Project Production Institute

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Looking for a problem





Where do we use oil?

We use oil primarily for cars



Oil for Transportation



If not oil, then what?

- Battery-electric
- Biodiesel
- Clean diesel
- Compressed natural gas
- Ethanol
- Hybrid
- Hydrogen ICE
- Hydrogen fuel cells
- Methanol
- Plug-in hybrid
- Photovoltaic Electric

What about Fuel Cells?



Where does hydrogen come from?



What about Fuel Cells?

Q: How many miles will one unit of electricity power a car?



Q: How many miles will one unit of biomass power a car?



Q: How many miles will one unit of biomass power a car?



- 1. logen enzymatic process, gallons of gasoline equivalent
- 2. Southern Company Services





1. Estimating the Net Energy Balance of Corn Ethanol, Shapouri, et al, USDA, 1995

2. 2.7 gal ethanol/bu / 1.39 gal ethanol/gge



ics

1. 1.658 x 10¹² miles in 2002 (DOT Bureau of Transportation Statistics)
2. cia.gov





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How about Cellulosic Ethanol?



- 1. Dr. Madhu Khana, University of Illinois
- 2. logen enzymatic process, gallons of gasoline equivalent
- 3. Pinnicle West Capital Corporation

Photovoltaic

Best-case Cellulosic Ethanol

Arable Land²

Q: What area is required to offset 50% of Passenger car miles driven in the USA?¹

1. 1.658 x 10¹² miles in 2002 (DOT Bureau of Transportation Statistics)
2. cia.gov



Well-to-Wheel Efficiency



Best Case Natural Gas

530 Wh/mi

Best Realistic Case Coal

Note: you don't need these fossil fuels for EVs

1697 Wh/mi



California Desert 553 MW ~360,000 cars



Battery electric wins in all ways

Potential Market

- 17 million vehicles sold each year (US)
- \$3B worth of sports cars (US)
- EVs sold in 2003 zero

EVs in 2003

















What happened to the other electric cars?

OEM Electric Vehicles available from 1998-2002 Produced to meet California Zero Emissions Mandate



Toyota RAV4 EV



Chevy S10 EV



Honda EV Plus



GM EV1



Ford Ranger EV



Chrysler EPIC EV

OEM Electric Vehicles available from 1998-2002 Produced to meet California Zero Emissions Mandate 2003: California Zero Emissions Mandate gutted All OEMs leave the electric vehicle business



Toyota RAV4 EV Out of Production



GM EV1 Out of Production



Chevy S10 EV Out of Production



Ford Ranger EV Out of Production



Out of Production



Chrysler EPIC EV Out of Production

What happened to the other electric cars?

"There simply weren't enough [EV-1 customers] at any given time to make a viable business proposition for GM to pursue long-term."

-GM spokesman Dave Barthmuss, Washington Post, 3/10/05

"The car never had appeal beyond a core group of technology enthusiasts and environmentalists."

Customer changing

- Average income of EV1 lessee >\$250K
- Prius eating into Lexus sales
- While gasoline was <\$1.50/gal (€0.37/liter)</p>



Automotive batteries stuck

- Invented in 1859
- Performance flat since mid-1900s



Consumer batteries getting better

- Higher energy density
- Higher power density
- Lower cost





Let's use lots of them!

- 18650s the only commodity Li-lon cells
- Made by many companies in vast quantities
- A single car will use thousands of cells
- Tesla will be a major buyer



What kind of car was possible?

- Mass?
- Acceleration?
- Power?
- Range?
- Cost?





Contours of Velocity Magnitude (m/s)

Spreadsheets and high school physics

- Force = Mass * Acceleration
- Acceleration = $\Delta v / \Delta t$
- Power = torque * 2π * rotational speed
- Cells have 207Wh/kg
- Cells hold 1800mAh





You really don't need Oil



...and EVs will be better

- Incredible torque curve (!)
- Almost no moving parts
- Can be refueled at home
- Super efficient
- Better driving experience

And you can still have fun (2003)



0-60 mph acceleration: ~4 seconds Well-to-wheel efficiency: >135 mpg equivalent EPA driving range: >200 miles

Customer solution plan

- Charging Stations?
- Dealership Strategy?
- Service Centers?



Production solution plan

- How do we make the "car" part?
- Where do we add value?
- Do we partner?



Product development plan

- Battery System
- Power Electronics
- Motor
- Vehicle Systems
- Actual "car"
- Home Charger
- Mobile Charger
- Sales systems
- Maintenance systems
- Engineering validation systems

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April 2004: 5 Employees

Series A funding led by Elon Musk







June 2008: 250 Employees Delivery!



Happy Customers



October 2008

• Elon Musk becomes CEO



Lessons Learned

- Hire ahead of need
- Correct hiring mistakes fast
- Product development is hard
- Going into production is harder
- Mission driven is great
- Customers can be partners

Where are we now?

Even GM is in...

"General Motors believes the future is all-electric," Mark Reuss, Head of Product. "We are far along in our plan to lead the way to that future world." – WIRED Oct 2, 2017



More choices

Electric-Car Boom Models by style and range available through 2020



Battery prices fall

Tumbling Battery Prices

Battery Price Forecast

Every time the global supply of batteries doubles, prices drop 19%

\$1,000 /kWh 600 200 2015 2020 2025 2030

Source: Bloomberg New Energy Finance

Bloomberg

Battery production climbs

Power Surge

China's share of lithium-ion battery production is forecast to hit 65 percent by 2021



Roadster 2020



Preliminary specifications: 0-60 mph acceleration: < 2 seconds Top speed: 250mph Well-to-wheel efficiency: > 135 mpg equivalent Driving range: > 600 miles



Recent developments

- UK to ban new ICE vehicles from 2040
- France to ban new ICE vehicles from 2040
- Norway to ban new ICE vehicles from 2025
- India to ban new ICE vehicles from 2030
- China considering ICE ban from 2030
- Volvo will sell only EV or Hybrids from 2019
- Bloomberg forecast EV price parity in 2025

What's next?

The future is about sustainability



Everything must change

- How we get our energy
- How products are made
- How food is produced
- How we live
- "If something cannot go on forever, it will stop" – Herbert Stein





Disrupting old industries

- Fun and profitable!
- Huge opportunities for cool solutions
- Think big... don't waste this opportunity



Batteries and Biology

- Batteries remake the automotive industry
- Batteries remake the utility power
- Developing countries skip oil and grid phase
- Decarbonized energy becomes abundant
- Synthetic biology remakes the meat industry
- Energy + biology remake farms