The Future of Ground Transportation is Electric

Martin Eberhard
Founder, 1st CEO, Tesla

Agenda

- Cars
  - Well-to-Wheel efficiency and footprint comparison
  - A bit about hydrogen fuel cells
  - Historical EV failures
  - What Tesla did differently
- Long-haul freight: trucks and trains
- Delivery trucks

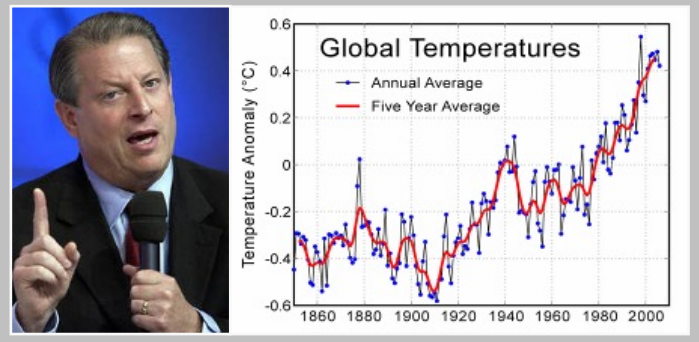
Not on the Agenda

- “Autonomous” driving, FSD, etc.
- Flying cars (or any other aircraft)
- Hyperloop or any other hype

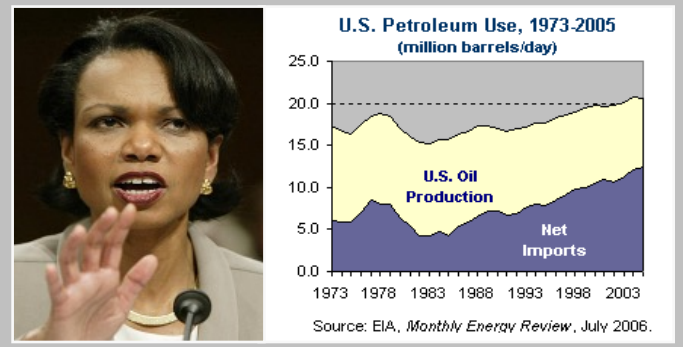
A slide from my 2005 Tesla pitch deck

2005 Oil Consumption:

a concern for both ends of the political spectrum



Global Warming



National Security

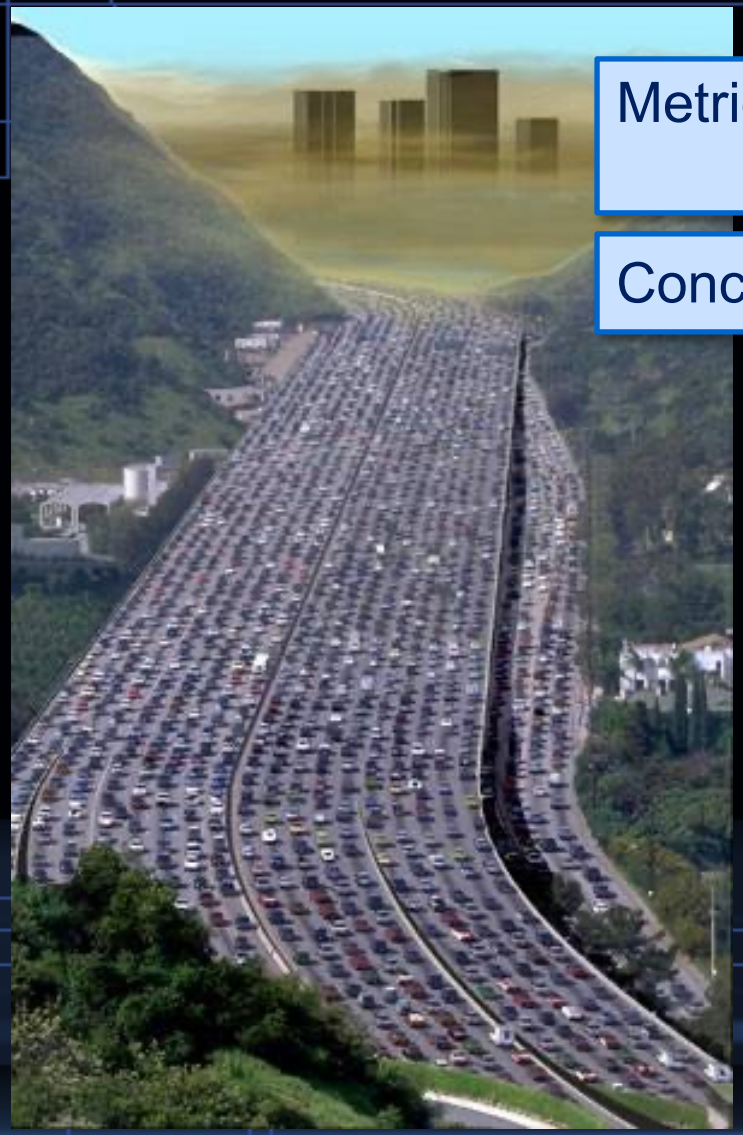
The Problem

950 Million cars in 2002

2.4 **Billion** cars by 2050

We can not power them all with oil

If not Oil, Then What?



Metrics: What is the resource consumption per kilometer?
What is the well-to-wheel carbon footprint per km?

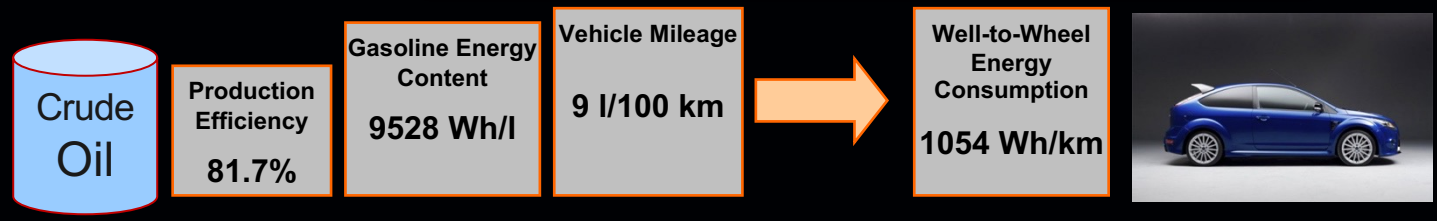
Conclusion: Electric cars are by far the best choice

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

Are Electric Vehicles Really Better?

Well-to-Wheel Energy Consumption

Pretty Good Gasoline Car: 9 l/100 km

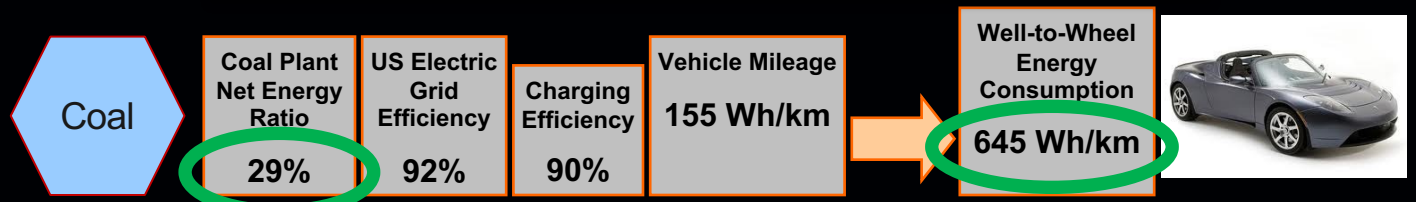


Best Case Gasoline Car: 5.7 l/100 km

Fuel energy content: *Well-to-Wheel Studies, Heating Values, and the Energy Conservation Principle, 29 October 2003, Ulf Bossel*
Vehicle mileage: US EPA www.fueleconomy.gov
Production Efficiency: *Well-to-Tank Energy Use and Greenhouse Gas Emissions of Transportation Fuels – North American Analysis, June 2001, by General Motors Corporation, Argonne National Laboratory, BP, ExxonMobil, and Shell*

Well-to-Wheel Energy Consumption

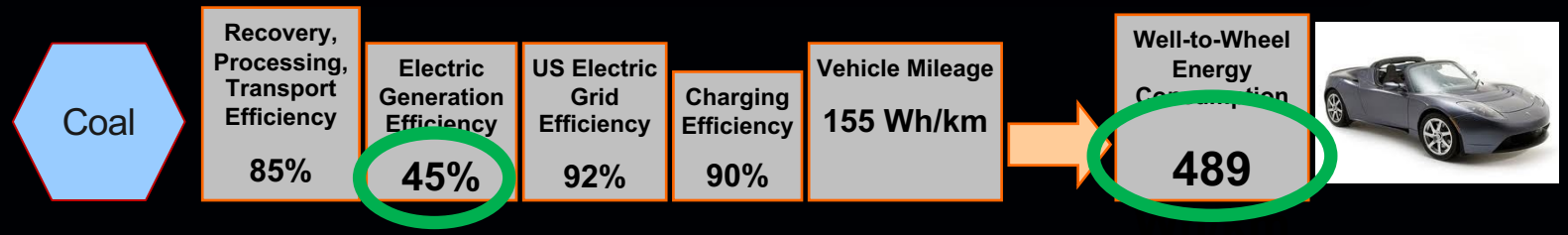
High Performance Electric Car: 155 Wh/km
Using ***Legacy Coal*** Electric Production



Coal net energy ratio: ***Life Cycle Assessment of Coal-fired Power Production by*** Pamela L. Spath, Margaret K. Mann, Dawn R. Kerr, page 41

Well-to-Wheel Energy Consumption

High Performance Electric Car: 155 Wh/km
using ***State-of-the-Art Coal*** Electric Production

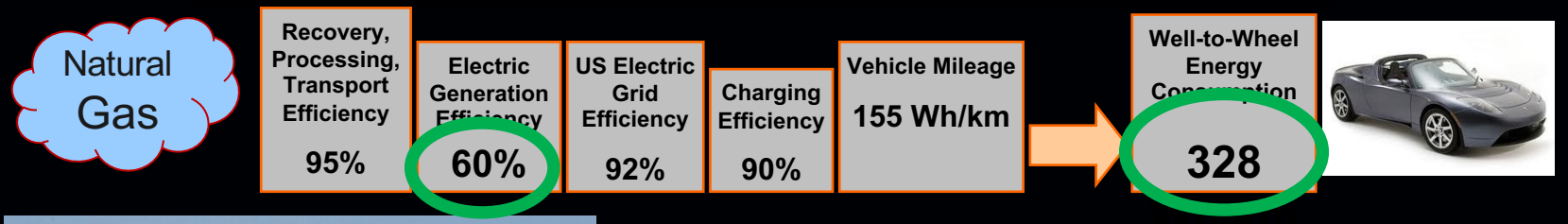


Isogo Power Plant in Japan

Coal net energy ratio: ***Life Cycle Assessment of Coal-fired Power Production by*** Pamela L. Spath, Margaret K. Mann, Dawn R. Kerr, page 41

Well-to-Wheel Energy Consumption

High Performance Electric Car: 155 Wh/km
using ***State-of-the-Art Natural Gas*** Electric Production



Baglan Bay Power Plant, Wales

Production efficiency and electric grid efficiency: *Well-to-Tank Energy Use and Greenhouse Gas Emissions of Transportation Fuels – North American Analysis, June 2001, by General Motors Corp., Argonne National Laboratory, BP, ExxonMobil, and Shell*

Well-to-Wheel Energy Consumption

Note: you don't need fossil fuels for EVs

Best Natural Gas

328 Wh/km

Best Coal

489 Wh/km

***Legacy* Coal**

645 Wh/km

Best Gasoline

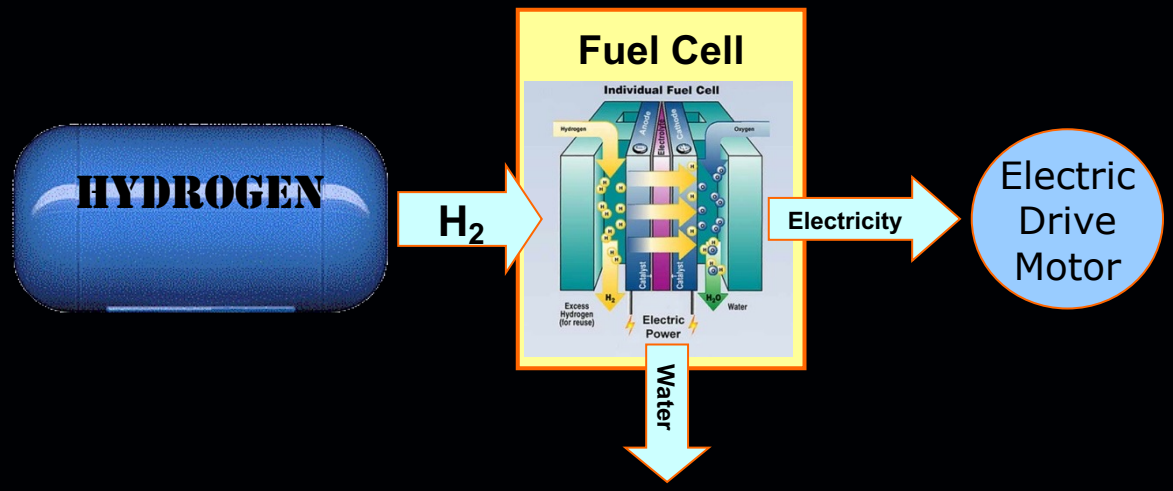
669 Wh/km

Pretty Good Gasoline

1055 Wh/km

My House
5.2 kW
1 fast car

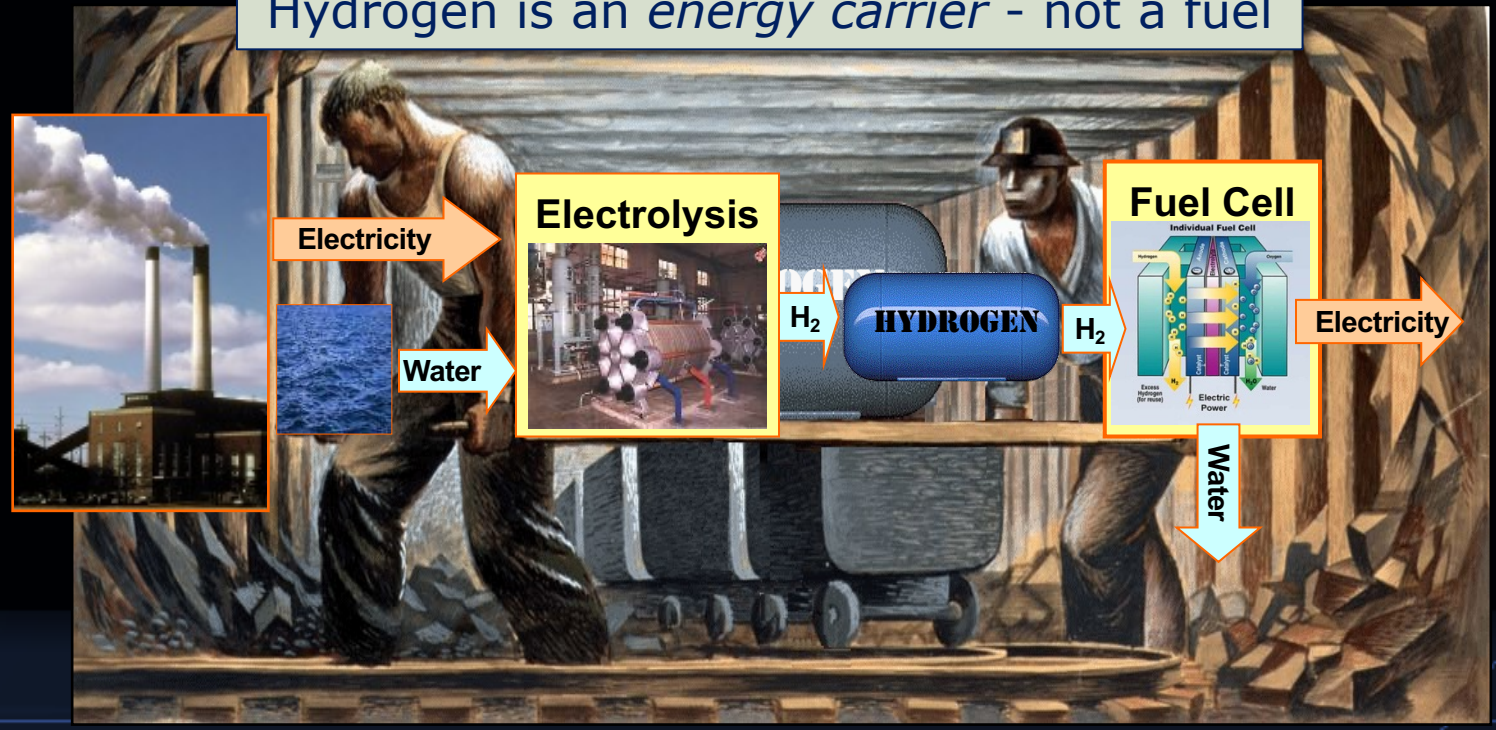
What About Hydrogen Fuel Cells?



What About Hydrogen Fuel Cells?

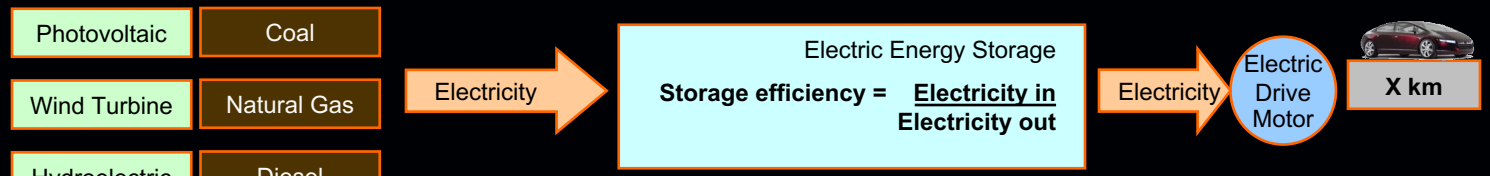
You Must Ask: *Where does hydrogen come from?*

Hydrogen is an *energy carrier* - not a fuel



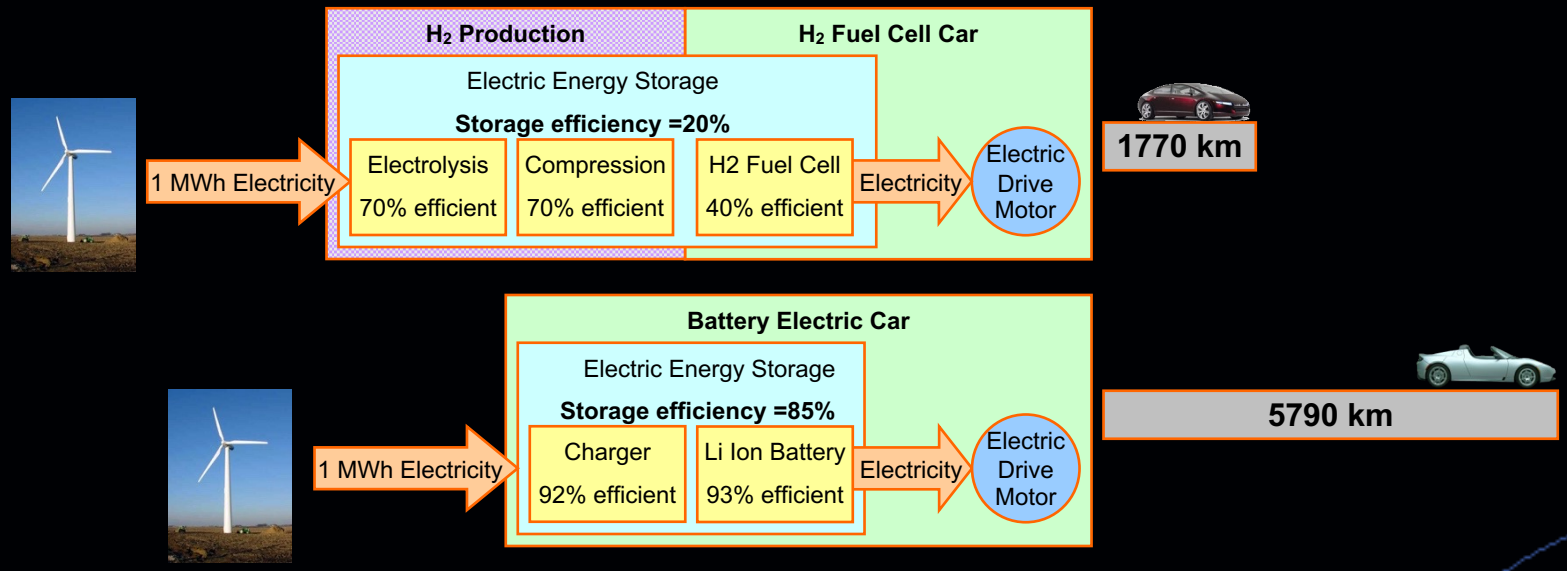
What About Hydrogen Fuel Cells?

Efficiency Matters



What About Hydrogen Fuel Cells?

Q: How far will one MWh of electricity power a car?



A: An electric car will go 3 times as far as a fuel cell car

What About Hydrogen Fuel Cells?

Q: How far will one MWh of electricity power a car?

3 MWh Electricity

H_2 Production

Electric Energy Storage

Storage efficiency =20%

Electrolysis 70% efficient

Compression 70% efficient

H_2 Fuel Cell Car

H2 Fuel Cell 40% efficient

Electricity

Electric Drive Motor

5310km

1 MWh Electricity

Battery Electric Car

Electric Energy Storage

Storage efficiency =85%

Charger 92% efficient

Li Ion Battery 93% efficient

Electricity

Electric Drive Motor

5790 km

A: An electric car will go 3 times as far as a fuel cell car

Or you would need 3 times the generating capacity

Real World Example
2015 Hyundai Fuel Cell

Driving Range: 426 km
H_2 Tank Capacity: 5.64 kg
Tank pressure: 690 bar

Natural gas to produce H_2: 24.5 kg
Natural gas to compress H_2: 1.8 kg
Total natural gas to fill tank: 26.3 kg

Natural gas mileage
426/26.3 = 16 km per kg

Real World Example
2015 Tesla Model S

Driving Range: 425 km
Battery Capacity: 85 kWh
Charging efficiency: 85%

Electricity to charge battery: 100 kWh
Natural gas to produce electricity: 11 kg
(assuming GE H-System Generator)

Natural gas mileage:
426/10 = 39 km per kg

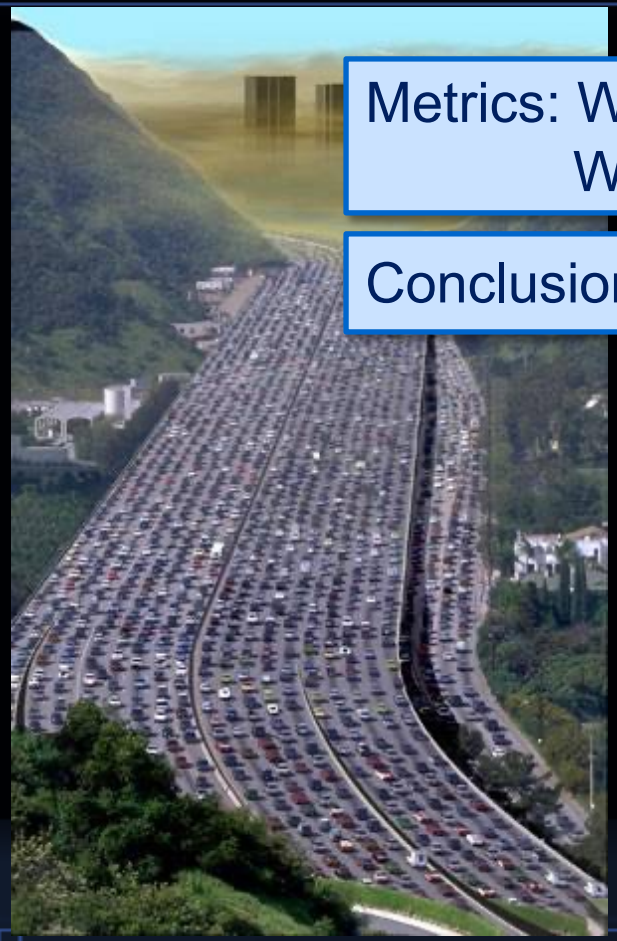
Real World Example
FCEV vs. BEV with the Same Fuel Source

Tesla Model S EV
Natural gas mileage
39 km/kg Nat. Gas

Hyundai Ioniq EV
Natural gas mileage
44 km/kg Nat. Gas

Hyundai FCEV
Natural gas mileage
16 km/kg Nat. Gas

If not Oil, Then What?

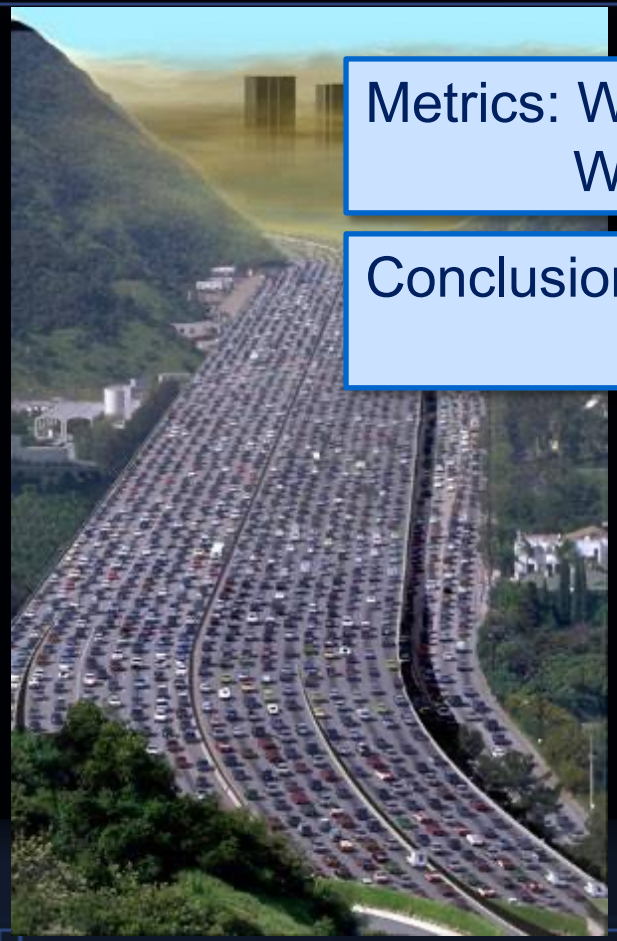


Metrics: What is the resource consumption per kilometer?
What is the well-to-wheel carbon footprint per km?

Conclusion: Electric cars are by far the best choice

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

If not Oil, Then What?



Metrics: What is the resource consumption per kilometer?
What is the well-to-wheel carbon footprint per km?

Conclusion: Electric cars are by far the best choice
(At least where cars make sense at all…)

- Biodiesel
- Clean diesel
- Compressed natural gas
- Ethanol
- Hydrogen ICE
- Hydrogen fuel cells
- Methanol
- Plug-in hybrid

The Electric Car in 2003

The Electric Car in 2003

The Electric Car in 2003

The Electric Car in 2003

"It attracted a lot of attention at Slamdance," Rohal says of the car he found in a parking lot and drove across the country.
(Photo by Courtney Koestler)

The Electric Car in 2003

The Electric Car in 2003

The Electric Car in 2003

Electric Vehicles did not appeal to car buyers

Appealing Cars in 2003

Appealing Cars in 2003

Appealing Cars in 2003

Appealing Cars in 2003

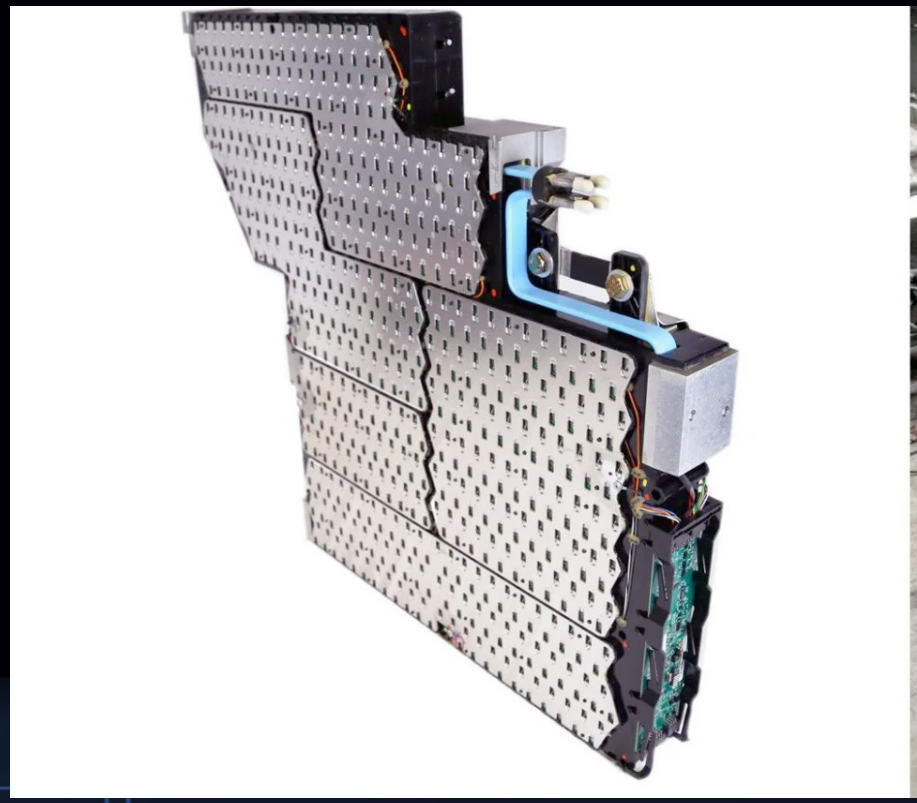
Appealing Cars in 2003

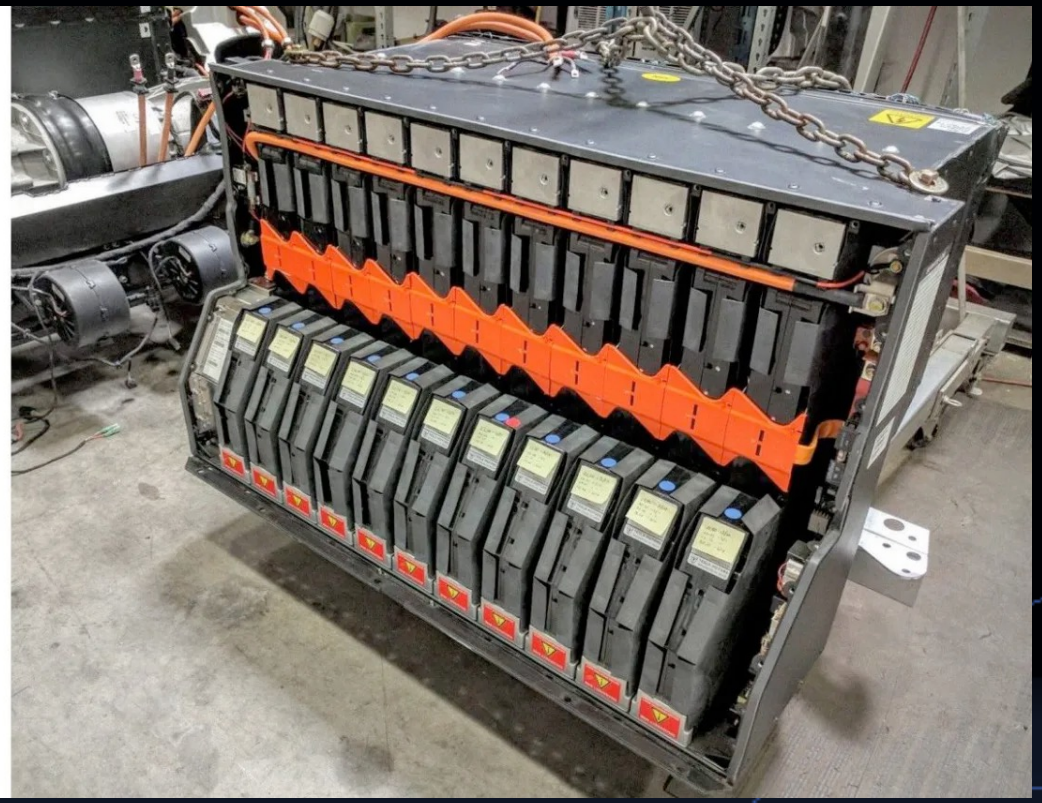
Appealing Cars in 2003

Obvious Conclusion:
EVs were not Sexy

Radical Idea #1
Revive the EV by making a *sexy* electric sportscar

Radical Idea #2
Fix the range problem with Lithium Ion batteries





(Somewhat) Radical Idea #3
Develop our own induction machines, eliminating magnets
(Hence the name 'Tesla')

And it worked: 2008 Tesla Roadster
0-60 MPH: 3.9 Sec. Range: 225 Miles

~2500 cars sold
Launched the first successful new American car company in a century

2003: The Electric Car Declared Dead.

2003: Tesla Founded to Revive the Electric Car.

2017: All Major OEMs Sell Electric Cars

2023: EVs are close to price parity

Long-Haul Trucks

Trucks versus Trains

- Diesel trucks: **154.1** metric tons of GHG per million ton-miles [1]
- Diesel-electric trains: **21.2** metric tons of GHG emissions per million ton-miles[1]

[1] D. Tolliver, P. Lu, and D. Benson, "Comparing Rail Fuel Efficiency With Truck and Waterway." Transp. Res. D: Transp. Enviro. **24**, 69 (2013)

Trucks vs Trains

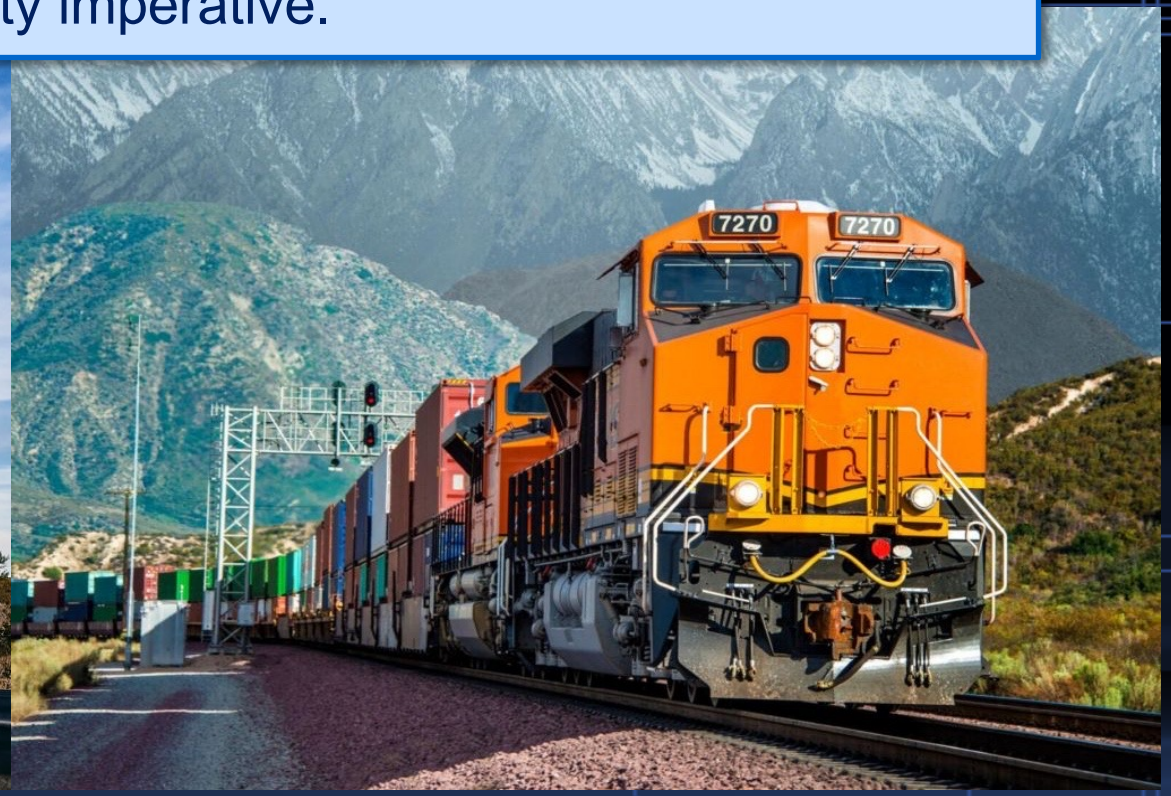
- Diesel trucks: 154.1 metric tons of GHG per million ton-miles [1]
- Diesel-electric trains: 21.2 metric tons of GHG emissions per million ton-miles[1]
- I expect a similar emissions delta between electric trucks and electric trains

Why is Trucking Cheaper in the USA?

- Roadways are publicly-built and tax-subsidized. Railways are not.
- As discussed in Dr. Bruce Hannon's class here at UIUC in 1980!

Yes, upgrading the USA rail infrastructure to be electric (and reliable) is a huge job!

But a **7:1** efficiency ratio makes seem pretty imperative.



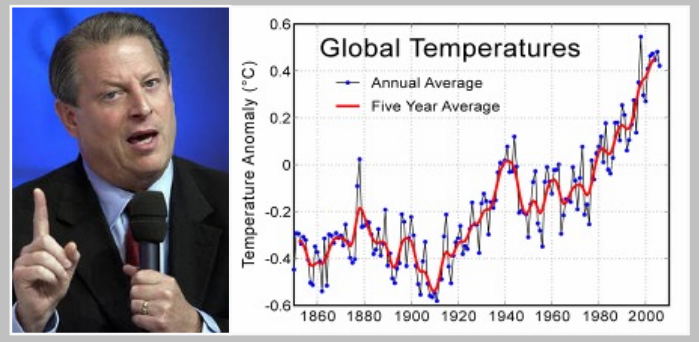
Delivery Trucks

- Typically, well-known routes
- Lots of time “idling”
- Ideally suited for electrification

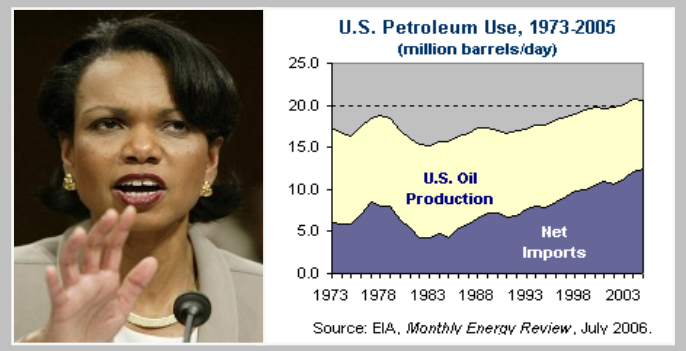
Finally, several credible electric delivery trucks

2005 Oil Consumption:

a concern for both ends of the political spectrum



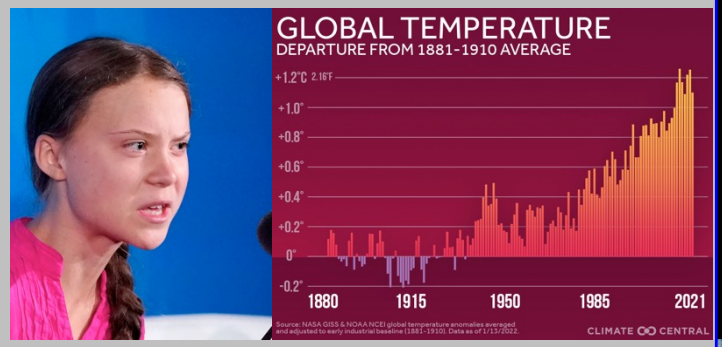
Global Warming



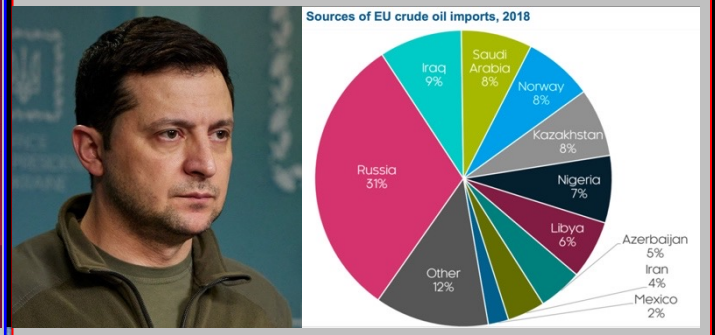
National Security

2023 Oil Consumption:

Same Slide, Different Pictures



Global Warming



National Security

For increasingly obvious reasons...
We must break our fossil fuel addiction


Thank You