ENGR-3000:

Renewable Energy, Technology, and Resource Economics

Introduction to Renewable Energy: Basic Energy Concepts

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World Learning

SIT Study Abroad

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Basic Energy Concepts: Outline

- Basic Energy Concepts
  - Force, Weight, Pressure
  - Kinetic and Potential Energy
  - Conservation of Energy
  - Energy and Power
- Capacity Factor
- Levelized Costs: the price of energy
- Worldwide Energy Consumption
- Finite Resources

Basic Concepts: Force and Weight

- From Newton's Second Law of Motion:

$$\text{Force} = \text{mass} \times \text{acceleration}$$

$$\text{units}: \quad [\text{kg}]\left[\frac{\text{m}}{\text{s}^2}\right] = \text{Newton}$$

$$\text{weight} = \text{mass} \times (\text{gravitational acceleration}), \quad g = 9.8\,\frac{\text{m}}{\text{s}^2}$$

$$\text{weight} = \text{density} \times \text{gravitational acceleration} \times \text{volume}$$

$$\text{units}: \quad \left[\frac{\text{kg}}{\text{m}^3}\right]\left[\frac{\text{m}}{\text{s}^2}\right]\left[\text{m}^3\right] = \left[\frac{\text{kg} \cdot \text{m}}{\text{s}^2}\right] = \text{Newton}$$

Pressure

- Pressure = force per unit area:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

$$\text{units}: \left[\frac{\text{Newton}}{\text{m}^2}\right] = \text{Pascal}$$

- Atmospheric pressure
  - one standard atmosphere = 101325 Pa
  - 1 “Bar” = 10^5 Pa, approximately equal to 1 atm.

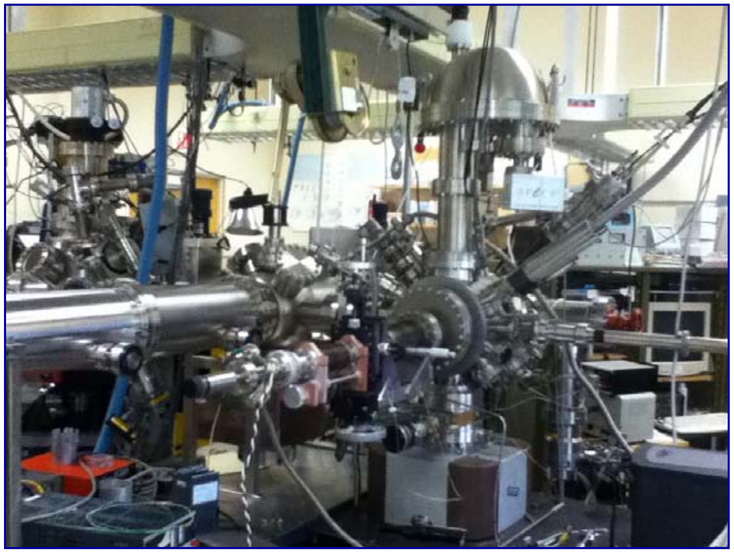
Absolute and Gage Pressure

Absolute Pressure:

- Measured relative to a perfect vacuum

Gage Pressure:

- Measured relative to atmospheric pressure



$$P_{gage} = P_{abs} - P_{atm}$$

Kinetic and Potential Energy

- The kinetic energy of an object is related to its mass and its velocity:

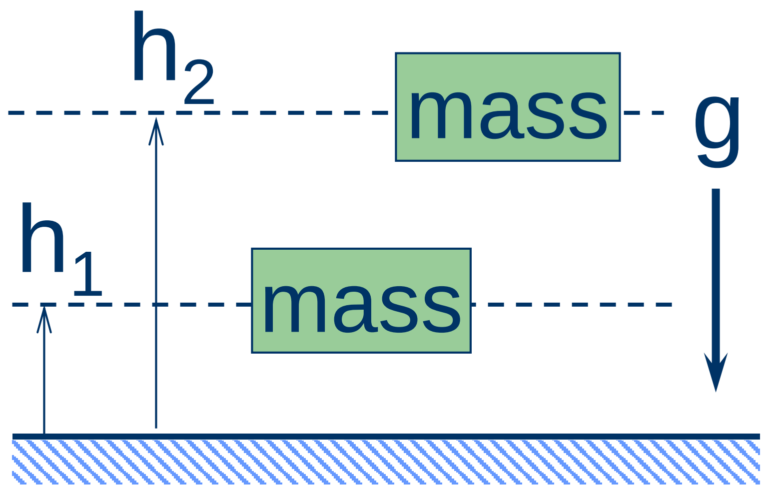
$$KE = \frac{1}{2} mV^{2}$$

- The change in potential energy of an object is related to its motion in a gravitational field

1 = Initial State

2 = Final State

$$\Delta PE = mgh_2 - mgh_1$$



Work, Energy, and Power

- Work and Energy

$$\text{Work} = \text{energy} = \text{force} \times \text{dis tan ce}$$

$$\text{units}: \ [\text{Newton}][\text{m}] = \text{Joule}$$

- Power is energy in motion

$$\text{Power} = \frac{\text{energy}}{\text{time}} = \text{force} \times \text{velocity} = \text{voltage} \times \text{current}$$

$$\text{units}: \ \left[\frac{\text{Joule}}{\text{s}}\right] = [\text{Newton}]\left[\frac{\text{m}}{\text{s}}\right] = [\text{volt}][\text{amp}] = \text{Watt}$$

Note: 1 hp = 550 ft·lbf/s = 746 Watts

Conservation of Energy

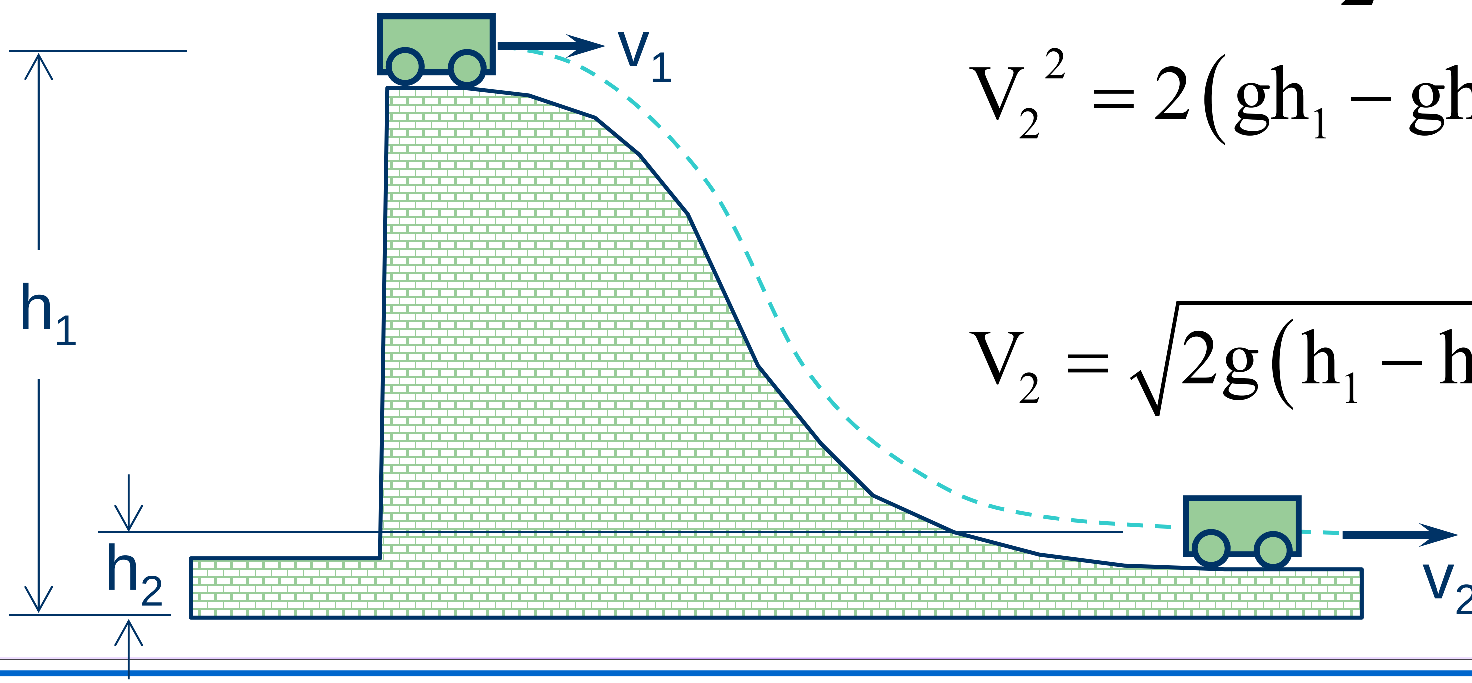
- Energy cannot be created or destroyed, only converted from one form to another:

$$mgh_1 + \frac{1}{2}mV_1^{\,2} = mgh_2 + \frac{1}{2}mV_2^{\,2} + \text{losses}$$

Set $V_1 = 0$, neglect losses: $gh_1 = gh_2 + \frac{1}{2}V_2^{\,2}$

$$V_2^{\,2} = 2\left(gh_1 - gh_2\right)$$

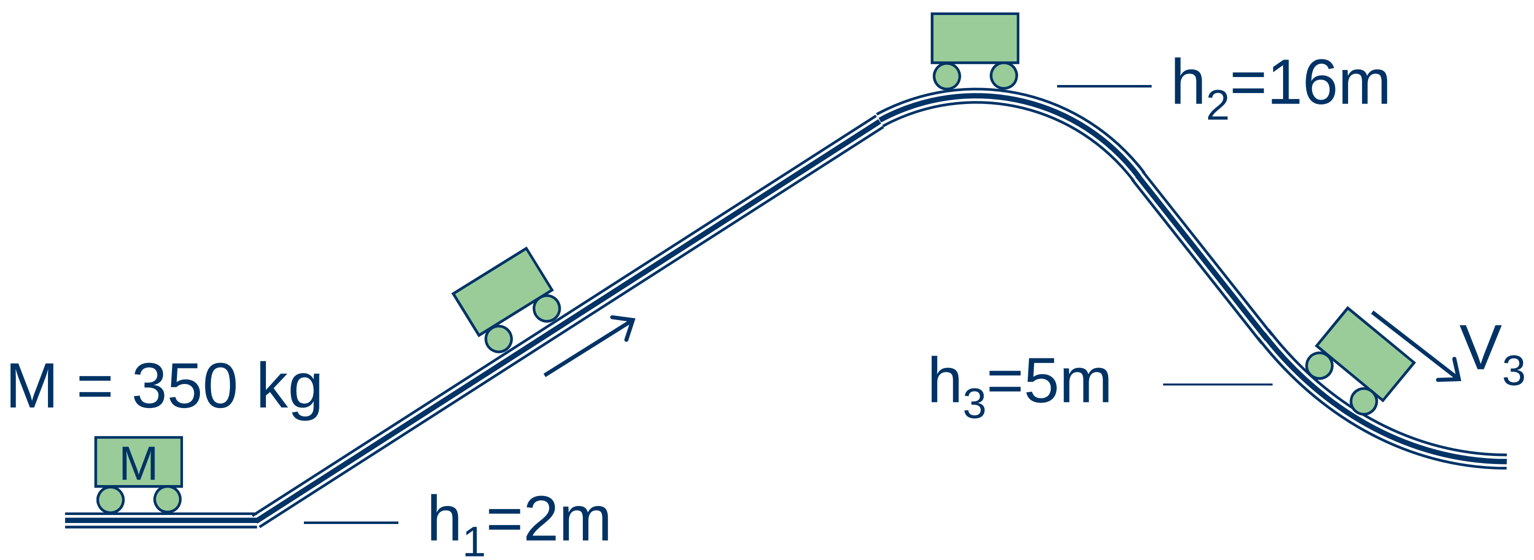
$$V_2 = \sqrt{2g\left(h_1 - h_2\right)}$$



Exercise: Potential and Kinetic Energy

A roller coaster car is pulled up a track (1→2) and then released to slide down the track (2 →3), neglect friction.

- Calculate the weight of the car ($g = 9.8\ m/s^2$)
- Determine the change in potential energy from 1 to 2
- Calculate the velocity of the car at 3
- Calculate the kinetic energy of the car at 3



Basic Units: Powers of Ten

deka (da)	10^{1}	deci (d)	10^{-1}
hecto (h)	10^{2}	centi (c)	10^{-2}
kilo (k)	10^{3}	milli (m)	10^{-3}
Mega (M)	10^{6}	micro (μ)	10^{-6}
Giga (G)	10^{9}	nano (n)	10^{-9}
Tera (T)	10^{12}	pico (p)	10^{-12}
Peta (P)	10^{15}	femto (f)	10^{-15}
Exa (E)	10^{18}	atto (a)	10^{-18}

Power and Energy

- If we multiply power by time we get energy:

$$1\text{kW} = 1\frac{\text{kJ}}{\text{s}}; \quad 1\text{kW}\cdot\text{s} = 1\text{kJ}$$

$$1\text{kW}\cdot\text{s}\left(\frac{\text{h}}{3600\text{s}}\right) = 1\text{kJ}$$

$$\text{so}: \ 1\text{kWh} = 3600\text{kJ}$$

- Economics of Renewable Energy
  - We install power capacity (MW) – capital costs
  - We sell energy (kWh) – annual revenue

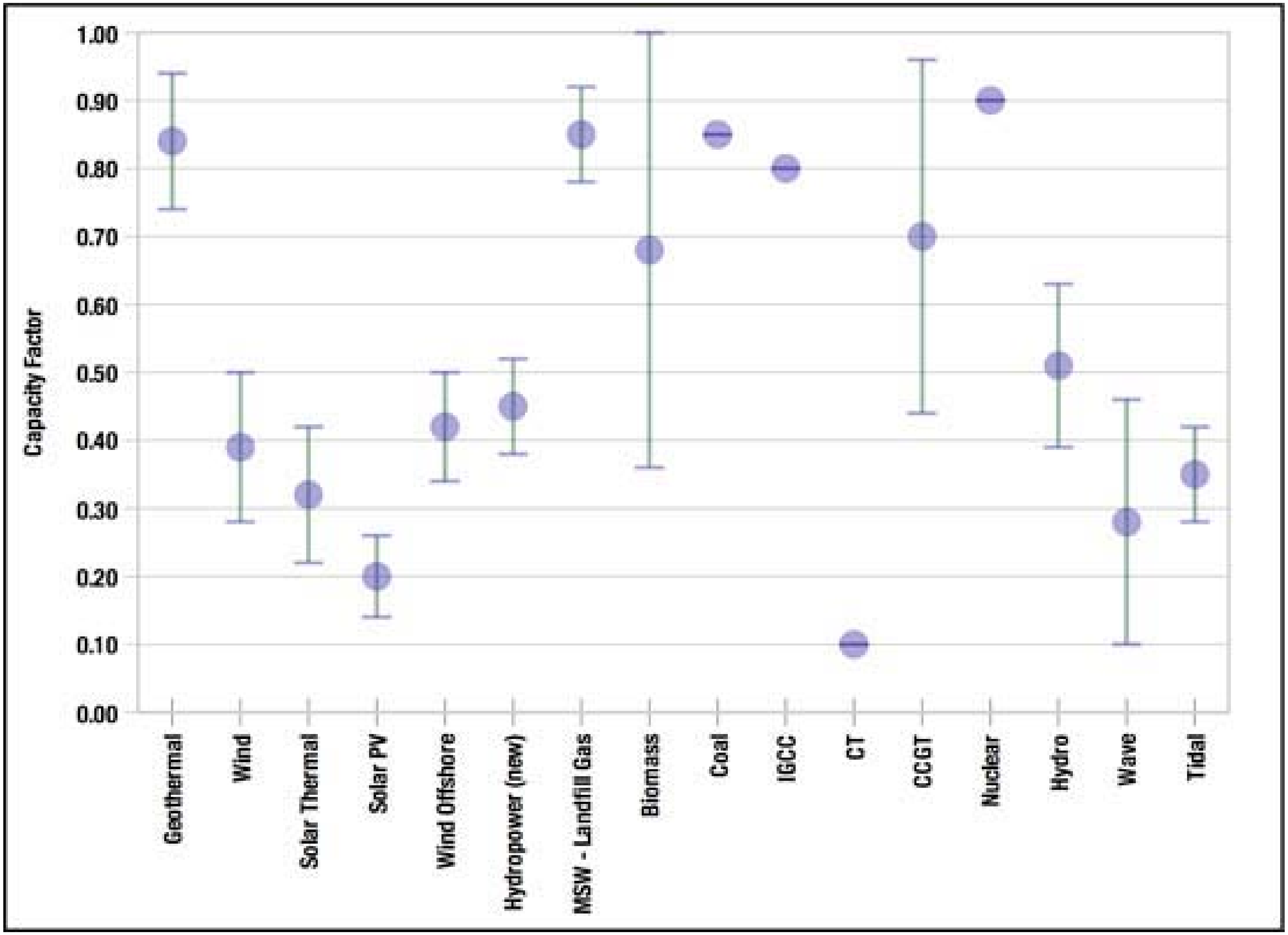
Capacity Factors: an Introduction

- The capacity factor of a device is the measured output divided by the maximum output based on the device's design specification
- The "Capacity factor" of a car could be determined as follows:

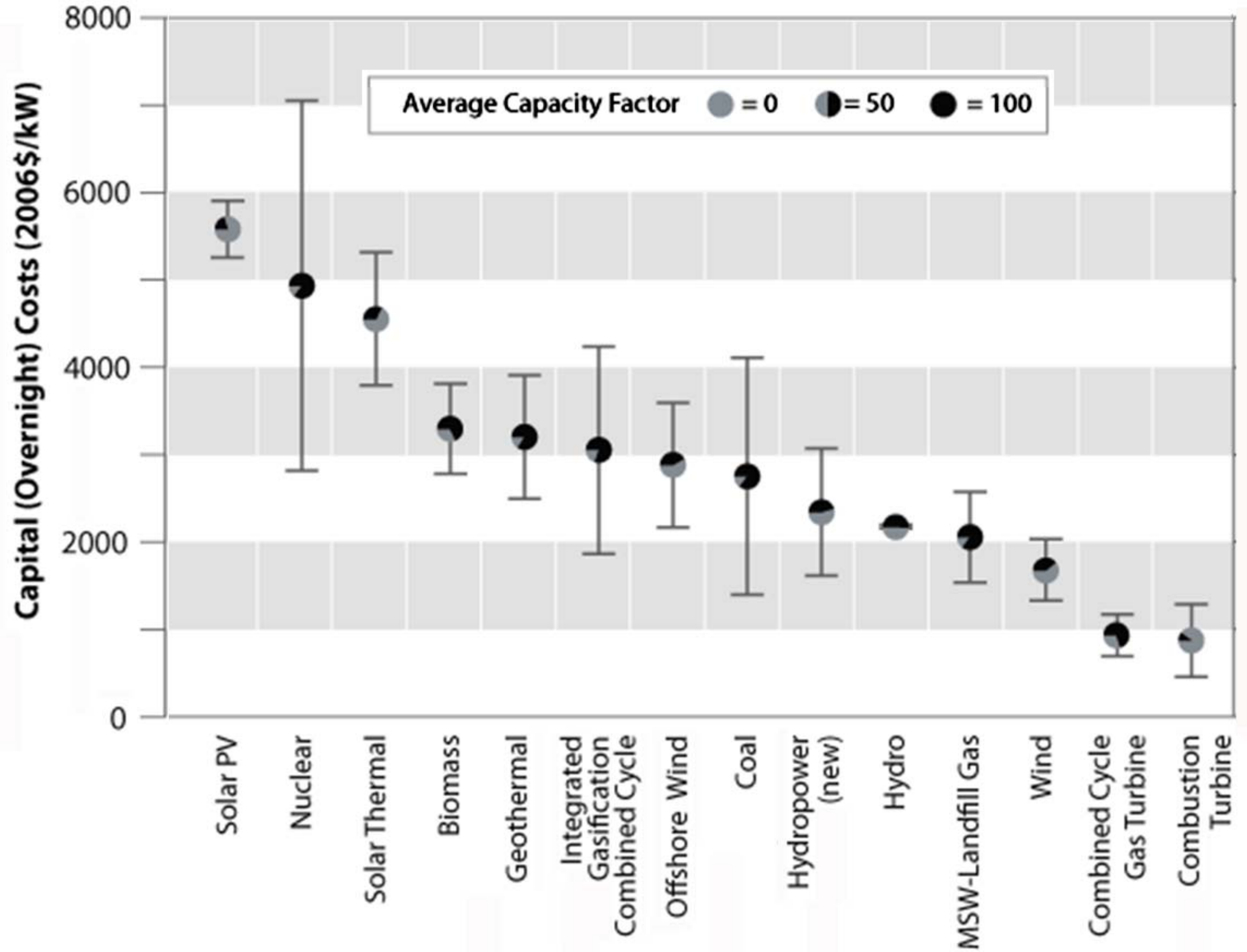
$$C = \frac{\text{miles driven in a year}}{\text{max. possible annual milage}}$$

  - What kind of car do you have?
  - How fast does it go?
  - How many miles did you drive last year?
  - From your answers (estimates) to the above questions, determine the capacity factor for your car

Capacity Factors of Energy Sources



Power Generation: Capital Costs and Capacity Factors



Source: http://www.nrel.gov/analysis/costs.html

Example: Capacity Factor

- An 1800kW wind turbine has a capacity factor of 0.32. Determine the annual energy production.

$$1800\text{kW}\left(8760\frac{\text{h}}{\text{y}}\right)=15.8\times10^{6}\frac{\text{kWh}}{\text{y}}$$

$$\left(15.8\times10^{6}\frac{\text{kWh}}{\text{y}}\right)(0.32)=5.1\times10^{6}\frac{\text{kWh}}{\text{y}}$$

$$5.1\times10^{6}\frac{\text{kWh}}{\text{y}}\left(\frac{10^{3}\,\text{W}}{\text{kW}}\right)=5.1\times10^{9}\frac{\text{Wh}}{\text{y}}$$

$$5.1\times10^{9}\frac{\text{Wh}}{\text{y}}\left(\frac{\text{GW}}{10^{9}\,\text{W}}\right)=5.1\frac{\text{GWh}}{\text{y}}$$

Exercise: Capacity Factor

- The London Array is an offshore wind farm comprised of 175 wind turbines, each rated at 3.6 MW. In 2015 this wind farm produced 2.49 TWh of electricity.

- ➢ Determine the total power capacity of this wind farm
- ➢ Using the 2015 energy output, estimate the capacity factor.

http://earthobservatory.nasa.gov/IOTD/view.php?id=82844

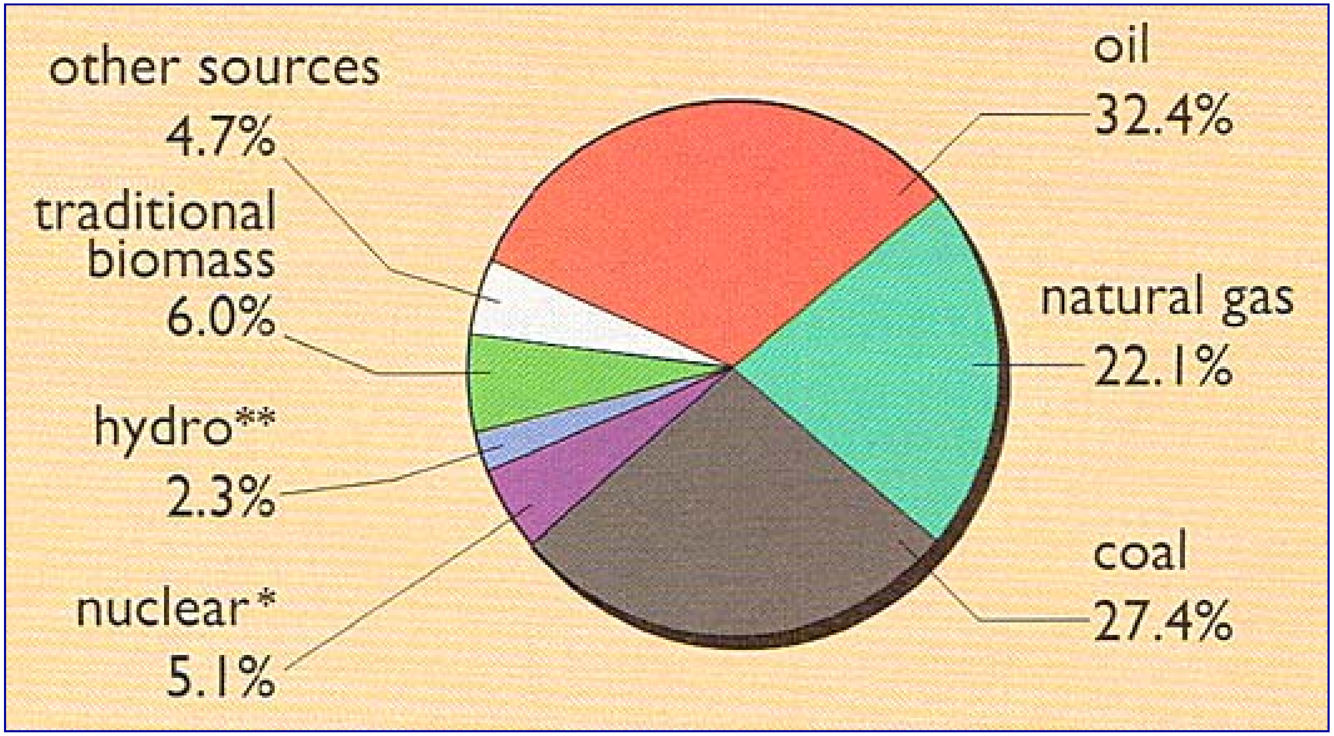
Power Generation: Levelized Costs $/MWh

Estimated Costs for New Generation Resources, 2022: Plant Type (Capacity Factor)	Capital Cost	Fixed O&M	Variable O&M (Incl. Fuel)	Transmission Investment	Total System Levelized Cost
Dispatchable Technologies					
Coal (85%)[1]	60.4	4.2	29.4	1.2	95.2
Combined Cycle (87%)	8.1	1.5	32.3	0.9	42.8
Advanced Nuclear (90%)[2]	69.4	12.9	9.3	1.0	92.6
Geothermal (90%)	24.6	13.3	0.0	1.4	39.4
Biomass (83%)	37.3	15.7	37.5	1.5	92.1
Hydro (75%)	29.9	6.2	1.4	1.6	30.1
Non-Dispatchable					
Wind (44%)	27.8	12.6	0.0	2.4	42.8
Offshore Wind (45%)	95.5	20.4	0.0	2.1	117.9
Solar PV (29%)	37.1	8.8	0.0	2.9	48.8
Solar Thermal, CSP (25%)[2]	128.4	32.6	0.0	4.1	165.1

U.S. Energy Information Administration, Annual Energy Outlook 2015[1], 2018[2], &2019.
https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

World Primary Energy Consumption (2009)

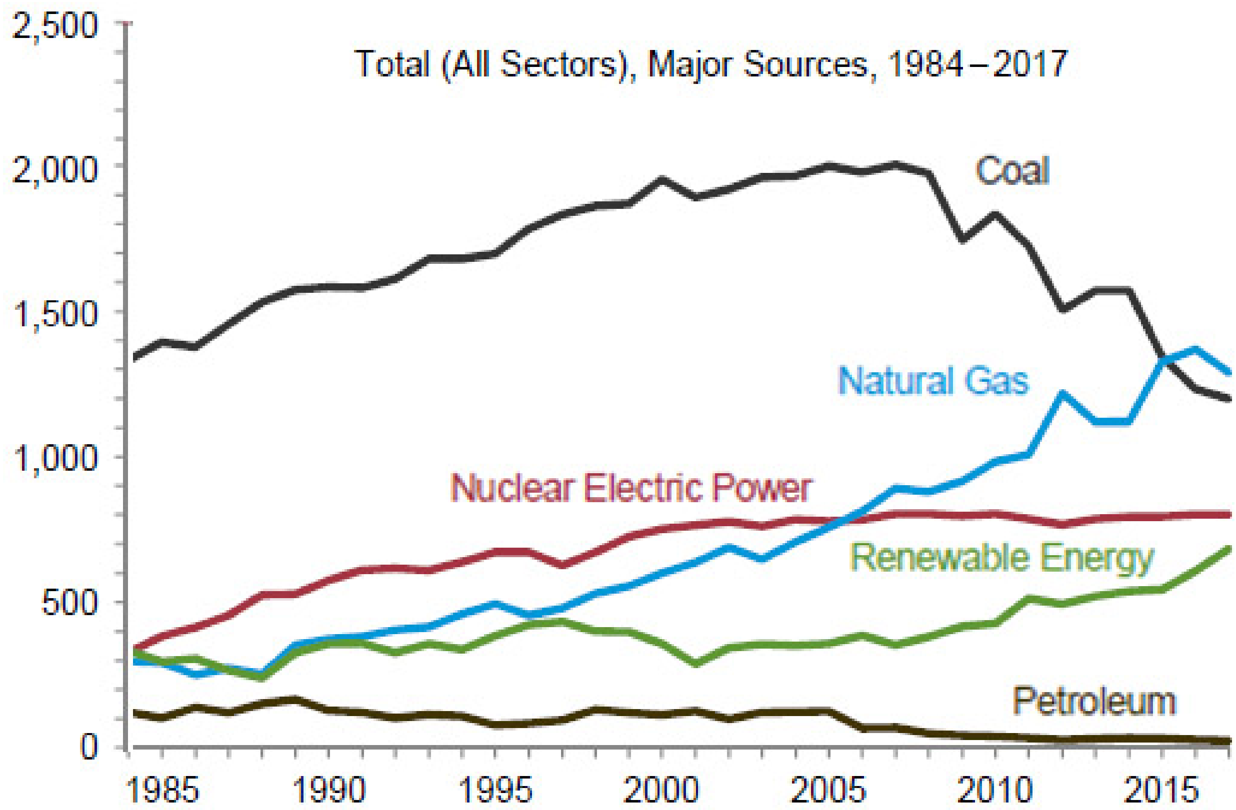
- Total worldwide energy consumption = 502 EJ
- 2009 Worldwide population = 6.8 billion
- Average rate of energy consumption = 15.9 TW



Boyle, Fig 1.2

Changes in Energy Supply Profile

- U.S. Net Electricity Generation (Billion kWh)



EIA Monthly Energy Review Feb 2019

World Population Trends

Country	2005	2015	2025	%
Japan	127.5	124.7	117.8	-7.6
Germany	82.4	81.9	80.6	-2.1
Russia	142.8	136.0	128.1	-10.3
USA	295.7	322.6	349.7	18.2
China	1306	1393	1453	11.2
India	1094	1274	1449	32.4
World	6449	7226	7959	23.4

Source: www.census.gov/ipc/www/idb/summaries.html; values in millions; percent change from 2005 to 2025

Average per capita energy consumption (2016 data)

$$611\,\text{EJ} = 611\times10^{18}\,\text{J}$$

$$\text{Population} = 7.46\times10^{9}\,\text{persons}$$

$$\frac{611\times10^{18}\,\text{J}}{7.46\times10^{9}\,\text{person}} = 81.9\times10^{9}\,\frac{\text{J}}{\text{person}}$$

$$81.9\times10^{9}\,\frac{\text{J}}{\text{person}}\left(\frac{\text{GJ}}{10^{9}\,\text{J}}\right) = 82\,\frac{\text{GJ}}{\text{person}}$$

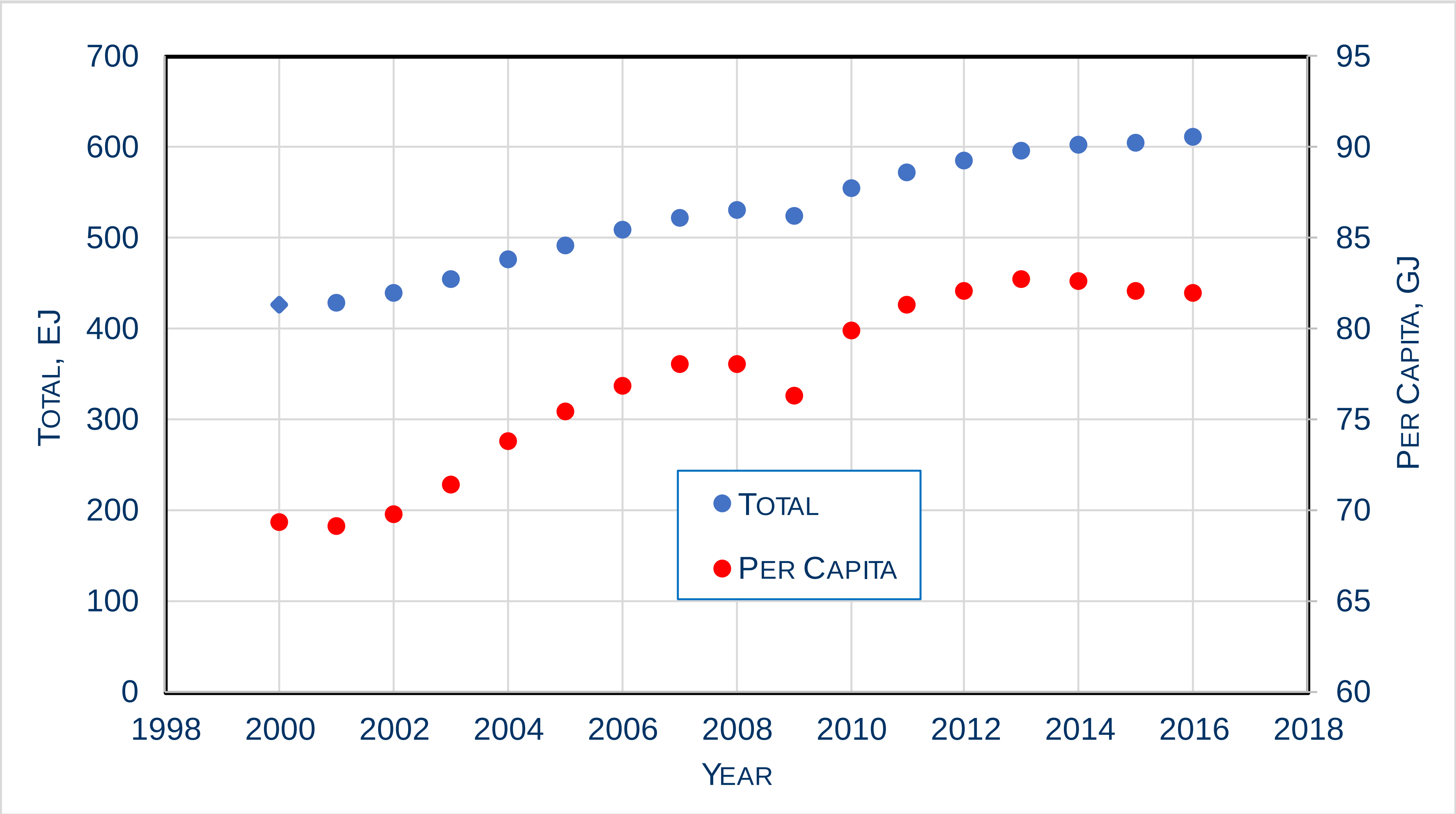
http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm

Per Capita Energy Consumption in GJ per Year (2006 → 2016 data)

Source http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm

Iceland:	568.6 → 671.9	Norway:	433.4 → 391.9
Kuwait:	495.6 → 420.6	Canada:	450.7 → 429.5
USA:	353.0 → 323.8	Australia:	292.1 → 260.6
Russia:	225.7 → 230.8	France:	190.6 → 160.1
Japan:	188.5 → 162.3	Germany:	187.3 → 177.5
UK:	170.6 → 140.9	S. Africa:	123.7 → 114.3
China:	59.3 → 104.6	Brazil:	54.0 → 63.3
Indonesia:	18.9 → 29.3	India:	16.8 → 23.1
Pakistan:	15.0 → 17.0	Nigeria:	8.3 → 9.0
Malawi:	2.0 → 1.6	Afghanistan:	0.6 → 4.2

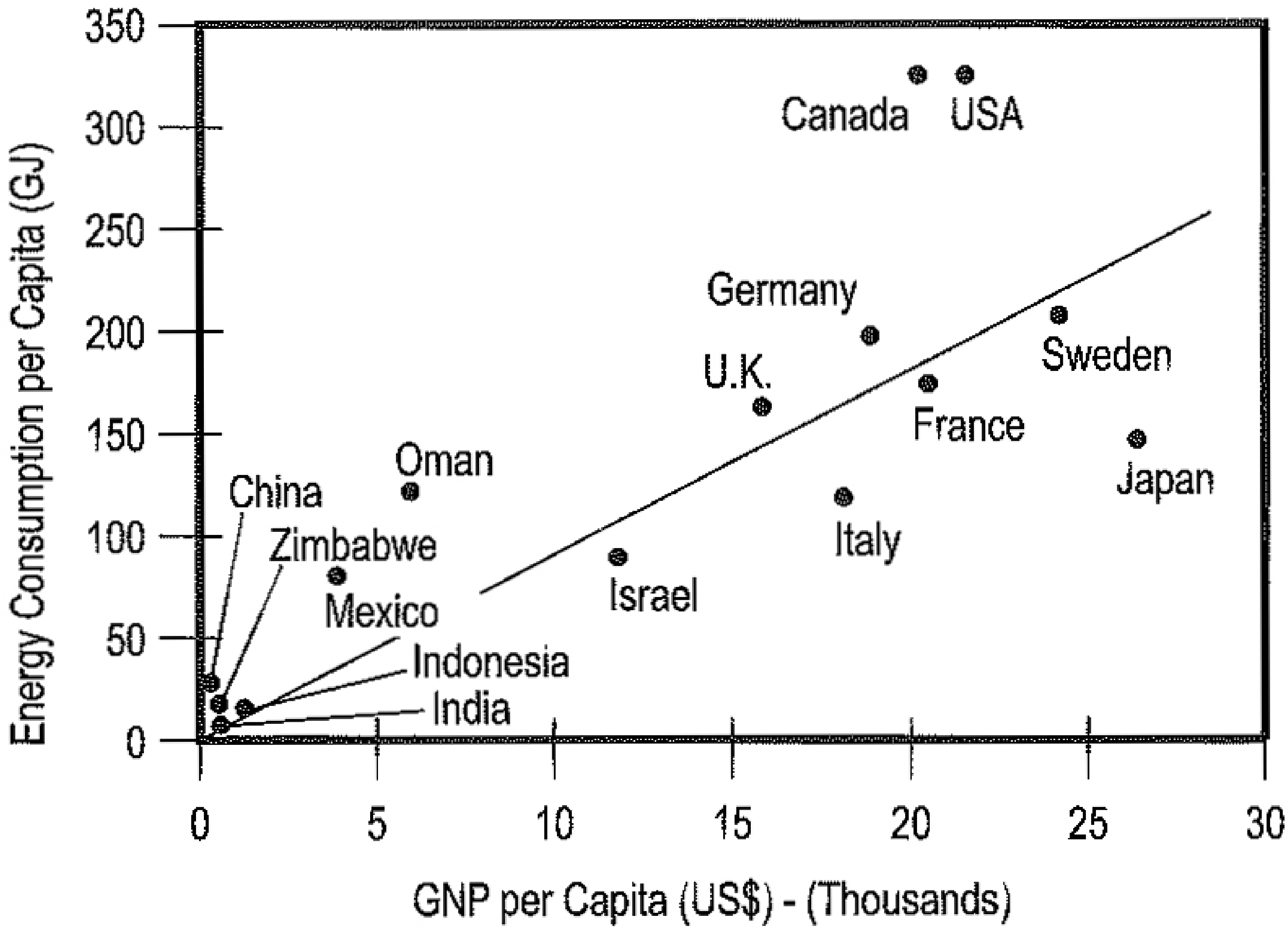
Worldwide Primary Energy Consumption



http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm

https://www.eia.gov/beta/international/data

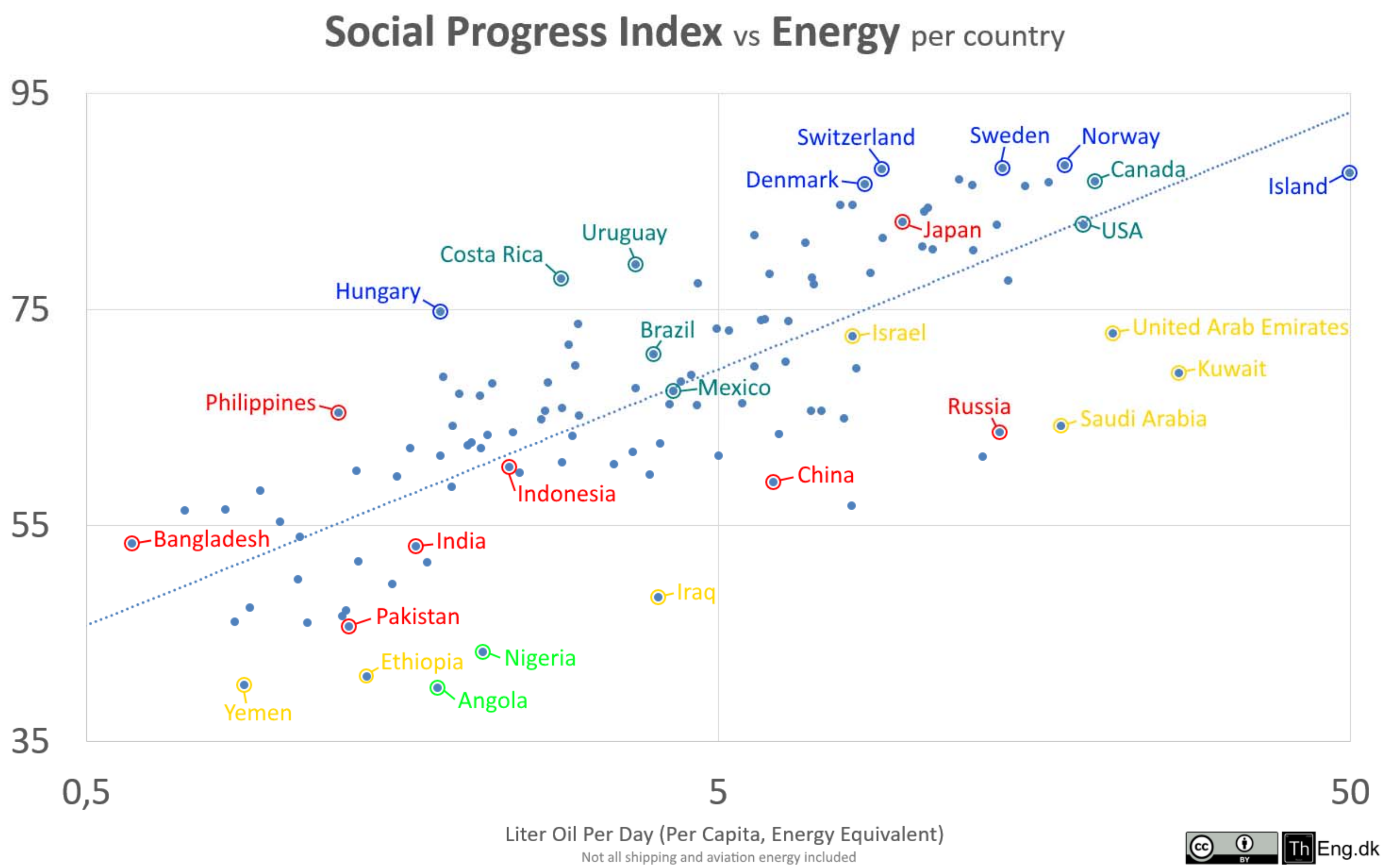
Energy Use vs. GNP



Tester, et. al., <u>Sustainable Energy: Choosing Among Options</u>, MIT Press, 2012

Social Progress Index vs Energy per Country

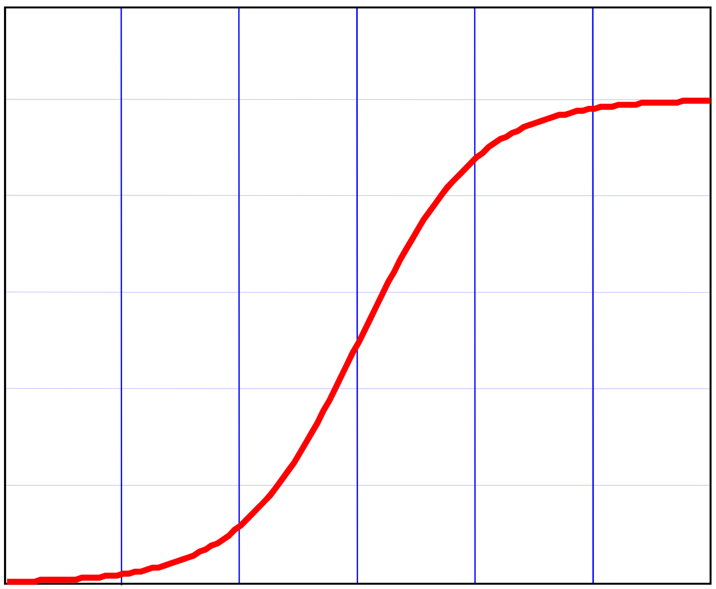
- Non-economic measures of societal well-being also correlate to energy use



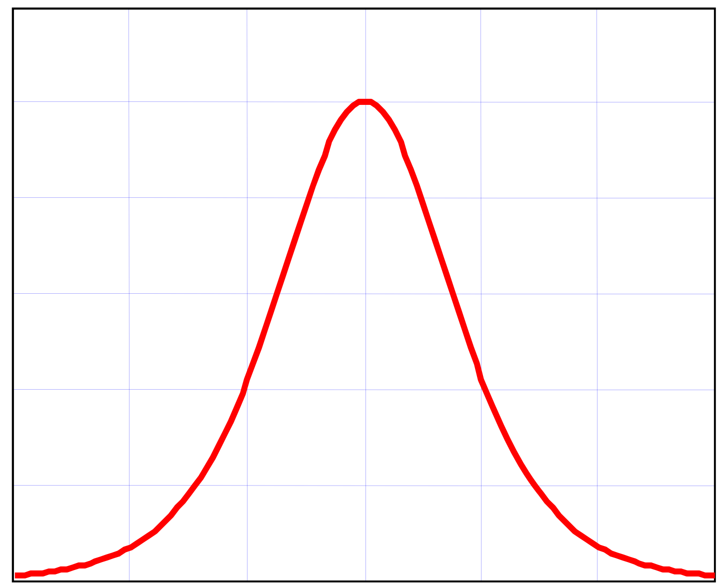
https://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita

Logistics Curve and Production Rate for a Finite Resource

- Production (Q)



- Production Rate (P)

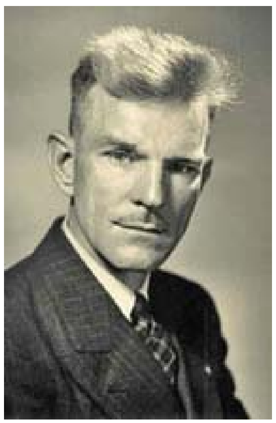


$$Q(t) = \frac{Q^{\infty}}{1 + ae^{-bt}}$$

$$P(t) = \frac{dQ(t)}{dt} \qquad Q^{\infty} = \int P(t)dt$$

US Oil Production: "Hubbert's Peak

- In 1956, Shell geophysicist M.King Hubbert predicted that US production (lower 48 states) would peak in the early 1970's. The actual peak occurred in 1970.



King Hubbert
1903-1989

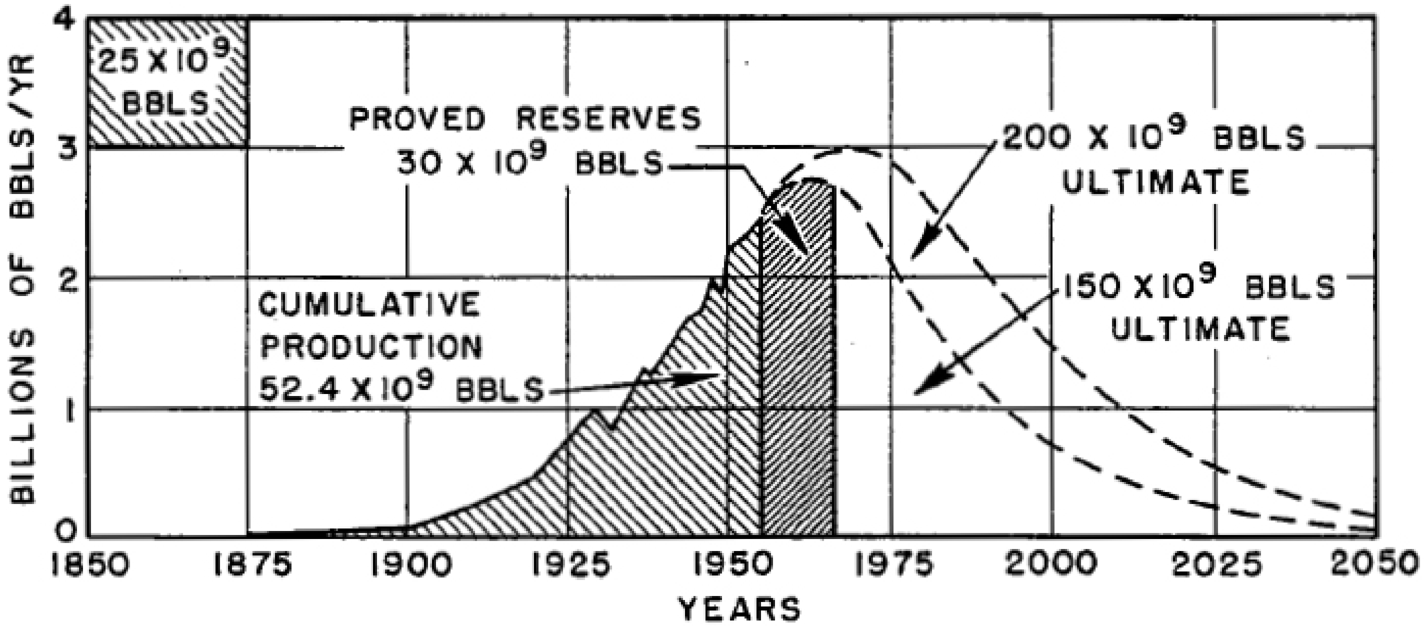


Figure 21 – Ultimate United States crude-oil production based on assumed initial reserves of 150 and 200 billion barrels.

Hubbert, M.K., "Nuclear Energy and Fossil Fuels," American Petroleum Institute, 1956

World Oil Production

- Hubbert's 1956 prediction, based on an estimate of 1.25 trillion barrels of ultimate discoverable oil

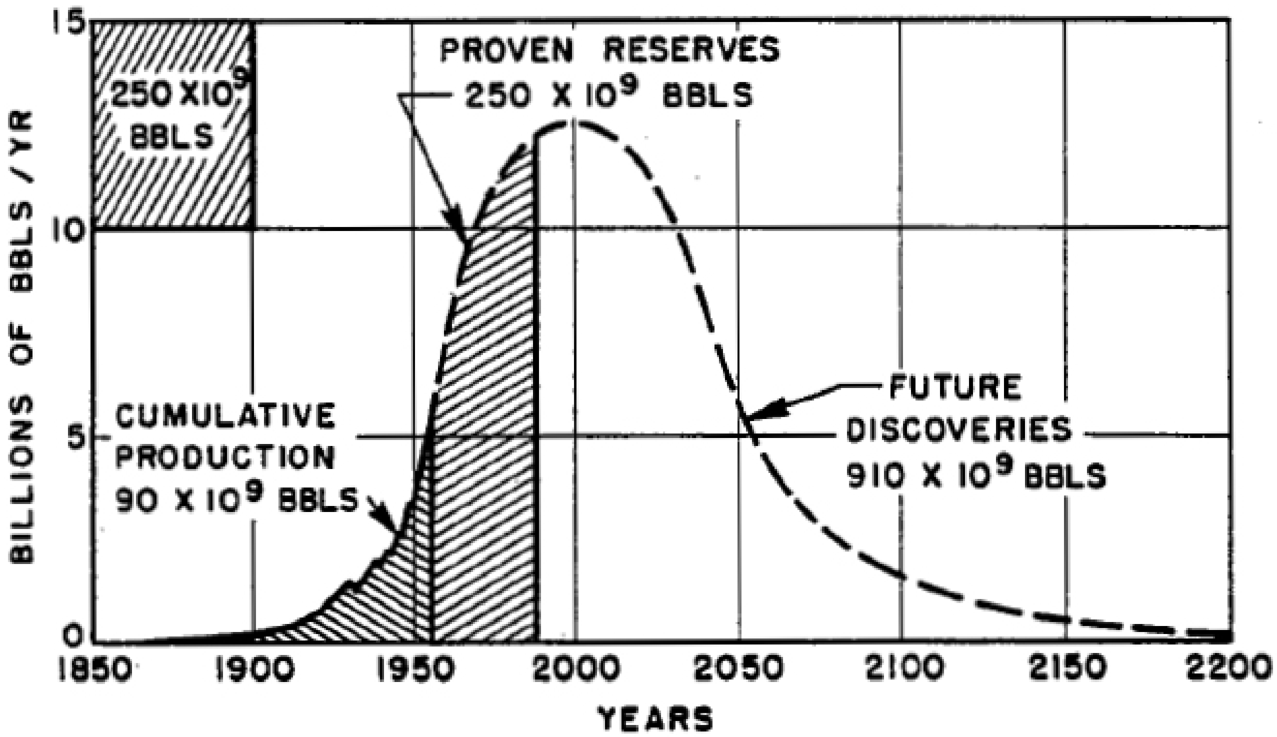
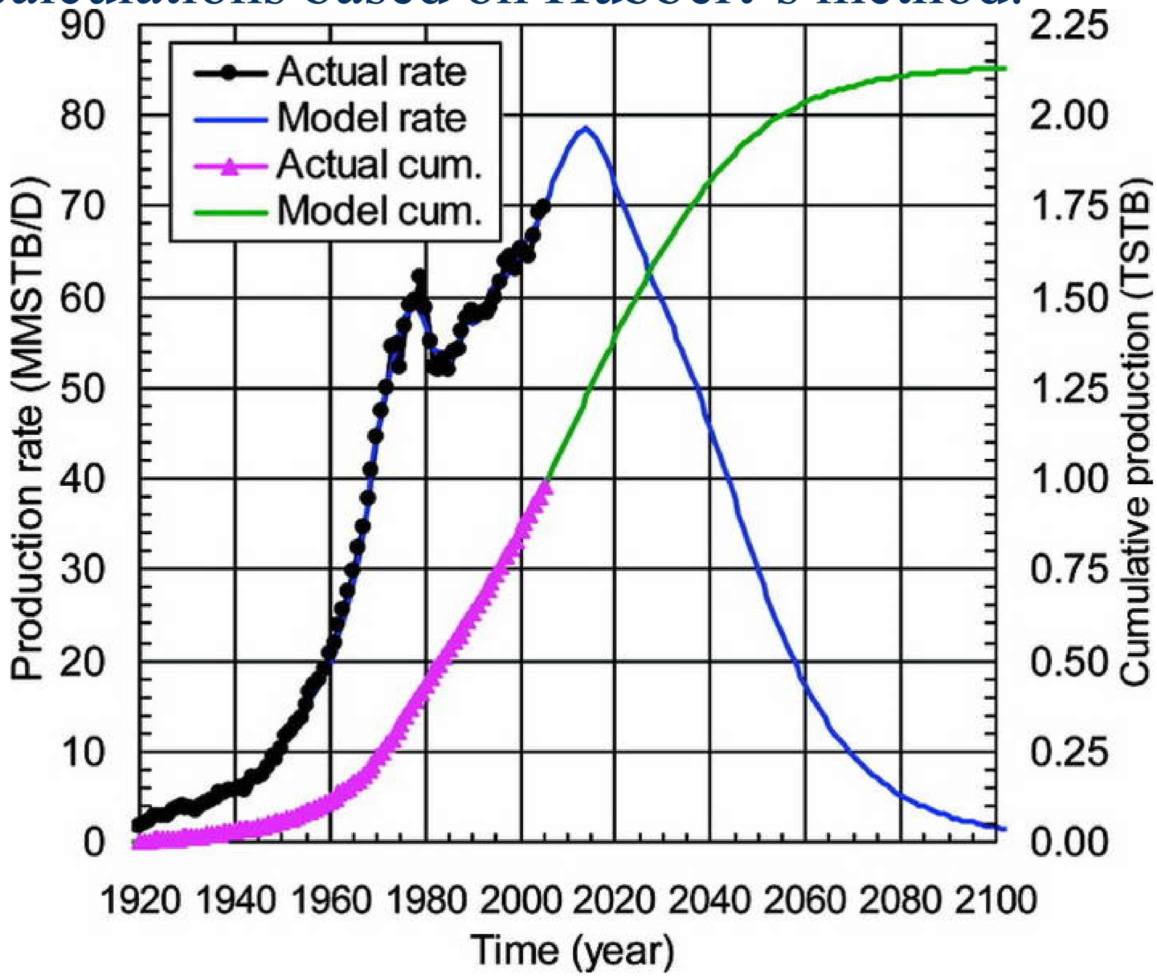


Figure 20 – Ultimate world crude-oil production based upon initial reserves of 1250 billion barrels.

Worldwide Oil Production (Conventional)

- Recent calculations based on Hubbert's method:



Nashawi et al, "Forecasting Peak World Crude Oil Production Using Multicyclic Hubbert Model," Energy Fuels 2010, 24, pp1788–1800.

Past, Present, and Future Oil Production

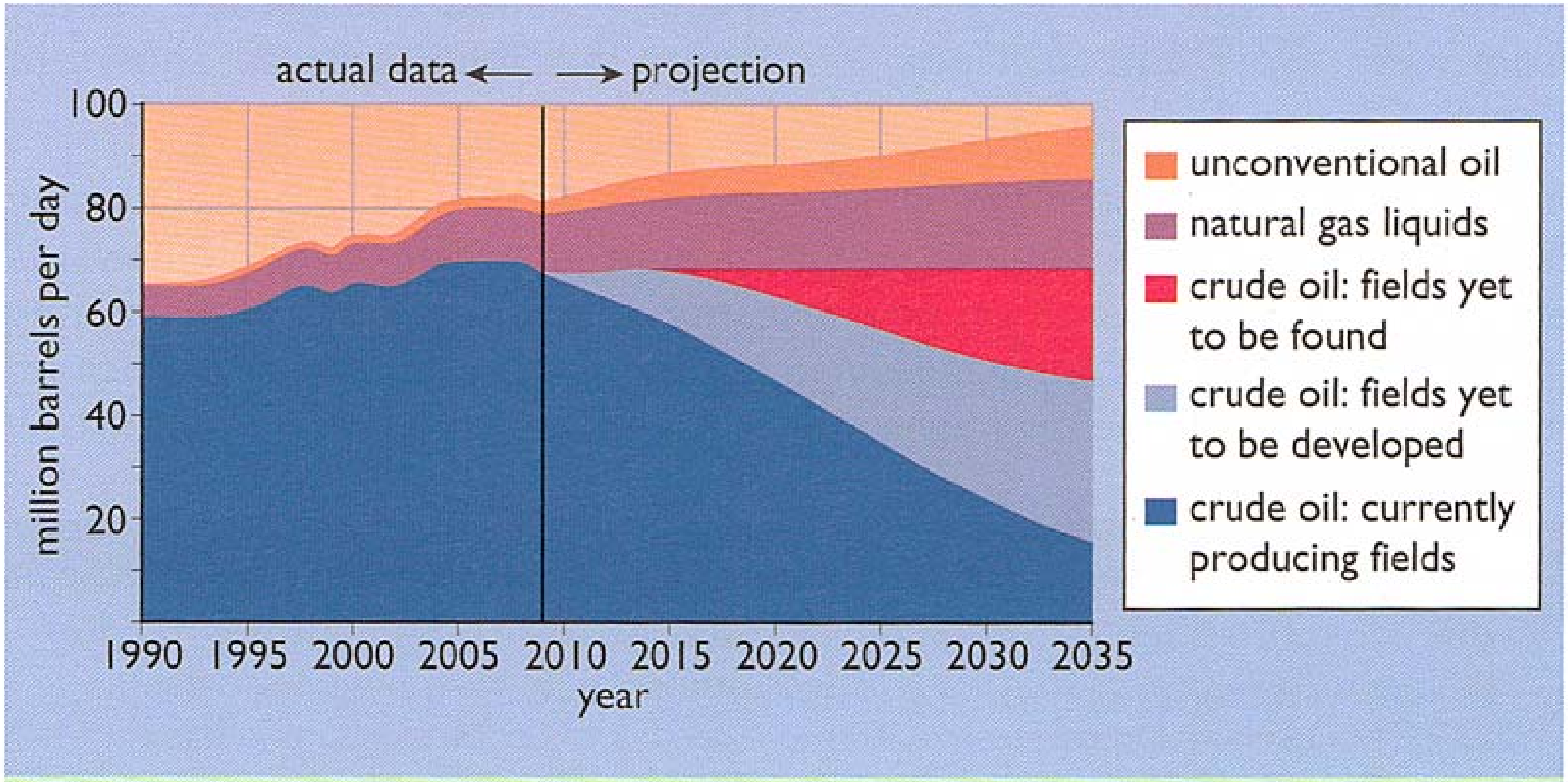
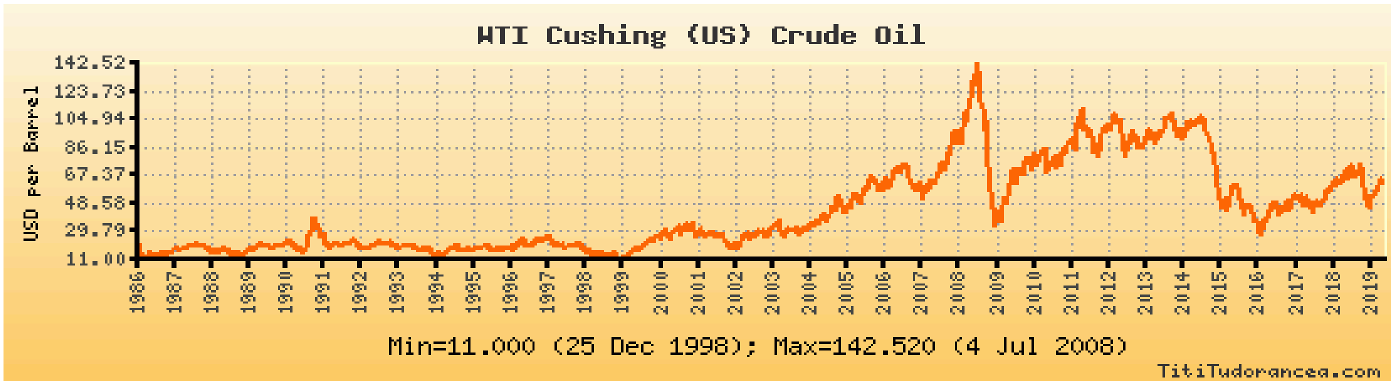
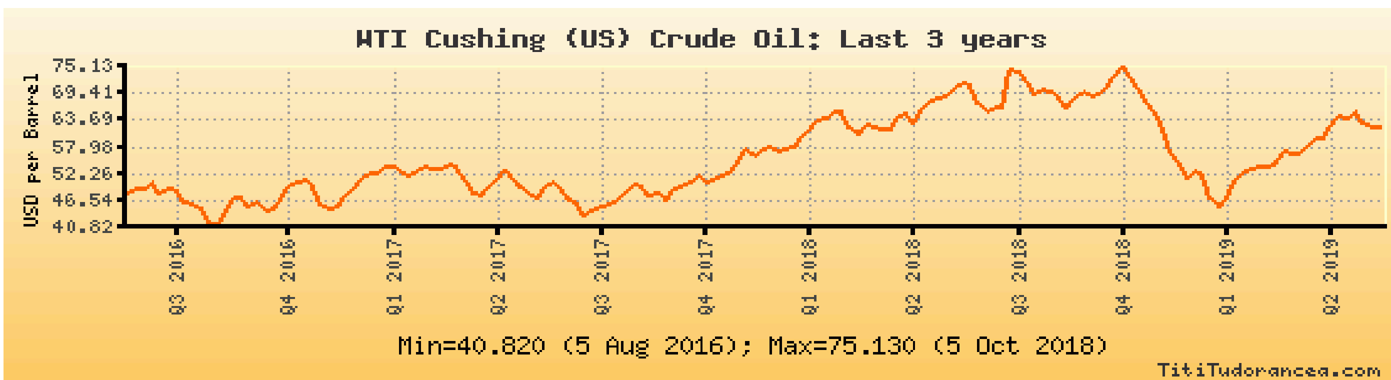


Figure 1.4 An International Energy Agency chart indicating the challenges involved in maintaining current levels of conventional oil production (source: IEA, 2010a)

Crude Oil Prices: The Latest Data





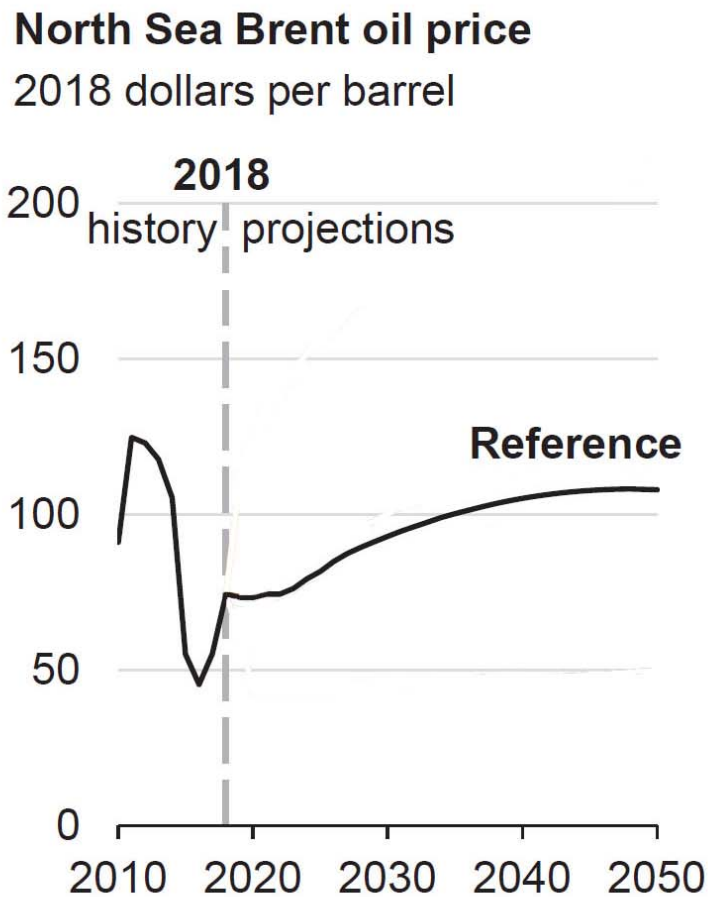
- As of 24 May 2019: Crude Oil Price = $68.69/bbl

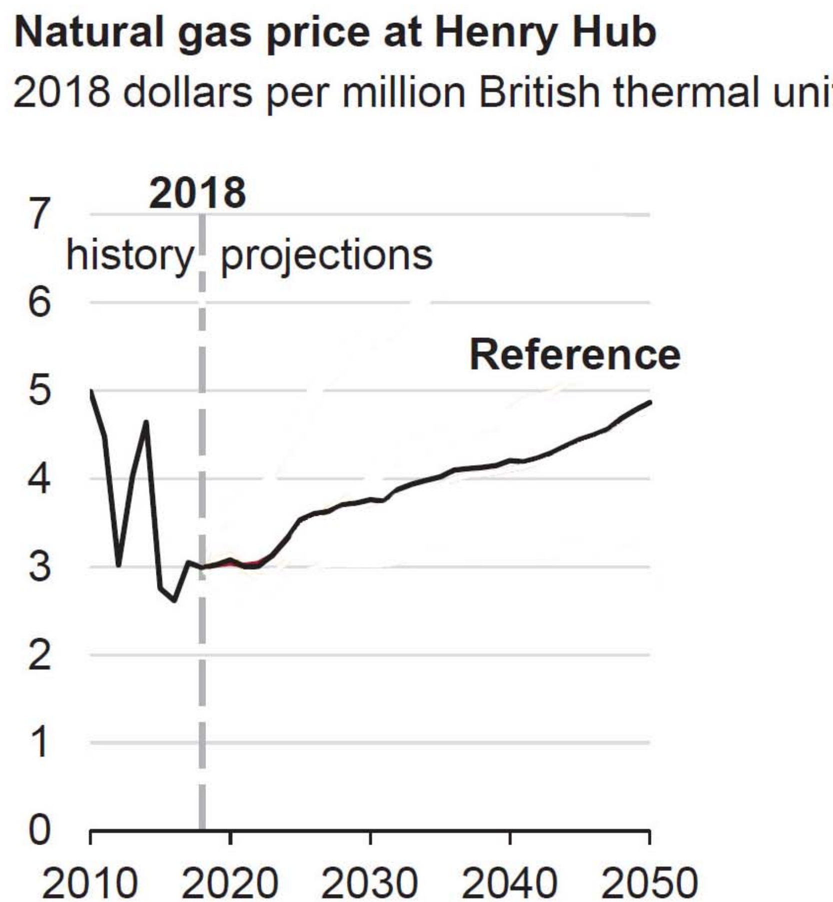
http://www.bloomberg.com/energy/

http://www.tititudorancea.com/z/wti_cushing_crude_oil_prices_graphs_history.htm

Current Oil Price Projections

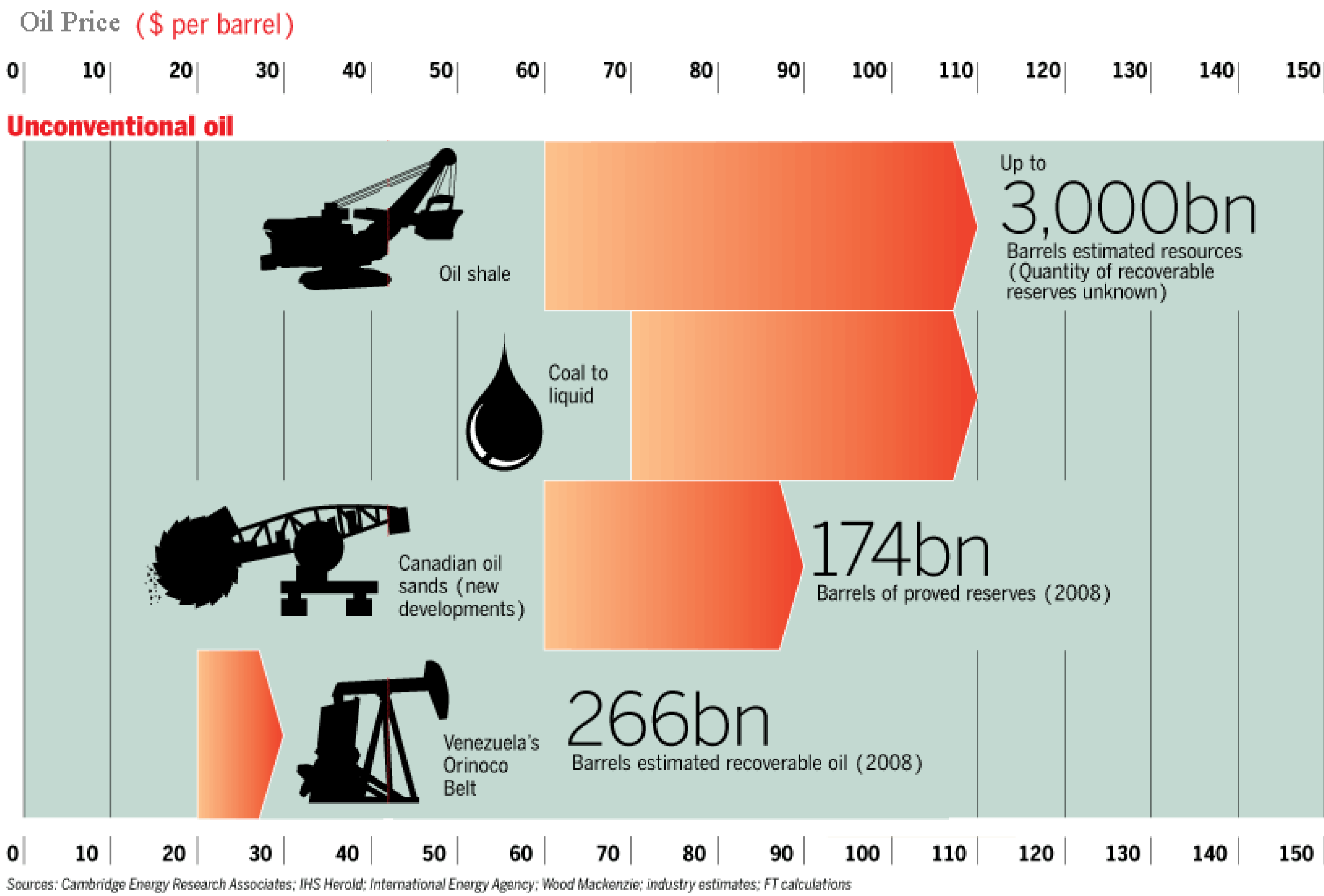
- Oil and natural gas are affected by assumptions about international supply and demand, and the development of U.S. shale resources





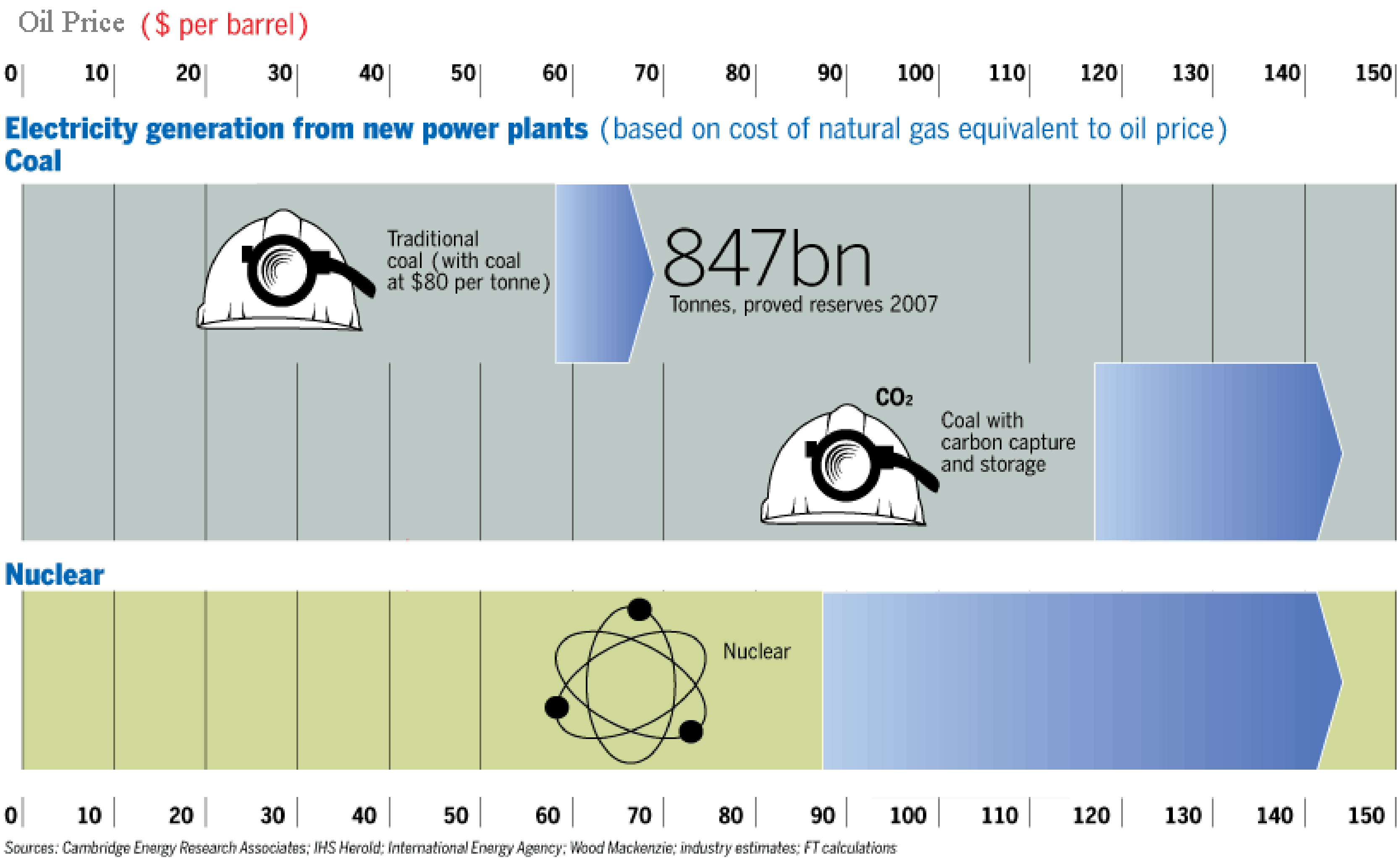
Unconventional Sources of Oil

- As the price of oil increases, other sources of fossil energy become economically competitive:



London Financial Times, Dec 2008. www.ft.com

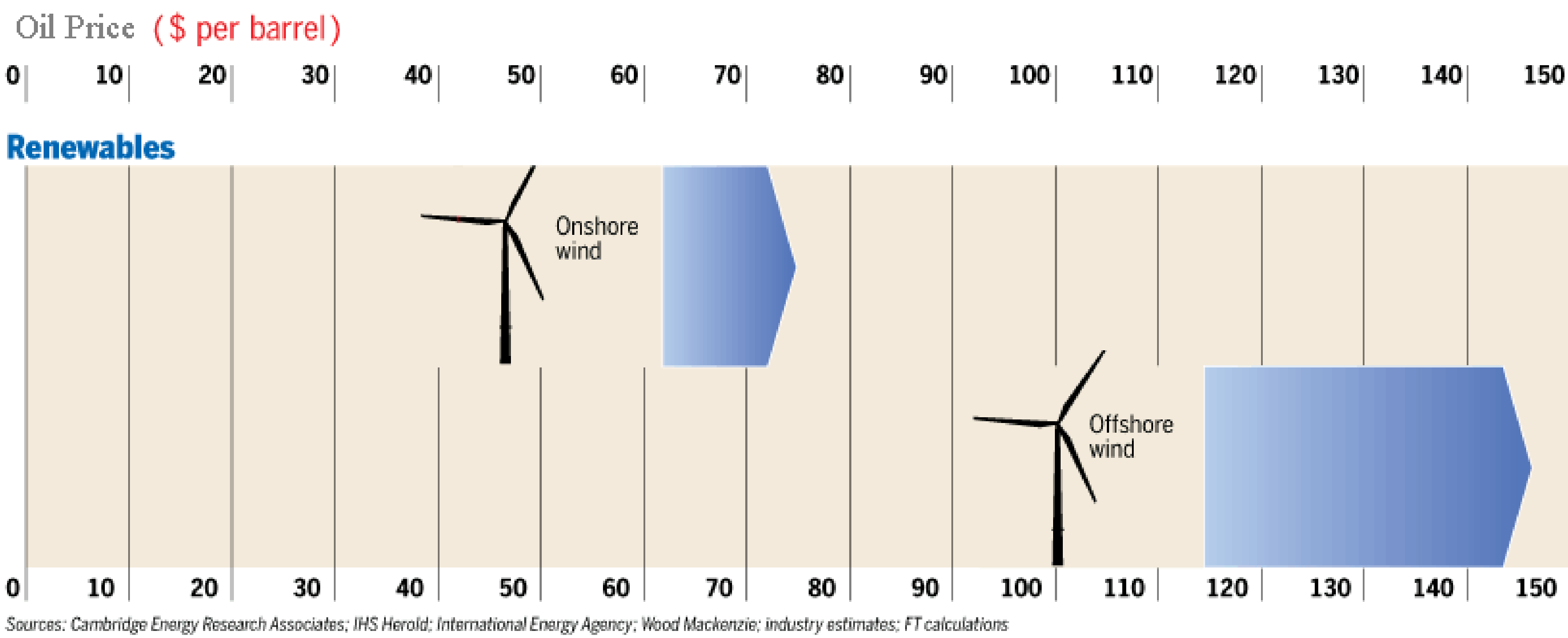
New Power Plants



London Financial Times, Dec 2008. www.ft.com

Renewable Energy: Example – Wind Power

- With current oil prices, land-based wind power is economically competitive as a source of energy.



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