# How high could $CO_2$ go?

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## *Fossil fuel proved reserves and rate of use.*

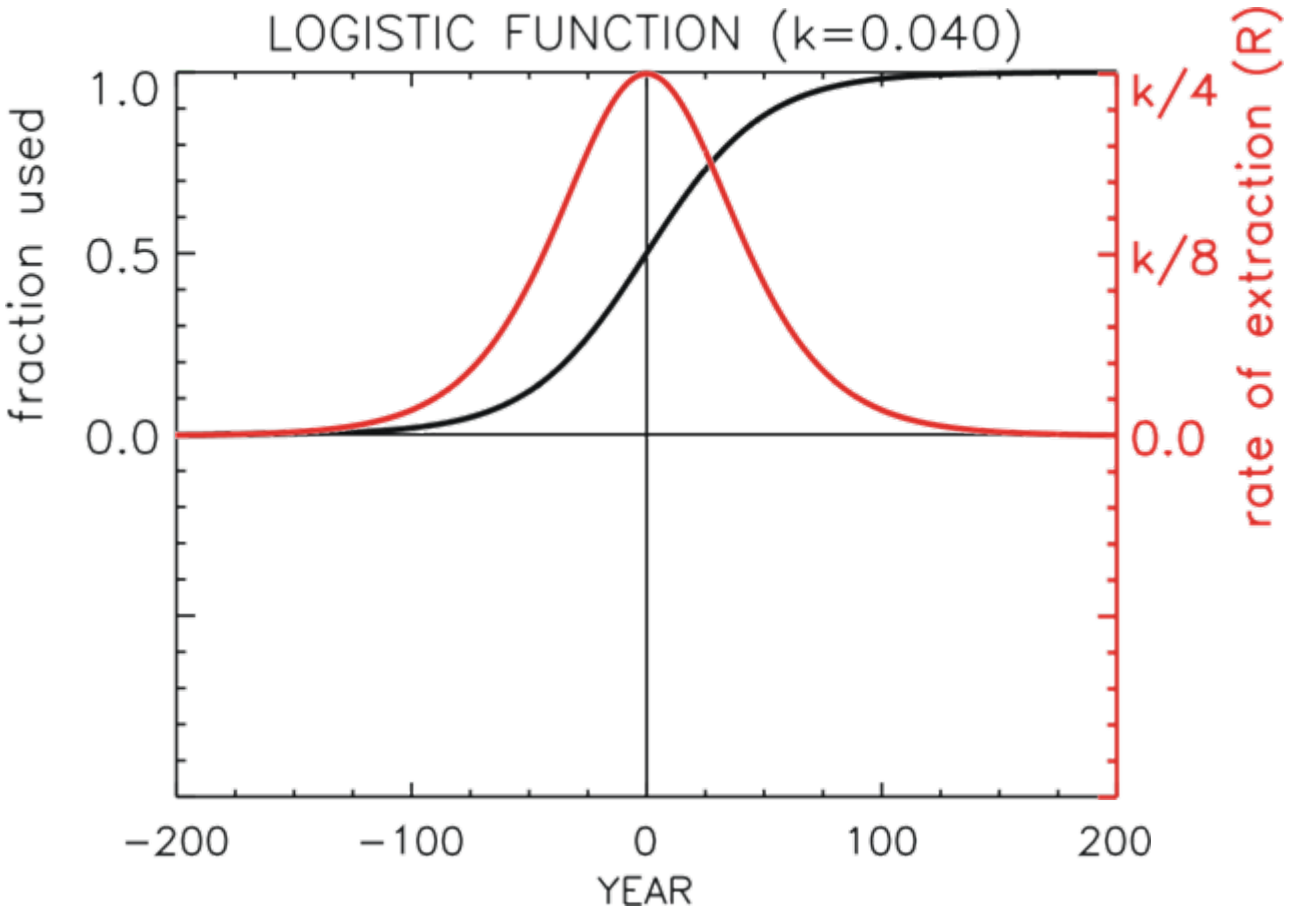
| | global | | | United States | | |
|---|---|---|---|---|---|---|
| | reserves | P | R/P | reserves | P | R/P |
| hard coal | 311 | 2.62 | 119 | 83 | 0.40 | 208 |
| soft coal | 135 | 0.47 | 287 | 47 | 0.19 | 247 |
| oil | 122 | 3.32 | 37 | 3.1 | 0.72* | 4.3* |
| natural gas | 97 | 1.52 | 64 | 3.2 | 0.31* | 10* |

***Proved reserves are the amount that can be recovered with existing available technology under present and expected local economic conditions.***

# EMISSIONS FROM FOSSIL FUEL BURNING

$R = dQ/dt = k\,Q\,(1-Q/N)$

Q cumulative extraction
R rate of extraction
k initial rate of growth
N total resource



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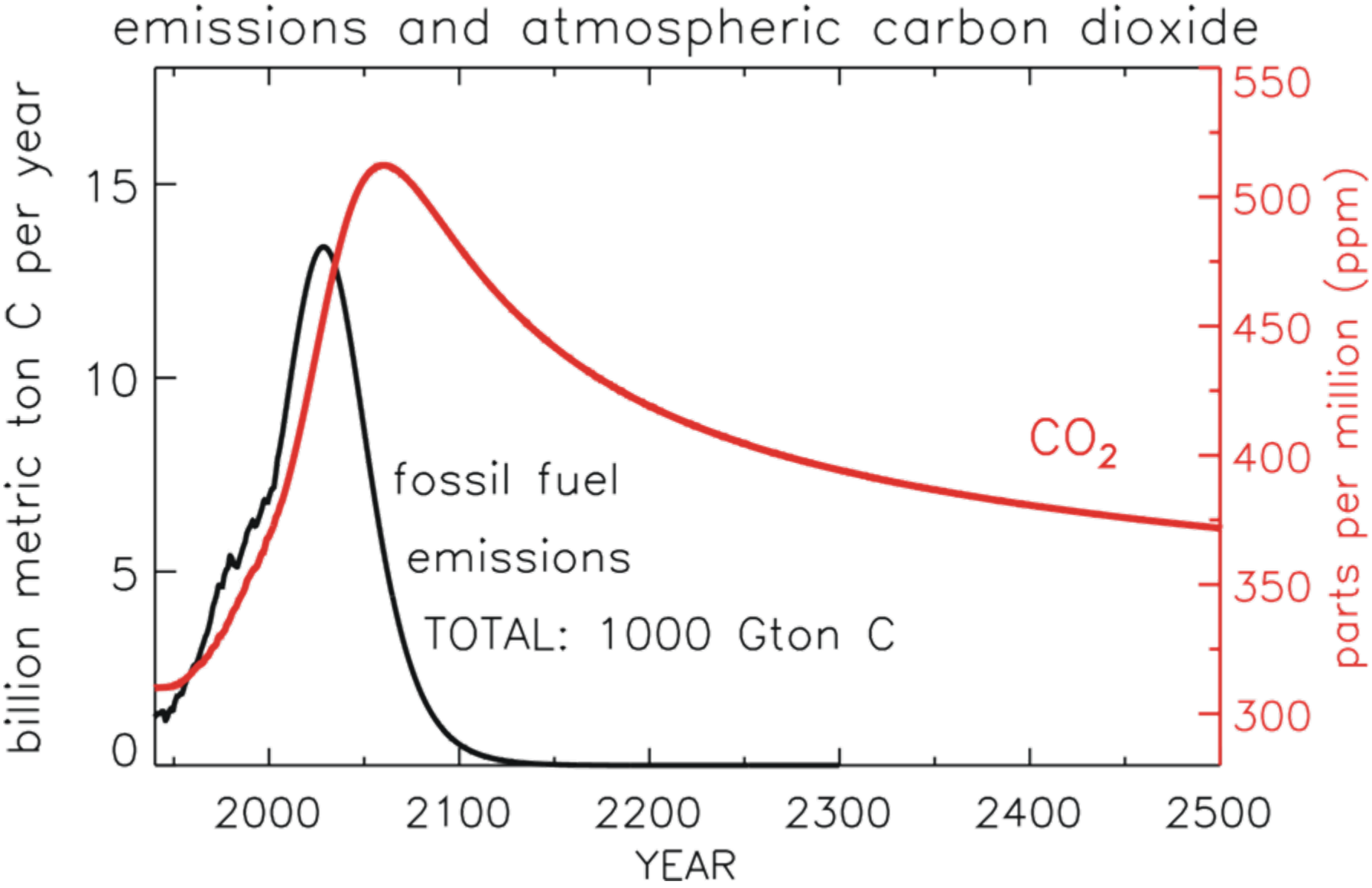

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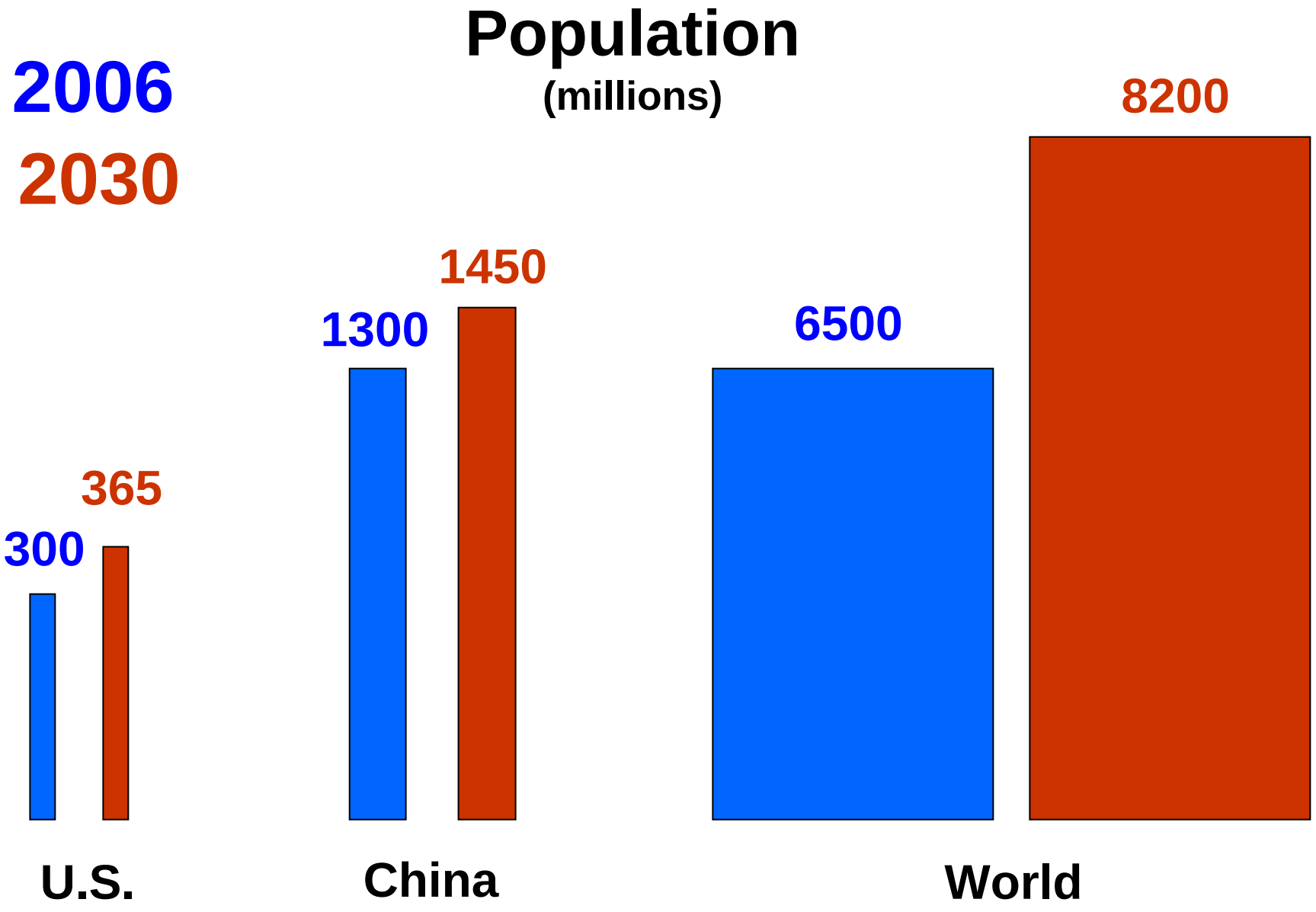
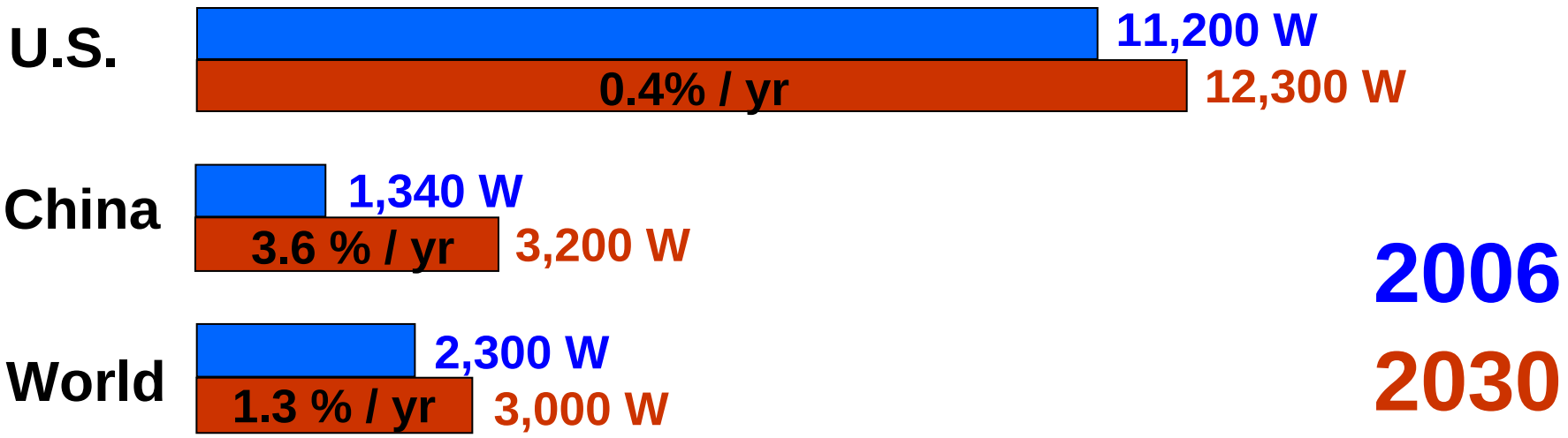



Source: U.S. Energy Information Administration

# Primary energy consumption per capita




- Global energy demand is expected to grow 60% from 2006 to 2030.
- If met by fossil fuels, atmospheric CO2 increase is expected to accelerate from 2.0 to 3.2 ppm/yr

Source of energy data: U.S. Energy Information Administration

## *Unconventional fossil fuel resources:*

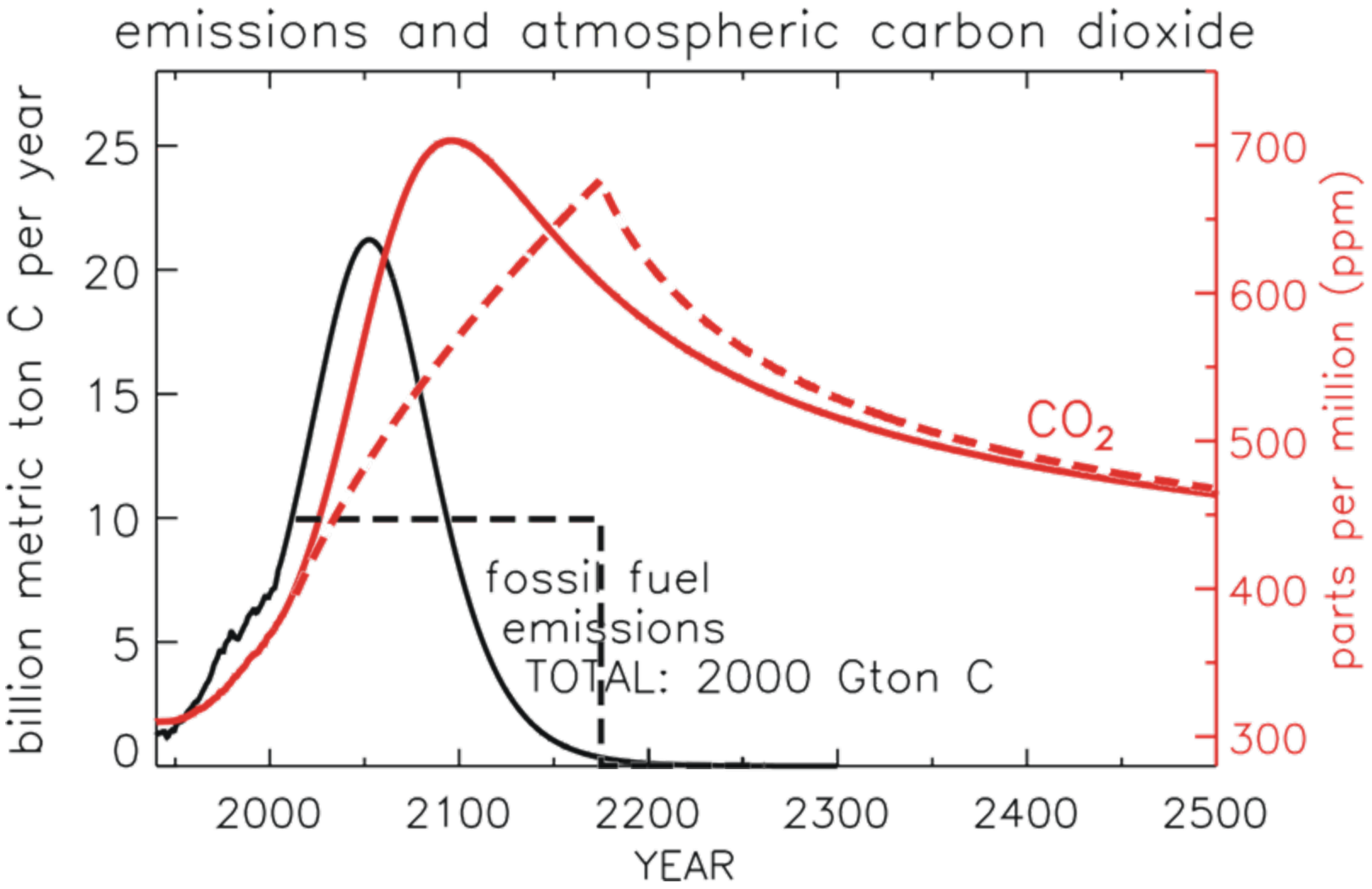
| | |
|---|---|
| **tar sands (mostly in Canada)** | **290 (Gton C)** |
| **extra heavy oil (mostly Venezuela)** | **230** |
| **shale (mostly United States)** | **400** |
| **deep offshore** | **100 ?** |

*Energy return on energy invested:*

| | |
|---|---|
| domestic oil (1970) | 25:1 |
| shale oil | 3:1 |
| tar sands | 2:1 |
| coal to liquids | 3:1 |

| | | |
|---|---|---|
| avg. heating value of U.S. coal in | 1960 | 30 Megajoule/kg |
| | 2004 | 20.5 |

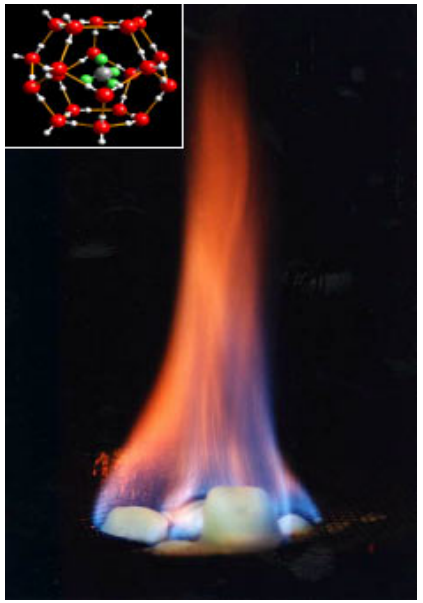
# EMISSIONS FROM FOSSIL FUEL BURNING



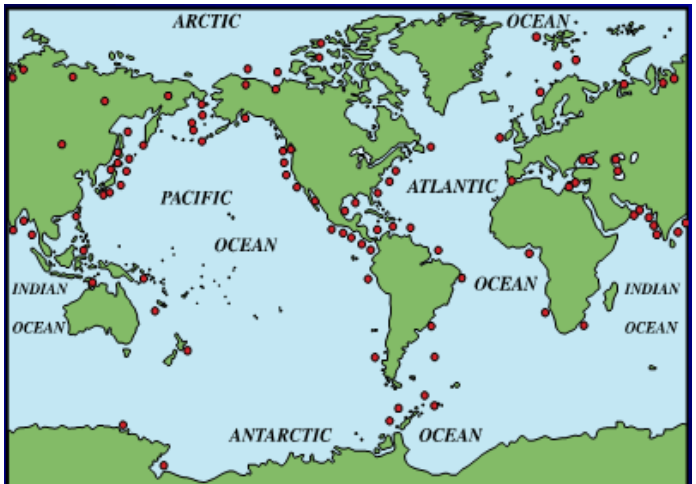
# Will warming feed further warming?

Photo: Geological Survey of Canada

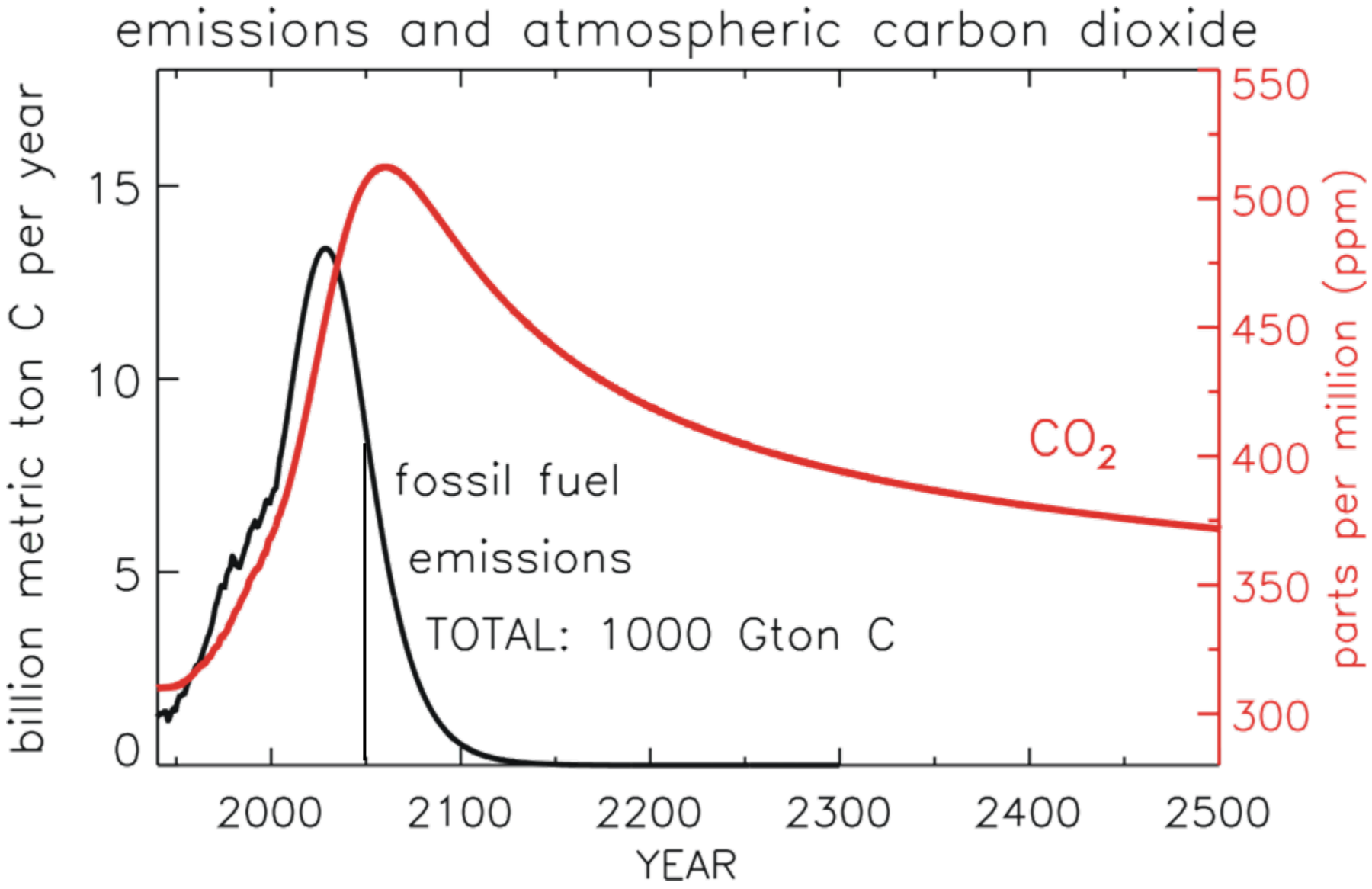
carbon in permafrost
500-900 Gton C



carbon in gas hydrates
500-2500 Gton C



# SOME IMPLICATIONS



# SOME IMPLICATIONS

| *annual emissions per capita:* | | |
|---|---|---|
| 2004 | U.S. | 5.6 ton C |
| 2004 | global avg. | 1.4 |
| 2004 | Sweden | 1.6 |
| 2004 | India | 0.4 |
| 2004 | China | 1.0 |
| 2050 | U.S. | 0.9 |
| 2050 | global avg. | 0.9 |

| *of which, in the U.S:* | |
|---|---|
| food | 0.9 ton |
| car | 1.4 |
| 1 RT DIA – Dulles | 0.2 |
| home (electricity) | 1.1 |
| home heating (N.Eng) | 1.0 |

Continued exponential growth is incompatible with our finite planet.

We need to develop a social and economic system to handle zero or negative growth of population and of use of resources.
Success equals negative growth!

# Can we remove ambient CO2 from the atmosphere?

Gibbs free energy of un-mixing 400 ppm CO2 from air  21.3 kJ/mol

biomass burning  ~400 kJ/mol C
200 M ton C crop residues