Thoughts on Manufacturing for Sustainability

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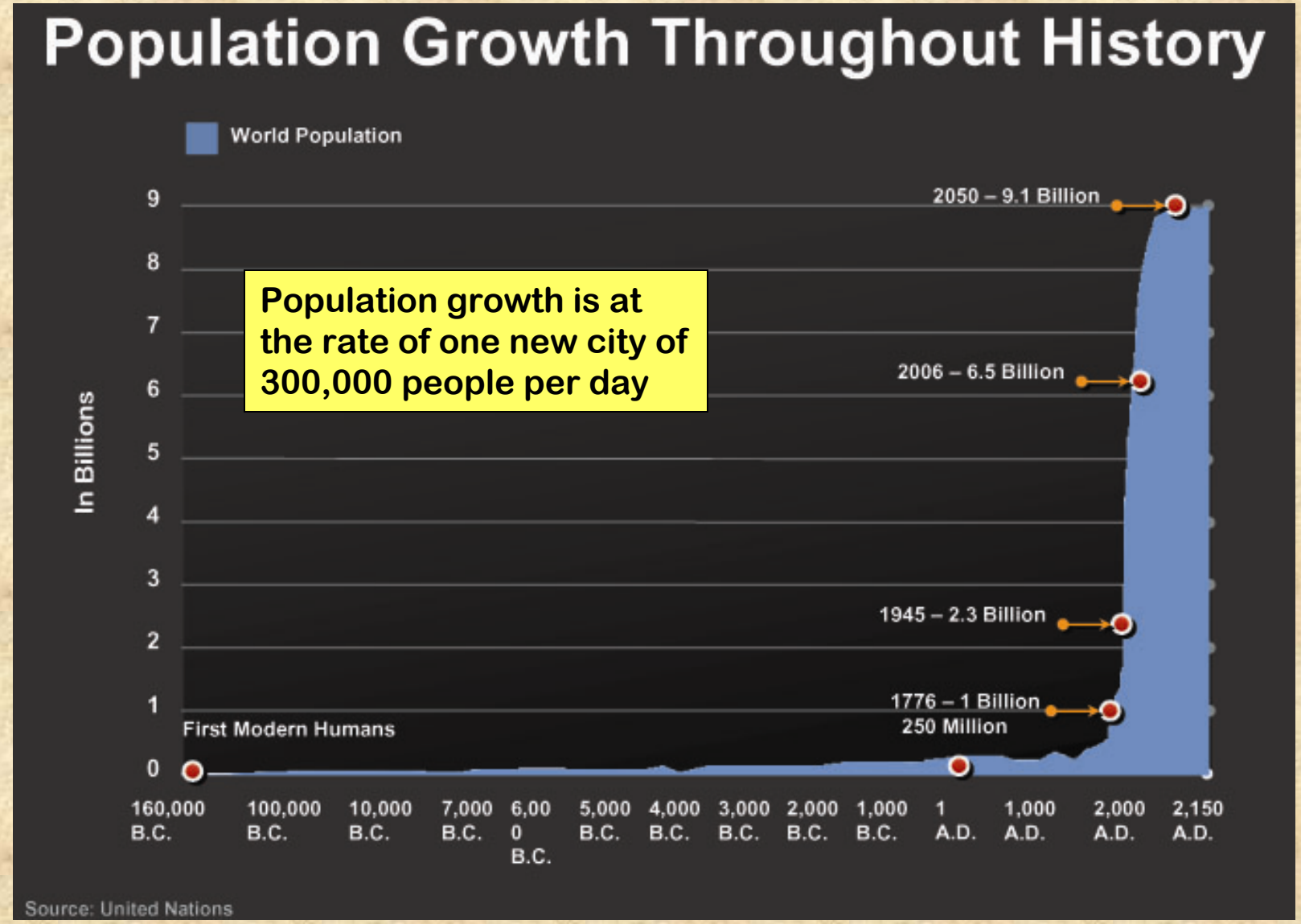
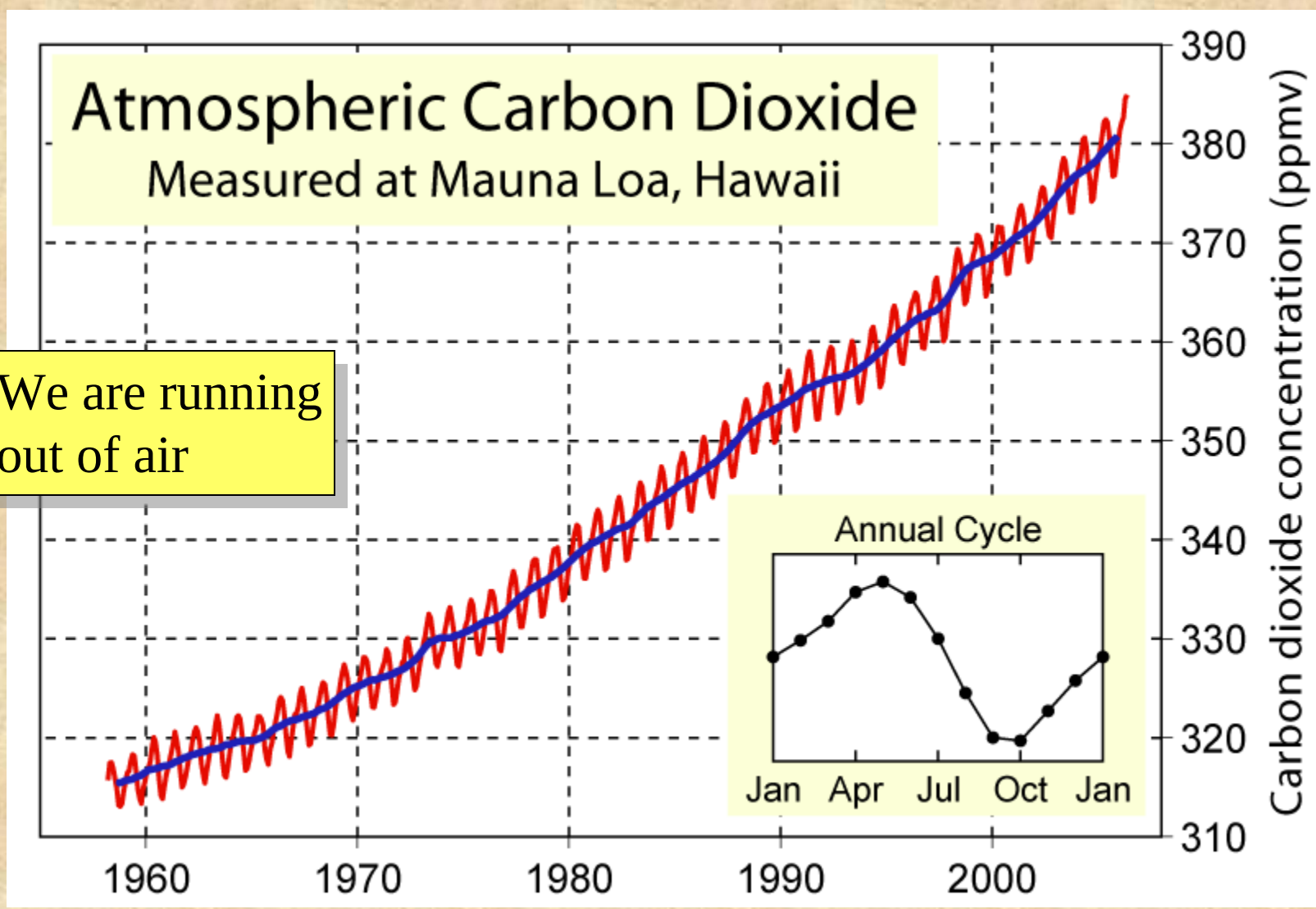

Population Growth Throughout History
World Population
In Billions
9
8
7
6
5
4
3
2
1
0
2050 – 9.1 Billion
2006 – 6.5 Billion
1945 – 2.3 Billion
1776 – 1 Billion
250 Million
First Modern Humans
Population growth is at the rate of one new city of 300,000 people per day
160,000 B.C.
100,000 B.C.
10,000 B.C.
7,000 B.C.
6,000 B.C.
5,000 B.C.
4,000 B.C.
3,000 B.C.
2,000 B.C.
1,000 B.C.
1 A.D.
1,000 A.D.
2,000 A.D.
2,150 A.D.
Source: United Nations

Energy Reserves

- Remaining fossil fuels: $4X10^{23}$ J
- Available nuclear fuel: $2.5X10^{24}$ J
- Solar flux: $3.8X10^{24}$ J/yr

The earth's energy reserves will last at least 1,000 years at current consumption rates (much less with rapid demand growth)

Reserves of Air



Major Challenges

- Not enough air
- Not enough water
- Not enough food
- Not enough space
- Not enough resources
- Jobs going off-shore
- Huge budget deficits

Response

- Manufacturing must—
  - Use less water
  - Use less energy
  - Produce less waste
  - Use fewer scare or toxic materials
  - Take less space
- Manufacturing must become more “friendly”—the concept of a positive environmental impact

A New Concept

ENERGY MANUFACTURING

Manufacturing: Feedstocks+Capital+Labor=Products

Energy Mfg: Feedstocks+Capital+Labor=Energy

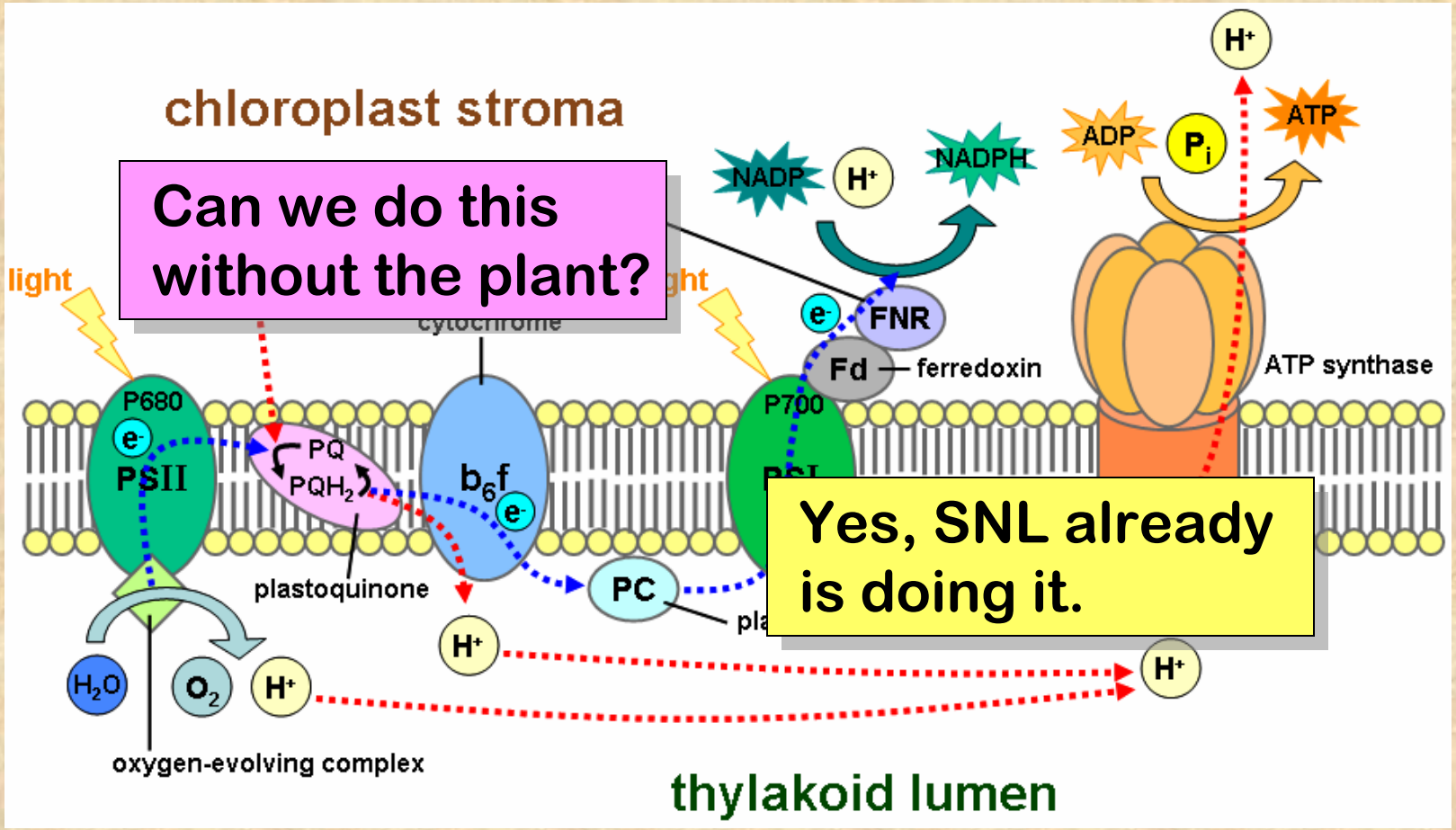
Sunlight Wind Air Water CO_2	Solar cells Wind mills Wave gen. Farms	Heat Electricity Gasoline Diesel Jet A

Energy Markets

- US (2005):
  - Oil 21M bbl/day (7.6 B bbl/yr) ~$1T
  - Coal 1,128M Short tons/yr ~$100B
  - Gas 22T cf ~$165B
  - Electricity (nuclear, hydro, renew), 11.5Q Btu
    - 4063.2B kWh (~$330B)
    - 1180.7B kWh (non-fossil) ~$100B
  - World oil 85M bbl/day ~$4T

Total world ~$5T/yr

Light to Chemical Energy



Integration of Design and Manufacture

- Co-optimize design and manufacture
  - Demands better modeling of manufacturing processes
  - Demands better optimization capabilities
  - Demands better understanding of decision making under uncertainty
- Can only be done well if the design and manufacture activities are co-located

Defining Sustainability

- All manufacturing has some impact on the environment—it cannot be avoided
- What is acceptable? What is sustainable?
- It is in the eyes of the beholder, there is no clear definition—people differ in what they want
- But sustainability should be a social choice

The Notion of Social Choice

- Society should choose
- What do “we” value, what do “we” want to preserve? What do “we” want to pass on to the next generation?
- The definition of sustainability should be defined in these terms by society, not by manufacturing enterprises acting unilaterally
- Society should vote on it

Arrow's Impossibility Theorem

- The purpose of a vote is to determine a societal preference
- A vote should satisfy certain "obvious" conditions:
  - Unanimity—if everyone wants A over B,C,D,…, we should choose A
  - Transitivity—if society chooses A over B and B over C, it should choose A over C
  - Irrelevance—a choice between A and B should not depend on the existence of C,D,E,…
  - Dictatorship—there should not be a dictator who decides irrespective of the preferences of the others
- AIT—any conceivable voting method that satisfies the first three conditions is necessarily a dictatorship

Societal Preference

- In fact, a rational societal preference is unlikely to exist
- A 3-person society chooses between A,B,C
  - P1 likes A>B>C and A>C
  - P2 likes B>C>A and B>A
  - P3 likes C>A>B and C>A
- The societal preference is A>B>C>A
- Every choice is the worst

How can Industry be Sustainable?

- The law (regulation and taxation—current and expected) is the best measure of societal preference
- Companies should be profit-maximizers within current and expected regulation
- Manufacturers cannot unilaterally make environmental impact tradeoffs that reflect societal preferences, and thus should not be defining sustainability themselves

What is our Role?

- Science can define the impact on the environment of various manufacturing activities
- Science can estimate the consequence of these impacts on society
- Science and engineering can present opportunities for change and estimate their costs
- We can present these data to society to effect rational societal choices

Manufacturing contributions to GDP and employment