Last Time…

Global Climate Models (GCM)

GCM Predictions

Changes in climate observed over the last few decades will be small compared to those that will occur before the end of this century

- Temperature changes
- Albedo
- Sea level
- Quantity of precipitation
- Ocean pH
- Intensity of major storms
- Frequency/severity of forest fires

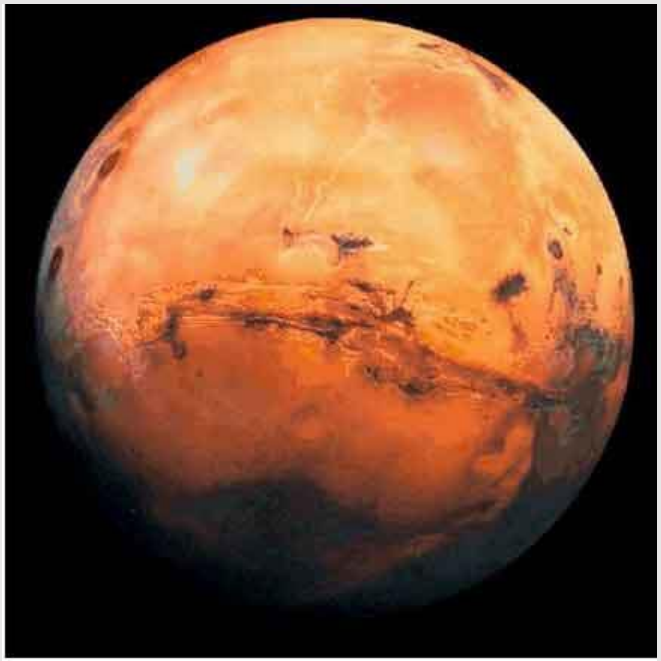
What are greenhouse gases?

Greenhouse gases are NECESSARY for life on Earth

Without GHGs, Earth would be similar to Mars

The EXTREMELY low concentration of GHGs means little heat. Temperatures can dip down to -120°C.

- The lowest recorded temperature in Antarctica was **–89.2 °C**



- Carbon dioxide (CO_2)
- Methane (CH_4)
- Tropospheric ozone (O_3)
- Nitrous oxide (N_2O)
- Chlorofluorocarbons (CFC)

Non-anthropogenic (non-human related):

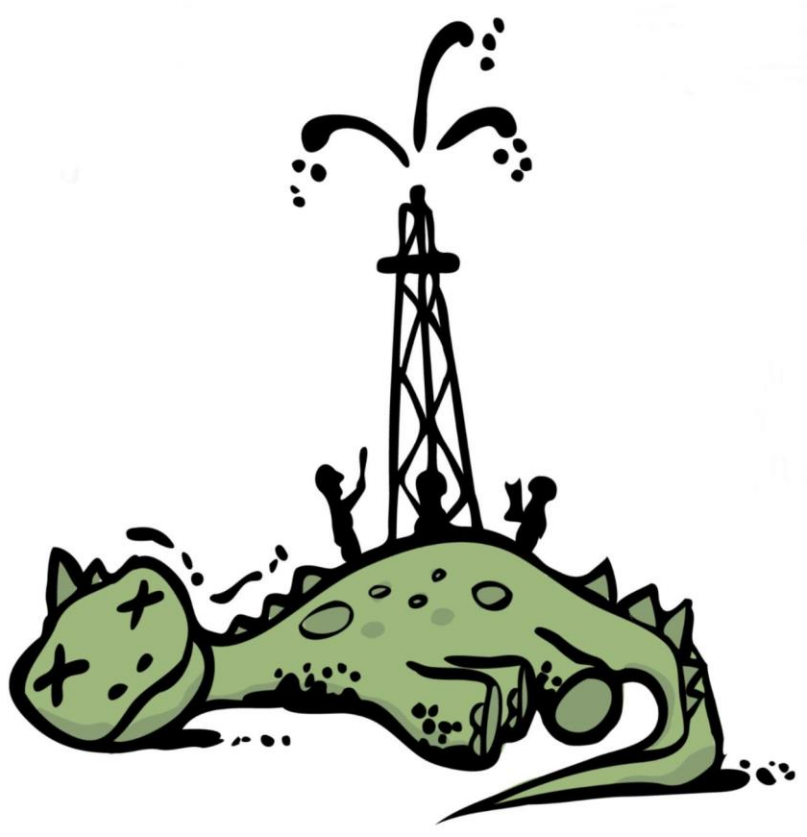
- Water (H_2O)

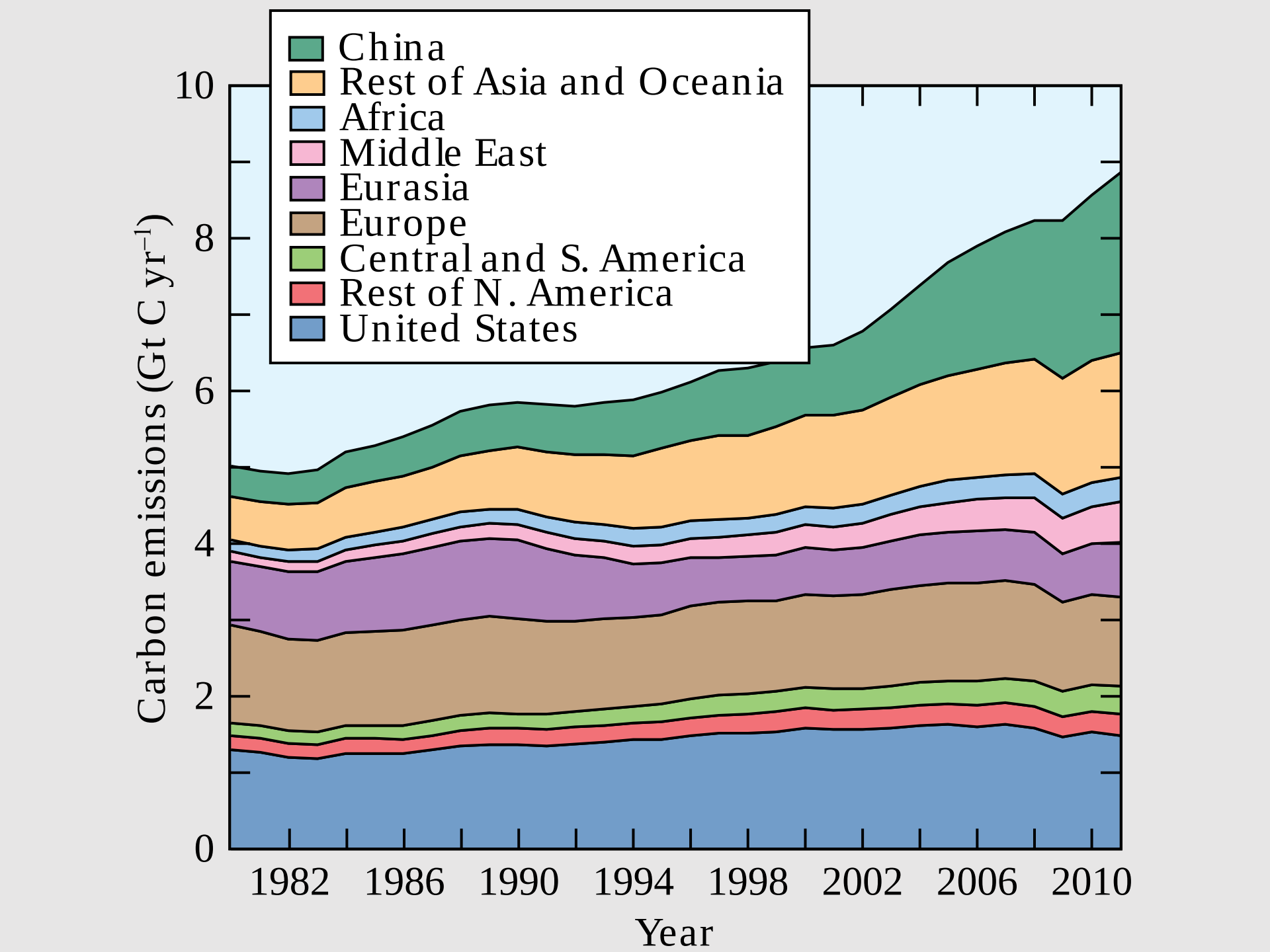
CO_2

- Highest in concentration and effect
- Responsible for about 33.3% of global warming that derives from human activities
- Natural sources: part of **limestone and other sedimentary rocks**. Released by weathering
  - –Weathering of silicate rock is a sink
- Natural sinks: photosynthesis and large bodies of water

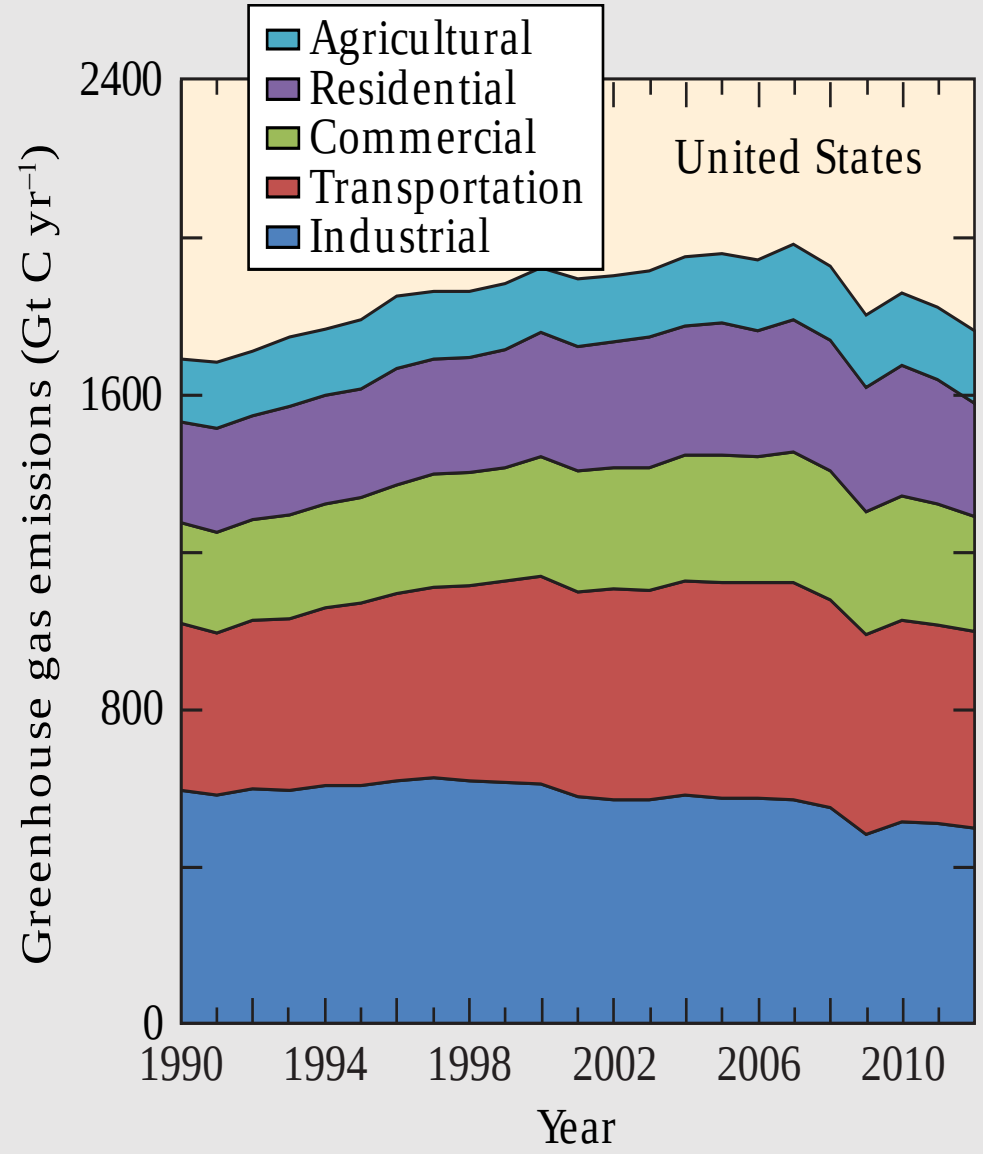
CO_2

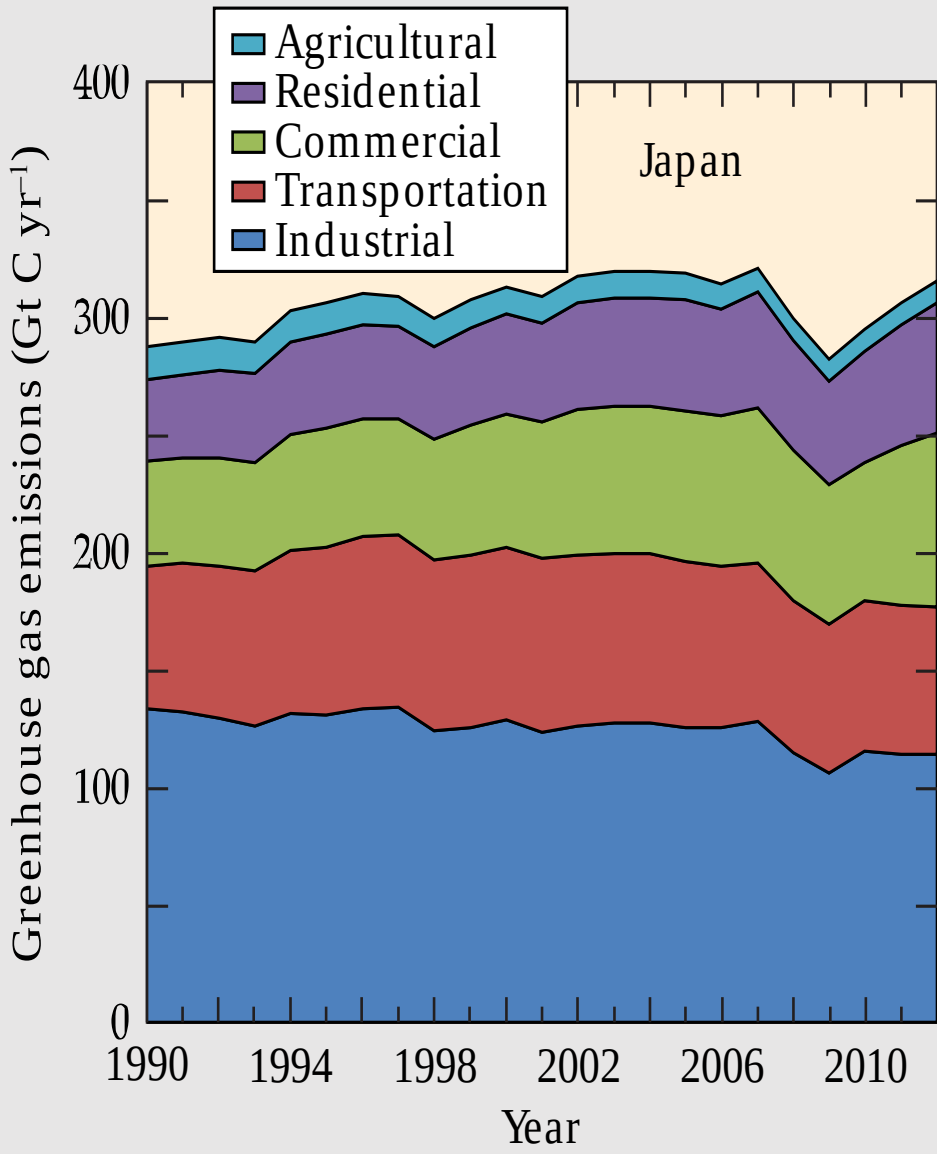
Anthropogenic sources: burning fossil fuel and cement production

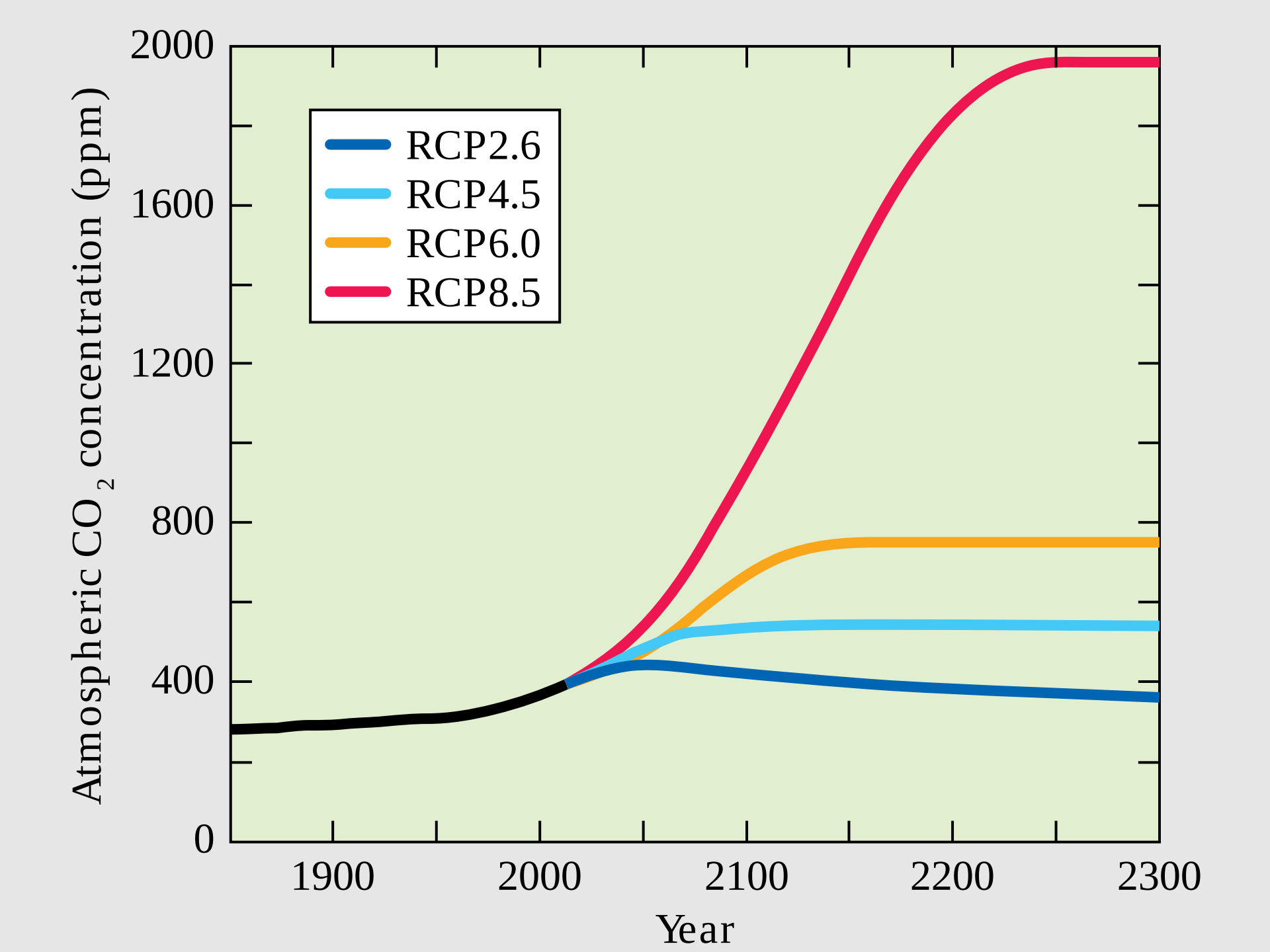



China
Rest of Asia and Oceania
Africa
Middle East
Eurasia
Europe
Central and S. America
Rest of N. America
United States
Carbon emissions (Gt C yr⁻¹)
0
2
4
6
8
10
1982
1986
1990
1994
1998
2002
2006
2010
Year

- CO_2 emissions from burning of fossil fuels increased by 58% from 1980 to 2006.
- US leads in emissions per person
- China surpassed US in total carbon emissions in 2006


Agricultural
Residential
Commercial
Transportation
Industrial
United States
2400
1600
800
0
1990
1994
1998
2002
2006
2010
Year
Greenhouse gas emissions (Gt C yr⁻¹)


Agricultural
Residential
Commercial
Transportation
Industrial
Japan
400
300
200
100
0
1990
1994
1998
2002
2006
2010
Year
Greenhouse gas emissions (Gt C yr⁻¹)


RCP2.6
RCP4.5
RCP6.0
RCP8.5
Atmospheric CO_2 concentration (ppm)
2000
1600
1200
800
400
0
1900
2000
2100
2200
2300
Year

Turning Carbon Dioxide Into Rock, and Burying It

NY Times, 2015. Thanks Corey Ching!

- Scientists i**njected hundreds of tons of water and carbon dioxide gas** 1,500 feet down **into layers of porous basaltic rock**, the product of ancient lava flows in Iceland
- The technique is designed to exploit the ability of **CO_2 to react with the rocks and turn into solid minerals**.
- Transportation and injection could cost about $17 per ton of CO_2, about twice the cost of transporting and injecting the gas alone. (These costs are on top of the much higher costs of capturing and separating $CO_2$from a power plant smokestack.)
- Because basalt is so reactive, **after a relatively short time** — a matter of years, not centuries — **most of the CO_2 should be mineralized, making long-term monitoring unnecessary**.

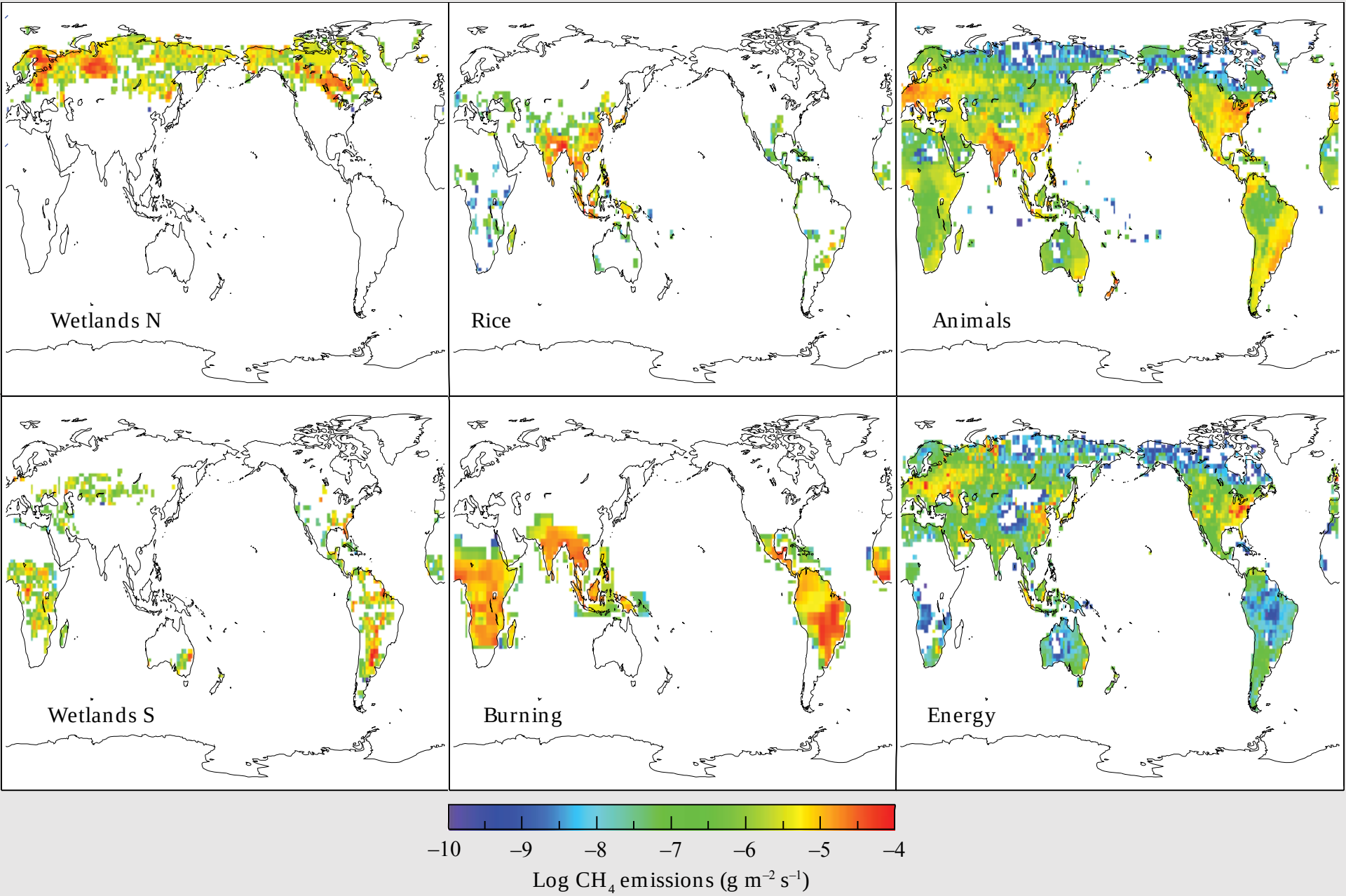
http://www.nytimes.com/2015/02/10/science/burying-a-mountain-of-co2.html?_r=0

Methane CH_4

- Accounts for about 15% of anthropogenic warming
- Emitted naturally by microorganisms doing anaerobic respiration

Anthropogenic sources:

- Rice paddies: Flooded soils become anaerobic and more soil microbes generate methane (marsh gas)
- Clearing of agricultural land by burning
- Domesticated ruminants (cows, sheep and goats)
- Natural gas extraction, processing, storage and transmission and distribution
- Released during coal mining


Wetlands N
Rice
Animals
Wetlands S
Burning
Energy
–10
–9
–8
–7
–6
–5
–4
Log CH4 emissions (g m–2 s–1)

Ozone O_3

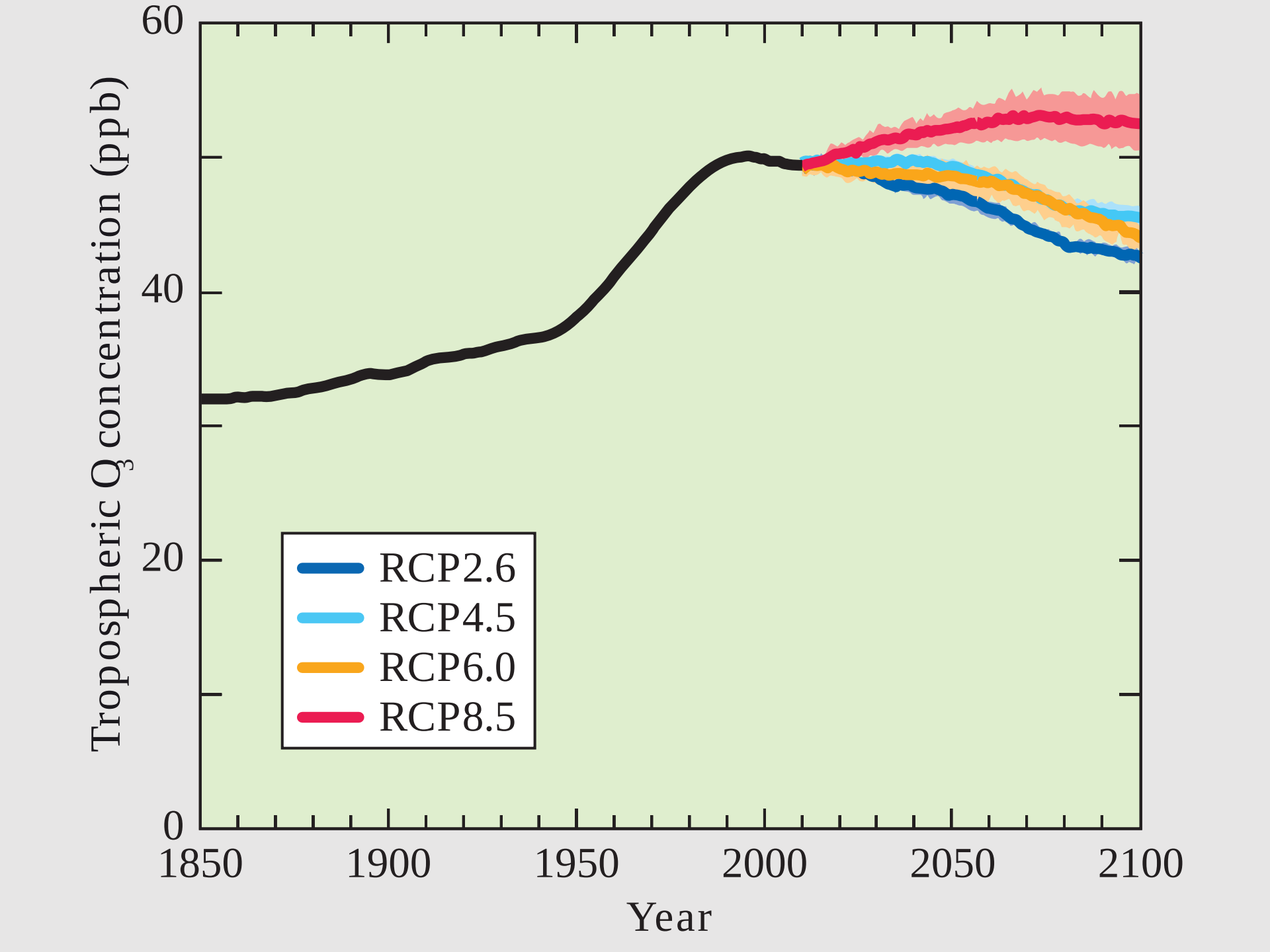
- In the upper atmosphere (stratosphere), protects us from UV radiation. Has a cooling effect.
- In the lower atmosphere (troposphere), comes from smog produced by vehicles, coal-burning power plants and industrial manufacturing sites.
  - Contributes about 13% to global warming.

Thanks Samuel Udo

https://news.vice.com/article/this-is-what-china-looks-like-when-its-cities-are-on-a-red-alert-for-smog

China smog sparks red alerts in 10 cities Dec. 24, 2015

- Red alerts trigger advisories for people to **stay inside, schools to stop classes, and restrict vehicle use.**
- Levels of PM2.5, the smallest and deadliest smog particles, rose as high as 303 micrograms a cubic meter in some parts of Beijing, and could top 500 in coming days - **more than 20 times the level considered safe by the World Health Organization**.
- Studies suggest as many as **1.4 million in the country die early because the smog - nearly 4,000 per day**.


60
40
20
0
Tropospheric O_3 concentration (ppb)
1850
1900
1950
2000
2050
2100
Year
RCP2.6
RCP4.5
RCP6.0
RCP8.5

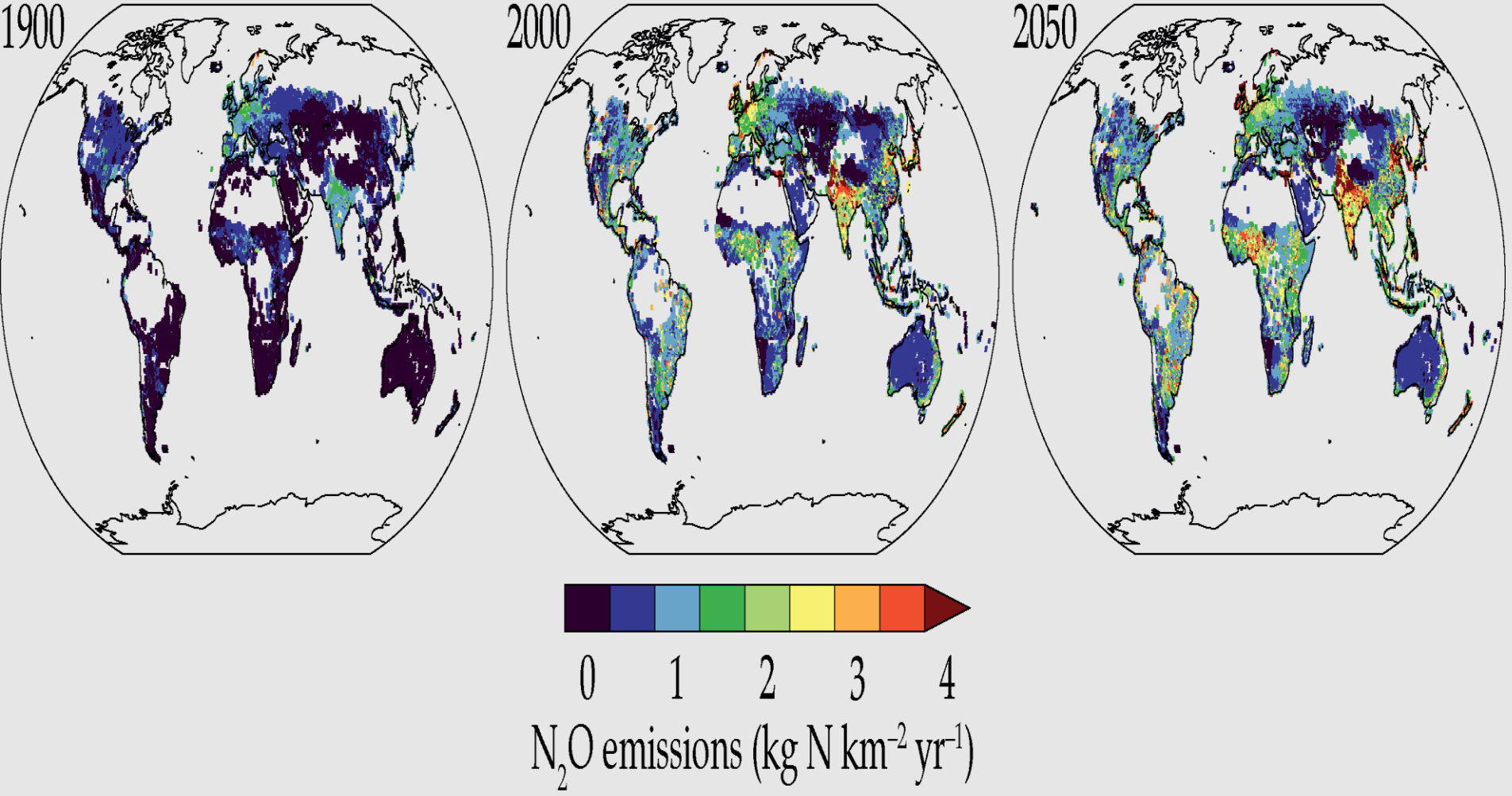
Nitrous Oxide N_2O

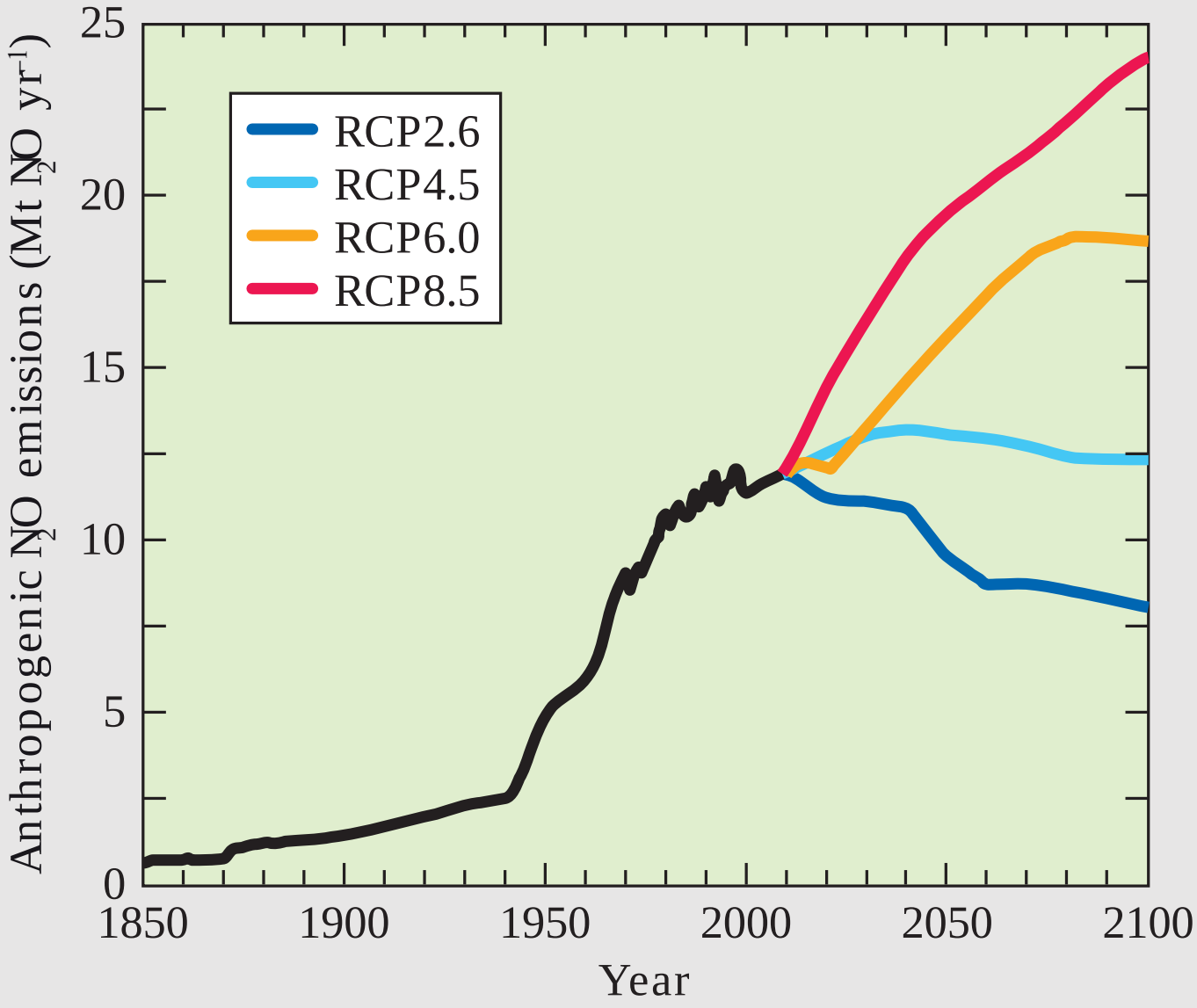
- Responsible for about 6% of anthropogenic warming.
- Naturally produced by microbes during anaerobic respiration.

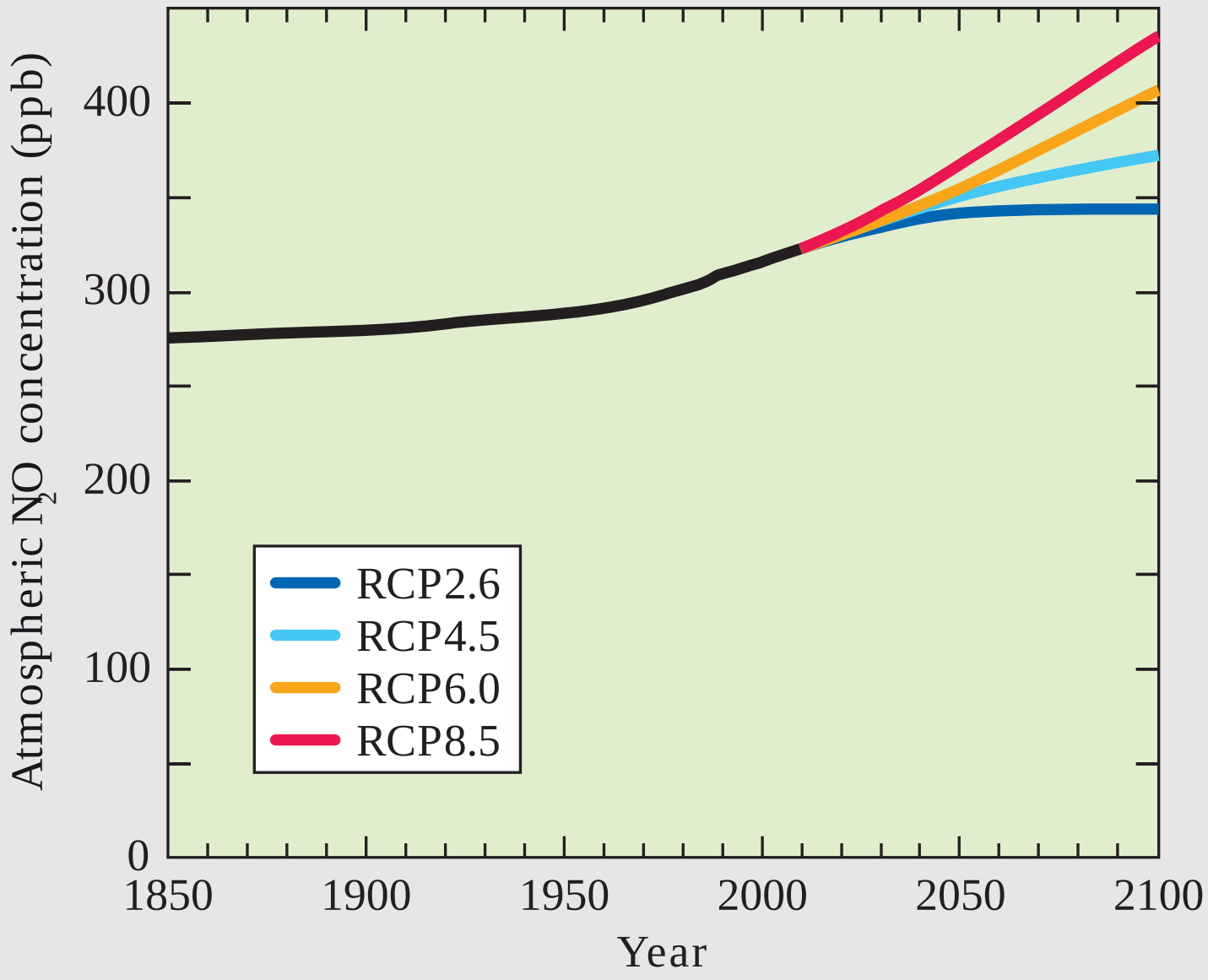
Anthropogenic sources

Microbial anaerobic respiration increased by agricultural irrigation and fertilizer.

Manufacture of nylon and nitric acid

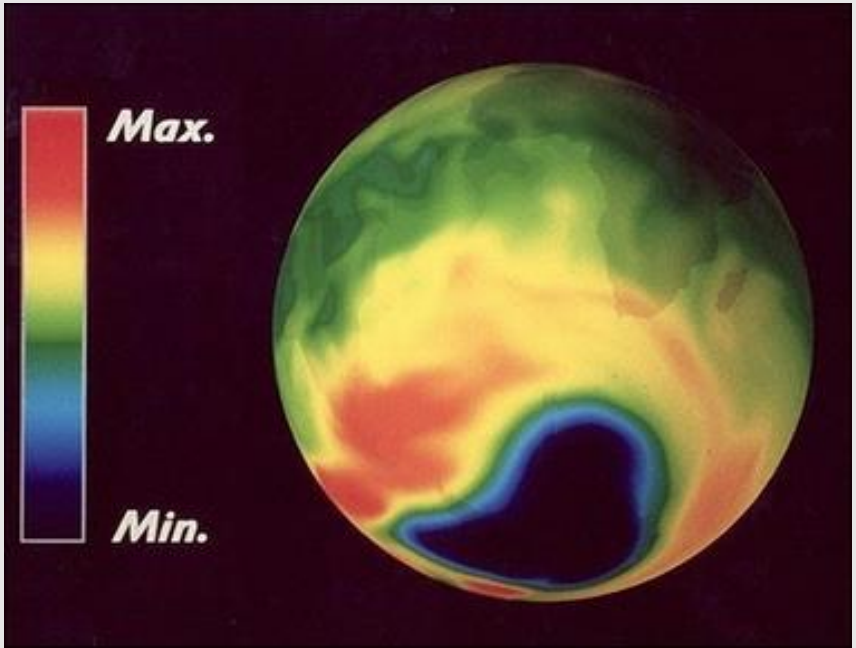

1900
2000
2050
0
1
2
3
4
N2O emissions (kg N km-2 yr-1)

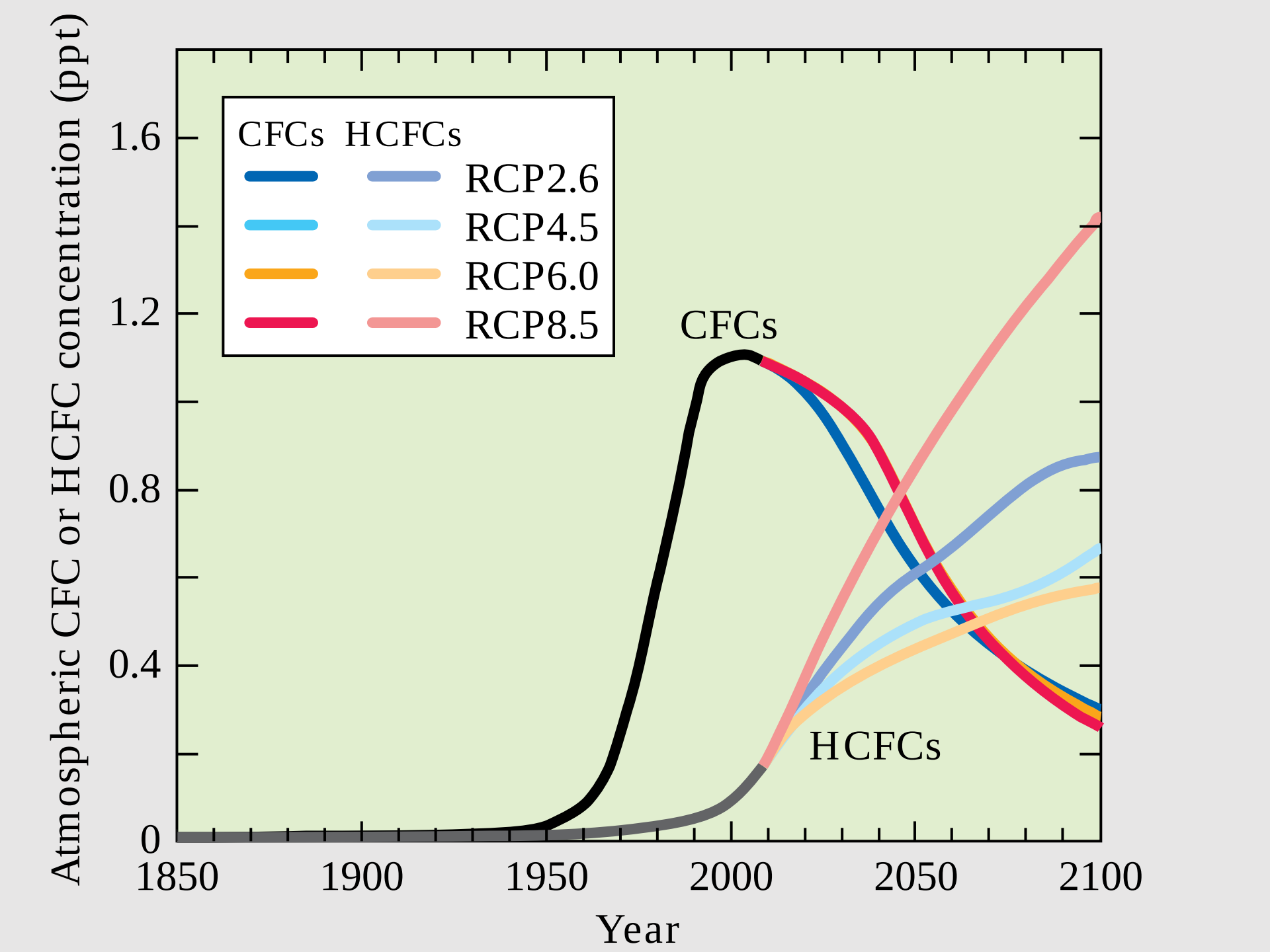

RCP2.6
RCP4.5
RCP6.0
RCP8.5
Anthropogenic N2O emissions (Mt N2O yr-1)
Year
0
5
10
15
20
25
1850
1900
1950
2000
2050
2100


Atmospheric N_2O concentration (ppb)
0
100
200
300
400
1850
1900
1950
2000
2050
2100
Year
RCP2.6
RCP4.5
RCP6.0
RCP8.5

Chlorofluorocarbons CFCs

- Used as refrigerants, propellants for aerosol sprays, cleaning solvents, and bubbles to expand foams.
- Deplete the ozone layer




Atmospheric CFC or HCFC concentration (ppt)
1.6
1.2
0.8
0.4
0
1850
1900
1950
2000
2050
2100
Year
CFCs HCFCs
RCP2.6
RCP4.5
RCP6.0
RCP8.5
CFCs
HCFCs

How will predicted climate changes affect the biosphere?

Direct effects of increased CO_2 on organisms

Rising CO_2

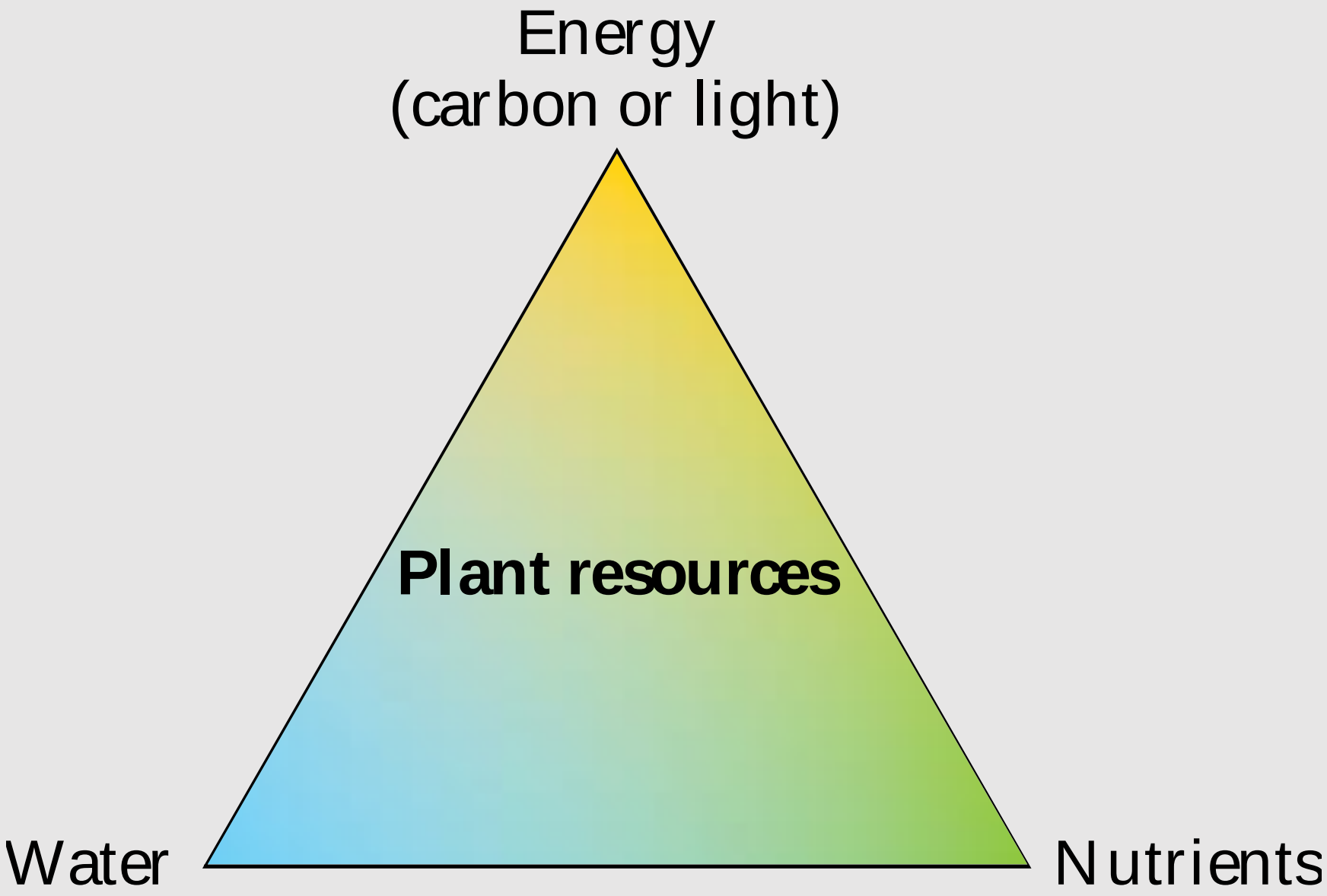
- Atmospheric concentration of 270 ppm during preindustrial times
- 390 ppm currently (.039%)
- Expected to reach 500 ppm-1000ppm (0.05%-0.10%) by 2100

HIGHER than any time during the last 20 million years

Direct effect on Humans?

- Loss of mental acuity at 2%-7.5%
- Loss of consciousness at 5%-10%
- Loss of life at 20%-30%

Time or Response	CO_2 concentration (%)
Ice-age levels	0.018-0.022
Preindustrial levels	0.026-0.028
Current levels	0.038-0.040
Predicted 2100 levels	0.05-0.10
Exhaled from lungs	5.3-5.9
Loss of mental acuity	2.0-7.5
Loss of consciousness	5.0-10.0
Loss of life	20.0-30.0


Energy
(carbon or light)
Plant resources
Water
Nutrients

Direct Effect of CO_2 on Plants

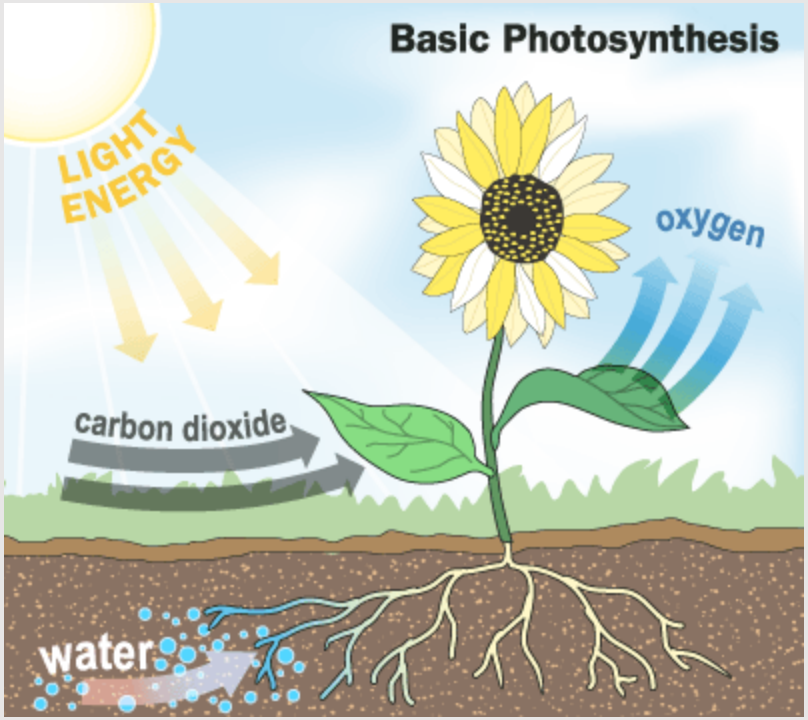
- Availability of energy
- Availability of water
- Acquisition of nutrients

Direct Effect of CO_2 on Plants

- Availability of energy
- Availability of water
- Acquisition of nutrients

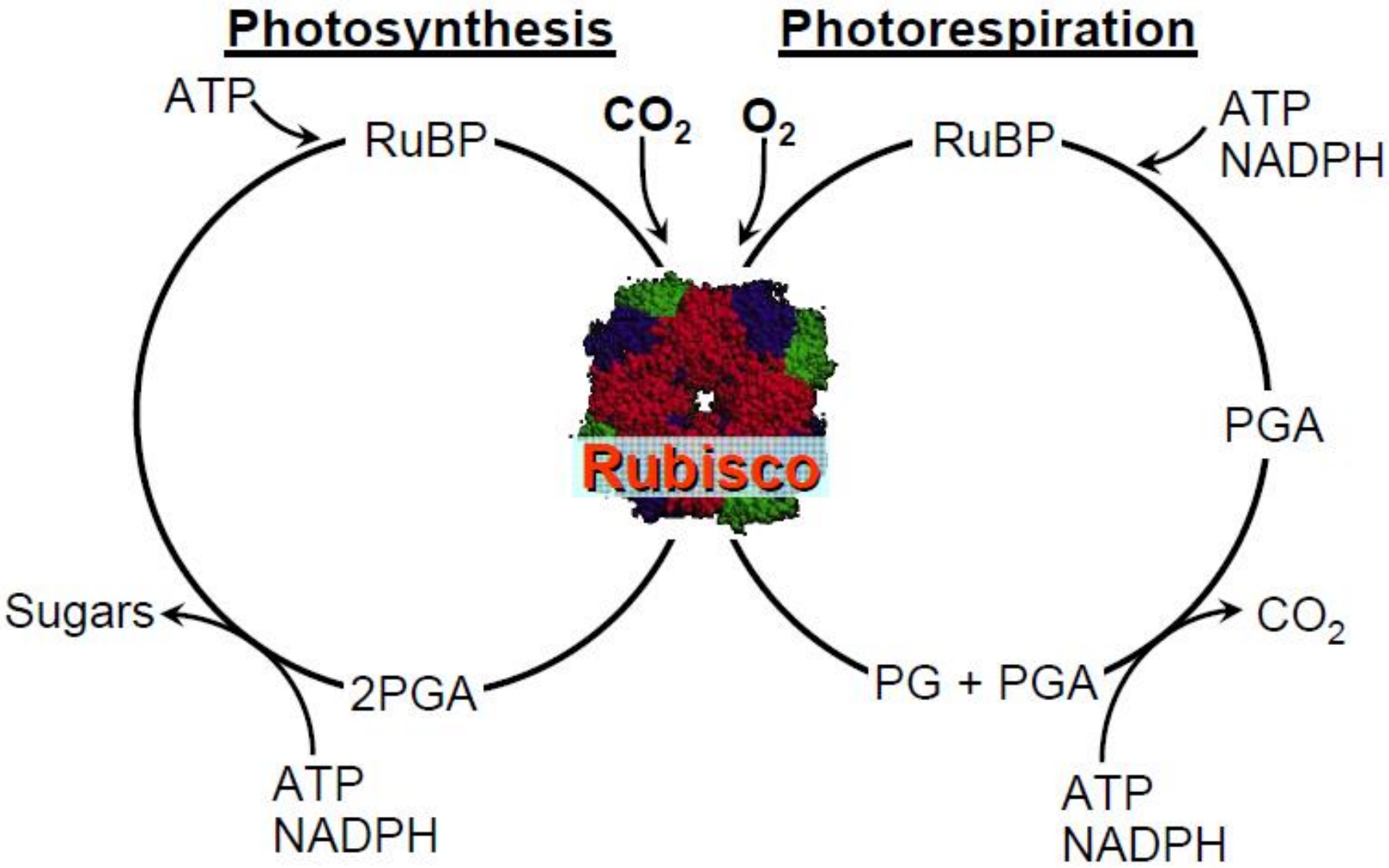
Photosynthesis

CO_2 + water + light → carbohydrates + oxygen

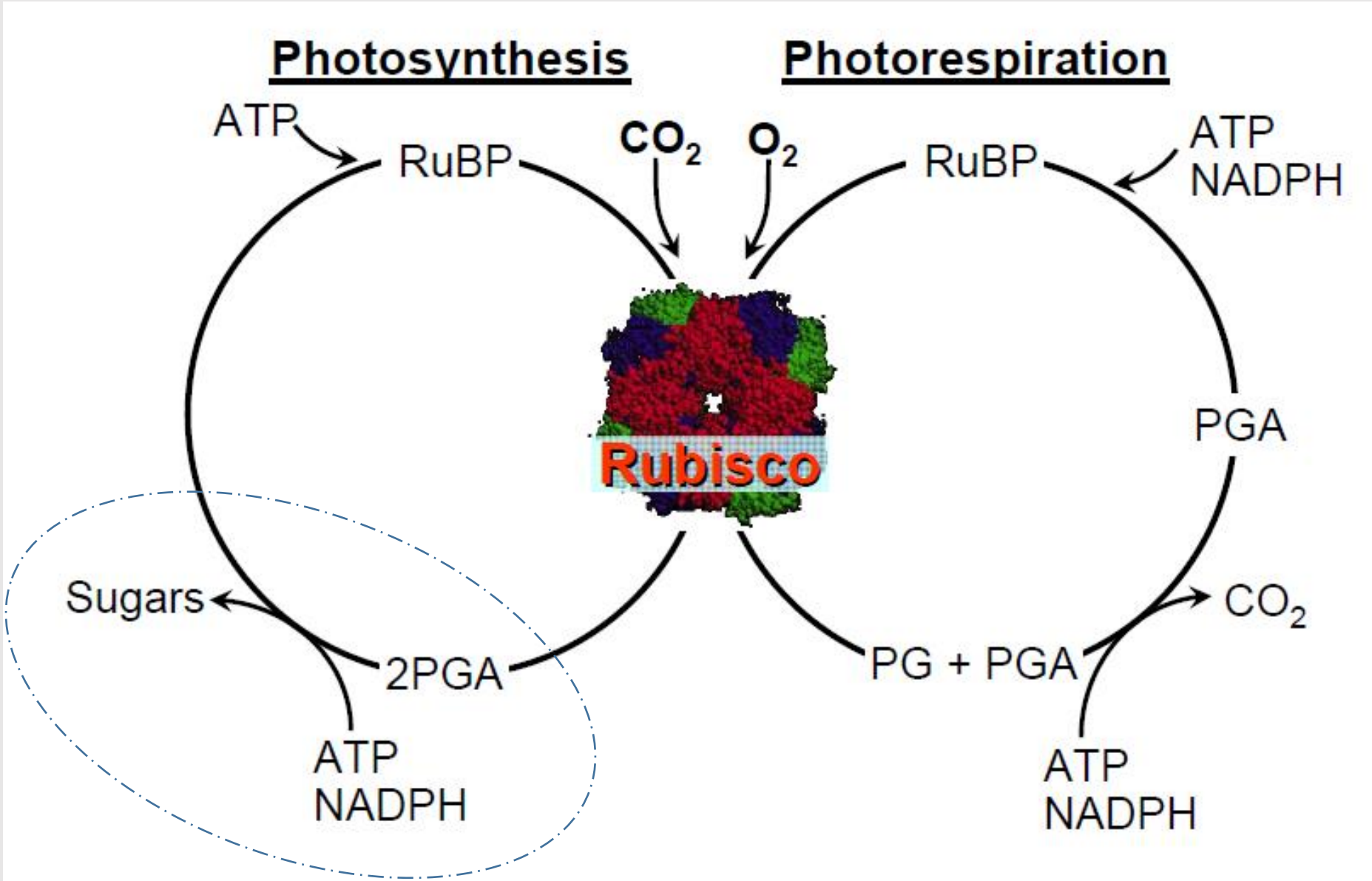


Converts ATP + NADPH into sugars (carbohydrates)

Rubisco enzyme is a catalyst

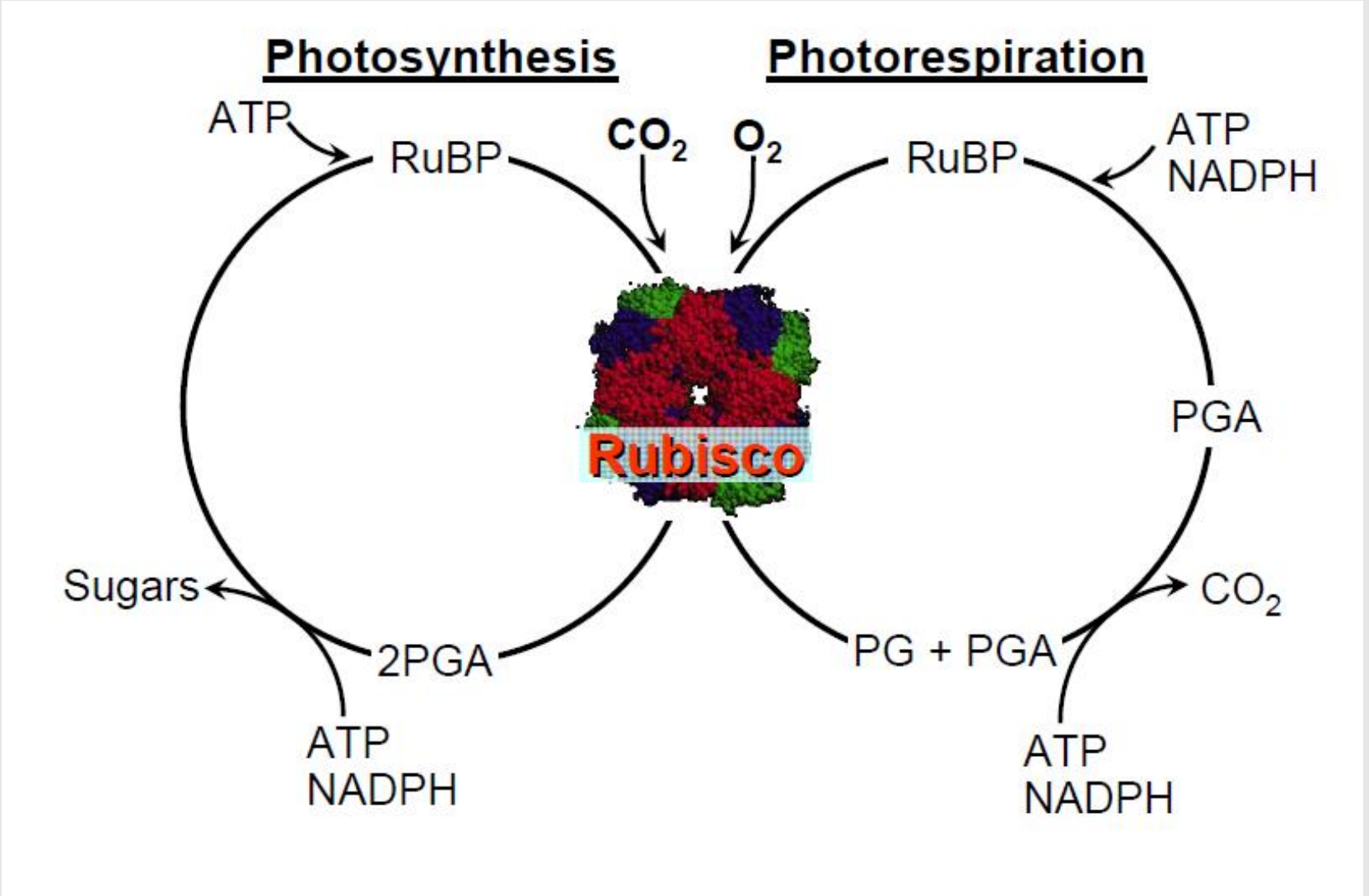


Rubisco enzyme is a catalyst



Photorespiration

No net production of energy (ATP, NADPH or sugar)



Photorespiration

No net production of energy (ATP, NADPH or sugar)