Sustainability: Principles and Practices
Spring 2014

PPT Set 7

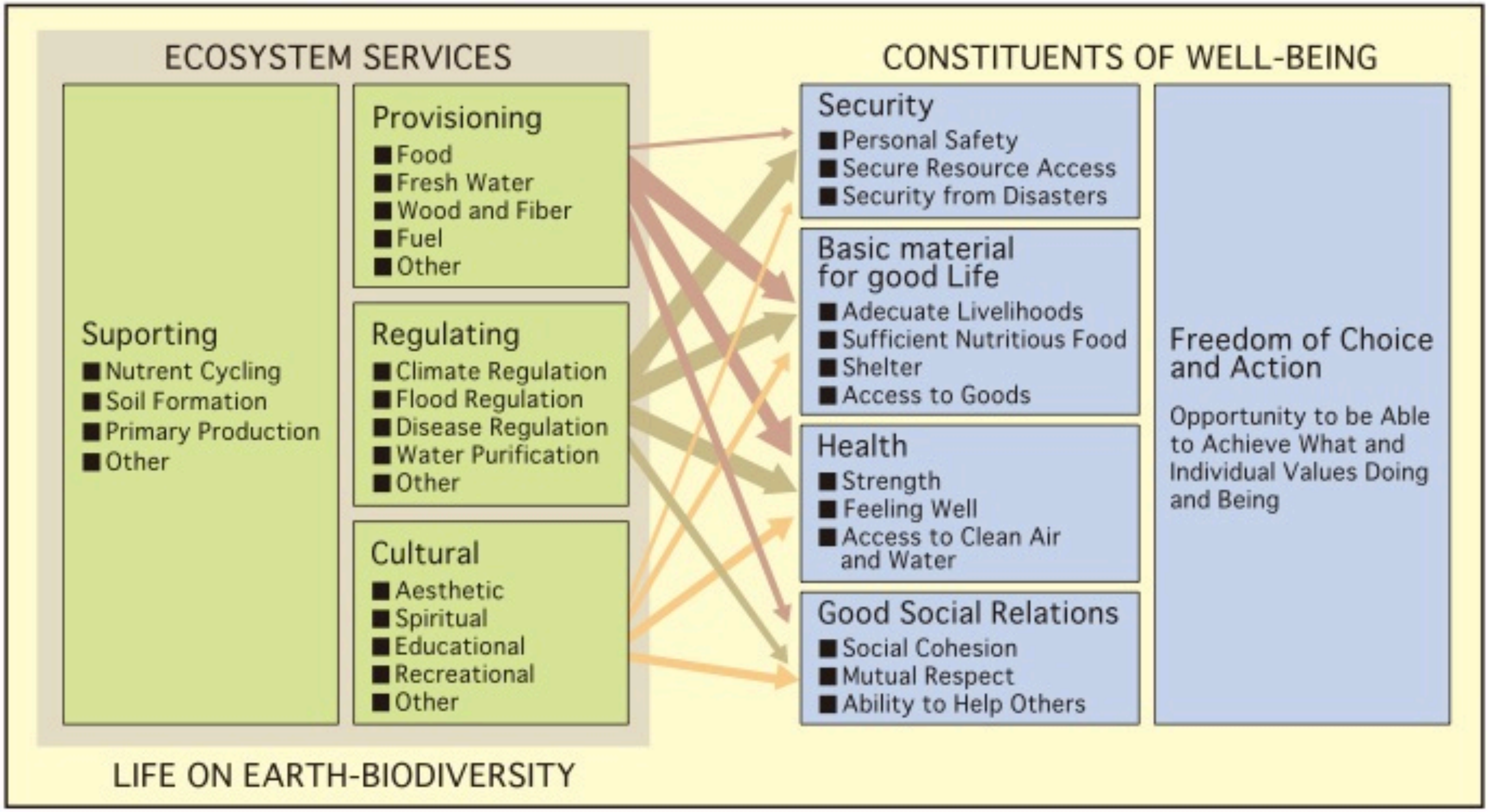
Professor Anthony Serianni

Agriculture, Food, Water, Waste

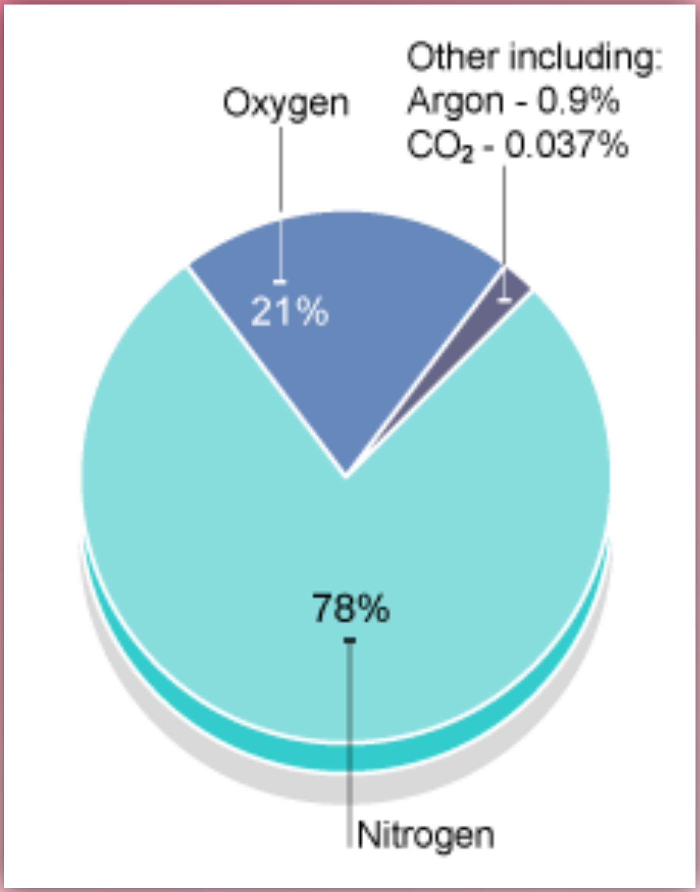
Video: Wendell Berry

Figure 2: Ecosystem Services and Human Well-Being

Source: *Millennium Ecosystem Assessment* [5]

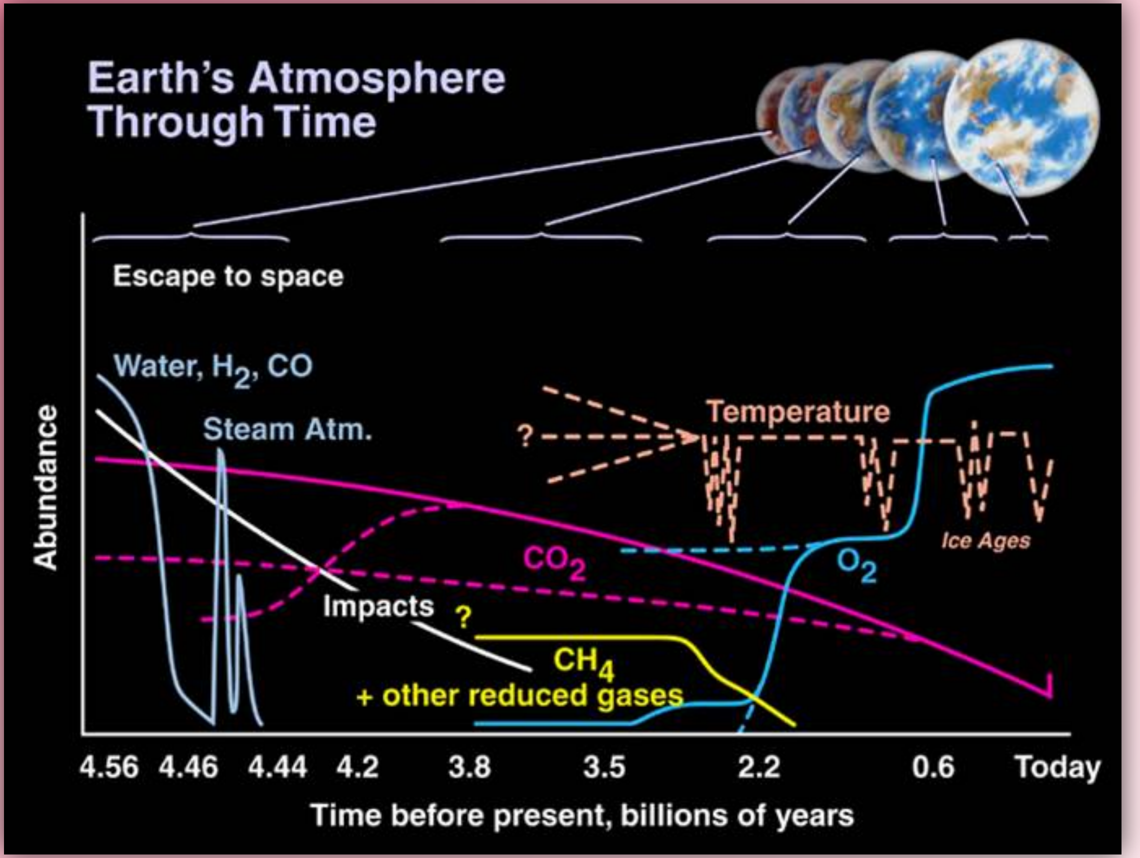


Atmospheric composition of Earth



Atmospheric nitrogen is the primary source of nitrogen in soil.

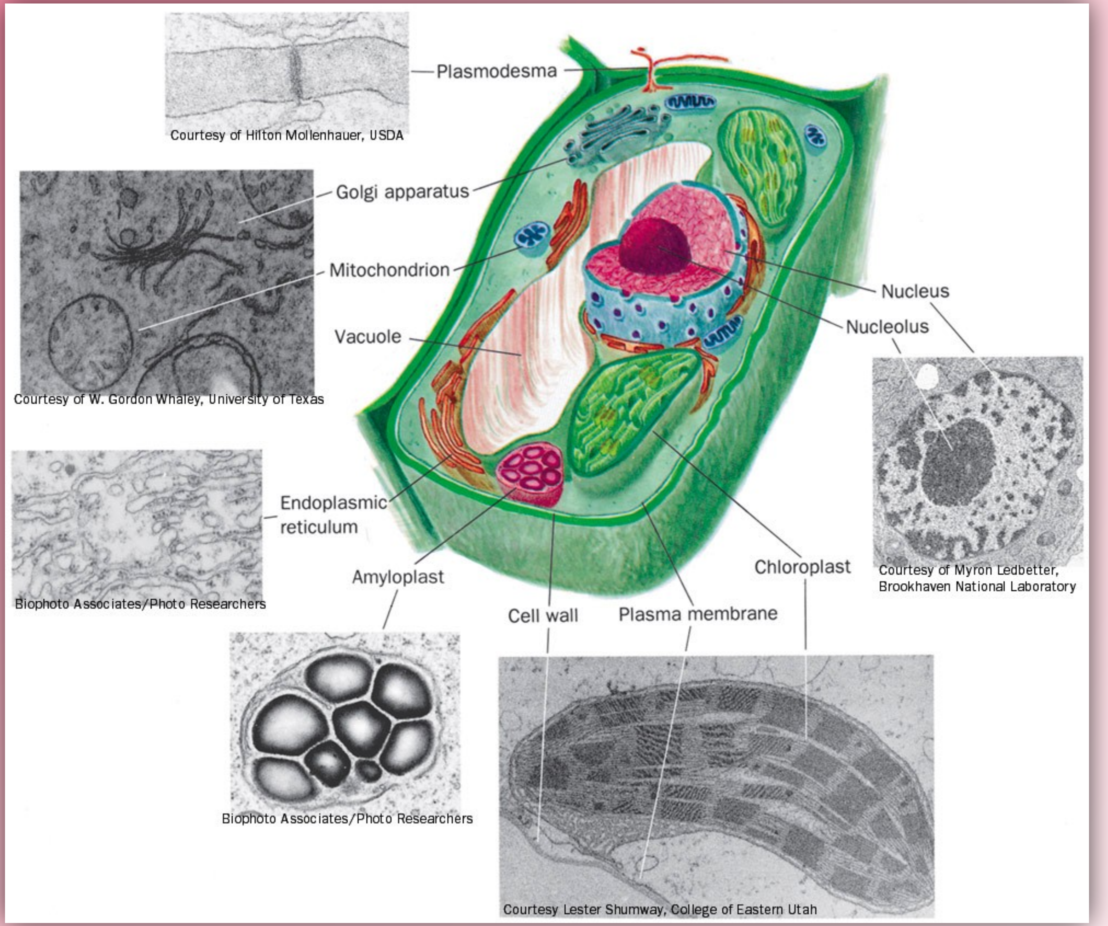
Earth's early atmosphere was reducing, but it is now oxidizing.



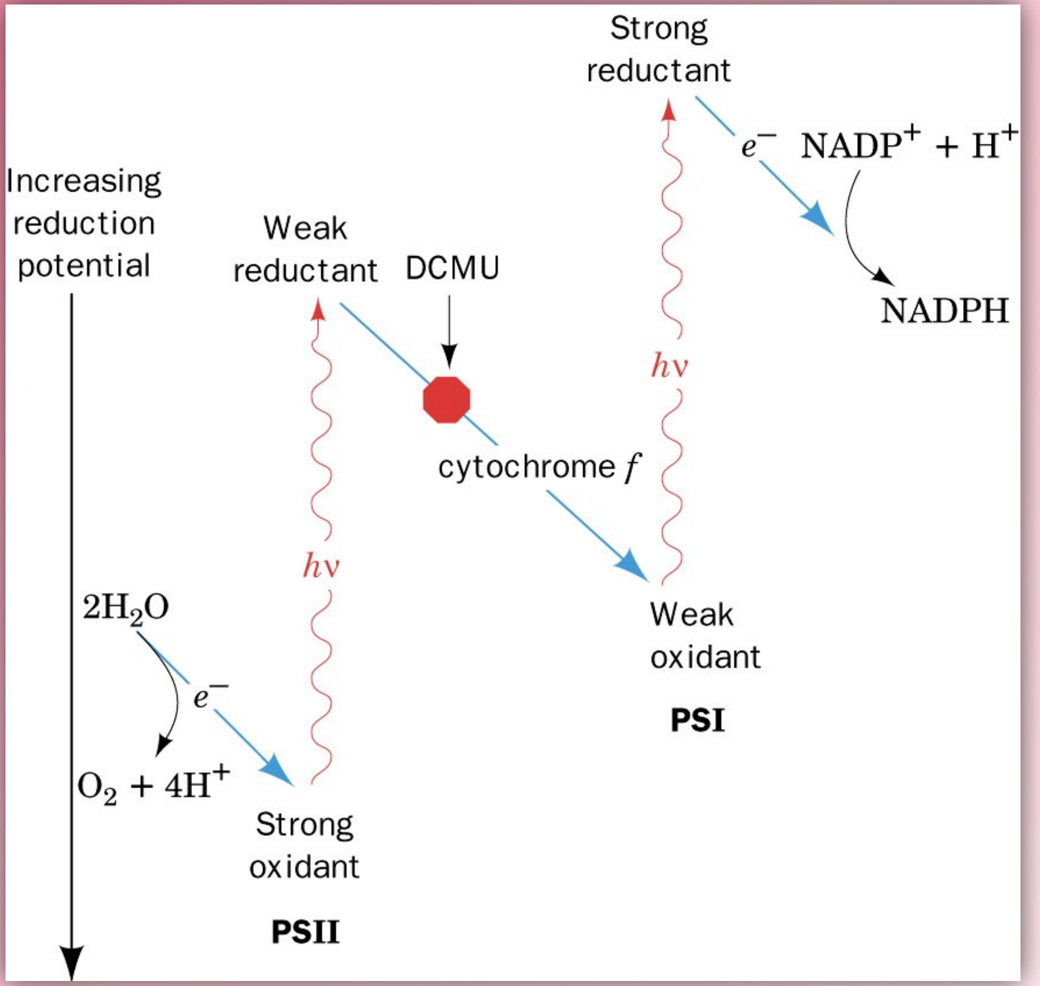
How do plants produce oxygen?

They convert (oxidize) H_2O to O_2 during photosynthesis (*i.e.*, free energy from the sun drives this oxidation).

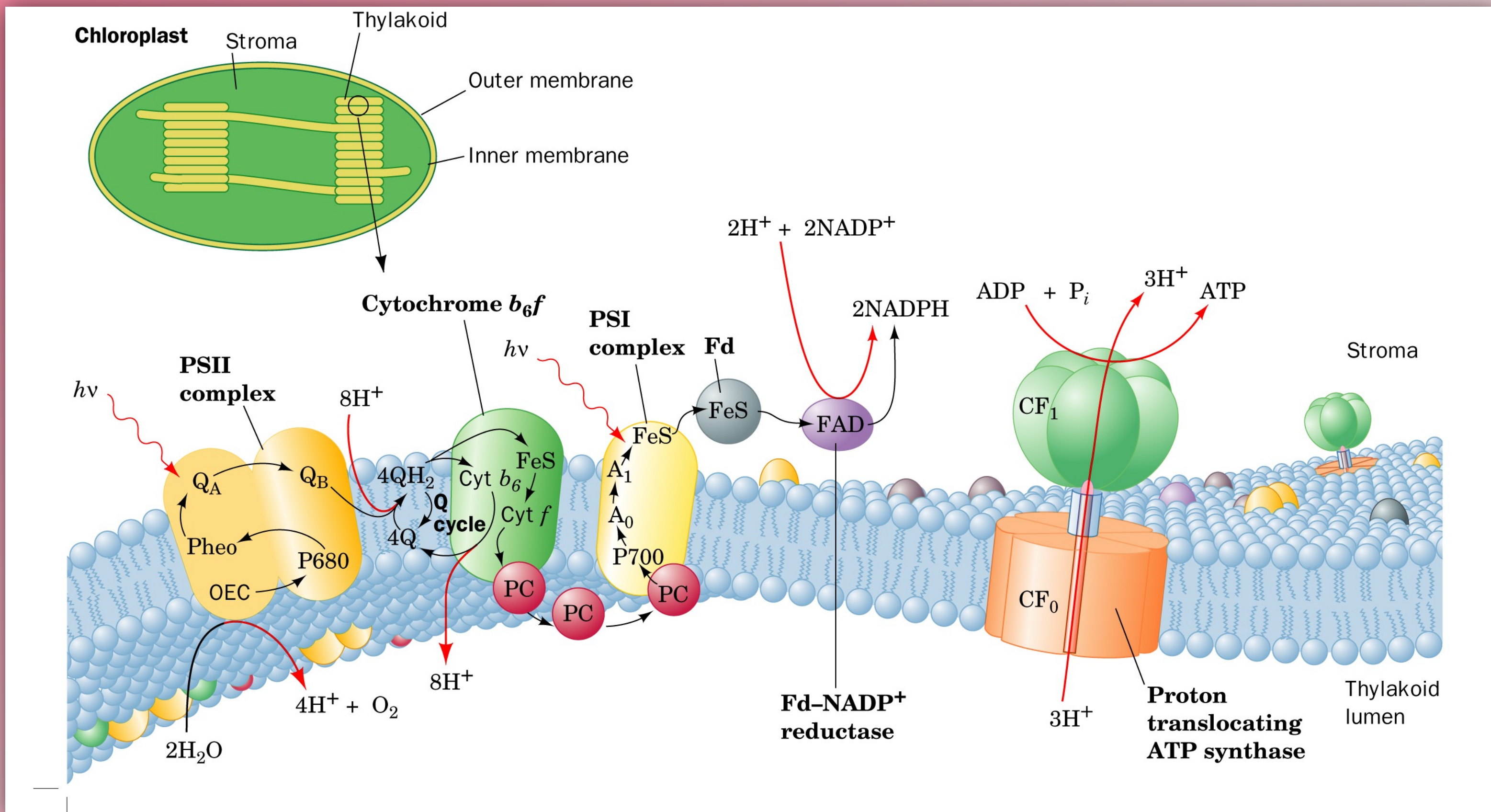
Drawing of a plant cell accompanied by electron micrographs of its organelles



The Z-scheme for photosynthesis in plants and cyanobacteria



Schematic representation of the thylakoid membrane (in plant chloroplasts) showing the components of its electron transport chain



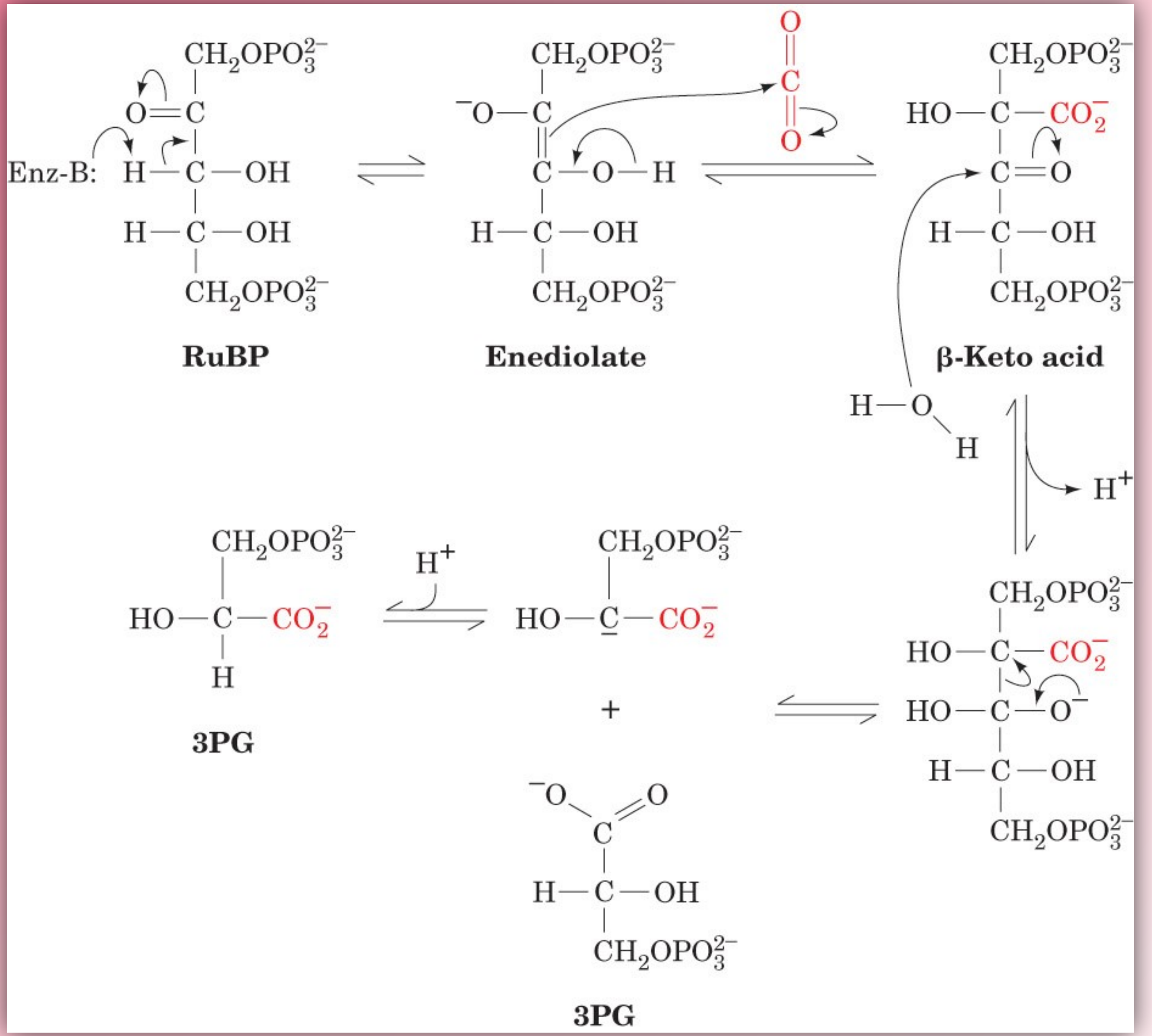
How do plants consume CO_2?

They insert (<u>fix</u>) the carbon atom in CO_2 into sugars using a specific enzyme.

The X-ray structure of tobacco CO_2-fixing enzyme, ribulose bisphosphate (RuBP) carboxylase, bound to an inhibitor

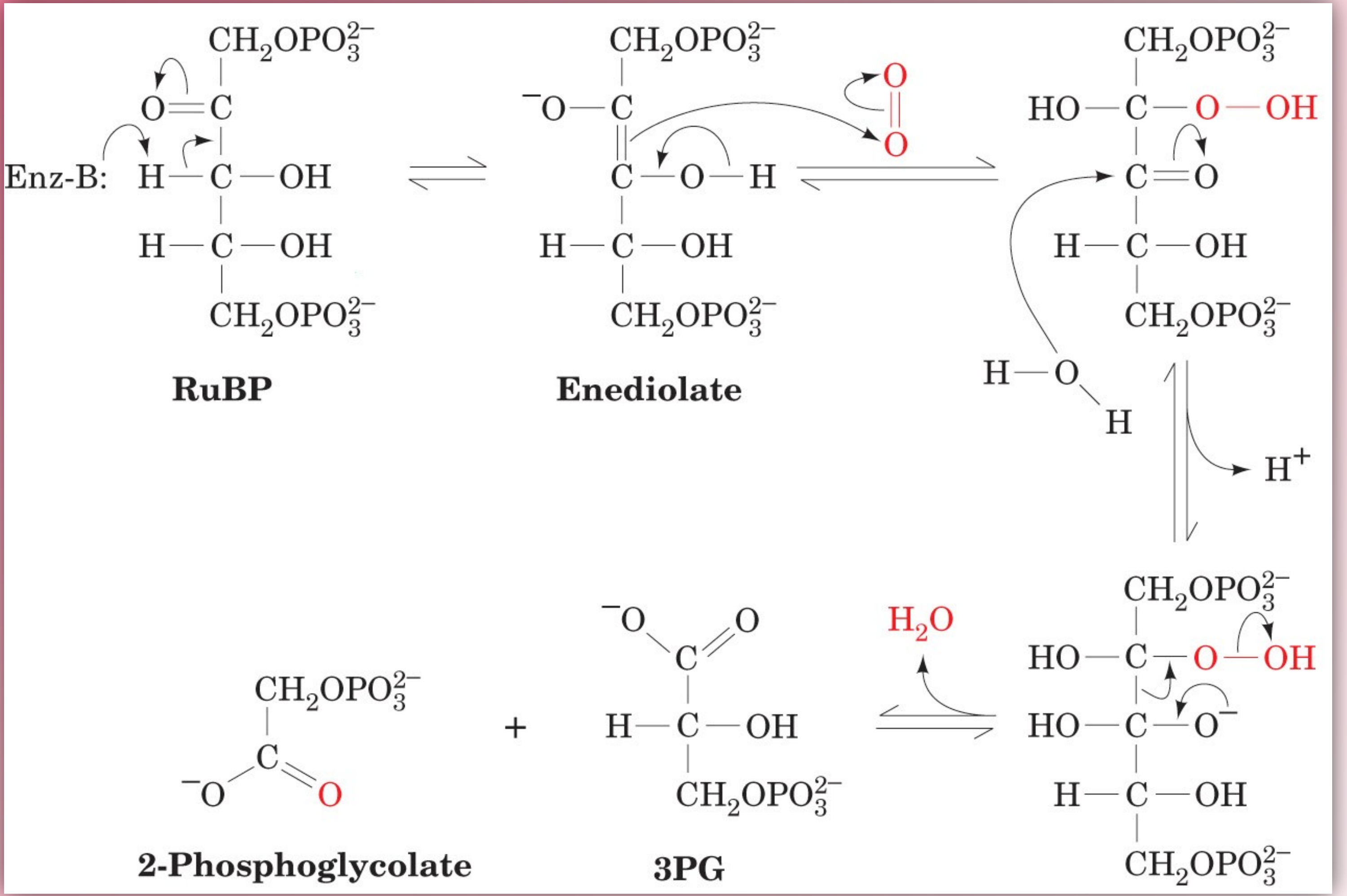
RuBP carboxylase is the most abundant enzyme in the biosphere.

Reaction mechanism: The CO_2-fixing reaction catalyzed by RuBP carboxylase



Plants also <u>fix</u> O_2 into sugars. This process is called photorespiration.

Reaction mechanism: The O_2-fixing reaction catalyzed by RuBP carboxylase–oxygenase



Nitrogen (N_2) fixation in the biosphere

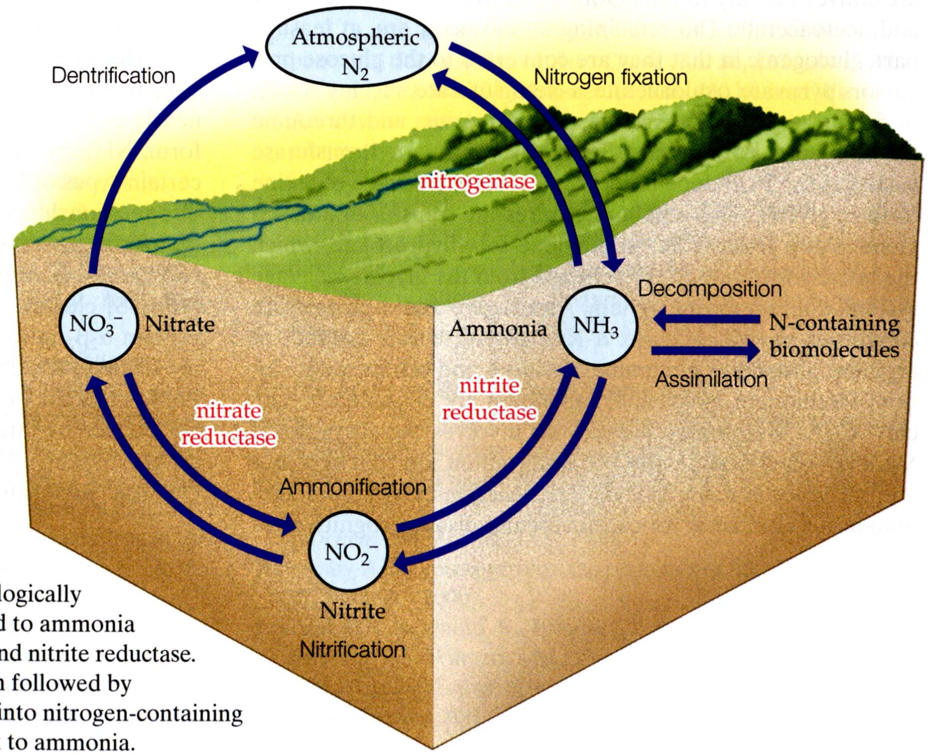
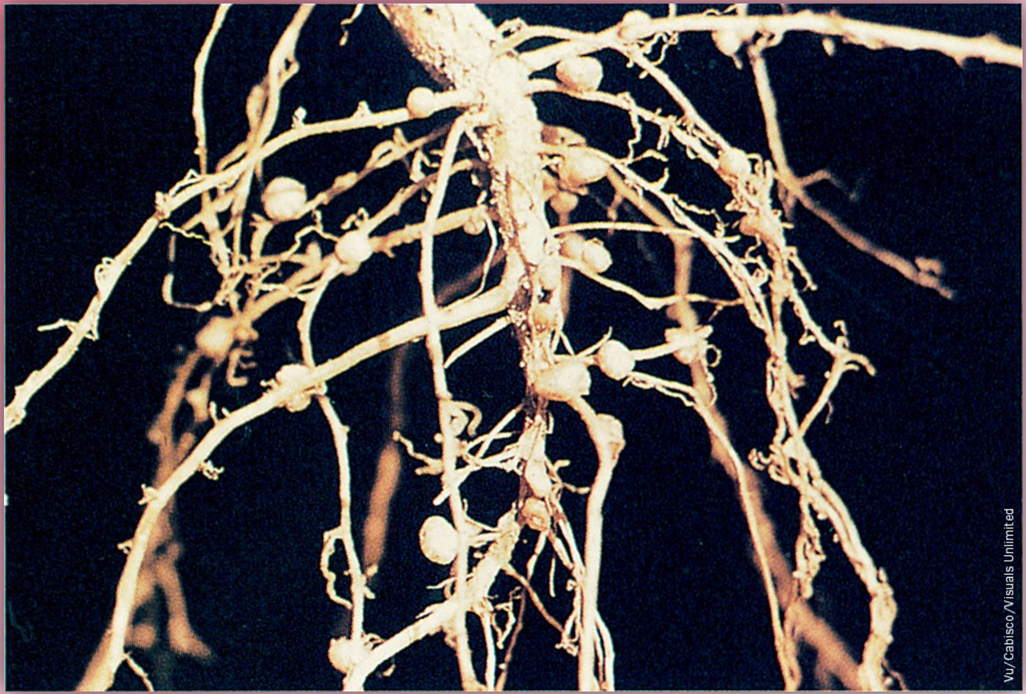


Figure 26-70 **The nitrogen cycle.** Nitrogen fixation by nitrogenase converts N_2 to the biologically useful ammonia. Nitrate can also be converted to ammonia by the sequential actions of nitrate reductase and nitrite reductase. Ammonia is transformed to N_2 by nitrification followed by denitrification. Ammonia may be assimilated into nitrogen-containing biomolecules, which may be decomposed back to ammonia.

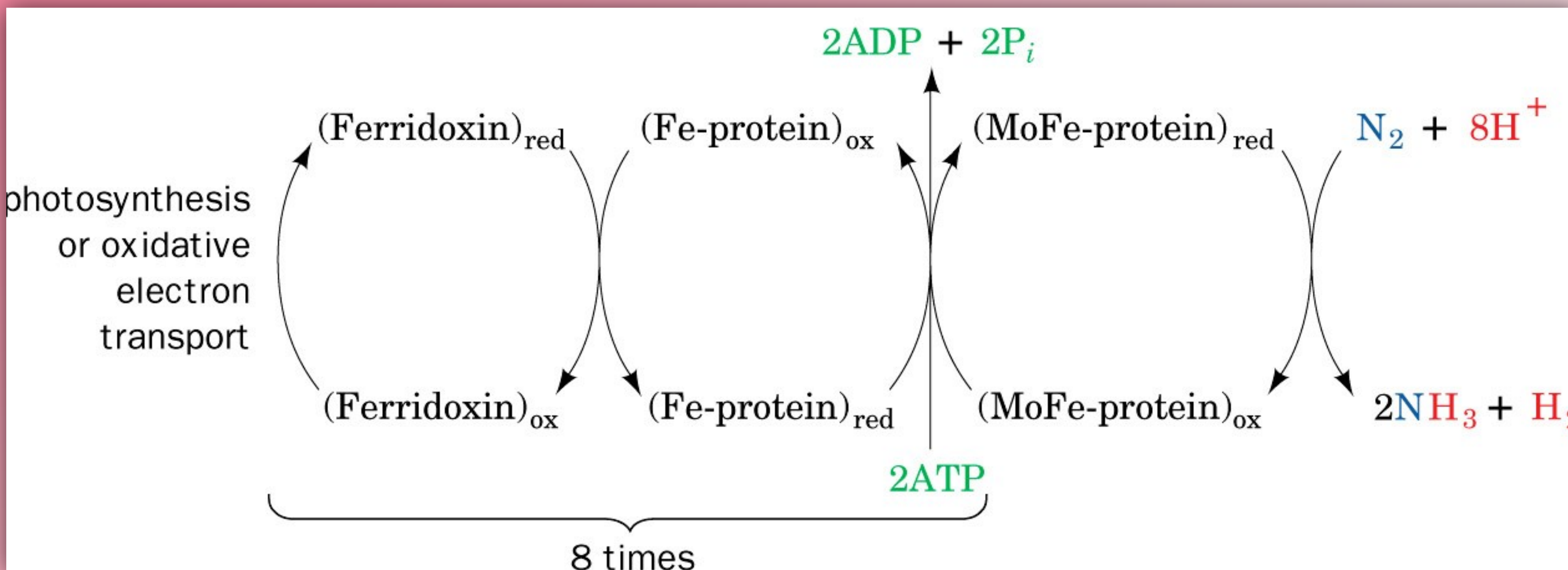
How does N_2 get converted to NH_3 in soil? (nitrogen fixation)

Photograph showing the root nodules of a legume (bird's foot trefoil).



A few strains of soil bacteria (diazatrophs) are able to fix N_2. One of these, *Rhizobium*, lives in symbiotic relationship with the root nodule cells of legumes.

The enzyme, nitrogenase, catalyzes the reduction of N_2 to ammonia (NH_3) in diazatrophs.

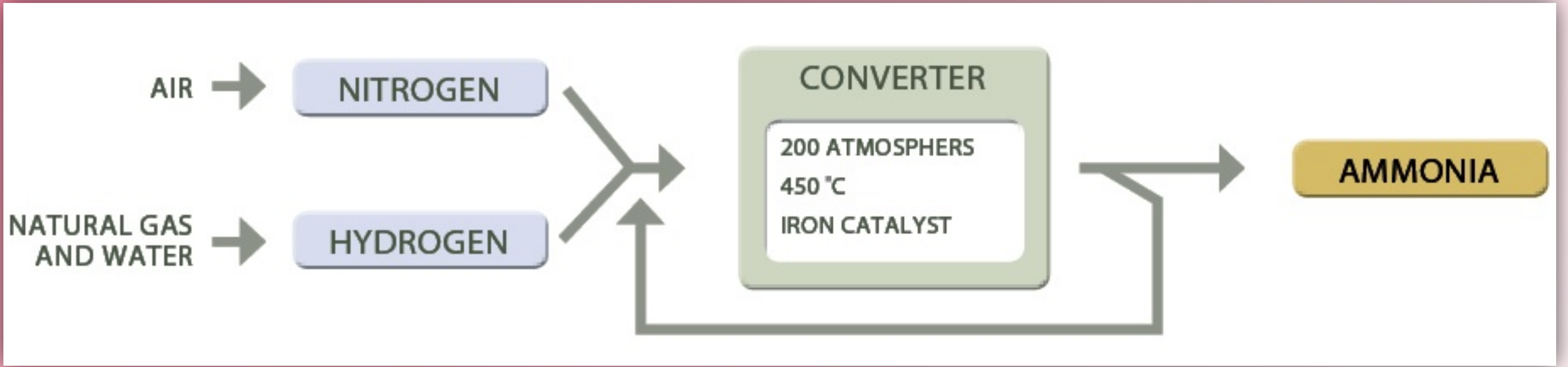


The flow of electrons in the nitrogenase-catalyzed reduction of N_2.

Most plants are non-legumes and therefore cannot maintain a symbiotic relationship with diazotrophs.

These plants must get their nitrogen from excess NH_3 (ammonia) deposited in the soil from N_2-fixing plants.

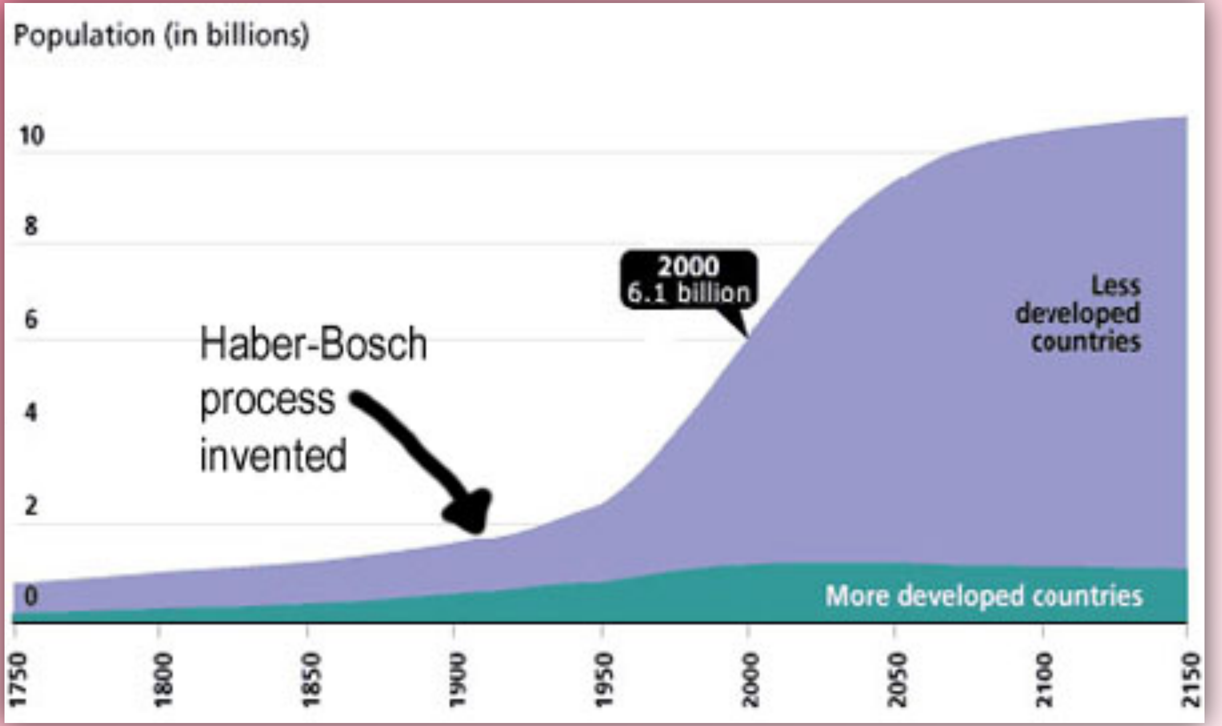
Fertilizers introduce absorbable nitrogen into the soil artificially (chemically).



The Haber-Bosch process (1920s): Chemical synthesis of ammonia from H_2 and N_2

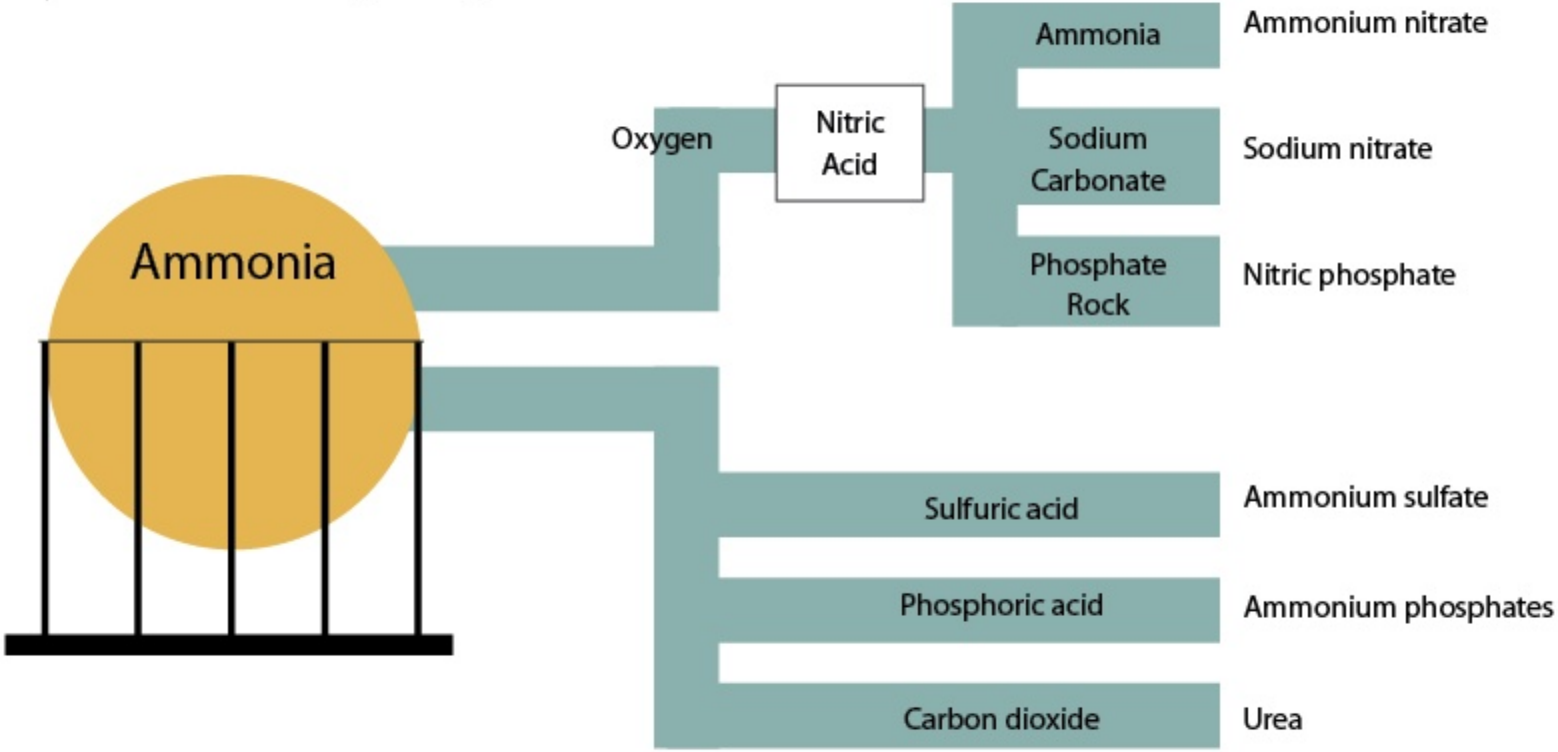
About 50% of the nitrogen atoms in your body were recently in a fertilizer factory.

Impact of Haber-Bosch on human population

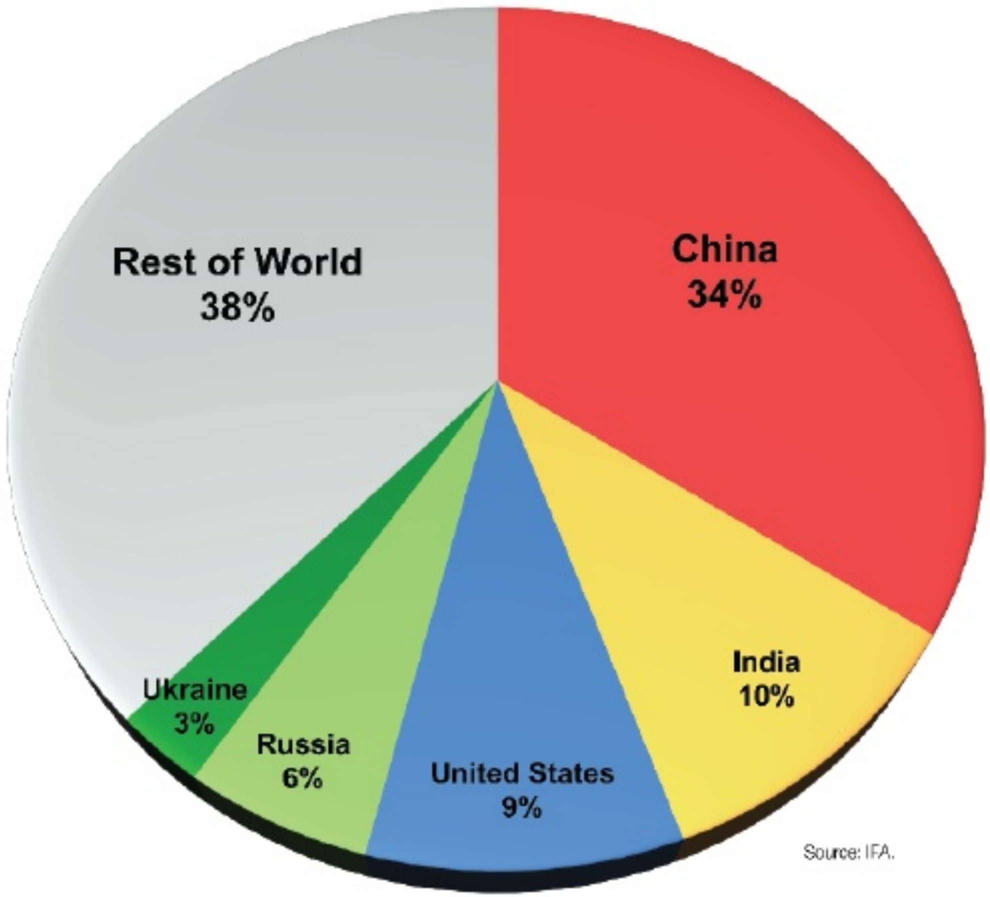


The Importance of Ammonia

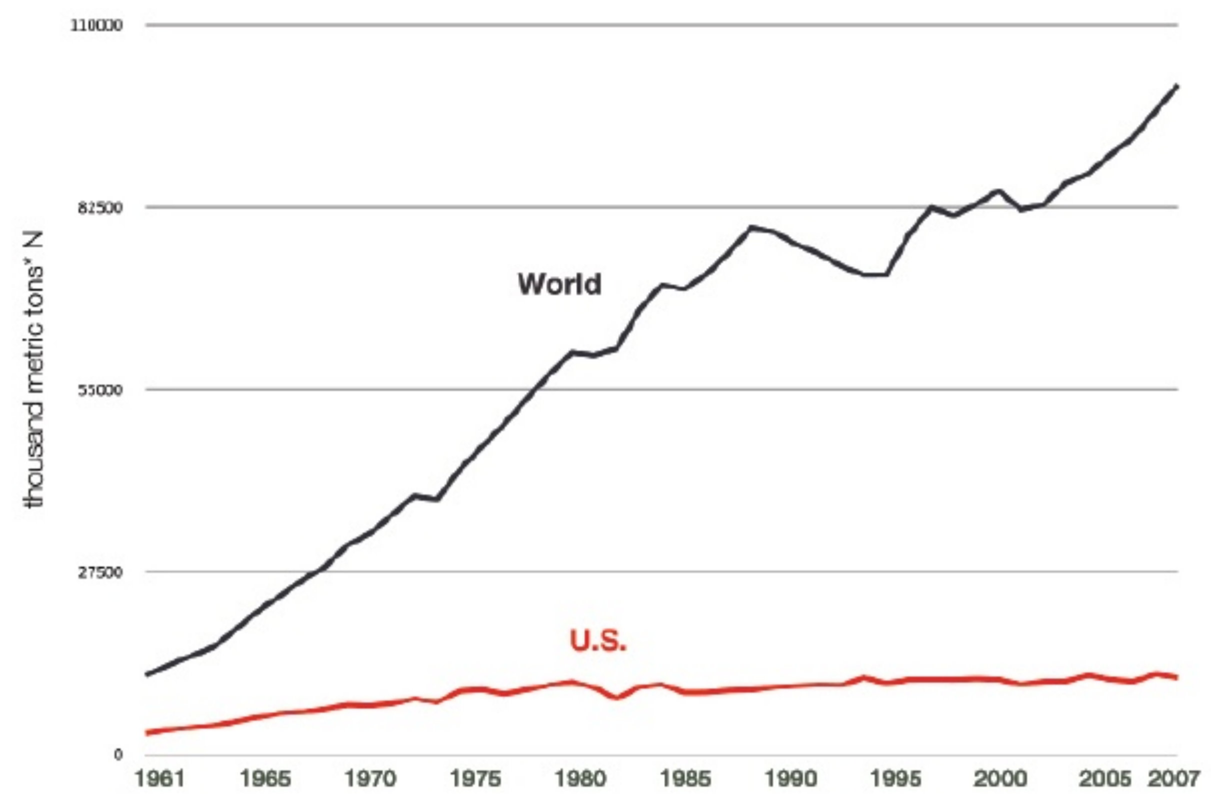
This process flow diagram shows how ammonia, a valuable fertilizer in its own right, is also an essential component of many of the other economically important fertilizer products farmers rely on. Ammonia price and availability are critically important to agriculture, and to anyone interested in abundant, affordable, high-quality food and fiber for a growing world.



Top World Nitrogen Fertilizer Producers - FY2007/08



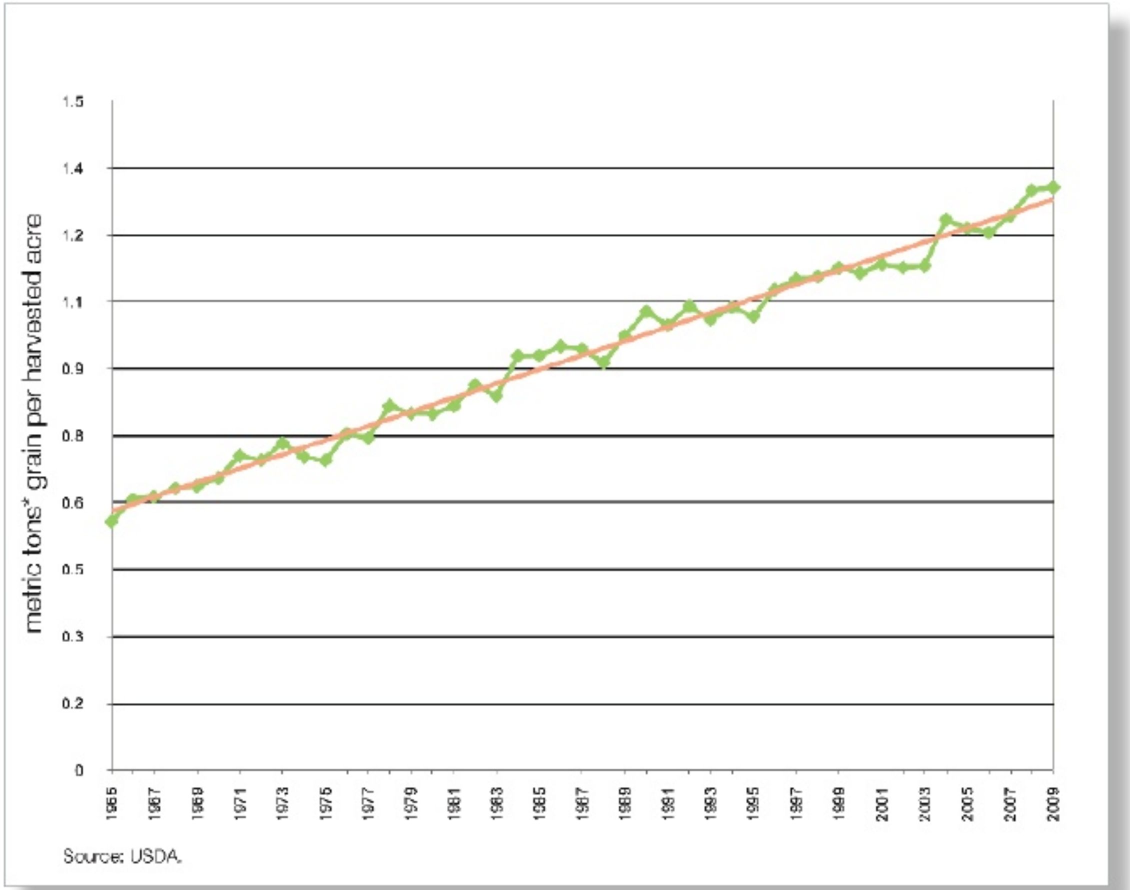
Total Nitrogen Consumption



*A metric ton is equal to 1,000 kilograms or 2,205 pounds

Source: IFA, TFI

World Grain Production per Acre



One of the most important roles fertilizer plays in world agriculture is in grain production. Grain includes corn, rice, wheat, sorghum, oats, millet and other cereal crops. Increasing grain production is what makes feeding a growing population possible, and in the second half of the 20th Century advances in varieties, fertilizer, and crop protection led to dramatic gains in production.

The graph illustrates the Green Revolution in action: Grain production increased from an average of about .6 ton per harvested acre in 1965 to more than 1.3 tons per harvested acre in 2009.

* A metric ton is equal to 1,000 kilograms or 2,205 pounds.

Agriculture

DEFINING AGRICULTURAL SUSTAINABILITY

Improving sustainability is a process that moves farming systems along a trajectory toward meeting various socially determined sustainability goals as opposed to achieving any particular end state. Agricultural sustainability is defined by four generally agreed-upon goals:

- Satisfy human food, feed, and fiber needs, and contribute to biofuel needs.
- Enhance environmental quality and the resource base.
- Sustain the economic viability of agriculture.
- Enhance the quality of life for farmers, farm workers, and society as a whole.

NRC, *Toward Sustainable Agricultural Systems In the 21st Century*, 2010

Expected increases in population and eating habits in different regions of the globe: 1995 to 2050

Table 1 : FAO Food Demand Forecast [2050 / 1995 Comparison]

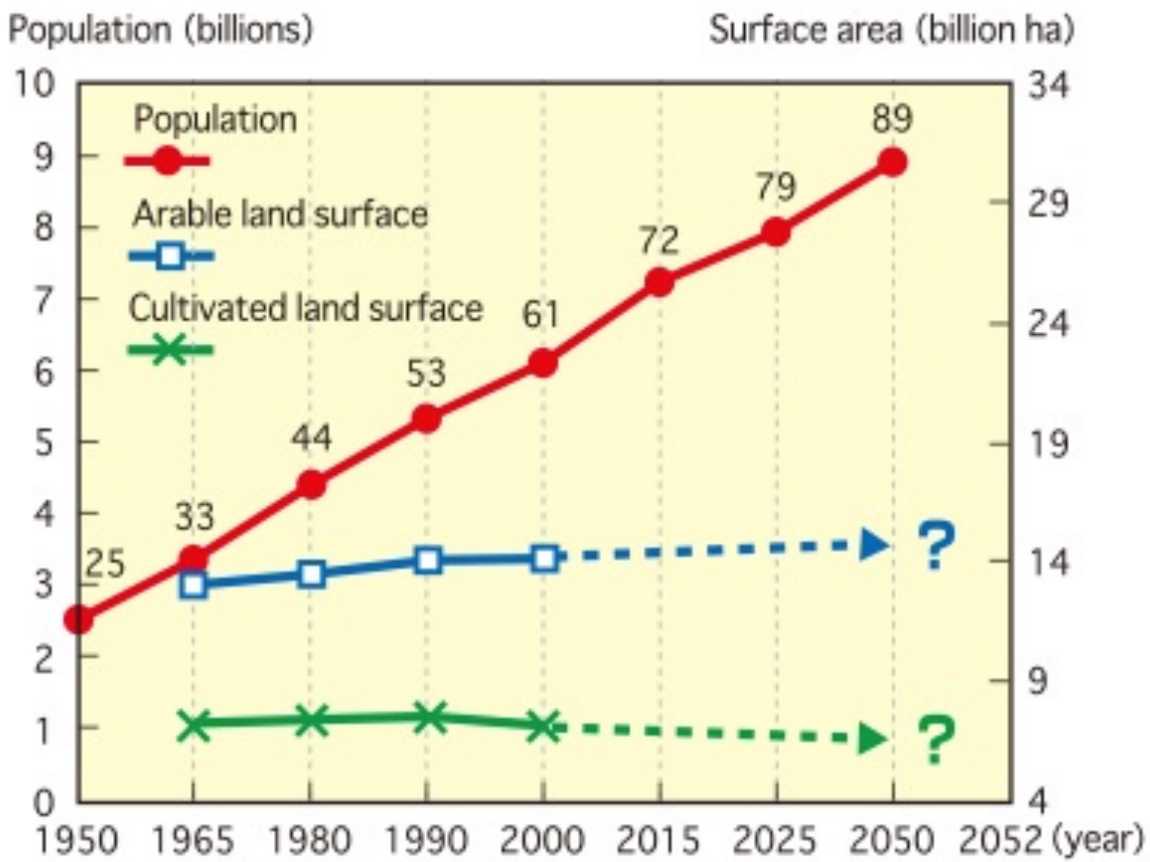
Source : *Food Requirements and Population Growth* [3]

(unit: times increase)

	Africa	Central and South America	Asia	North America	Developing Countries	Developed Countries	Globally
Population Increase	3.14	1.80	1.69	1.31	1.95	1.02	1.76
Changing Eating Habits	1.64	1.07	1.38	1.00	1.40	1.00	1.28
Total	5.14	1.92	2.34	1.31	2.74	1.02	2.25

Figure 1 : World Population and Arable and Cultivated Land Surface Area

Source: compiled from data in *World Prospects The 2002 Revision*, FAOSTAT [2]



Post World War II contributors to increased crop yields

- fertilizers
- pesticides
- herbicides
- irrigation
- plant breeding/genetic engineering

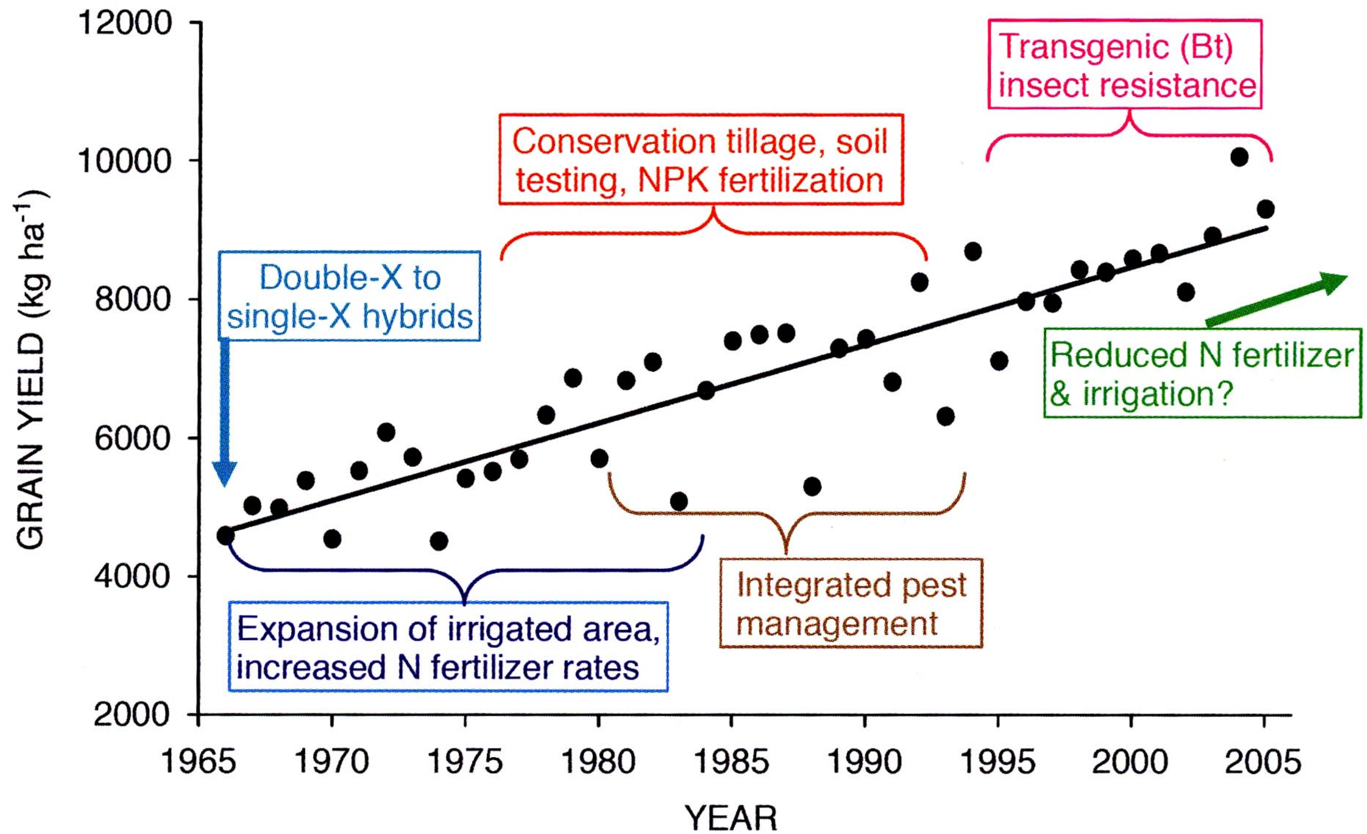


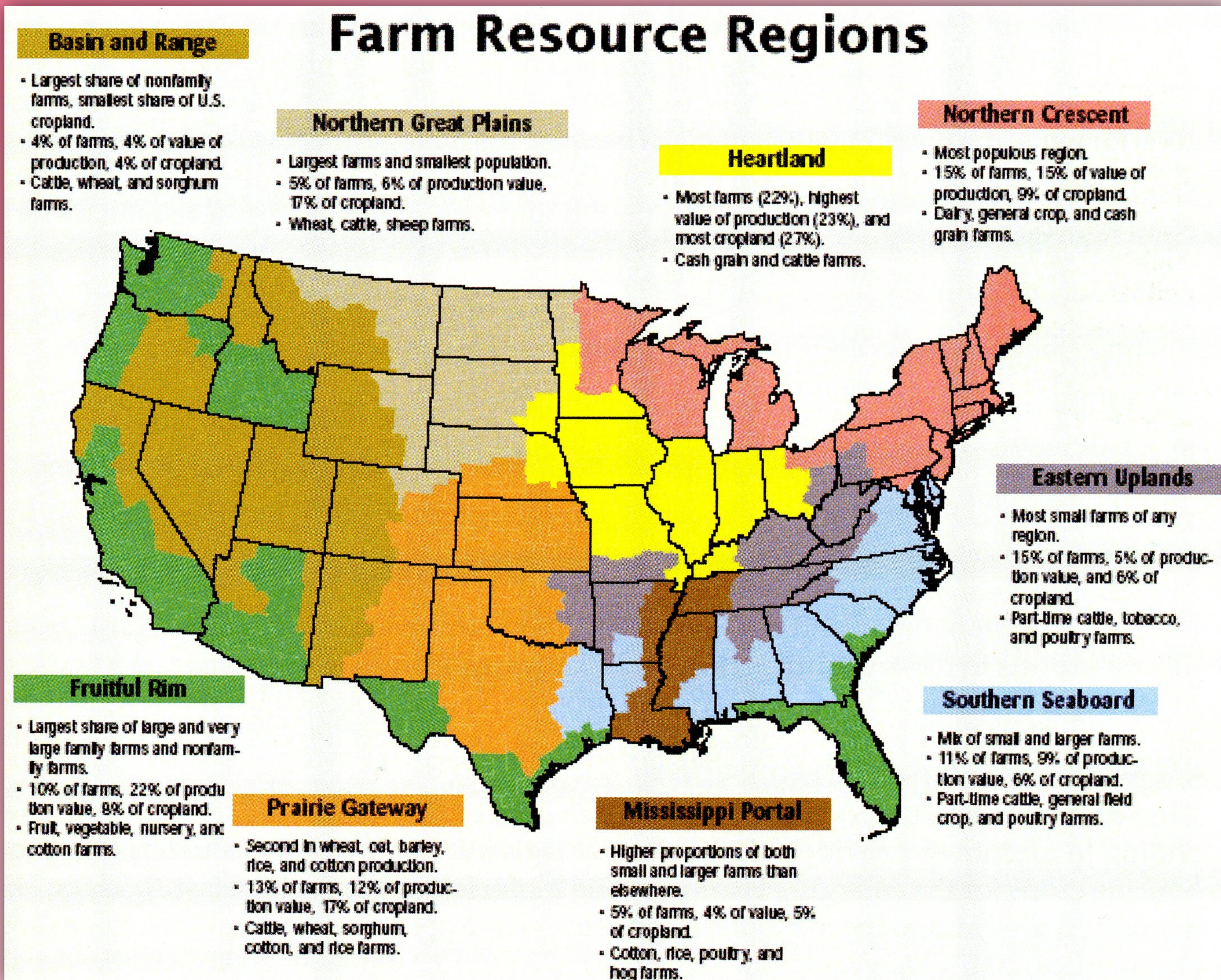
FIGURE 2-4 U.S. maize yield trends, 1966–2005, and the technological innovations that contributed to this yield advance.
SOURCE: Cassman and Liska (2007). Reprinted with permission from Wiley.

1 hectare = 10,000 square meters = 2.47 acres

The world uses over 4 billion pounds of pesticides each year. In 2007, according to the EPA's Toxic Release Inventory, industry disposed of, or released, 4.1 billion pounds of toxins and hazardous substances into the environment.

Hawken, *The Ecology of Commerce*, 2010

Farming resources in the United States



Distribution of agricultural commodities in the US

TABLE 2-2 Relative Importance of Different Commodities in U.S. Agriculture, 2002

Commodity Type	Percentage of U.S. Total: Farms Raising Commodity	Farm Sales from Commodity	U.S. Harvested Cropland
Livestock			
Beef cows	37.4	22.5	na
Horses	25.5	0.7	na
Sheep and goats	7.7	0.3	na
Poultry	4.6	11.9	na
Milk cows	4.3	10.1	na
Hogs and pigs	3.7	6.2	na
Crops			
Forages (all)	41.6	3.0	21.2
Grains and Oilseeds (any)	22.8	19.9	66.7
Corn grain	16.4		22.5
Soybean	14.9		23.9
Wheat	8.0		15.0
Corn silage	4.9		2.2
Oats	3.0		0.7
Barley	1.2		1.3
Rice	0.4		1.1
Fruit, Nuts, and Berries	6.2	6.9	1.9
Vegetables and Potatoes	3.0	6.4	3.0
Nursery/Greenhouse	2.6	7.3	0.3
Tobacco	2.7	0.8	0.1
Cotton	1.2	2.0	4.1

NOTES: Percent of farms raising each commodity = Number of farms reporting inventories of each livestock species or number of farms reporting acreage of each crop/Total number of farms in the United States.
Percent of U.S. farm sales by commodity = Sales of each commodity/Total U.S. farm sales.
Percent of U.S. harvested cropland = Percent of harvested acres in each crop/Percent of all U.S. harvested cropland.

The most commonly raised commodities in US agriculture are beef cattle, horses and forages (plant material eaten by grazing livestock).

The most economically important farm commodities are grains, poultry, dairy products and specialty crops; these are typically raised on a small fraction of US farms. **These commodities involve production systems that use most of the energy, fertilizers, agrichemicals and hired labor in the US.**

From a landscape perspective, most US cropland is planted to corn, soybean, forage crops and wheat.

There is growing concern that prime farmland near urban areas is being lost to non-agricultural uses through development, and that the reversal of this development is politically difficult and expensive.

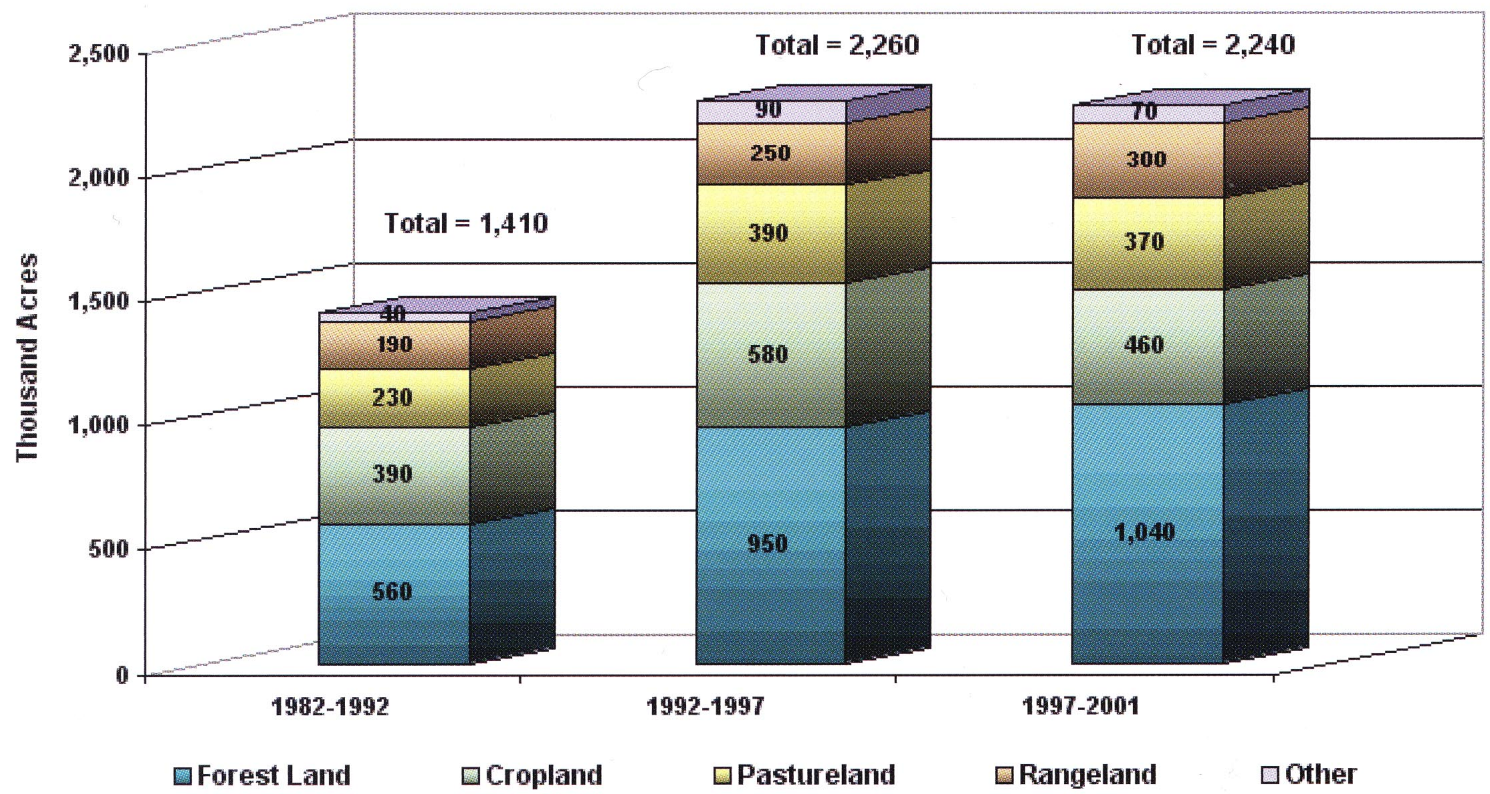


FIGURE 2-8 Conversion of agricultural and other lands to developed uses in the United States between 1982 and 2001.
SOURCE: USDA-NRCS (2003).

TABLE 2-4 Changing Size Structure of U.S. Farms, 1997–2007

	Percent of U.S. Farms				Percent of U.S. Farm Sales			
Farm Sales Class	1997	2002	2007	Gain-Loss	1997	2002	2007	Gain-Loss
< $10,000	55.3	59.3	59.8	+4.5	1.7	1.4	0.9	–0.8
$10,000–$99,999	28.7	26.0	24.0	–4.8	11.3	9.8	6.2	–5.1
$100,000–$249,999	8.6	7.5	6.7	–1.9	15.1	12.7	8.1	–7.0
$250,000–$499,999	4.1	3.8	4.2	+0.1	15.8	14.2	11.2	–4.6
$500,000+	3.2	3.3	5.3	+2.1	56.1	61.9	73.5	+17.4

SOURCE: U.S. Census of Agriculture, 2007 (USDA-NASS, 2009).

Mid-sized farms sales categories ($10,000-$249,000) are declining in importance, while small farms have increased in number and large farms have rapidly increased their share of total US farm production value.

The declining numbers of independent mid-sized farms impact rural community life, small business entrepreneurial innovation, and a wide range of "agarian" values (Wendell Berry).

Soil Erosion

The greater the percentage of ground cover (residue or mulch), the lower is the soil loss ratio (SLR) due to water and wind (no-till methods).

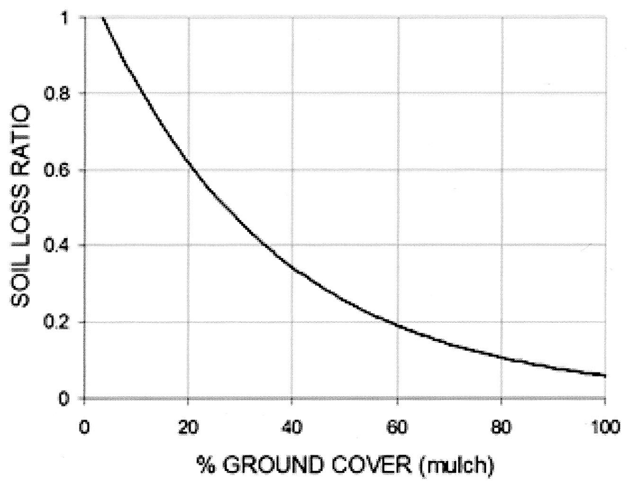


FIGURE 3-1 Soil loss ratio and percent ground cover.
SOURCE: McCarthy et al. (1993). Reprinted with permission from the University of Missouri Extension.

30% ground cover = erosion reduced by 1/2

The soil loss ratio (SLR) is an estimate of the ratio of soil loss under actual conditions to losses experienced under the reference condition of clean-tilled continuous-fallow conditions (the reference condition).

An example of a non-linear relationship in agriculture

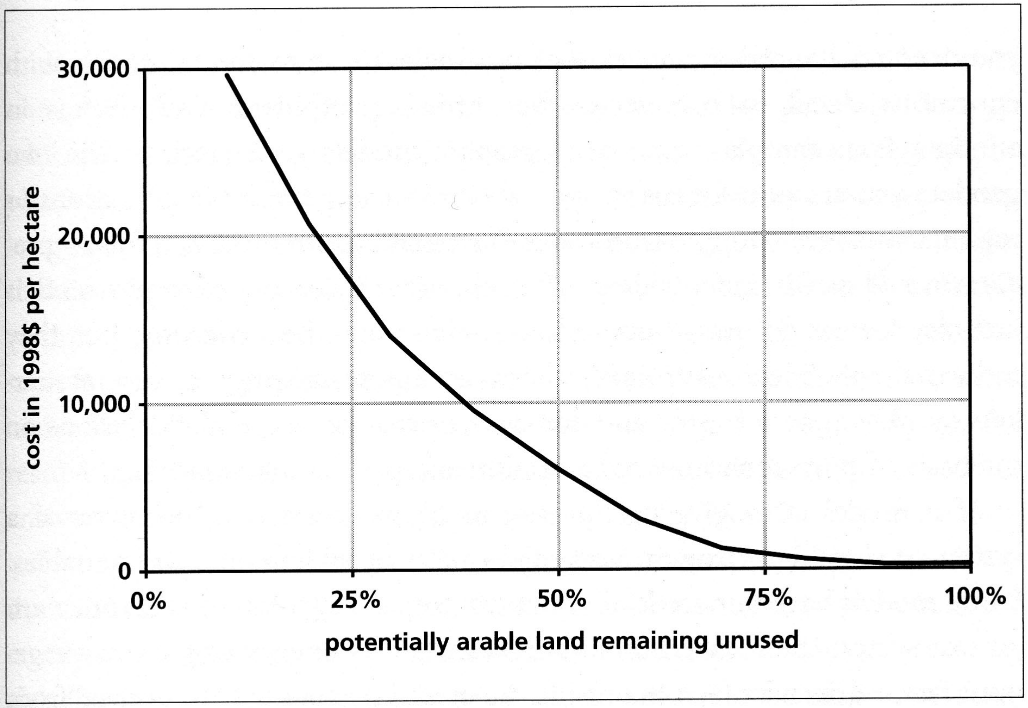


FIGURE 4-2 Development Costs of New Agricultural Land
World3 assumes that the cost of bringing new land into agricultural use increases as the amount of potentially arable land drops. (Source: D. L. Meadows et al.)

This behavior is similar to that giving rise to the energy cliff.

Examples of Practices That Contribute to Sustainability

Production Practices

- **Conservation (or reduced) tillage systems** have contributed to reducing water-caused soil erosion and surface runoff of nutrients, chemicals, and crop residues. Increased understanding of how conservation or reduced tillage can work with different crops and soil types to reduce energy use and labor has led to increased adoption of those practices.
- **Cover cropping** provides ground cover to protect soil and provide other services, including maintaining soil organic matter, providing nutrients to subsequent crops (green manures), trapping excess nutrients in the soil profile following harvest of the primary crop, and preventing leaching losses (catch crops). However, cover crops are not widely planted because of technical, economic, and environmental limitations.
- **Crop diversity, including rotations, intercropping, and using different genetic varieties** can contribute to improving soil quality and managing pests and diseases and is particularly important in the management of organic cropping systems. Although incorporation of diversity in cropping systems has increased in some regions, it fluctuates widely with commodity prices.
- **Traditional plant breeding and modern genetic engineering (GE) techniques** have resulted in crop varieties with increased yields, pest and disease resistance, enhanced water-use and nutrient-use efficiencies, and other important traits. GE has the potential to contribute a number of solutions for problems, but new varieties need to be tested rigorously and monitored carefully by objective third parties to ensure environmental, economic, and social acceptability and sustainability before they are released for planting.
- Many technologies for **efficient water use** such as metering, improved distribution of high-pressure water, and low-pressure, directed-use systems offer promise to address water scarcity. **Water reuse** is another strategy for addressing water scarcity, but the biological and chemical quality of the reclaimed water requires careful monitoring. **Best management practices (BMPs)**, including nutrient management planning, surface and subsurface drainage management, field buffer strips, riparian area management, and livestock manure management, have been developed to mitigate the runoff of agricultural nutrients and chemicals into the nation's surface and ground waters. Effectiveness of BMPs at the watershed scale depends, in part, on the coordinated actions of all farms in a watershed.
- **Soil and plant tissue tests, nutrient management plans, and precision agriculture technologies** help farmers to increase their farms' productivity, input-use efficiency, and economic returns by reducing unnecessary use of agricultural fertilizers, pesticides, or water. Experimental and field studies suggest that impacts and economic benefits of those practices and tools can be variable across time and space.

Effect of agriculture on climate

The two major GHGs emitted from US agriculture are nitrous oxide (N_2O) and methane (CH_4). The N_2O comes from soil management activities such as fertilizer use, manure application, and growing N_2-fixing crops. The CH_4 comes from enteric fermentation of ruminant animals. The agricultural sector is the largest contributor to N_2O and CH_4 emissions in the US; both of these gases have significantly higher global warming potential than CO_2.

Impact of agriculture on GHG emissions: Methane

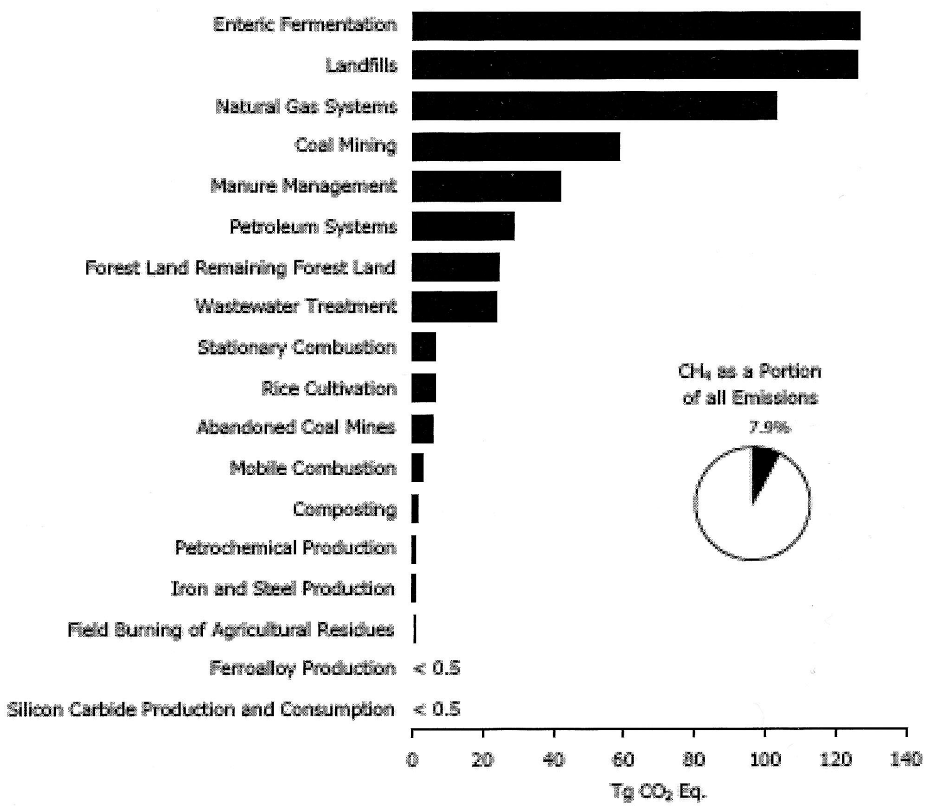


FIGURE 2-10 Methane emission from different sources in the United States.
SOURCE: EPA (2008).

One teragram (Tg) = 1 million metric tons

In 2006, agriculture was responsible for 6.4% of the total GHG emissions in the US.

Impact of agriculture on GHG emissions: Nitrous oxide

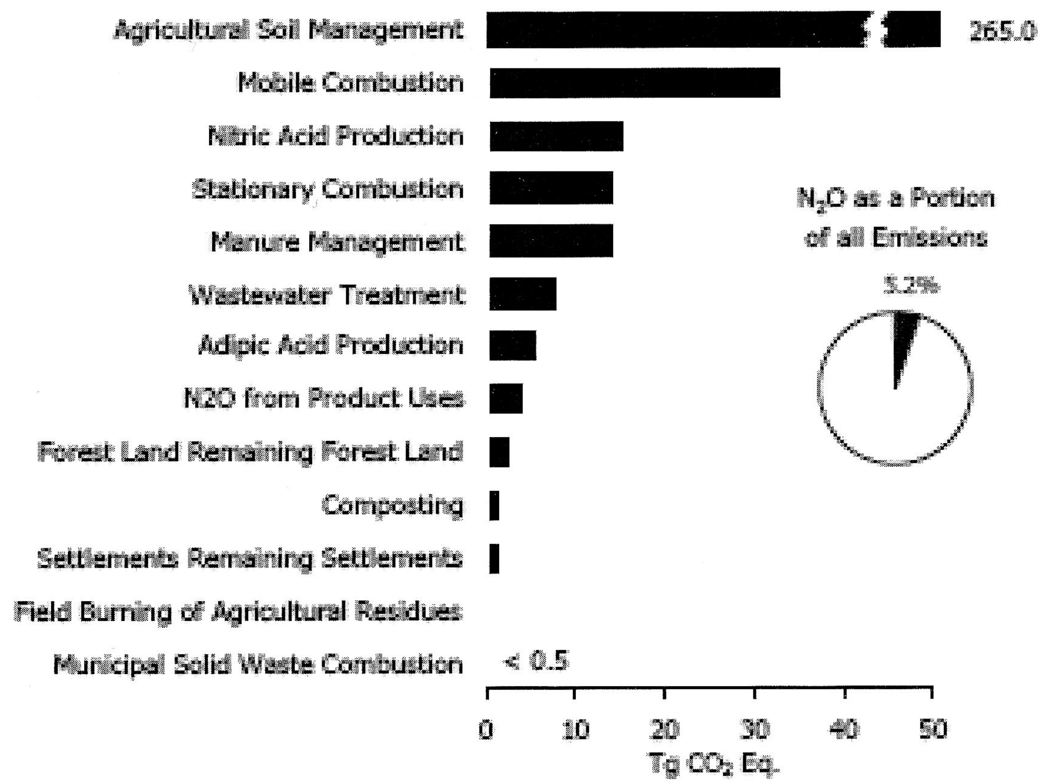


FIGURE 2-11 Nitrous oxide emission from different sources in the United States. SOURCE: EPA (2008).

Agriculture and groundwater overdrafting

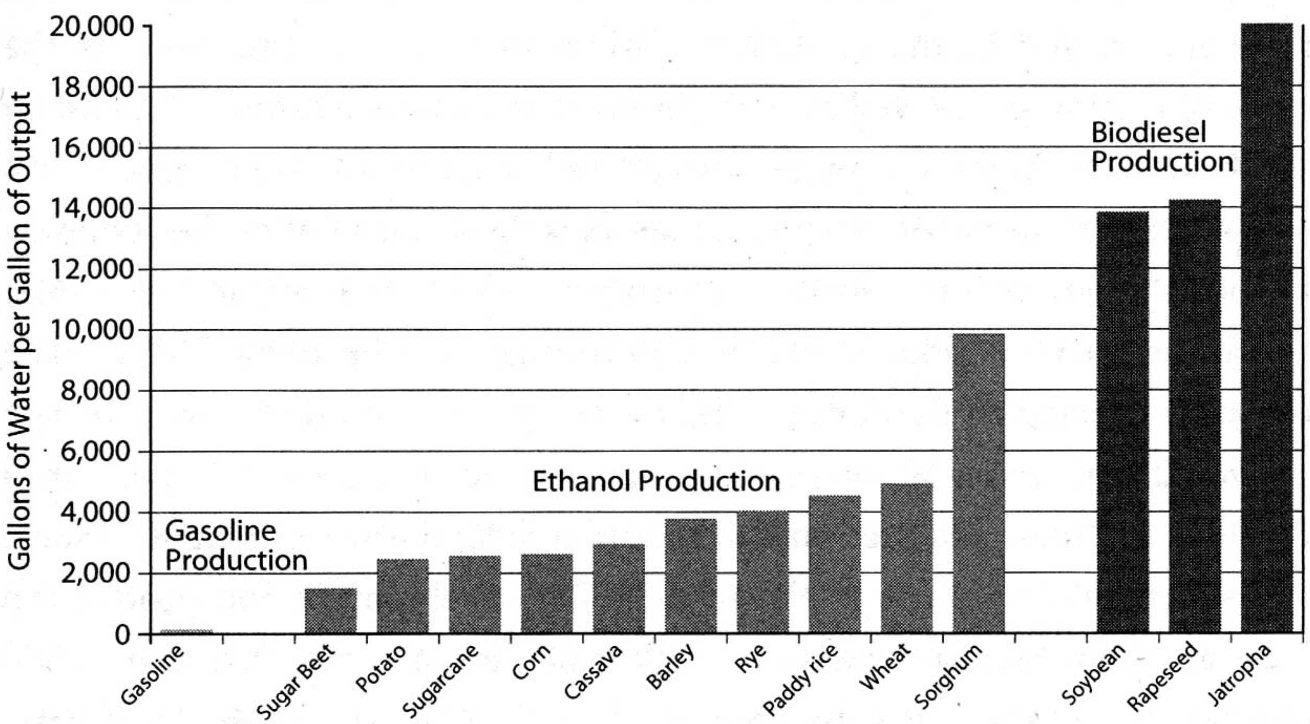
Overdrafting of the Ogallala Aquifer

The success of large-scale farming in areas lacking adequate precipitation and reliable perennial surface water depends heavily on pumping ground water for irrigation. In the Midwestern United States, ground water overdrafting of the Ogallala or High Plains aquifer presents a significant long-range problem. This aquifer is a large underground reservoir that encompasses portions of eight states ranging from South Dakota to Texas. About 27 percent of the total irrigated land in the United States overlies this aquifer system, which yields about 30 percent of the nation's ground water used for irrigation. The water is used to produce corn, wheat, cotton, alfalfa, and soybean; some of those crops are used to support about 40 percent of the U.S. supply of feedlot beef (USDA-ERS, 2005b). In addition, the aquifer system provides drinking water to 82 percent of the people who live within its boundary (Dennehy, 2000).

Water-level declines started to occur in the Ogallala aquifer soon after the beginning of extensive ground water irrigation development following the end of World War II. By 1997, 13.7 million acres were being irrigated by ground water from the aquifer, accounting for some 20 percent of all U.S. irrigation. Because withdrawals exceed natural recharge, the water table has been declining (Colaizzi et al., 2009). By 1980, water levels in the Ogallala aquifer in parts of southwestern Kansas, New Mexico, Oklahoma, and Texas had declined more than 100 feet (Luckey et al., 1981). Some croplands in Texas have suspended the use of irrigation with ground water because of its expense relative to the value of the crops grown. In effect, the Ogallala aquifer is a nonrenewable resource, similar to a coal mine. The current pumping of groundwater for irrigation is permanently depleting (or mining) ground water quantities available for future uses (Kneese, 1986).

Interactions: Influence of biofuel production on water consumption

FIGURE 18.2. Full-cycle water requirements for biofuel production.



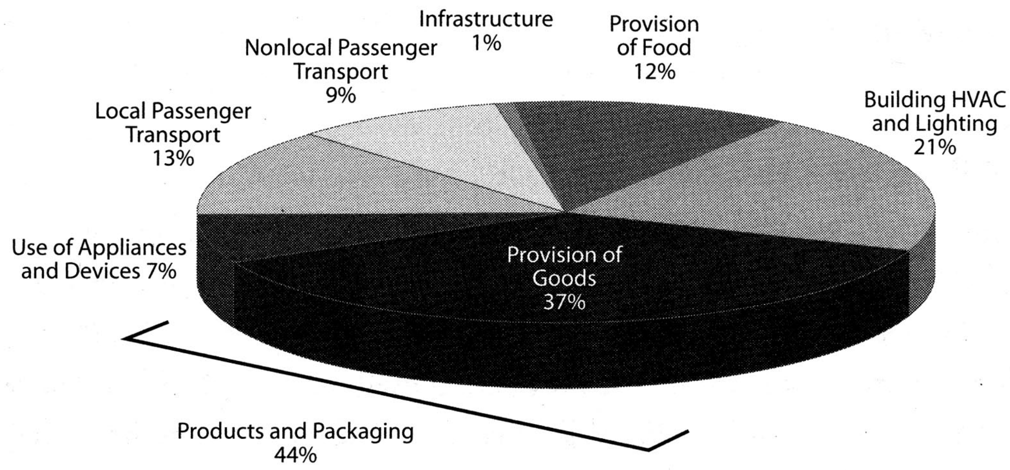
Source: Winnie Gerbens-Leenes et al., "The Water Footprint of Bioenergy," *Proceedings of the National Academy of Sciences* 106, no. 25 (June 23, 2009), 10219–10223.

Fridley, in *The Post-Carbon Reader*, 2010

Waste

A consumption-based analysis (full life-cycle): Provision, use and disposal of products and packaging accounts for ~44% of US GHG emissions.

FIGURE 28.2. Consumption-based view of sources of U.S. greenhouse gas emissions, 2007, including emissions from products made abroad and consumed in the United States.



Source: Joshuah Stolaroff, "Products, Packaging and U.S. Greenhouse Gas" Emissions (Athens, GA: Product Policy Institute, September 2009).

The Post-Carbon Reader, 2010

Every American consumes about 36 pounds of resources a week. ~2000 pounds of waste are discarded to support this consumption.

Hawken, *The Ecology of Commerce*, 2010

Hazardous wastes are the result of an industrial system that is linear, that is, one in which products are neither recycled nor returned.

1200 of an estimated 90,000 hazardous waste sites in the US have been designated as priority cleanup areas under the Superfund Law.

Hawken, *The Ecology of Commerce*, 2010

Human health consequences of hazardous waste

Because of the slow maturation of human beings, we have not had sufficient time to understand the multigenerational health consequences of exposure to hazardous materials. Certain man-made compounds, particularly in the chlorinated hydrocarbon family, are mistakenly recognized by the human body as hormone messengers, providing the wrong information to cells and bodily functions, information that is confusing to the body, possibly leading to serious damage.

Hawken, *The Ecology of Commerce*, 2010

The proliferation of man-made compounds being introduced into the environment is far greater than *the rate and capacity at which they can be researched and understood*.

Any time a system creates by-products that harm rather than support life, it is a form of waste, and by definition it is uneconomical. An enduring and true economy does not create waste that is useless.

Hawken, *The Ecology of Commerce*, 2010

A system diagram for food life-cycle: production to disposal

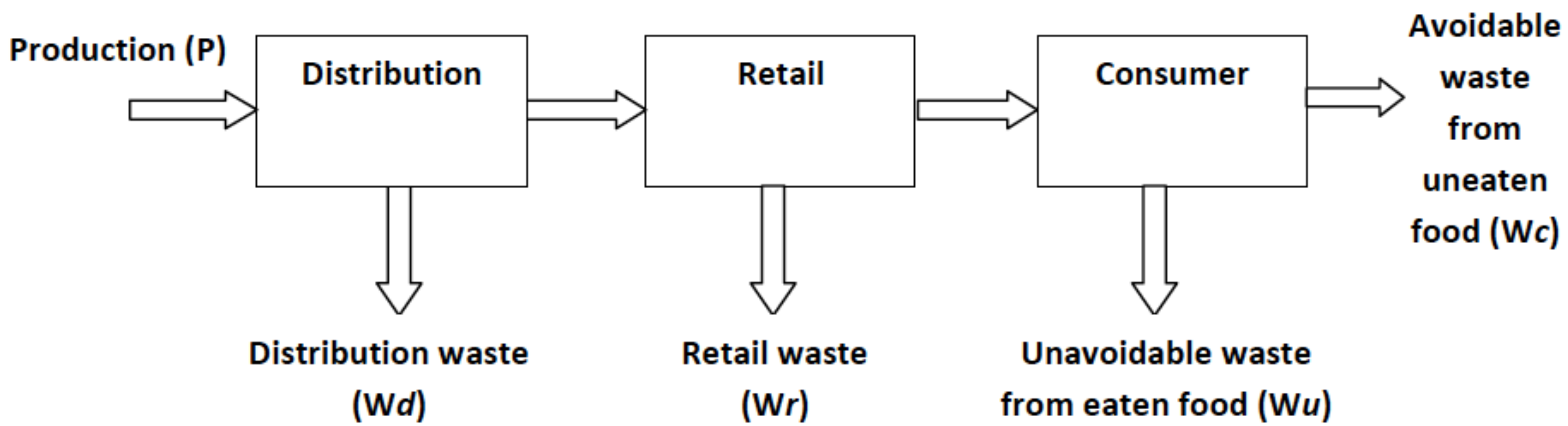


Figure 1 Life-cycle model of material flow from production to disposal

TABLE 2 US annual food production, consumption and avoidable waste in 2009 (MMT/year)

Category	Production P	Consumption C	Distribution Waste Wd	Retail Waste Wr	Consumer Waste Wc	Total Avoidable Waste Wa
Beef	8.09	5.26	0.00	0.35	0.72	1.07
Pork	6.48	3.78	0.00	0.28	1.16	1.44
Chicken	7.80	4.50	0.00	0.31	1.42	1.73
Other Meats	1.95	1.27	0.00	0.08	0.14	0.21
Fish & Shellfish	1.98	1.29	0.00	0.17	0.25	0.42
Cheese	4.90	3.93	0.00	0.33	0.64	0.97
Milk & Yogurt	26.47	18.63	0.00	3.18	4.66	7.84
Other Dairy	5.70	4.18	0.00	0.62	0.90	1.52
Butter, Fats & Oils	10.88	7.23	0.00	2.08	0.87	2.95
Eggs	4.48	2.93	0.07	0.40	0.40	0.86
Sweeteners	18.00	12.82	0.00	1.98	3.20	5.18
Nuts	1.28	1.08	0.00	0.08	0.12	0.20
Legumes	0.96	0.81	0.00	0.06	0.09	0.15
Grains	27.02	18.89	0.00	3.24	4.89	8.13
Vegetables	37.60	21.91	1.95	2.96	8.72	13.63
Fruits & Juices	29.48	17.59	0.90	2.65	5.56	9.11
Total	193.10	126.13	2.92	18.76	33.73	55.41

MMT/year = million metric tons per year

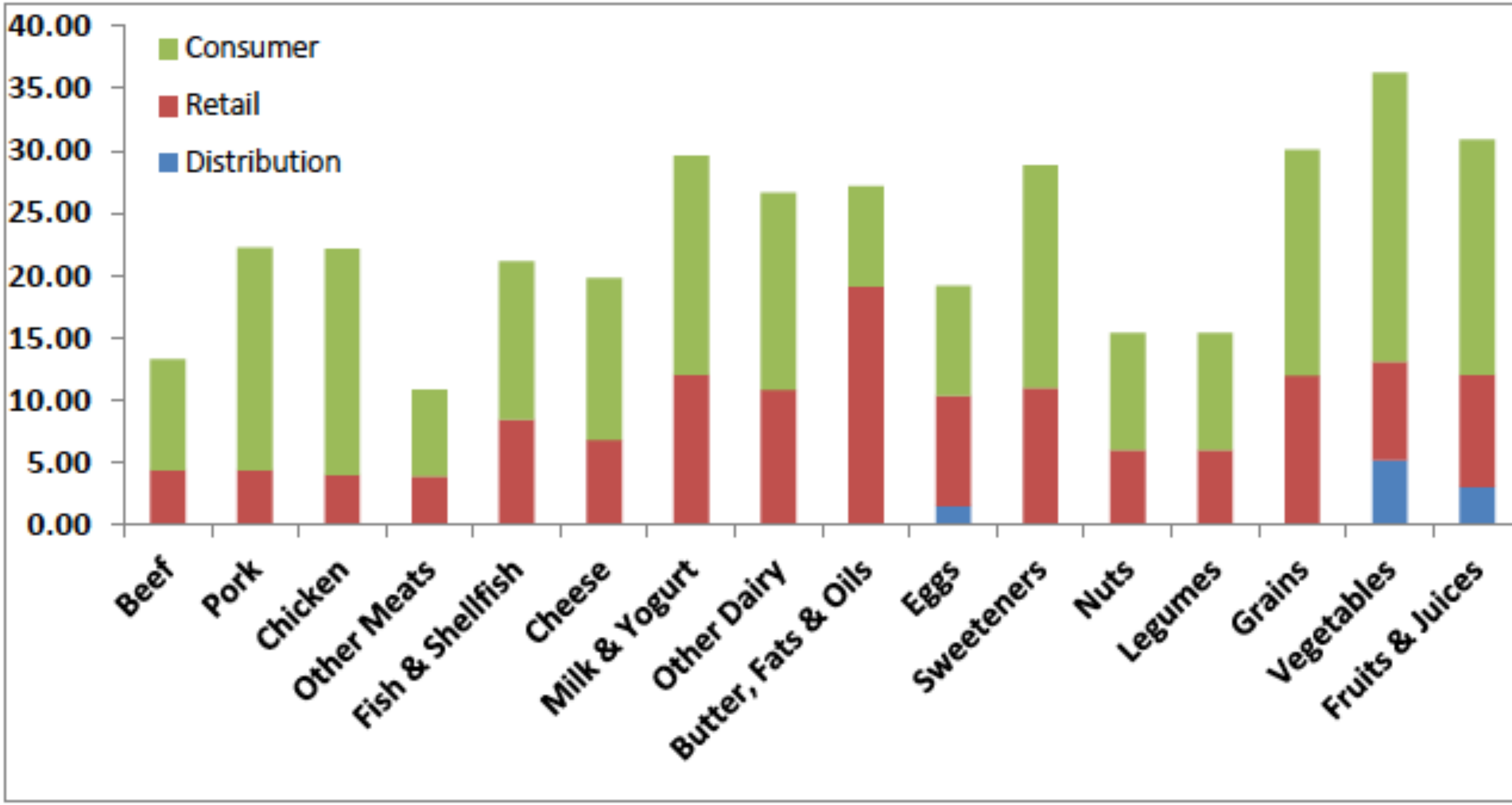


Figure 3 US annual avoidable food waste in 2009 as percentage of production

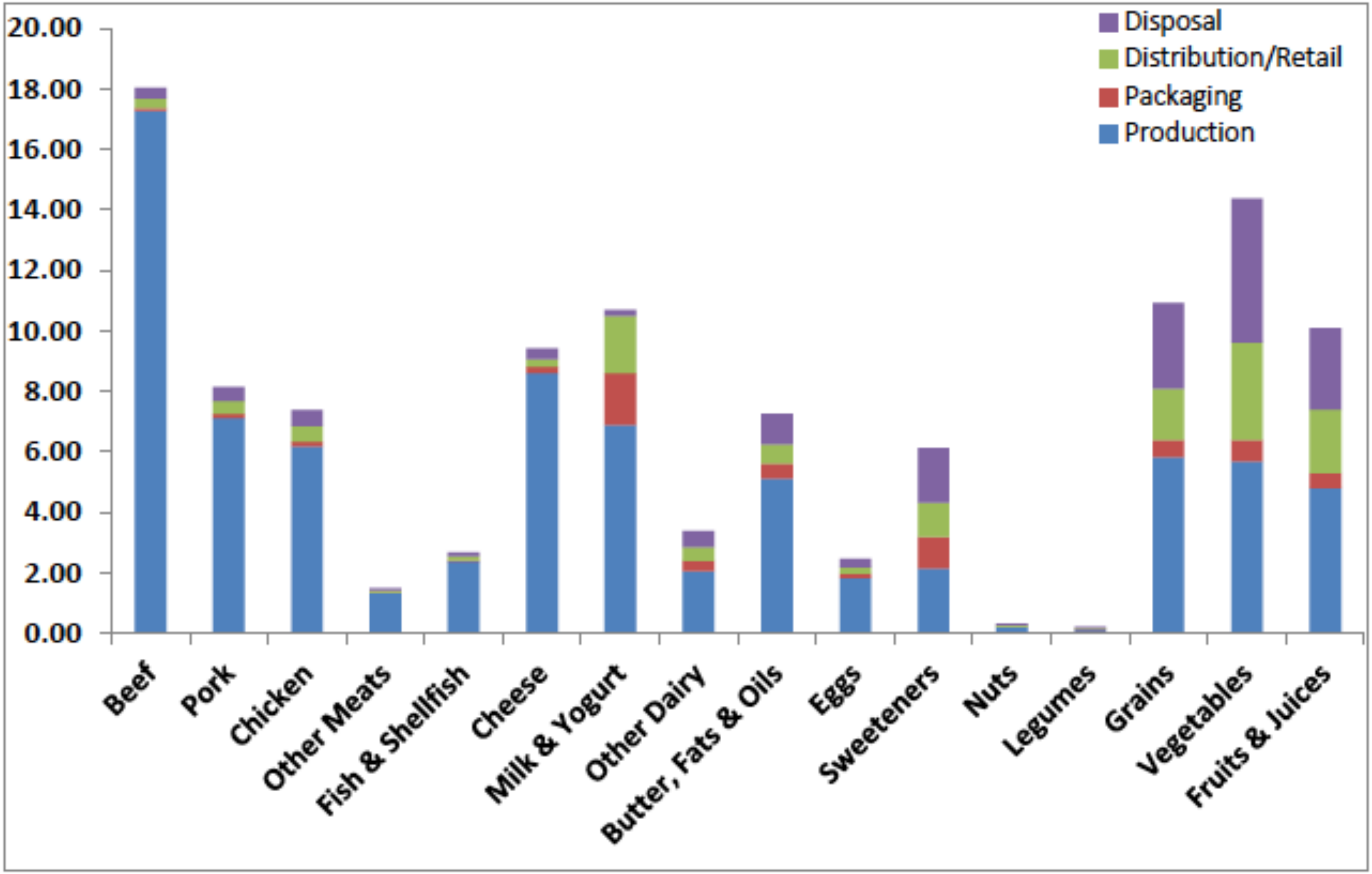


Figure 4 GHG emissions from avoidable US food waste in 2009 (MMT CO2e/year)

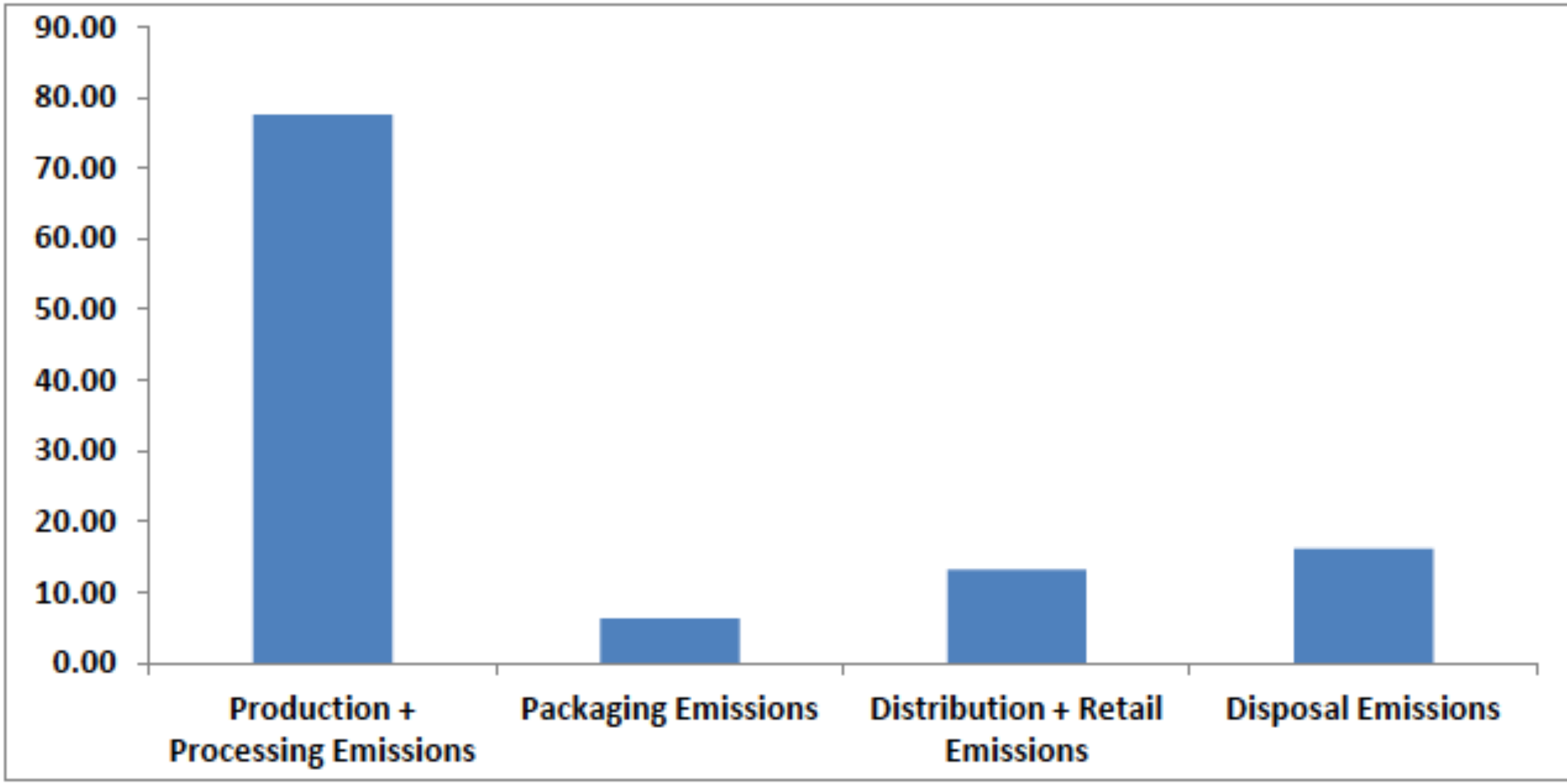


Figure 5 Total GHG emissions from avoidable US food waste in 2009 (MMT CO2e/year)

The total avoidable food waste at the distribution, retail and consumer levels amounts to over 55 MMT/year, representing nearly 29% of annual production by weight. Over 60% of this waste occurs at the consumer level. The production, processing, packaging, distribution, retail and disposal of this wasted food results in GHG emissions of at least 113 MMT CO_2e/year, which is equivalent to 2% of US national emissions. Beef is the single largest contributor to this, producing 16% of all wasted emissions, because of its high emissions intensity. All animal products together contribute 57% of the wasted emissions, even though they make up only 30% of the waste by weight. Over two-thirds of the emissions occur in the production and processing of food commodities.

External costs of technology: Electronic waste (e-Waste)

E-Waste in 2007 – Was it Trashed or Recycled

Products	Total disposed** (million of units)	Trashed (million of units)	Recycled (million of units)	Recycling Rate (by weight)
Televisions	26.9	20.6	6.3	18%
Computer Products*	205.5	157.3	48.2	18%
Cell Phones	140.3	126.3	14	10%

*Computer products include CPUs, monitors, notebooks, keyboards, mice, and "hard copy peripherals", which are printers, copiers, multi's and faxes.
**These totals don't include products that are no longer used, but stored.

Source: EPA [1]

Electronics TakeBack Coalition www.electronicstakeback.com

Modern landfills contain discarded products that were made from valuable materials that required effort and expense to extract and make – billions of dollars' worth of material assets. This waste is the ultimate product of an industrial system that is designed <u>on a linear, one-way cradle-to-grave model</u>.

McDonough & Braungart, *Cradle To Cradle*, 2002

To achieve universal design solutions, manufacturers design for a worst-case scenario – they design a product for the worst possible circumstance, so that it will always operate with the same efficacy.

Universal design approaches to typical product development tend to overwhelm and ignore natural and cultural diversity, resulting in less variety and greater homogeneity (and greater fragility).

McDonough & Braungart, *Cradle To Cradle*, 2002

Waste and pollution are not necessarily the results of corporations doing something morally wrong. They are the consequences of <u>outdated and unintelligent design</u>. Poor design……perpetuates **intergenerational tyranny** – tyranny over future generations through the effects of present actions.

McDonough & Braungart, *Cradle To Cradle*, 2002

The Response by Business

Eco-Efficiency: doing more with less; reduction is a central tenet of eco-efficiency.

The Four R's: Reduce, Reuse, Recycle and Regulate

Recycling is actually downcycling; recycling reduces the quality of the material over time; it can actually increase contamination of the biosphere.

Downcycling can be expensive for businesses because it forces materials into more lifetimes than they were originally designed for, a complicated and messy conversion and one that itself expends energy and resources.

McDonough & Braungart, *Cradle To Cradle*, 2002

The Alternative: Eco-Effectiveness

The key is not to make human industries and systems smaller, as propounded by Eco-Efficiency, but rather to design them to get bigger and better in a way that replenishes, restores, and nourishes the rest of the world.

McDonough & Braungart, *Cradle To Cradle*, 2002

The Earth's major nutrients – carbon, oxygen and nitrogen – are cycled and recycled. Waste equals food. This is a cyclical cradle-to-cradle biological system.

Over time, we have evolved from a cradle-to-cradle culture to a cradle-to-grave culture. We need to go back to a cradle-to-cradle culture to achieve sustainability.

McDonough & Braungart, *Cradle To Cradle*, 2002

To eliminate the concept of waste means to design things – products, packaging and systems – from the very beginning with the understanding that waste does not exist.

Products can be composed of either materials that biodegrade and become food for biological cycles, or of technical materials that stay in closed-loop technical cycles in which they continuously circulate as valuable nutrients for industry.

McDonough & Braungart, *Cradle To Cradle*, 2002

Economy as ecosystem