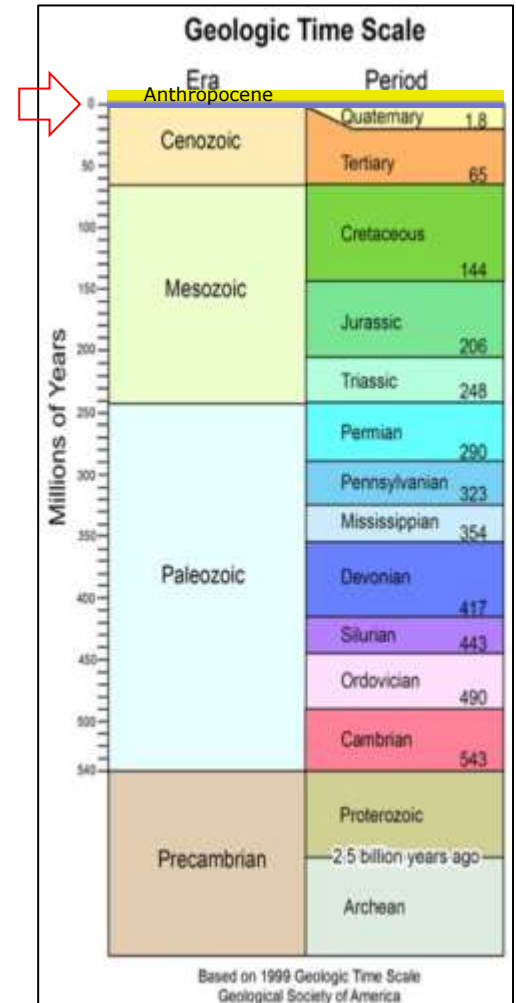


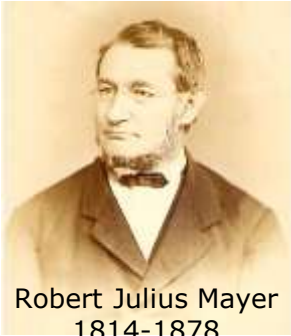
Agenda for Section (Sustainability @ "Anthropocene")

Grand picture Habitat and resource utilization

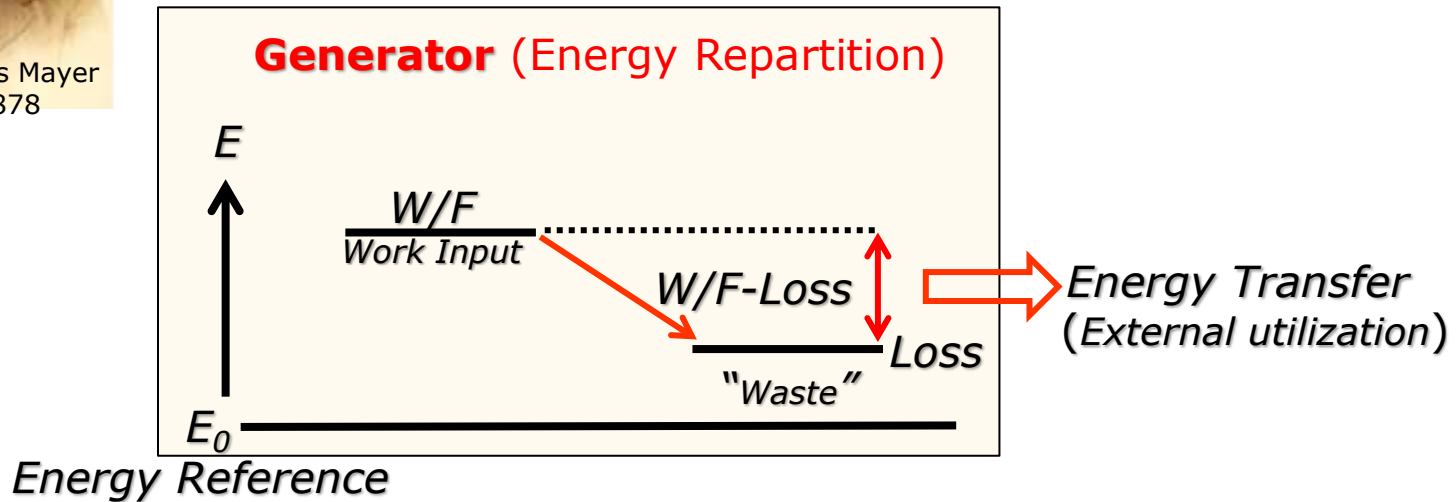
- Energy concept, human utilization of Energy
- Tools and fuels in human history
- Sustainability of Future Human Activity & Life on Earth
 - Limit to growth, Club of Rome, Socio-economic/ecological network.
- Finite resources: arable land and water for food production, materials for fabrication & construction, fuels for machinery & transportation,
 - Human eco-footprint, choices, and dilemmas,
- Energy utilization and environment,
 - Energy consumption and human development
 - External costs of energy consumption,
 - Correlations with planetary climate, greenhouse effect.



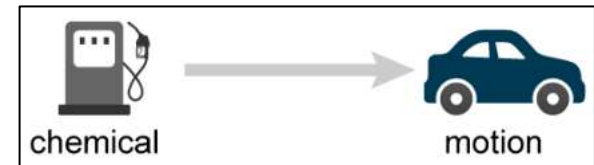
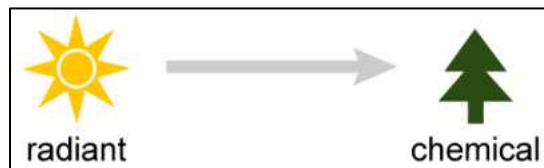
Schematic of Human Energy Utilization



Conservation of Energy = 1st Law of Thermodynamics (TD)
Energy in an isolated system can never be created or destroyed.
It can only be transformed. **Only energy differences count.**



Examples
For Energy
Conversion



Direct (Internal) vs. Indirect (External) Energy Costs

The real direct costs of energy production by a given method or power plant :

“**Levelized cost of electricity** (energy)” per kWh, 1-year average.

= What consumer must pay for 1 kWh from a provider

$$LCOE = \frac{\text{annuity}_N \cdot C_{\text{capital}} + (\text{Operations} + \text{Maintenance})_{\text{fixed}}}{8760 \cdot \text{Capacity} - \text{Factor}} + (\text{Operations} + \text{Maintenance})_{\text{variable}} + \text{fuel}$$

Annuity: break-even return on the capital after N years of operation. Estimates are based on Life Cycle Analysis (“from cradle to grave”).

Often neglected, but potentially much more significant, and harder to estimate in terms of \$\$:

→ → “**External Costs of Energy**”

External Costs of Energy Production/Consumption

Direct and indirect costs and consequences that are typically not included in price of primary energy carriers (or charged to consumers)

- Pollution: reduced air, water, and land quality → public health, economic cost,
- Reduction of water quantity → agriculture, public health (food),
- Physiological & aesthetic (audio, visual) effects → quality of life,
- Ecological effects from accidental spills and persistent waste release,

- Addition of heat-trapping gases (GHG) to atmosphere → large changes climate/environment, large economic costs,
- Destruction of arable and wet land, forests → lasting economic cost,
- Ocean acidification, changes marine bio environment, food chain,
- Stressing animal/fish habitat,

- Limits to energy security: Susceptibility to external political pressure from energy producers,
- Military defense of access to foreign primary energy resources.

Examples



Extern E Cost: London Fog in the Past (?)



In December of 1954, a poisonous mix of dense fog and black coal soot killed thousands of Londoners in four days.

In December of 1954, a poisonous mix of dense fog and black coal soot killed thousands of Londoners in four days. London/UK was at that time the most populous city in Europe. Depending on analysis, anywhere from 4 thousand to 12 thousand citizens died as a result. At its worst, visibility in London was reduced to one foot. Bad visibility in and of itself won't kill you unless you're clumsy and reckless. The problem with this smog is that it contained sulphur dioxide, hydrochloric acid, fluorine compounds and other poisons. Mean concentrations of smoke and sulphur dioxide at 12 daily test-sites increased sharply on the first day of the incident and, after 3 to 4 days, averaged 1.6 mg/m³ and 0.7 parts per million respectively, or about 5 to 6 times normal. At individual sites in the central London area concentrations rose to 10 times normal. Statistics compiled by medical services found that the fog had killed 4,000 people. Most of the victims were very young, elderly, or had pre-existing respiratory problems.

Extern E Cost: Donora/PA Industrial Smog of 1948

7
ESTS External Cost



Taken at noon on October 29, 1948, this picture shows the deadly smog blanketing Donora.

NOAA Oceanservice Education

The 1948 Donora Smog was due to a historic air inversion resulting in smog. Killed 20 people and sickened 7,000 more. Donora/PA a mill town near Pittsburgh. Hydrogen fluoride and Sulfur dioxide emissions from U.S. Steel Donora Zinc Works and American Steel & Wire plant frequent occurrences. More severe due to temperature inversion. Pollutants mixed with fog and formed thick acrid smog that over Donora for five days. "In three days, 20 people died... After the inversion lifted, another 50 died and hundreds more had damaged lungs and hearts." (After Wikipedia)

Los Angeles/CA, Then & Today

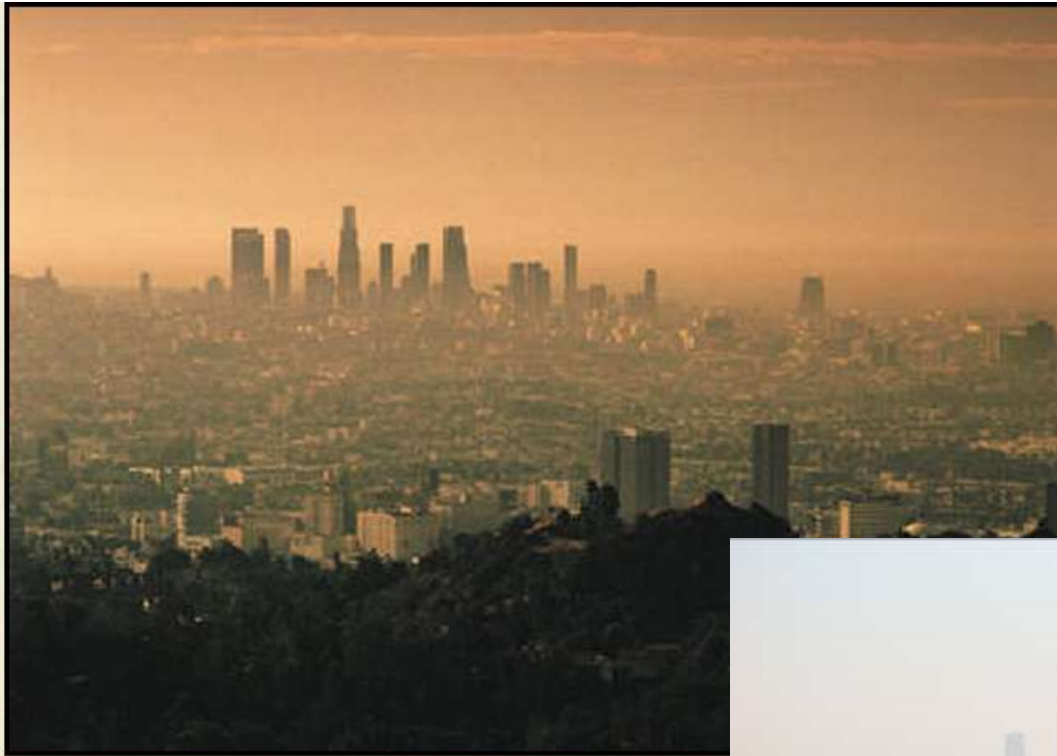


Image courtesy of U.S. EPA

<http://cfpub.epa.gov/airnow/index.cfm?action=>



Where a child lives can greatly affect his or her risk for asthma. According to a new study by scientists at Columbia University, neighborhood differences in rates of childhood asthma may be explained by varying levels of air pollution from trucks and residential heating oil. (Credit: © mario beauregard / Fotolia)



Apr. 30, 2009

Apr. 30, 2009 — The 10th annual American Lung Association State of the Air report released April 29 finds that six out of ten Americans--186.1 million people -- live in areas where air pollution levels endanger lives.

Direct External Costs of Energy Consumption



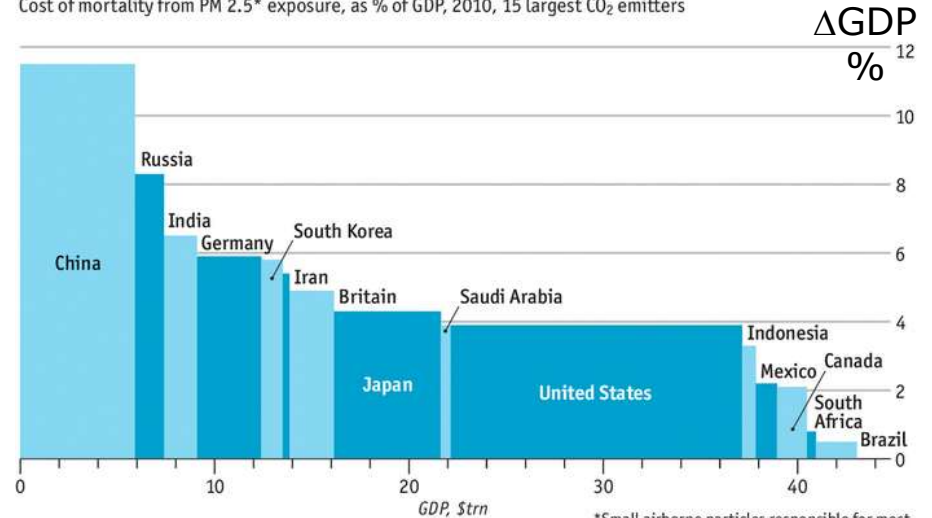
Dangerous:
Beijing Smog > 2010
2020s: Much reduced



Sulfur, nitrogen oxides, particulates from China's coal-fired power plants → acid rain on Seoul/SK, Tokyo/JP, particulate pollution in Los Angeles (J. Geophys. Res.).

Loss of life & health → economic costs.
\$(10-13)M/capita

Cost of mortality from PM 2.5* exposure, as % of GDP, 2010, 15 largest CO₂ emitters



Source: New Climate Economy

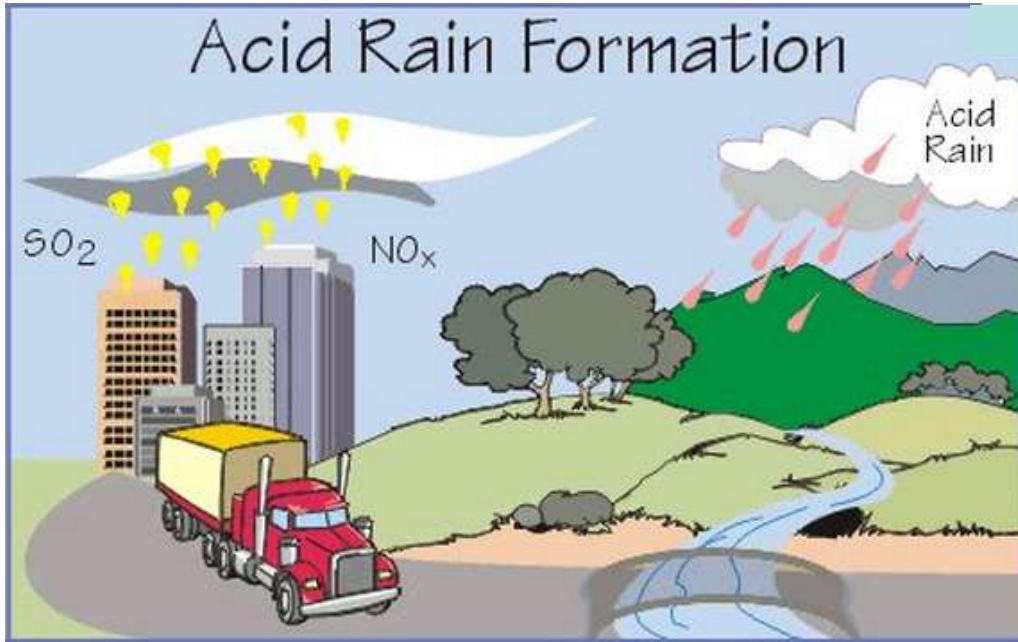
*Small airborne particles responsible for most of the health effects of outdoor air pollution

New Delhi/India "Gate of India"
2021 (l) vs. < 2019(r)

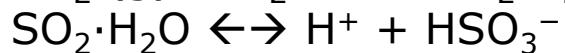
During pandemic lockdown (left), absence of automotive traffic clears air of smog, which is normally present (right panel)



Direct External Costs: Air Pollution, Acid Rain



Certain types of coal and oil burn with emission of carbonic, sulfuric, and nitrous oxides



SO₂ in air rains down and pollutes soil and waters, increases the acidity levels of rivers, lakes and seas → kills aquatic life. Taken up in soil → can kill vegetation. (U.S. 1960s-1970s)

External Costs of Energy Consumption

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ESTS External Cost

Indonesia: Oil fires to clear rain forest for (oil) palm plantations



Canadian production from oil sands destroys landscape



Toxic pollution from oil/gas drilling



Dan River Steam Station (Duke Energy)

Primary Ash Basin

Dan River

Eden North Carolina Coal Ash Spill 2/7/2014

External Costs of Energy Consumption



Satellite Radar imaging of forest in Central African Republic shows depletion (in black) of healthy forest (in red) by inhabitants to produce charcoal.

"Charcoal Web"
(Radar image: NASDA, Radar Technologies France)

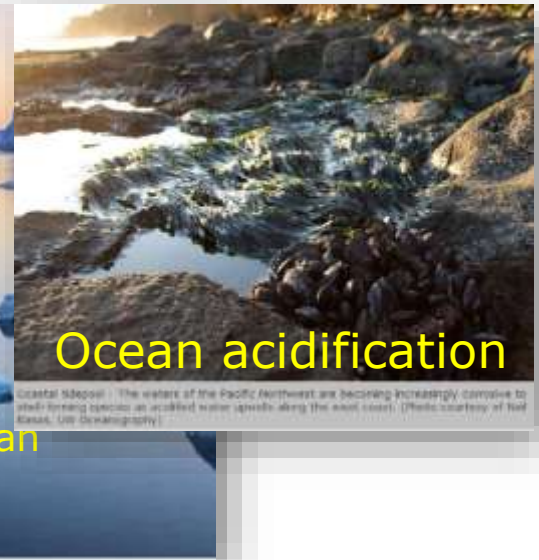
Long-term indirect effects due to anthropogenically enhanced warming,



Dwindling/unclean water resources in Africa



Melting Sea Ice in Arctic Ocean
(Economist)



Ocean acidification

Coastal Upwelling - The waters of the Pacific Northwest are becoming increasingly corrosive to shell-forming species as acidified water spirals along the west coast. (Photo courtesy of Neil Cross, US Oceanography)

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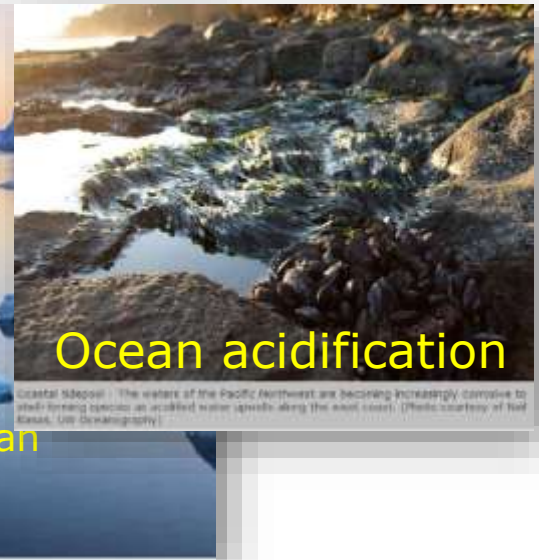
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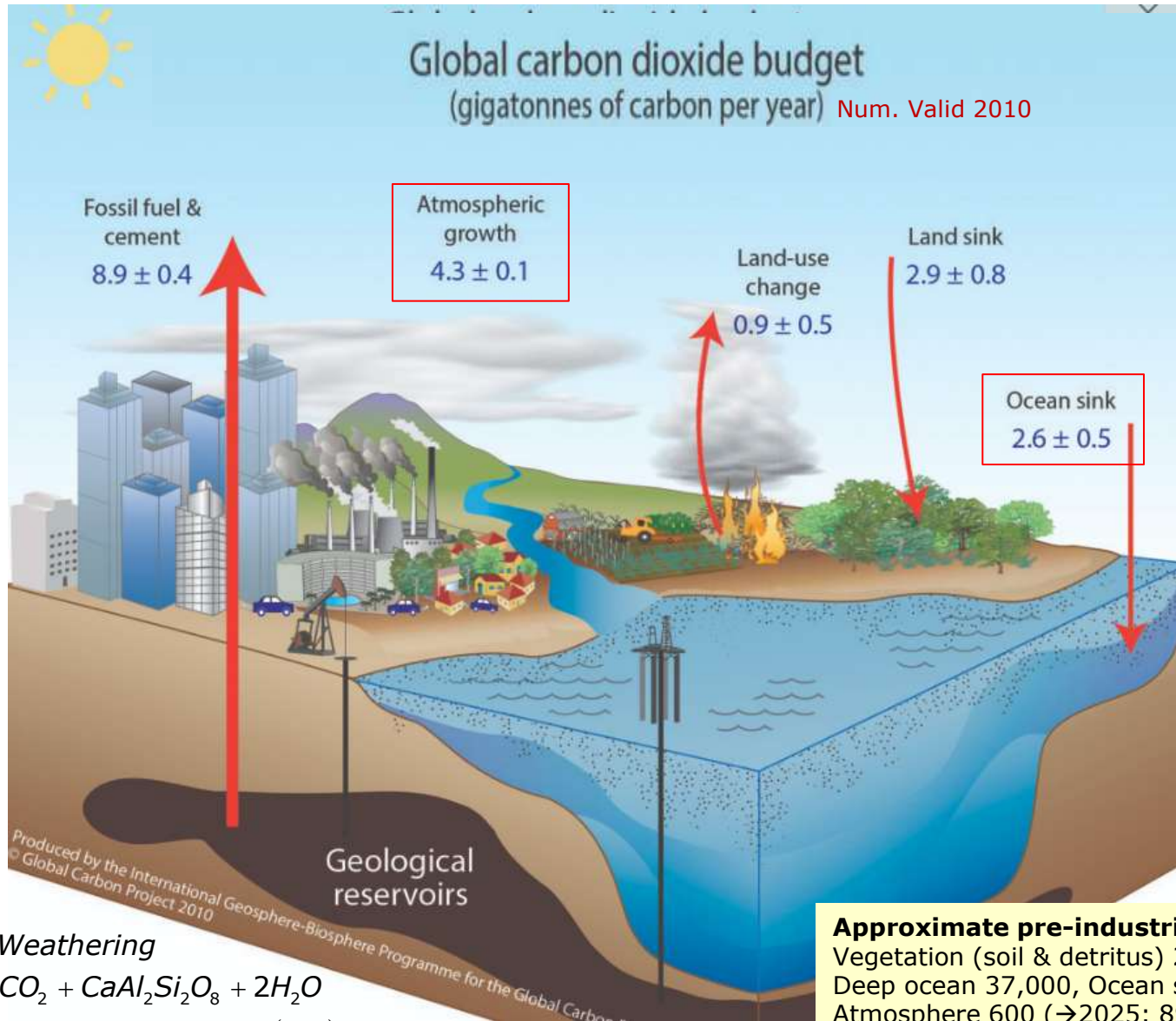
Melting Sea Ice in Arctic Ocean
(Economist)



Ocean acidification

Coastal Acidosis - The waters of the Pacific Northwest are becoming increasingly corrosive to shell-forming species as acidified water spills along the west coast. (Photo courtesy of Neil Cross, US Oceanography)

External Systemic Cost: Changing Carbon Cycle



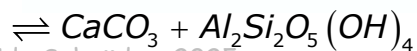
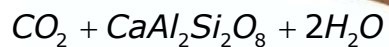
Man-induced changes in Earth's Carbon Cycle between surface and ocean reservoirs. Anthropogenic changes (+ or -) due to burning fossil fuel, land use, ... ~1%.

Red up arrows: anthropogenic flows
Zero= pre-industrial flow.
Units: 10⁹ tons of carbon per year (GtC/a).

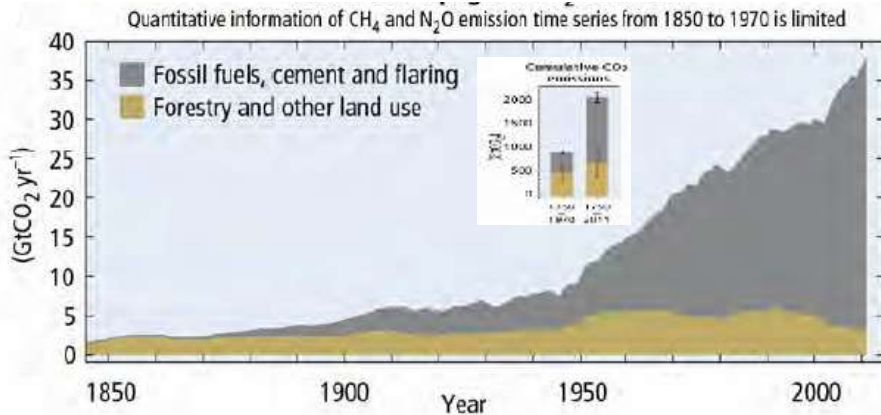
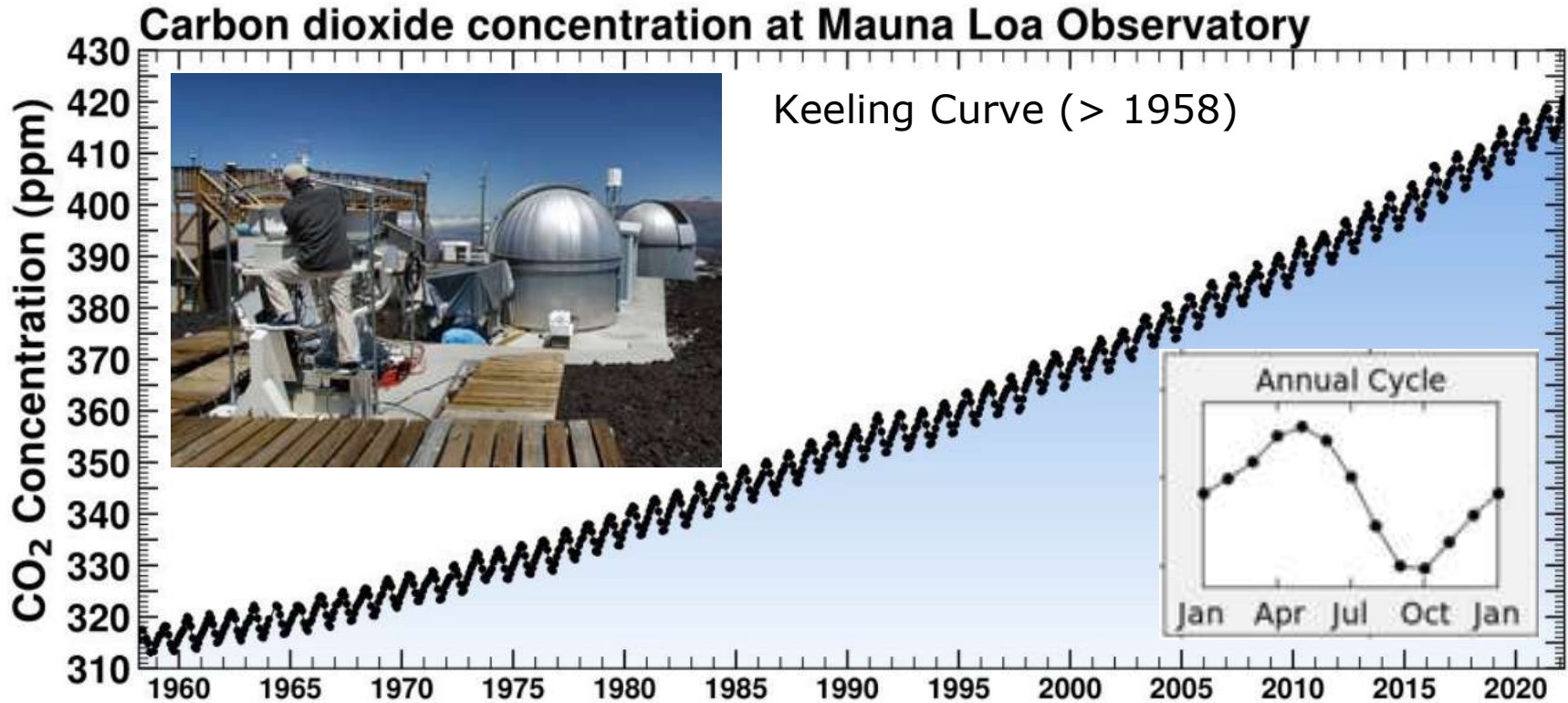
Emissions (2012):
+9.6 Gt C/a =
+36.2 Gt CO₂ equ./a
2018:36.7 Gt
(NOAA)

Approximate pre-industrial inventory carbon (Gt)
Vegetation (soil & detritus) 2,300, Surface oceans 900,
Deep ocean 37,000, Ocean sediments 150
Atmosphere 600 (→2025: 895), Known resources 3,700

Weathering



Tracing Atmospheric CO₂

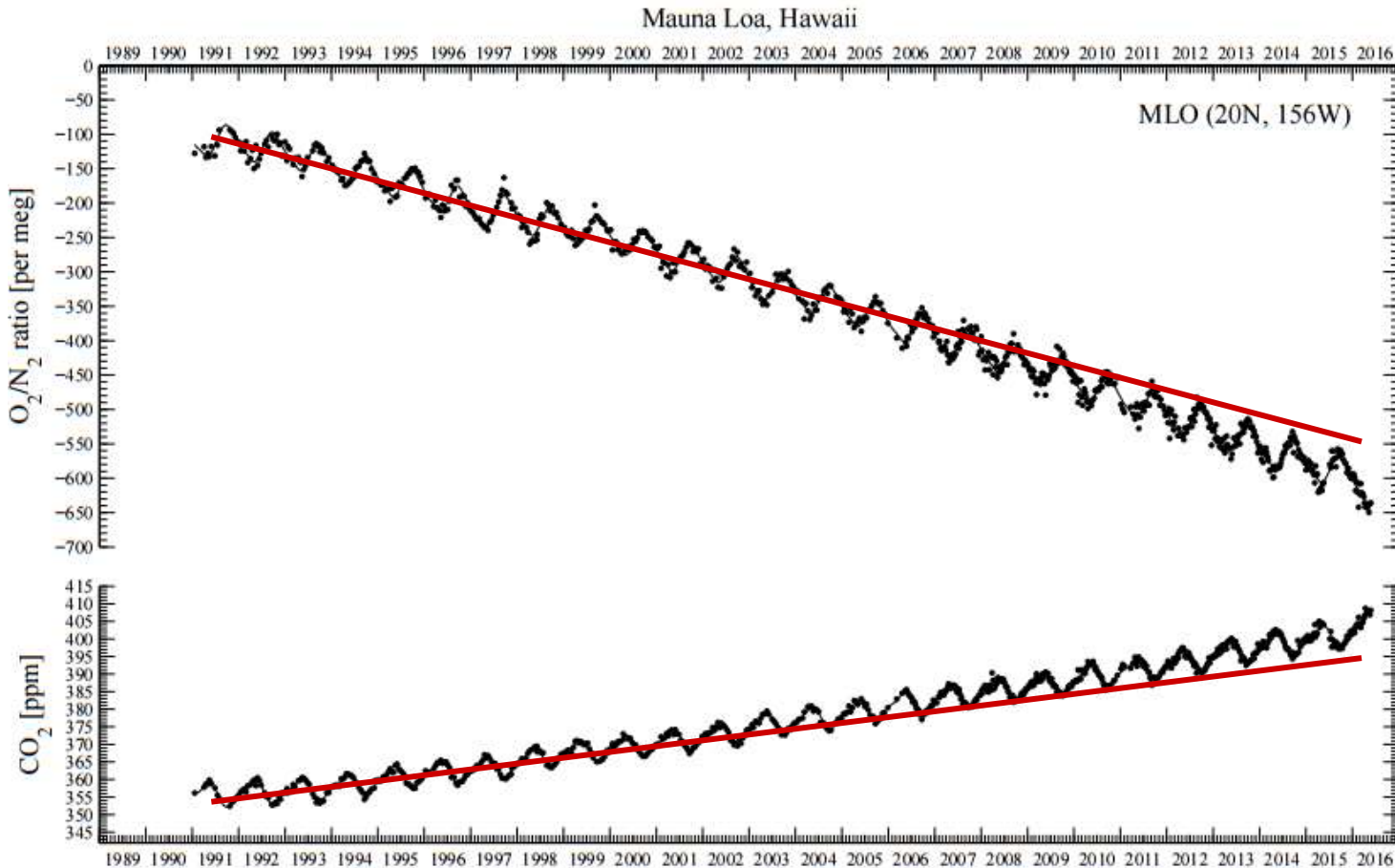


IPCC reports: Anthropogenic emissions are large, have increased and will further increase in future. → Future extent will depend on public policies.

Correlated Changes in Atmospheric Composition

O₂ depletion → correlation with CO₂ ?

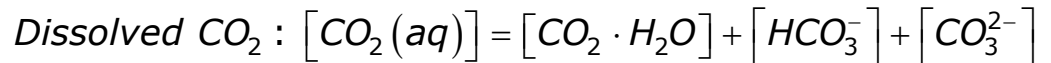
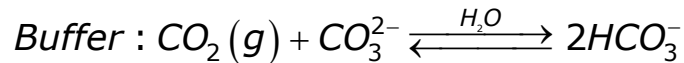
Both have oscillatory pattern, non-linear long-term trends.



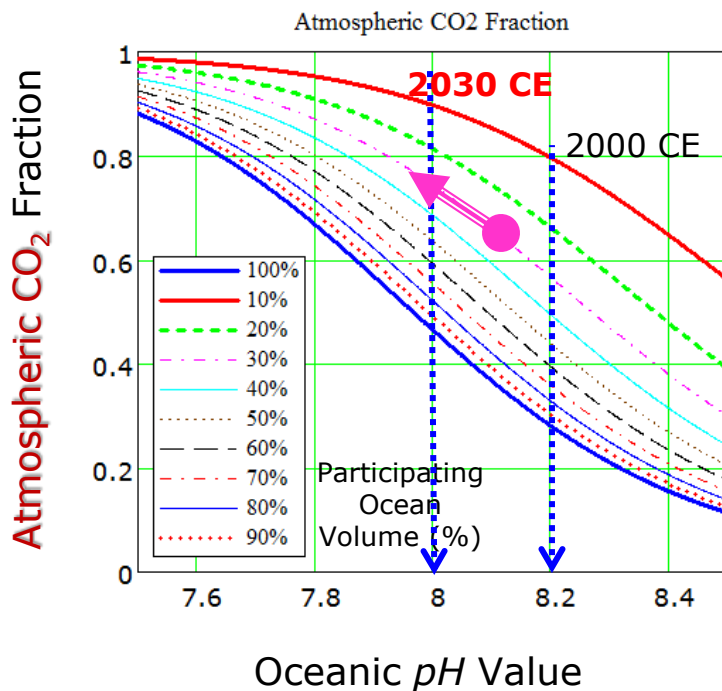
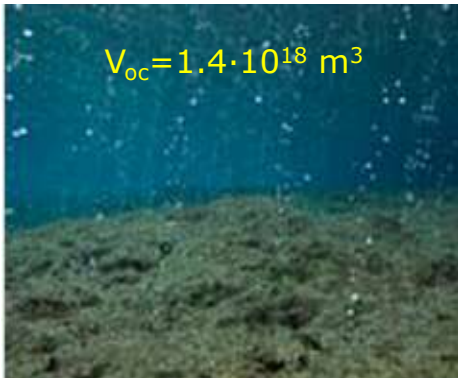
Extern E Cost: Ocean Pollution (CO₂ Uptake)

Ocean absorbs 1.7 Gt CO₂/a

Carbonate Chemistry



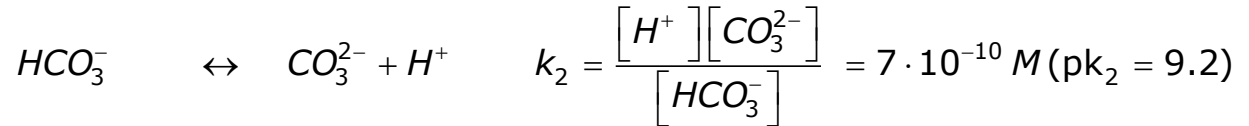
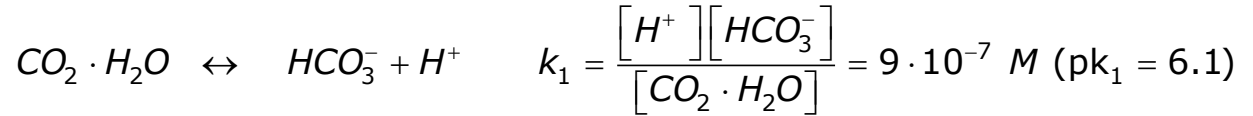
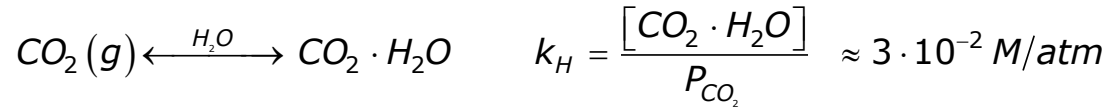
$$[\text{CO}_2(aq)]_{\text{equ}} = k_H P_{\text{CO}_2} \left(1 + \frac{k_1}{[\text{H}^+]} + \frac{k_1 k_2}{[\text{H}^+]^2} \right)$$



Alkaline buffer action of ocean water declines with decreasing *pH* value
 → smaller fraction of CO₂ is taken up by ocean.
 Average oceanic *pH* has dropped by 0.1 (8.2 → 8.1) within last 15 years, $\Delta T > 0$. →
 Decreased CO₂ uptake: 70% → 50%
 (if 100% of the ocean waters participate, less if only surface layers)

Non-linear positive feedback:
 Added CO₂ release decreases uptake by ocean waters.

Oceanic CO₂ Chemistry



$$[\text{CO}_2(aq)] = [\text{CO}_2 \cdot \text{H}_2\text{O}] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}]$$

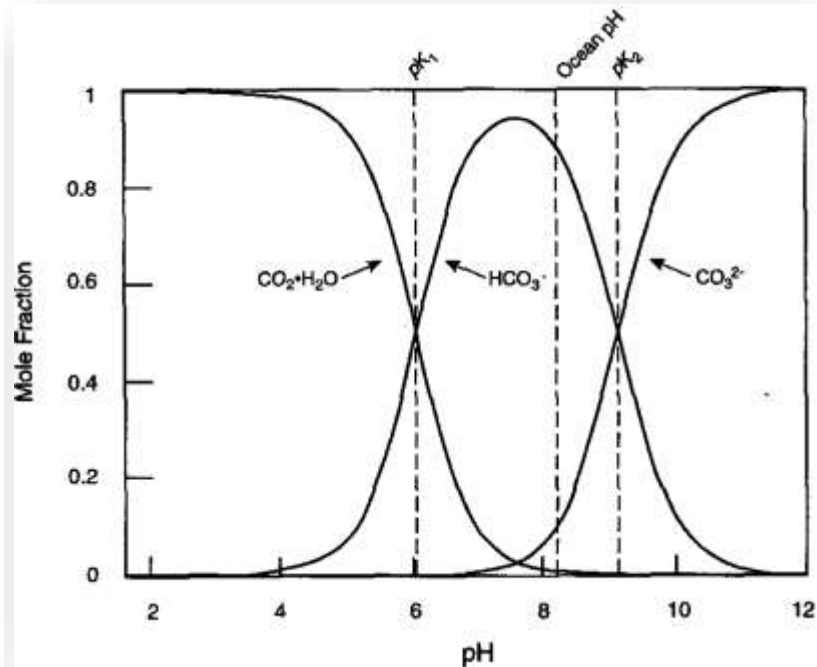
$$[\text{CO}_2(aq)] = k_H P_{\text{CO}_2} \left(1 + k_1/[\text{H}^+] + k_1 k_2/[\text{H}^+]^2 \right)$$

Average oceanic pH = 8.1 dropped from 8.2 in 1999 → 25% decrease in alkalinity (increase in acidity).

Alkalinity sustained by weathering of rock (CaCO₃) of continents → river runoff → buffer.

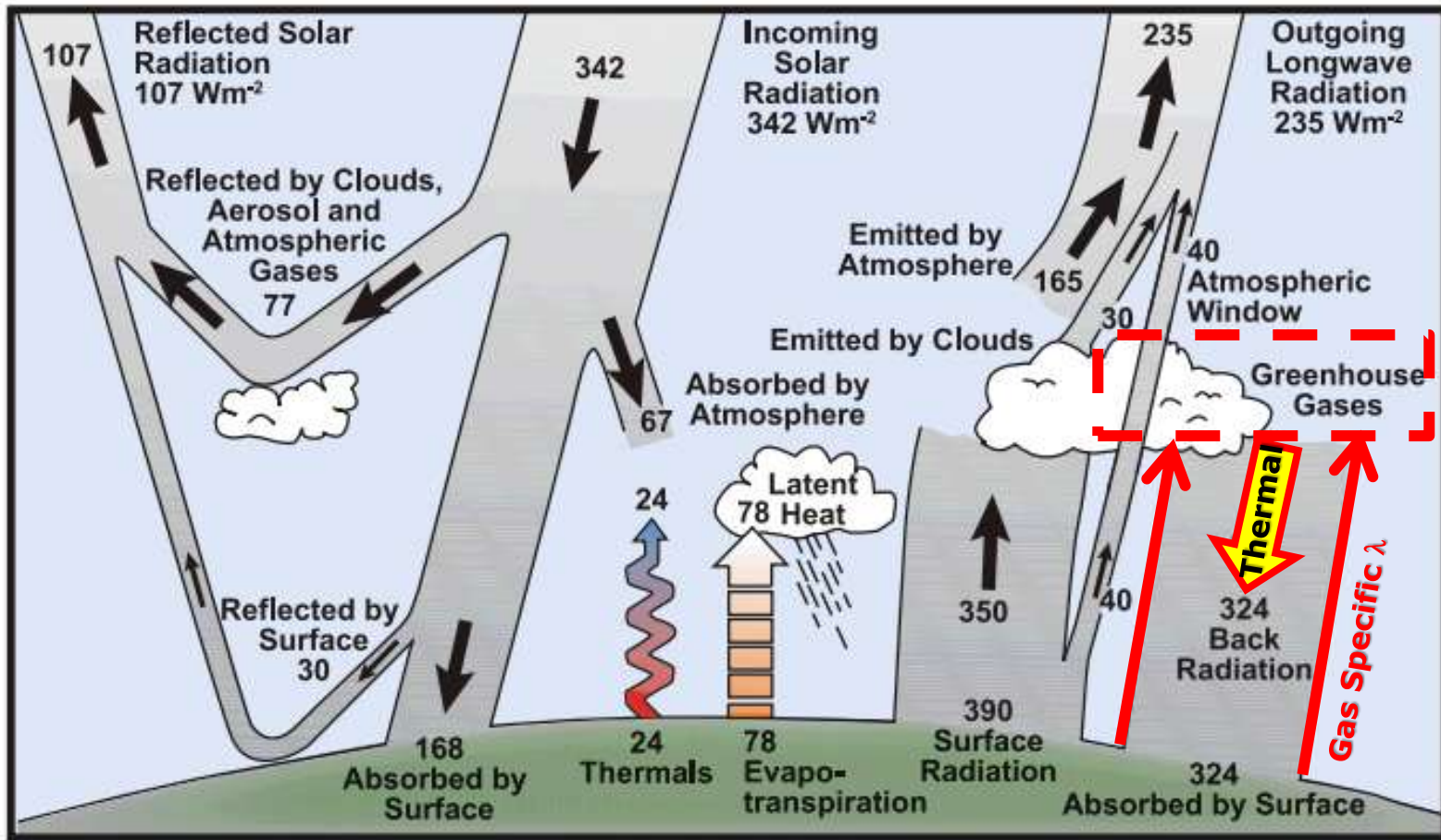
But acidity increases 10x faster than estimated by climate models (in 2000).

(National Geographic News Oct. 28, 2010)



D.J. Jacob, *Atmospheric Chemistry*, Princeton, 1999

Earth's Radiation Balance (GH Effect)

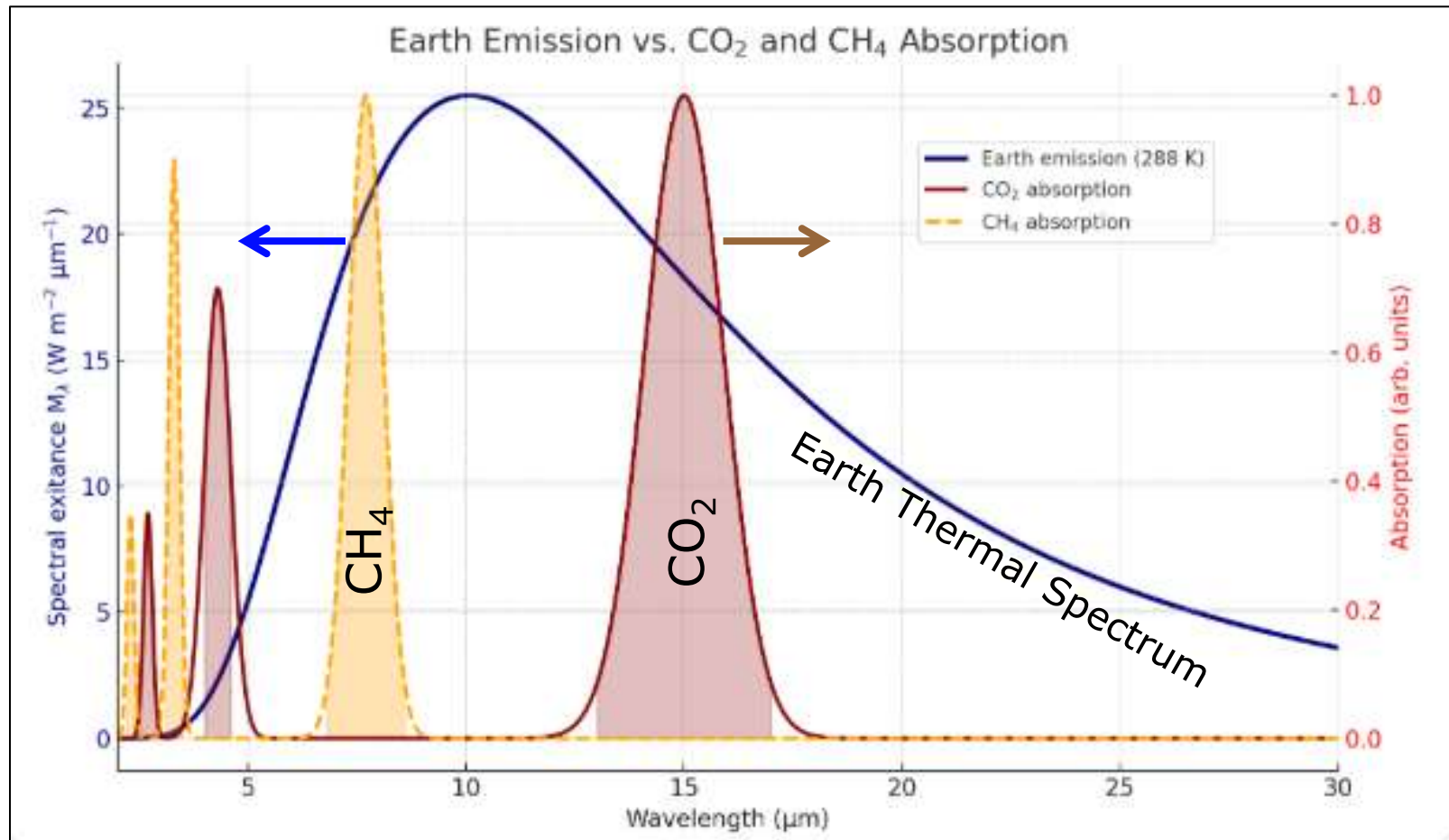


FAQ 1.1, Figure 1. Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).

Modified after IPCC AR4 Report:

<http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter1.pdf>

Atmospheric Capture of Earth' Back Radiation



Atmospheric CO₂ and CH₄ absorb strongly at wavelength where surface emits thermal radiation. This energy heats the troposphere, which radiates back to surface (feedback loop).

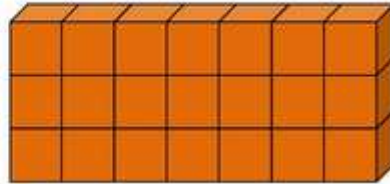
Global Warming Potential (GWP) rel. CO₂

1 pound of CH₄



=

21 pounds of CO₂



Main efficiency factors:

- 1) Effectiveness to trap heat (GWP#)
- 2) Abundance in atmosphere
- 3) Residence/lifetime in atmosphere

CO₂: GWP := 1 (reference).
Lifetime in Earth's atmosphere ~100 a.

CH₄: GWP = 21
Lifetime in Earth's atmosphere ~12 a.

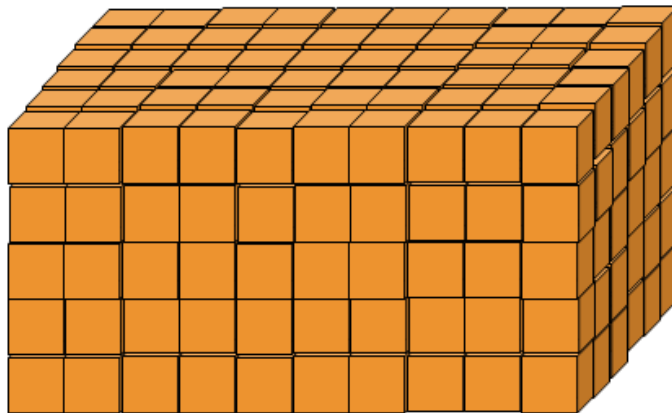
N₂O: GWP = 300
Lifetime in Earth's atmosphere ~120 a.

1 pound of N₂O



=

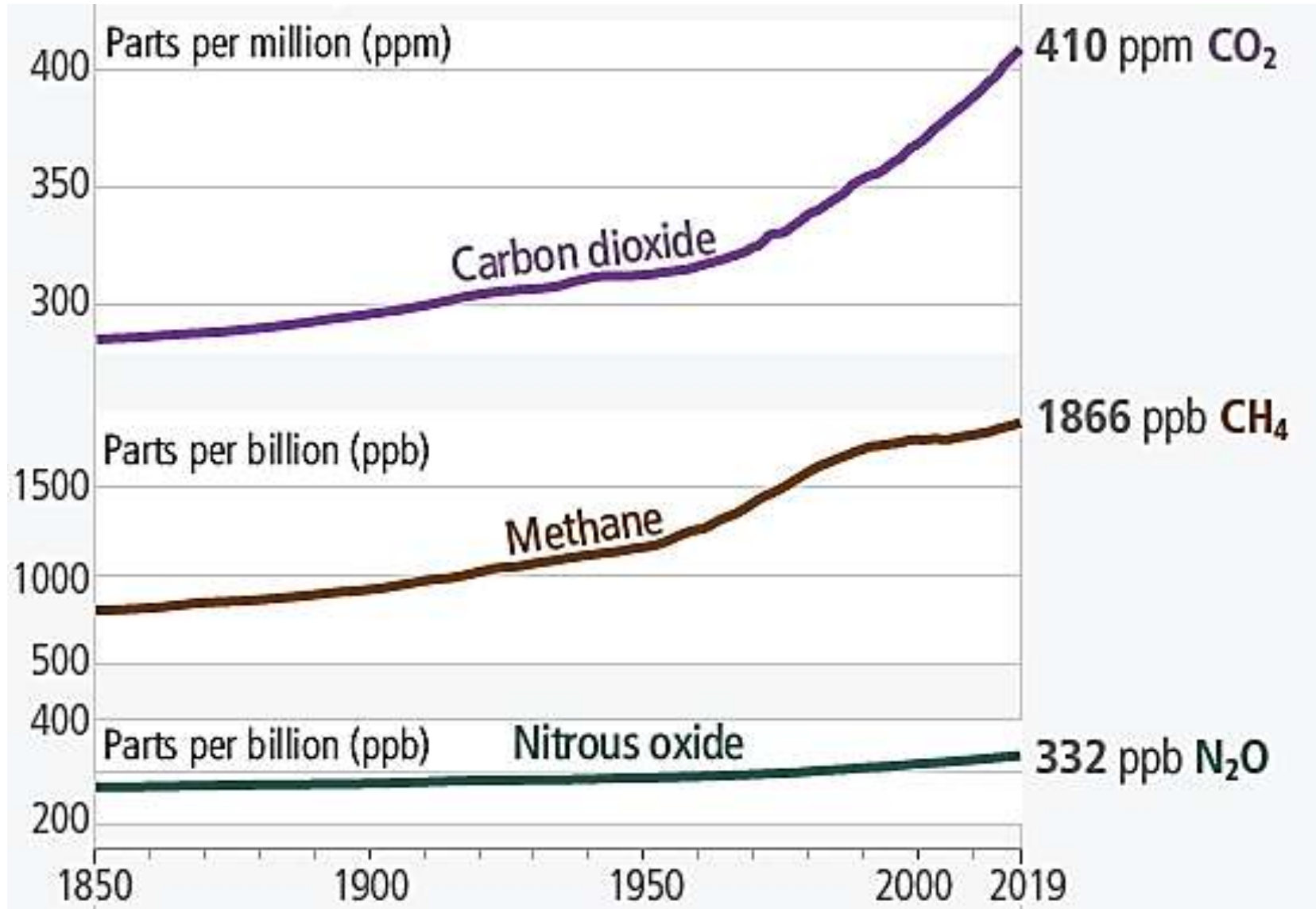
300 pounds of CO₂



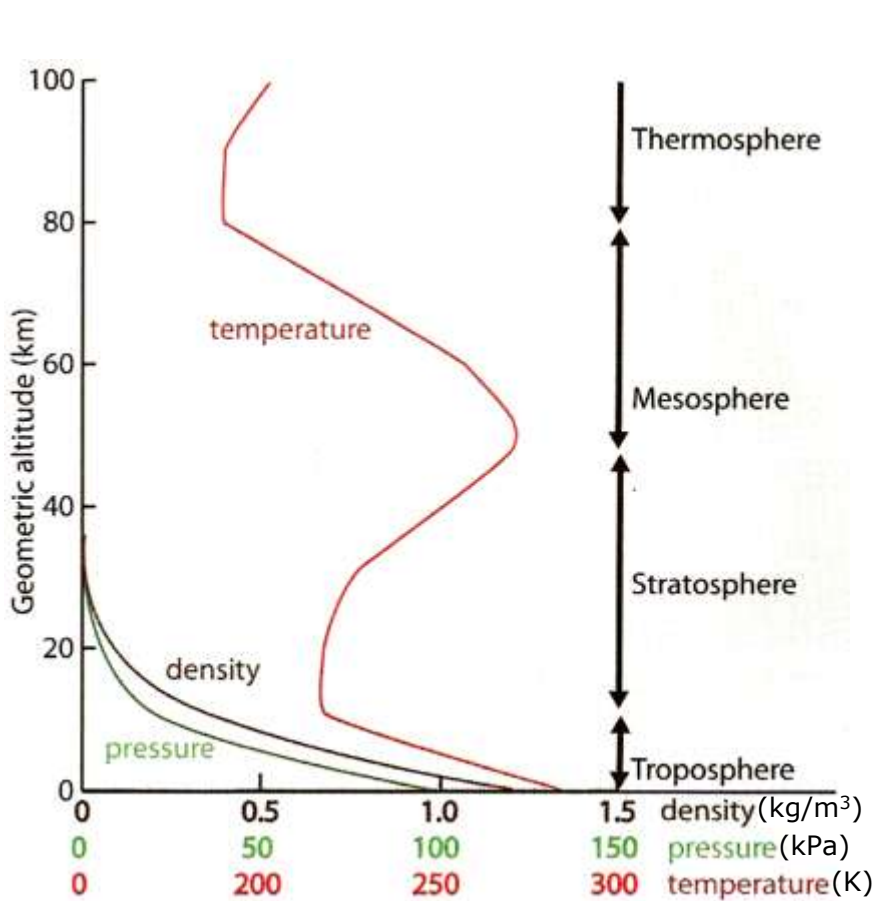
1 pound of SF₆

16,300 pounds of CO₂

Concentration of Greenhouse Gases (1850-2019)



Changing Standard Earth Atmosphere



Gas	Mixing Ratio	
	Volume (ppm)	Volume (%)
Nitrogen	781,000	78
Oxygen	209,500 →	21 →
Argon	9,340	0.934
Carbon dioxide	394 → 416 ↑	0.039 → 0.0426 ↑
Neon	18	0.0018
Helium	5.24	0.0005 ↑
Methane	1.79 → 1.9 ↑	0.00018 → 0.00019 ↑
Krypton	1.14	0.00011
Hydrogen	0.55	0.000055
Nitrous oxide	0.33	0.000033
Carbon monoxide	0.1	0.00001
Xenon	0.09	0.000009
Ozone	0-0.07	0-0.000007

These numbers are for a dry atmosphere; the water content of the atmosphere is on average 0.4% (1-4% at the surface).

Pressure units: 1 Pa (Pascal) = 1 kg/ms²
 1 atm = 1.013·10⁵ Pa = 760 Torr,
 1 bar = 1.0·10⁵ Pa,
 R= 8.3144598 J/(mol·K)

Barometric Law

$$P(z) = P(0) \cdot e^{-z/H}$$

height scale

$$H = \frac{R \cdot T}{M_{air} \cdot g}$$

