Evaluation of Future Availability of Primary Fuel Cell Feedstocks of Importance to the Introduction of Commercially Available Fuel Cell Vehicles in the Near Future

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GOALS

- Analyze:
  - Impacts of fuel cell vehicle introduction
  - Impact of fuel cell vehicle introduction on US energy dependence
  - Strategies for fuel cell vehicle fueling
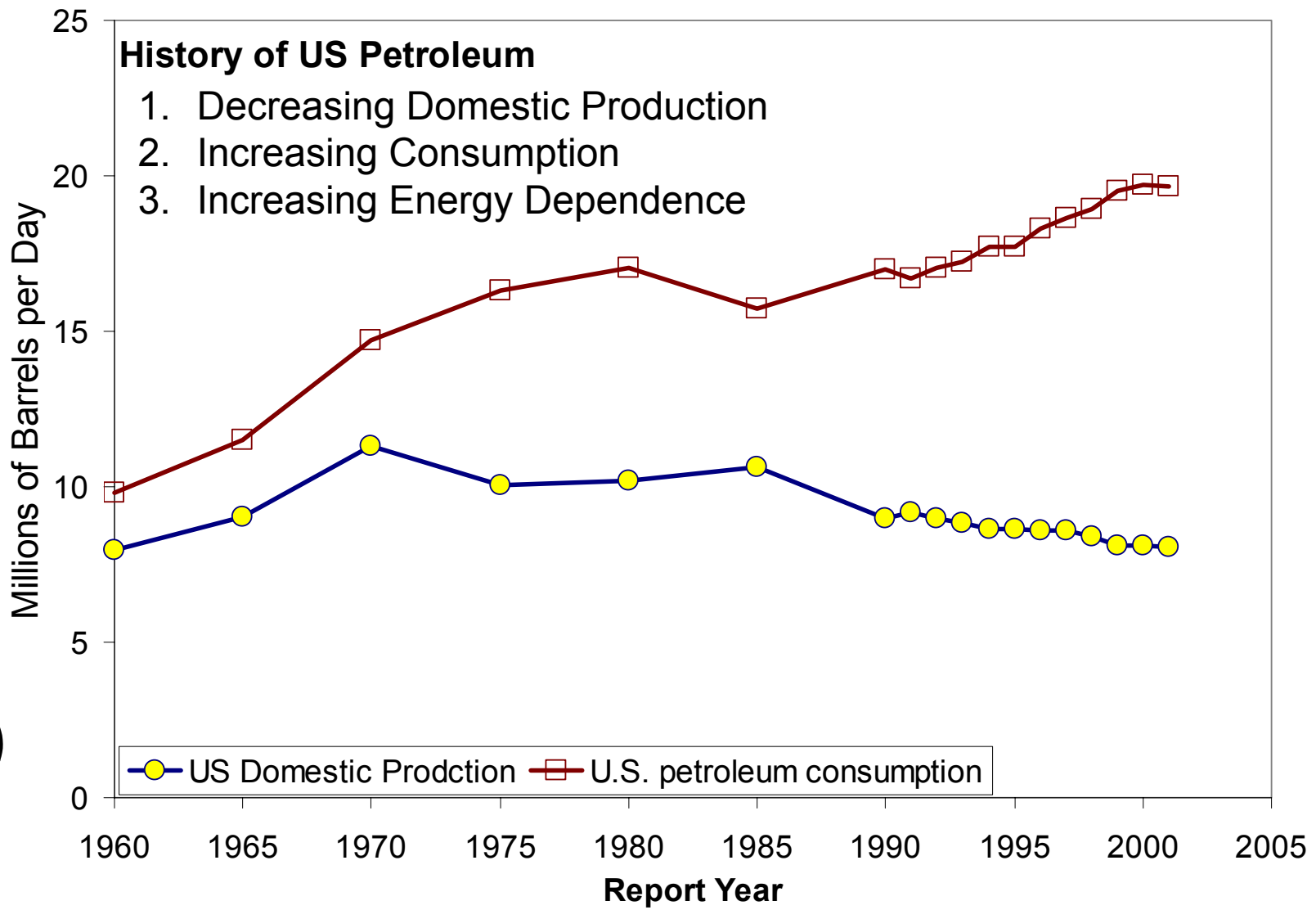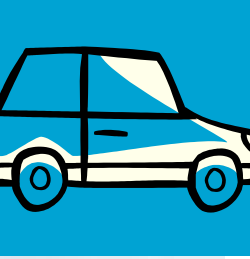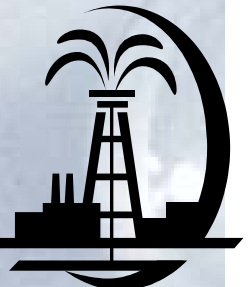
Introduction

- Focus on Transportation Sector for Energy Dependence Reduction
  - Transportation Sector Energy Consumption in 2000:
    - ~ **27%** of overall US energy consumption
    - ~ **66%** of total US petroleum consumption
    - ~ **160%** higher than US petroleum production
  - Modern IC Engines thermal efficiency (15-20%)
  - Modern Fuel Cell Engines thermal efficiency (30-40%)

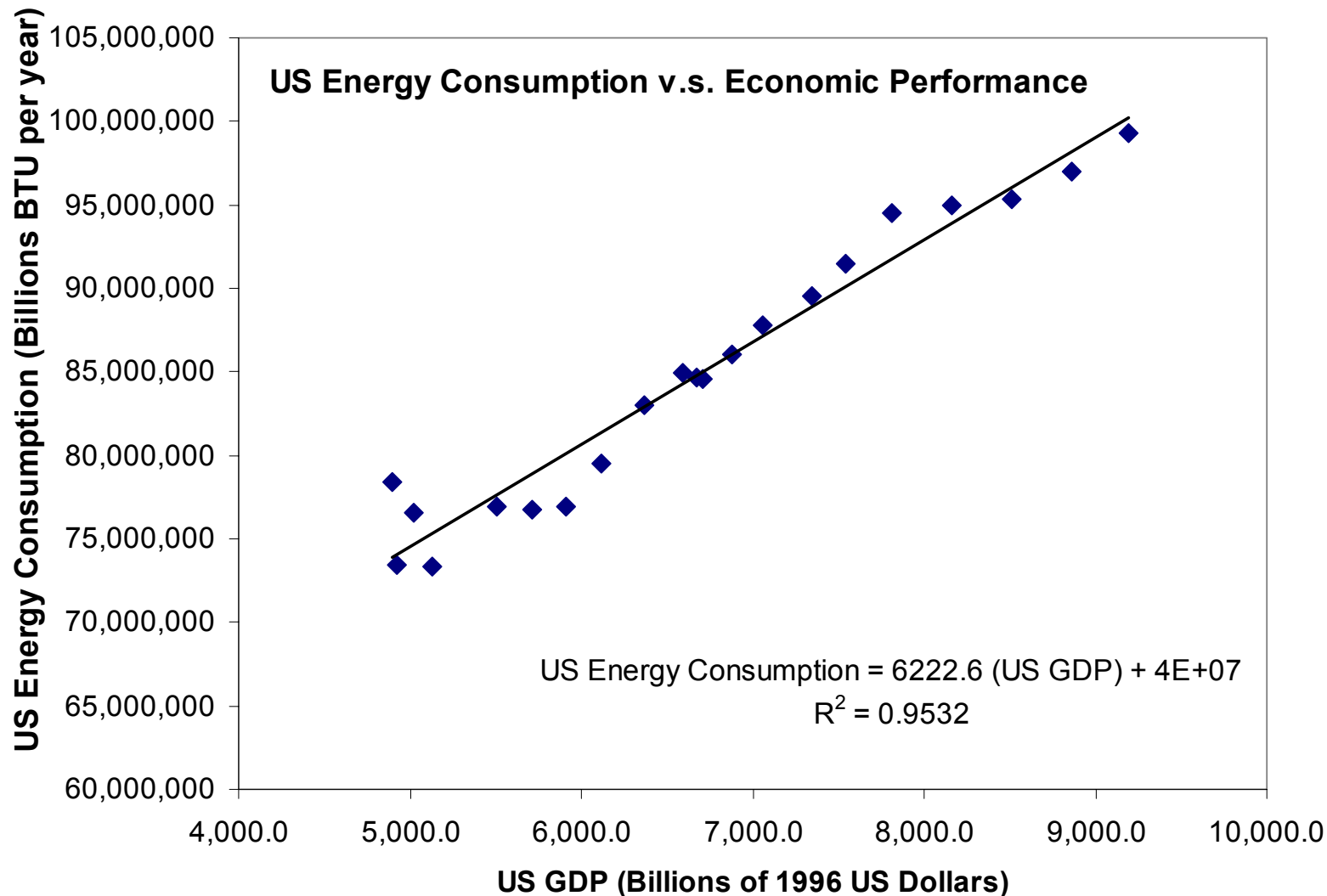# Current US Energy Environment Petroleum

History of US Petroleum
1. Decreasing Domestic Production
2. Increasing Consumption
3. Increasing Energy Dependence

Millions of Barrels per Day

Report Year

US Domestic Prodction — U.S. petroleum consumption

Energy and The Economy

US Energy Consumption v.s. Economic Performance

US Energy Consumption = 6222.6 (US GDP) + 4E+07

R^2 = 0.9532

X-axis: **US GDP (Billions of 1996 US Dollars)** — 4,000.0 to 10,000.0

Y-axis: **US Energy Consumption (Billions BTU per year)** — 60,000,000 to 105,000,000

US Energy Resources
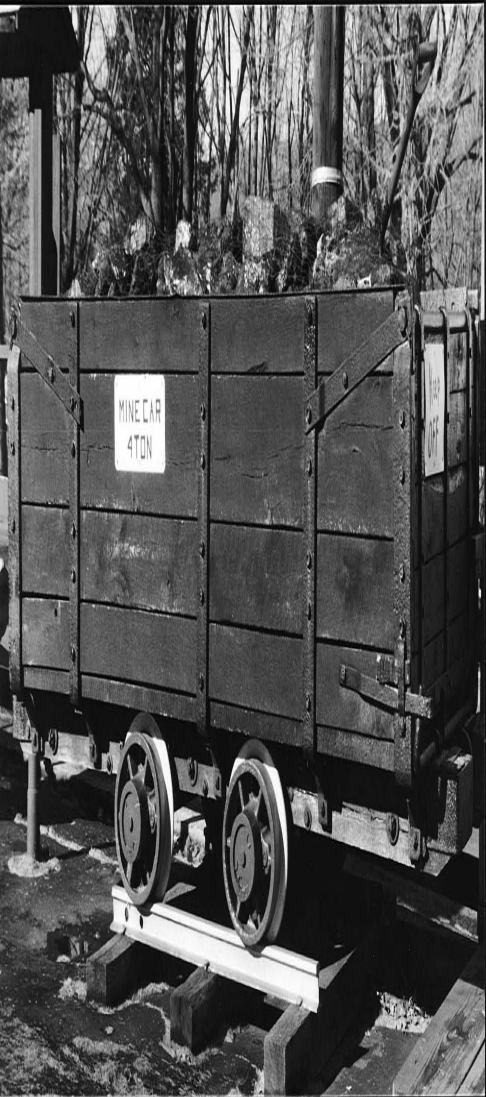
- Coal[1]: ~8.7×10^7 trillion BTU
- NG[2]: ~1.3×10^6 trillion BTU
- Petroleum[3]: ~2.1×10^6 trillion BTU

SOURCES:
1. "US Coal Reserves: 1997 Update" Energy Information Administration, US Department of Energy (DOE), Washington, DC 1997.
2. "Electrical Power Annual 2000, Volume 1" Energy Information Administration, US Department of Energy (DOE), Washington, DC 2001.
3. "World Petroleum Assessment 2000, Executive Summary" U.S. Department of the Interior, U.S. Geological Survey, Reston, VA 2000.

Introduction – Fuel Cells
Basic Operation
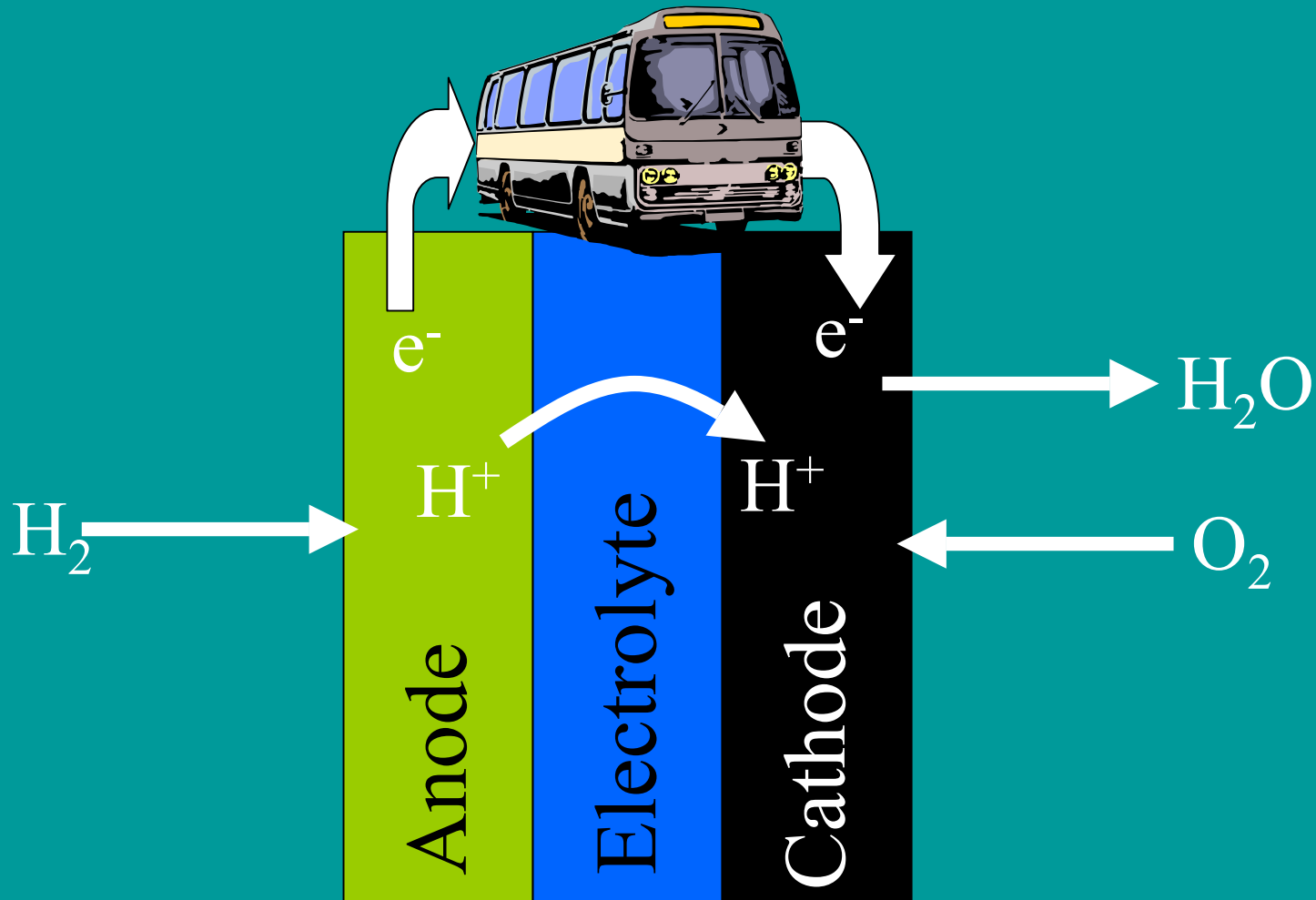
The Hydrogen Question: From Where ?

- Sources
  - Water
    - Requires electricity or very high temperatures.
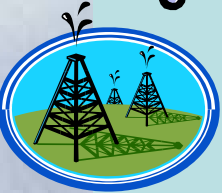 - Petroleum Products
    - Technology is yet to be proven. Complex molecular structure reduces the efficiency of the process.
  - Natural Gas
    - Proven technology using catalytic, endothermic reactions.
  - Coal
    - Could be gasified and reformed. Technology not yet proven.

Hydrogen Transportation and Distribution Hurdles

- Hydrogen is a gas
  - Low energy density
  - High diffusivity
  - Liquid hydrogen is an alternative
    - ~30-40% of the chemical energy is lost to liquefaction
    - Boil off rates of 0.3 to 0.6% per day
    - Boil off during transfer may be up to 50%
- Virtually no hydrogen transportation and distribution infrastructure exists

The Methanol Alternative

- Easily reformed at relatively low temperatures
- Proven reforming technology
- Liquid
  - Compatible with existing fuel transportation infrastructure
- Can be produced from
  - Coal
  - Natural Gas
  - Biomass

Methodology

- Economic Growth Projections and Assumptions

US GDP in billions of chained 1996 dollars
Source: US Department of Commerce- Bureau of Economic Analysis
www.bea.gov/bea/dn/gdplev.xls
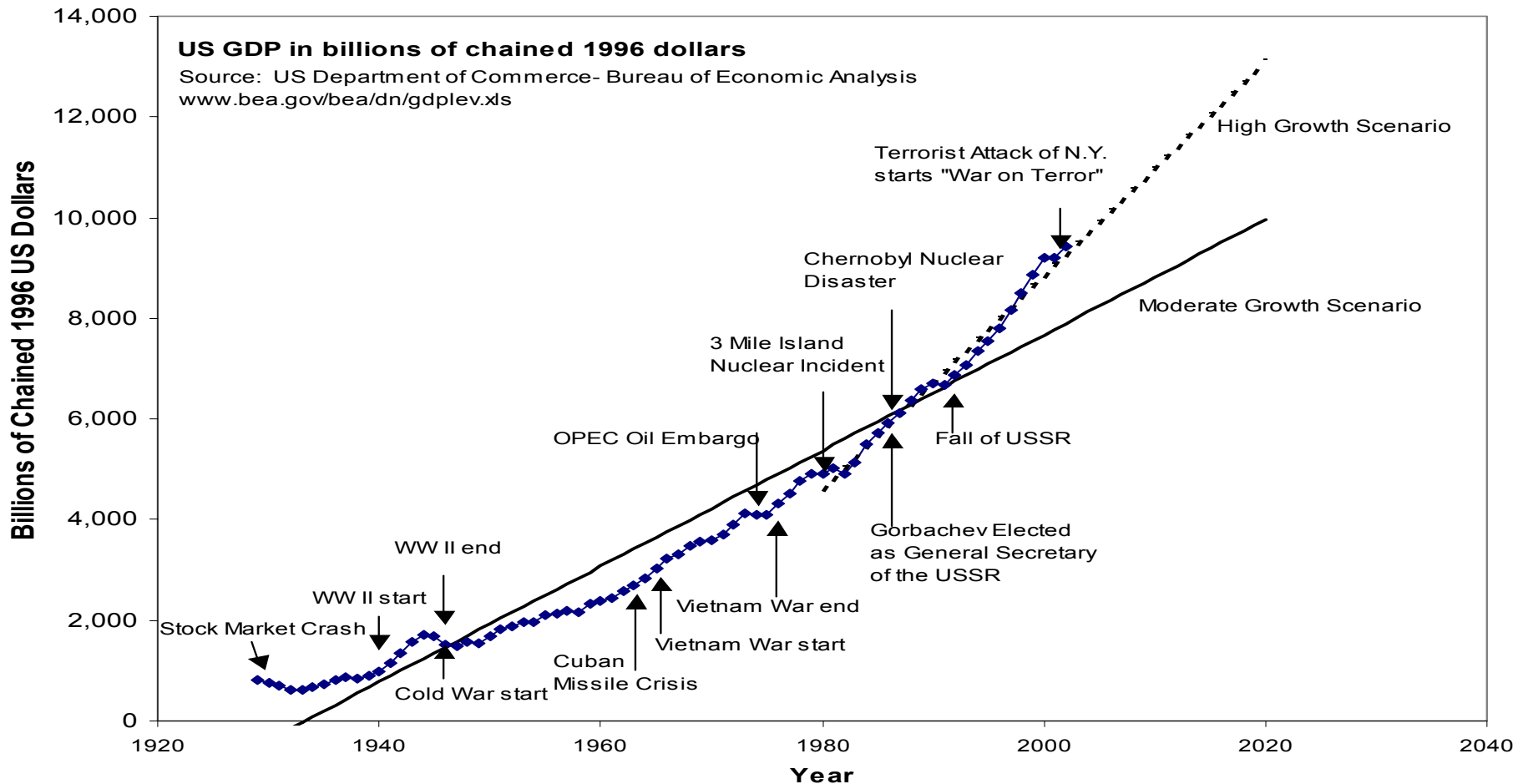
US GDP and Energy Consumption Forecast

	Low Growth 2020	High Growth 2020
GDP (Billions of Chained 1996 US Dollars)	10×10^3	13×10^3
Energy Consumption (Billion BTU/year)	102×10^6	121×10^6

Sector Forecasts

Notes: Primary consumption includes coal, natural gas, petroleum, nuclear electric power, hydroelectric power, wood, waste, alcohol fuels, geothermal, solar, wind, net imports of coal coke, and net imports of electricity.

Electrical Energy = 3514.4GDP + 7E+06
R^2 = 0.9865

Transportation = 1794.3GDP + 1E+07
R^2 = 0.9841

Primary Energy Consumption (Billion BTU/year) (y-axis)

US GDP (Billions of 1996 US Dollars) (x-axis)

Legend:
- ◆ Residential
- ▲ Industrial
- ✳ Electrical Energy Sector
- —— Linear (Transportation)
- ■ Commercial
- ✕ Transportation
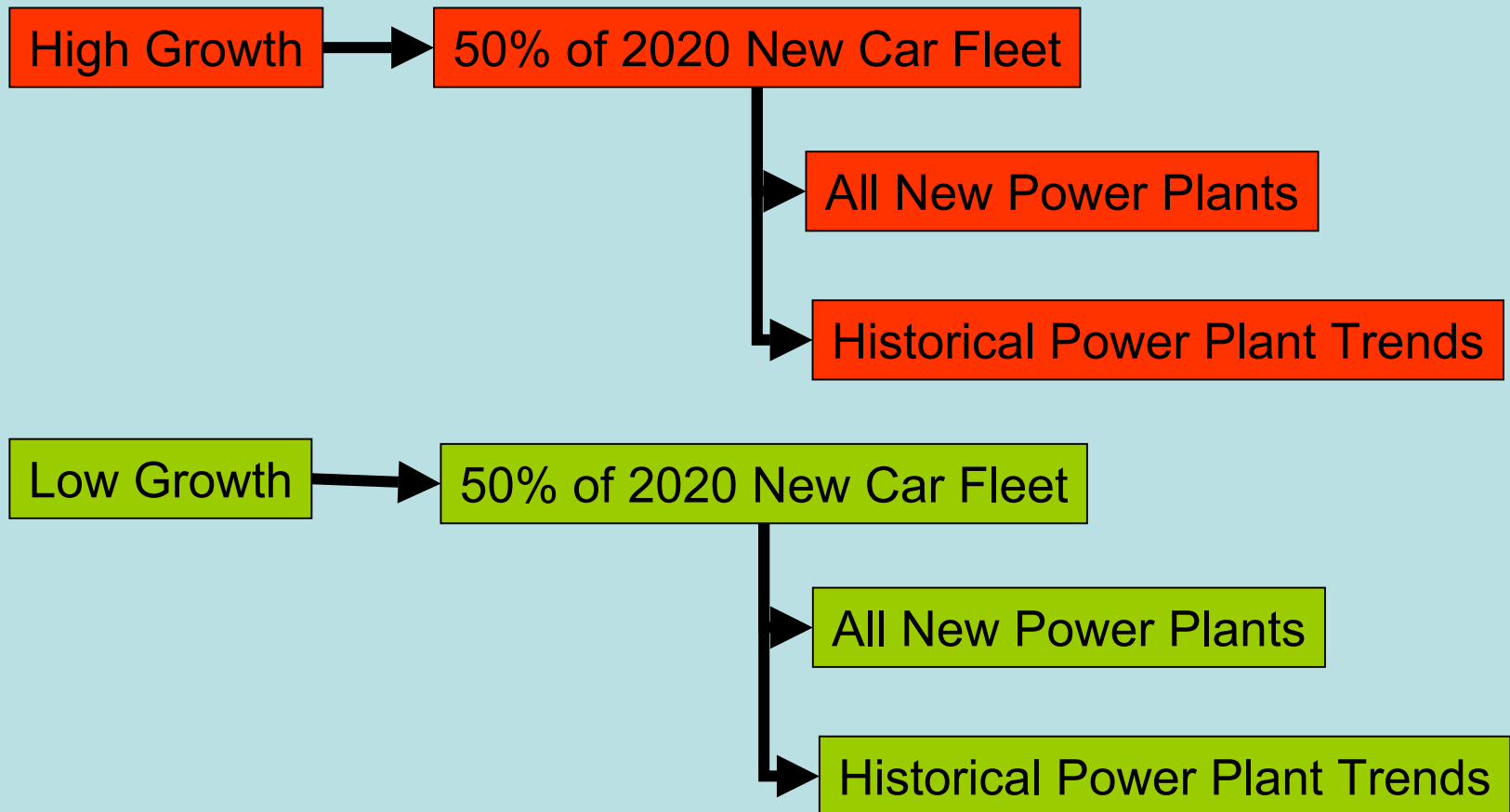- —— Linear (Electrical Energy Sector)

2020 Energy Consumption

- 50% of light and heavy duty vehicles:
  - 10×10^6 to 12×10^6 Billion BTU/yr
- Electrical Sector:
  - 45% of Total US primary energy consumption
  - 46×10^6 to 55×10^6 Billion BTU/yr
  - Historically:
    - ~53% Coal derived
    - ~13% Natural Gas derived

Natural Gas Scenarios

Assuming that natural gas derived methanol is used for transportation

High Growth → 50% of 2020 New Car Fleet

All New Power Plants

Historical Power Plant Trends

Low Growth → 50% of 2020 New Car Fleet

All New Power Plants

Historical Power Plant Trends

Natural Gas Consumption in 2020 Scenario Results

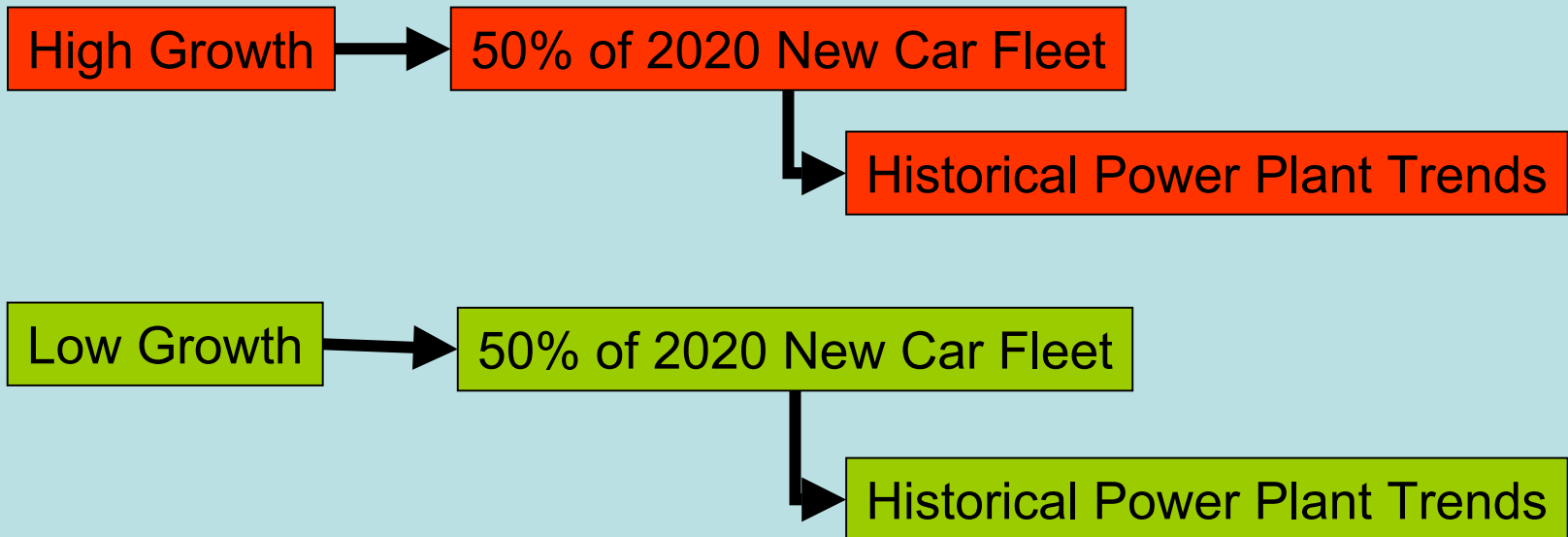|		2020 Natural Gas Electrical and Heating Load	
	2020 Natural Gas Transportation Load	Historical Trend	All future power plants are natural gas fired
High Economic Growth	12×10^6 billion BTU/year	30×10^6 billion BTU/year	57×10^6 billion BTU/year
Low Economic Growth	10×10^6 billion BTU/year	26×10^6 billion BTU/year	46×10^6 billion BTU/year

Natural Gas Resource Resilience

- If US stopped importing natural gas from now to 2020.

Years to 2020 Natural Gas Resource Depletion at 2020 Consumption Rate				
	Low Growth Historical Scenario	High Growth Historical Scenario	Low Growth No New Coal Plants Scenario	High Growth No New Coal Plants Scenario
Fed. Lands not Included	17	9	8	4
Fed. Lands Included	20	16	9	5

Coal Study Scenarios

Assuming coal derived methanol is used for transportation

| High Growth | → | 50% of 2020 New Car Fleet |

Historical Power Plant Trends

| Low Growth | → | 50% of 2020 New Car Fleet |

Historical Power Plant Trends

Coal Results

- If only domestic coal were used:

	Total Coal Consumed from 2000-2020 (billion BTU)	Percentage of Resource Consumed from 2000-2020	2020 Coal Resource (billion BTU)	2020 Years to Resource Depletion
Low Growth	582×10^6	0.67	8.64×10^{12}	2,375
High Growth	643×10^6	0.74	8.64×10^{12}	2,015

Conclusions

- Natural Gas:
  - Similar situation to petroleum likely if used as preferred alternative vehicle transportation feedstock
- Coal:
  - Bountiful
  - Could easily cover future US transportation needs
  - Greater environmental impact, especially greenhouse gas emissions
- Methanol:
  - Versatile fuel
  - Possible alternative to gasoline or diesel

Questions