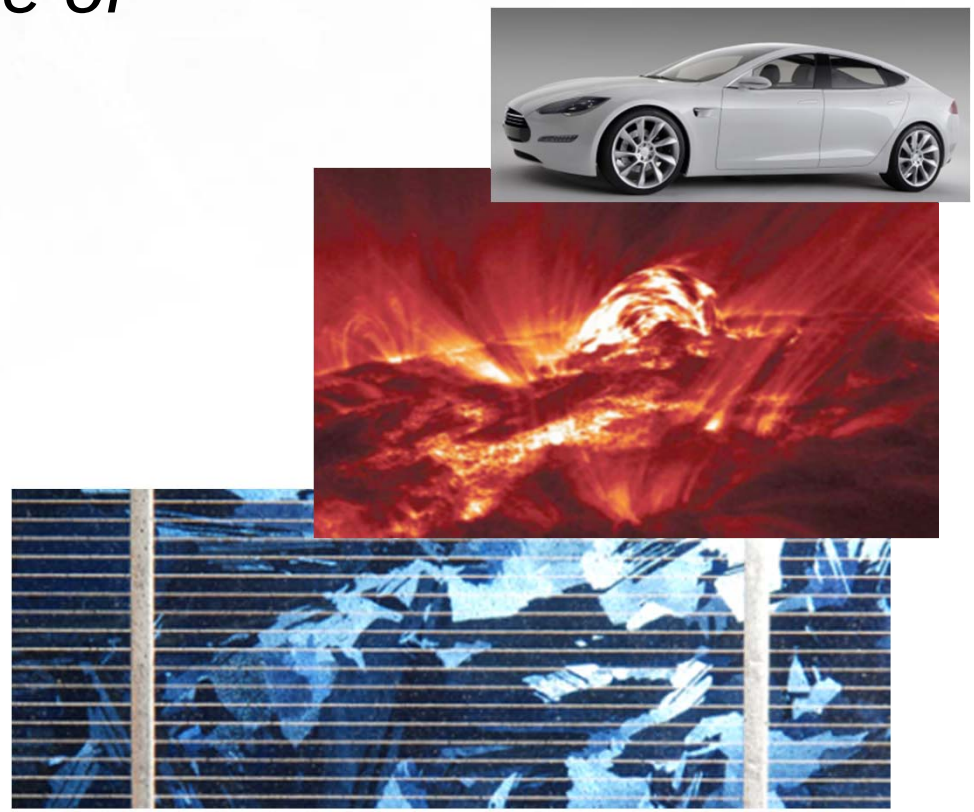
Renewable Energy and the EV:
The dawning of the age of Aquarius?



Randy Dunton
March 2012

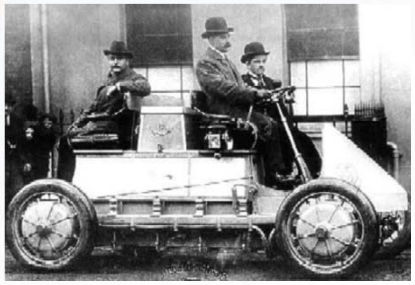
outline

- 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?

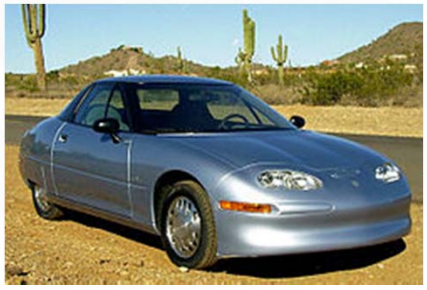
EVs & Solar

- 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



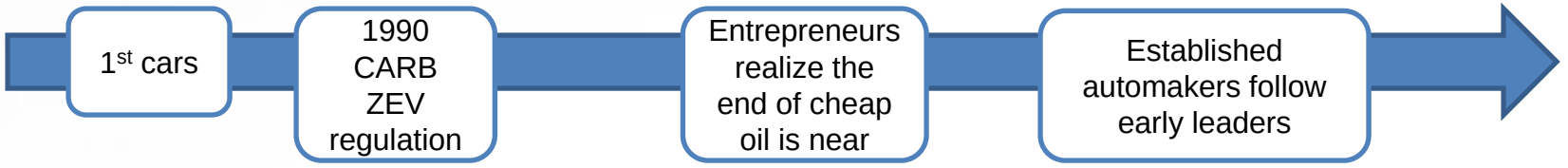
1900's: first practical automobiles



1996 GM EV1

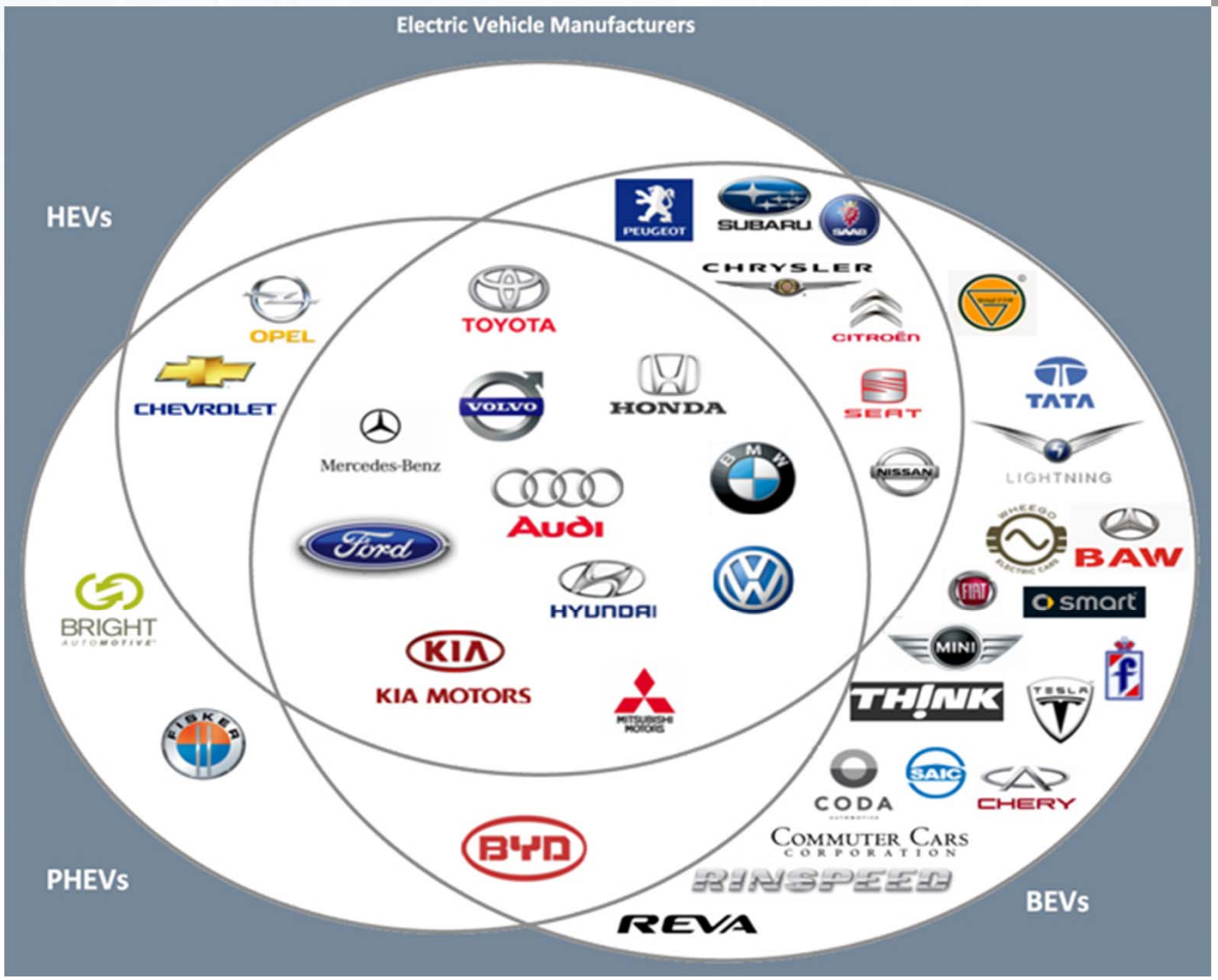
2008 Tesla Roadster

2010 Nissan Leaf



- 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

EV manufacturers



- 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

- Tesla founded in 2003, Development started in 2004, Unveiled in 2006, offered to the public in 2008
- 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)

Image source Tesla Motors

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

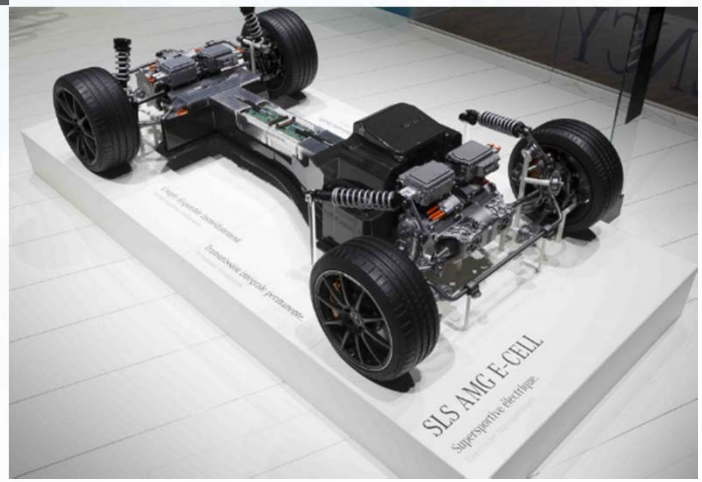
- Nov. 2011 pre-production demo program
- Launch mid 2012 (USA)
- 70-123 Mile range
- 90 mph top speed
- 6h recharge at 240V
- $36’600
- Lithium ion battery

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

102EX PHANTOM EXPERIMENTAL ELECTRIC (02/2011)

Audi R8 E-tron

Audi A3 E-tron

BMW active-e

BMW i7

BMW i3

- 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

(BMW) Mini EV

Renault Fluenze
(replaceable battery)

Mercedes A-class EV

Tesla model X

GM Spark EV

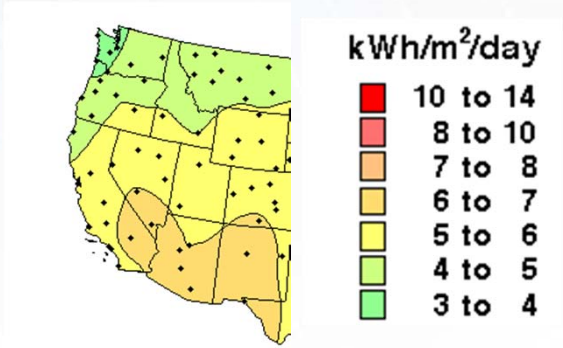
Cost per mile (direct economics only)

assumptions	average over 10 years						2012	2022	aver.		
cost of Diesel	$ 7.10	Gal					$ 4.20	$ 10.00	$ 7.10	Gal	
cost of gasoline	$ 6.50	Gal					$ 4.00	$ 9.00	$ 6.50	Gal	
cost of electric energy	0.15	KWh					$ 0.12	$ 0.17	$ 0.15	KWh	
miles/year	12000	miles	32.9	miles /day							
maintainance/year (gas/diesel)	$ 350.00										
maintainance/year electric only	$ 50.00										
life of car	10	years									
							city		Highway		
car	year	MSRP (no tax) min	max	MPG min	max	fuel (G/D/E)	KWh/m 3)	cost/mile fuel	cost/year fuel	cost/mile fuel	cost/year fuel	cost/mile all 2)
Chevy Volt	2012	$ 32,780	$ 38,500	95	93	E/G		$ 0.07	$ 821.05	$ 0.07	$ 838.71	$ 0.37
Audi A4 sedan	2012	$ 32,500	$ 36,400	21	30	G		$ 0.31	$3,714.29	$ 0.22	$2,600.00	$ 0.52
BMW 3 series 328i	2011	$ 34,600	$ 40,000	18	28	G		$ 0.36	$4,333.33	$ 0.23	$2,785.71	$ 0.55
BMW 3 series 335d	2011	$ 44,150	$ 48,000	23	36	D		$ 0.31	$3,704.35	$ 0.18	$2,166.67	$ 0.58
Toyota Prius V	2012	$ 26,400	$ 30,000	40	44	G		$ 0.16	$1,950.00	$ 0.15	$1,772.73	$ 0.40
Nissan Leaf 1)	2012	$ 27,700	$ 29,750			E	0.34	$ 0.05	$ 593.23	$ 0.05	$ 593.23	$ 0.28
VW Jetta TDI	2012	$ 27,840	$ 29,000	30	42	D		$ 0.24	$2,840.00	$ 0.17	$2,028.57	$ 0.43
	note:	1) Nissan Leaf uses $4.1 for 100 miles (at 12 cents/KWh, 100miles = 34KWh) ~same as assuming 106MPG at $4/gal										
		2) using full MSRP and maintainance + fuel costs (no residual value)										
		3) KWh/mile = 34KWh/100 miles = 0.34KWh/m -> $0.12 / KWh -> 4.1 cents/mile										

Conclusions: (depending on your projections for oil)

- 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/(100miles/charge) (with AC or heater running)

- (34KWh/charge) x (40 miles/day) / (100 miles/charge) = 13.6KWh/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 = 2'400W = 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)

Image courtesy of NREL, American Solar Electric

Photovoltaics & EV vs. bio-fuels

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

CO_2 emission EV vs. ICE [1)]

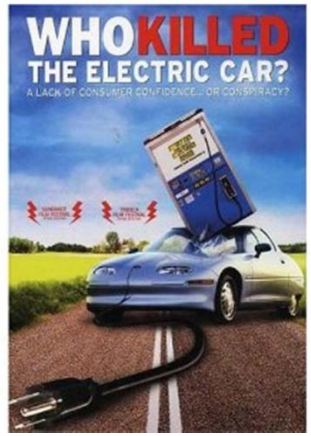
- EV's today must charge using coal & natural gas as part of the energy mix
- An EV recharged from the existing US grid electricity emits about 6.5 oz. (CO_2)/mi)
- A conventional US-market Internal Combustion Engine (ICE) vehicle emits 14 oz.(CO_2)/mi (including the production and distribution of gasoline)

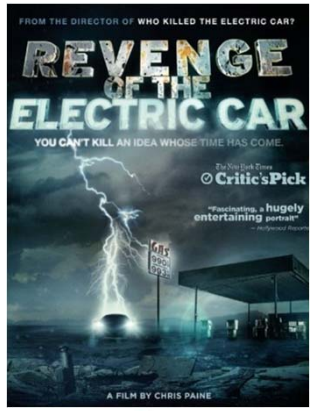
- As we transition to renewable energy the situation only improves naturally
- Coal is far from perfect - but the lesser evil compared to fossil fuel based oil

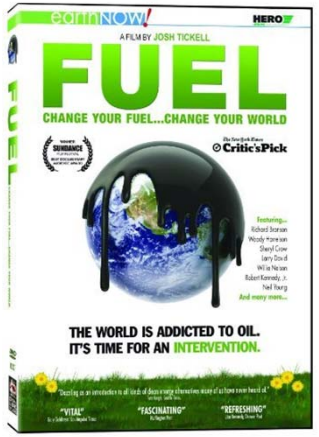
1) Wheel to Well Analysis of Evs - MIT Electric Vehicle Team, April 2008

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