Plug-in Hybrid Cars (PHEVs)

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Terminology

HEV = Hybrid Electric Vehicle  
Electric car = Battery Electric Vehicle (BEV)  
or Plug-in Hybrid Electric Vehicle (PHEV)  
ICE = Internal Combustion Engine car (gasoline or diesel)

Energy = kilowatts-hours (kWh)  
Power = Energy/time = kilowatts (kW)

Pluginamerica.org, insideevs.com, plugshare.com
My Experience with PHEVs

• 2005: Bought a 2005 Toyota Prius.
• 2009: Had Prius converted to a Hymotion PHEV.
• 2006: Bought a 2006 Toyota Highlander Hybrid (HiHy).
• 2013: Attempted to convert HiHy to a PHEV-failed!
• 2016: Bought a 2016 Toyota RAV4 Hybrid
PHEVs as a Bridge to BEVs

• Has no “range anxiety”.
• Provides an introduction to the advantages of electrical propulsion.
• Greatly reduces emissions of an HEV.
• Can mostly be fueled at home.
One reason why electric cars are so important, especially when solar fueled!

Passenger Travel Energy Use

kWh/passenger/mile

Taxis: 4.6
PHEV versus HEV

Same components as in an HEV +

- Larger battery (Prius 1.3 kWh vs Prius Prime 8.8 kWh)
- Different eCVT
- Different computer controls to allow motion using battery only until its charge gets below some value
- Charger to connect to a charging station to charge the larger battery (3.3 kW or 6.6 kW)
- External J1772 receptacle for 120-volts or 240-volts charging
- Portable charging station stored in trunk for 120-volts charging anywhere; some can be converted to 240-volts
- Dash display to show the State Of Charge (SOC)
  - and energy usage
  - and location of level-2 charging stations
Regeneration for HEVs, PHEVs & BEVS

• The electric motor is used as a generator to charge the battery.
• When brakes are engaged except in emergencies and at very low speeds, due to kinetic energy.
• When going down a hill due to gravity.
• When accelerator is not being depressed, due to kinetic energy.
EPA Driving Cycles

Urban Cycle: much stop and go

Highway Cycle: mostly steady driving

May not fit your driving method.
PHEV Monroney Label for 2011 Chevrolet Volt Gen 1

2017 Chevy Volt

Fuel Economy and Environment

Fuel Economy

- Electricity: 106 MPGe, 31 kWh per 100 miles
- Gasoline Only: 42 MPGe, 2.4 gallons per 100 miles

Driving Range

- All electric range: 53 miles
- Combined city/highway: Gasoline only

You save $3,750 in fuel costs over 5 years compared to the average new vehicle.

Annual fuel cost

- $650

Fuel Economy & Greenhouse Gas Rating

- 1 (Best)

Smog Rating

- 6

This vehicle emits 51 grams CO₂ per mile. The best emits 0 grams per mile. Producing and distributing fuel & electricity also create emissions; learn more at fueleconomy.gov.
## 2017 Prius Prime Plus

**Fuel Economy and Environment**

### Fuel Economy

<table>
<thead>
<tr>
<th>Electricity + Gasoline</th>
<th>Gasoline Only</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>133 MPGe</strong> 0.0 gallon per 100 miles</td>
<td><strong>54 MPG</strong> 1.9 gallon per 100 miles</td>
</tr>
<tr>
<td>combined city/highway</td>
<td>combined city/highway</td>
</tr>
</tbody>
</table>

### Driving Range

<table>
<thead>
<tr>
<th>Electricity + Gasoline</th>
<th>Gasoline Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 miles</td>
<td>540</td>
</tr>
</tbody>
</table>

### Annual fuel cost

- **$600**

### Fuel Economy & Greenhouse Gas Rating (tailpipe only)

- **10**
- **10** Best

### Smog Rating (tailpipe only)

- **8**
- **10** Best

*Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle. The average new vehicle gets 26 MPG and costs $7,000 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at $2.49 per gallon and 10.13 per kWh in. MPGe is miles per gasoline gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.*

[fueleconomy.gov](http://fueleconomy.gov)  
Calculate personalized estimates and compare vehicles
Charging a PHEV

• All have standard SAE J1772 inlet.
• Comes with portable level-1 120-volts charging station. It can be converted to 240-volts.
• Can be charged at all level-2 240-volts charging stations. ~9 are in Blacksburg.
• Cannot be charged at level-3 480-volts DC charging stations.
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.

Chevy Volt Gen-2: 0-30 mph in 2.6 seconds!
Fracking for tight oil

Area under depletion curves is the sum of the amount already extracted plus the estimated reserves or more.
Guess of global tight-oil fracking
Exponential Rise
Doubling time = 5.5 years
Many people, including politicians, don’t understand exponential growth. Of course, renewable electricity will level off in the far future.

Linear fits for coal, gas & nuclear

Exponential fit for renewables

More likely natural-gas future, since US extraction will peak ~2018.
US Tax Credit for Plug-In Vehicles

• For vehicles acquired after December 31, 2009, the credit is equal to $2,500 plus, for a vehicle which draws propulsion energy from a battery with at least 5 kilowatt hours of capacity, $417, plus an additional $417 for each kilowatt hour of battery capacity in excess of 5 kilowatt hours. The total amount of the credit allowed for a vehicle is limited to $7,500.

• The credit begins to phase out for a manufacturer’s vehicles when at least 200,000 qualifying vehicles have been sold for use in the United States (determined on a cumulative basis for sales after December 31, 2009).
Expiration of EV Tax Credits

Current Expectations For $7,500 Federal Credit Phase-Out For Major US EV Makers.
Grey shaded areas are expected cumulative future sales in thousands.
Colored blocks indicate stage of the Federal credit a particular OEM is at.
Chevrolet Volt PHEV (Gen 2)

- Electric Range: 53 miles
- Total Range: 420 miles
- Battery Capacity: 18.4 kWh, 14 usable
- Hybrid Efficiency: 42 MPG
- Electric Efficiency: 106 MPGe
- MSRP: $33,220
- Federal Tax Credit: $7,500
Chevrolet Volt PHEV (Gen 2)

- Engine: 1.5-liter, 101 hp (75 kW) \[1\text{-hp} = 0.7457\text{-kW}\]
- 2 Motor/Generators
  - 64-hp (48 kW) - MGA
  - 117-hp (87 kW) - MGB
- Effective power: 149-hp (111-kW)
- 2 Planetary gear sets – PG1 & PG2
- Three clutches
  - one a ratchet – CR
  - two computer operated – C1 & C2)
- Battery: 192 Li-Ion cells, 360 volts, 120 kW, 403 lbs
Chevrolet Volt 2017

Battery = 18.4 kWh
Usable = 14 kWh
Planetary Gear Set

- Ring Gear
- Sun Gear
- Planet Gears
- Planet Gears Carrier
2 EV modes & 2 extended-range modes:
- EV1: C1 on, C2 off, C3 off
- EV2: C1 off, C2 on, C3 off
- ER1: C1 on, C2 off, C3 on
- ER2: C1 off, C2 on, C3 on
NEW 2016 VOLTEC

Based on US patent 8,602,938 + GM SAE paper 2015-01-1152

ICE
75kW/140Nm

MGA
48kW / 118Nm
Economical ferrite motor

Power electronics

18.4kWh

MGB
87kW / 280Nm
Rare-earth NdFeB motor
Powerful and efficient for low RPM

OCW (44)
Ratchet clutch: prevents ICE and ring from spinning backwards

Clutch 1 (42)

Clutch 2 (40)

Planetary Gear 1 (36)

Planetary Gear 2 (38)

Wheels
Chevrolet Volt 2017

EV Motion

- Both motors, MGA & MGB, connected to the 2 sun gears, PGA & PGB.
- PG1 ring gear is ratcheted to only spin forward
- PG2 ring gear is fixed to not rotate.
- Both planet-carriers connect to the wheels through a fixed-gears box.
**CD1: ONE MOTOR EV MODE**

**Mode CD1: (74)**

**One Motor EV**

**When:** Electric drive CD
Low & medium torque demand.
Any speed including reverse.
+ CS mode low speed & low torque.

**How:** MGB is on. MGA & ICE are off
Clutch 1 is open, Clutch 2 is closed.
MGB also does regenerative braking.

**Why:** Most efficient since MGB is efficient for low torque.

- **MGB**
  - 87kW / 280Nm
  - Rare-earth NdFeB motor
  - Powerful and efficient for low RPM
  - Does all driving in CD1

- **ICE Off**
- **MGA Off**
- **Power electronics**
- **OWC:** (44)
  - One-way clutch: Unloaded
- **Planetary Gear 1:** (36)
- **Planetary Gear 2:** (38)
- **Torque** vs **Speed**
Different gear ratios give a wider torque band.
Both motors, MGA & MGB, connect to the 2 sun gears, PGA & PGB.
MGA connects to PG2 ring gear through clutch C1.
Engine connects to PG1 ring gear.
Both planet-carriers connect to the wheels through a fixed-gears box.

ER1: E powers wheels & MGA to charge battery.
ER2: C1 & C2 engaged, E & MGB power wheels.
ER3: C1 engaged, E & MGA power wheels, MGB charges battery.
Mixed Mode

Mode CS1: (54)
Low Extended Range or Input Split

When: Hybrid drive CS
High torque demand: 0-60km/h
Low torque demand: 20-40km/h

How: ICE power is split between wheels and generator MGA.
MGA’s electric output is sent down to MGB to power the wheels.
At low speed & torque ICE is off and vehicle temporarily drives in CD1
Engine starts at CD1->CD2 by spinning up MGA.
CS2: FIXED RATIO EXTENDED RANGE

Mode CS2: (56)
Fixed Ratio Extended Range

When:
High torque demand: 70-110km/h
Low torque demand: 40-60km/h

How:
Full ICE output power is sent to wheels. ICE RPM is tied to vehicle speed (fixed ratio).
MGA is off and locked via clutches 1 & 2.
MGB may drive wheels using battery power to give extra boost for overtake sprints.
MGB does regenerative braking.
At low output torque demand MGB recharges battery to keep ICE at efficient BFC by increasing ICE torque.
Between CS1→CS2 modes MGA spins down and Clutch 2 closes.

Why:
Most efficient as it avoids most electric conversion losses.
**CS3: HIGH EXTENDED RANGE MODE**

**Mixed Mode**

**Mode CS3:** (56)

*High Extended Range or Compound Split*

**When:**
- High torque demand: above 110km/h
- Low torque demand: above 60km/h

**How:** ICE output power is mechanically split between wheels and the ring of PG2. This effectively gives a higher gear ratio. By controlling the RPM of MGA and by turning MGB slowly or backwards the ICE RPM and torque can be controlled. The energy siphoned off by MGB is sent up to MGA or to the battery during regenerative braking. Between CS2->CS3 modes MGB powers off allowing Clutch 2 to open with no torque.
Voltec Gen-2 eCVT

- The new transmission is lighter and has lower cost.
- Lower cost is achieved by using a smaller traction motor with fewer rare earth materials along with using an integrated inverter.
- Linking the 2 motors provides more torque (higher acceleration) than for Voltec Gen-1.
- We may see this new transmission, or slightly modified variants of it, in other General Motors plugin and non-plugin hybrids in the future.
- This new transmission is great engineering!
Volt Driving Modes

- **Normal**: Linear map the accelerator pedal.
- **Sport**: Remaps accelerator pedal to nearer top.
- **Mountain**: Holds the battery at 45% SOC.
- **Hold**: Holds battery at % SOC when switched on.
- **L on shift knob**: Increased regeneration to allow 1-pedal driving.
Volt Regeneration Increase

• L driving mode allows 1-pedal driving.
• Paddle behind left side of steering wheel increases regeneration (on demand).

Same as for Chevrolet Bolt EV
Battery Thermal Management
Chevrolet Volt/Bolt-EV Method

Refrigeration for cooling and resistance heating for glycol in warm weather.

Keep battery plugged in after charging in cold or hot weather.
Toyota Prius Prime 2017

Many details about Toyota Prius Prime PHEV
Brochure
Quick Reference Guide
Owner’s Manual

Battery = 8.8 kWh
Toyota Prius Prime PHEV

- Electric Range: **25 miles**
- Total Range: **640 miles**
- Battery Capacity: **8.8 kWh**
- Hybrid Efficiency: **54 MPG**
- Electric Efficiency: **133 MPGe**
- MSRP: **$27,100**
- Federal Tax Credit: **$4,500**

Uses a similar ratchet or one-way clutch as for the Chevy Volt, so both motors can drive the wheels in EV mode at higher speeds. It can use EV mode up to 84 mph.

ICE has 40% efficiency!
Prius Prime LiIon 2017
Prius Prime LiIon Battery
Prius Prime Console

Premium: 11.6” portrait screen
Advanced: Heads-Up Display at bottom of windshield
This is not correct. Only MG1 connects to a PGS. MG2 connects to an other gears arrangement.

Detailed breakdown of Prius Prime eCVT
Prius Prime Driving Modes

• Drive: Default HEV mode with linear map of accelerator.
• ECO: Maps accelerator toward bottom.
• PWR: Maps accelerator toward top; reduces AC.
• HV EV: “Electric Vehicle” mode, EV up to 84 mph or low battery.
• EV AUTO: Electric mode unless battery low or high acceleration.
• B: Uses ICE braking, for going down hills.
Ford C-Max Energi PHEV

- Electric Range: 20 miles
- Total Range: 670 miles
- Battery Capacity: 7.9 kWh
- Hybrid Efficiency: 38 MPG
- Electric Efficiency: 88 MPGe
- MSRP: $27,120
- Federal Tax Credit: $4,007
Ford Fusion Energi PHEV

- Electric Range: 21 miles
- Total Range: 670 miles
- Battery Capacity: 7.9 kWh
- Hybrid Efficiency: 42 MPG
- Electric Efficiency: 97 MPGe
- MSRP: $33,900
- Federal Tax Credit: $4,007
Honda Clarity PHEV

- Electric Range: 47 miles
- Total Range: 330 miles
- Battery Capacity: 17 kWh
- Hybrid Efficiency: 48 MPG
- Electric Efficiency: 110 MPGe
- MSRP: <$40,000
- Federal Tax Credit: $7,500
Other PHEVs

- **Chrysler Pacifica Hybrid**
  - Electric Range: 33 miles
  - Total Range: 570 miles
  - Hybrid Efficiency: 32 MPG
  - Electric Efficiency: 84 MPGe
  - Battery Capacity: 16 kWh
  - MSRP: $41,995
  - Federal Tax Credit: $7,500

- **Audi A3 Sportback e-tron**
  - Electric Range: 16/17 miles
  - Total Range: 380/430 miles
  - Hybrid Efficiency: 35/39 MPG
  - Electric Efficiency: 83/86 MPGe
  - Battery Capacity: 8.8 kWh
  - MSRP: $39,500
  - US Tax Credit: $4,502
Other PHEVs

- **Volvo XC90 T8 AWD PHEV**
  - Electric Range: ~16 miles
  - Total Range: 350 miles
  - Hybrid Efficiency: 25 MPG
  - Electric Efficiency: 53 MPGe
  - Battery Capacity: 10.4 kWh
  - MSRP: $67,800
  - US Tax Credit: $4,585

- **BMW i3/i3s REx (Range Extender)**
  - Electric Range: **97 miles**
  - Total Range: **180 miles (2.4-gallons gas tank!)**
  - Hybrid Efficiency: 35 MPG
  - Electric Efficiency: 111 MPGe
  - Battery Capacity: **33.2 kWh**
  - Gasoline Capacity: **2.4 gallons**
  - Generator: 33.5 hp
  - MSRP: $48,300
  - US Tax Credit: $7,500
Other PHEVs

- **BMW 740e xDrive AWD**
  - Electric Range: 14 miles
  - Total Range: 340 miles
  - Hybrid Efficiency: 27 MPG
  - Electric Efficiency: 64 MPGe
  - Battery Capacity: 9.2 kWh
  - MSRP: $90,700
  - US Tax Credit: $4,668

- **BMW 530e**
  - Electric Range: 15 miles
  - Total Range: 370
  - Hybrid Efficiency: 31 MPG
  - Electric Efficiency: 72 MPGe
  - Battery Capacity: 9.2 kWh
  - MSRP: $52,400
  - US Tax Credit: $4,668
Other PHEVs

- **BMW 330e**
  - Electric Range: 14 miles
  - Total Range: 350 miles
  - Hybrid Efficiency: 31 MPG
  - Electric Efficiency: 71 MPGe
  - Battery Capacity: 7.6 kWh
  - MSRP: $44,100
  - US Tax Credit: $4,001

- **BMW X5 xDrive40e**
  - Electric Range: 14 miles
  - Total Range: 540 miles
  - Hybrid Efficiency: 24 MPG
  - Electric Efficiency: 56 MPGe
  - Battery Capacity: 9.2 kWh
  - MSRP: $63,200
  - US Tax Credit: $4668
Other PHEVs

- **BMW i8**
  - Electric Range: 15 miles
  - Total Range: 330 miles
  - Electric Efficiency: 76 MPGe
  - Battery Capacity: 7.1 kWh
  - MSRP: $143,400
  - US Tax Credit: $3793

- **Kia Niro PHEV**
  - Battery Capacity: 8.9 kWh
  - Electric Efficiency: 76 MPGe
  - US Tax Credit: $4,502
Other PHEVs

• **Mercedes E350e**
  – Electric Range: 10 miles
  – Total Range: 410
  – Electric Efficiency: 93 MPGe
  – Battery Capacity: 6.2 kWh
  – MSRP: $39,900
  – US Tax Credit: $4043

• **Mercedes GLC 350e**
  – Electric Range: 12 miles
  – Total Range: 450
  – Electric Efficiency: 109 MPGe
  – Battery Capacity: 8.7 kWh
  – US Tax Credit: $4,085
Other PHEVs

- **Mercedes GLE 550e**
  - Electric Range: 10 miles
  - Total Range: 460 miles
  - Hybrid Efficiency: 21 MPG
  - Electric Efficiency: 43 MPGe
  - Battery Capacity: 8.7 kWh
  - MSRP: $66,300
  - US Tax Credit: $4,085

- **Mitsubishi Outlander PHEV AWD**
  - Electric Range: 22 miles
  - Electric Efficiency: 131 MPGe
  - Battery Capacity: 12 kWh
  - US Tax Credit: $5,836
  - MSRP: $35,500/$42,235

World’s first plug-in-hybrid SUV
Mitsubishi Outlander PHEV AWD

World’s first plug-in-hybrid SUV
CHAdeMO fast-charging port
Two 120-volts outlets (1.5-kW AC)
Lowest price PHEV SUV in U.S.
Other PHEVs

• **Kia Optima PHEV**
  – Electric Range: 27 miles
  – Hybrid Efficiency: 40 MPG
  – Electric Efficiency: 103 MPGe
  – Battery Capacity: 9.8 kWh
  – US Tax Credit: $4,919

• **Volkswagen Golf GTE PHEV**
  – Electric Range: 22 miles
  – Hybrid Efficiency: 45 MPG
  – Electric Efficiency: 95 MPGe
  – Battery Capacity: 8.7 kWh
  – US Tax Credit: $4,085
Other PHEVs

- **Hyundai Sonata Plug-In Hybrid**
  - Electric Range: 27 miles
  - Total Range: 600 miles
  - Hybrid Efficiency: 40 MPG
  - Electric Efficiency: 99 MPGe
  - Battery Capacity: 9.8 kWh
  - US Tax Credit: $4,919

- **Hyundai Ioniq Plug-In Hybrid**
  - Electric Range: 27 miles
  - Hybrid Efficiency: 50 MPG
  - Electric Efficiency: 105 MPGe
  - Battery Capacity: 8.9 kWh
  - US Tax Credit: $4,085
Other PHEVs

- **Porsche Cayenne S E-Hybrid**
  - Electric Range: 14 miles
  - Total Range: miles
  - Hybrid Efficiency: 47 MPG
  - Electric Efficiency: 27 MPGe
  - Battery Capacity: 10.8 kWh
  - US Tax Credit: $5,300
  - MSRP: $86,995

- **Porsche Panamera S E-Hybrid**
  - Electric Range: 23 miles
  - Hybrid Efficiency: 27 MPG
  - Electric Efficiency: 51 MPGe
  - Battery Capacity: 14.1 kWh
  - US Tax Credit: $7,500
  - MSRP: $185,450
Other PHEVs

• **MINI Cooper AWD PHEV**
  – Electric Range: 17 miles
  – Total Range: miles
  – Hybrid Efficiency: MPG
  – Electric Efficiency: 135 MPGe
  – Battery Capacity: 7.6 kWh
  – US Tax Credit: $3793
  – MSRP: $37,650

• **Range Rover Sport P400e**
  – Electric Range: ~31 miles
  – Battery Capacity: 13.1 kWh
  – US Tax Credit: $5880
Other PHEVs

• **Volvo XC40 SUV PHEV**
  – Electric Range: 25 miles
  – Battery Capacity: 9.7 kwh
  – US Tax Credit: $4,919

• **Ford F-150 pickup HEV, PHEV or BEV?**
  – [XL-Hybrids F-150 PHEV Conversion](#)
Electric-Car Boom
Models by style and range available through 2020

SUVs/Trucks
- Land Rover Defender
- Toyota RAV4
- Trumpchi GS4
- Jaguar I-Pace
- Tesla pickup
- BMW i5
- M-B EQ
- Audi e-tron Quattro
- Porsche E-sport
- Tesla Roadster
- Tesla Model X
- NIO ES8
- Chehenglia SUV
- BYD e6
- M-B B-Class
- Nissan Leaf 2*
- Budd-e
- Mitsubishi eX
- Tesla Model Y*
- NIO EP9
- Exagon Furtive
- Tesla Roadster*
- Audi R8 E-tron
- Faraday FF91
- NIO Eve E-tron

Sports cars
- Mahindra eVerito
- Hyundai Ioniq
- Renault DeZir
- Fiat 500e
- Seat Mii*
- Mahindra e2o
- Bolloré Bluesummer
- BMW mini e
- VW e-Up
- Smart
- Kandi Panda
- Renault Twizzy
- ForTwo
- Ford Transit
- Tata Iris
- Peugeot Partner
- ChangAn EMBO
- Renault Kangoo
- Yamaha Niken

Sedans
- SAIC E-Lavida
- CODA EV
- Honda Clarity
- BAIC EU260
- BYD e5
- JAC iE V4
- Renault Fluence
- BMW i3
- VW e-Golf
- Chevy Bolt
- YW I.D.
- Tesla Model S
- LeEco LeSEE
- Faraday FF91

Hatchbacks
- Kia Ray
- Hyundai BlueOn
- M-B E-Cell
- Chevy Spark
- Ford Focus
- M-B E-Cell
- Nissan Leaf
- BYD T3
- Tesla Model 3
- NIO ES8

Runabouts
- Mitsubishi i-MiEV
- Fiat 500e
- VW e-Up
- Seat Mii*
- Mahindra e2o
- Bolloré Bluesummer
- BMW mini e
- VW e-Bulli

Small vans
- Nissan NV200
- Tata Iris
- M-B Vito
- ChangAn EMBO
- Renault Kangoo
- BYD T3
- VW I.D. Buzz

Miles of electric range
0 50 100 150 200 250 300 350
I3 Rex total range is only 180 miles.
Better metric to compare PHEVs: Gallons/10,000-Miles is about how much gasoline would be used in one year. Multiply by $/Gallon to get an estimate of the yearly fuel cost.
Better metric to compare PHEVs: Gallons/10,000-Miles is about how much gasoline would be used in one year. Multiply by $/Gallon to get an estimate of the yearly fuel cost.
BEV MPGe
&
Calculated $\text{MPGc(PHEV)} = \text{MPGh} + \text{MPGe} \times e\text{Range}/150$
Electricity as Backup for Transportation when Fuel Gasoline becomes Scarce

• **Gasoline will become scarce** as world oil extraction rate decreases.

• **Plug-in hybrid vehicles** can travel 20-55 miles without gasoline, which should be sufficient for getting necessities for living.

• **Electricity to charge the vehicles’ batteries** can be obtained from **many sources**: national grid, local electric storage, local photoelectric panels, local wind generators and local fuel cells using many different fuels.
State of Charge of a Battery of a Plug-in Hybrid over a Day.

Politics of Plug-In Hybrids?

• How to pay for roads with no gas taxes?
• Will there be different rates for “traction electricity” and “house electricity” and, thus, different meters to register the amount used?
• Will there be special state and federal taxes on “traction electricity”? 
• 17 states charge fees for EVs.
Annual State Fees 2015 (PHEVs & BEVs)

West Virginia, Michigan, Minnesota, Indiana, Oklahoma, Tennessee, California and South Carolina by 2017.
Global Electric Cars (PHEVs & BEVs)

Figure 1 • Evolution of the global electric car stock, 2010-16

Notes: The electric car stock shown here is primarily estimated on the basis of cumulative sales since 2005. When available, stock numbers from official national statistics have been used, provided good consistency with sales evolutions.
New PEV sales compared to HEV sales over their respective 24 month introductory periods

U.S. Electric Cars (PHEVs & BEVs)

CA
OR
WA
HI
VT
CO
MI
UT
CT
MA

EVs as Portion of New Car Sales, 2016
When will all cars be electric?

- **Norway**: All new cars electric by 2025
- **Germany, India**: All new cars electric by 2030
- **Britain, France**: All new cars electric by 2040
- **China, California**: Studying all new cars electric
- **U.S.**: Over half of cars will be electric by 2030.
- **Audi**: 40% of luxury cars will be electric by 2030; BEVs will soon have 400-miles range, and eventually 500 miles.
- **VW**: 50 new BEVs from VW group by 2025
- **GM**: 20 new BEVs by 2023
- **Ford**: Plans a 400-miles BEV by 2020
Exponential Rise of World Electric Cars

Doubling time = 1.5 years
When will all cars be electric?
(BEV & PHEV)

Doubling time = 1.5 years

Once autonomous cars take over, it will probably happen faster.
When will all cars be electric? (BEV & PHEV)

Doubling time = 0.5 years at about 2030.
Charging PHEVs

• Most charging will occur at home in a garage, driveway or parking space.

• **Level-1:** 120-volts AC, **1.12-kW**, for all BEVs & PHEVs (Everywhere!) *(SAE-J1772 cord that comes with the PHEV)*

• **Level-2:** 240-volts AC, **3.3-kW & 6.6-kW charging station** with SAE-J1772 plug for all BEVs & PHEVs *(Your parking space, Kroger, InnVT, Campus Automotive)*

• **SAE-J1772 cord that comes with the PHEV** can have a [pigtail that allows level-2 charging](#) with a standard 240-volts outlet.

• The Mitsubishi Outlander PHEV allows fast charging *(CHAdeMO)*.
Light-Pole Charging Stations
Why Not Fuel-Cell (FCEV) Cars?

- They are very complicated:
  - Requires a 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 & ships.
We Need a Rational **National Energy System Design**

- Fuel cells, solar photoelectric panels, hydropower, wind, geothermal and biofuel electricity generators at homes, work sites and parking garages to charge electric and hybrid vehicles’ batteries and feed energy into the national electric grid. All possible fuels are used for the fuel cells. That is, *create a distributed multi-source energy system* to supplement, and eventually replace, huge coal, natural gas and nuclear electric power plants.

- Electric and plug-in hybrid vehicles that *automatically connect to the national grid and local energy sources* when parked at homes, work sites and parking garages.

- Plugged-in vehicles serve as national/local grid energy storage devices when at rest and drive away as fully charged vehicles for travel. They also serve as electric power backup at the home location.

- Use **biodiesel made from new and recycled vegetable/animal oils and other wastes** as fuels for long-distance hybrid-vehicle travel between recharging sites. Also, made from algae and bacteria?

- Use the remaining fossil fuels to *develop the infrastructure* needed to accomplish the items given above on a large scale, instead of merely as fuel for transportation.