Renewable Energy and the EV: *The dawning of the age of Aquarius?*

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• The potential of EVs powered by the sun
• Brief history of EV
• Who is developing EVs today?
• Near term BEV models
• Cost per mile comparisons
• How much energy they will need and how much solar PV is that exactly?
• EV = green?
• What about bio-fuels?
Our great dependency on oil drives much of our hardship and tension; the high cost of living, pollution, geo-political difficulties, and resource wars - are all attributed to oil.

The countries with oil reserves suffer as well; oil riches destroy democracies and corrupt the politicians that should be serving the public - it does so with it’s seductive and powerful wealth for the few that control it.

By *democratizing* energy production with distributed solar power-plants, and driving vehicles that are environmentally sound has the potential to greatly improve life on earth.

We all play a role here by the choices we make.
Major milestones of the EV

- Electric cars were popular in the mid 19th century and early 20th century, providing comfort and ease of operation that could not be achieved by gasoline cars of the time.
- Advances in gas engine technology (starter) and with greater range the age of oil began.
- 1990’s California Air Resources Board (CARB) “zero emissions” vehicle requirement enacted.
- Automakers developed a handful of early designs which were withdrawn from the market once lawmakers and regulators scrapped the CARB deadlines and goals…
- The global recession in 2008 led to a desire for less wasteful automobiles, leading to today’s revival.
- Tesla delivered an expensive but very practical Roadster, while Nissan, Mitsubishi delivered more affordable examples for the larger population.
• Nearly all automotive suppliers have some form of EV or plug-in hybrid to offer the market

• HEV - hybrid electric vehicle

• PHEV - plug-in HEV

• BEV - battery electric vehicle
Battery only EV (BEV) vehicles in order of approximate availability in the USA
Tesla Roadster

- Seating for 2 - $109,400
- ~240 miles per charge
- recharge in 45 minutes, normal charging ~3-4 hours (full)
- 0-60 in 5.6 seconds - 120 mph top speed
- 53 kWh battery pack ($0.12/KWh = $6.4 to fully charge)
- Energy needs: 20 to 30 kWh every 100 miles
  1) Assuming 25 kWh/100 miles and utility power ~$0.12/KWh = (25KWh x $0.12/KWh = $3 energy costs for 100 miles (3 cents/mile)
- Battery life span of ~7 years
- 185KW motor (288hp)

1) Source Wikipedia
Image source Tesla Motors
Nissan Leaf

- Early development of EV technology in 1997, planning started in 2007, EV-11 prototype 2009, production in 2010
- Seating for 5 - $33’000
- ~100 (62-138) miles per charge (EPA)
  - ~68 miles on a hot day (110F) ~49mph average speed cross-town
- recharge in 30 minutes (80%) or normal charging in 8-20 hours
- 0-60 in 9.9 seconds - 93 mph top speed
- 24KWh battery pack (8 year 100’000 mile warranty)
- ~34KWh/100miles (worst case EPA data)
- Assuming 34 KWh/100 miles and utility power ~$0.12/KWh = (34KWh x $0.12/KWh = $4.1 energy costs for 100 miles (4.1 cents/mile)
- Lifespan for battery 5-10 years (70-80% capacity)
- 80KW motor (110hp)
Mitsubishi “MiEV”

- “Electrics will constitute 20 percent of Mitsubishi’s global shipments by 2020” (Shinichi Kurihara, CEO of Mitsubishi Motors America)

- Four adults
- “early 2012”, ~$29’125
- 62 mile range, $3.60 per charge ($0.12/KWh)
- 16KWh Lithium ion battery
- 8 year 100’000 mile warranty on battery
- 0-60 MPH in 15 seconds
Tesla Model S

• Seating for 5 adults and 2 children - $57’500 (-$7’500)
• ~160 miles per charge (42KWh battery) (24 kWh/100 mi) (at 55mph)
• 0-60 in 5.6 seconds - 125 mph top speed
• Delivery July 2012 (certain models)
• 42KWh battery pack (optional 65 and 85 KWh)
• 62 miles restored per hour of charging (240V) & 80% charge in 45 minutes (commercial-level charging), normal charging 3-5 hours
• Motor 220KW (300hp) (unofficial)
• Sold out production for 1st year (7000 orders)
Smart ED

- Phase one in 2007, in Jan. 2011 phase II units began field testing in several cities in the United States (lease $600/mo.) - Phase III mass production with the 2012 model year Sept 2012 ($22'000)

- Seating for 2
- 30KW motor (41HP)
- 16.5 kWh lithium-ion battery
- 3 hours from 20-80% charge, 8 hours fully charged (240V outlet)
- 0-60 MHP in 13 seconds
- Top speed 75MPH
- Range: 63-98 mile range
- “Available now at select dealers”
Ford Focus Electric (2012)

- Seating for 5
- $39,200 base price
- ~70 - 100 miles per charge
- 23KWh battery
- Rapid charging in 3-4 hours
- 84 mph top speed
- Early availability restricted to NY, NJ, and CA, AZ is mid-2012
Honda Fit EV

- Nov. 2011 pre-production demo program
- Launch mid 2012 (USA)
- 70-123 Mile range
- 90 mph top speed
- 6h recharge at 240V
- $36’600
- Lithium ion battery
Toyota RAV 4 EV

- 1st generation in 1997, 80-110 miles /charge (1484 sold)
- 2nd generation in joint development with Tesla in 2010
- 37KWh (usable) Lithium ion battery
- 80-120 mile range
- 0-60 MPH in 9.3 sec.
- Late 2012 expected production, for California only, limited production for first 3 years
- assembled in Ontario Canada, drivetrain by Tesla in Palo Alto
Mercedes SLS AMG E-Cell

- Late 2012 production
- Carbon fiber chassis
- one motor on each wheel – total 525 bhp
- 48 kWh lithium-ion battery
- 0 to 60mp/h in 4 seconds
- est. $250’000
Prototypes / concepts / limited lease

- All price and performance categories are being considered
- Many new developments around carbon fiber chassis for power/weight
Prototypes / concepts / limited lease

- Honda EV1
- VW Blue-e-motion
- Jaguar C-X75 (hybrid)
- Fiat 500 EV
- Renault Fluenze (replaceable battery)
- (BMW) Mini EV
- Mercedes A-class EV
- Tesla model X
- GM Spark EV
## Cost per mile (direct economics only)

### Assumptions
- Average over 10 years (2012-2022)
- Cost of Diesel: $7.10 per gal
- Cost of Gasoline: $6.50 per gal
- Cost of Electric Energy: $0.15 per KWh
- Miles/year: 12,000
- Maintenance/year (gas/diesel): $350.00
- Maintenance/year Electric only: $50.00
- Life of car: 10 years

### Car Specifications

| Car          | Year | MSRP (no tax) min | max | MPG min | max | fuel (G/D/E) | KWh/mile | cost/mile fuel | cost/year fuel | cost/mile fuel | cost/year fuel | cost/mile fuel | cost/year fuel | cost/mile fuel |
|--------------|------|-------------------|-----|---------|-----|--------------|-----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| **Chevy Volt** | 2012 | $32,780           | $38,500 | 95      | 93  | E/G          | $0.07     | $821.05        | $0.07          | $838.71        | $0.07          | $838.71        | $0.07          | $838.71        |
| **Audi A4 sedan** | 2012 | $32,500           | $36,400 | 21      | 30  | G            | $0.31     | $3,714.29      | $0.22          | $2,600.00      | $0.22          | $2,600.00      | $0.22          | $2,600.00      |
| **BMW 3 series 328i** | 2011 | $34,600           | $40,000 | 18      | 28  | G            | $0.36     | $4,333.33      | $0.23          | $2,785.71      | $0.23          | $2,785.71      | $0.23          | $2,785.71      |
| **BMW 3 series 335d** | 2011 | $44,150           | $48,000 | 23      | 36  | G            | $0.31     | $3,704.35      | $0.18          | $2,166.67      | $0.18          | $2,166.67      | $0.18          | $2,166.67      |
| **Toyota Prius V** | 2012 | $26,400           | $30,000 | 40      | 44  | G            | $0.16     | $1,950.00      | $0.15          | $1,772.73      | $0.15          | $1,772.73      | $0.15          | $1,772.73      |
| **Nissan Leaf 1)** | 2012 | $27,700           | $29,750 | E       | 0.34 | G            | $0.05     | $593.23        | $0.05          | $593.23        | $0.05          | $593.23        | $0.05          | $593.23        |
| **VW Jetta TDI** | 2012 | $27,840           | $29,000 | 30      | 42  | D            | $0.24     | $2,840.00      | $0.17          | $2,028.57      | $0.17          | $2,028.57      | $0.17          | $2,028.57      |

**Note:**
1) Nissan Leaf uses $4.1 for 100 miles (at 12 cents/KWh, 100 miles = 34KWh) ~same as assuming 106MPG at $4/gal
2) Using full MSRP and maintenance + fuel costs (no residual value)
3) KWh/mile = 34KWh/100 miles = 0.34KWh/m -> $0.12 / KWh -> 4.1 cents/mile

### Conclusions:

- EV is ~75% the cost/mile of a hybrid or small turbo diesel automobile
- EV is ~½ the cost of a standard gasoline powered car
40 miles is the average commute per day in the USA: how much in terms of solar PV?

Energy needs: Nissan Leaf uses ~34KWh/(100 miles/charge) (with AC or heater running)
- \( (34\text{KWh/charge}) \times (40 \text{ miles/day}) / (100 \text{ miles/charge}) = 13.6\text{KWh/day} \) is needed for charge
  - if buying your power = $1.63/day @ 12c/kWh = 4.1 cents/mile

PV production: Overall PV DC to AC system efficiency of ~87%
- Phoenix gets about 6.5 peak sun hours (PSH) per day average per year
- 13.6 KWh AC per day / 6.5 PSH per day = 2.1 KW AC per peak sun hour must be produced
- 2.1 KW AC / 87% efficient = 2.4 KW DC per peak sun hour

- A typical 260W module produces ~200W DC (hot)
- about ~12 modules will run a Nissan Leaf in Phoenix (12 X 200W = 2400W = 2.4KW)

- Build cost $4.0/W -> 2.4 KW DC x $4.0/W = $9'600 (pre incentive) (pay ~½)
- So for ~$5000 you can build an “energy pump” that can fill your car each day for 25 years (cost: $200/year)
Biofuels will play a very important role in our future, it seems, airplanes and heavy equipment work best with liquid fuels, however…

- How far a car can drive based on either of the following forms of energy, each produced from 100m x 100m (2.5 acres) of land

- Electric cars are about four times more energy efficient than fuel based cars (internal combustion engines vs. battery & electric motor)

- Fuel engines create heat (~15-20% efficient) wasting the majority of the energy
- Electric motors are very (90%) efficient, as are batteries, so ~80% efficient overall

- Biofuel plants are not efficient solar energy harvesters (1-2%) relative to semiconductor based solar electricity (14-18%), and the result is this huge difference in land needs

- In other words, it is clear that if the goal is to maximize energy efficiency, the goal is all-electric cars
CO₂ emission EV vs. ICE ¹)

- EV’s today must charge using coal & natural gas as part of the energy mix
- An EV recharged from the existing US grid electricity emits about 6.5 oz. (CO₂)/mi
- A conventional US-market Internal Combustion Engine (ICE) vehicle emits 14 oz. (CO₂)/mi (including the production and distribution of gasoline)

- As we transition to renewable energy the situation only improves naturally
- Coal is far from perfect - but the lesser evil compared to fossil fuel based oil

¹) Wheel to Well Analysis of Evs - MIT Electric Vehicle Team, April 2008
Reference materials

- “Who killed the electric car?”
  - http://www.whokilledtheelectriccar.com/

- “Revenge of the electric car”
  - http://www.revengeoftheelectriccar.com/

- “Fuel”
  - http://thefuelfilm.com/
Backup information

Mazda-kaan EV