Mid-term Review: the Science of Energy

BIG 101: Energy

.What is energy?

forms, total conservation, heat as the end product

.How to calculate energy?

energy yield in food, fuel, CO_2 emission

.How do human activities consume energy?

food, fossil fuel (origin, reserve, coal vs. oil vs. gas, hydro-carbon economy),
steam engine, internal combustion engine, power, efficiency, electricity production

.Our energy use rises with time.

agricultural production, non-food energy use,
global warming (cause, Earth in deep history, impacts)

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)

. Industrial revolution started with Coal.

. Our modern life depends on oil heavily.

. But future: gas?

Economist, Aug 3, 2013

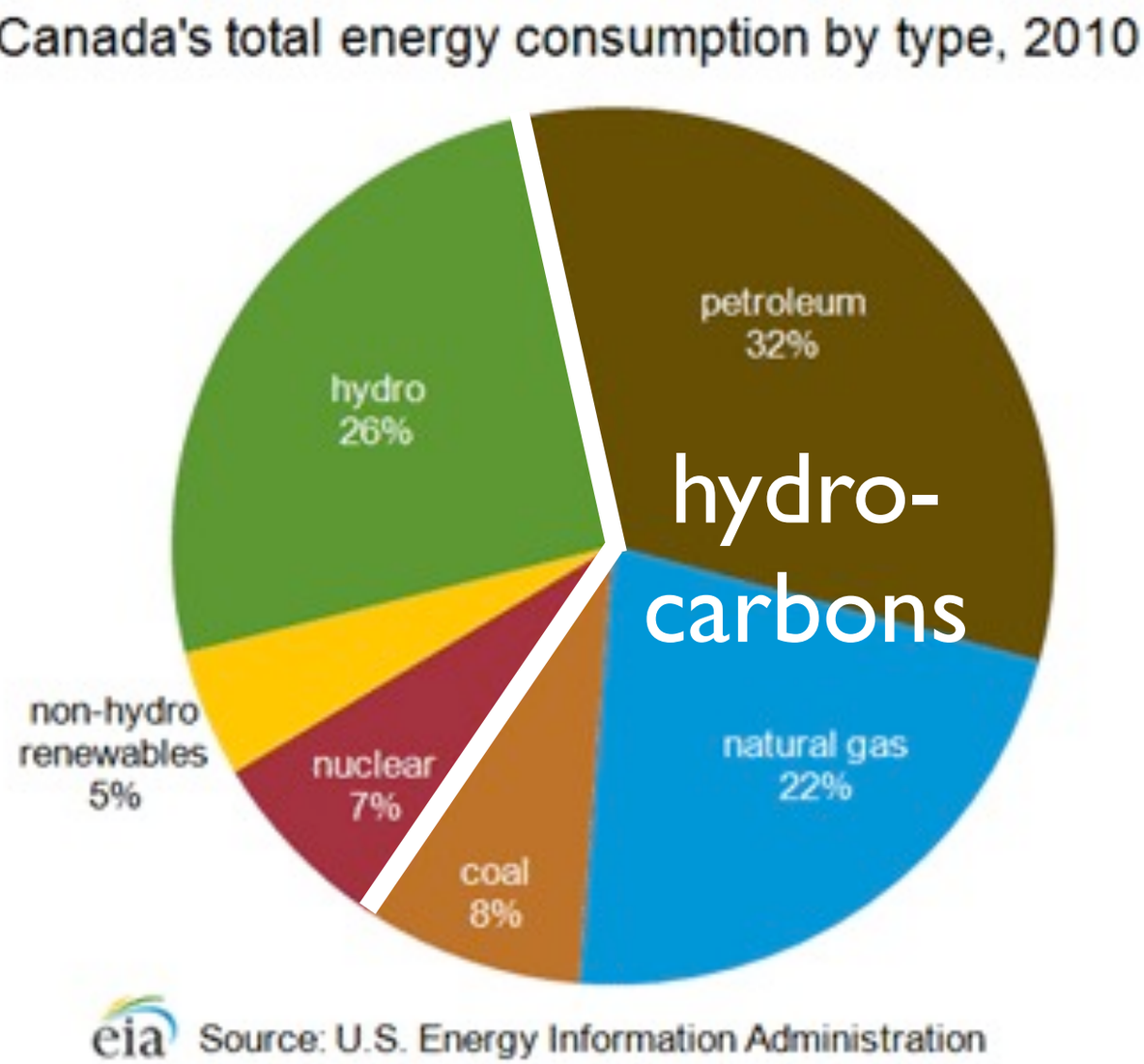
We believe that demand [for oil], not supply, could decline...

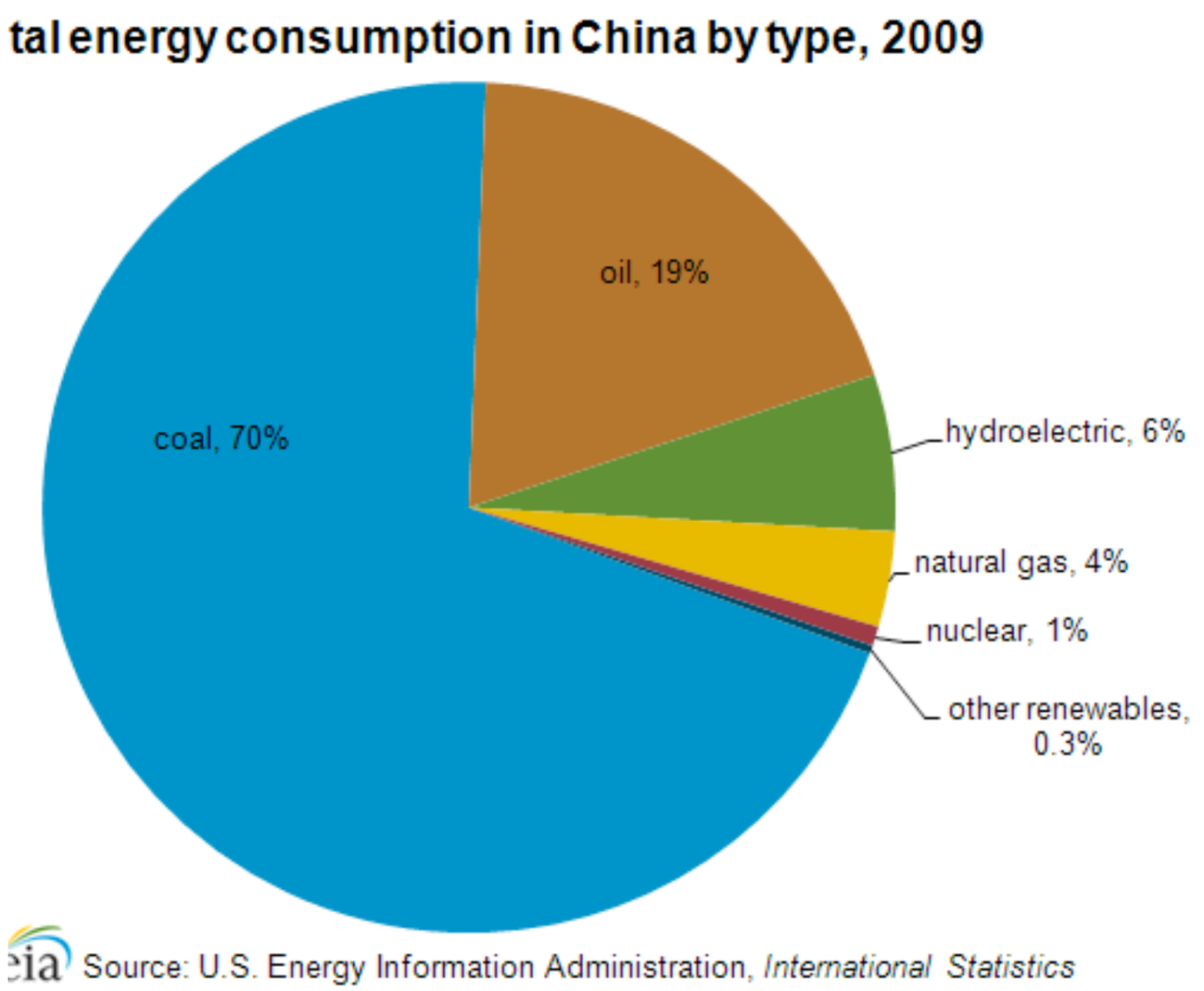
The first revolution was... "fracking"...to release huge supplies of [shale gas]...

The other great change is in automotive technology....

... [but a range of other economic factors]

Why the different energy use pattern?

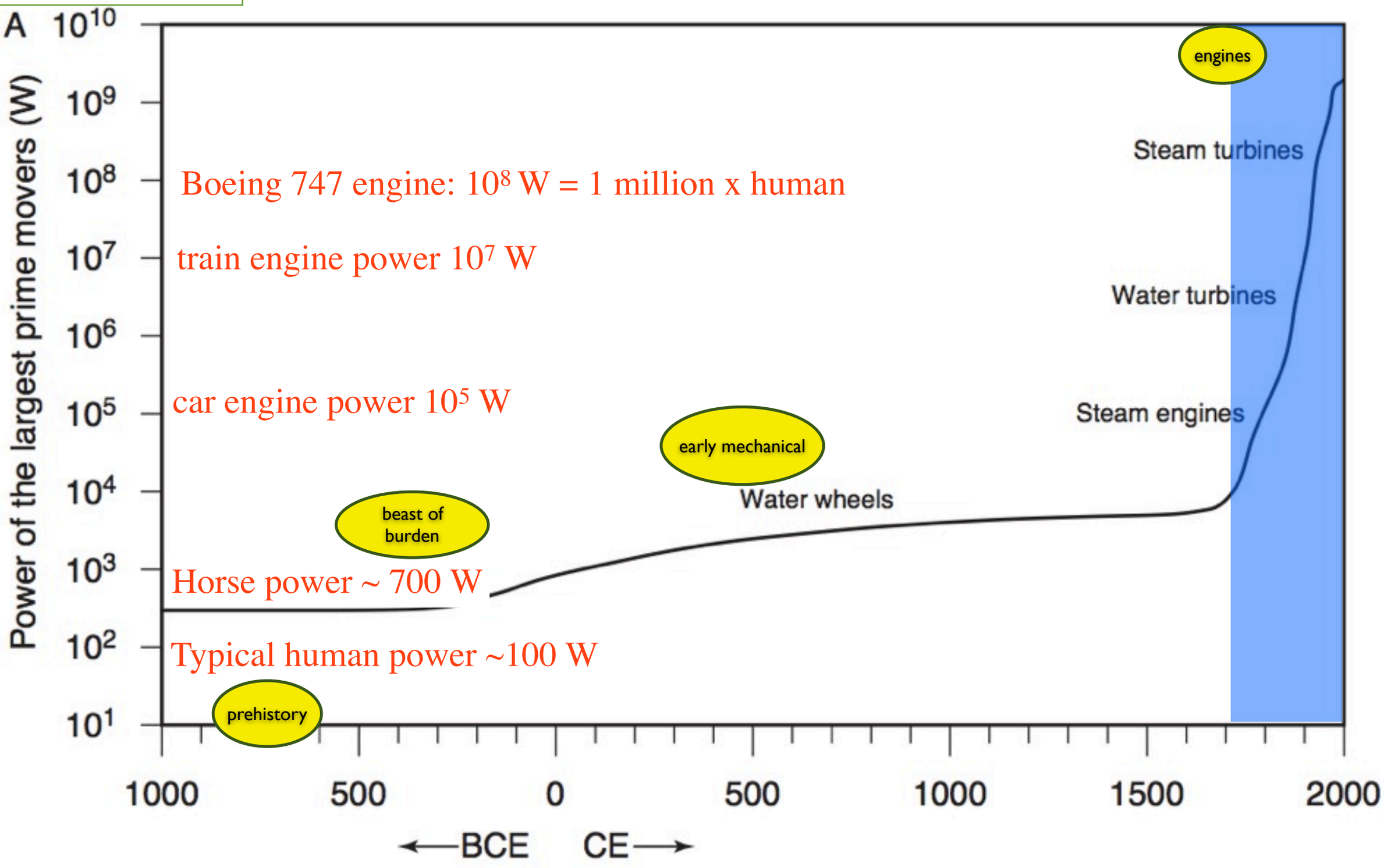




Maximum **power** of prime movers grew over the past 3000 years (Smil '04)

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

Logarithmic scale



$$\textbf{Efficiency of engines} = \frac{\text{mechanical energy output}}{\text{fuel chemical energy input}}$$

Efficiency critically impacts the civilization.

. 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

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,

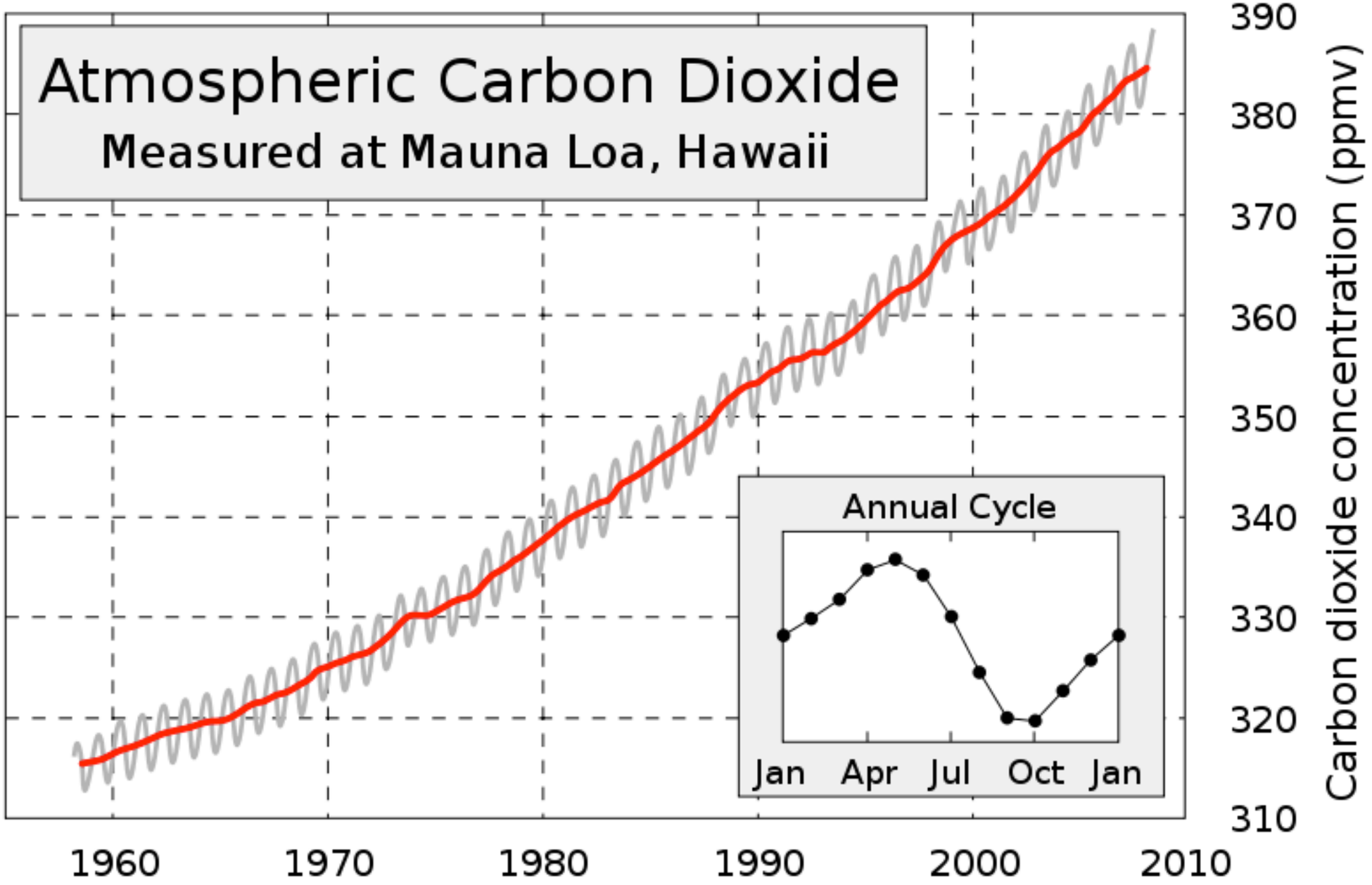
.natural gas is relatively 'cleaner'

.for per kWH of electricity, multiply by 3

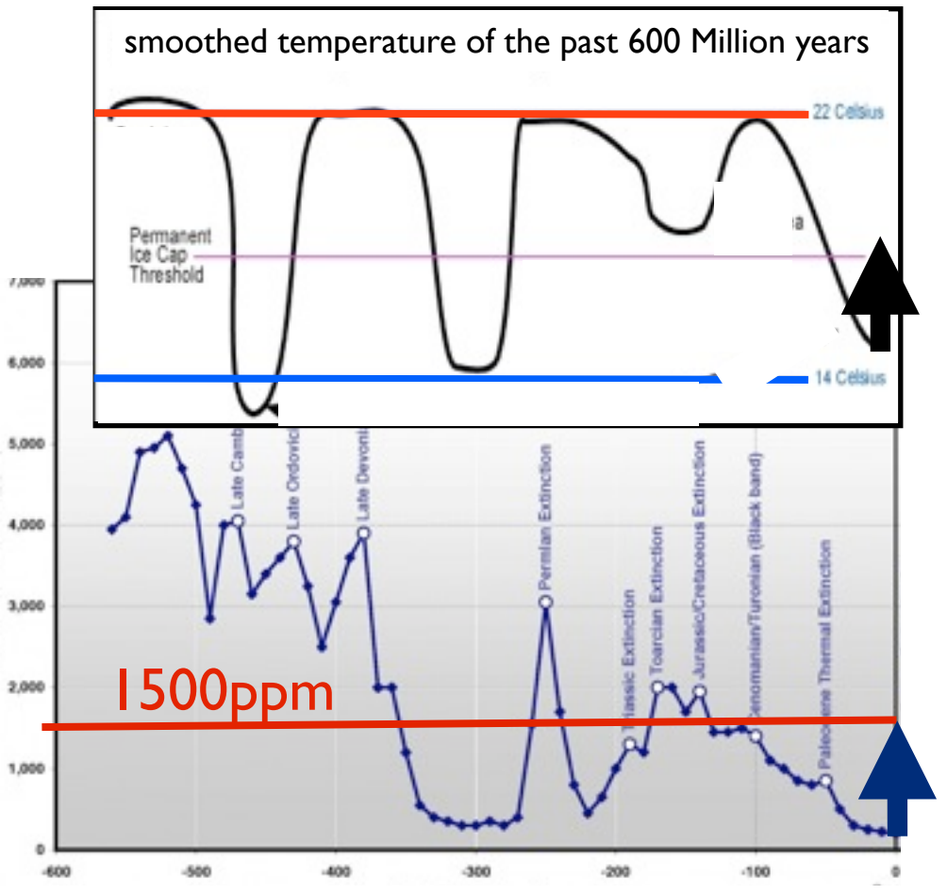
One kilogram of CO_2 for every hour of your fridge.

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

currently 380ppm
business as usual: 1500ppm by 2100

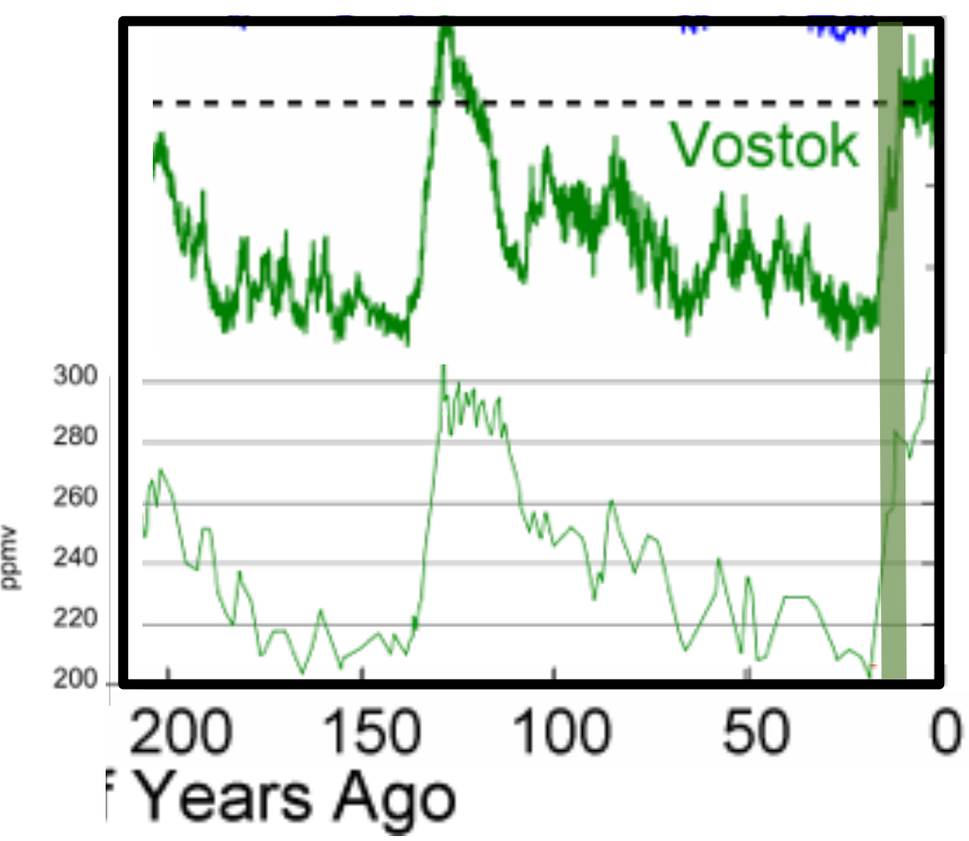


. each fridge uses ~ 1 kilo-watt power
.how many refrigerators in the world now.
.how many in the future



Summary: Earth in Deep History

- we are currently in an 'ice-house';
- climate on Earth is guaranteed stable on long timescales (thermometer: water & rock)
- but short swings unavoidable(nastiness)
- swings can be triggered by...

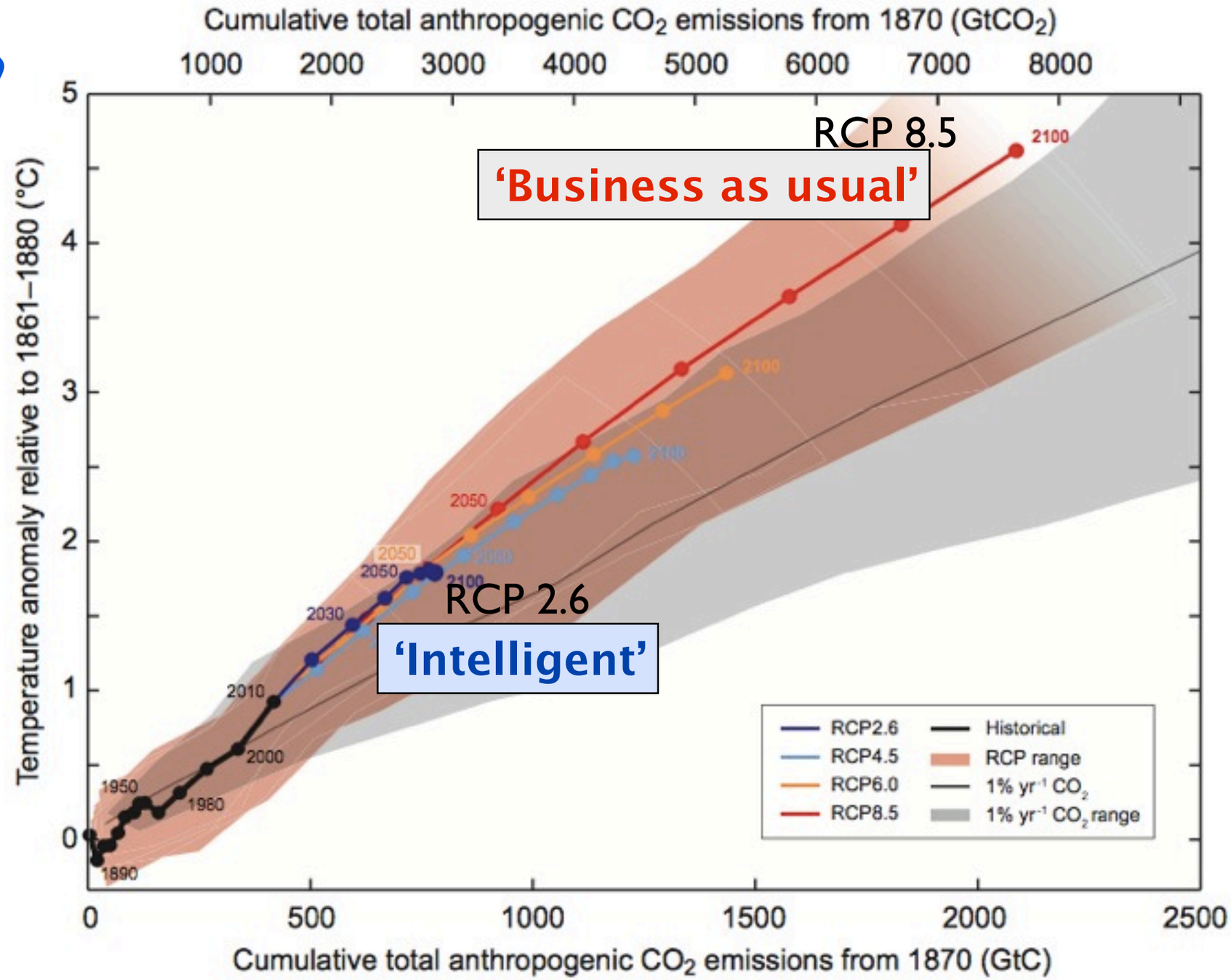


celestial forces:
- Sun, Moon, other planets
- (changing Earth's orbit/tilt)
- large asteroid impacts...

terrestrial forces:
- super-volcanoes, continent shifts,
- ocean currents...

life forces:
- bacteria evolution, trees, human....

If we don't do anything, how bad could it get?



1) Every CO_2 doubling raises T by 1.5 - 4°C (IPCC '13)
2) Global warming has already occurred, and may accelerate
3) CO_2 continues to accumulate in atmosphere even if emission reduced.
4) Ocean can slowly absorb (hundreds of yrs timescale)

Progression of human society: energy

	when	food production	average energy need	prime mover
gatherer/ hunter		~ 1person/ km^2	~2000 kcal/ day (~ 100W)	human
shifting agricultural, settled farming	10,000 yrs ago	~ 100x		beast of burden, early mechanical
industrial revolution	1850s			steam engine
green revolution	1960s	1000x		
post-industrial			100x (Canadian)	internal combustion engines

the Kardhashev Scale & The Rapa Nui Disaster

•Energy use of a civilization rises with time (population growth, life style improvement...).

•Soviet astronomer N. Kardashev proposed to categorize civilizations by its total energy use (1964).

•Type 0: power from organic fuel (fossils, plants), starting space-flights, vulnerable to environmental/ societal/medical failures
•Type I: power from hydrogen fusion, total power use ~ solar energy on Earth, planetary colonization, terra-forming...
•Type II: power from other exotic processes, total power use ~ total solar output, interstellar travel...
•Type III....

•With a total power use of ~ 20 Terra-watt, we are in Kardashev scale Type 0.72. If lucky, we may transition to Type I in a few hundred years (1000x higher power use).

•Some cultures died off earlier (e.g., Rapa Nui)