Futures of Energy for Transportation

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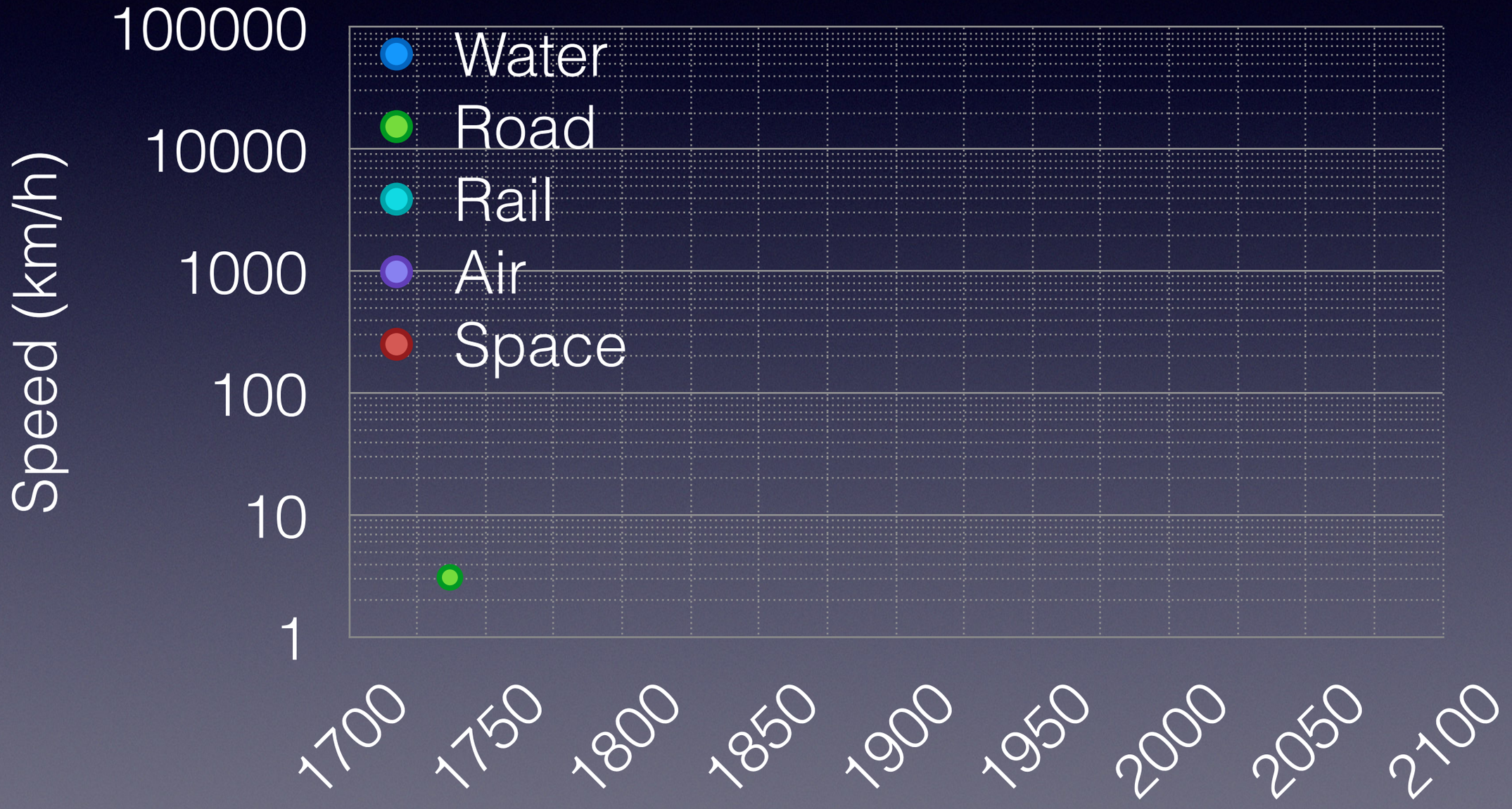
Abstract:

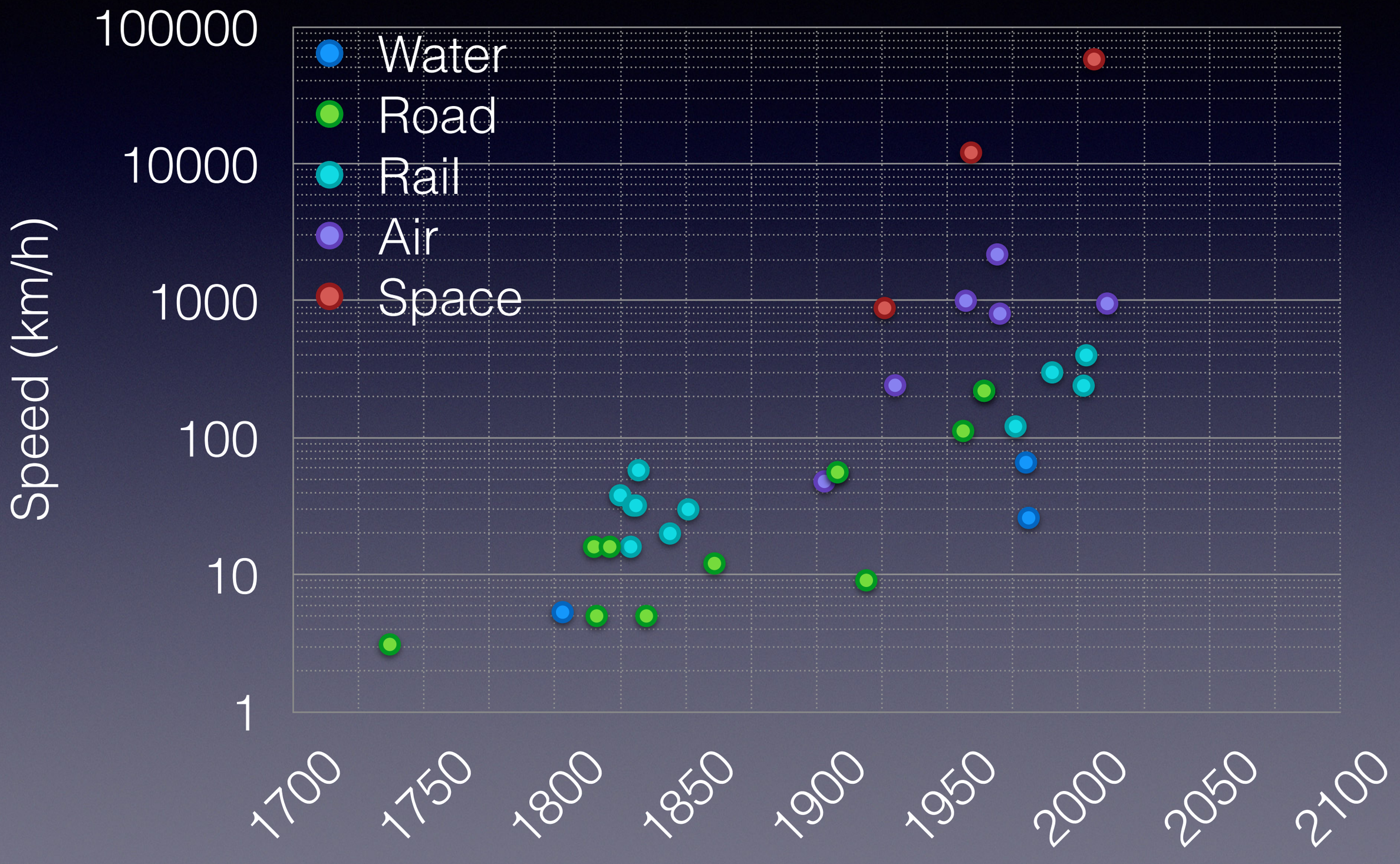
Vehicles powered by electricity or other non-oil-based energy sources will eventually become a mainstay of the American garage. As the market adjusts and early adopters experiment with new vehicles, each energy source, be it electricity, fuel cells, biofuels, natural gas, or something else, may come 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

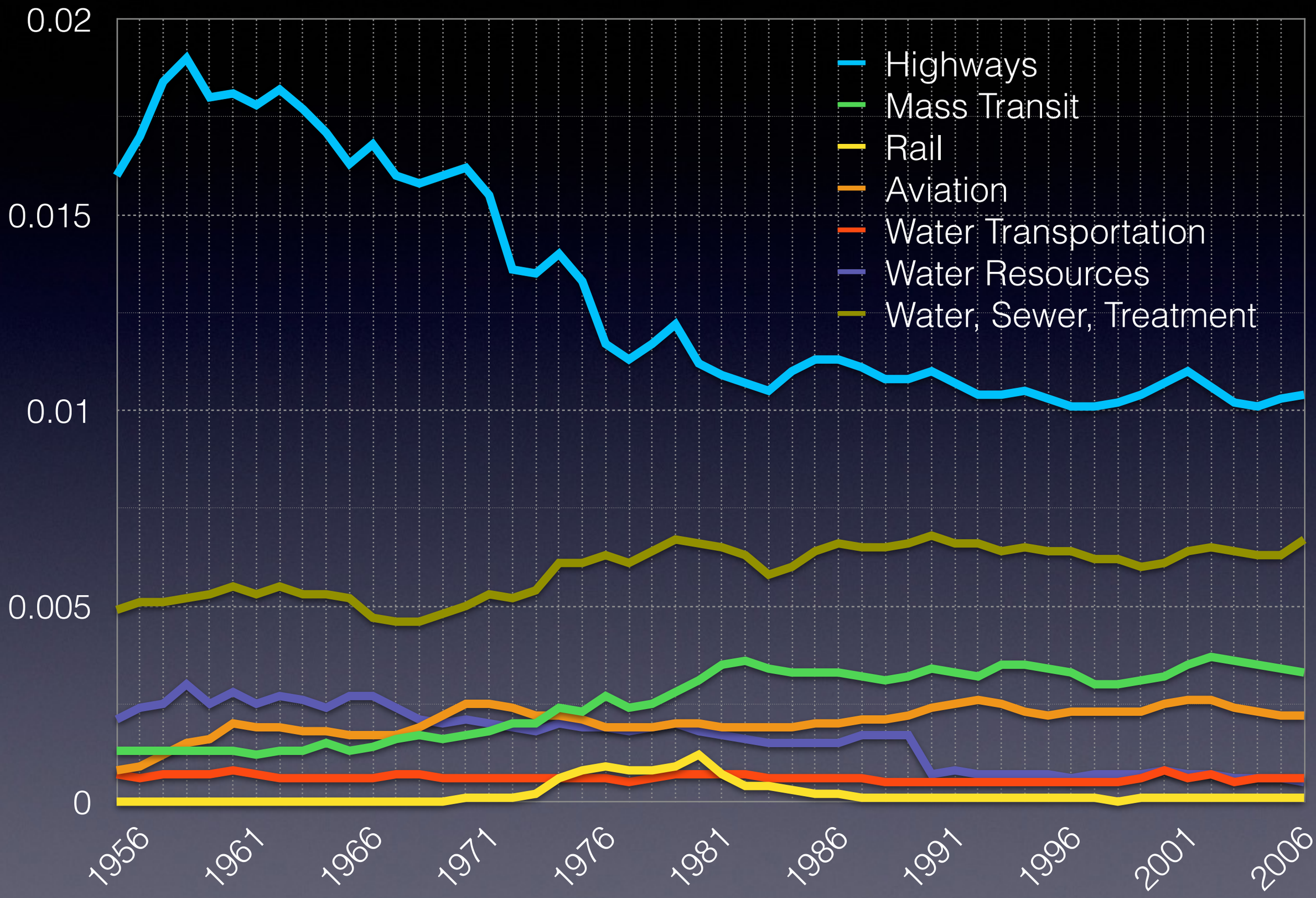
Speed vs. Time (movie)



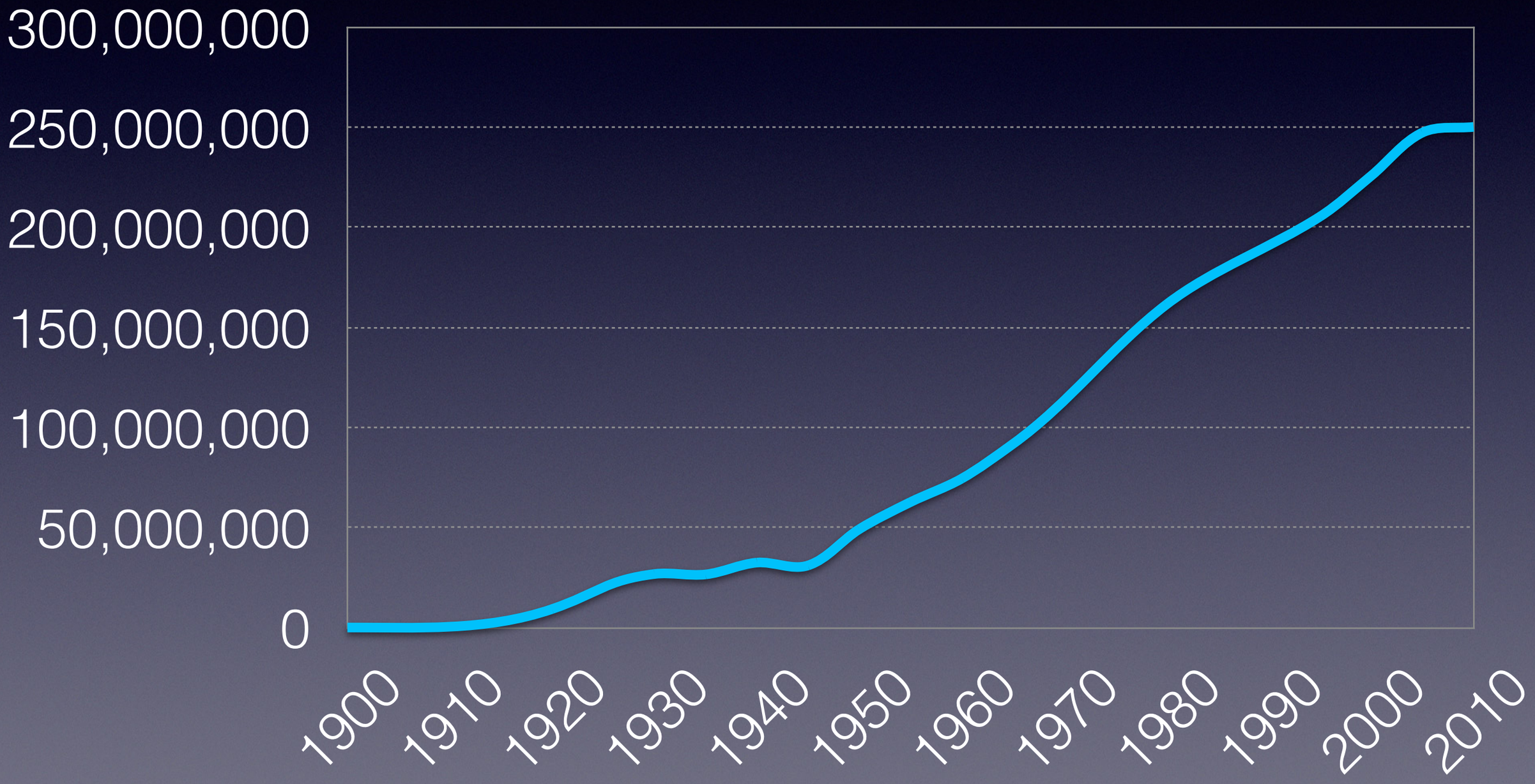
Speed vs. Time

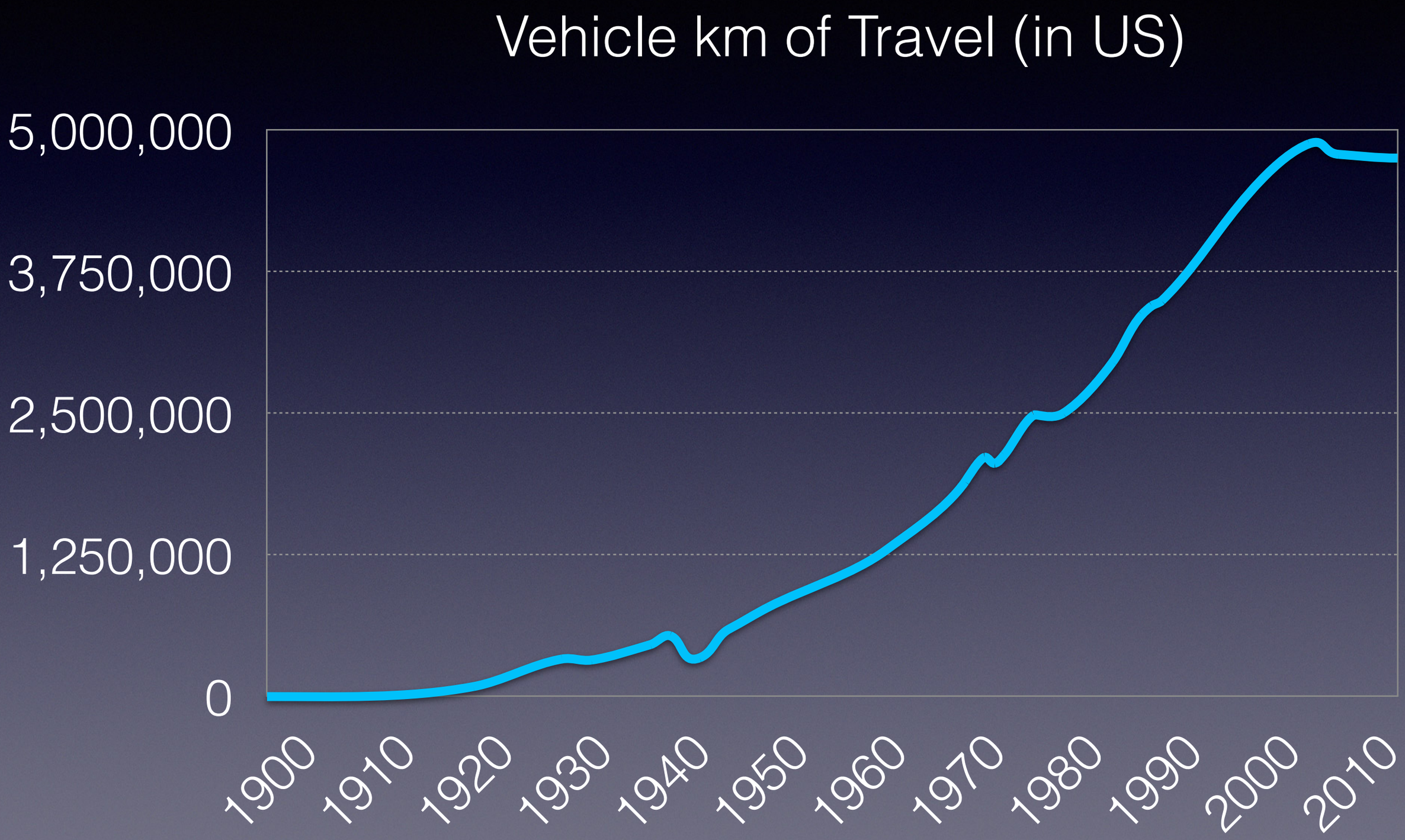


Public Infrastructure Spending as Share of GDP

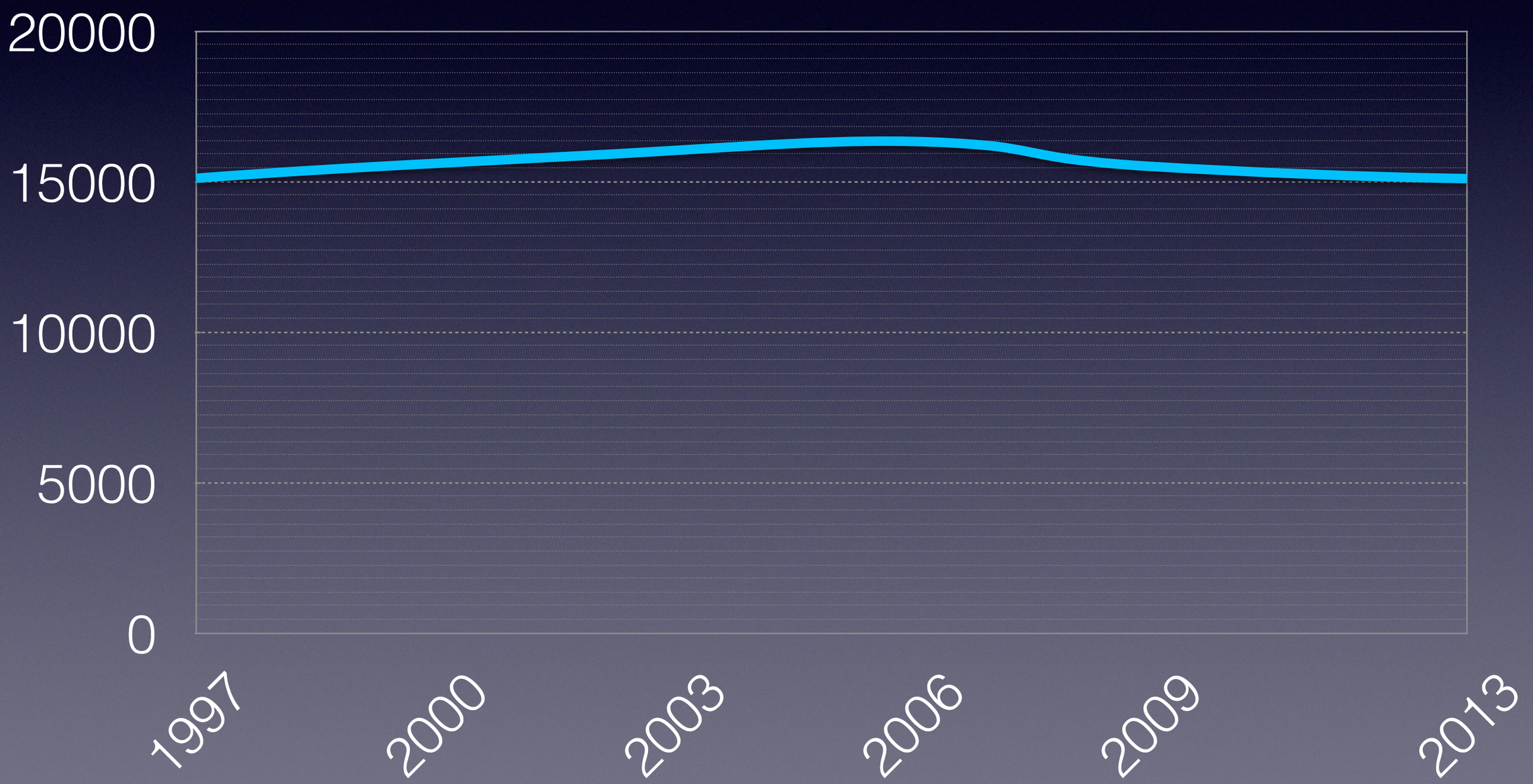


Registered Motor Vehicles (in US)

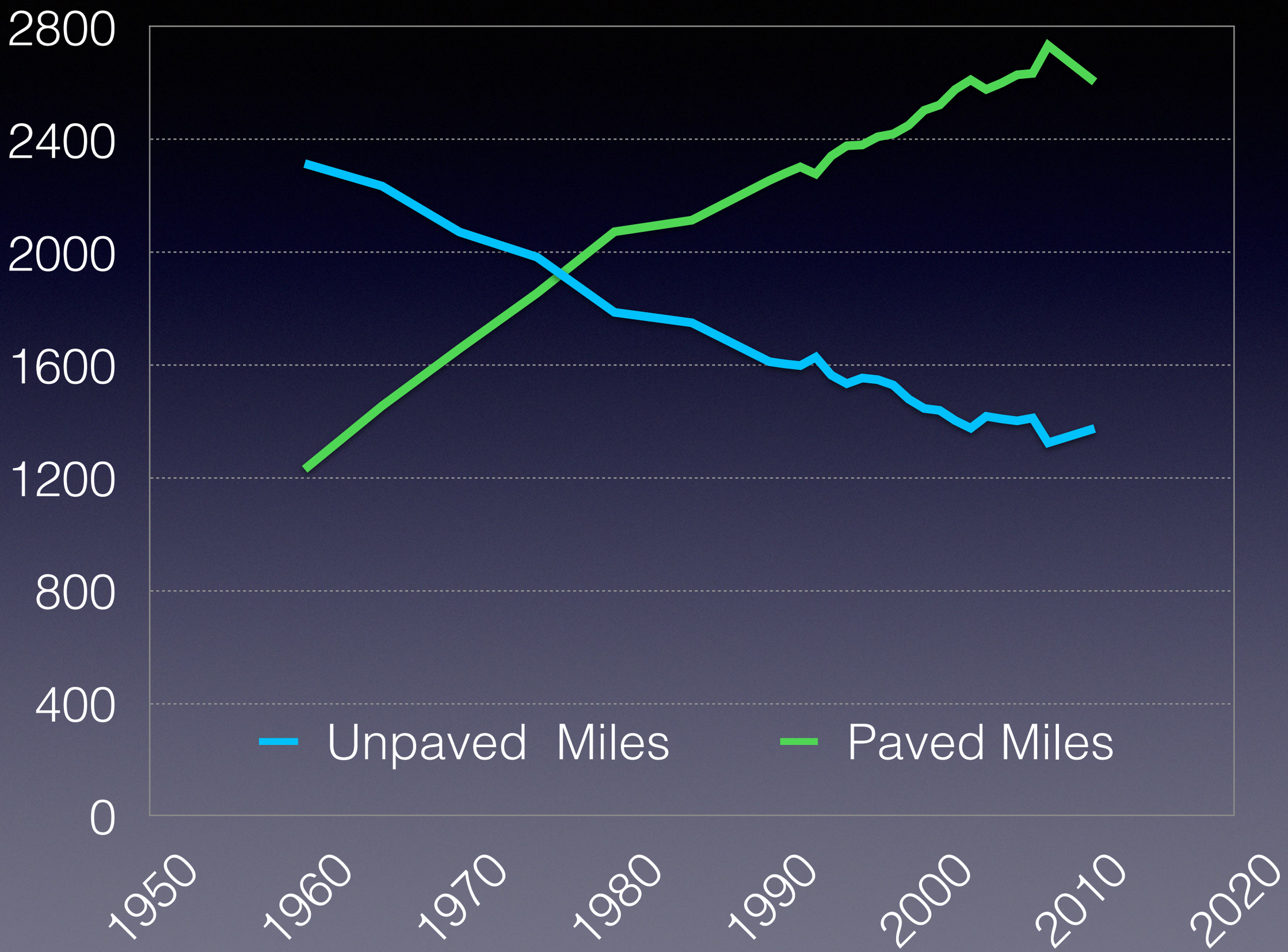


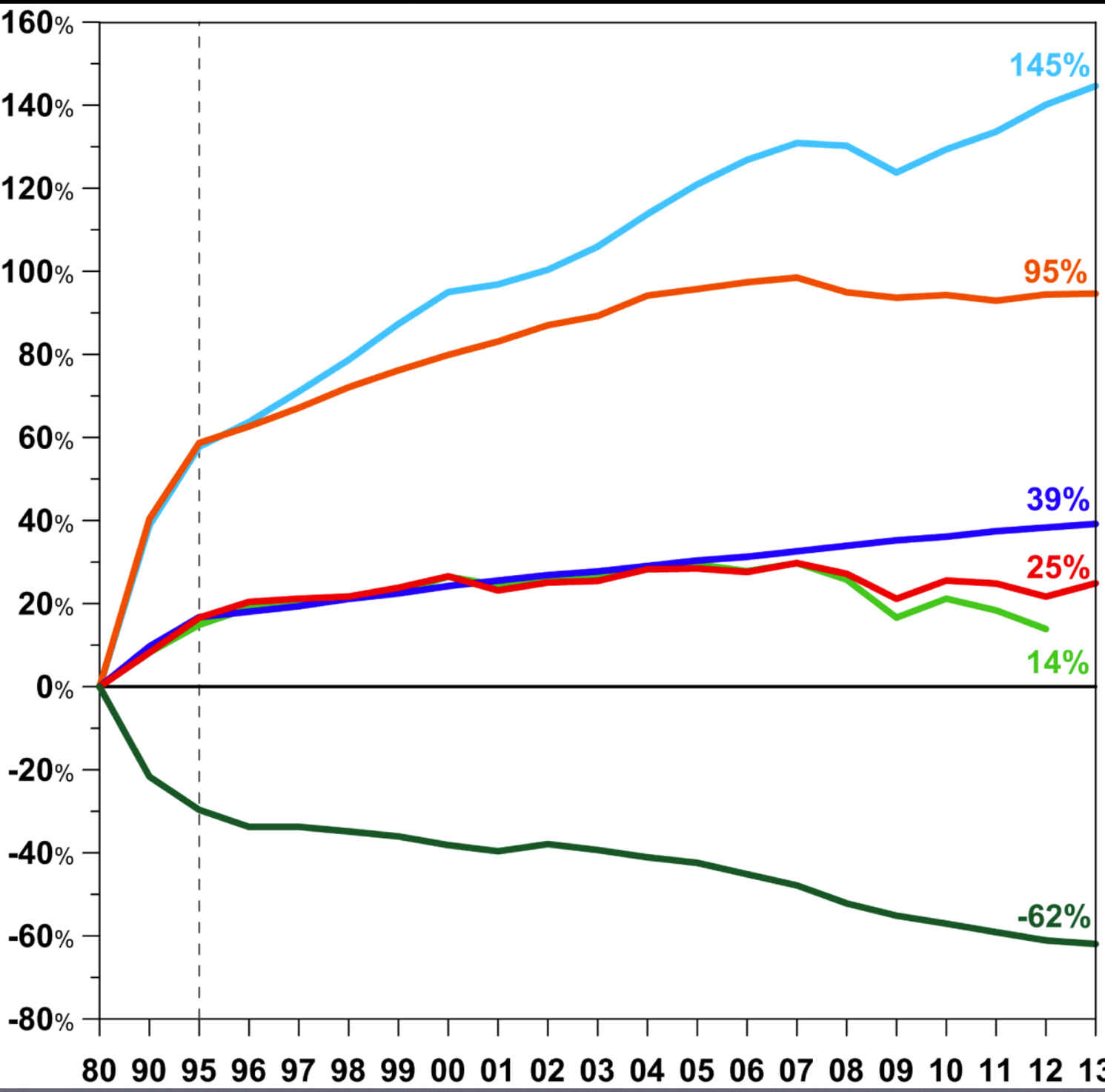

Vehicle km of Travel (in US)
5,000,000
3,750,000
2,500,000
1,250,000
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Vehicle km of Travel / Capita (in US)



Miles of Road in US





Gross Domestic Product

Vehicle Miles Traveled

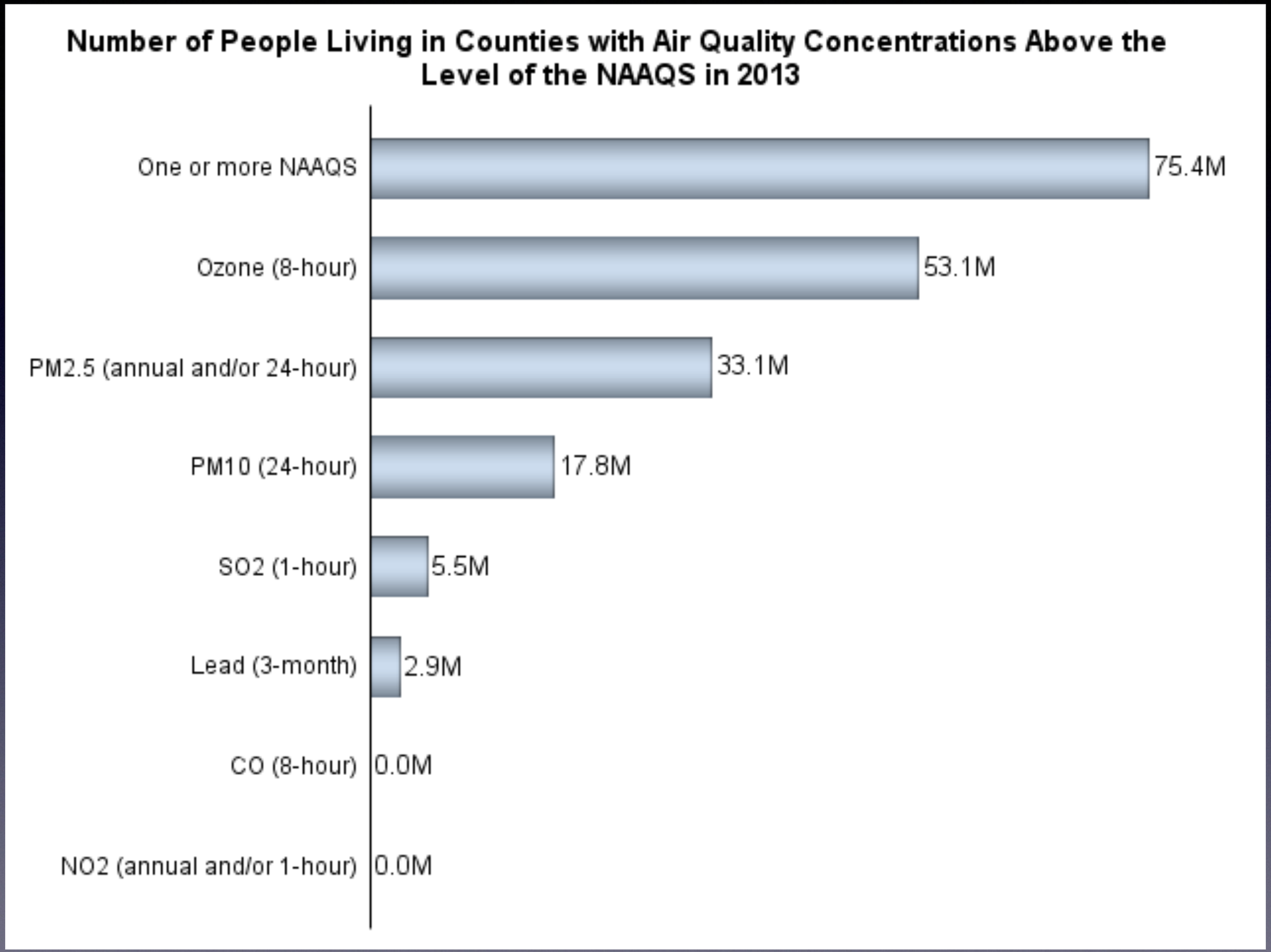
Population

Energy Consumption

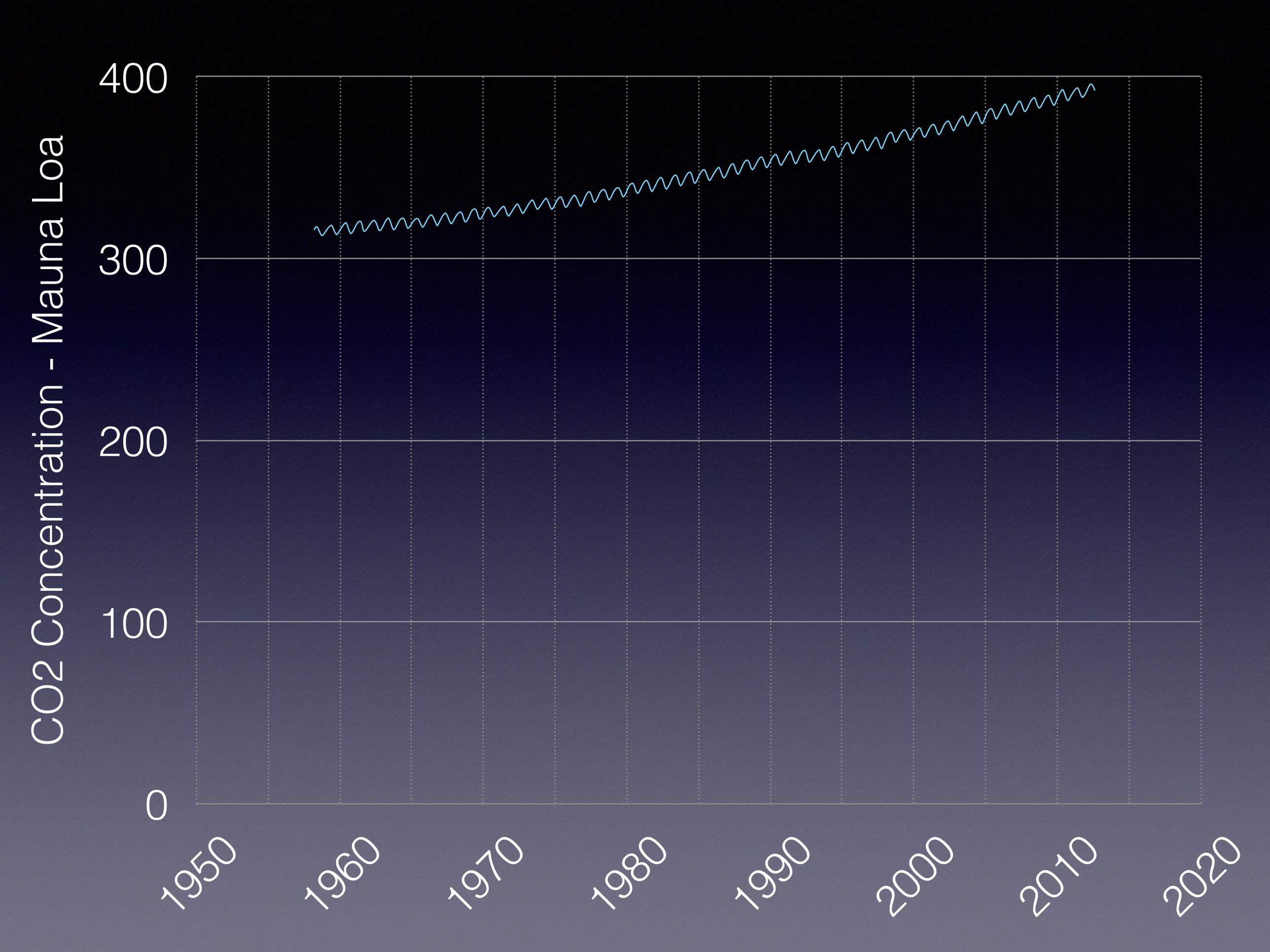
CO_2 Emissions

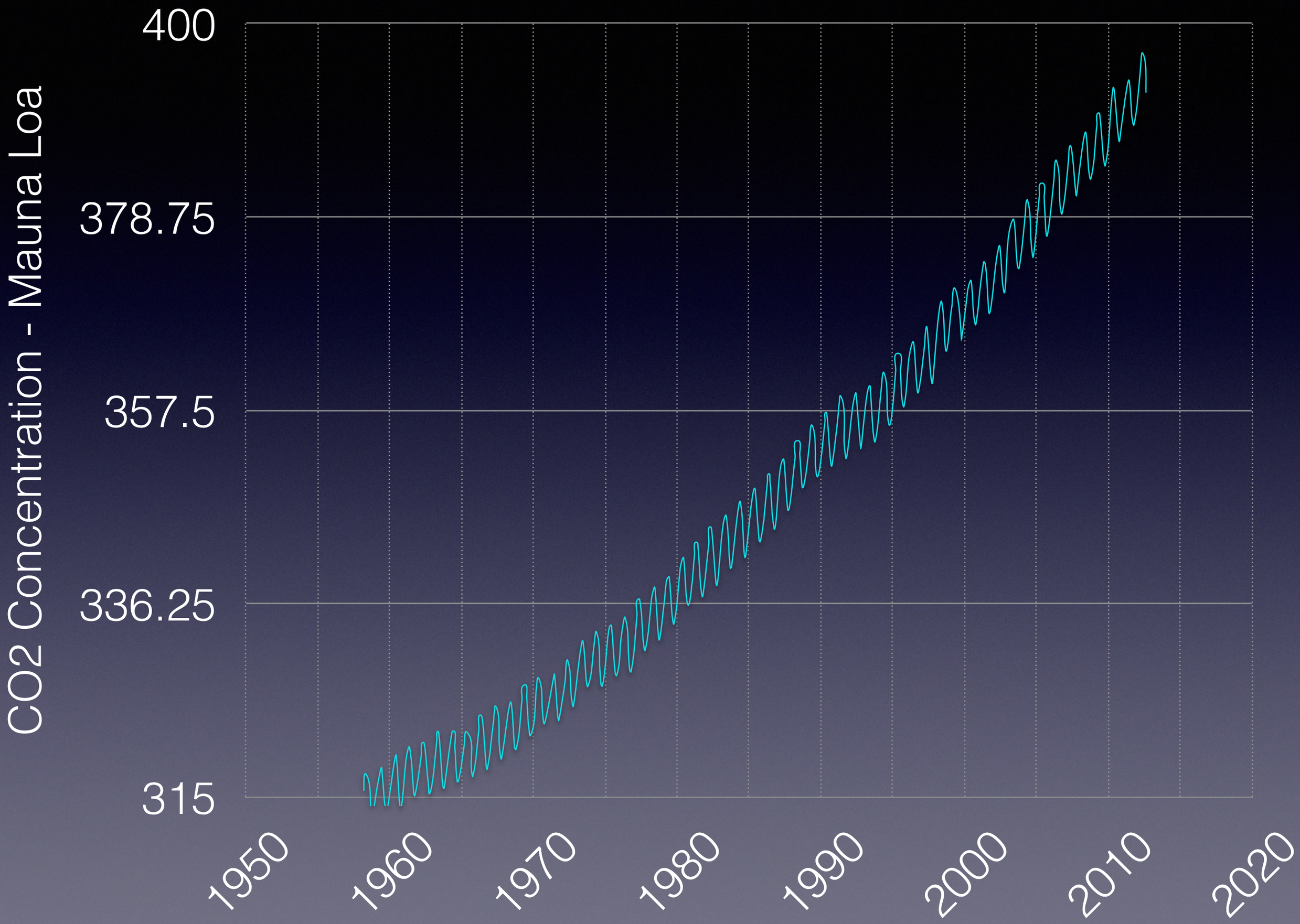
Aggregate Emissions
(Six Common Pollutants)

Source: EPA


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

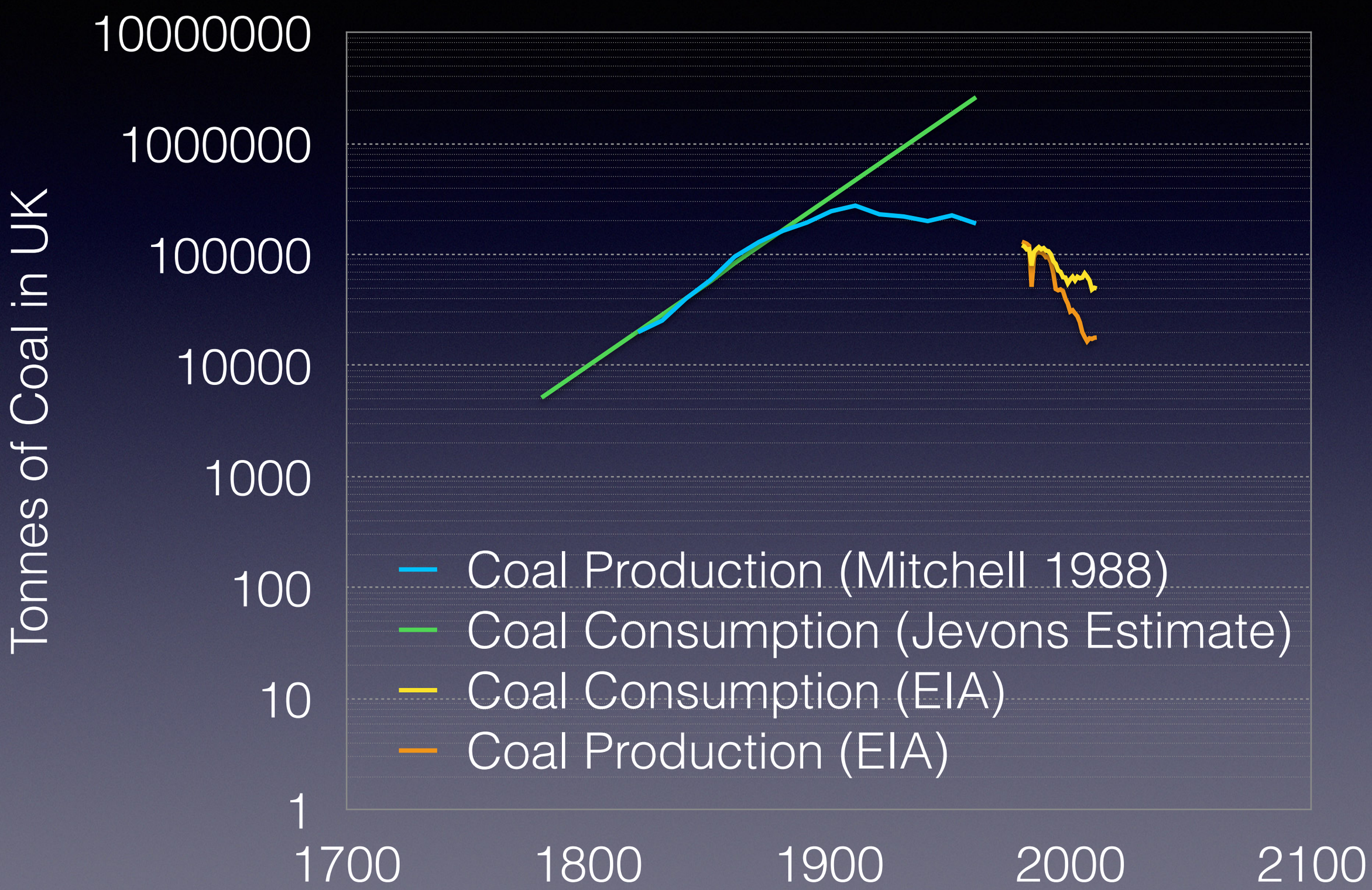
Source: EPA


CO2 Concentration - Mauna Loa
400
300
200
100
0
1950
1960
1970
1980
1990
2000
2010
2020


400
378.75
357.5
336.25
315
CO2 Concentration - Mauna Loa
1950
1960
1970
1980
1990
2000
2010
2020

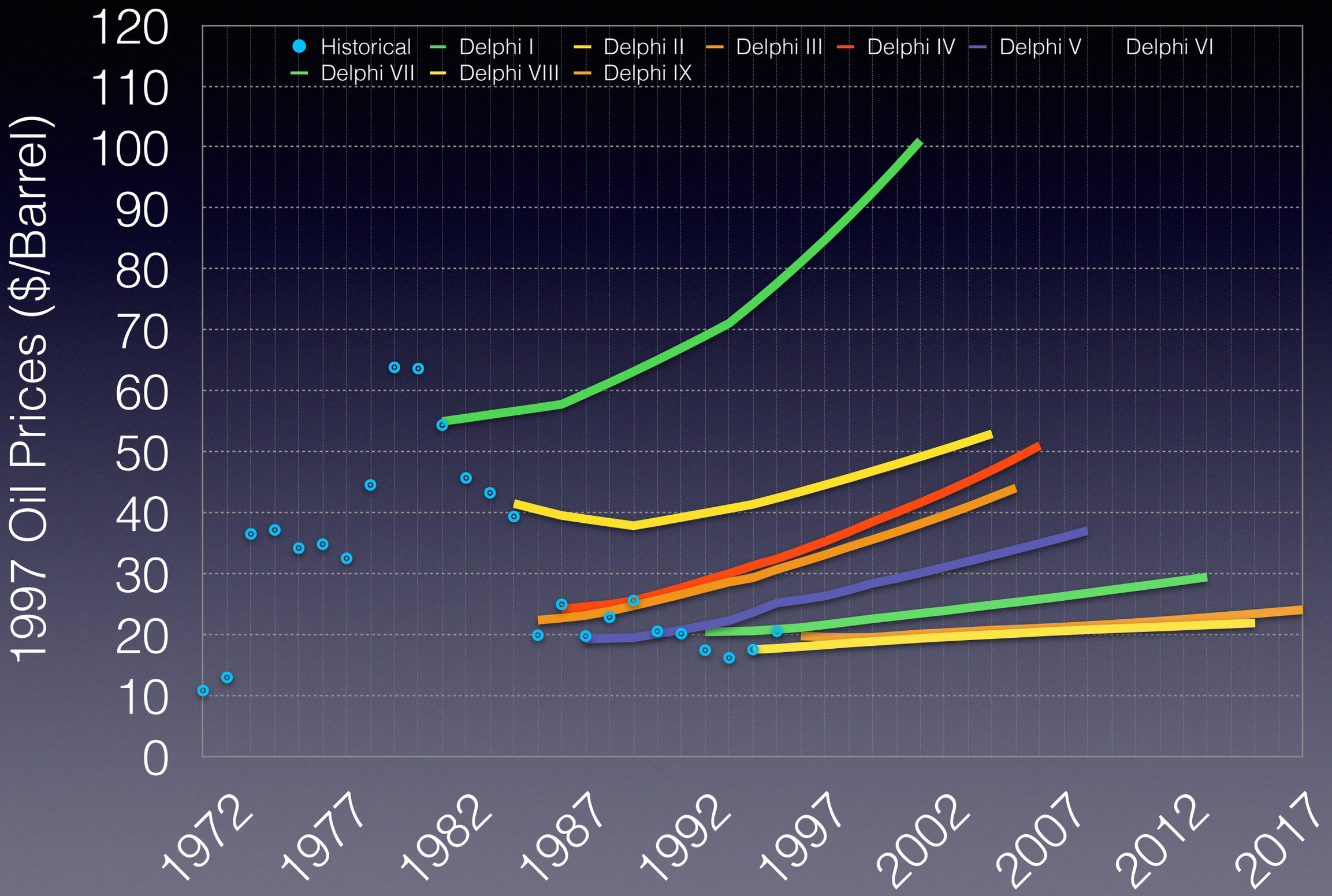
Forecasting

UK (Jevons prediction vs. actual)



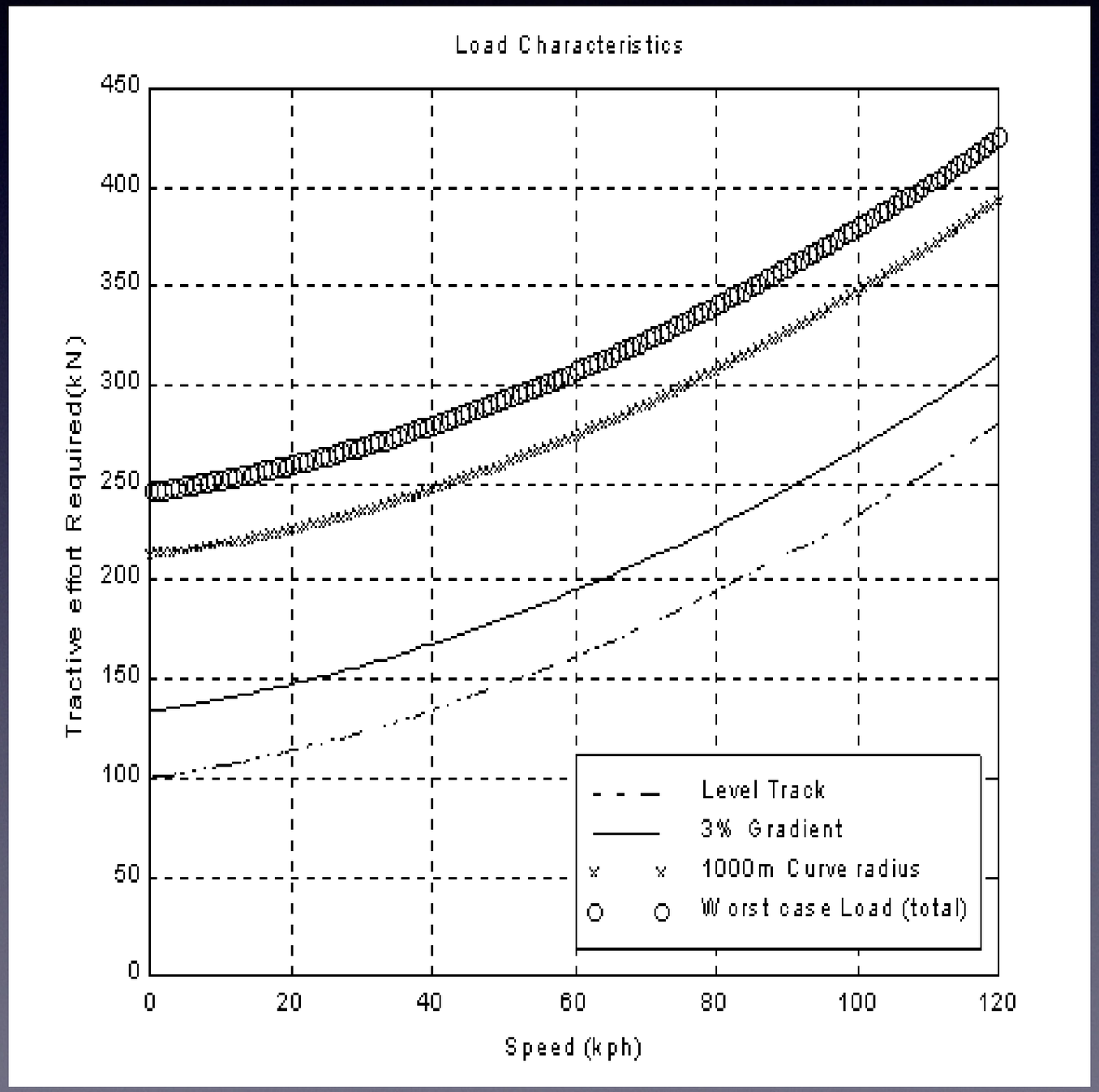
Things that are unsustainable do not sustain

Comparison of Historical Oil Prices and Delphi Forecasts

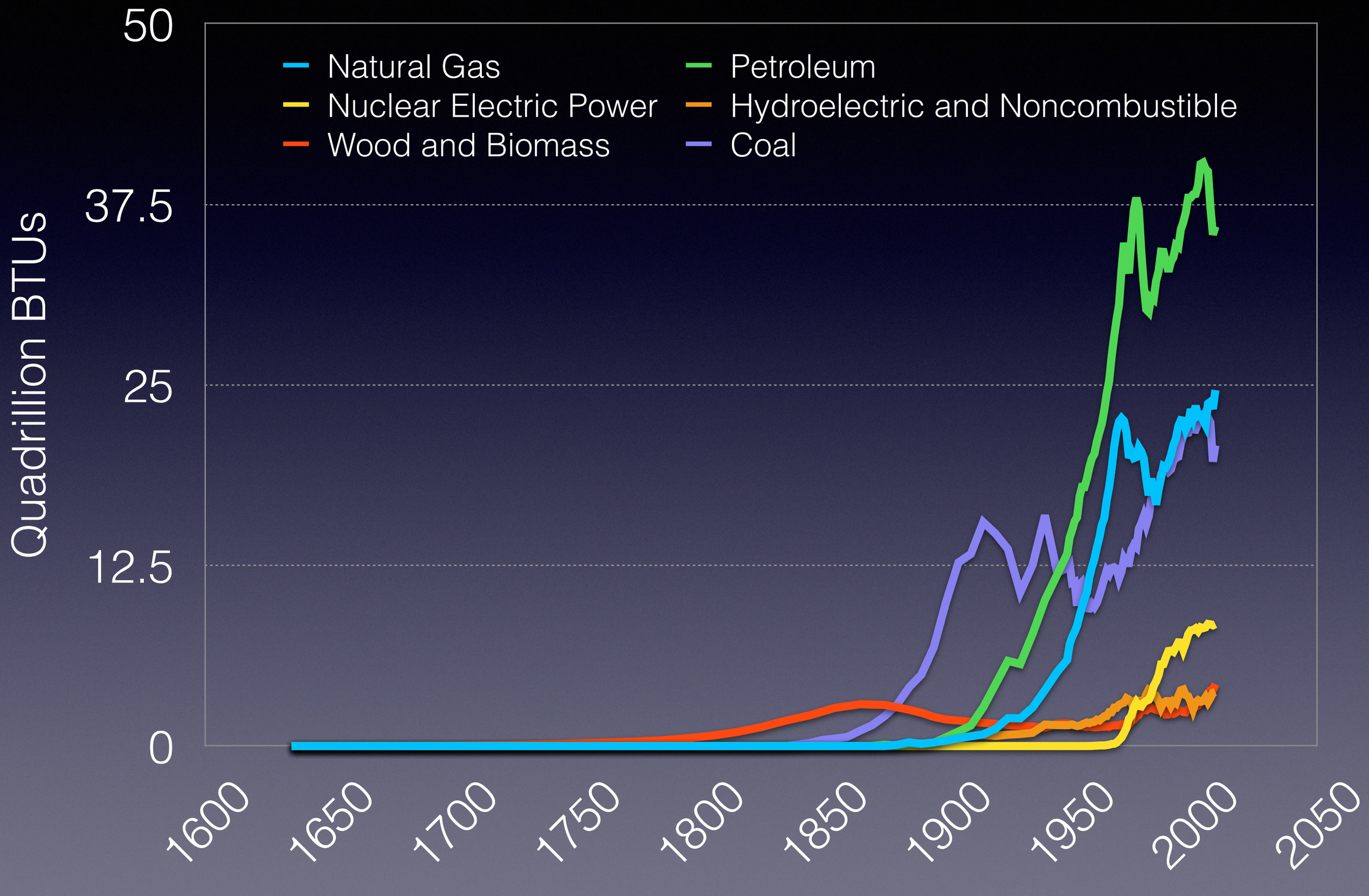


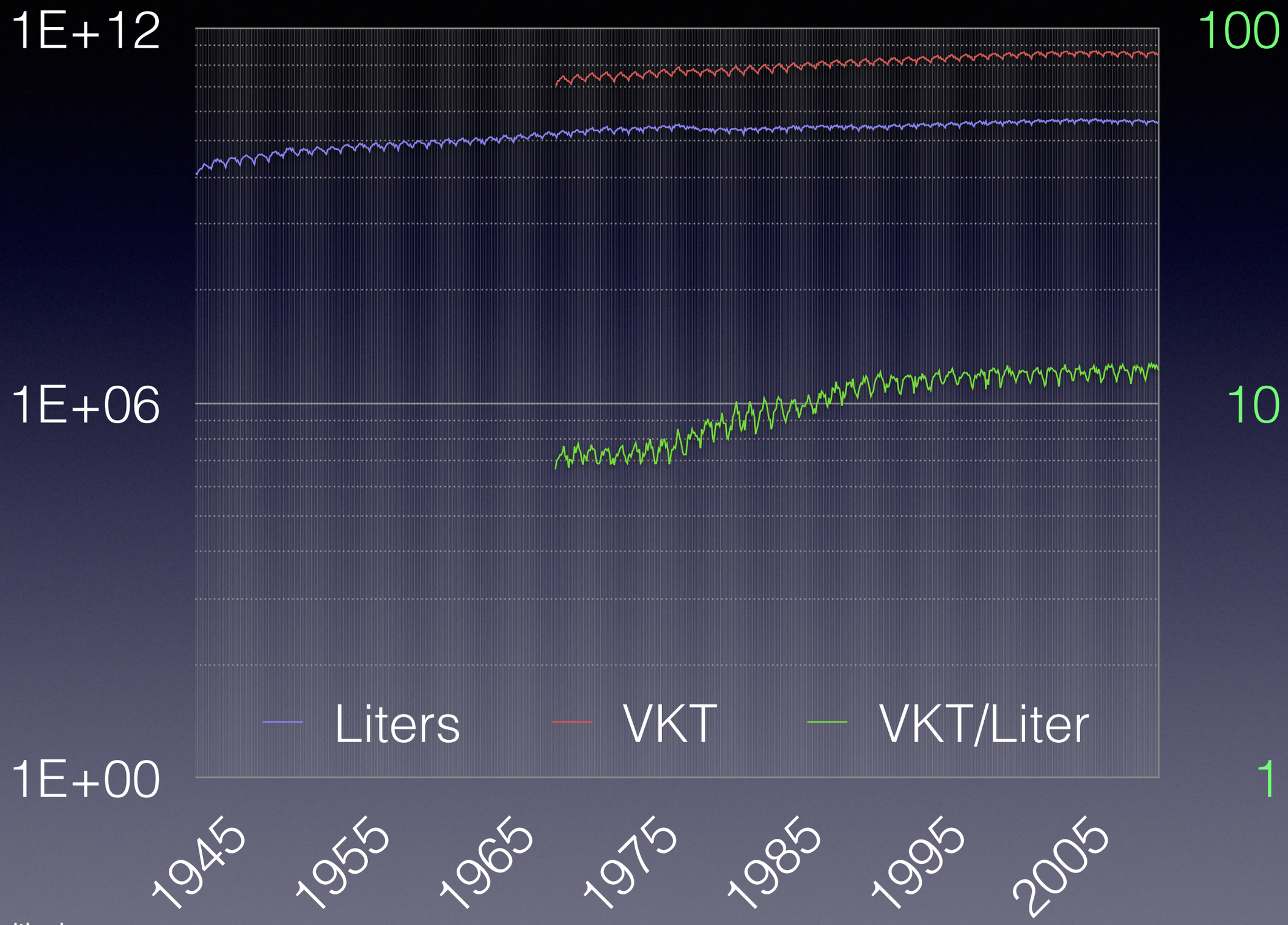
Energy

Energy is Required to Move Mass

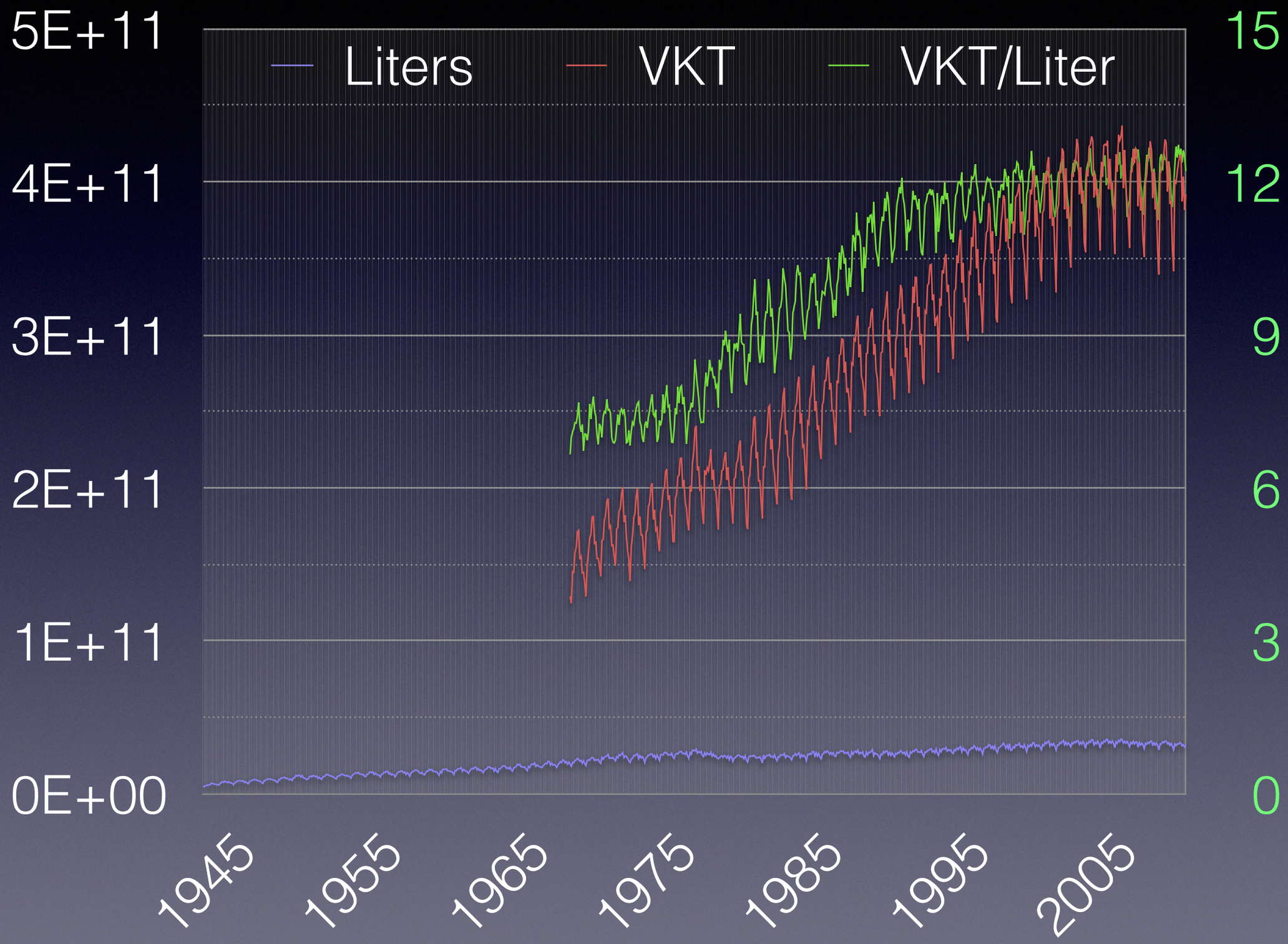


US Energy Use



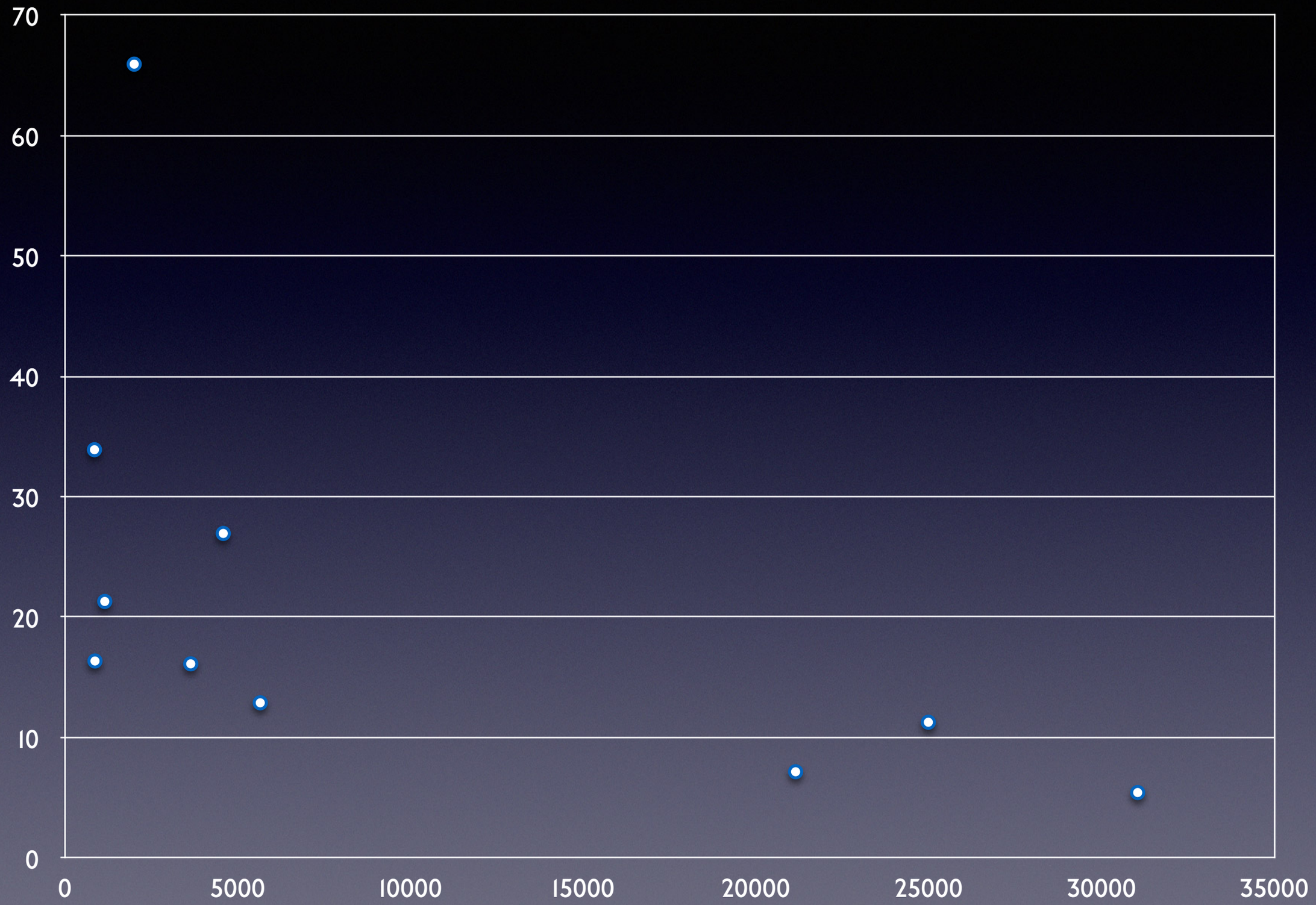


Logarithmic


Liters
VKT
VKT/Liter
5E+11
4E+11
3E+11
2E+11
1E+11
0E+00
15
12
9
6
3
0
1945
1955
1965
1975
1985
1995
2005

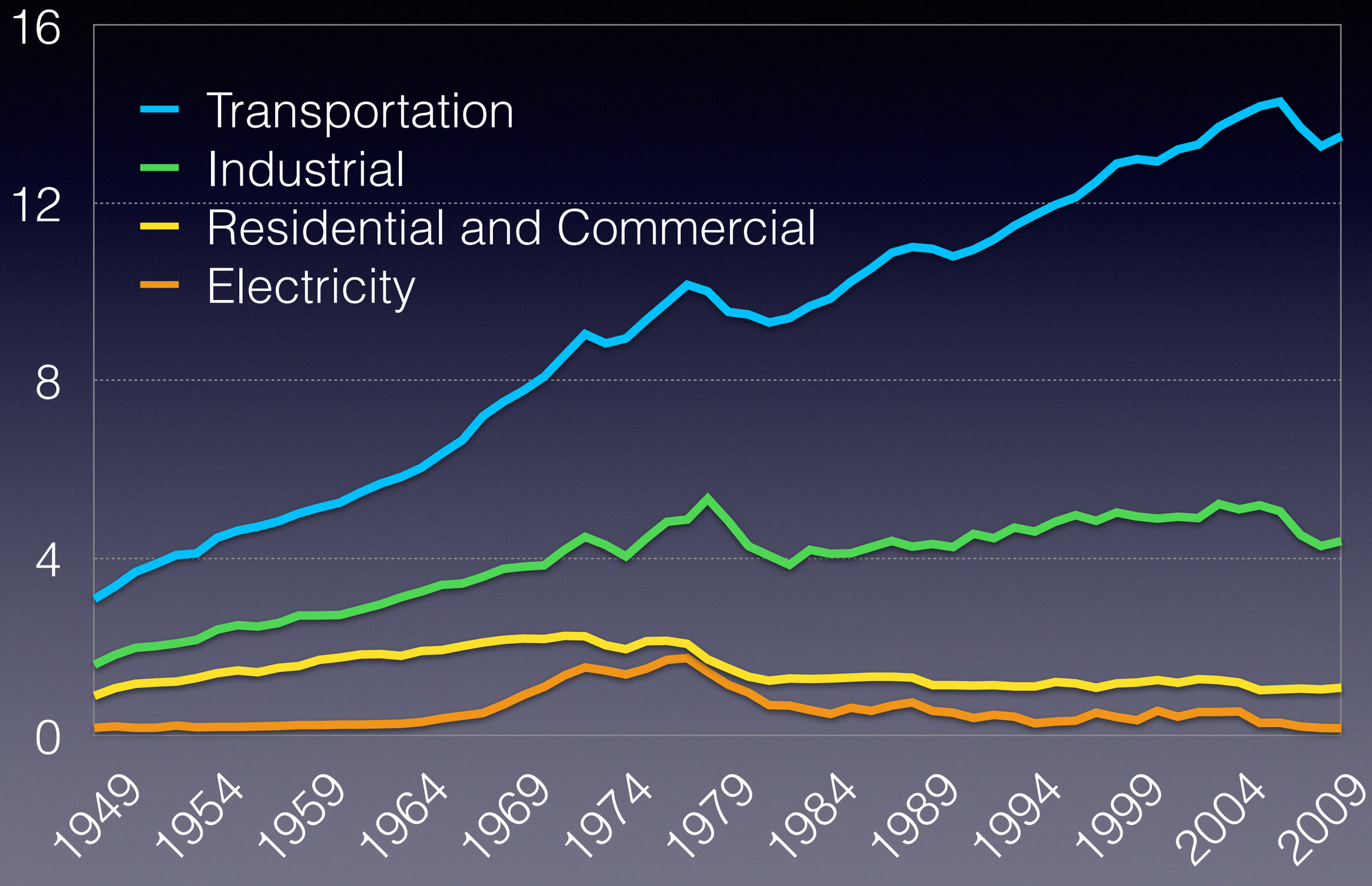
Linear

Thousands of BTU per 1999 $ GDP

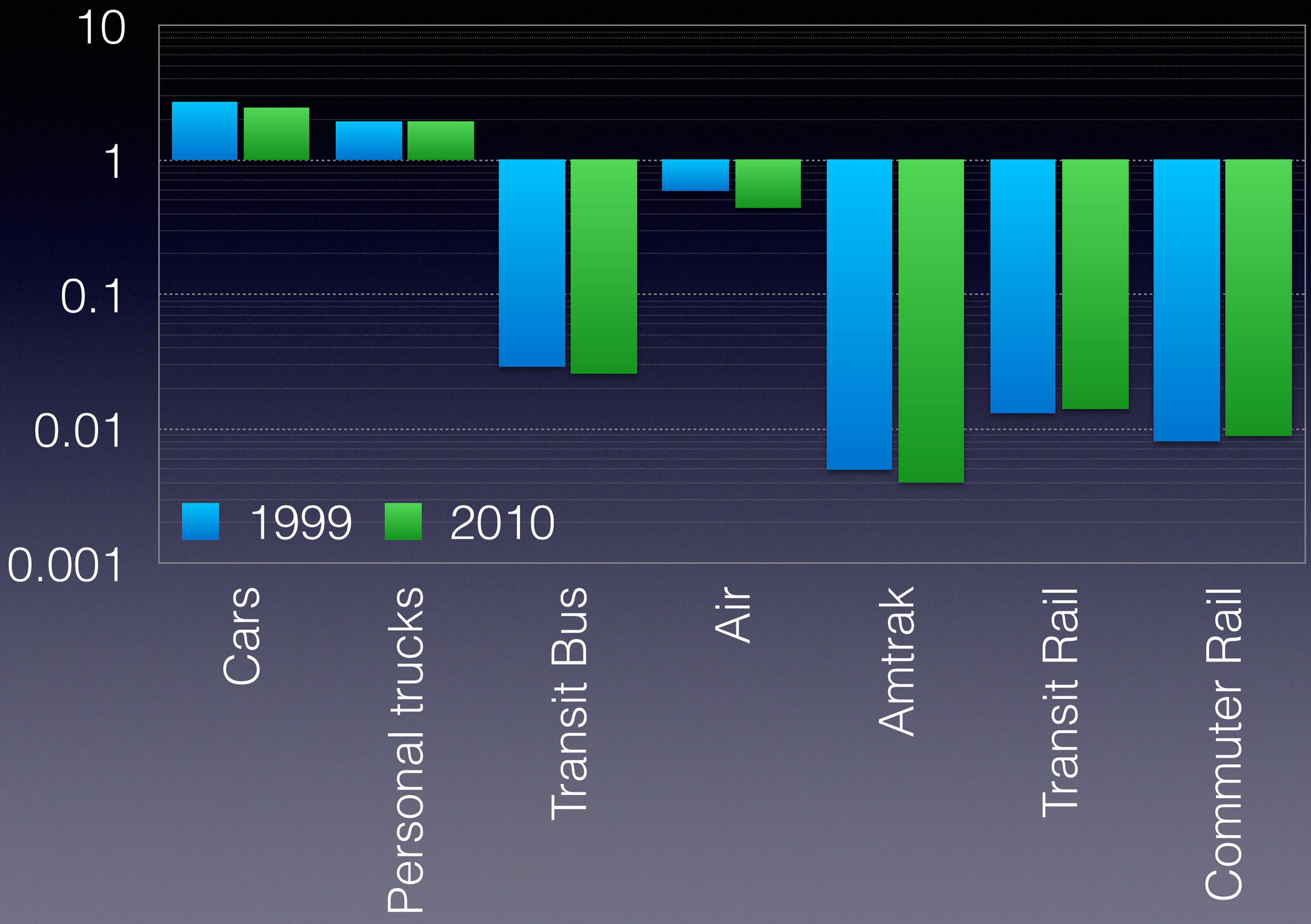


GDP per Capita

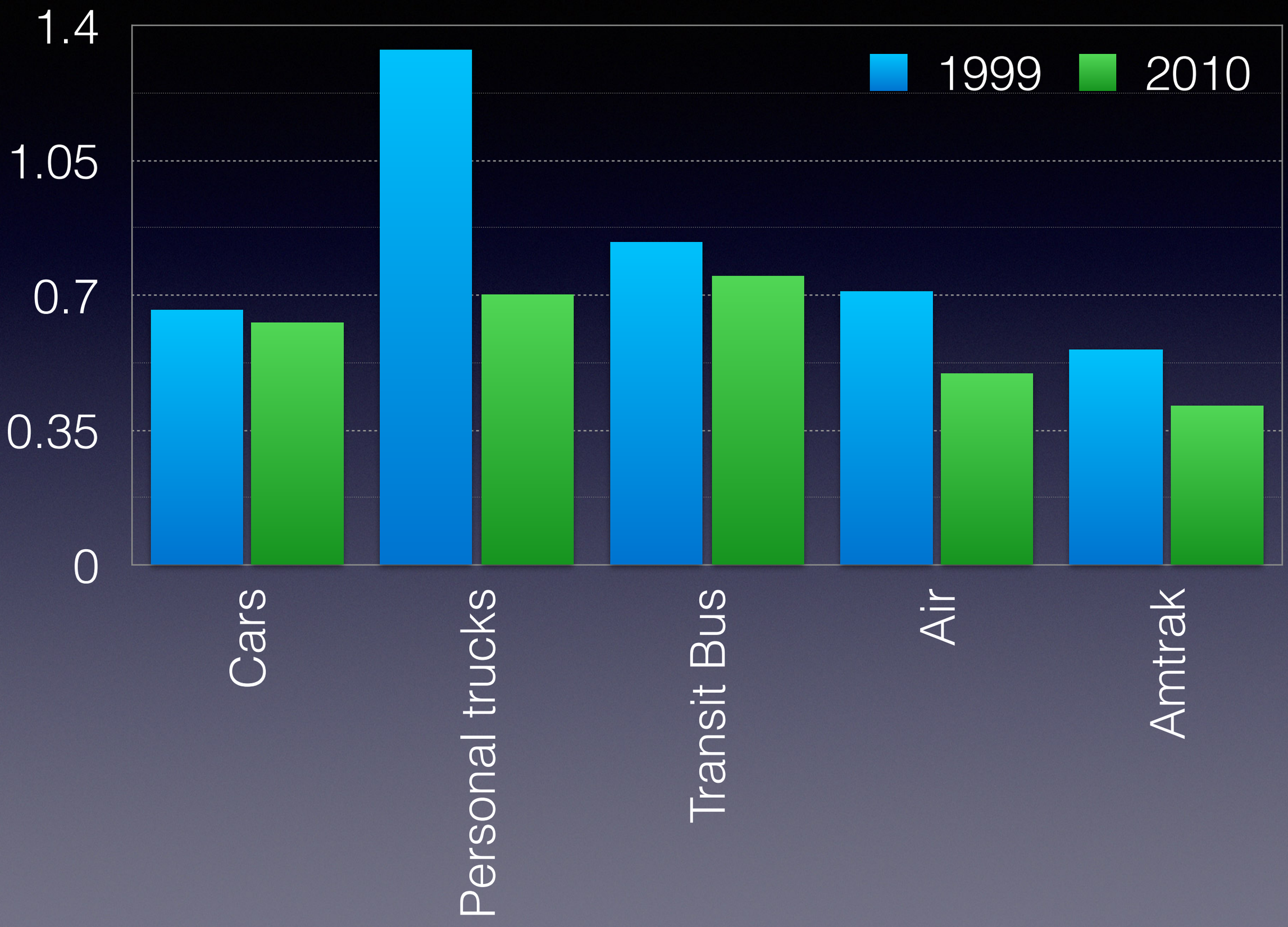
Energy use in United States (Millions of barrels per day)



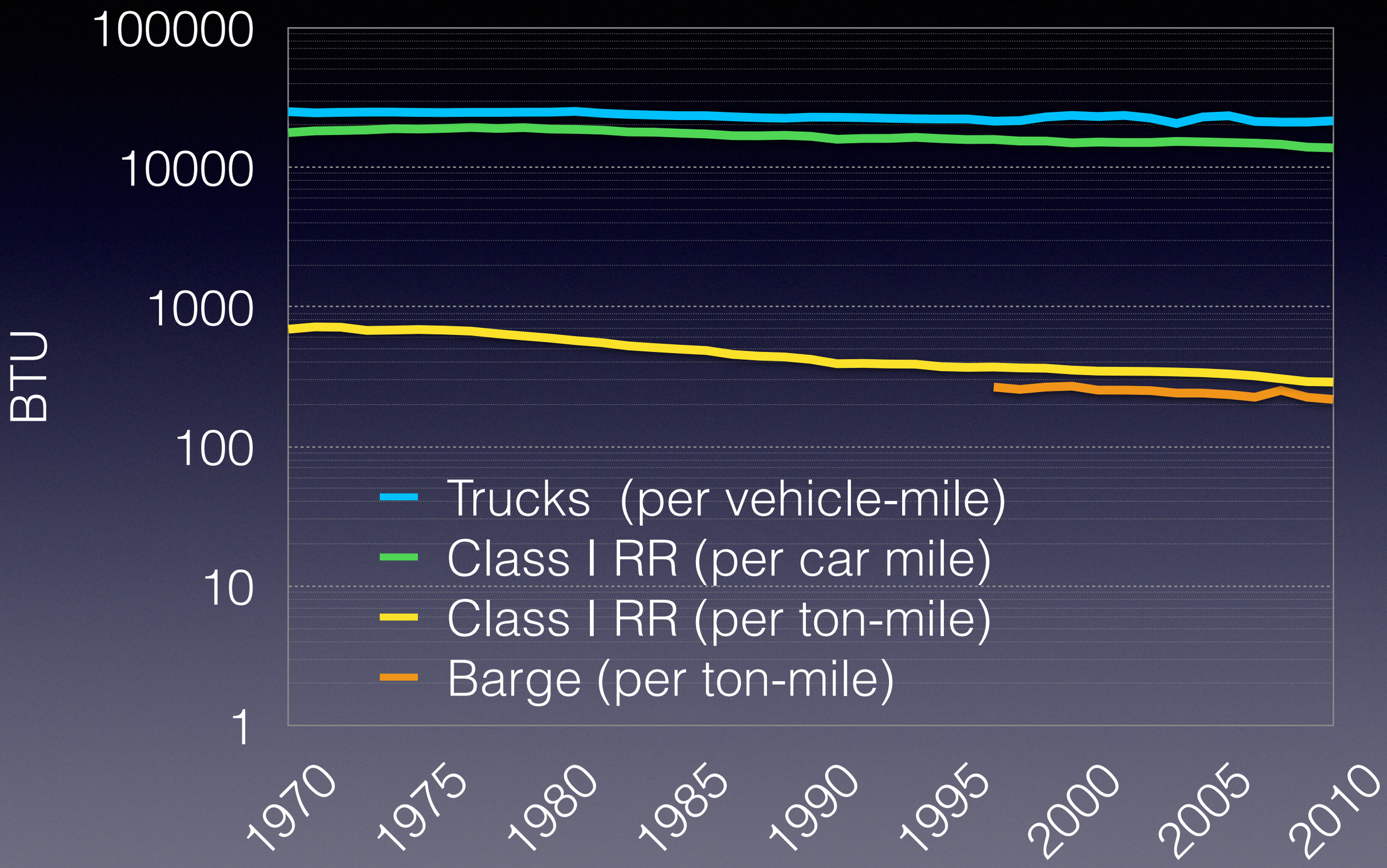
Energy Use (Trillion kWh)



Energy Intensity (kWh/Passenger-km)

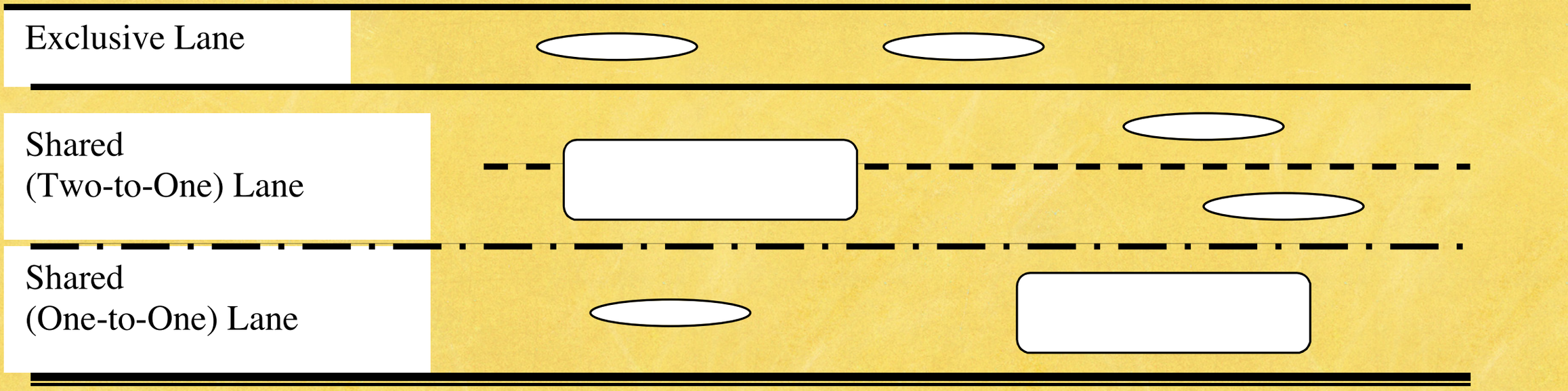


Energy intensity of freight



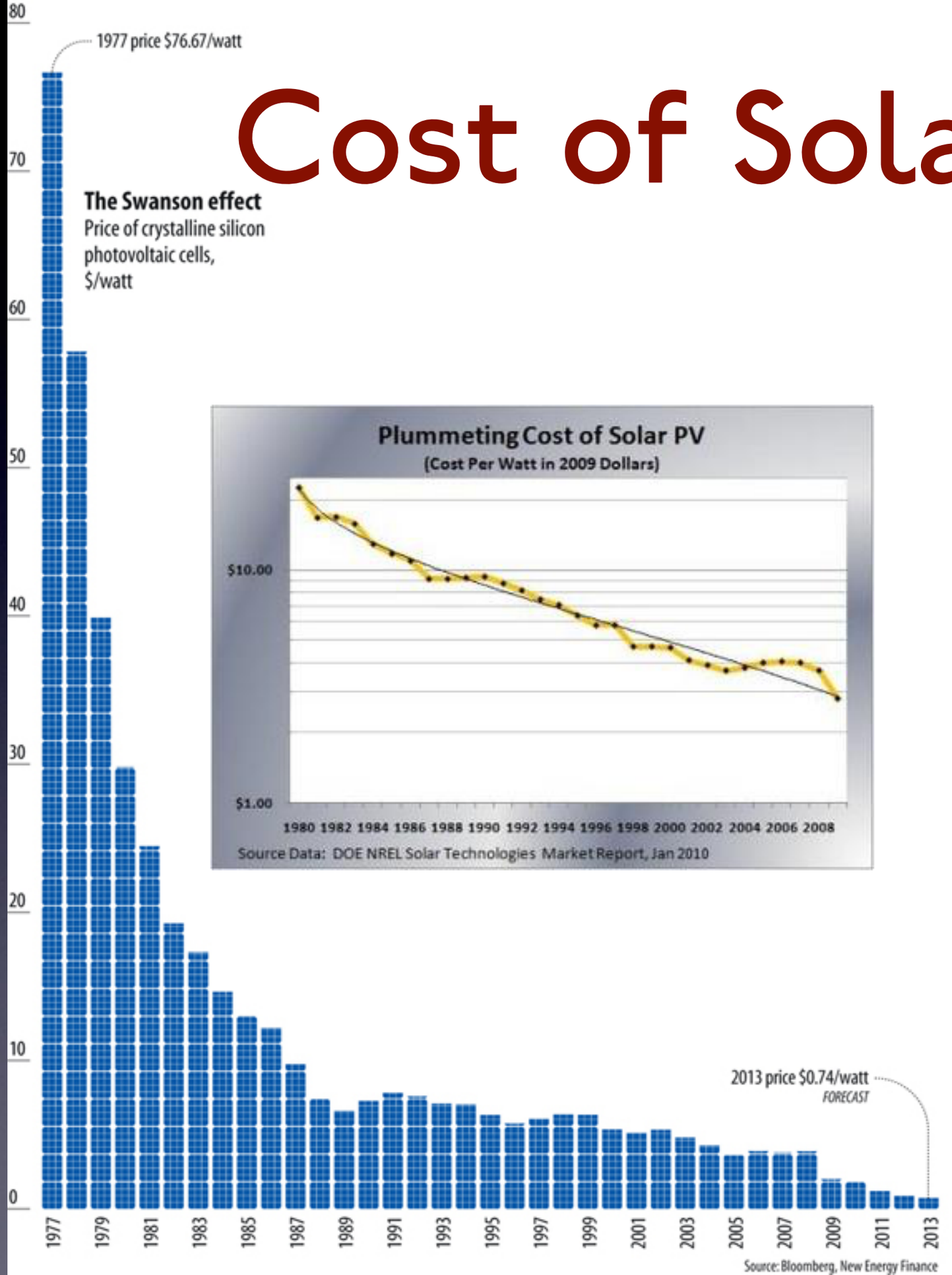
Steam, Electric, Gasoline

- 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.

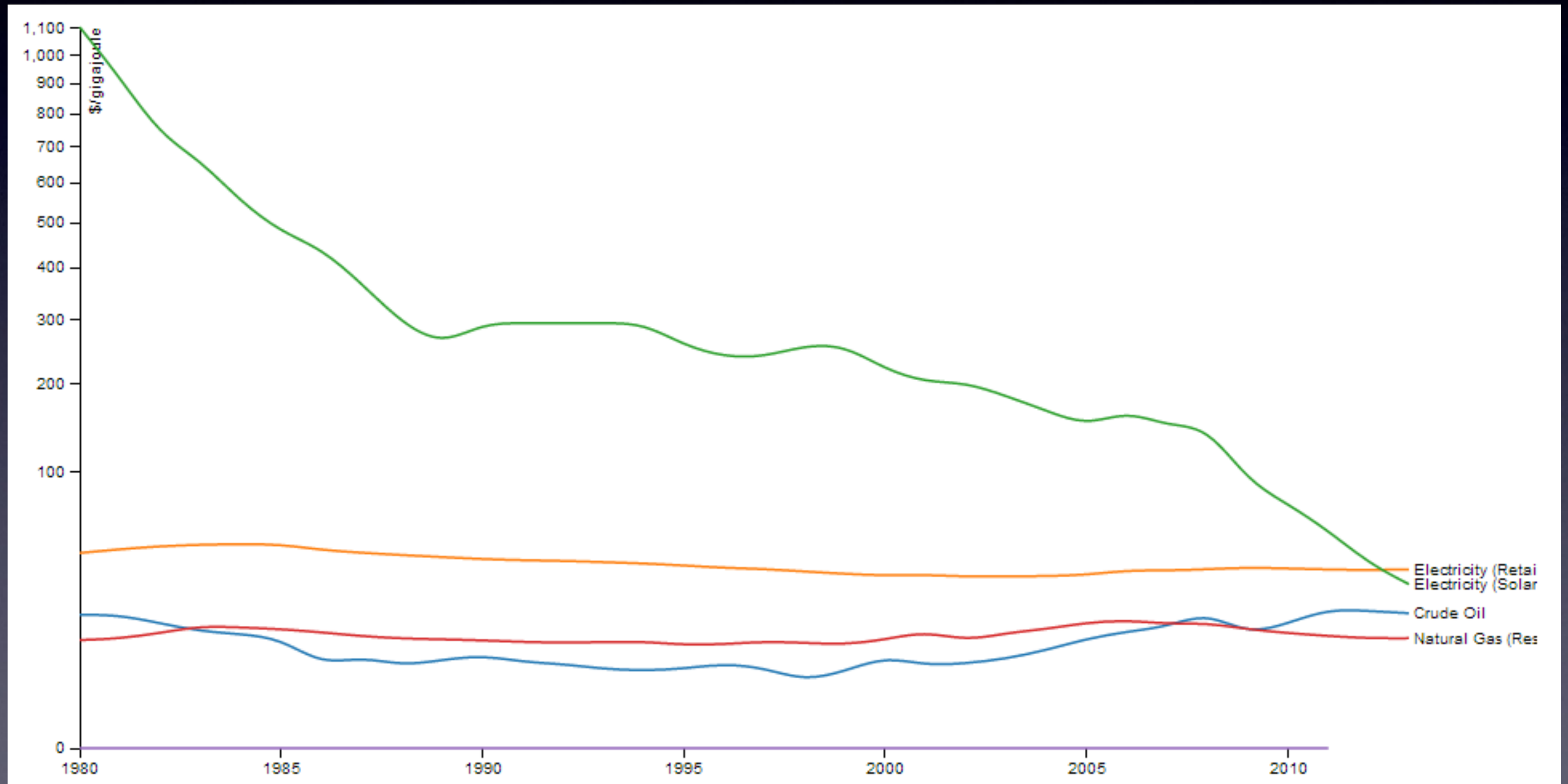


Alternative Vehicles, Alternative Highways

Cost of Solar



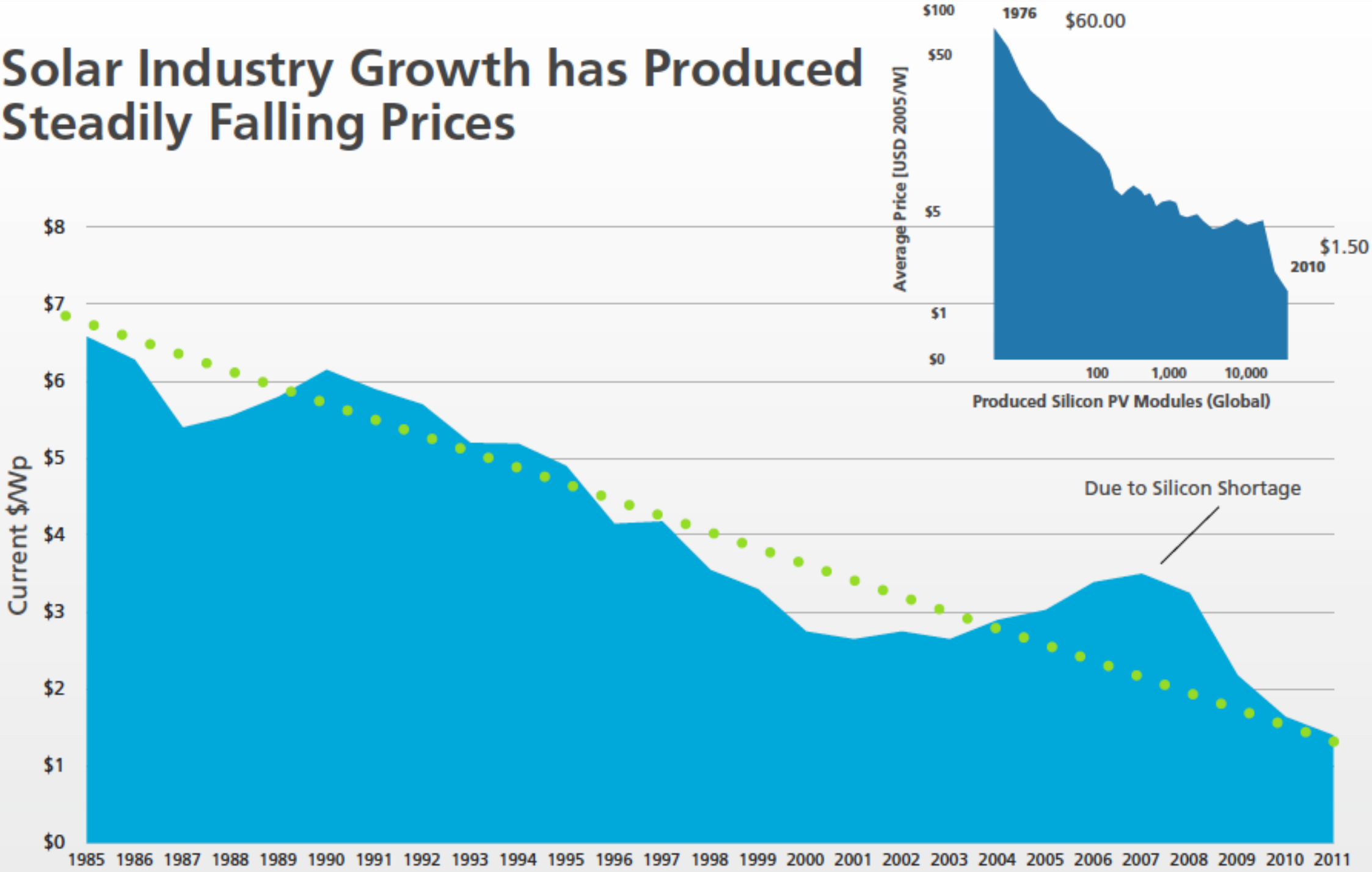
Solar 2



http://cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/

Solar 3

Solar Industry Growth has Produced Steadily Falling Prices

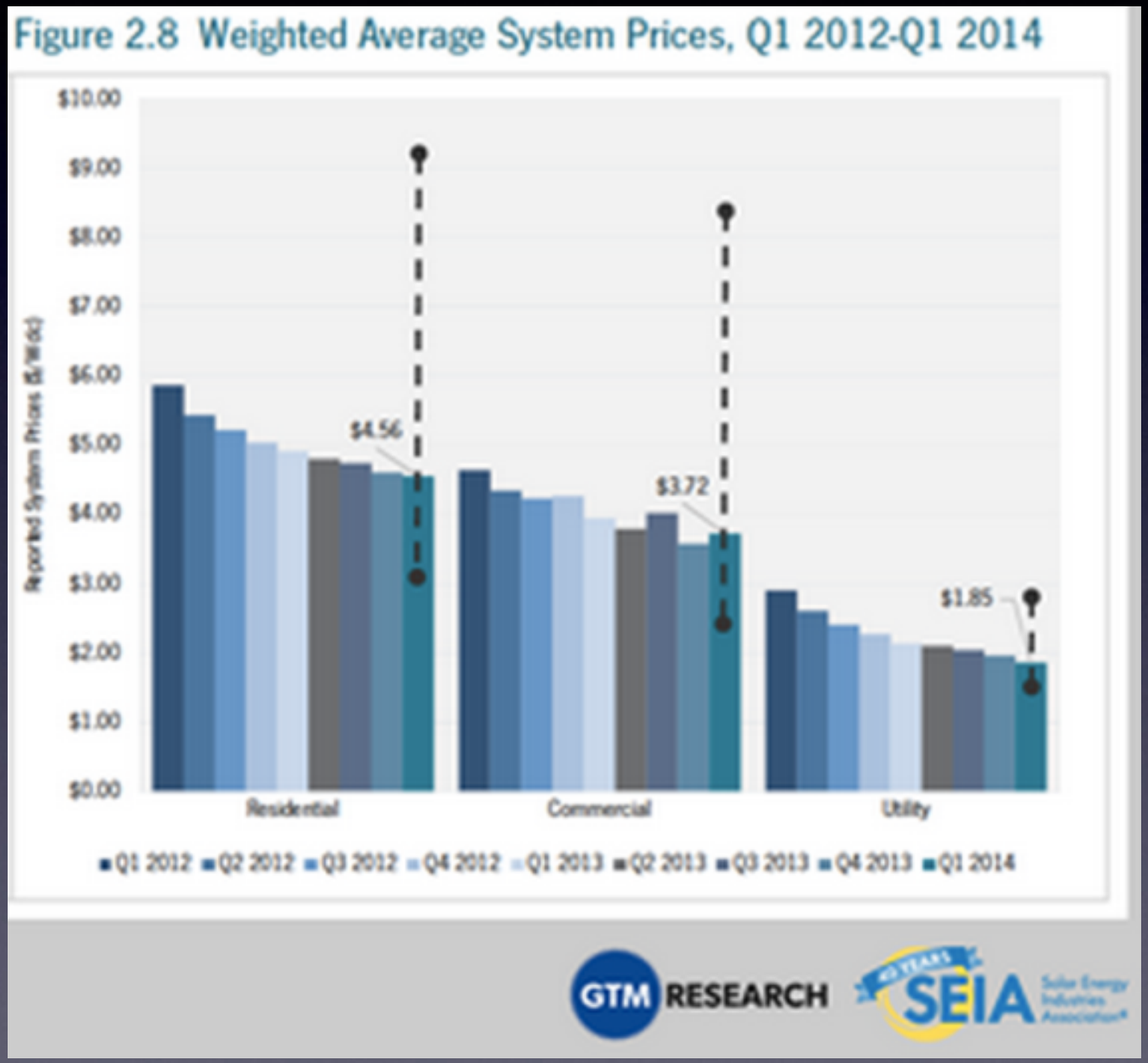


Module Pricing Trends 1985-2011

http://cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/

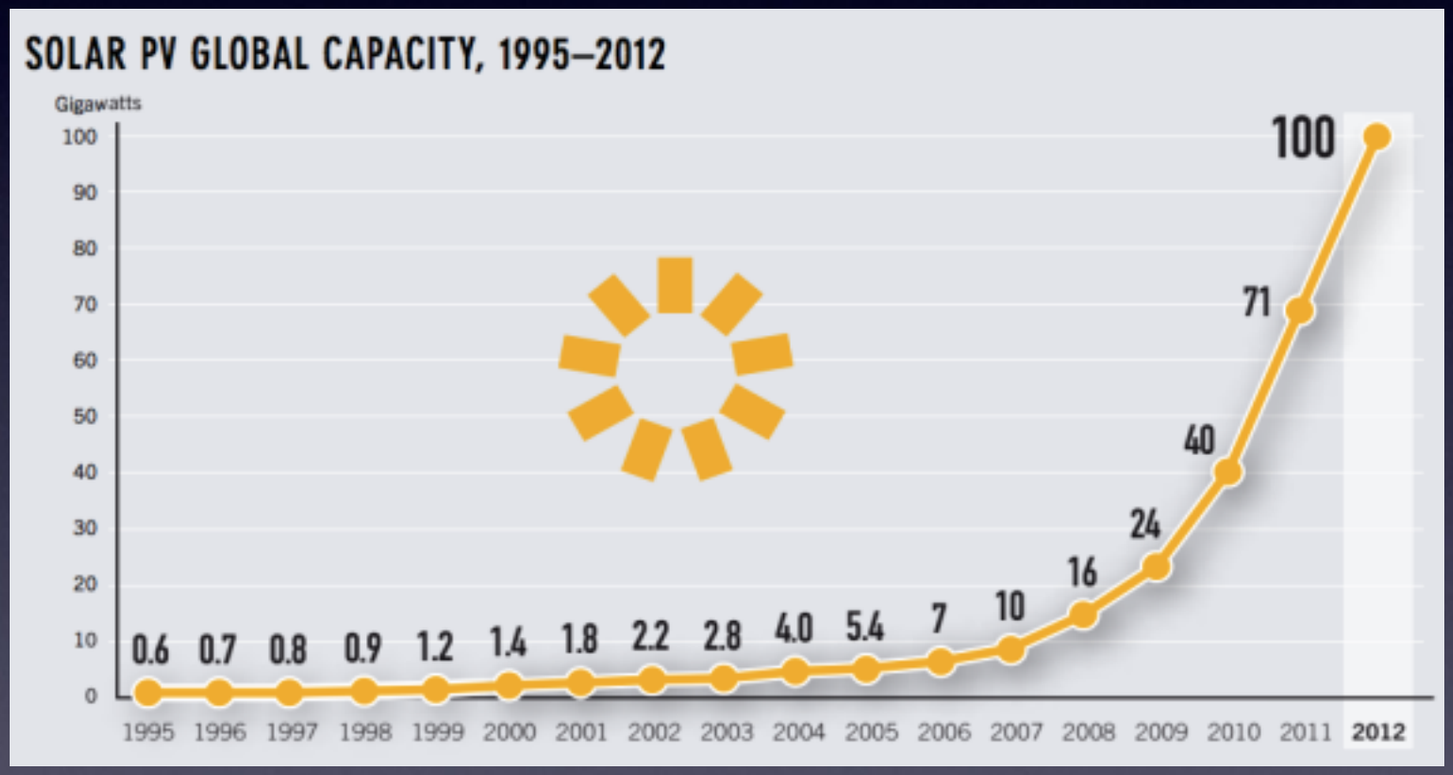
Sources: 1976 -1985 data from IPCC, Final Plenary, Special Report Renewable Energy Sources (SRREN), May 2011; 1985-2010 data from Paula Mints, Principal Analyst, Solar Services Program, Navigant; 2011 numbers based on current market data

Solar 4



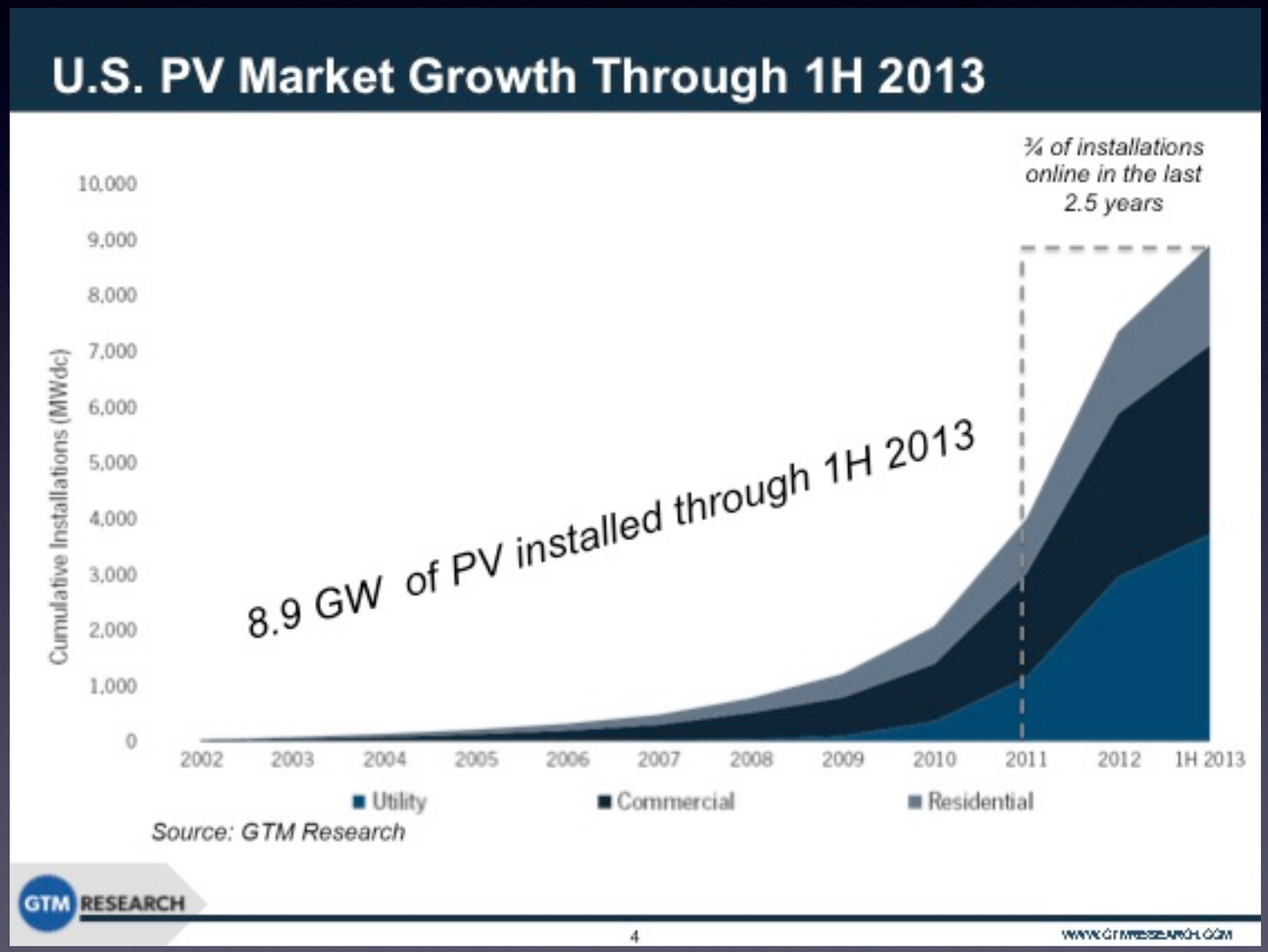
http://cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/

Solar 5



http://cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/

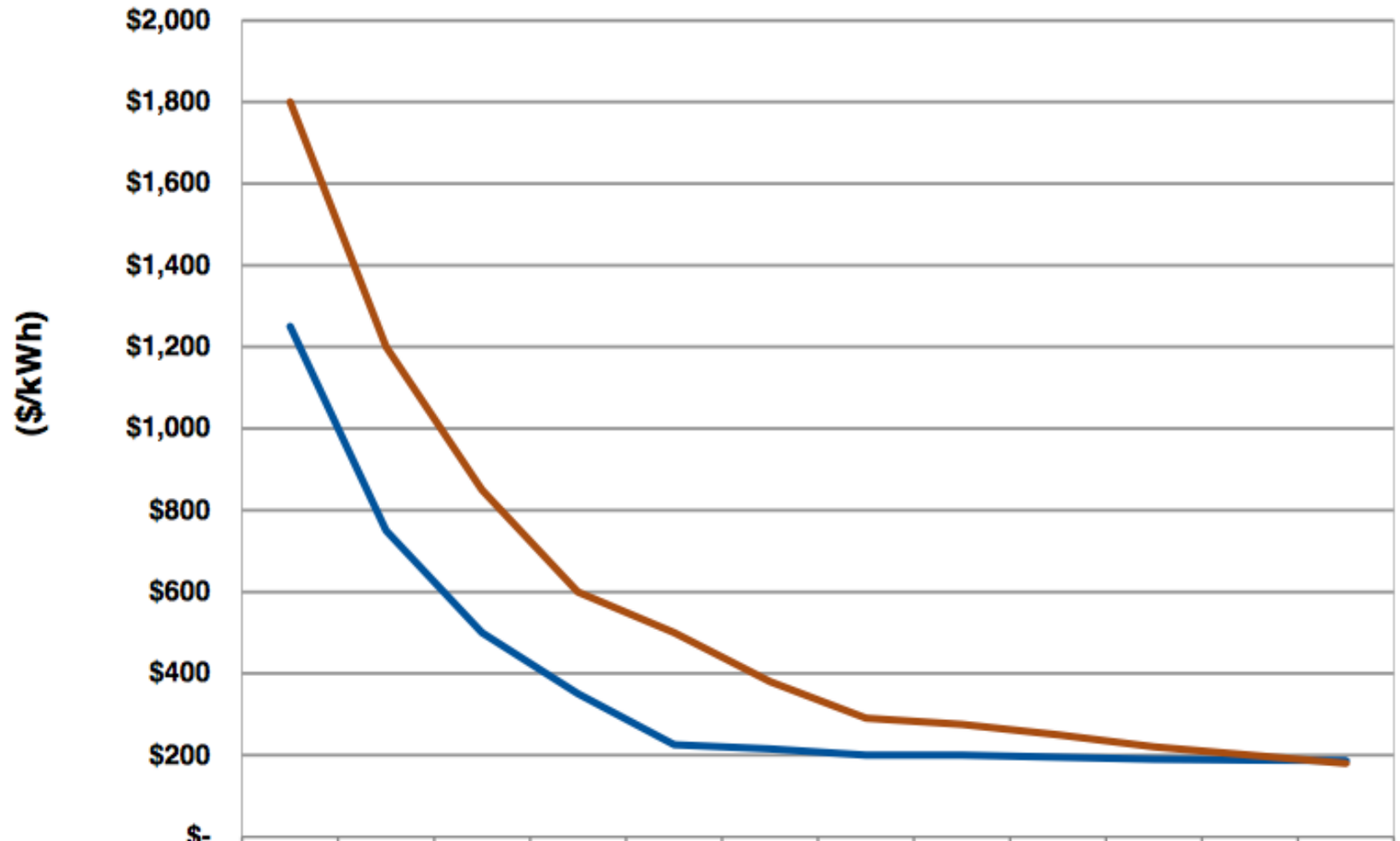
Solar 2



http://cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/

Battery Pricing

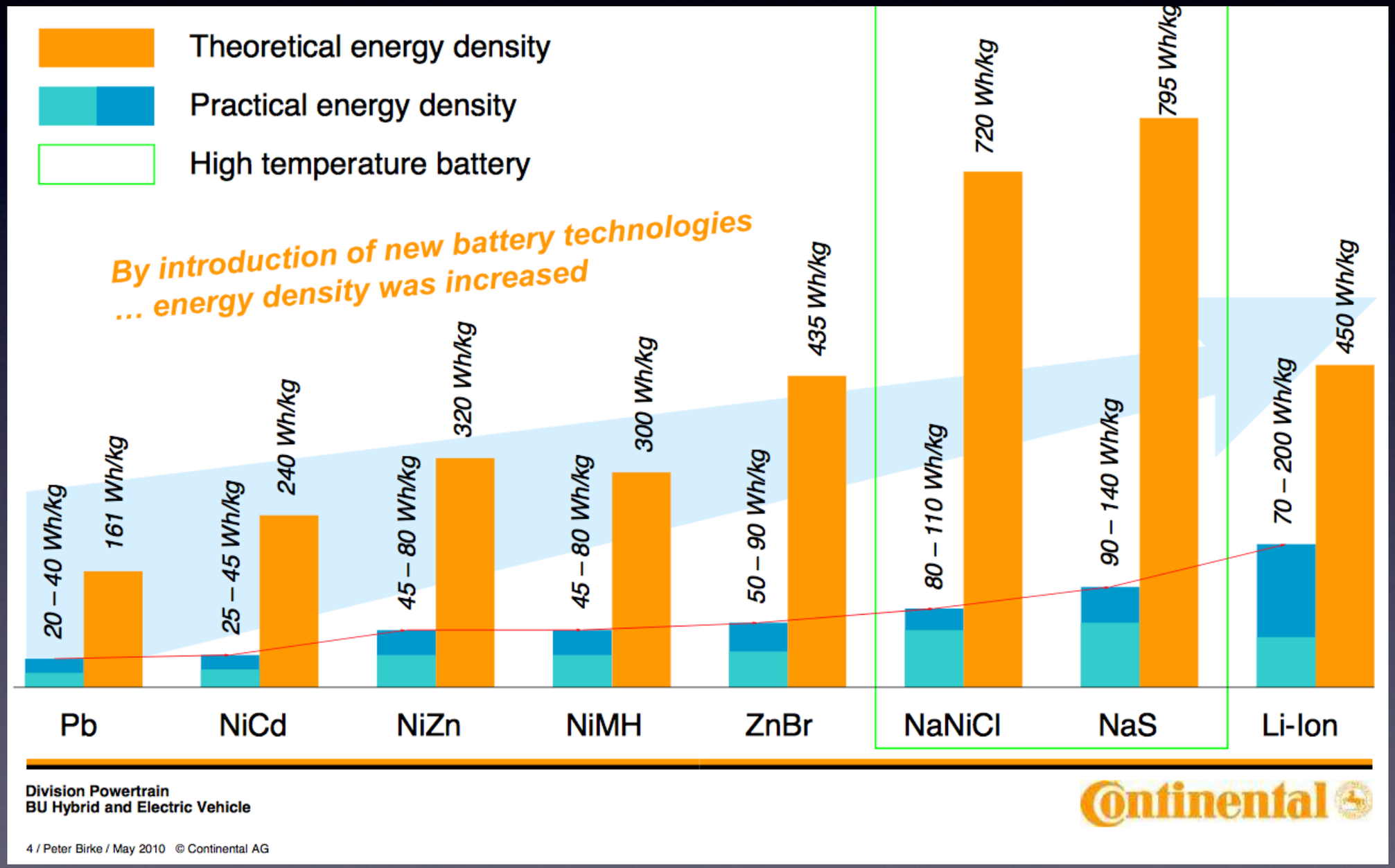
Lithium Ion Battery Pricing by Cell Type: 2009-2020



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Consumer Electronics Li-ion	1,250	750	500	350	225	215	200	200	195	190	188	187
Large Format Li-ion	1,800	1,200	850	600	500	380	290	275	250	220	200	180

(Source: Navigant Research)

Batteries are getting better



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

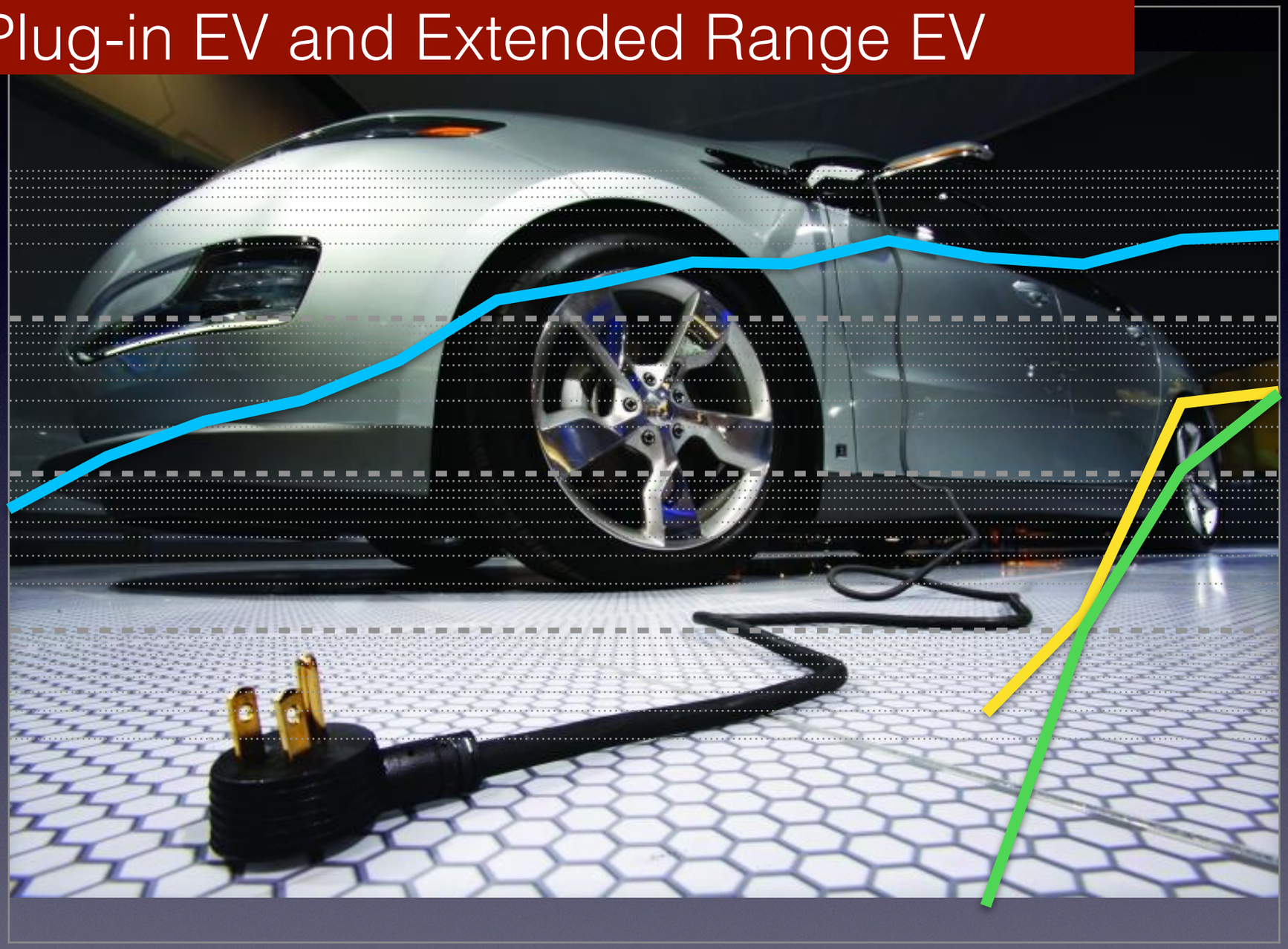
https://en.wikipedia.org/wiki/Lithium–air_battery

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

- Hybrid EV
- Battery EV
- Plug-in EV and Extended Range EV



10.000%

1.000%

0.100%

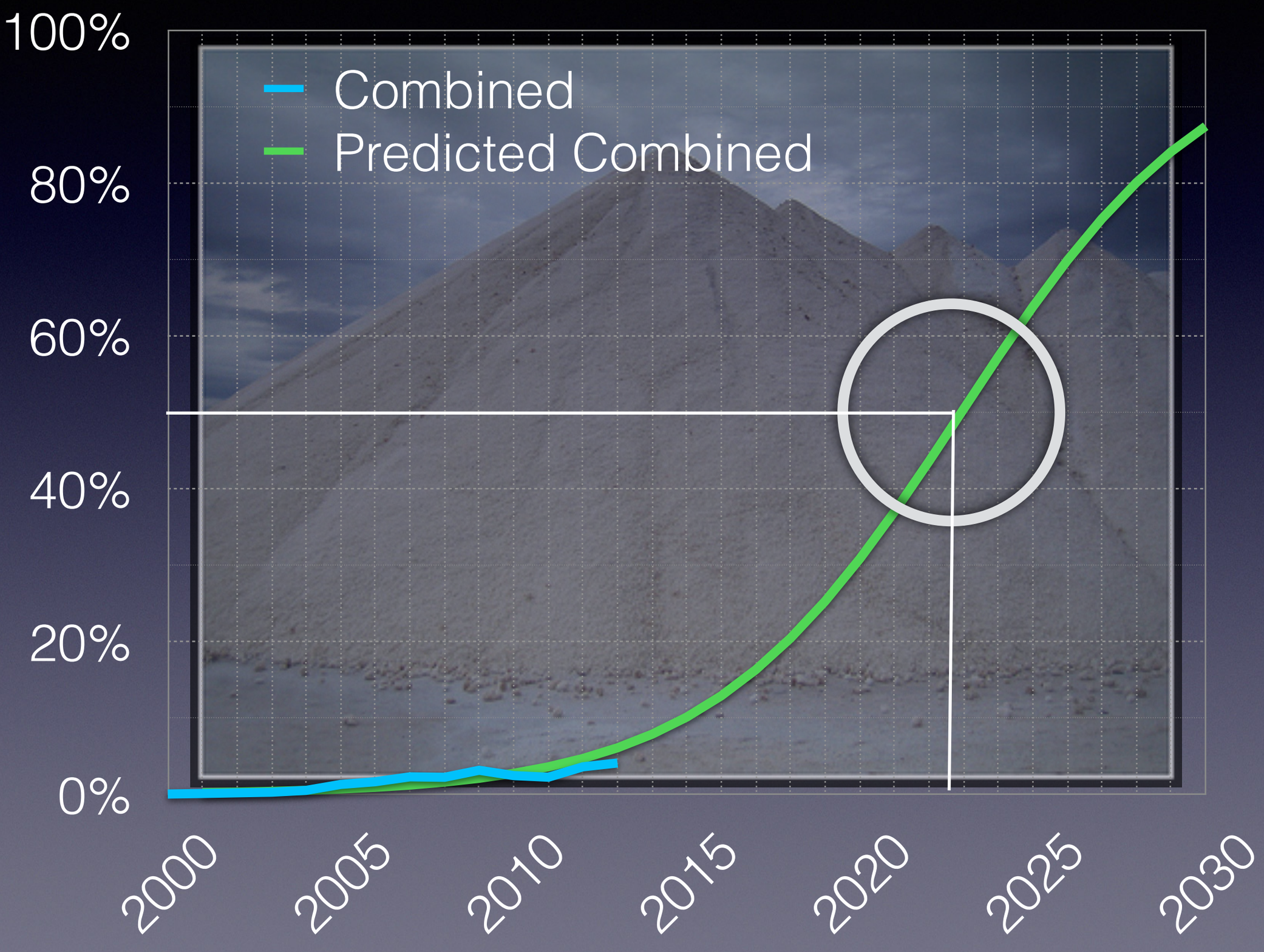
0.010%

0.001%

Log

2000 2002 2004 2006 2008 2010 2012

US EV New Car Market Share: Logistic Growth Curve



Innovation

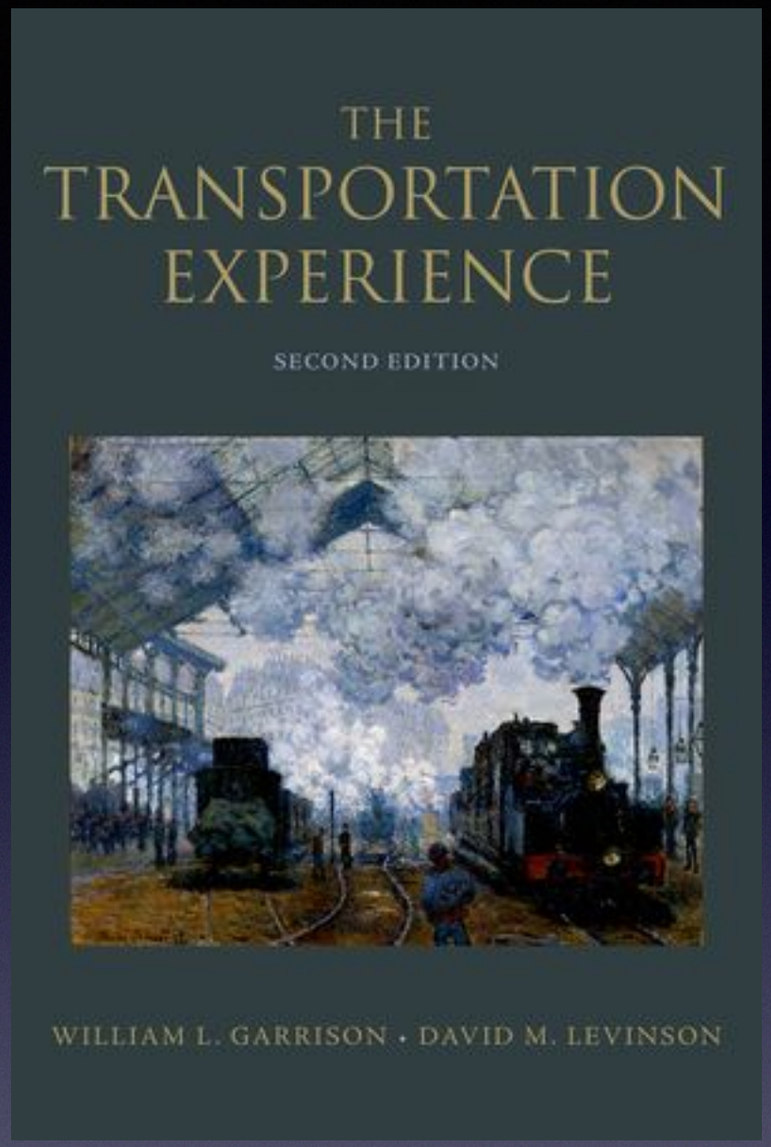
- ~10x improvement on some relevant dimension to justify switching energy platform
- Relevant dimensions: Cost, Speed, Size, Pollution, Comfort, Range

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/mplshistory/?id=10



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