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., Chevrolet Volt)
BEV = Battery Electric Vehicle (e.g., Tesla Model 3)
EV = PHEV or BEV

tinyurl.com/BEVs2019
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
  – Almost no 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

99-217 mph
18,000 miles in 2018!
Plans for 24,000

New maglev train
Passenger rail in United States

Planned High-Speed Rail in U.S.
Electric Vehicles vs Gasoline Vehicles

GHG Emissions

Note: The MPG (miles per gallon) value listed for each region is the combined city/highway fuel economy. The GHG emissions equivalent to driving an EV is calculated based on the most recent version. Comparisons include gasoline and electricity fuel production/consumption data from the latest year available. The 50 MPG US average is a sales-weighted average based on where EVs were sold in 2011-2017.

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

65 mpg ICEV for Tesla Model 3.

2018 data: ICEV = 80 MPG
2015 data: ICEV = 68 MPG

With solar panels on house
ICEV = infinite MPG!
Well to Wheel Greenhouse Gas Emissions Comparison

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

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<td>GHG emissions (g/mi)</td>
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</tr>
<tr>
<td><strong>Gasoline</strong></td>
<td>500</td>
<td>400</td>
<td>300</td>
<td>200</td>
<td>100</td>
<td>50</td>
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<td><strong>Plug-in hybrid</strong></td>
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</tbody>
</table>
Average BEV vs Average ICEV Fuel Cost

- **2018 US average ICEV MPG** = 22
- **2018 average BEV MPGe** = 102 (1 gallon = 33.7 kWh)
  - *Tesla Model 3* = 130 MPGe!
- **2019 US average \$/gallon** = $2.49
- **2018 US average \$/kWh** = $0.125
- ICEV \$/mile = $2.49/22 = **$0.113**
- BEV \$/mile = $0.125/3.03 = **$0.0413**
- **ICEV/BEV = 2.74**
- Electricity price is more stable than gasoline price.
U.S. average monthly gasoline and crude oil prices, 2008–2018

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.
Most Efficient BEV vs Most Efficient HEV

Hyundai Ioniq Electric vs Prius Eco Fuel Cost

- Toyota Prius Eco (hybrid) MPG = 56
- Hyundai Ioniq Elect. MPGe = 136
- 2019 US average $/gallon = $2.49
- 2018 US average $/kWh = $0.125
- ICEV $/mile = $2.49/56 = $0.0445
- BEV $/mile = $0.125/4.04 = $0.0309
- ICEV/Honda-Ioniq-Electric = 1.44
  - About ½ of average BEV vs average ICEV
Tesla Model 3 vs. Toyota Corolla — 5 Year Cost Estimates

High gas price, high electricity price scenario

<table>
<thead>
<tr>
<th>Cost</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$30,052</td>
<td>Toyota Corolla LE Hybrid</td>
</tr>
<tr>
<td>$31,690</td>
<td>Tesla Model 3 SR+ (Least expensive TM3 with 240-miles range)</td>
</tr>
<tr>
<td>$31,802</td>
<td>Toyota Corolla L</td>
</tr>
<tr>
<td>$37,839</td>
<td>Toyota Corolla XSE</td>
</tr>
</tbody>
</table>

Assumptions: $5/gallon for gasoline, $0.20/kWh for electricity, 15,000 miles/year, maintenance estimates from Edmunds and Paul Fosse/CleanTechnica, $3,750 tax credit for Model 3, $5,000 down payment and 5.5% 5-year loan for remaining portions of upfront costs of cars, Kelley Blue Book estimates for 5-year resale value. Full analysis here: https://cleantechnica.com/tag/tesla-model-3-vs-toyota-corolla/

Chart: CleanTechnica • Source: CleanTechnica
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!
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.](https://www.toxco.com) awarded $9.5-million DOE grant to recycle lithium batteries.
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.
Enjoyment!

• Very quiet.
• High acceleration!
• Most battery charging overnight at home.
  – No fumes or bad weather when charging.
• Much free < 10-kW charging.
• Low center of gravity enhances safety and performance (heavy battery underneath).
• One-pedal driving.
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.
The amount left to be extracted for the red curve is 2.3 times the estimated reserves!
Current crude-oil price = $55/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!
Don’t depend on natural gas to replace gasoline for ICEVs!
Renewables are Passing Coal for U.S. Electricity Generation

Renewables = hydropower, wind, solar, geothermal and biomass.
(Note in inclusion of 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 bends downward because U.S. extraction is peaking.
Tesla Model 3

<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 ?</td>
<td>220</td>
<td>131</td>
<td>$35,400</td>
</tr>
<tr>
<td><strong>Standard Range Plus</strong></td>
<td><strong>240</strong></td>
<td><strong>133</strong></td>
<td><strong>$38,990</strong></td>
</tr>
<tr>
<td>Long Range ?</td>
<td>325</td>
<td>130</td>
<td>$45,900</td>
</tr>
<tr>
<td>AWD</td>
<td>310</td>
<td>116</td>
<td>$47,990</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>310</td>
<td>116</td>
<td>$54,990</td>
</tr>
</tbody>
</table>

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.
Chevrolet Bolt EV

Range: 238 miles      MPGe: 119      Price: $36,620

US 2018 average price of a light vehicle was $37,577.
## Nissan LEAF II e-Plus

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range (miles)</th>
<th>Efficiency (MPGe)</th>
<th>Price</th>
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<tbody>
<tr>
<td>LEAF</td>
<td>150</td>
<td>112</td>
<td>$29,990</td>
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<tr>
<td>LEAF ePlus</td>
<td>226</td>
<td>108</td>
<td>$37,445</td>
</tr>
</tbody>
</table>

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

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

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

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

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

Range: 243 miles  MPGe: 101  Price:
## Tesla Model S

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range (miles)</th>
<th>Efficiency (MPGe)</th>
<th>Price</th>
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<tbody>
<tr>
<td>Standard Range ?</td>
<td>285</td>
<td>109</td>
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<tr>
<td>Long Range (AWD)</td>
<td>370</td>
<td>111</td>
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<tr>
<td>Performance (AWD)</td>
<td>345</td>
<td>104</td>
<td>$99,990</td>
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Autopilot software included in all 3 versions.
Order online.
? = phone order.
Free Supercharging!
## Tesla Model X

![Tesla Model X](image)

<table>
<thead>
<tr>
<th>Model</th>
<th>EPA Range (miles)</th>
<th>Efficiency (MPGe)</th>
<th>Price</th>
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<tbody>
<tr>
<td>Standard ?</td>
<td>295</td>
<td>93</td>
<td>$83,000</td>
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<tr>
<td>Long Range (AWD)</td>
<td>325</td>
<td>87</td>
<td>$84,990</td>
</tr>
<tr>
<td>Performance (AWD)</td>
<td>325</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

<table>
<thead>
<tr>
<th>Price</th>
<th>Range</th>
<th>MPGe</th>
<th>0-60</th>
<th>Cargo</th>
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</thead>
<tbody>
<tr>
<td>$70,495</td>
<td>234</td>
<td>76</td>
<td>4.5</td>
<td>51</td>
</tr>
</tbody>
</table>
## Audie e-Tron

<table>
<thead>
<tr>
<th>Price</th>
<th>Range</th>
<th>MPGe</th>
<th>0-60</th>
<th>Cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td>$74,800</td>
<td>204</td>
<td>74</td>
<td>3.5</td>
<td>29</td>
</tr>
</tbody>
</table>
# BEV Comparisons

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

**TM3SR+** = Tesla Model 3 Standard Range +; **CBEV** = Chevy Bolt EV; **NePlus** = Nissan LEAF ePlus
**TMX** = Tesla Model X; **JiPace** = Jaguar iPace; **AeTron** = Audie eTron

Cargo = back seats in upright position
Volkswagen BEV Plans

VW plans to move quickly from ICEVs to BEVs!

50 BEV models
22 million BEVs
By 2028!

MQB = VW ICEV platform; MEB = VW BEV platform
VW plans to invest 1,2 milliarden € in Zwickau.

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

ID.
ID. Buzz
ID. Crozz

Porsche Taycan
VW ID. Vizzion & ID. Beach Buggy
Tesla Model 3 Drive Train

AWD (Dual Motor) has another motor in front.
Electric Trucks

- Rivian electric pickup and SUV (rivian.com).
- Tesla pickup to be announced probably in late 2019.
- Ford F150 electric promised.
- Many Electric trucks promised
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

• 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 156 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.
I have used several of them.
I recommend installing level-2 240-volts charging stations at Sweet Springs, Union, Rainelle & Hillsboro WV.
Tesla Superchargers

About 450 stations, average 6 stalls. Building about 1/day.

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

Roper home charger: 9.6 -kW; Tesla Superchargers: 150-kW being updated to 250-kW.
Sweet Springs WV Tesla drivers are well located with 4 Superchargers at 65-128 miles.
Tesla Model 3 trip from Blacksburg VA to Fort Worth TX

TM3 wants 5 Supercharging stops; I need 3 stops/day over 2 days. Charge to 100% at hotel.
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 Chargers Plans

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

Total = 450 stations, average of 6 stalls

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

Cycle 2 investments will be made in 18 metropolitan areas across the country.
Other U.S. Charging Networks

- Blink ~1680 sites
- Chargepoint ~6083 sites
- eVgo ~774 sites
- Greenlots ~392 sites
- Semaconnect ~1166 sites
- Webasto ~164 sites

Many < 10-kW chargers have no fee to use.
### Fast Chargers in the U.S.

<table>
<thead>
<tr>
<th>CHAdeMo</th>
<th>CCS</th>
<th>Supercharger</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,140 stations</td>
<td>1,888 stations</td>
<td>678 stations</td>
</tr>
<tr>
<td>3,010 charging outlets</td>
<td>3,525 charging outlets</td>
<td>6,340 charging outlets</td>
</tr>
</tbody>
</table>

Filters chosen:
- United States
- Electric
- Types: DC Fast
- Connectors/outlets: CHAdeMO
- Access: Public

- United States
- Electric
- Types: DC Fast
- Connectors/outlets: SAE CCS
- Access: Public

- United States
- Electric
- Types: DC Fast
- Connectors/outlets: Tesla
- Access: Public

**CHAdemo, CCS, and Supercharger - Alternative Fuels Data Center, Aug. 20, 2019**

Teslas can use CHAdemo stations as well as Superchargers with a $450 adapter, for a total of **2818 locations and 9350 charging stations**!
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

The exponential time constant is about 2.2 years.
World Light Vehicles (Assume 4-billion leveling off.)

The electric-data asymptotic time constant is about 16 years.