Futures of Energy for Transportation

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Abstract:

Vehicles powered by electricity or other non-oil-based energy sources will eventually become a mainstay of the American garage. As the market adjusts and early adopters experiment with new vehicles, each energy source, be it electricity, fuel cells, biofuels, natural gas, or something else, may come to temporarily dominate a market niche. But in the end, economies of scale suggest that one technology will win out for a long time. And so the battle for the automobile now looks much like it did at the beginning of the twentieth century.
Context
Speed vs. Time (movie)

Flying Wagons

- Water
- Road
- Rail
- Air
- Space
Vehicle km of Travel / Capita (in US)
Number of People Living in Counties with Air Quality Concentrations Above the Level of the NAAQS in 2013

- One or more NAAQS: 75.4M
- Ozone (8-hour): 53.1M
- PM2.5 (annual and/or 24-hour): 33.1M
- PM10 (24-hour): 17.8M
- SO2 (1-hour): 5.5M
- Lead (3-month): 2.9M
- CO (8-hour): 0.0M
- NO2 (annual and/or 1-hour): 0.0M

Source: EPA
Forecasting
Things that are unsustainable do not sustain
Comparison of Historical Oil Prices and Delphi Forecasts

![Graph comparing historical oil prices and Delphi forecasts from 1972 to 2017. The graph shows historical oil prices in blue diamonds and Delphi forecasts in different colors for each year from Delphi I to Delphi VI. The y-axis represents 1997 oil prices in dollars per barrel, while the x-axis represents the years from 1972 to 2017. The Delphi forecasts for each year are shown as lines on the graph, illustrating the predictions for the future of oil prices.](attachment:image.png)
Energy
Energy is Required to Move Mass
US Energy Use

Quadrillion BTUs

- **Natural Gas**
- **Petroleum**
- **Nuclear Electric Power**
- **Hydroelectric and Noncombustible**
- **Wood and Biomass**
- **Coal**

Quadrillion BTUs

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Legend:
- Natural Gas
- Petroleum
- Nuclear Electric Power
- Hydroelectric and Noncombustible
- Wood and Biomass
- Coal
Energy use in United States (Millions of barrels per day)

- Transportation
- Industrial
- Residential and Commercial
- Electricity
Energy Intensity (kWh/Passenger-km)

- Cars: 0.70 kWh/Passenger-km (1999), 0.65 kWh/Passenger-km (2010)
- Personal trucks: 1.35 kWh/Passenger-km (1999), 1.15 kWh/Passenger-km (2010)
- Transit Bus: 0.80 kWh/Passenger-km (1999), 0.85 kWh/Passenger-km (2010)
- Air: 1.00 kWh/Passenger-km (1999), 0.95 kWh/Passenger-km (2010)
- Amtrak: 0.35 kWh/Passenger-km (1999), 0.40 kWh/Passenger-km (2010)
Energy intensity of freight

- Trucks (per vehicle-mile)
- Class I RR (per car mile)
- Class I RR (per ton-mile)
- Barge (per ton-mile)

BTU

In early years of automobile product (1890s, 1900s) Steam, Electric, and Gasoline power were competing.

Electrics were backed by significant figures like Thomas Edison, as well as many entrepreneurs. Gasoline engines were backed by future significant individuals like Henry Ford (who had worked at Detroit Edison), and many other entrepreneurs. By 1913, Henry Ford was loaning money to Edison to develop EV.

Clearly Electric won. Why?

Electrics had shorter range and lower speed. Could add more batteries, but each additional battery added weight, which reduced the efficiency of other batteries.

1909 advent of self-starter in gasoline cars. Note self-starter was electrically (battery) powered. Gasoline-powered vehicles become huge market for batteries.

This can be thought of as a type of Endo-symbiosis, like the chloroplasts in plants or mitochondria in animals become organelles in cells.
Shared (One-to-One) Lane

Shared (Two-to-One) Lane

Exclusive Lane

Alternative Vehicles, Alternative Highways
Cost of Solar

The Swanson effect
Price of crystalline silicon photovoltaic cells, $/watt

Plummeting Cost of Solar PV
(Cost Per Watt in 2009 Dollars)

Source: DOE NREL Solar Technologies Market Report, Jan 2010

2013 price $0.74/watt
FORECAST

Source: Bloomberg, New Energy Finance
Solar 2

Solar Industry Growth has Produced Steadily Falling Prices

Solar 4

Figure 2.8 Weighted Average System Prices, Q1 2012-Q1 2014

Solar 5

Solar 2

U.S. PV Market Growth Through 1H 2013

8.9 GW of PV installed through 1H 2013

Source: GTM Research

Batteries are getting better

By introduction of new battery technologies ...

... energy density was increased

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http://www.theengineer.co.uk/energy-and-environment/news/breathing-lithium-air-battery-has-higher-energy-density-than-li-ion/1018213.article

http://en.wikipedia.org/wiki/Lithium–air_battery

http://arstechnica.com/science/2012/06/lithium-air-battery-advance-could-be-jaw-dropping-improvement-over-li-ion/
Car Sharing Can Break Range Anxiety

- Get car you need when you need it. Most trips well below EV range NOW.
- Li-Air as supplement to Li-Ion
US EV New Car Market Share: Logistic Growth Curve

Combined
Predicted Combined
Innovation

• ~10x improvement on some relevant dimension to justify switching energy platform

• Relevant dimensions: Cost, Speed, Size, Pollution, Comfort, Range
Methanol

- Methanol from drilling etc. doesn’t fully address CO2.
- Biofuels are expensive
- Petroleum is abundant and infrastructure exists
- Electricity/batteries are getting steadily better
- Cars are getting more efficient
- Travel demand in US is dropping
Burning Questions

http://www.hclib.org/pub/search/specialcollections/mlshistory?id=10