Mitigation Strategies for Atmospheric Carbon

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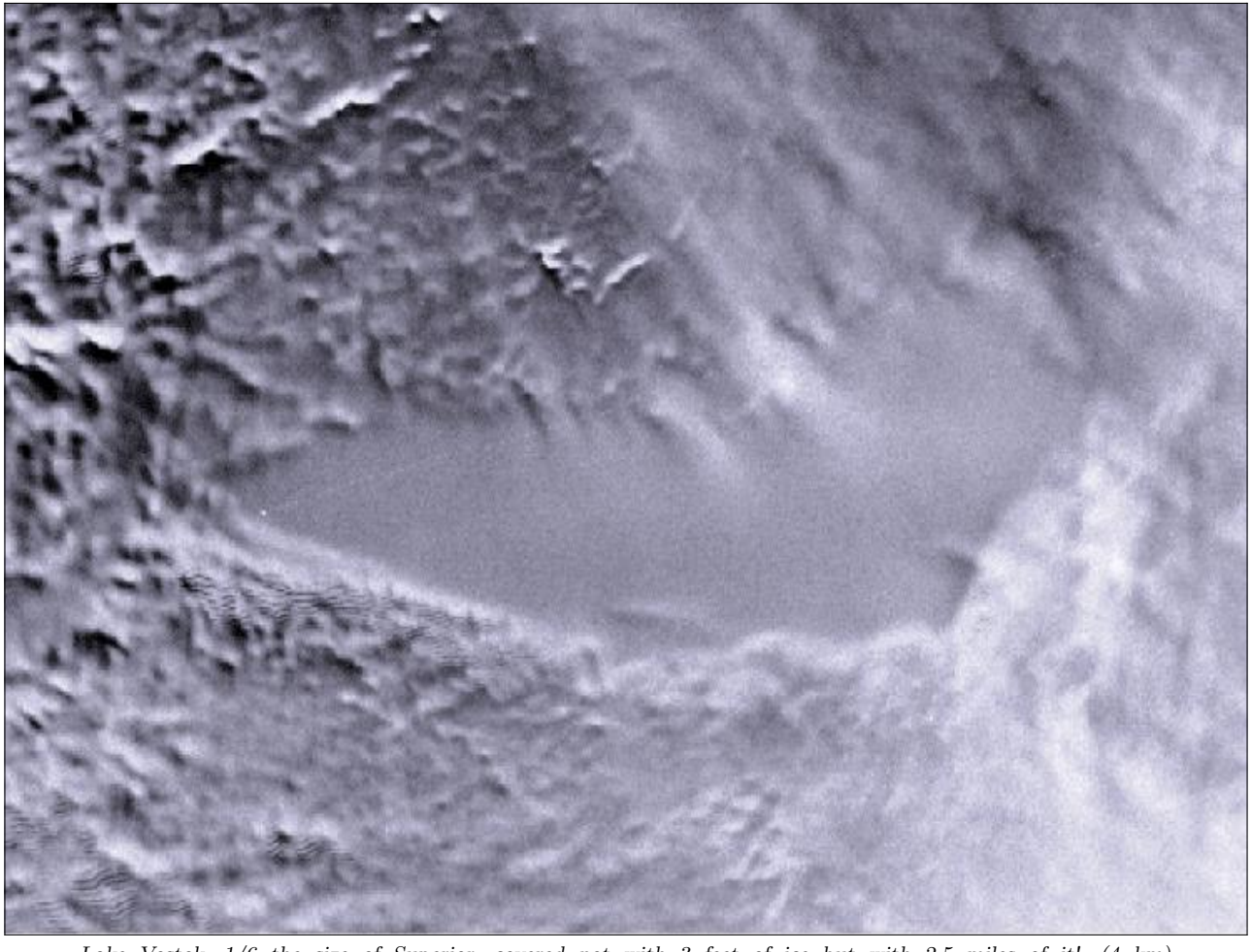
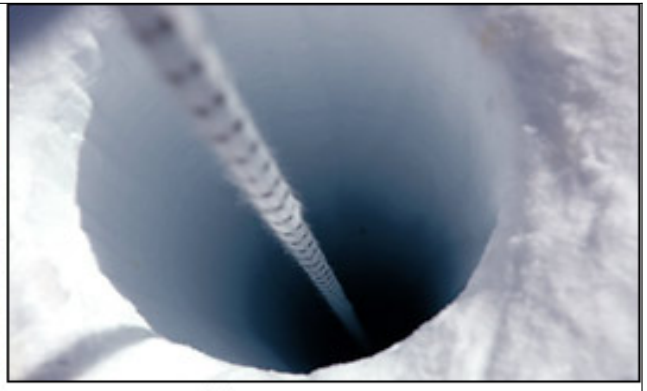
Outline

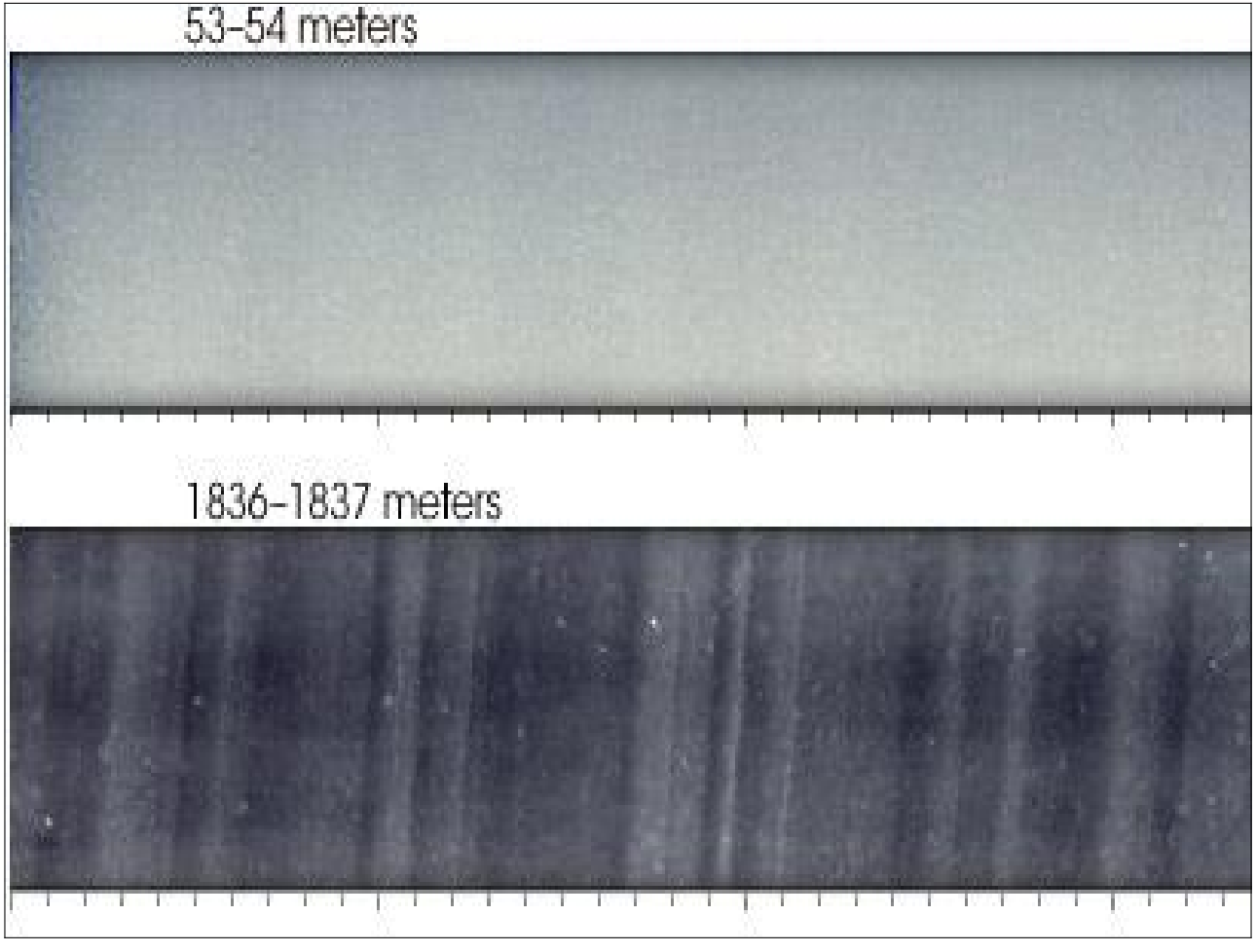
1. What needs mitigation?
2. How did we get where we are?
3. How will the earth change?
4. Can we solve huge world problems?
5. Holding the earth's thermostat constant
6. Turning the thermostat back down

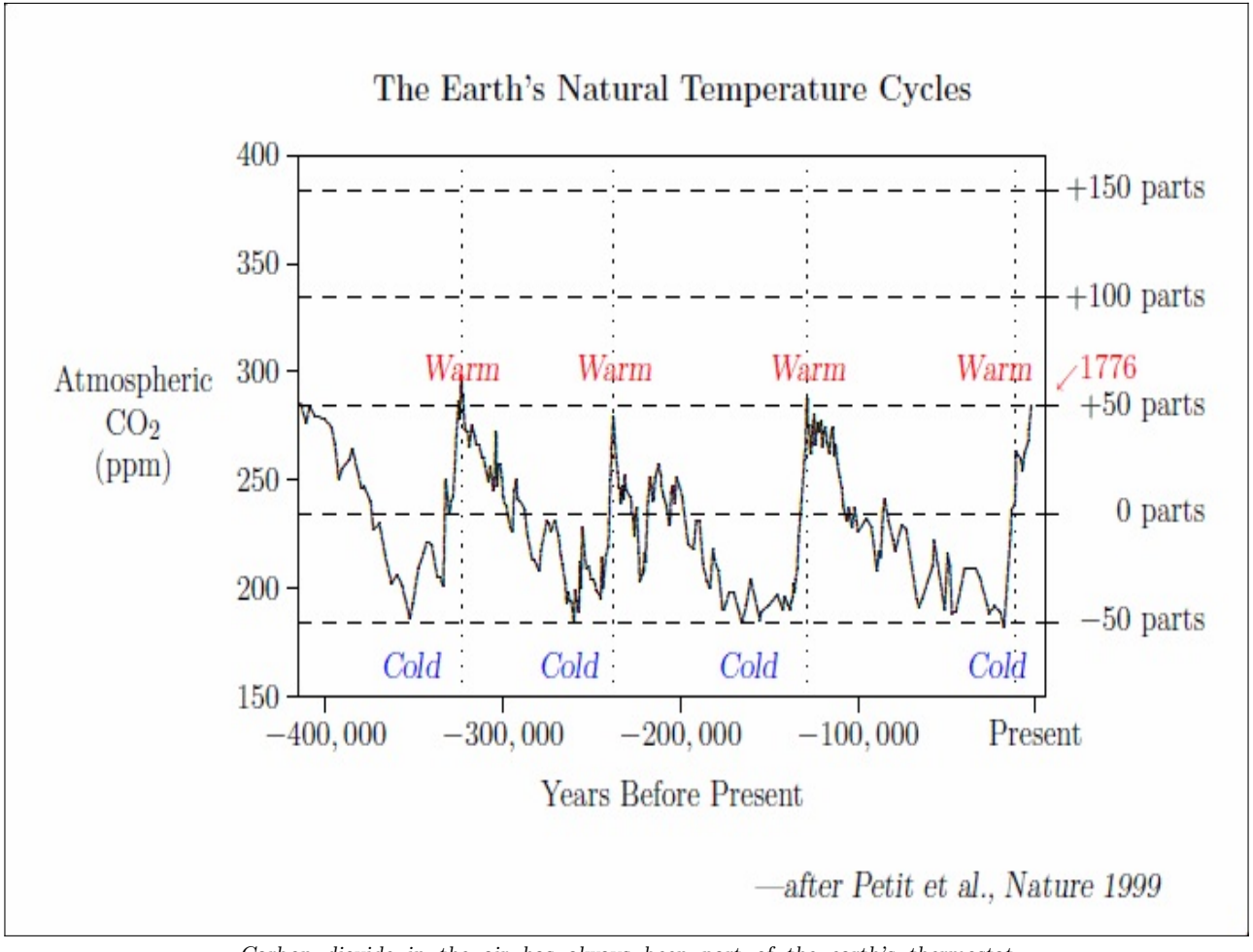
Events relevant to present climate began thousands of years ago.



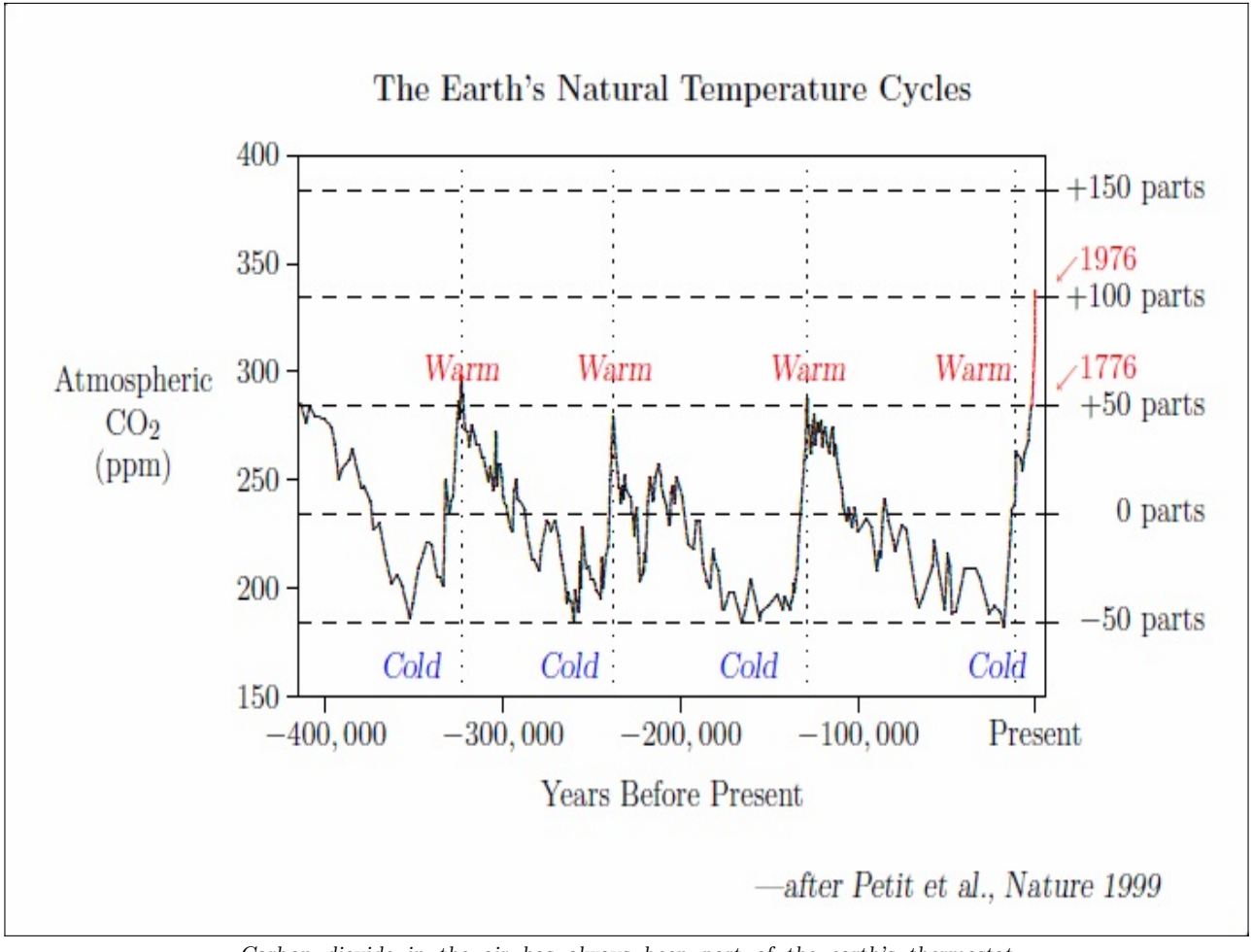
Lake Vostok, 1/6 the size of Superior, covered not with 3 feet of ice but with 2.5 miles of it! (4 km)




53–54 meters
1836–1837 meters



Carbon dioxide in the air has always been part of the earth's thermostat



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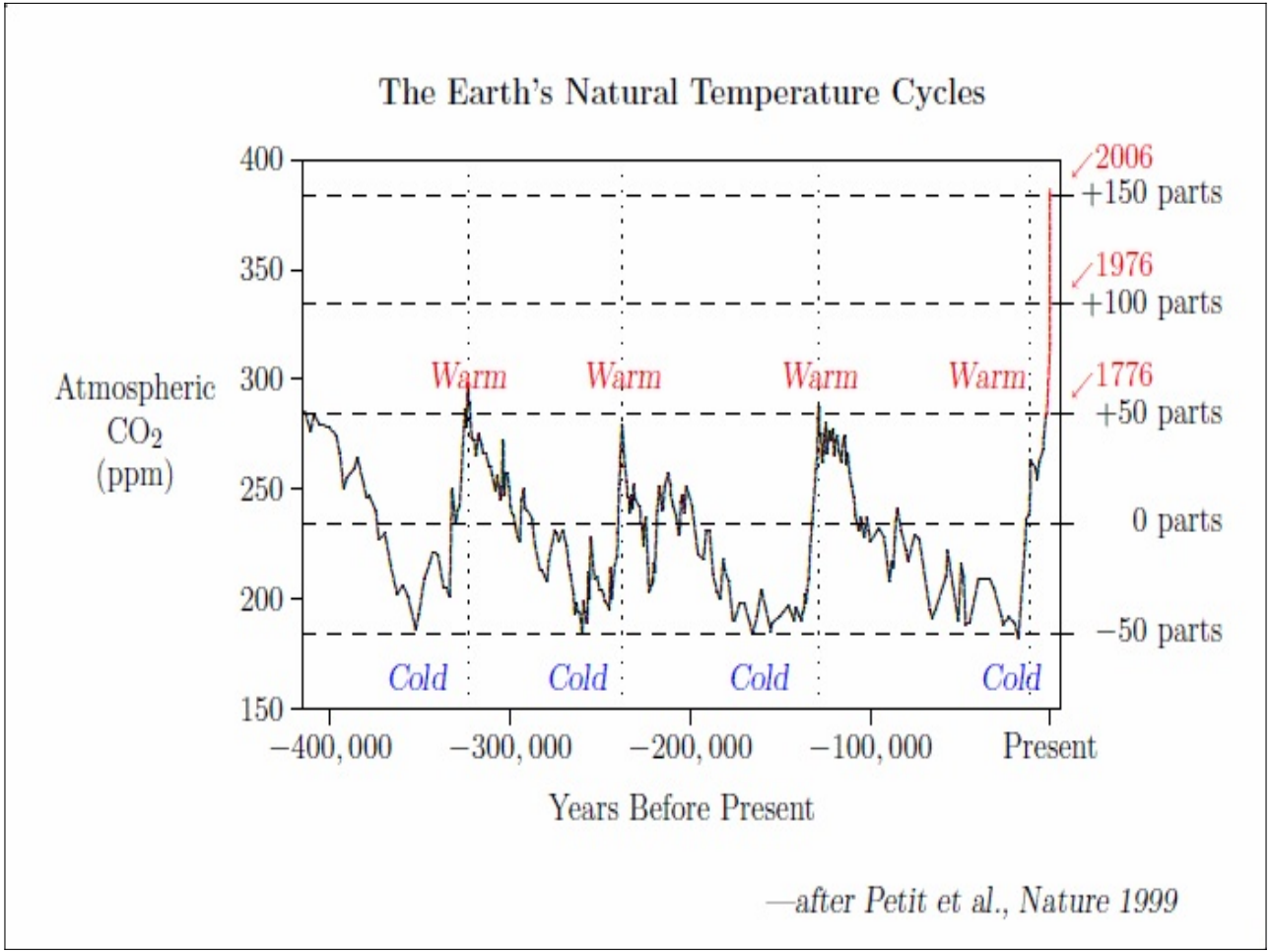

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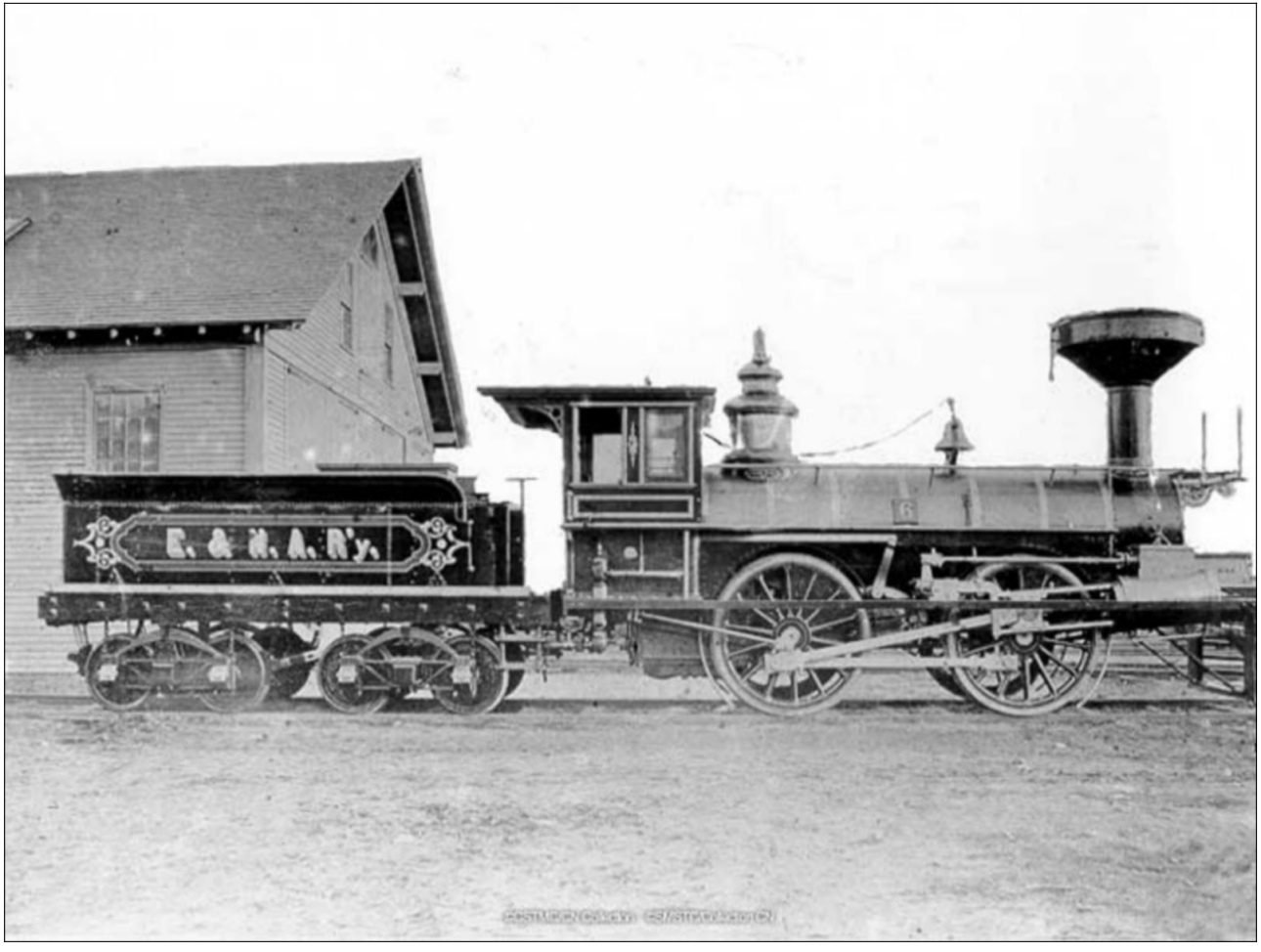
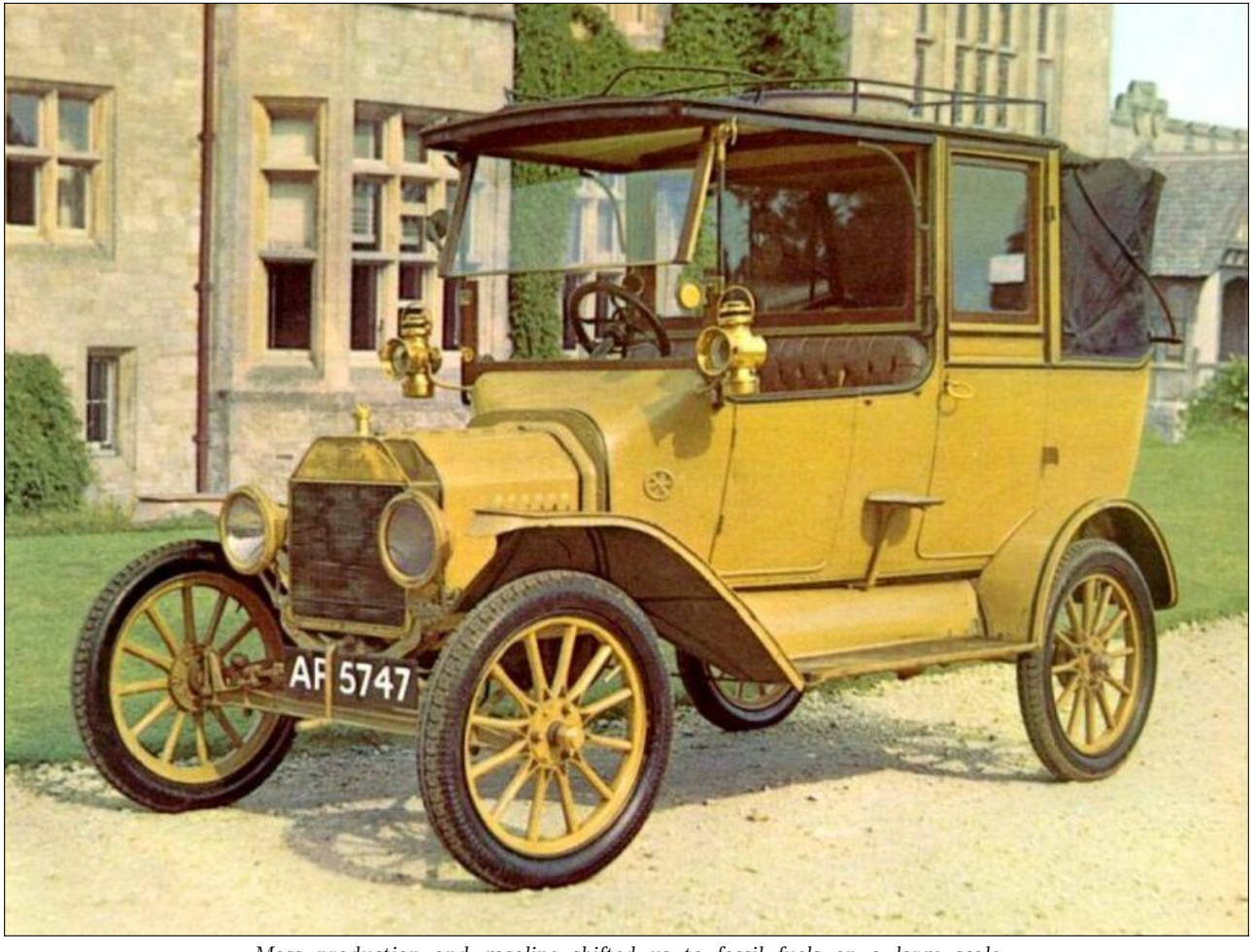
For millennia we sat around campfires recycling carbon to the air

For millennia agriculture provided renewable transportation fuels



Early trains that settled the west were powered by wood, often harvested less renewably

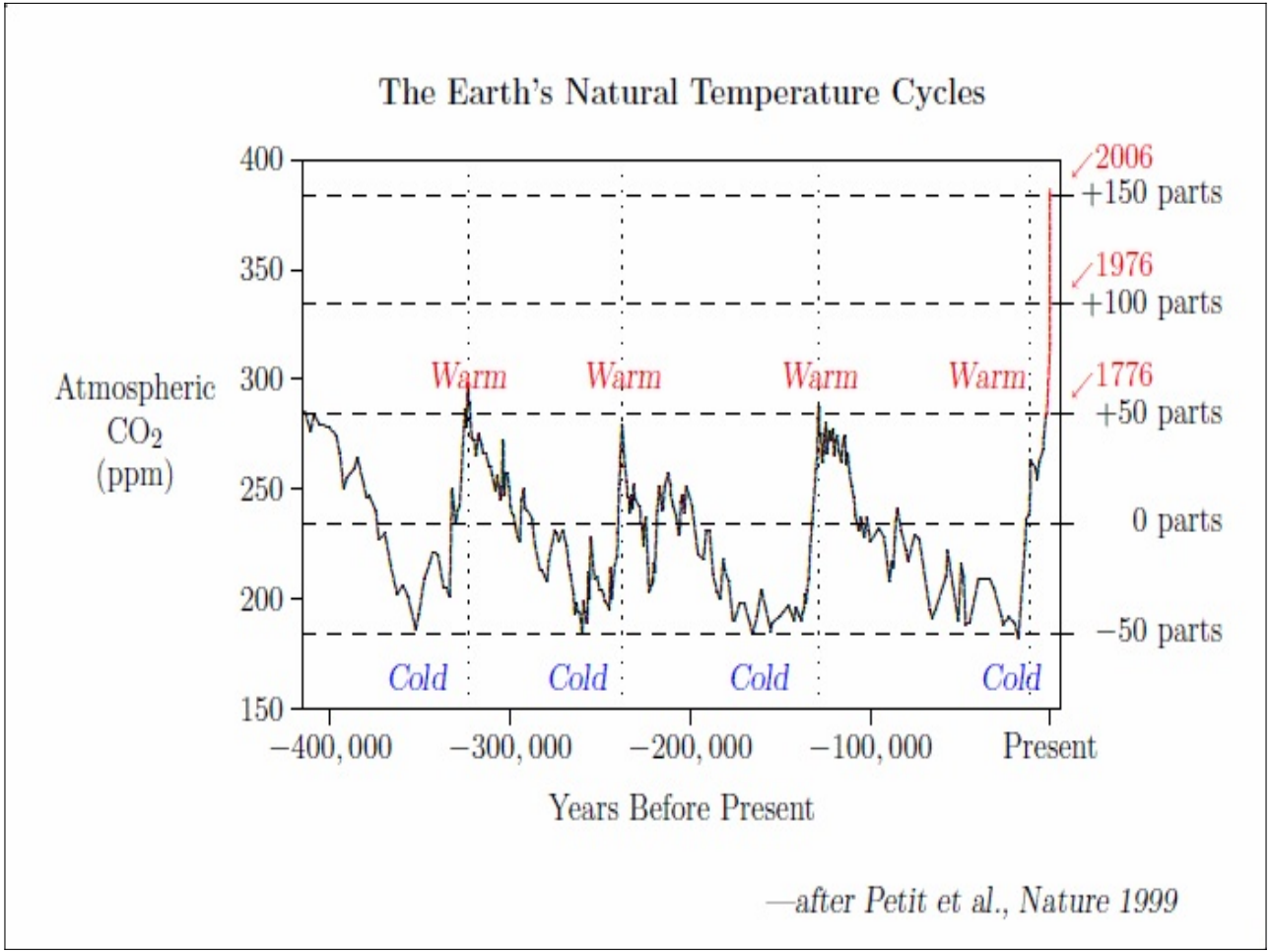
The Leyland Steam Lawnmower, 1890s.



Mass production and gasoline shifted us to fossil fuels on a large scale

And this developed into a marvelous transportation system unimagined in 1900

Together with other enormous developments energy use



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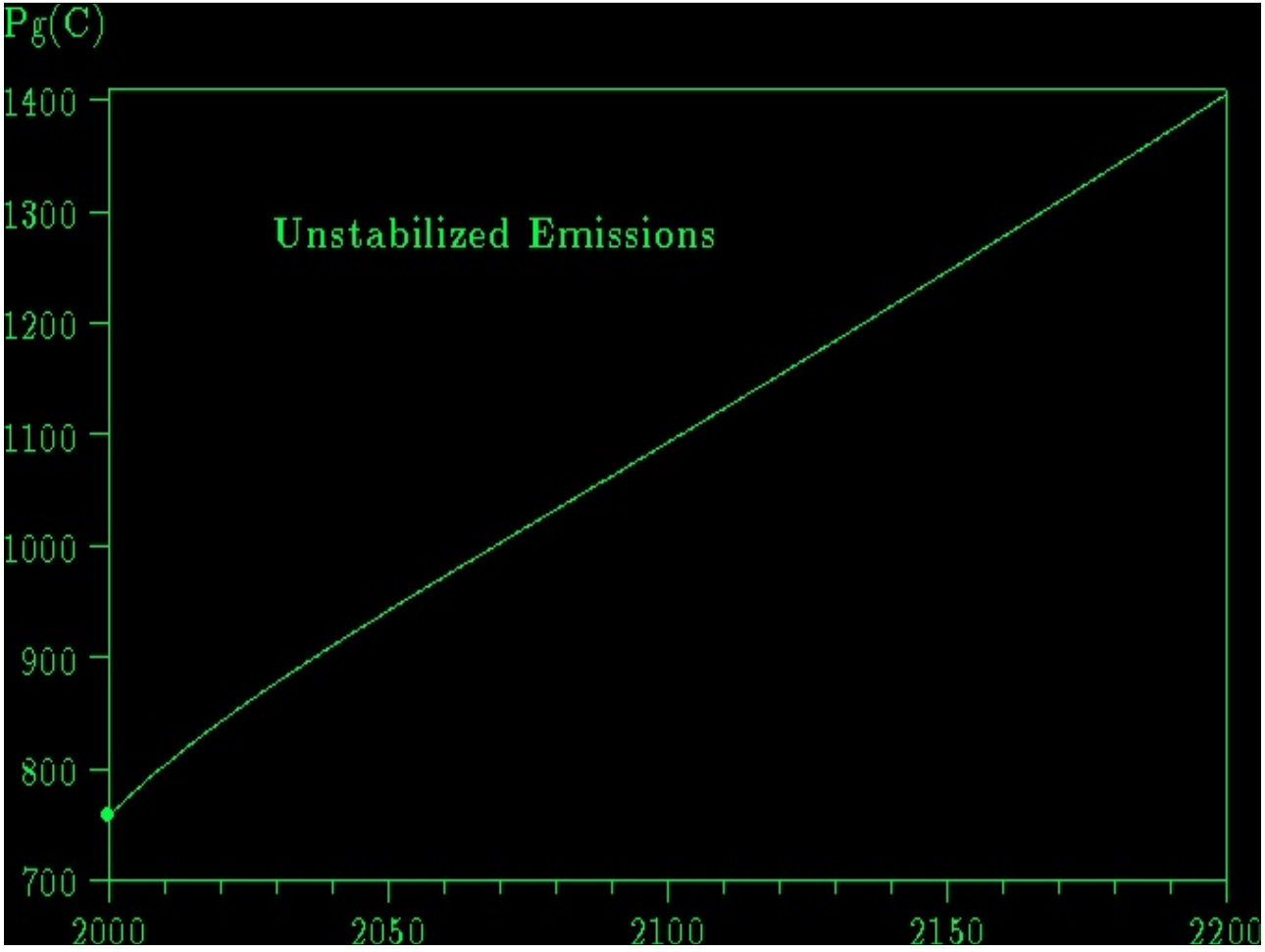
Pg(C)
1400
1300
1200
1100
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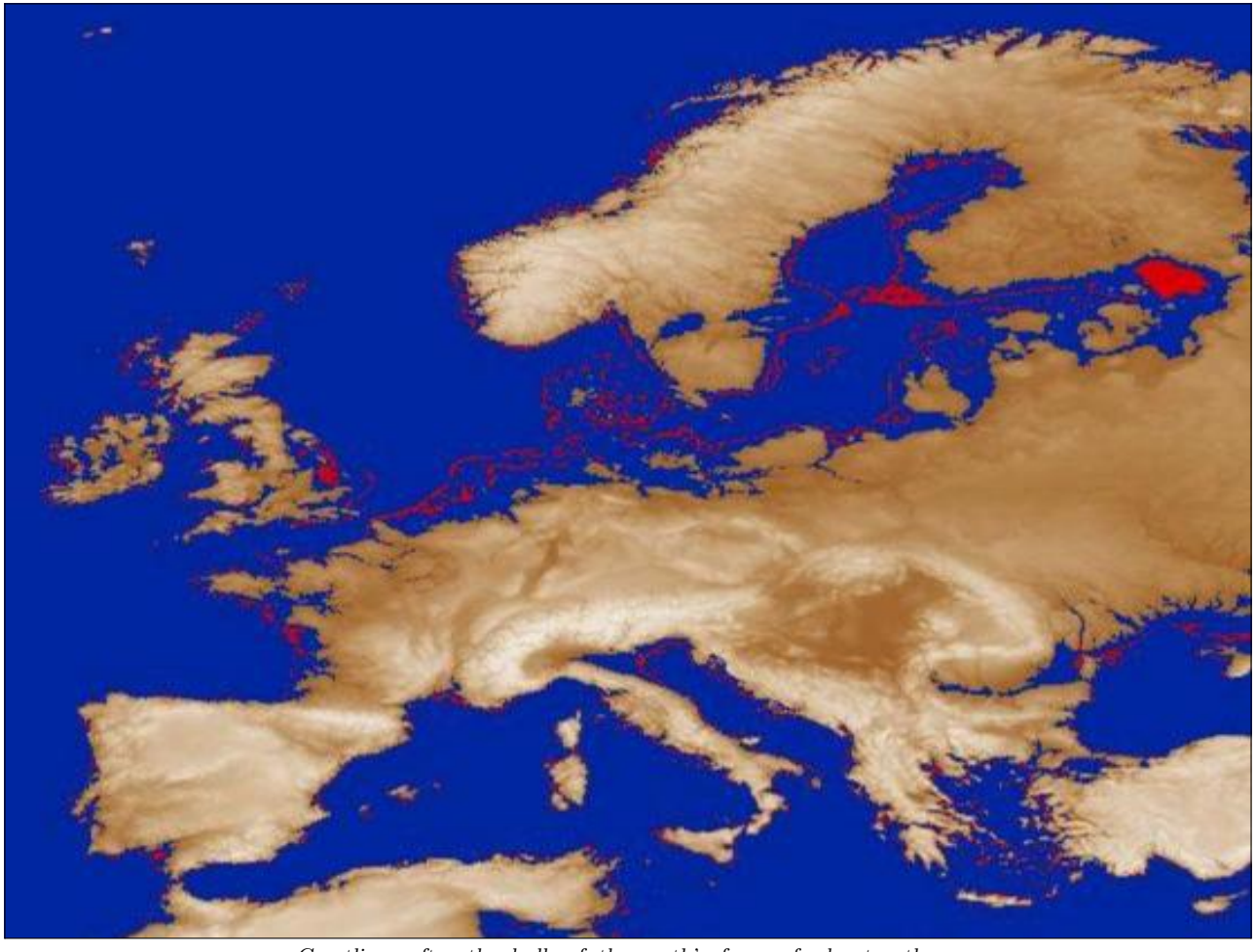
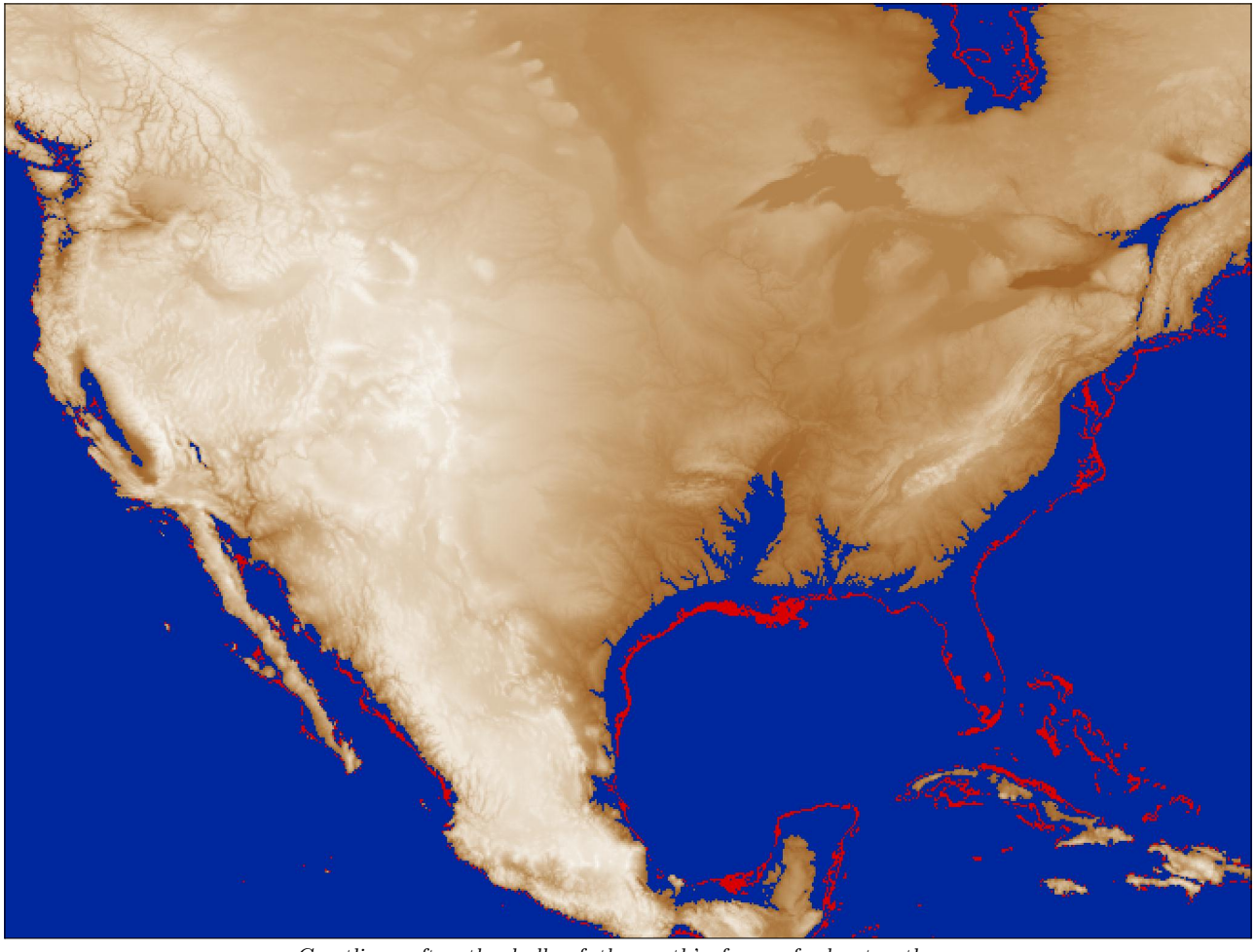
800
700
Unstabilized Emissions
2000
2050
2100
2150
2200

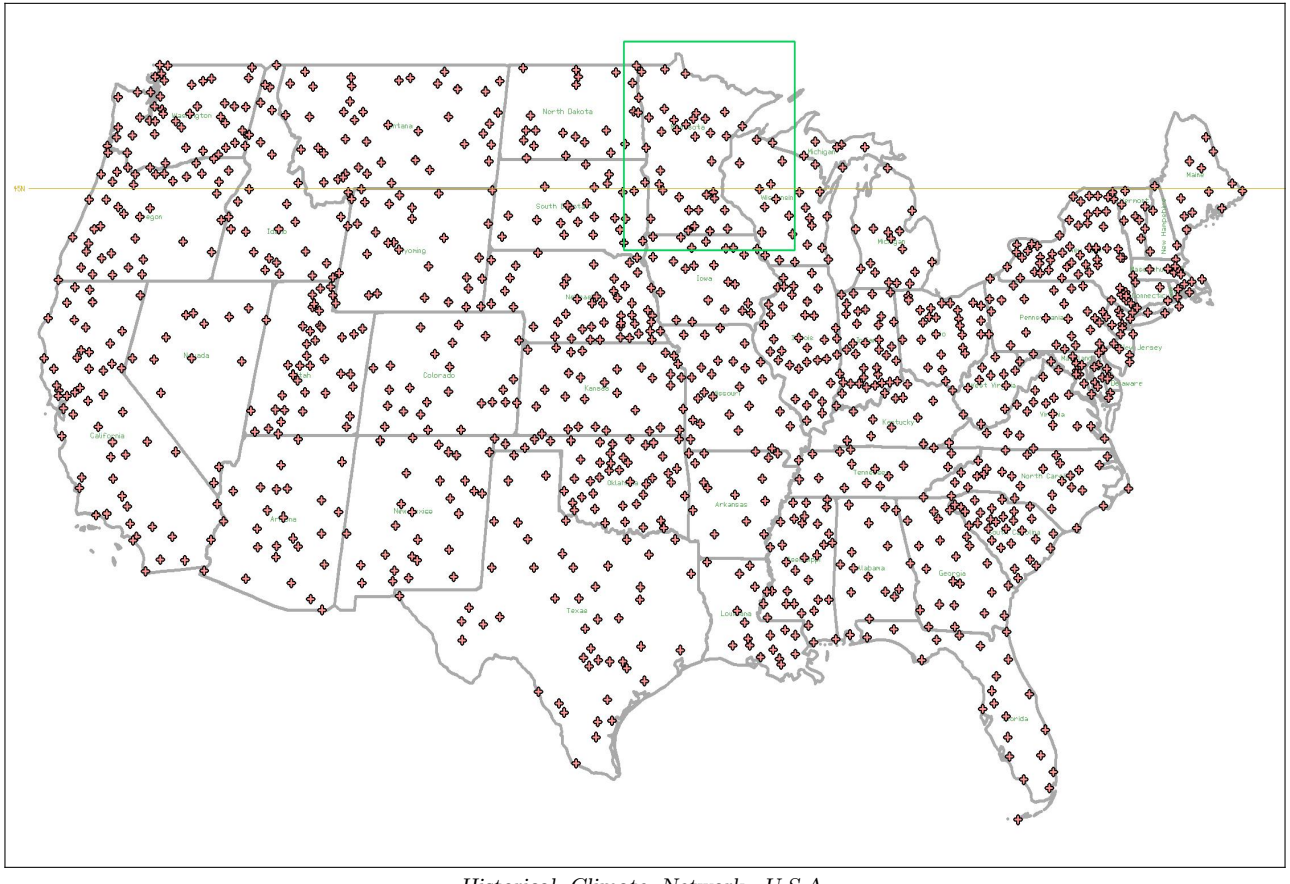


Coastlines after the bulk of the earth's frozen freshwater thaws

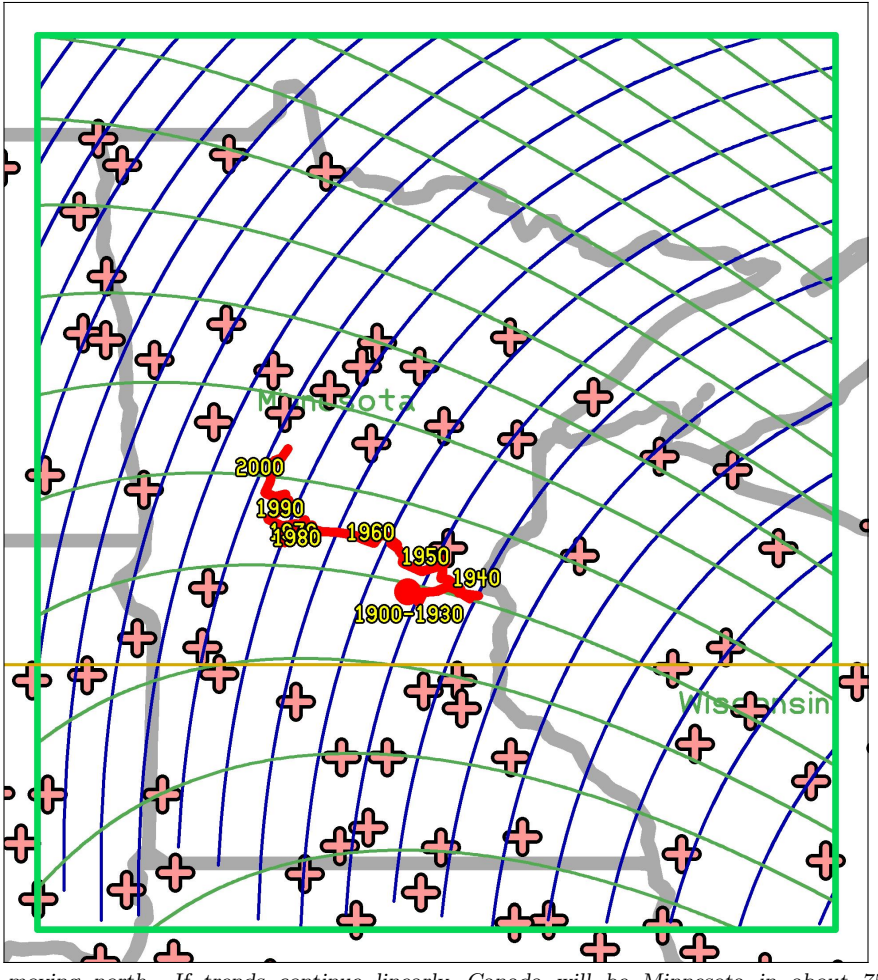


Coastlines after the bulk of the earth's frozen freshwater thaws

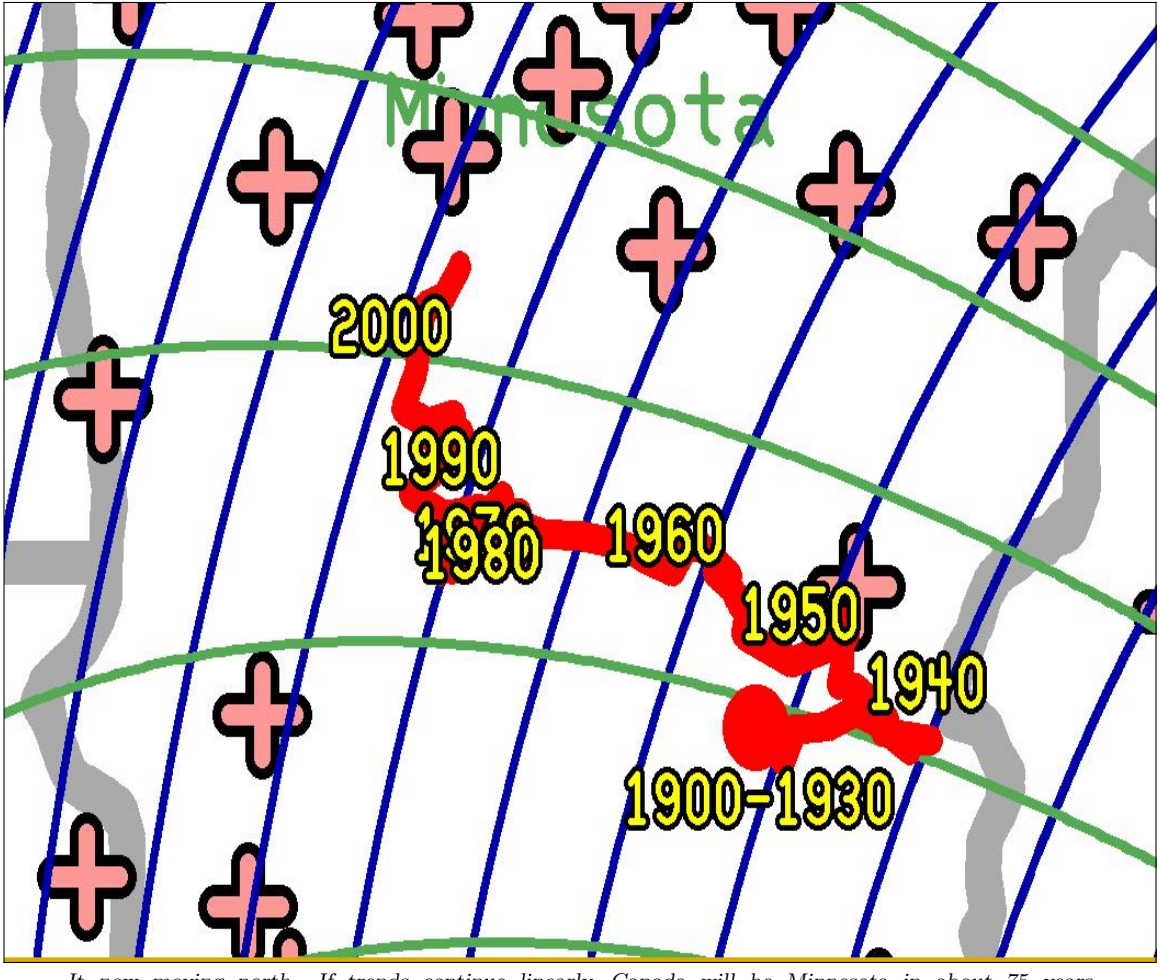
What will be the effect on North America's triple ecotone?



Historical Climate Network, U.S.A.



It now moving north. If trends continue linearly, Canada will be Minnesota in about 75 years



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1930-2002

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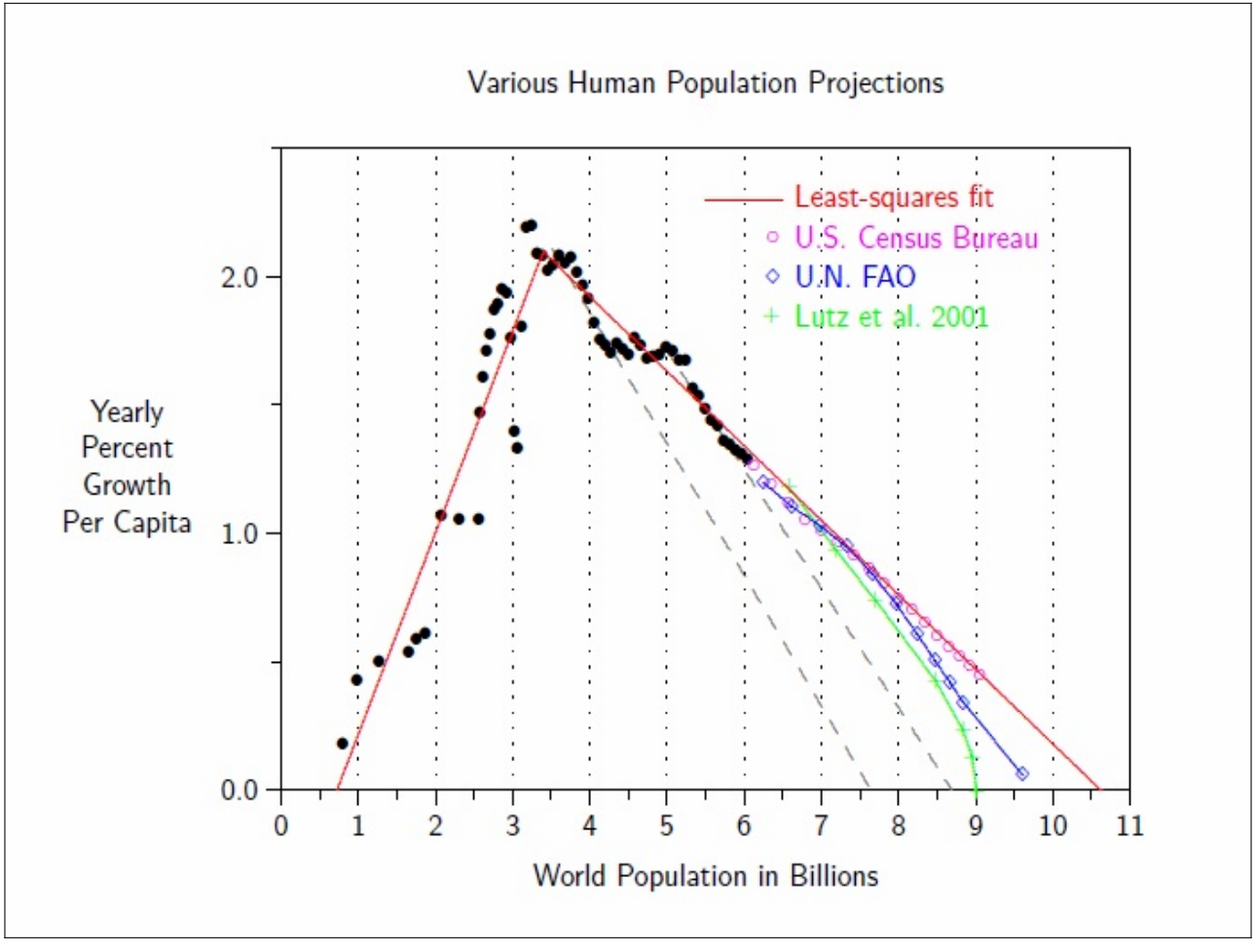
We have already accomplished cautious successes at healing major self-inflicted wounds:

1. Atmospheric nuclear fallout all but gone.

We have already accomplished cautious successes at healing major self-inflicted wounds:

2. Human population growth – the population bomb – defused.


Various Human Population Projections
Least-squares fit
U.S. Census Bureau
U.N. FAO
Lutz et al. 2001
Yearly
Percent
Growth
Per Capita
2.0
1.0
0.0
0
1
2
3
4
5
6
7
8
9
10
11
World Population in Billions

We have already accomplished cautious successes at healing major self-inflicted wounds:

3. Sulfuric acid rain restored to 19th century limits over large areas.

We have already accomplished cautious successes at healing major self-inflicted wounds:

4. Ozone hole is closing up.

We have already accomplished cautious successes at healing major self-inflicted wounds:

5. The Cuyahoga River hasn't caught fire for almost 40 years.

We are presently very wasteful. This hybrid vehicle is efficient, 400 miles per gallon per ton of cargo

And all liquid-fuel vehicles are still inefficient compared with purely electric ones

Unless all things that can be invented already have been invented, the 21st century will bring new inventions not now foreseen.

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Stabilization wedges

Socolow and Pacala of Princeton describe 15 current technologies, of any seven of which will stabilize emissions for 50 years:

1. Increase fuel economy for all cars to 60 mpg over 50 years

Stabilization wedges

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3. Cut carbon emissions by 1/4 in buildings and appliances projected for 2054

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11. Introduce carbon capture and storage at 800 1-GW coal plants

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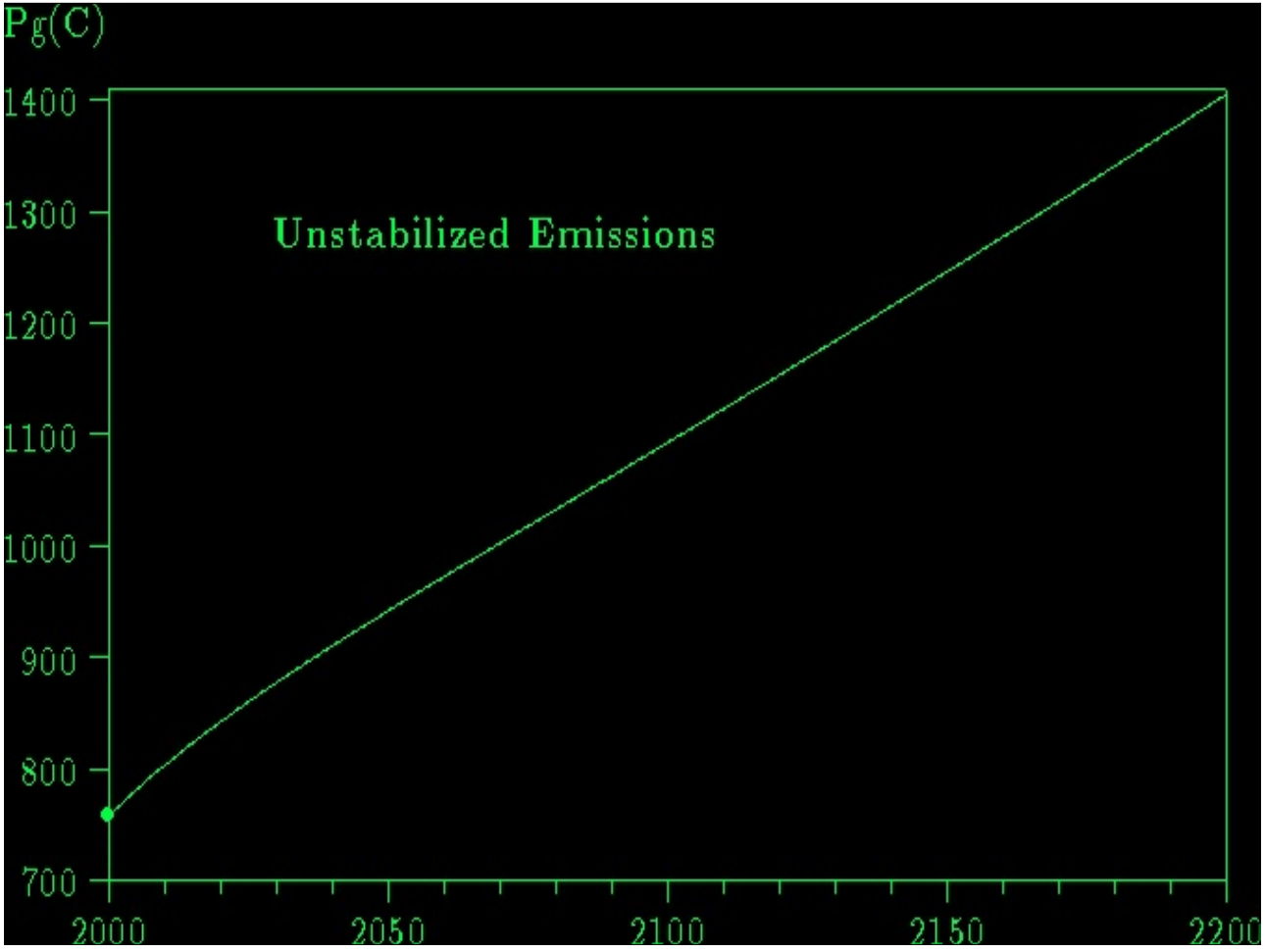
A sixteenth may come from new biofuels grown on idle and degraded farmland across the world.

Stabilization wedges

Socolow and Pacala of Princeton describe 15 current technologies, of any seven of which will stabilize emissions for 50 years:

1. Increase fuel economy for all cars to 60 mpg over 50 years
2. Reduce distance travelled per car by 1/2
3. Cut carbon emissions by 1/4 in buildings and appliances projected for mid-century
4. Decrease tropical deforestation to zero and establish 300 Mha of new tree plantations
5. Apply conservation tillage to all cropland (10 times current usage)
6. Add 2000 1-GW-peak photovoltaic plants (700 times current capacity)
7. Add 2 million 1-MW-peak windmills (50 times current capacity)
8. Add 4 million 1-MW-peak windmills for H2 fuel cells (100 times current capacity)
9. Produce twice today's coal power output at 40% waste instead of 60% waste (68% in 2004)
10. Replace 1400 1-GW 50%-waste coal plants with gas plants
11. Introduce CCS at 800 1-GW coal or 1600 1-GW natural gas
12. Introduce CCS at plants of 250 MtH_2/year from coal or 500 MtH_2/year from natural gas
13. Introduce CCS at synfuels plants producing 30 million barrels a day from coal
14. Add 700 1-GW nuclear power plants (twice current capacity)
15. Add 100 times current Brazil or U.S. ethanol production (one-sixth of world cropland)

    A sixteenth may come from new biofuels grown across the world.


Pg(C)
1400
1300
1200
1100
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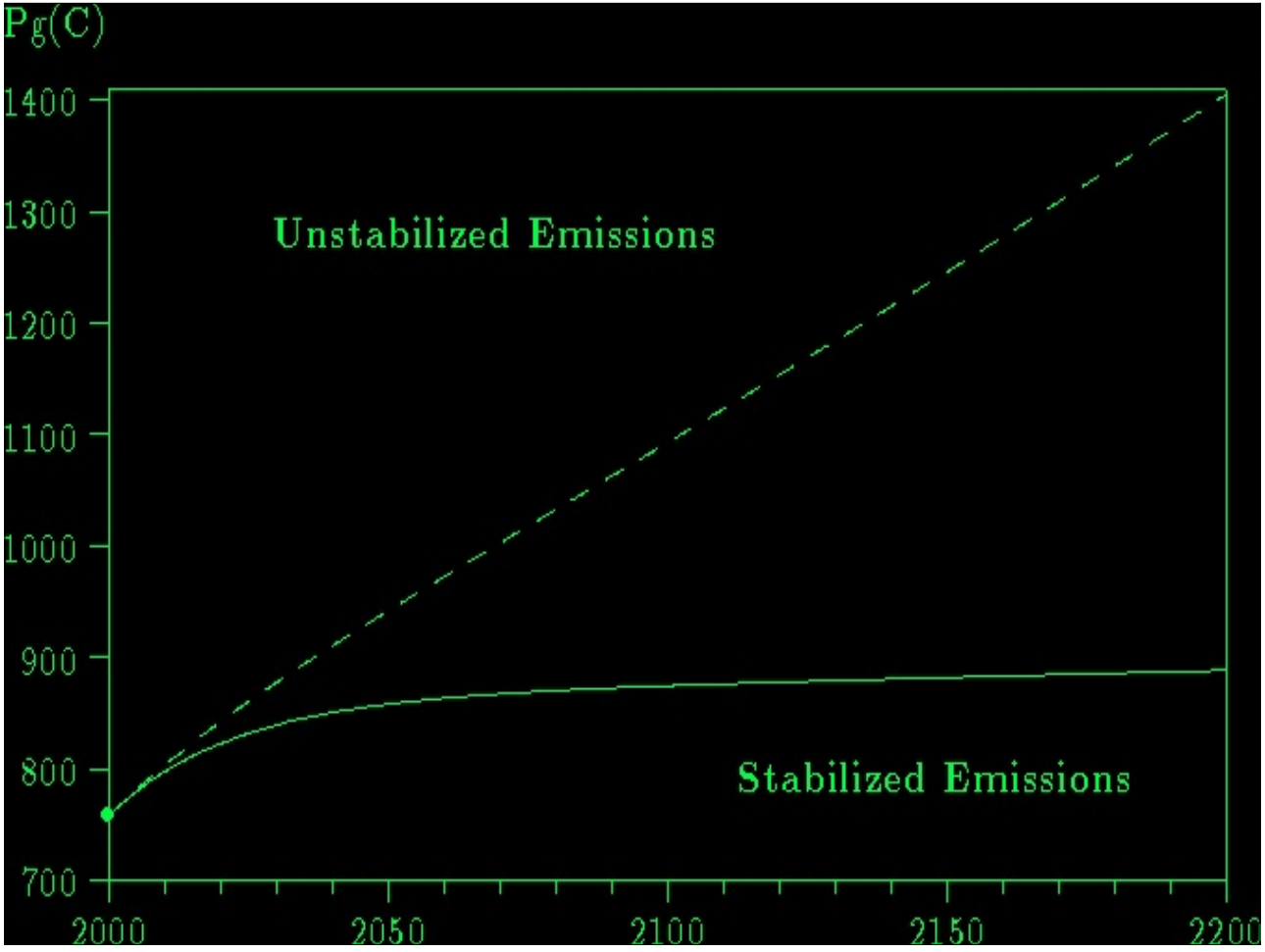
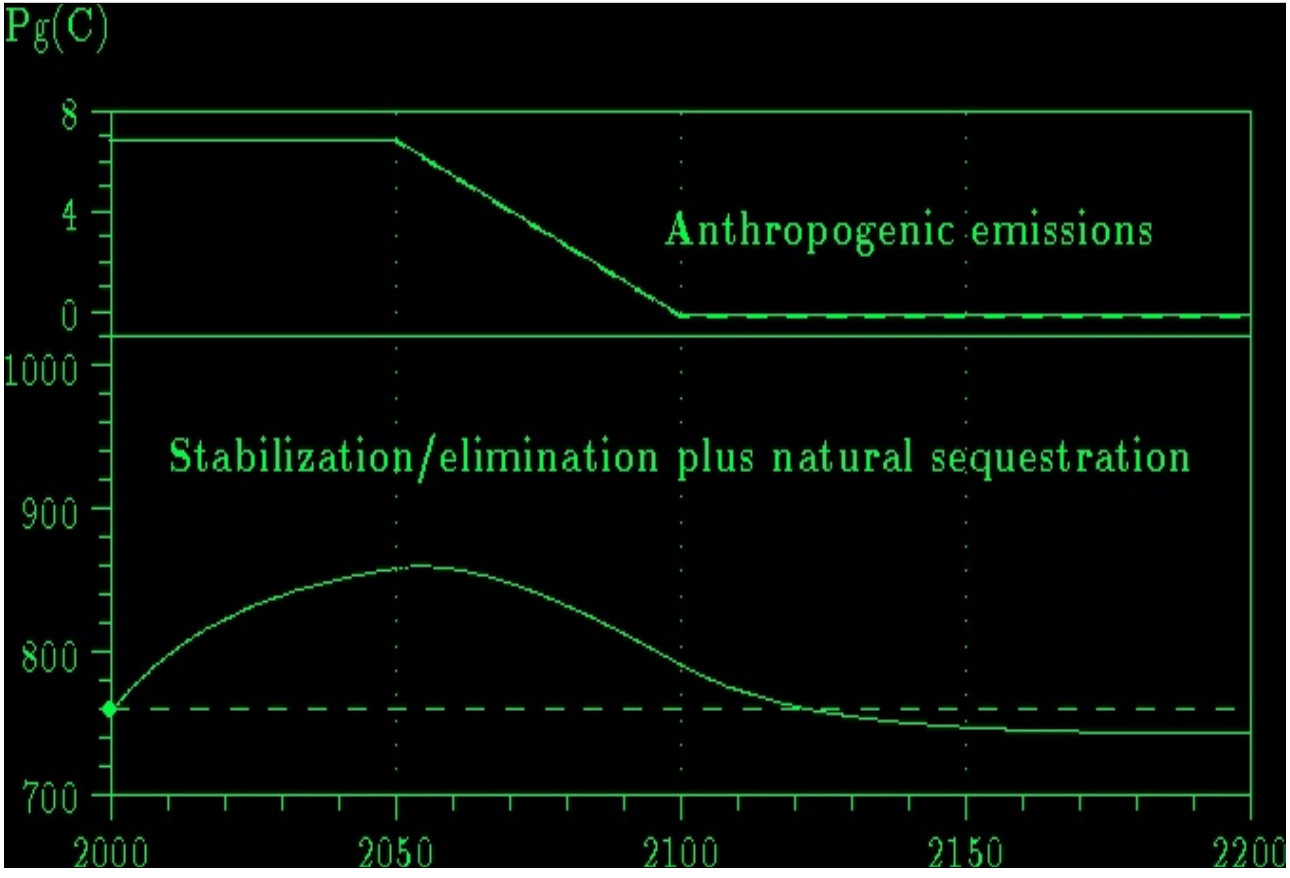
900
800
700
Unstabilized Emissions
2000
2050
2100
2150
2200


Pg(C)
1400
1300
1200
1100
1000
900
800
700
2000
2050
2100
2150
2200
Unstabilized Emissions
Stabilized Emissions


Pg(C)
8
4
0
Anthropogenic emissions
1000
900
800
700
Stabilization/elimination plus natural sequestration
2000
2050
2100
2150
2200

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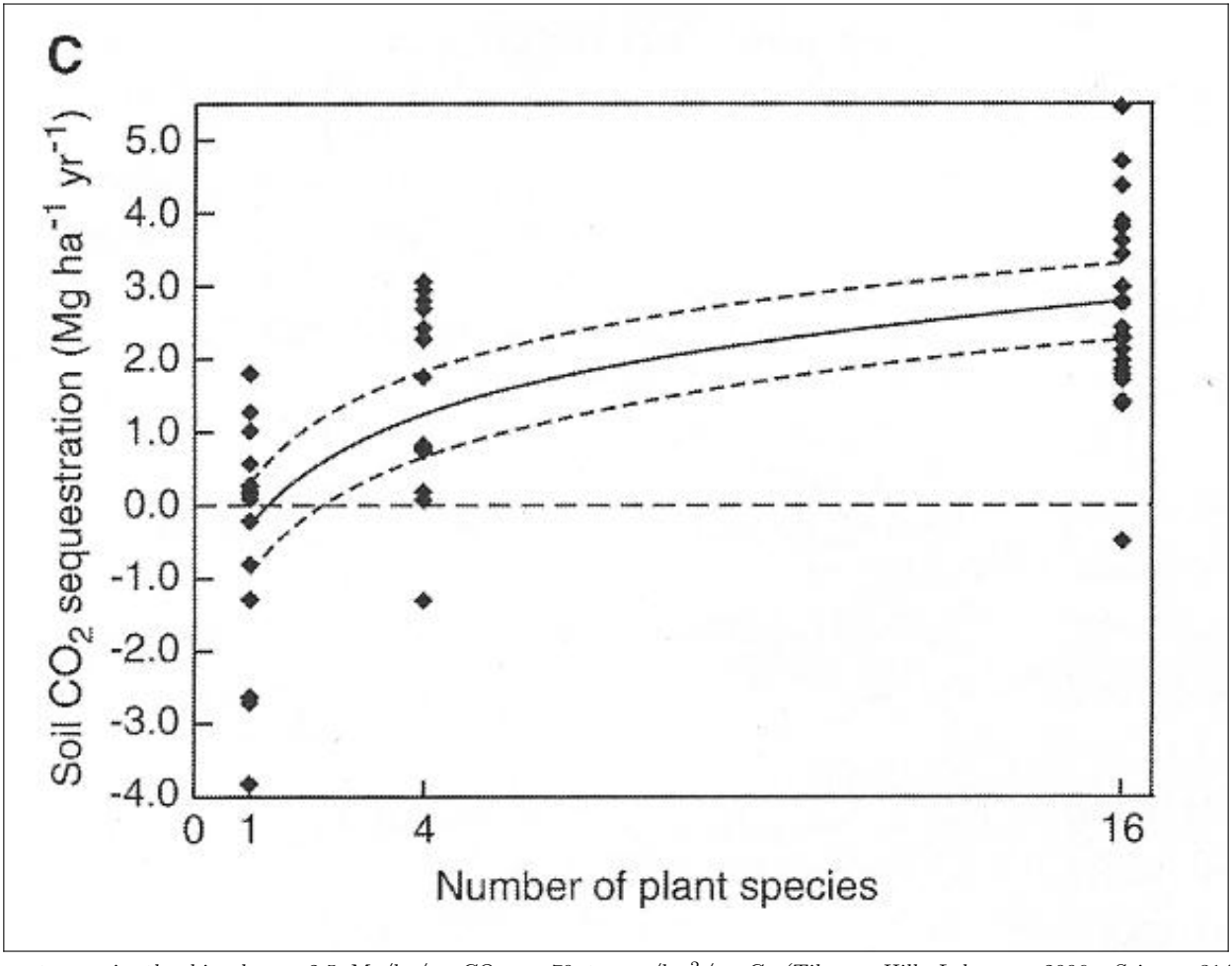
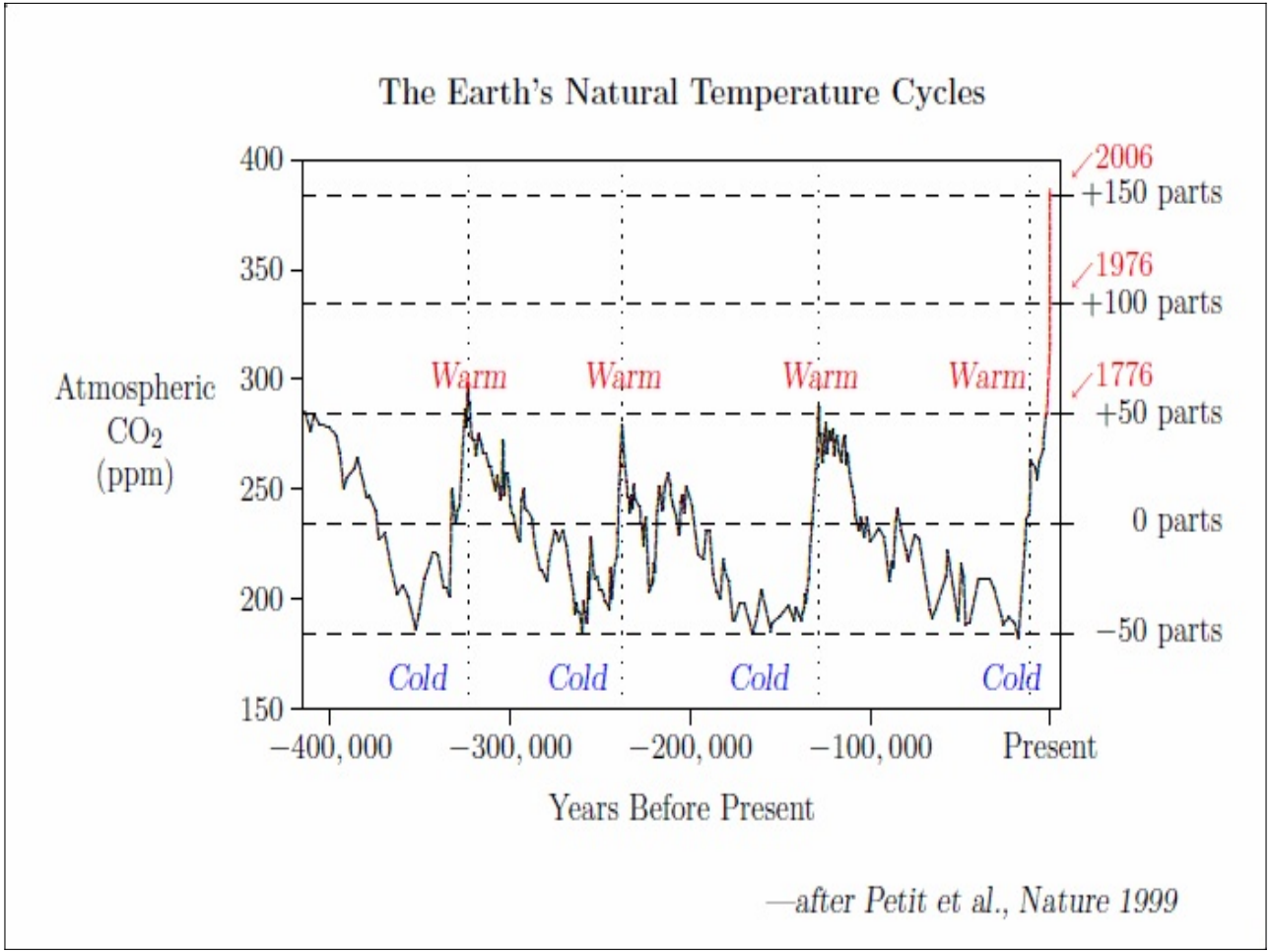


Carbon storage in the biosphere. 2.5 Mg/ha/yr CO_2 = 70 tonnes/km^2/yr C. (Tilman, Hill, Lehman. 2006. Science 314:1598)



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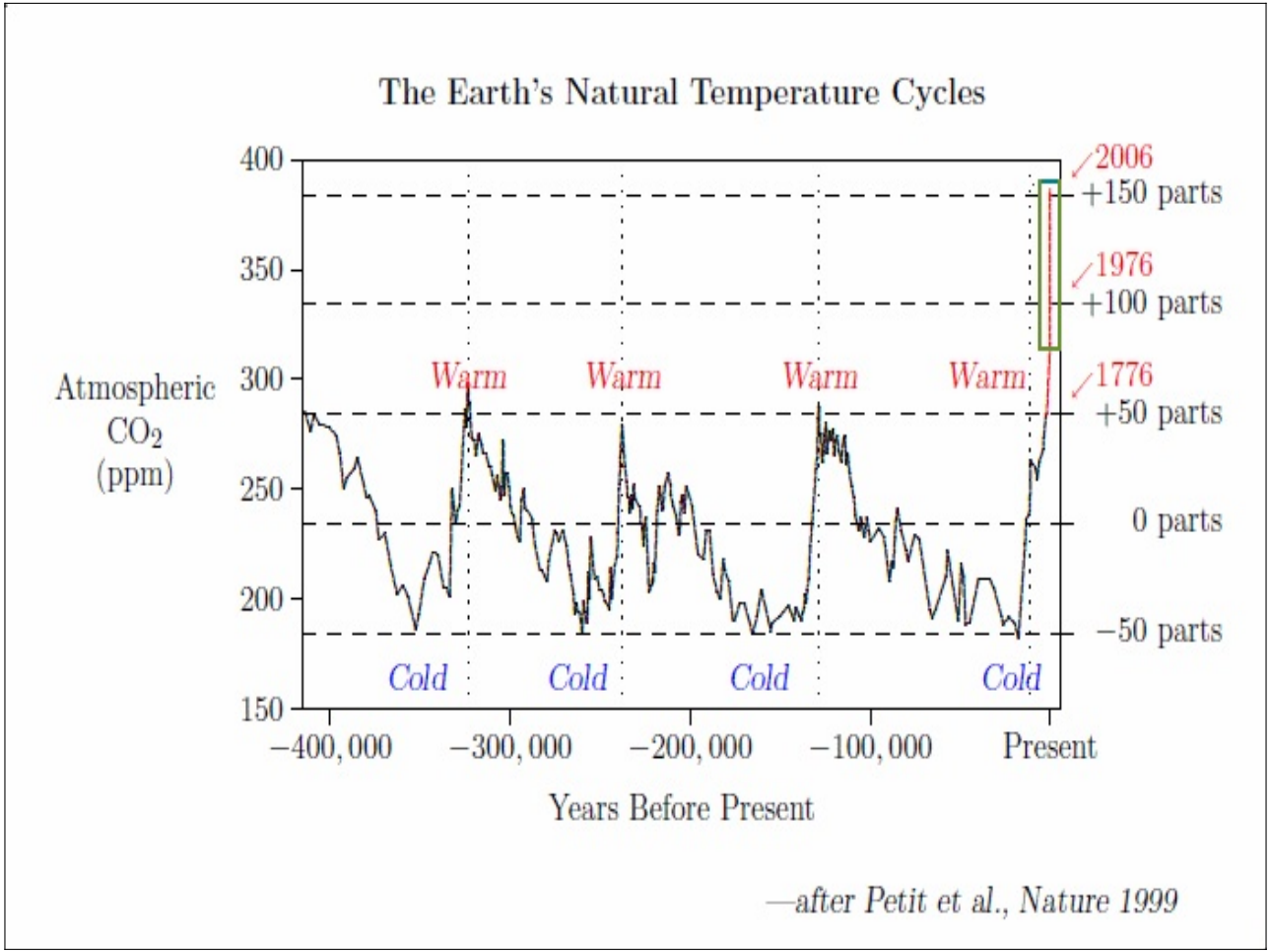

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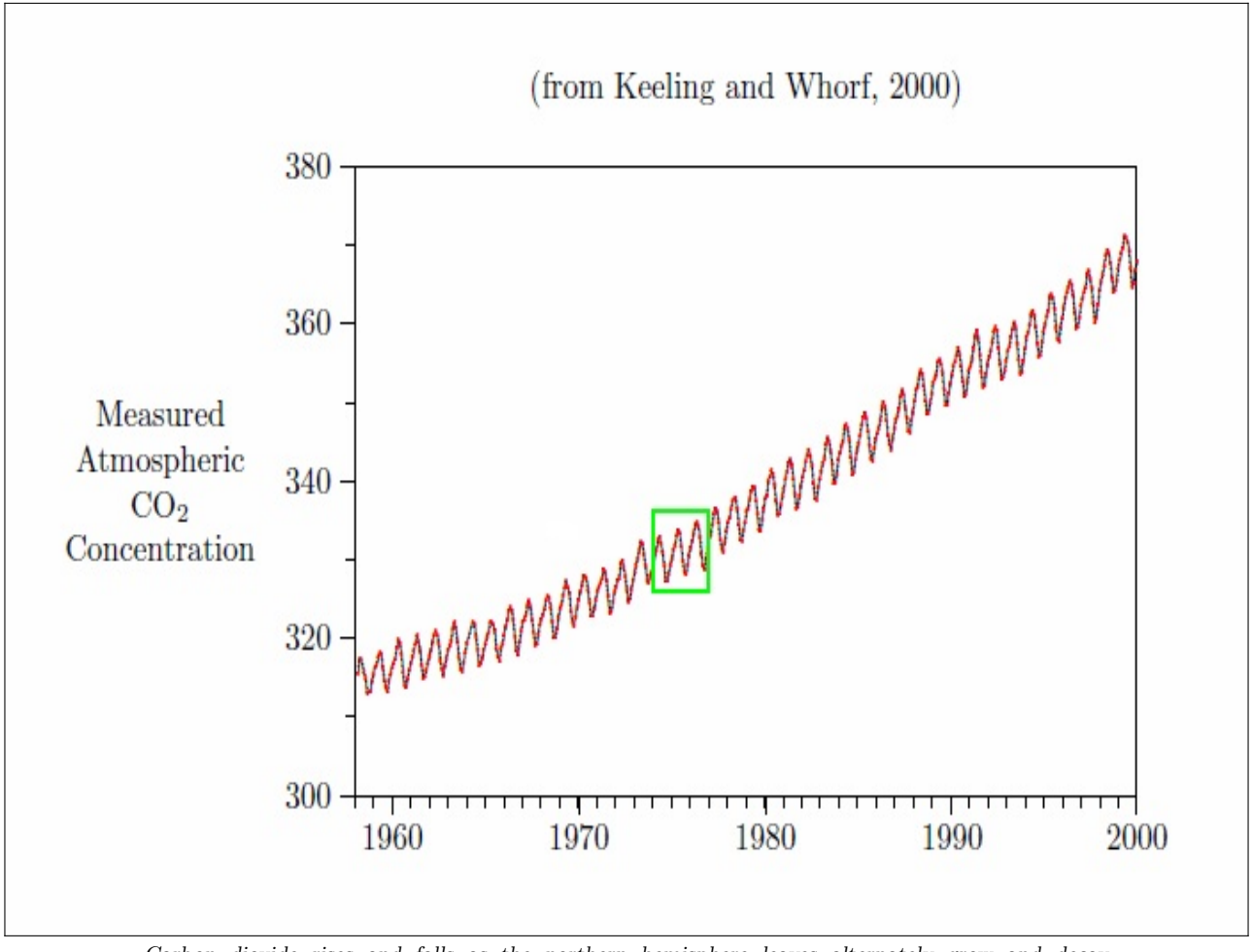
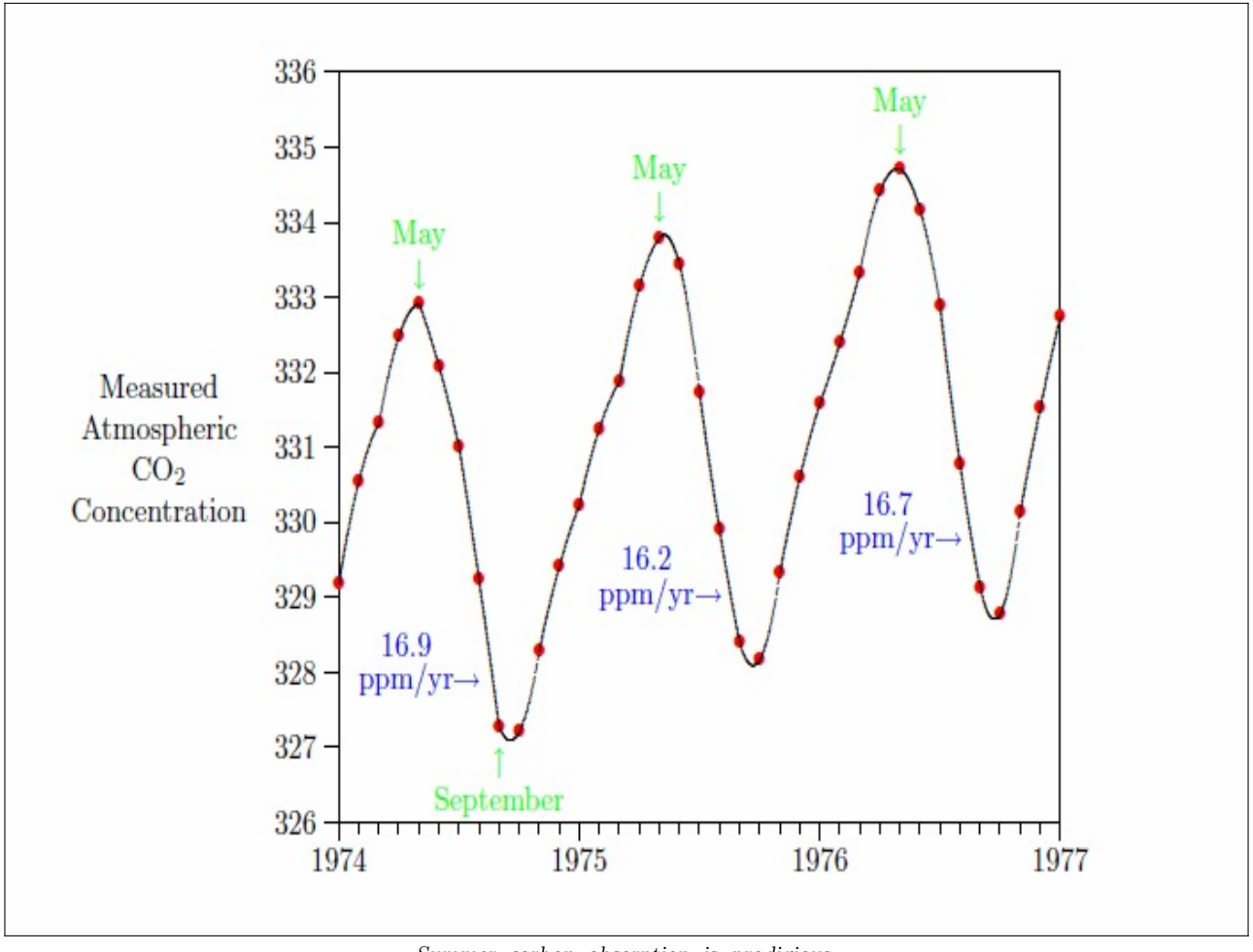
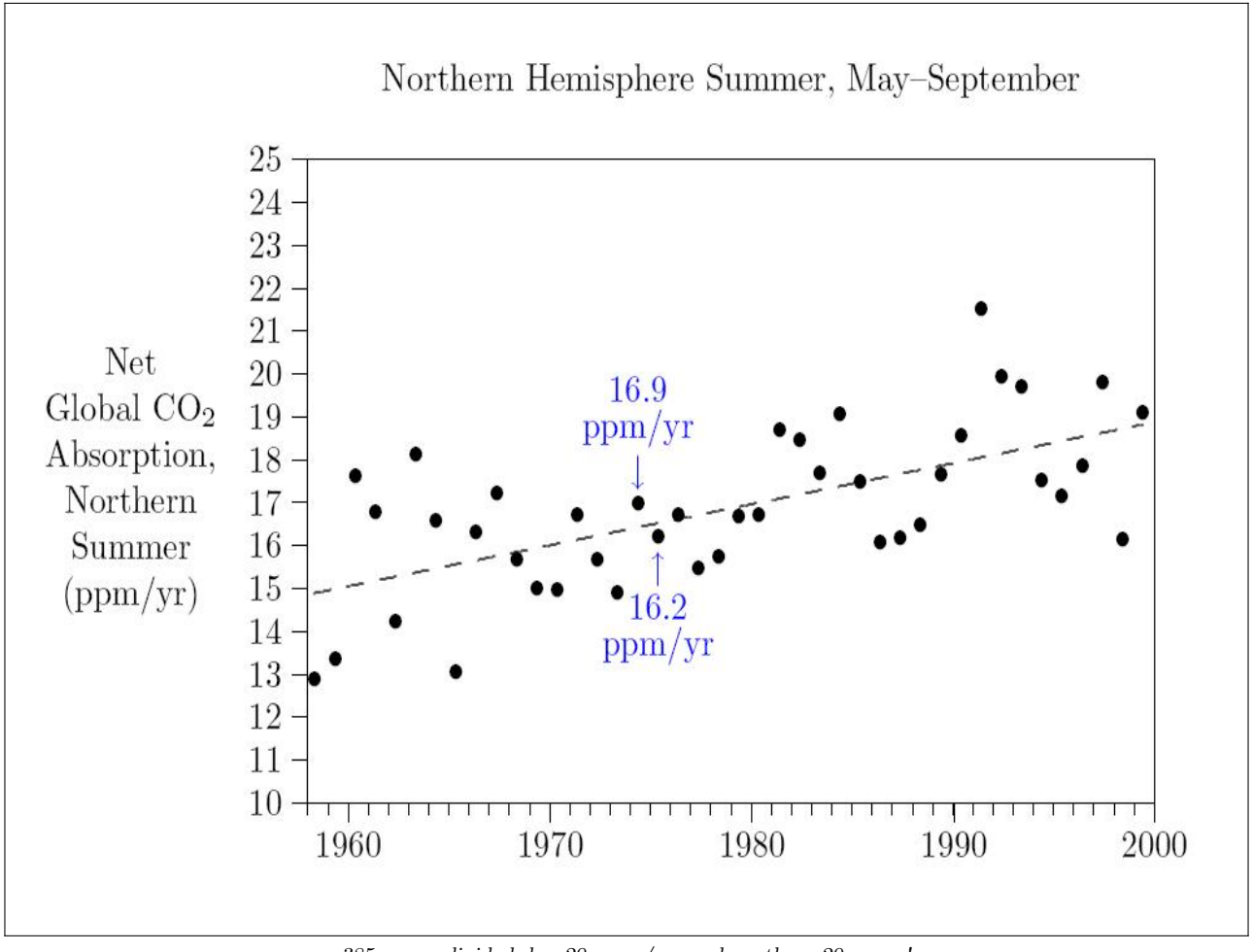


Carbon dioxide rises and falls as the northern hemisphere leaves alternately grow and decay



Summer carbon absorption is prodigious.



385 ppm divided by 20 ppm/yr = less than 20 years!

Ten-step recipe for removing carbon from the biosphere and returning it to the crust of the earth (called carbon capture and storage)

1. Compress air to condense out liquid nitrogen, leaving almost pure oxygen.
2. Sell the liquid nitrogen, e.g. as air conditioning agent.
3. Burn carbon fuel (e.g., grass, wood) in pure oxygen, but starved of oxygen.
4. The result is largely carbon monoxide and hydrogen, both explosive gases.
5. Ignite the result in an internal combustion engine (e.g. gas turbine) to generate electricity, again adding pure oxygen.
6. The result is carbon dioxide and water (steam).
7. Condense the result in a steam engine (e.g., steam turbine) to generate more electricity.
8. The result is carbon dioxide gas and hot liquid water.
9. Use the hot water to heat homes, greenhouses, etc.
10. Compress the carbon dioxide and or chemically convert it and store it where it will stay put for a long time.

This recipe makes the resultant electricity expensive, but if the goal is removing carbon from the biosphere, electricity is a free byproduct. This method produces money.

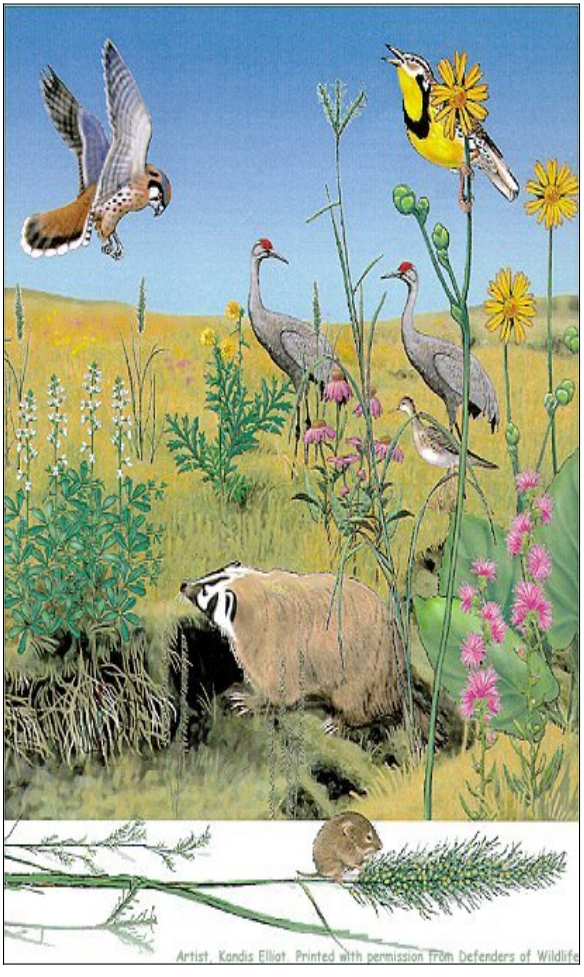
Other proposals for removing carbon also consume money throughout their operation.

Ten-step recipe for removing carbon from the biosphere and returning it to the crust of the earth (called carbon capture and storage)

Geological injection of carbon dioxide is done on a large scale in several places on earth today (e.g., Schlepner, North Sea; Weyburn Canada / Beulah ND; Salah, Algeria).

The carbon dioxide is being stored in fossil fuel deposits, but sequestration is partially defeated because the carbon dioxide is is being used to push new fossil fuel from the deposits.

An emerging technology.



Whole Earth Dynamics

This is a solvable problem. We should be able to turn down the earth's thermostat, cleanse its waters, restore degraded farmland, and help wildlife, all while generating renewable energy.