Our Energy Endowment:

. our good fortune with ‘fossil fuel’

-- woody plants 360-300 million yrs ago made coal
-- marine planktons made oil/gas

. our ‘fossil fuel’ dependency may come to an end?

-- reserve-to-production ratio 50-100 yrs
-- environmental issues

. with the exceptions of nuclear energy and geothermal, all our energy reserves come eventually from the Sun (coal, oil, gas, hydro, solar, wind, tide, biofuel...)

The wood you burn in your fireplace.
The gasoline that powers your car.
The coal that is used to generate electricity (not in Ontario...)
The wind energy that propels your sailboat.
The electrical energy generated at Niagara Falls.
The natural gas that heats your home....

'Homeless' Planets May Be Common in Our Galaxy

18 May 2011 1:53 pm | 0 Comments

NASA/JPL-Caltech/R. Hurt

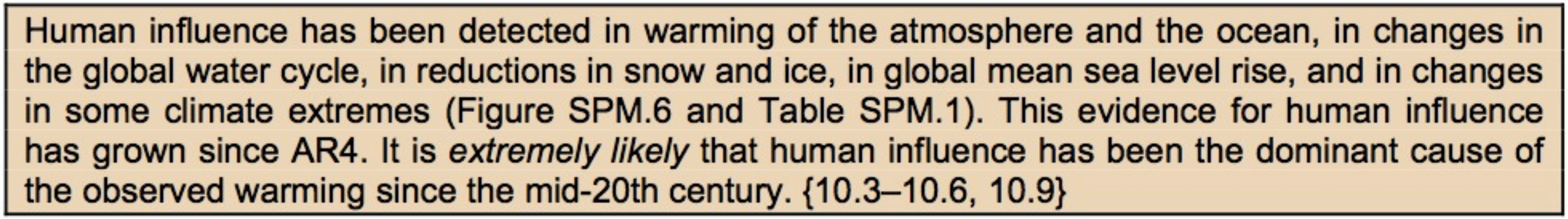
Starless. Astronomers have the best evidence yet for free-floating planets.

Our galaxy could be teeming with "homeless" planets, wandering the cosmos far from the solar systems of their birth, astronomers found. The study could help clear up a long-running debate of whether free-floating planets really exist, and how common they are

'free-floating planets'

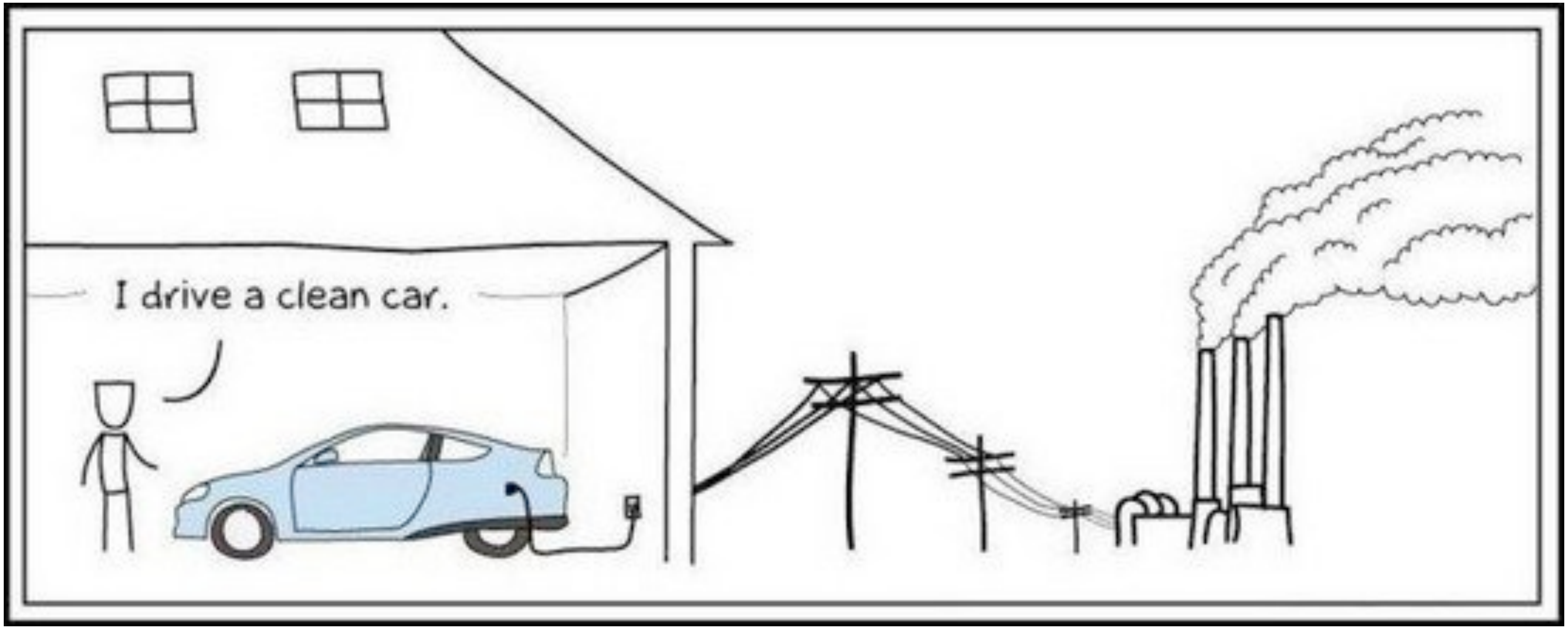
(artist conception)

Last Friday, the 5th Assessment Report of IPCC



Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (Figure SPM.6 and Table SPM.1). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. {10.3–10.6, 10.9}

Burning Fossil Fuels



- *energy in food & fuel*
- *power of burning*
- *efficiency*
- *numbers matter!*

Readings:
1) Smil, Energy, Beginners' Guide, Chapter 3 & 4 (same as last week)
Readings:
2) Muller, Energy for Future Presidents, Section IV, the properties of Energy
3) *ibid*, Chap. 19 (Clean Coal)

Ontario, Aug

Can I live on wild blueberries?

Let's estimate how many blueberries I can pick in a day:

- after picking ~ 8 hours, I got ~ 5000 berries;
- each berry ~ 1 gram, 5000 g.
- 10% sugar, so ~ 500 g sugar;
- **each gram of sugar yields ~ 4 kilo-calories** (kcal, or just Cal);

--- 2000 kcal

Let's estimate how much energy I need every day:

- basal metabolic rate (**BMR) ~ 1200 kcal/day,** ~ 60W light bulb
- realistic need ~ 2500 kcal/day (food intake of average Canadian)

(spent energy in getting there, climbing the hills, watching out for bears...)

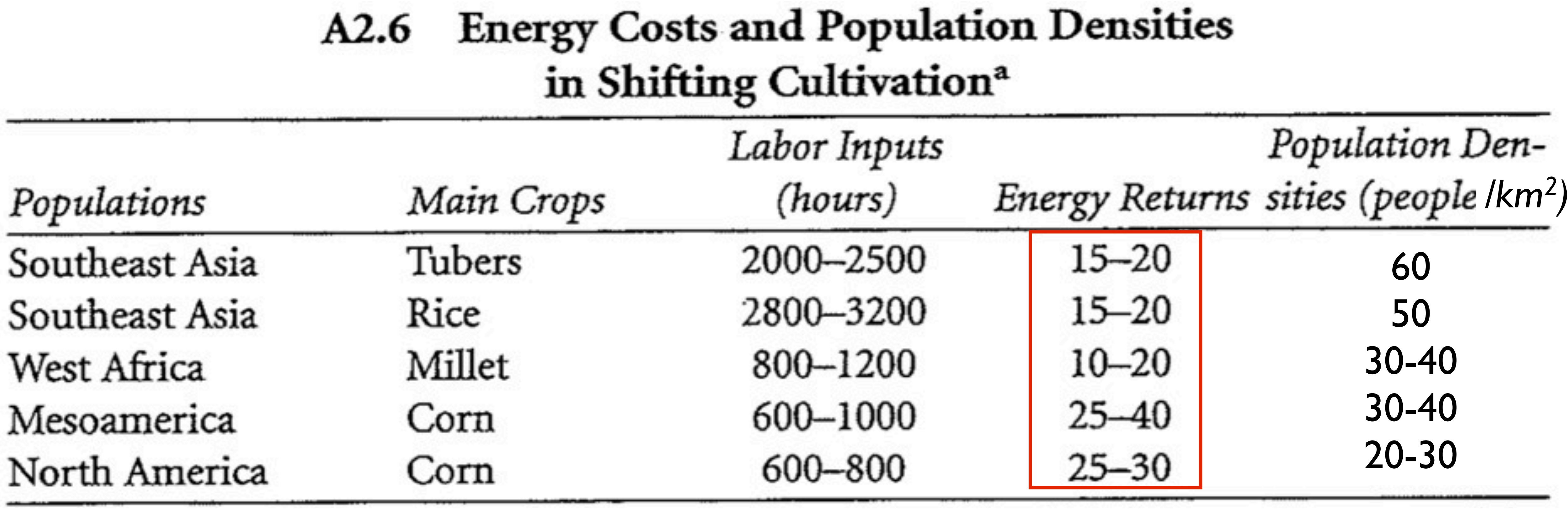
- so blueberries give me an energy return that is barely one.

. gathering roots yields a higher energy return (30-40)
. why we are mostly herbivorous (hunting less energy return)
. why monkey/human need Vitamin-C in diet
. hunter-gatherers have to be nomadic
. migration out of Africa ~ 1 million yrs ago

The drive for energy forces us to evolve from hunter-gatherers to agricultural societies

1) foraging society: < 1 person/km^2

2) shifting agricultural: 20-60 person/km^2



A2.6 Energy Costs and Population Densities in Shifting Cultivation[a]

Populations	*Main Crops*	*Labor Inputs (hours)*	*Energy Returns*	*Population Densities (people /km^2)*
Southeast Asia	Tubers	2000–2500	15–20	60
Southeast Asia	Rice	2800–3200	15–20	50
West Africa	Millet	800–1200	10–20	30-40
Mesoamerica	Corn	600–1000	25–40	30-40
North America	Corn	600–800	25–30	20-30

3) settled farming (river valleys): 100-200 person/km^2

"the availability of energy from cultivated crops determined the size of communities and permitted the emergence of cities" -- last lecture

2) shifting agricultural: ~ 20 person/km^2, energy return ~20

Kayapo tribe (Brazil); shifting agriculture (slash-and-burn);

.each (temporary) village ~ 200 people; why?
. high energy return allows cultural/art/language...

Maximum population on Earth?

3) Settled agriculture (10,000 yrs ago, 100 person/km^2)

ancient Athens: population 300,000

If all land on Earth used for farming, the Earth can support

total land area (km^2) x 100 person/km^2 ~ 15 billion

However, only ~10 % of land arable

4) the Green Revolution (1960s, ~ 1000 person/km^2)

high-yield grain, irrigation, fertilizer, pesticide, intensive farming...

That was food only.

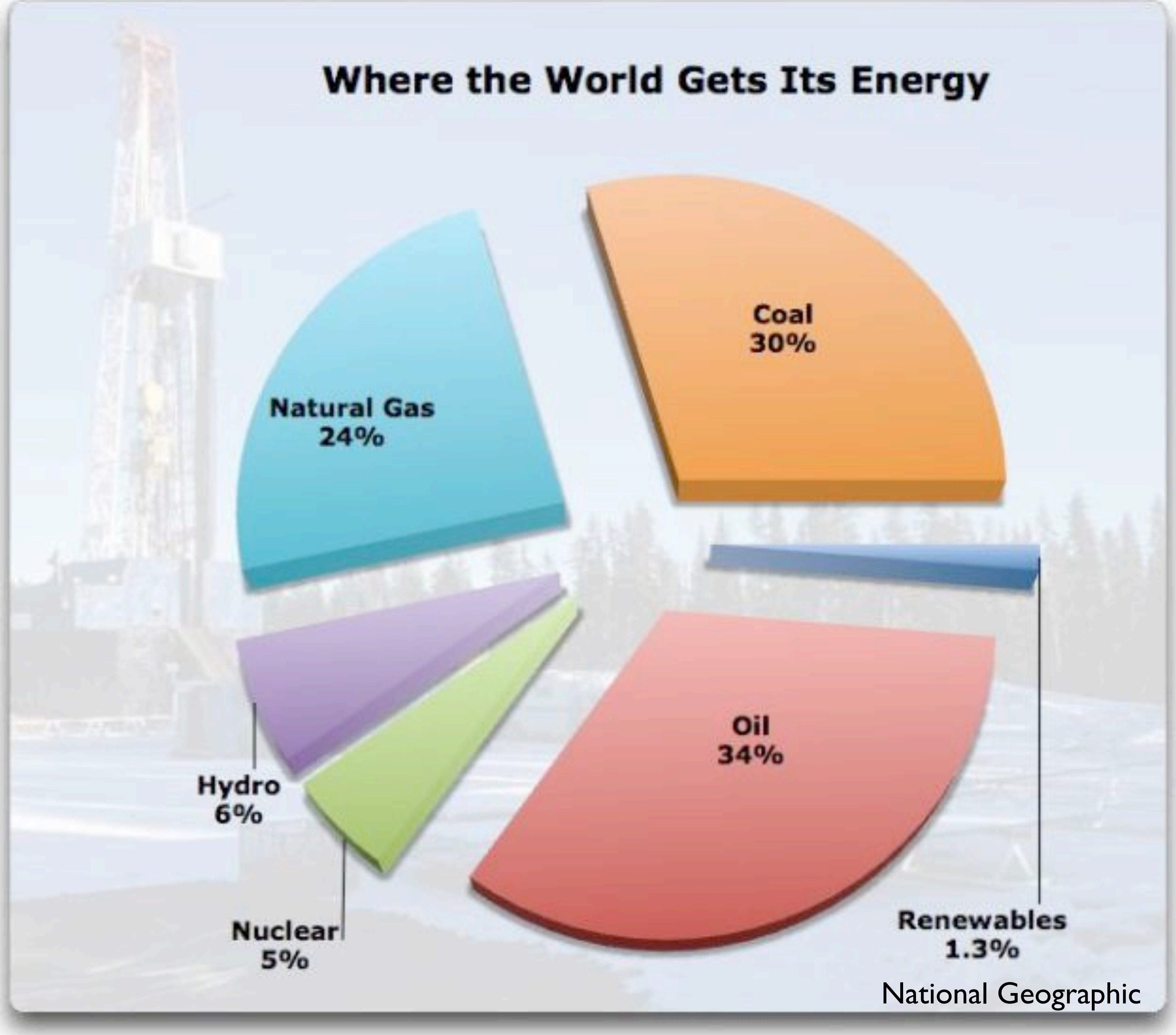
A post-industrial human uses 100x more energy than in food.

- average canadian uses 7.4 tons-of oil-equivalent (toe) of energy per year (heating, transportation, entertainment, education, food...).

- equivalent to ~ 200,000 kcal/day, or 800 hours of blueberry picking, per day.

Our comfortable lifestyle (high energy need) is made possible by fossil ‘blueberries’ that grew over millions of years.

--- oil/coal/gas reserve formed over ~ 100 million years
--- reserve-to-production ratio ~ 100 yrs
--- consumption rate/formation rate ~ 1 million:1



National Geographic

Most energy that is used world-wide is obtained from carbon-based fuels such as oil, coal and natural gas.

"hydrocarbon": C_xH_y

Life itself is fundamentally dependent for energy on carbon based substances (carbohydrates).

"carbohydrate": $C_x(H_2O)_y$

Question: where is electricity?

Energy yield of fuels

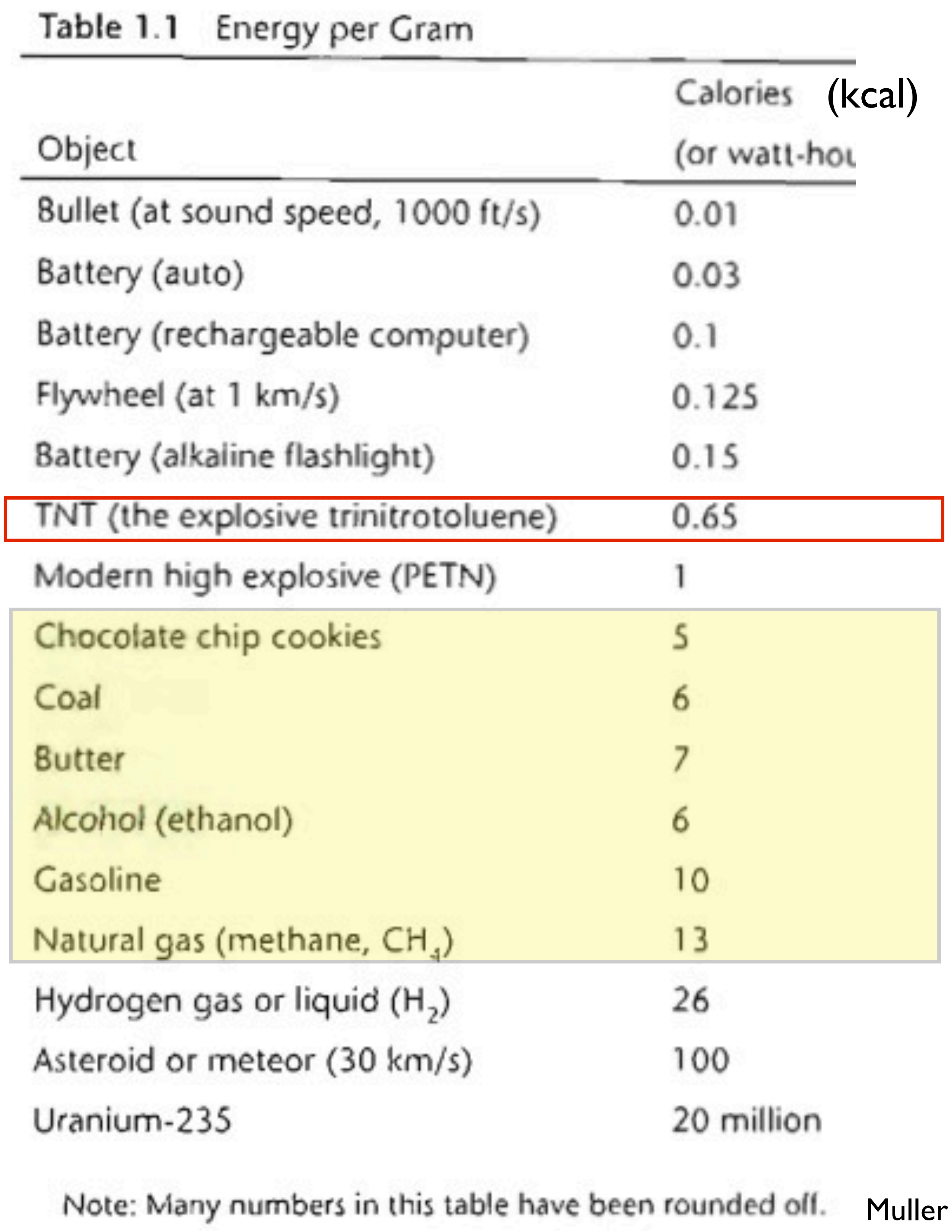


Table 1.1 Energy per Gram

Object	Calories (kcal) (or watt-hou
Bullet (at sound speed, 1000 ft/s)	0.01
Battery (auto)	0.03
Battery (rechargeable computer)	0.1
Flywheel (at 1 km/s)	0.125
Battery (alkaline flashlight)	0.15
TNT (the explosive trinitrotoluene)	0.65
Modern high explosive (PETN)	1
Chocolate chip cookies	5
Coal	6
Butter	7
Alcohol (ethanol)	6
Gasoline	10
Natural gas (methane, CH_4)	13
Hydrogen gas or liquid (H_2)	26
Asteroid or meteor (30 km/s)	100
Uranium-235	20 million

Note: Many numbers in this table have been rounded off.

1 gram sugar~ 4 kcal

1 gram of fuel ~ 10 kcal ~ 10 watt-hour
1 kilogram of fuel ~ 10 kilo-watt-hour (kWH)

all hydrocarbon/carbohydrate yield similar energy per unit weight.

Why?

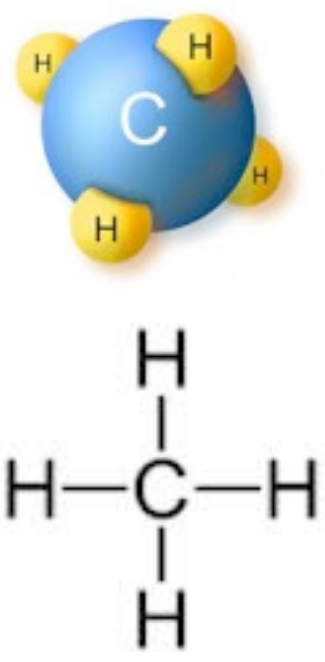
"hydrocarbon": C_xH_y
"carbohydrate": $C_x(H_2O)_y$

Muller '10 (Physics & Technology for future presidents)

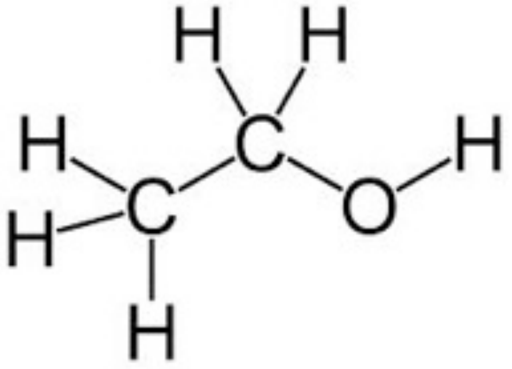
1) carbon compounds (more than 10 million known) -- very long chains of interconnecting C-C bonds allows carbon to form an almost infinite number of compounds; the basis of organic chemistry.

$O=C=O$

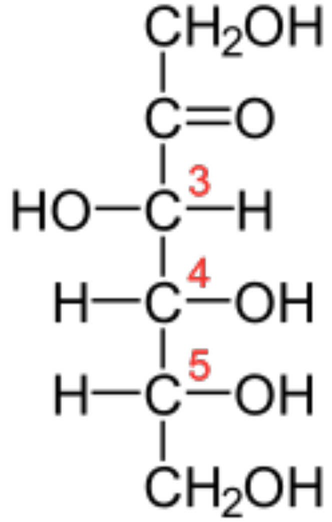
carbon dioxide



Methane



Ethanol (alcohol)

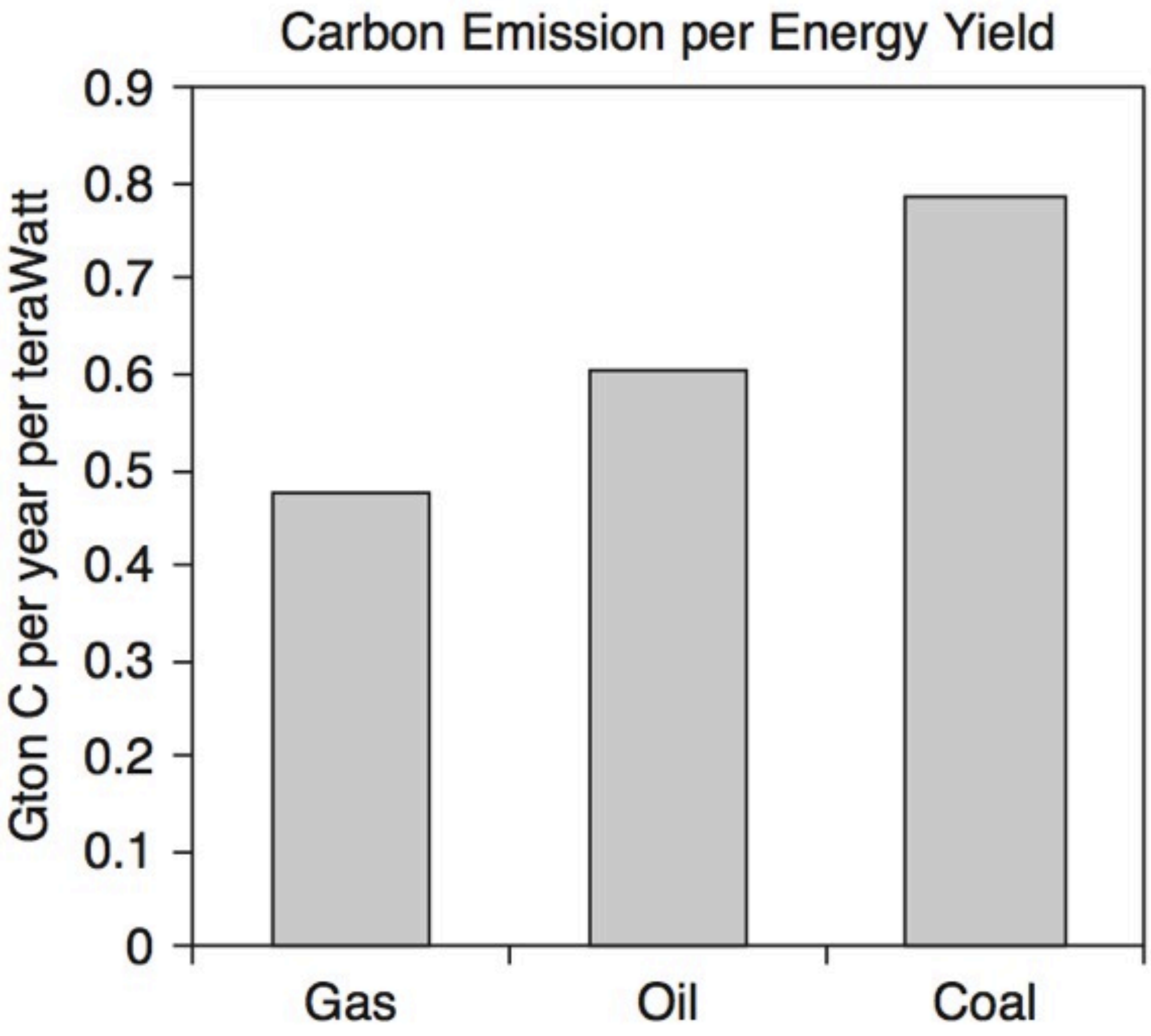


Fructose (sugar, $C_6H_{12}O_6$)

2) when each carbon atom is combusted to form CO_2, ~ same amount of energy is released.

3) Hydro-carbon and carbohydrate have similar # of carbon atoms per unit weight.

A corollary:
burning of different fuels emits
~ same amount of CO_2 for the same energy



Archer ’10, p110

all fossil fuels:
same weight,
~same energy,
~same CO_2

Energy: how much exercise after snacking on a Mars bar?

How much energy a Mars bar gives?

- one Mars bar ~ 50 gram of sugar, or 200 kcal of energy (1 g ~ 4 kcal)
- it also has fat, which has a slightly higher energy content, but ignore
- my body converts 20% to useable energy, **40 kcal**, the rest is turned to body heat

How much energy to climb one meter?

- **gravitational energy = mass x g x height**
- g is the Earth's gravitational attraction, and is 9.8 m/s^2
- mass ~ 50 kilograms,
- gravitational energy ~ 500 Joules ~ **0.12 kcal** for one meter

So to shake off those calories, I have to climb

- 40 kcal/0.12 kcal = 330 meters, or ~ **100 floors**

Nutrition Facts

Serving Size: 1 bar (1.76 oz) (50g)

Amount Per Serving	
Calories 234	Calories from Fat 104
	% Daily Value*
Total Fat 11.5 g	**18%**
Saturated Fat 3.63 g	**18%**
Trans Fat	
Cholesterol 8.5 mg	**3%**
Sodium 85 mg	**4%**
Potassium 162.5 mg	**5%**
Total Carbohydrate 31.35 g	**10%**
Dietary Fiber 1 g	**4%**
Sugars 26.05 g	
Sugar Alcohols	
Protein 4.05 g	
Vitamin A 27.5 IU	1%
Vitamin C 0.35 mg	1%
Calcium 84 mg	8%
Iron 0.55 mg	3%

=

This is why weight-loss is so hard!

an average Canadian uses ~ 200,000 kcal/day,
or, ~ 1,000 Mars Bars/day.

Burning fossil fuel:

.access to large amount of energy

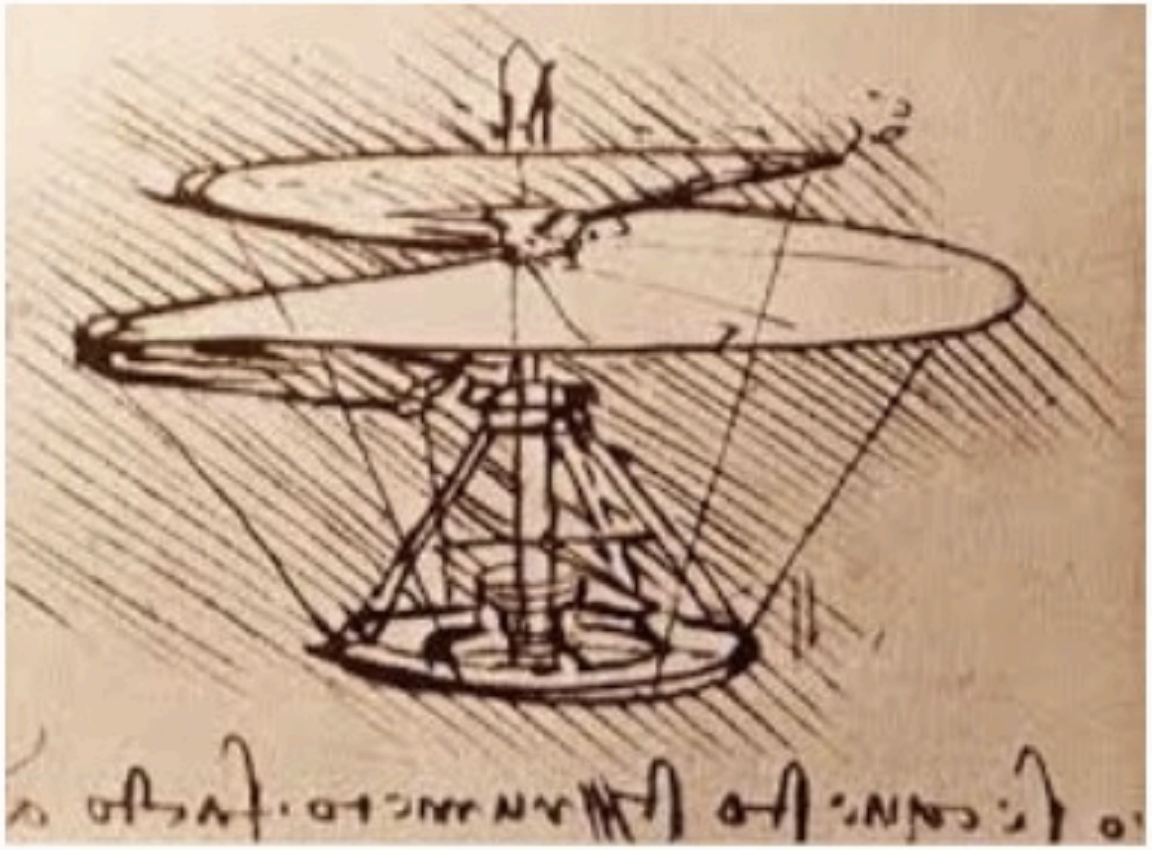
.access to huge power

Da Vinci Decoded: Toronto team wins human-powered helicopter challenge

July 26, 2013 | Carolyn | Comments (0)

foil !

In 1493 Leonardo da Vinci sketched his idea for a human-powered flying machine:



Over 500 years later, a team from the University of Toronto has won a 33 year old competition by designing, building and flying a human-powered helicopter:

UofT Engineering

https://www.youtube.com/watch?feature=player_embedded&v=syJq10EQkog

The point is,

human **power** is minuscule compared to that from fossil fuel burning

James Watt (1736-1819), Scottish inventor, made steam engine practical; fundamental to Industrial revolution

Power: energy produced per unit time

(say, per second, per hour...)

Unit of power: Watt (W)

= 1 Joule/second = 0.24 cal/sec ~ 21 kcal/day

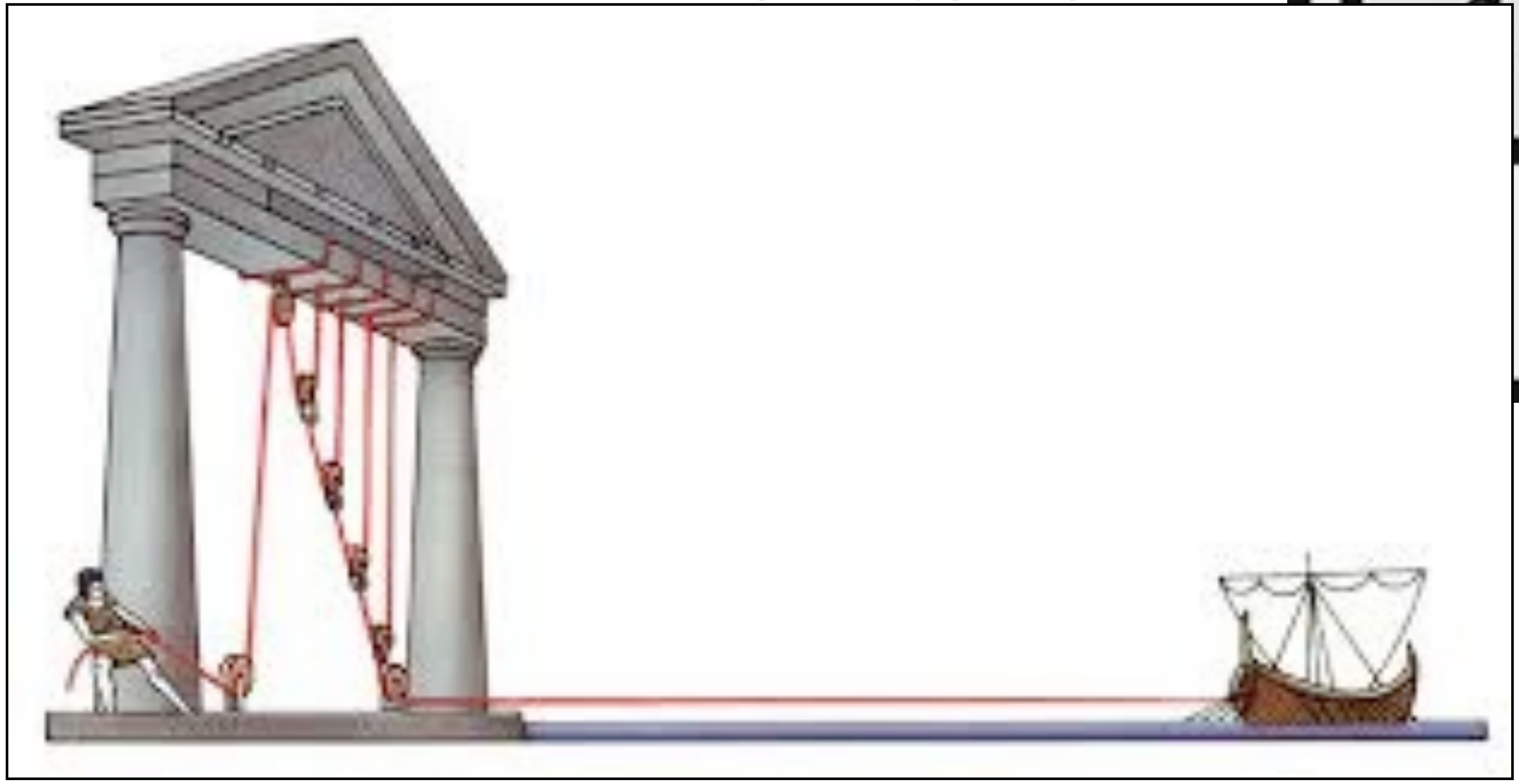
BMR: heat power ~ 60 W ~ a typical laptop
aerobic class : mechanical power ~100 W
human-helicopter cyclist: mechanical power ~ 400 W

One of the many inventions:

(to compensate for our small power)

Pulley

Archimedes (~200BC) reputedly pulled an entire warship using pulleys

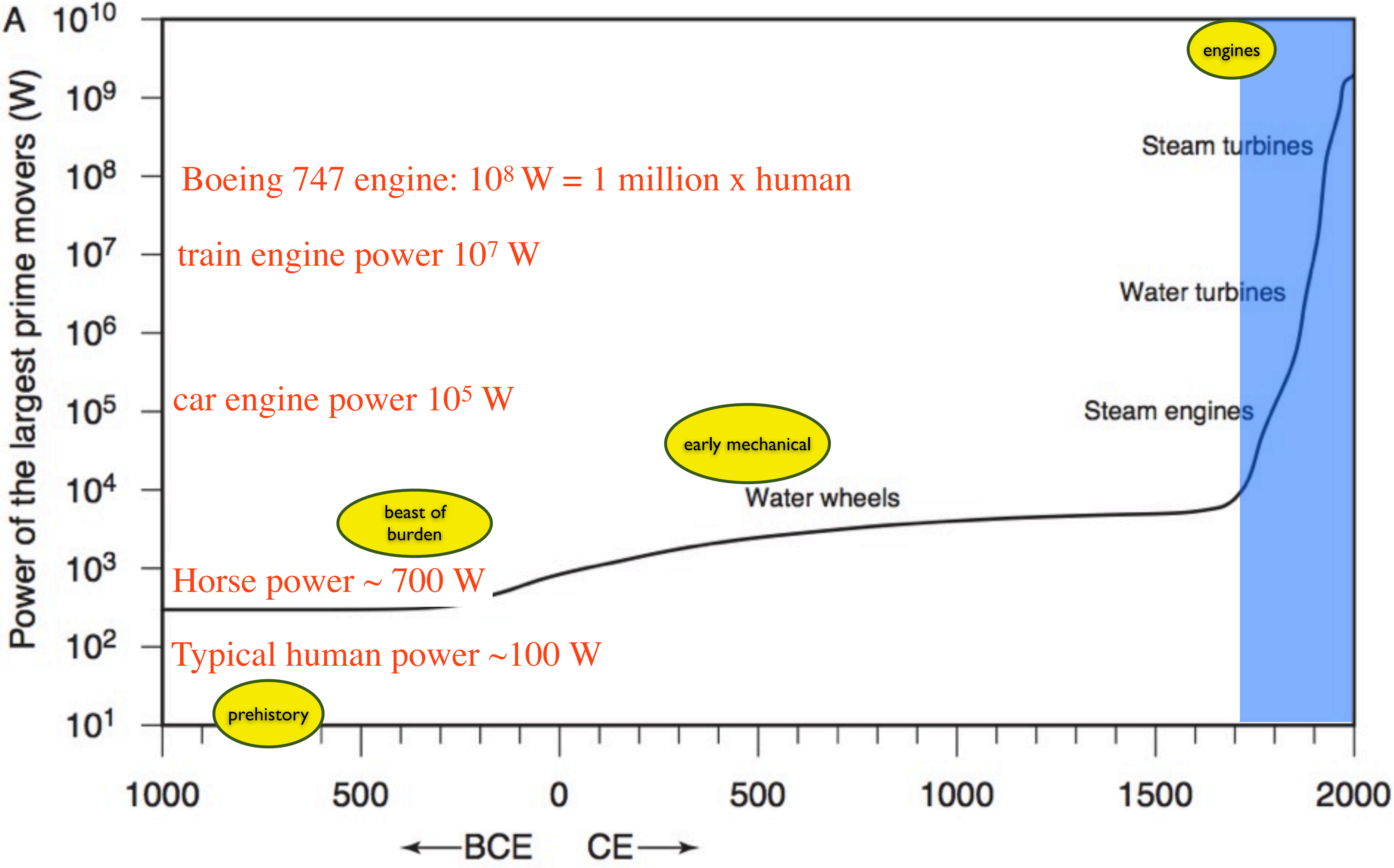


Power limited. But can put in more energy (pull heavy stuff up) by spending a longer time at it.

Maximum power of **prime movers** grew over the past 3000 years (Smil ’04)

Prime movers – animals, devices and machines that convert naturally available energy into mechanical energy;

Logarithmic scale



engines

Boeing 747 engine: 10^8 W = 1 million x human

train engine power 10^7 W

car engine power 10^5 W

early mechanical

beast of burden

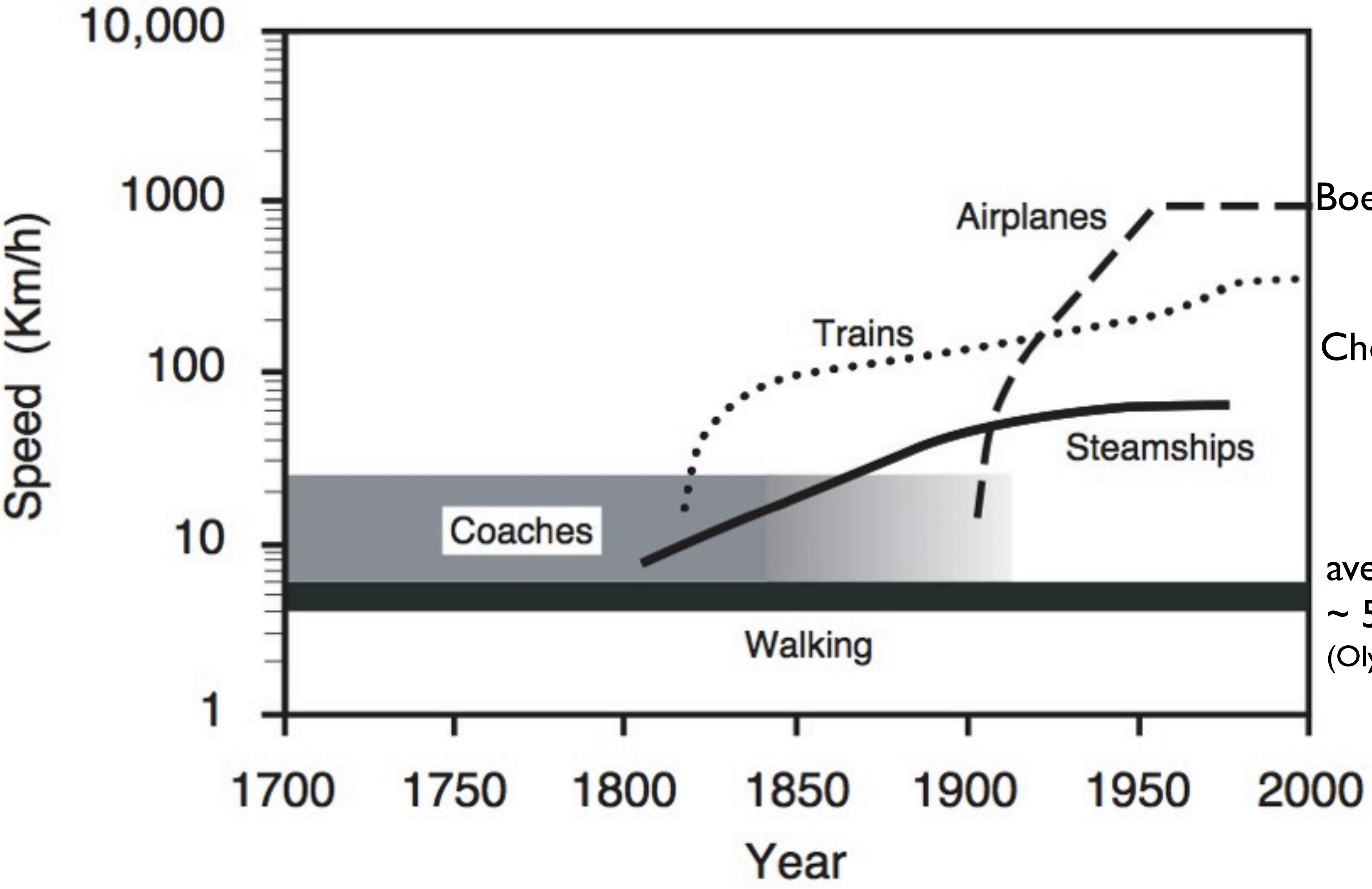
Horse power ~ 700 W

Typical human power ~100 W

prehistory

Watt & Boulton steam engine 1817

What is power good for? one example -- Mobility.



Boeing 747: ~1000km/h

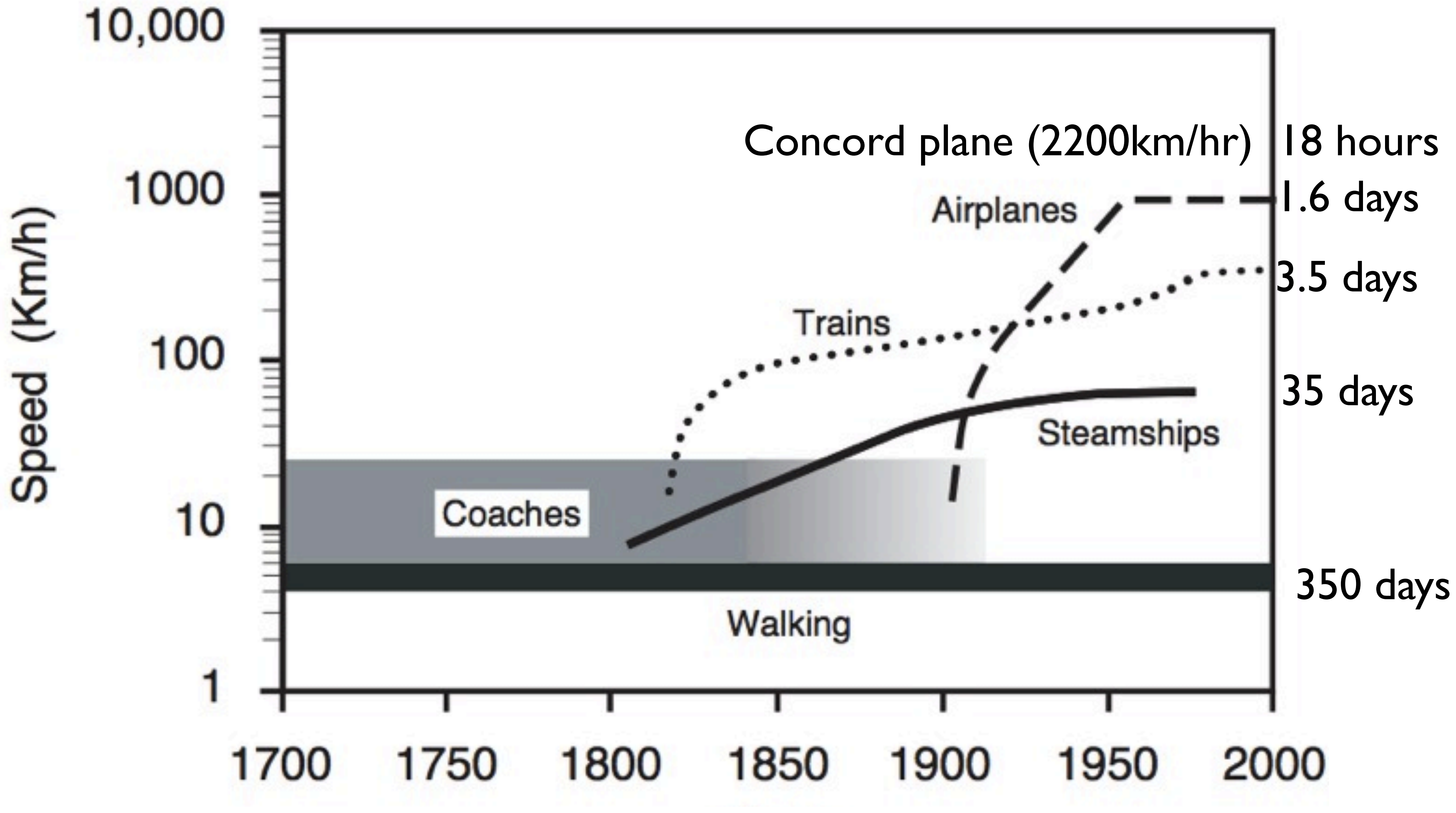
Cheetah: ~120km/h

average walker:
~ 5km/h
(Olympic sprinter: 36km/hr)

FIGURE 3 Maximum speeds of transportation during the years 1700–2000.

Smil ’04

Another way to think about Speed:
time to circumnavigate the globe (40,000 km)



jet lag

World war I/II

British Empire 1800

Genghis Khan 1200

Alexander the Great
300BC

Implications:

trade, globalization, tourism, speed/scale of war, inter-racial marriages... what else?

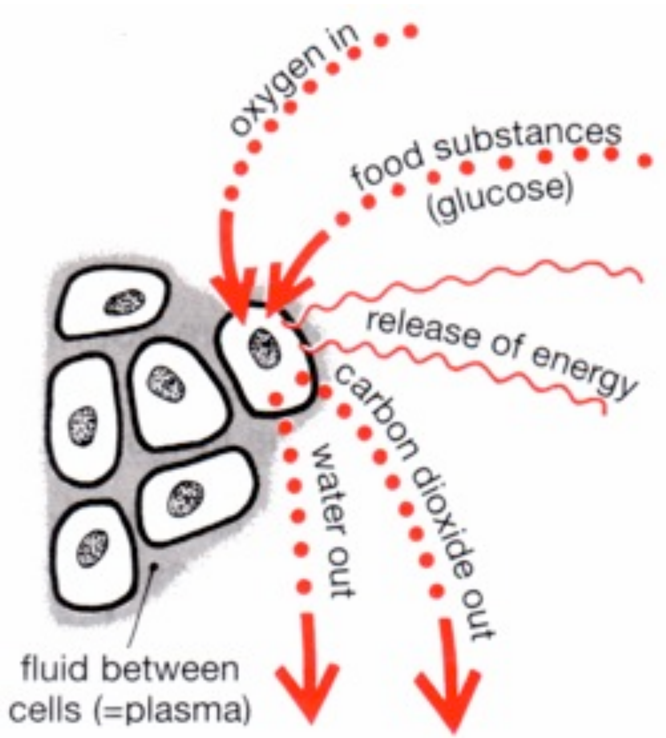
How does fossil fuel burning yield such high POWER?

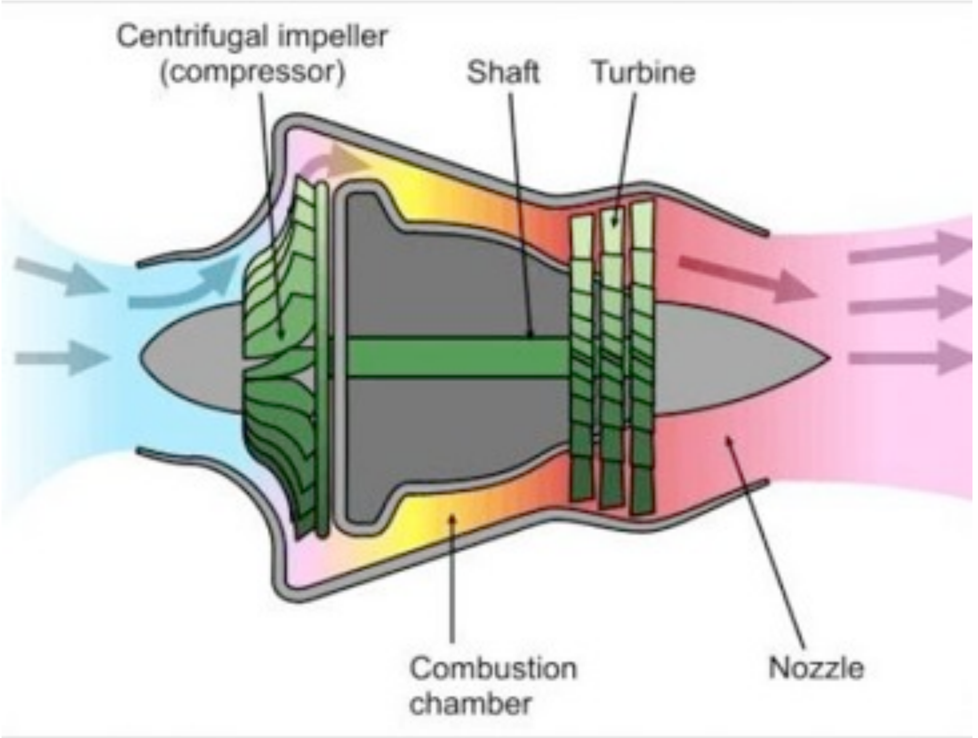
respiration/
combustion

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + ENERGY

Sugar, Oxygen, Carbon dioxide, Water

Each unit weight of fuel contributes ~ same energy.
Larger power means more burning per unit time.





respiration: e.g. lung
slow diffusion of molecules;
low temperature ‘burning’
(chemical reaction slow)
many complex chemical steps;

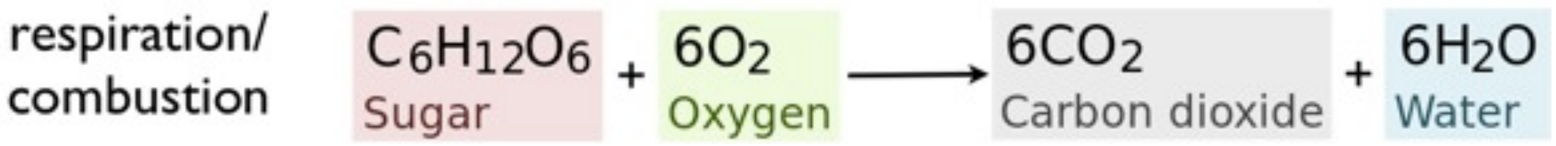
combustion: e.g. jet engine
air compressed to enhance O_2 ;
rapid mixing of fuel and air;
high temperature burn (high reaction rates);
one step to completion.

How do fossil fuels generate mechanical energy?

When matter in jug heated, it expands.
This generates the
mechanical energy

if "matter" = water, external combustion engine
(steam engine)
if "matter" = air, internal combustion engine

After this matter does work, it cools down.



respiration/
combustion

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

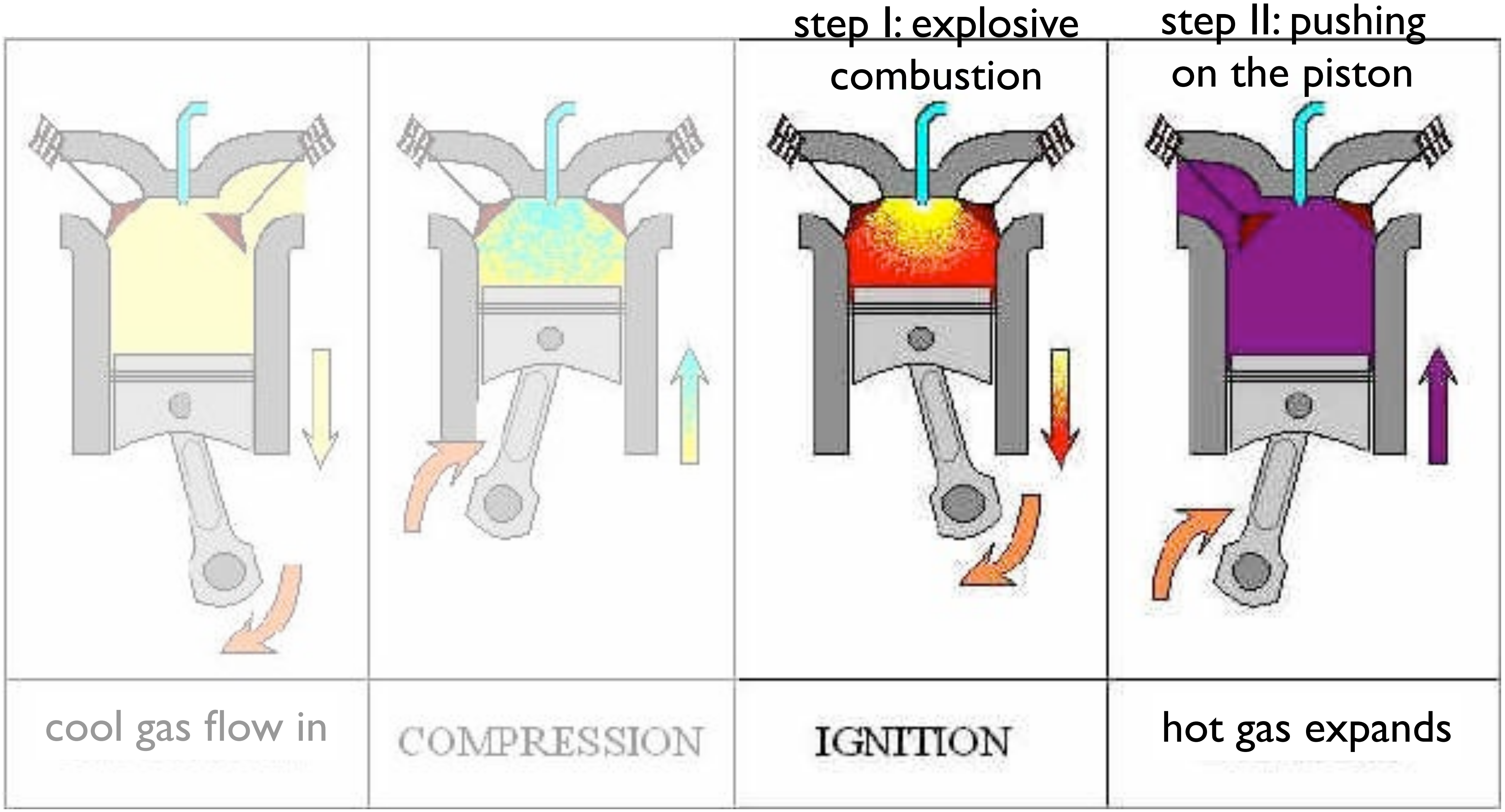
+ heat (thermal energy)

External Combustion Engine
. steam engine; steam turbine; bulky
. water turned to steam to do work
. uses coal, gas, oil
. improved by Scottish James Watt 1781
. much of electricity generation today

Internal Combustion Engine
.car, aircraft, boat engine... compact
. gas is heated to do work
.uses liquid fuel (oil).
. invented by Belgium Jean Lenoir 1858
. first automobile 1886 (Benz)

A Heat Engine burns fuel to do work

I. burns fossil fuel (turns chemical energy into heat),
II. pushes piston (turns heat into mechanical energy)



a 4-stroke internal combustion engine

Efficiency

- Step I: combustion

  Turning other energy into heat (thermal energy) is easy. can be 100% efficient.

- Step II: turning heat into mechanical energy

  this always comes with some cost.

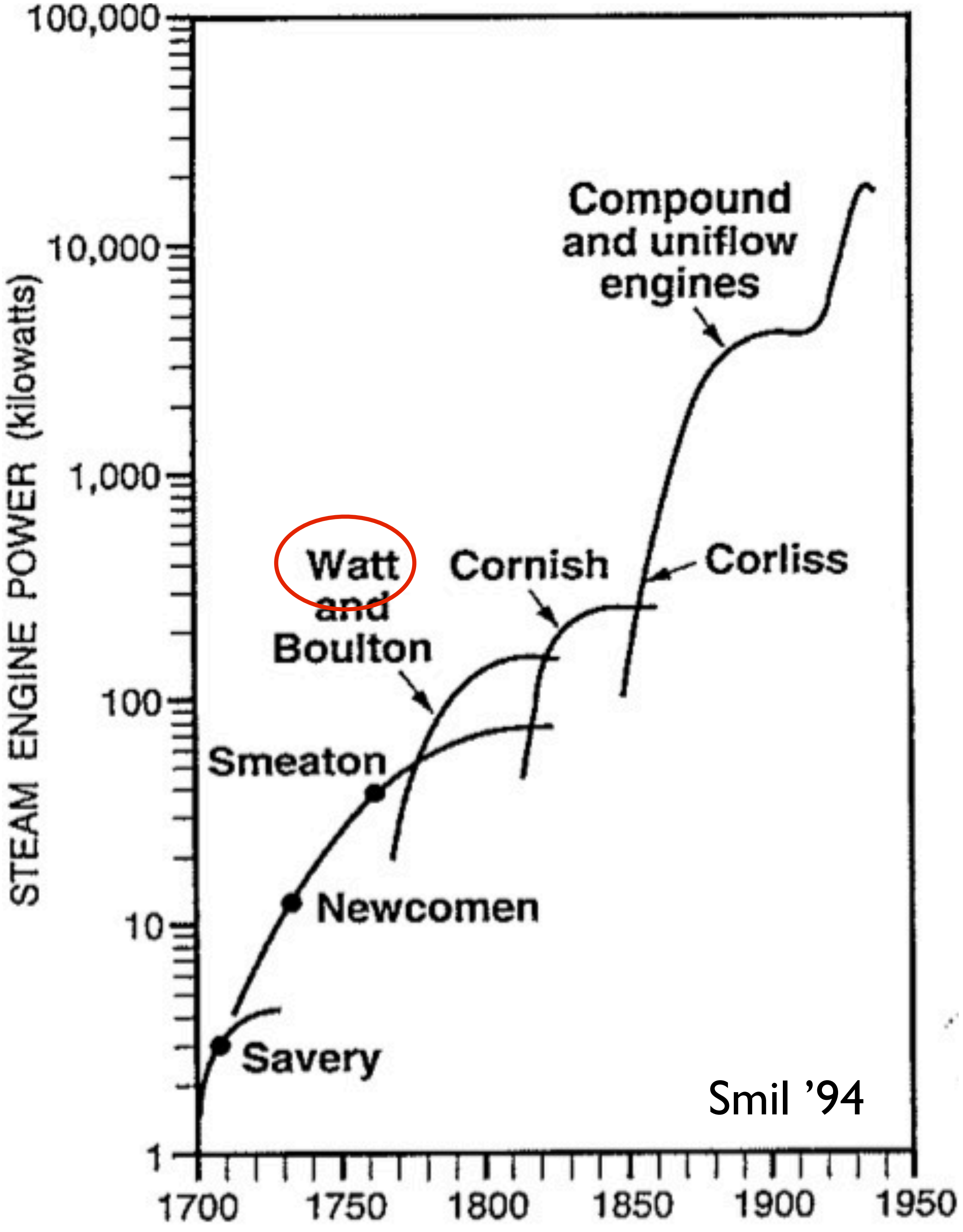
define

$$\text{efficiency} = \frac{\text{mechanical energy output}}{\text{fuel energy input}}$$

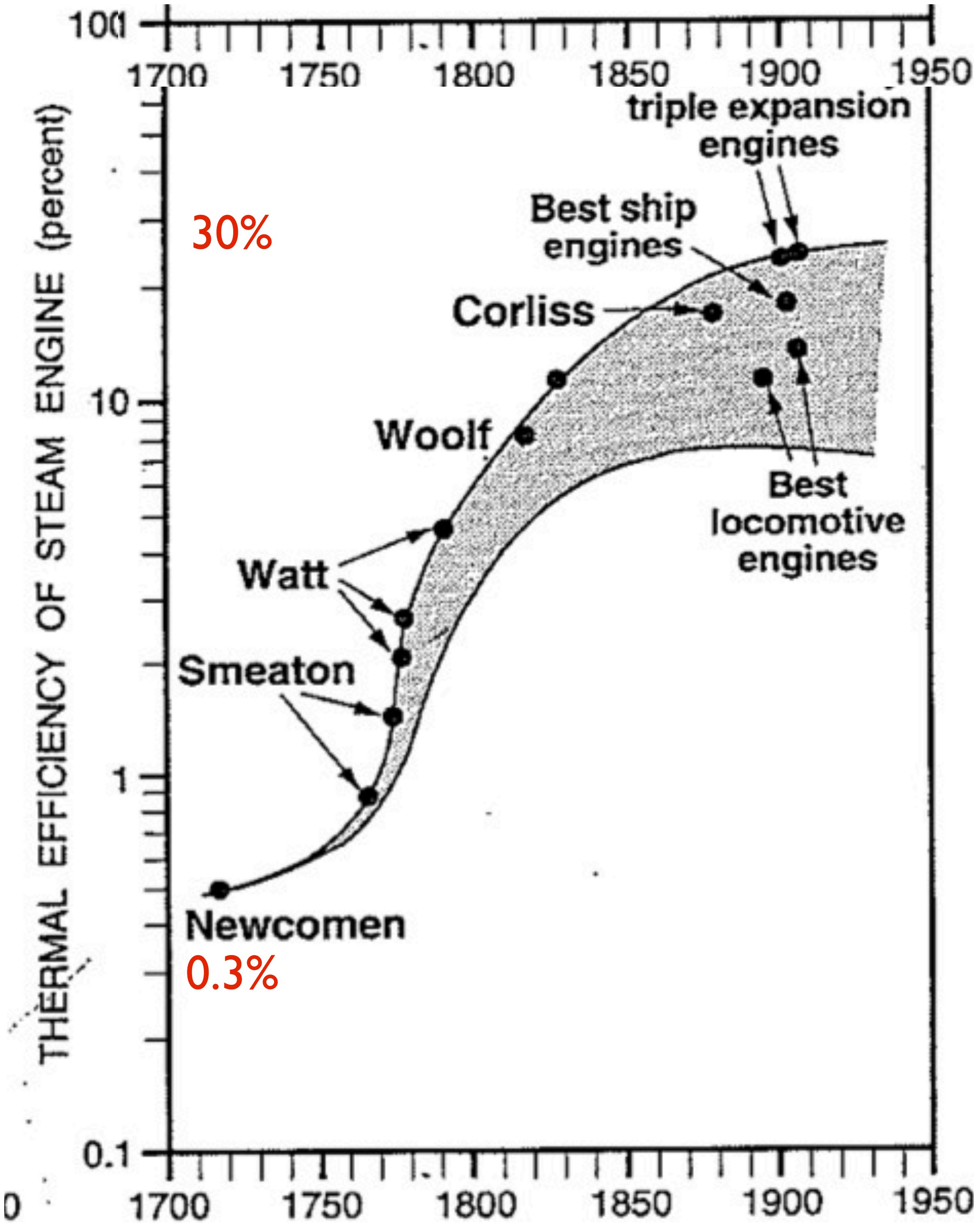
- Efficiency critically impacts the civilization.

evolution of steam engine: **power & efficiency**

power growth a factor of ~10,000 = efficiency boost (~100) x faster fuel intake



Smil ’94



Efficiency of engines

. human turns food into mechanical energy: ~ 20%

each kcal of food we eat, we get 0.2 kcal to use

. 1st generation steam engine (1720) produces mechanical energy with efficiency ~ 0.5%

. modern day internal combustion engine: ~30%

30% of gasoline in your car actually does something

. power plants (steam turbine) produce electricity: ~30%

future target: 60%

. the rest is heat and must be removed (cooling)

coal cogeneration: if heat recaptured and used for heating

Efficiency determines economics?

	3%	30%	100%
fossil fuel exhaustion		50-100 yrs	
CO_2 emission (1 kwH of electricity)		1 kilogram	
50 liter gasoline		1000 km	
airfare to asia		~$1,000	
salary?			

modern heat engine efficiencies: ~ 30%

There is a physical limit to heat engine efficiency.

heat engine: convert heat to mechanical work

Total Energy is Conserved.

-- the 0th law of thermodynamics

There is no machine of perpetual motion

-- the 1st law of thermodynamics

There is also no heat-engine of 100% efficiency

-- the 2nd law of thermodynamics.

Sadi Carnot: 1796-1832, French physicist, 'father of thermodynamics'

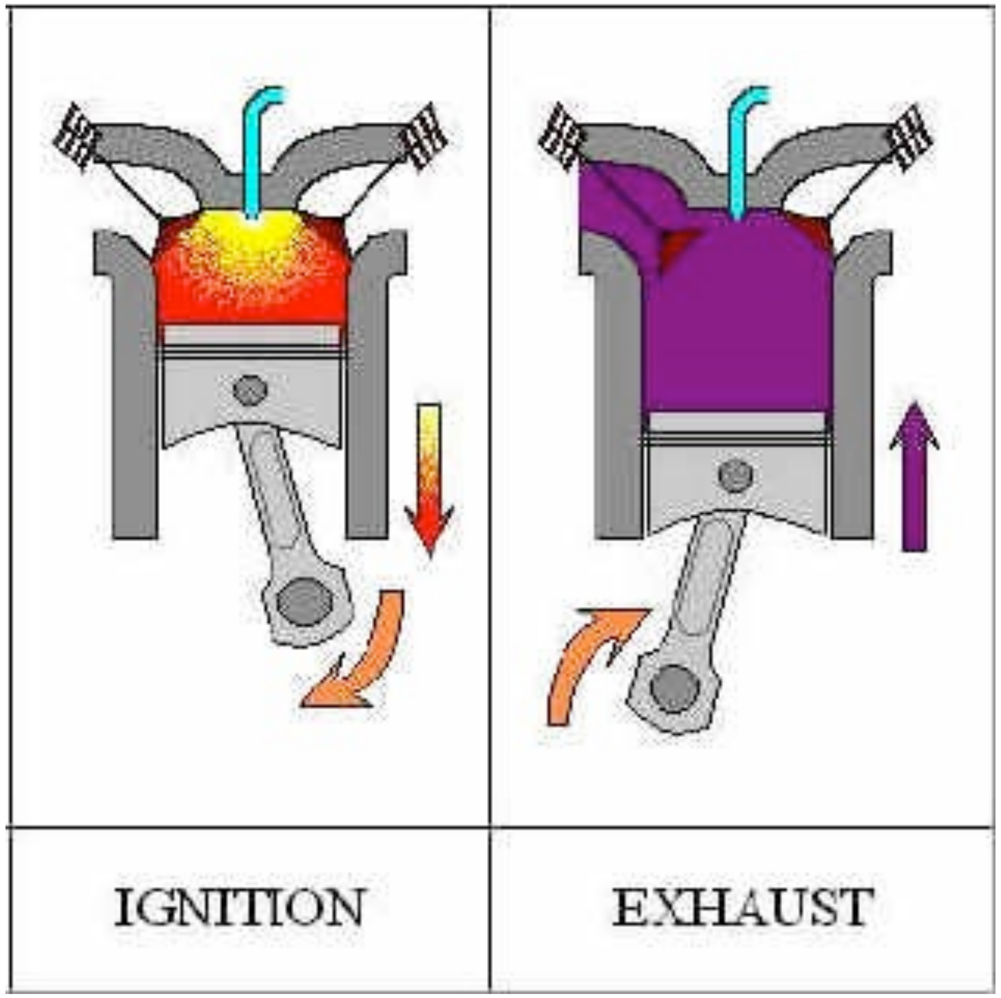
The theoretical maximum efficiency (an ideal engine)

depends on the upper and lower operating temperatures of the engine

$$1 - T_{cold}/T_{hot}$$

ideal engine: no friction, reversible cycles, also called 'carnot-engine'

Why?



Efficiency is less than unity because some heat is taken away by the exhaust.

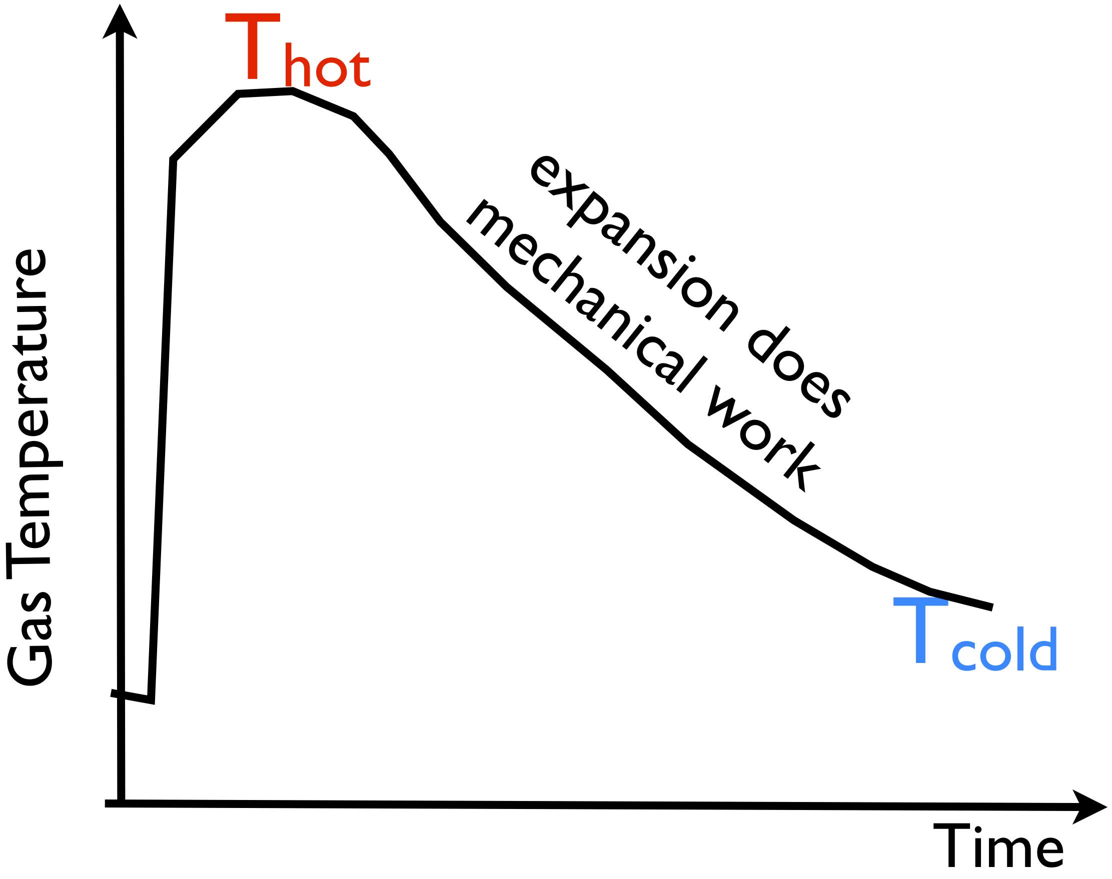
T_{hot} :temperature at burning
T_{cold} :temperature of exiting exhaust

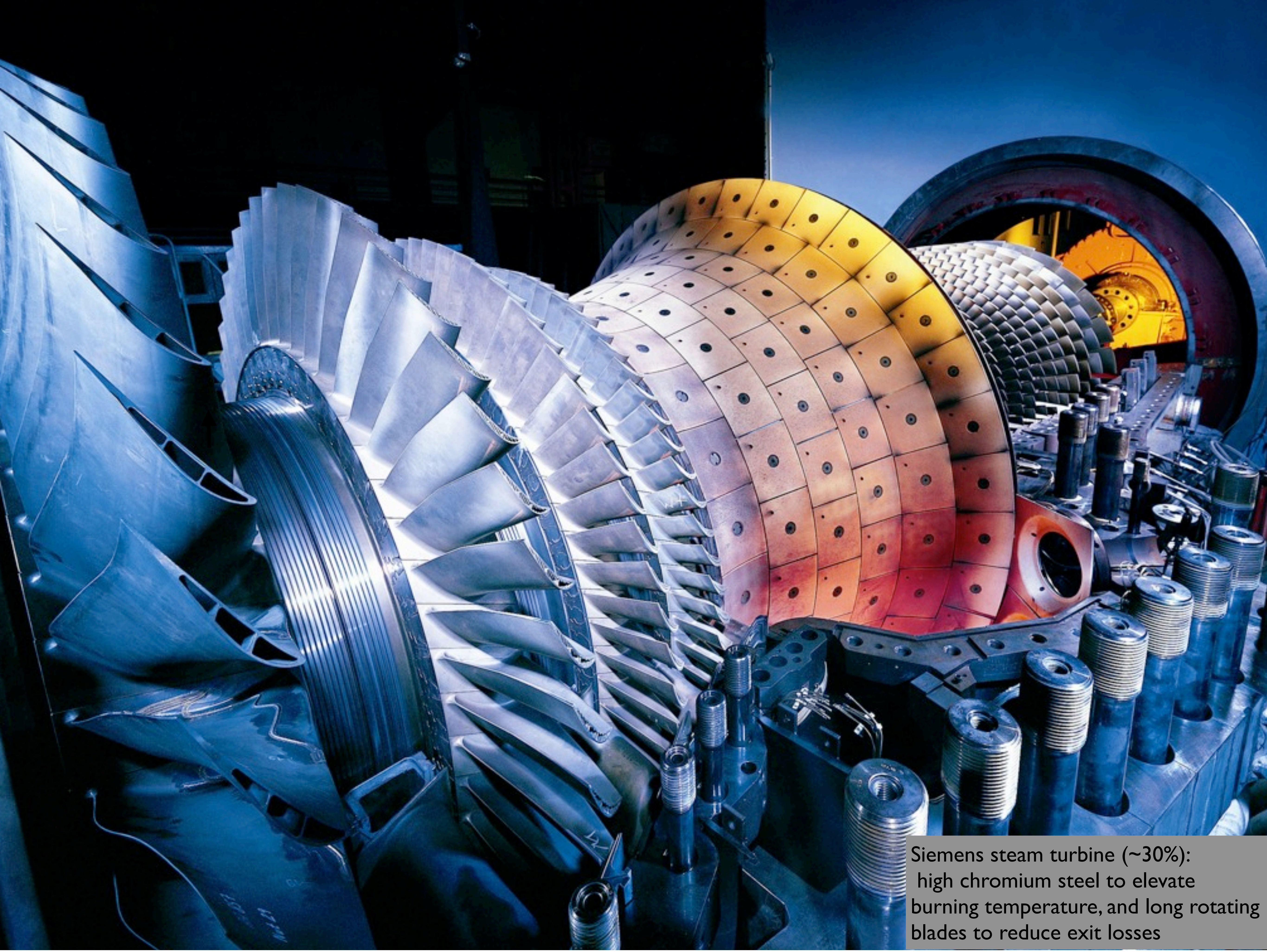
The lost fraction ~ T_{cold}/T_{hot}

So maximum efficiency = $1 - T_{cold}/T_{hot}$

(realistic engines have lower efficiencies due to engineering issues, this is the physical limit.)

To increase efficiency, we would like to .....





Siemens steam turbine (~30%):
high chromium steel to elevate burning temperature, and long rotating blades to reduce exit losses

What's the Big Idea? Temperature Rising

- Many technical advances throughout history have been linked to the ability to sustain ever higher temperatures.
  - The progression from the Bronze Age to the Iron Age is related to the fact that iron requires higher temperatures than copper.
- Superior tools (for example, in agriculture) led to greater productivity and superior weaponry which facilitated the capture of territory and resources.
- The development of more effective ovens, kilns and forges played a critical role in human ability to raise temperatures in a controlled way.

. Raising the burning temperature in combustion engines increases the fuel efficiency.

Case Study: Efficiency of a car

theoretical maximum efficiency: $1 - T_{cold}/T_{hot}$

- a car engine is made of metal (typically iron), melting temperature T ~ 1200°C (~1500 Kelvin, definition: 0°C = 273 Kelvin above absolute zero)

- car exhaust T ~ 200°C (~ 500 K)

- theoretically, max. efficiency = 1 - 500K/1500K = 2/3 ~ **67%**

- real engines have other practical concerns: friction, metal expansion, engine heat loss, incomplete burn...

- modern gasoline car engine efficiency ~ **30%**

  .~70% not used in turning the crankshaft; lost in exhaust heat or else.
  .engine tuned to maximize fuel efficiency at ~ 90 km/hour (the speed limit!)

As a side-note:

Our definition of energy efficiency: work done/fuel energy

Distinct from energy efficiency used to describe, e.g., fuel economy, coefficient of performance.

examples:

1) hybrid car has ~ 30% engine efficiency, but higher overall fuel economy because it turns kinetic energy to battery energy at braking.

2) your fridge and air-conditioner work as heat-pump, not heat engine. If well designed, can have a coefficient of performance of 4-6.

More in later lectures

Another Case Study: the cost of electricity

Energy = Power x Time
kWH = kilo-watt x Hour

Electricity in Toronto costs ~10¢/kWH (kilo-watt-hour). Why?

hint: $/kg ? kWH/kg ? % ?

	coal	natural gas	oil
fuel cost ($/kg)	$0.06	$0.23	$1.4
fuel energy content (kWH/kg)	6	13	10
fuel efficiency	30%	30%	30%
cost of electricity ($/kWH)	*3¢*	*6¢*	*50¢*

Numbers from Muller '10, '12

$$\text{Cost of Electricity [\$/kWH]} = \frac{\text{Cost of Fuel [\$/kg]}}{\text{Energy Content [kWH/kg]}} \times \frac{1}{\text{Efficiency}}$$

- Other costs associated with electricity: transport cost, admin, customer service...

- gas heating vs. electricity heating

. natural gas for heating costs $0.02/kWH (=$0.23/13)
. electric heater costs... $0.10/kWH
--- **electrical energy is more valuable than heat.**

Check the units:

$$[\$/\text{kWH}] = \frac{[\$/\text{kg}]}{[\text{kWH}/\text{kg}]}$$

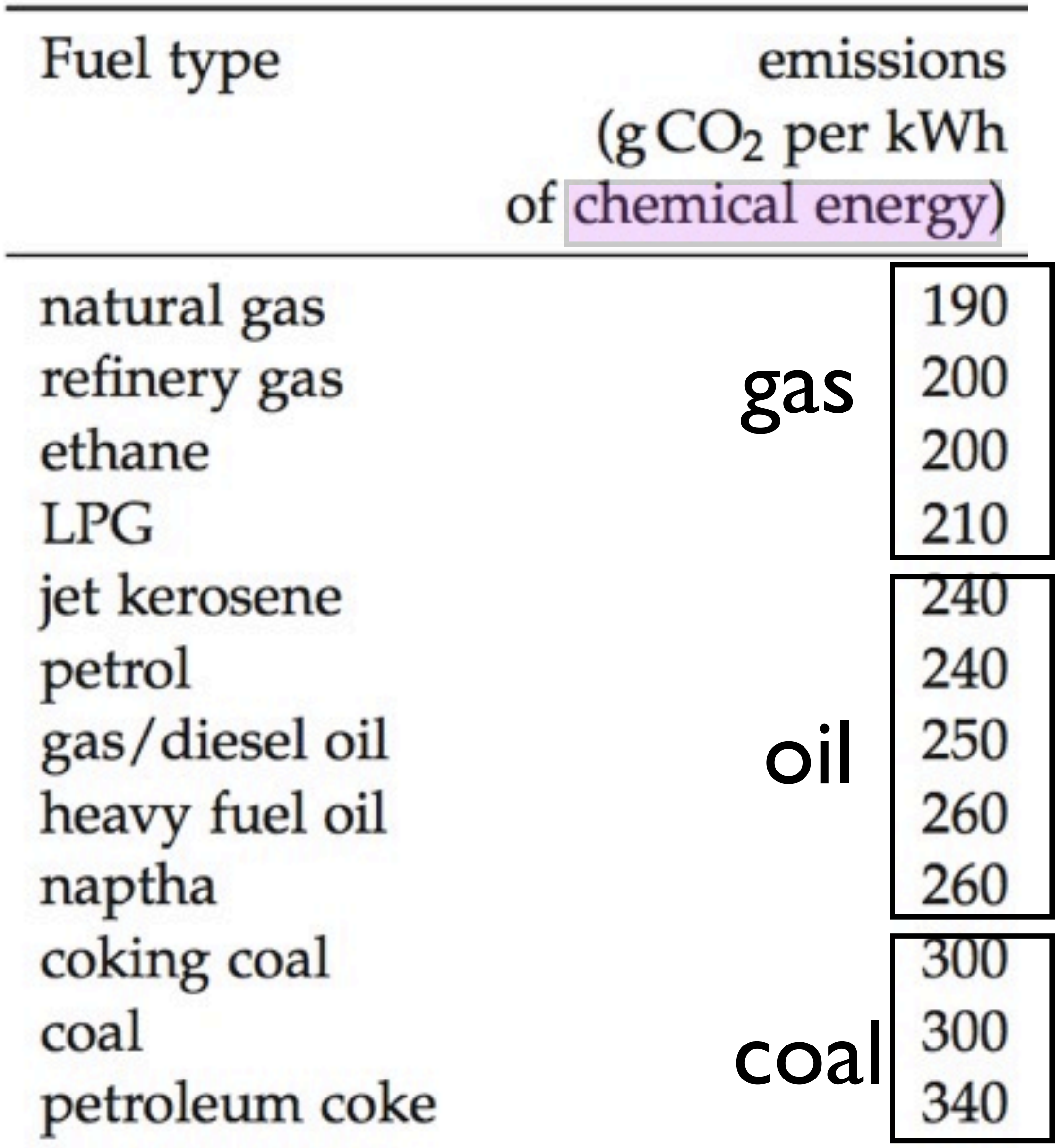
Where to invest?

Electricity in Toronto costs ~10¢/kWH (kilo-watt-hour).
Actually mostly generated by nuclear power and hydro.

	electricity generation	*¢/kWH (true price)*
US	70% by coal+gas	
China	mostly coal	
Virgin Islands	oil	

http://en.wikipedia.org/wiki/Electricity_pricing

All fuel emits roughly same amount of CO_2 (for the same energy)



Fuel type		emissions ($g\,CO_2$ per kWh of chemical energy)
natural gas	gas	190
refinery gas		200
ethane		200
LPG		210
jet kerosene	oil	240
petrol		240
gas/diesel oil		250
heavy fuel oil		260
naptha		260
coking coal	coal	300
coal		300
petroleum coke		340

MacKay ’09

.for each kWH of chemical energy, all emit ~ 200 g of CO_2,

.natural gas is relatively ‘cleaner’

.for per kWH of electricity, multiply by 3

One kilogram of CO_2 for every hour of your fridge.

fuel type	coal	natural gas	oil
cost of electricity ($/kWH)	$0.03	$0.06	$0.50
CO_2 emission (kg/kWH of electricity)	1	0.5	0.75

Food for thought -- future of fossil fuel burning

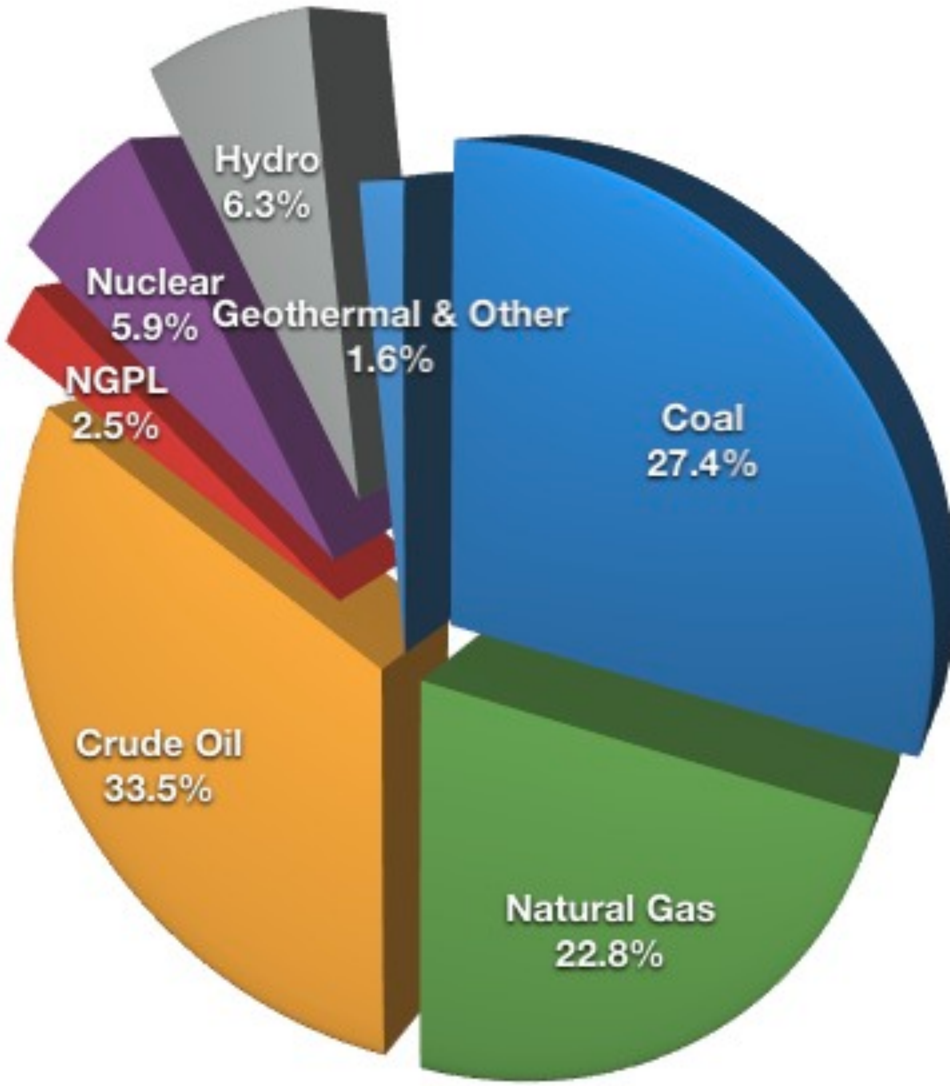
.Coal is cheap. Gas is 'clean'.

-- Why such a heavy reliance on oil?
  What is the future for oil?

-- Electricity generation from gas?

-- Can developing world switch away from coal?

-- what is the CO_2 footprint if use only gas?



World Energy Mix (2008)
EIA

Summary

. fossil fuels bump up accessible energy & power

all fossil fuels ~ 10 kWH/kg

. efficiency of heat engine,

currently ~ 30%

. emission of fossil fuel burning

~ 1kg of CO_2 for1kWH of electricity (one hour of fridge use)

not discussed:

. transport/ease of use for different fuel types