPGe</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Range *</td>
<td>220</td>
<td>131</td>
<td>$35,900</td>
</tr>
<tr>
<td>Standard Range Plus</td>
<td>250</td>
<td>141</td>
<td>$39,990</td>
</tr>
<tr>
<td>Long Range *</td>
<td>325</td>
<td>130</td>
<td>$45,900</td>
</tr>
<tr>
<td>AWD</td>
<td>322</td>
<td>116</td>
<td>$48,490</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>310</td>
<td>116</td>
<td>$56,990</td>
</tr>
</tbody>
</table>

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

Average gasoline car in 2018: 25 MPG

Federal tax credit = $1875 until 31 Dec 2019.

US 2018 average price of a light vehicle was $37,577.
Tesla Model 3 Dash
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.
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>$29,990</td>
</tr>
<tr>
<td>LEAF ePlus</td>
<td>226</td>
<td>108</td>
<td>$37,445</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>373</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 all 3 versions. Order online. ? = phone order. Free Supercharging!
# Tesla Model X AWD

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range</th>
<th>MPGe</th>
<th>Price</th>
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</thead>
<tbody>
<tr>
<td>Long Range (AWD)</td>
<td>328</td>
<td>87</td>
<td>$84,990</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>305</td>
<td>85</td>
<td>$104,990</td>
</tr>
</tbody>
</table>

*Autopilot software included in all 3 versions. Order online.*

? = phone order.

*Free Supercharging!*
# Jaguar i-Pace AWD

<table>
<thead>
<tr>
<th>Price</th>
<th>Range</th>
<th>MPGe</th>
<th>0-60</th>
<th>Cargo</th>
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<tbody>
<tr>
<td>$69,500</td>
<td>253</td>
<td>76</td>
<td>4.5</td>
<td>51</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>
<th>Cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>$56,100</td>
<td>186</td>
<td>97</td>
<td>6.8</td>
<td>29</td>
</tr>
<tr>
<td>55</td>
<td>$74,800</td>
<td>242</td>
<td>94</td>
<td>5.5</td>
<td>29</td>
</tr>
</tbody>
</table>
Tesla Model 3 Drive Train

AWD (Dual Motor) has another motor in front.
## BEV Comparisons

<table>
<thead>
<tr>
<th>Model</th>
<th>Price</th>
<th>Range</th>
<th>MPGe</th>
<th>0-60</th>
<th>Cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM3SR+</td>
<td>$38,990</td>
<td>240</td>
<td>132</td>
<td>5.3</td>
<td>15</td>
</tr>
<tr>
<td>CBEV</td>
<td>$37,595</td>
<td>238</td>
<td>119</td>
<td>6.5</td>
<td>16.9</td>
</tr>
<tr>
<td>NePlus</td>
<td>$37,445</td>
<td>226</td>
<td>108</td>
<td>7</td>
<td>23.6</td>
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<tr>
<td>TMX</td>
<td>$84,990</td>
<td>325</td>
<td>96</td>
<td>4.4</td>
<td>88</td>
</tr>
<tr>
<td>JiPace</td>
<td>$70,495</td>
<td>234</td>
<td>76</td>
<td>4.5</td>
<td>51</td>
</tr>
<tr>
<td>AeTron</td>
<td>$74,800</td>
<td>204</td>
<td>74</td>
<td>3.5</td>
<td>29</td>
</tr>
</tbody>
</table>

**Notes:**
- TM3SR+ = Tesla Model 3 Standard Range +
- CBEV = Chevy Bolt EV
- NePlus = Nissan LEAF ePlus
- TMX = Tesla Model X
- JiPace = Jaguar i Pace
- AeTron = Audi eTron

**Cargo:** back seats in upright position
BEV Comparisons

BEVs Range (miles) & Price

<table>
<thead>
<tr>
<th>Range Rank</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV:</td>
<td>TMSLR</td>
<td>TMXLR</td>
<td>TM3LR</td>
<td>TM3AWD</td>
<td>TMXS</td>
<td>TMSS</td>
<td>CBoltEV</td>
<td>HyKonaE</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>
To find a Star rating (1-5) for a specific car.

NHTSA Star Ratings
Volkswagen BEV Plans

MQB = VW ICEV platform; MEB = VW BEV platform

Volkswagen investiert 1,2 Milliarden € in Zwickau.

50 BEV models
22 million BEVs
By 2028!

MQB = VW ICEV platform; MEB = VW BEV platform
VW plans to move quickly from ICEVs to BEVs!
Volkswagen BEV Plans

ID. ID. Buzz
No specs yet

ID. Crozz

ID. Vizzion

ID. Beach Buggy
## Volvo Polestar 2

<table>
<thead>
<tr>
<th>Range (mi)</th>
<th>0-60 mph (s)</th>
<th>MPGe</th>
<th>Price</th>
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</thead>
<tbody>
<tr>
<td>275</td>
<td>4.5</td>
<td>119</td>
<td>$63,000</td>
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</tbody>
</table>
Volvo XC40 Recharge

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

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

Average gasoline car in 2018: 25 MPG

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

<table>
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<th>Model</th>
<th>EPA Range (miles)</th>
<th>Efficiency (MPGe)</th>
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<tbody>
<tr>
<td>Standard Range RWD</td>
<td>230</td>
<td><strong>102</strong></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 Supercars: **Porsche Taycan**

<table>
<thead>
<tr>
<th>Model</th>
<th>Range (mi)</th>
<th>MPGe</th>
<th>Price</th>
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</thead>
<tbody>
<tr>
<td>4S</td>
<td></td>
<td></td>
<td>$116,590</td>
</tr>
<tr>
<td>Turbo</td>
<td>201</td>
<td>69</td>
<td>$150,900</td>
</tr>
<tr>
<td>Turbo S</td>
<td></td>
<td></td>
<td>$185,000</td>
</tr>
</tbody>
</table>

[https://electrek.co/2019/12/11/porsche-taycan-turbo-201-mile-epa-range/]
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>$200,000</td>
</tr>
</tbody>
</table>
BEV Mini-Compacts

**Smart ForTwo Electric**
68 miles 75 mph $24,550

**Chevrolet Spark EV**
82 miles 89 mph $13,500

**Mini Cooper SE Electric**
110 miles $29,900
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>
Aerodynamics of Pickup Trucks

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

Drag coeff. = 0.39 at 60 mph.

Drag coeff. = 0.56 at 60 mph.

Drag coeff. = 0.59 at 60 mph.

The model does not include the wheels.
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
  - Hydrogen fuel cell
- **Volvo Semi**
- **Daimler Semi**
- **Autonomous Trucks**  
  - **Volvo Vera**
ZEV, LEV & PZEV Vehicles

• **ZEV**: Regulation that requires automakers to sell electric cars and trucks; the exact number of vehicles is linked to the automaker’s overall sales within the state.

• **LEV**: Sets maximum emissions allowed; **ULEV, SULEV**.

• **PZEV**: “...has zero evaporative emissions from its fuel system, has a 15-year (or at least 150,000-mile) warranty on its emission-control components, and meets Super Ultra Low Emissions Vehicle (SULEV) tailpipe-emission standards”
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.
Other battery chemistries are possible; e.g. solid state.
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 CBEV when it gets below 30% up to about 70% (about once a week), unless there will be a long trip next day.
- I like to have ~15% 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 stations in Shanghai China! Plans to finally have all Superchargers on solar energy.
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 = 60% 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: 359 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 = 60% of maximum power for battery fillup.
Tesla Superchargers Upgrades

120-kW V2s are being upgraded to 150-kW, so first two bars will be decreased by $\frac{1}{4}$th.

- **V2 Superchargers**:
  - 120 kW

- **V3 Superchargers**:
  - 120 kW
  - 250 kW

*With on-route battery warmup*
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

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

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

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

Roper home charger: 9.6–kW; Tesla Superchargers: 150-kW being updated to 250-kW.
The Lynchburg Supercharger will have 250-kW capability!
The 2 gray arrows show the SCs being built in Salem VA, near Roanoke and I-81, and Lynchburg. The one at Lynchburg allows direct Tesla travel between Blacksburg/Roanoke and Richmond and direct travel between Charlottesville and northern North Carolina.
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 1st night.
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!
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?
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.
Plug-In Hybrids (PHEV)

• Toyota Prius Prime: 25 miles EV @ 133 MPGe
• Mitsubishi Outlander: 22 miles EV @ 70 MPGe, AWD
• Honda Clarity: 47 miles EV @ 110 MPGe
• Chrysler Pacifica: 33 miles EV @ 84 MPGe, van
• BMW Rex: 72 miles EV, 2.4-gallons gasoline
• Ford Fusion Energi; 19 miles EV @ 103 MPGe
• Hyundai Ioniq: 29 miles EV @ 119 MPGe
• Kia Niro/Optima: 27 miles EV @ 105 MPGe
• Several more expensive (Cadillac, Porsche, Volvo, etc.)
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.