School of Civil Engineering
FACULTY OF ENGINEERING

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Resource recovery from wastewater to support sustainable economic growth

Miller Alonso Camargo-Valero
Bio-Resource Systems

https://www.youtube.com/watch?v=jw8W-MX19kQ

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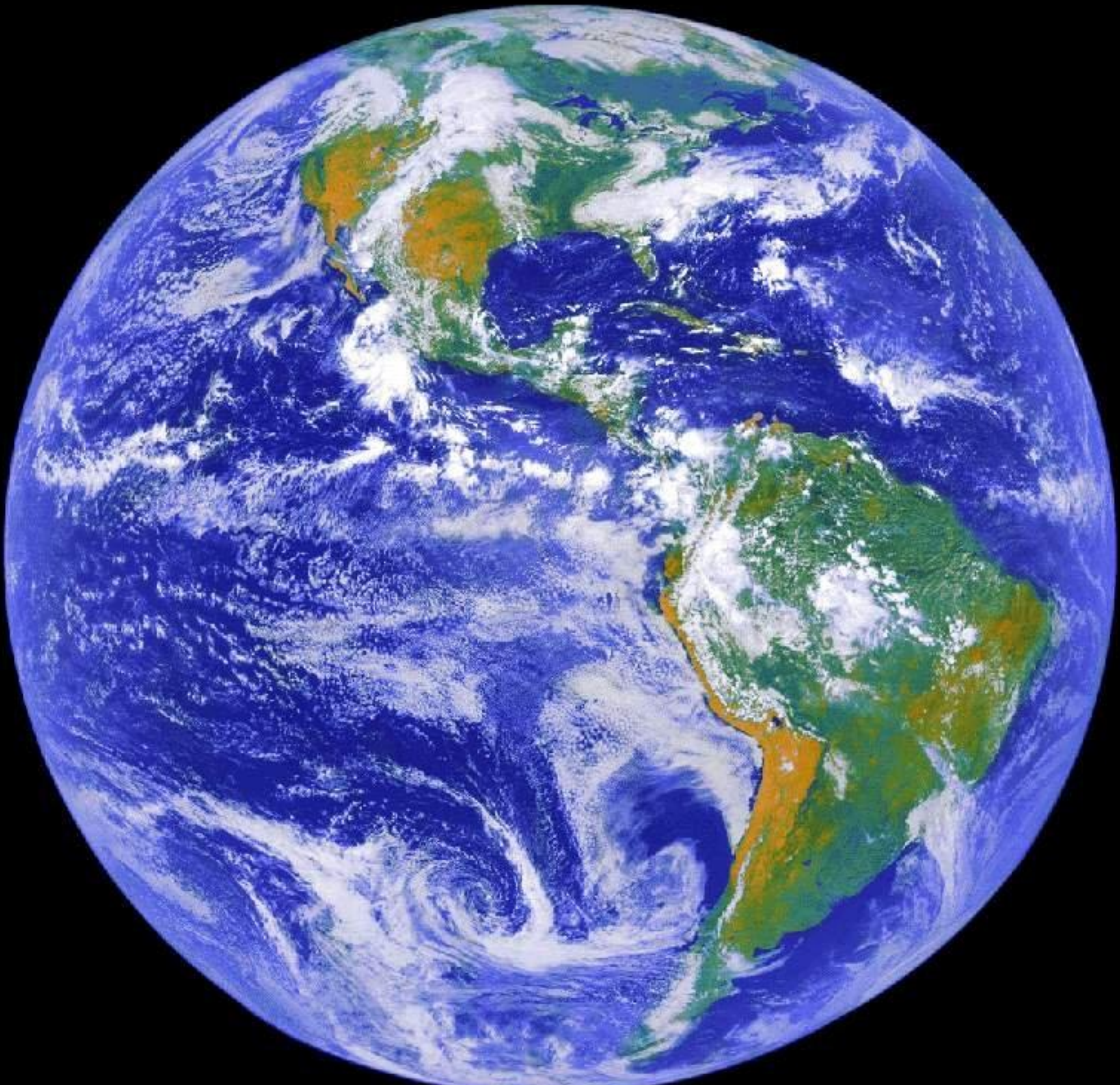
iPHEE

III Catedra Julio Garavito Armero
Universidad Nacional de Colombia
20 April 2016, Bogotá, Colombia


THE
FIFTH ELEMENT


earth

Product description:

- Only one of its kind
- 4.53 billion years old
- 7 billion people
- 10-14 million species
- 510,072,000 km^2 of surface area
- 2/3 of its surface covered by water
- Earth's mass made of 32.1% Fe, 30.1% O_2, 15.1% Si,13.9% Mg, 2.9% S, 1.8% Ni, 1.5% Ca,1.4% Al, 1.2% others. Earth's atmosphere made of 78% N_2 and 21% O_2

MADE IN OUR SOLAR SYSTEM

Earth, Fire, Water and Air

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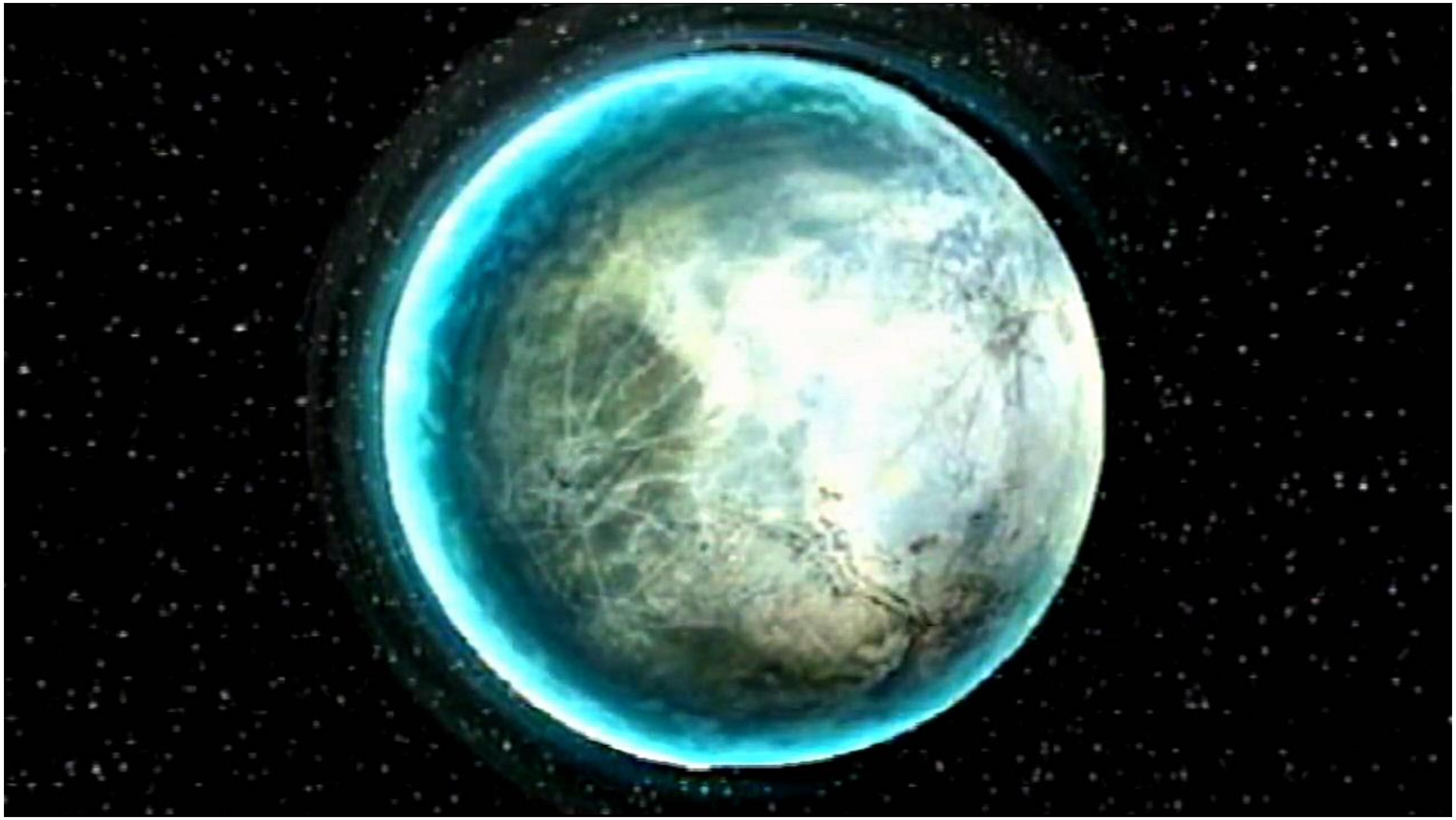
Aether



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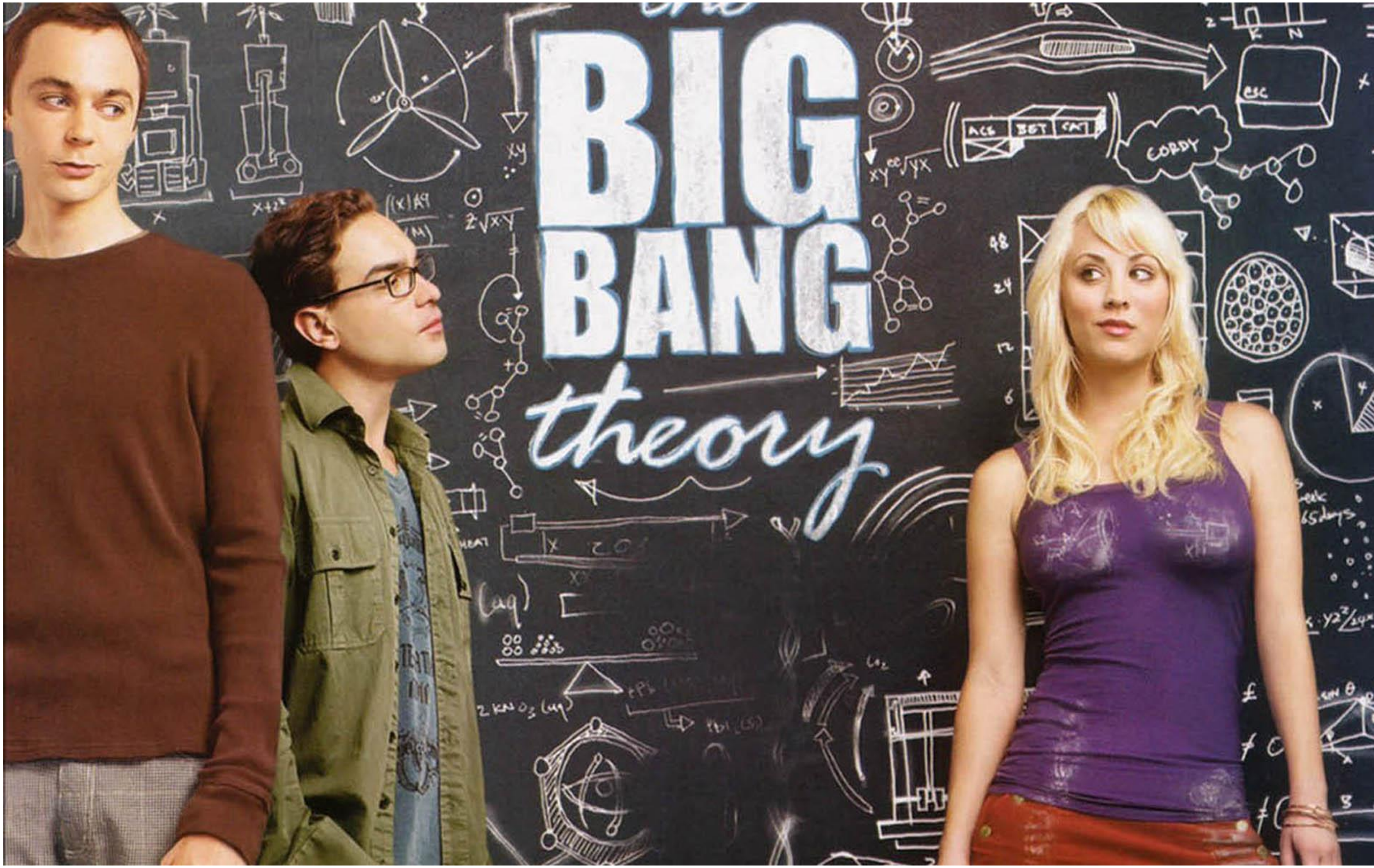

Not this one!!!!

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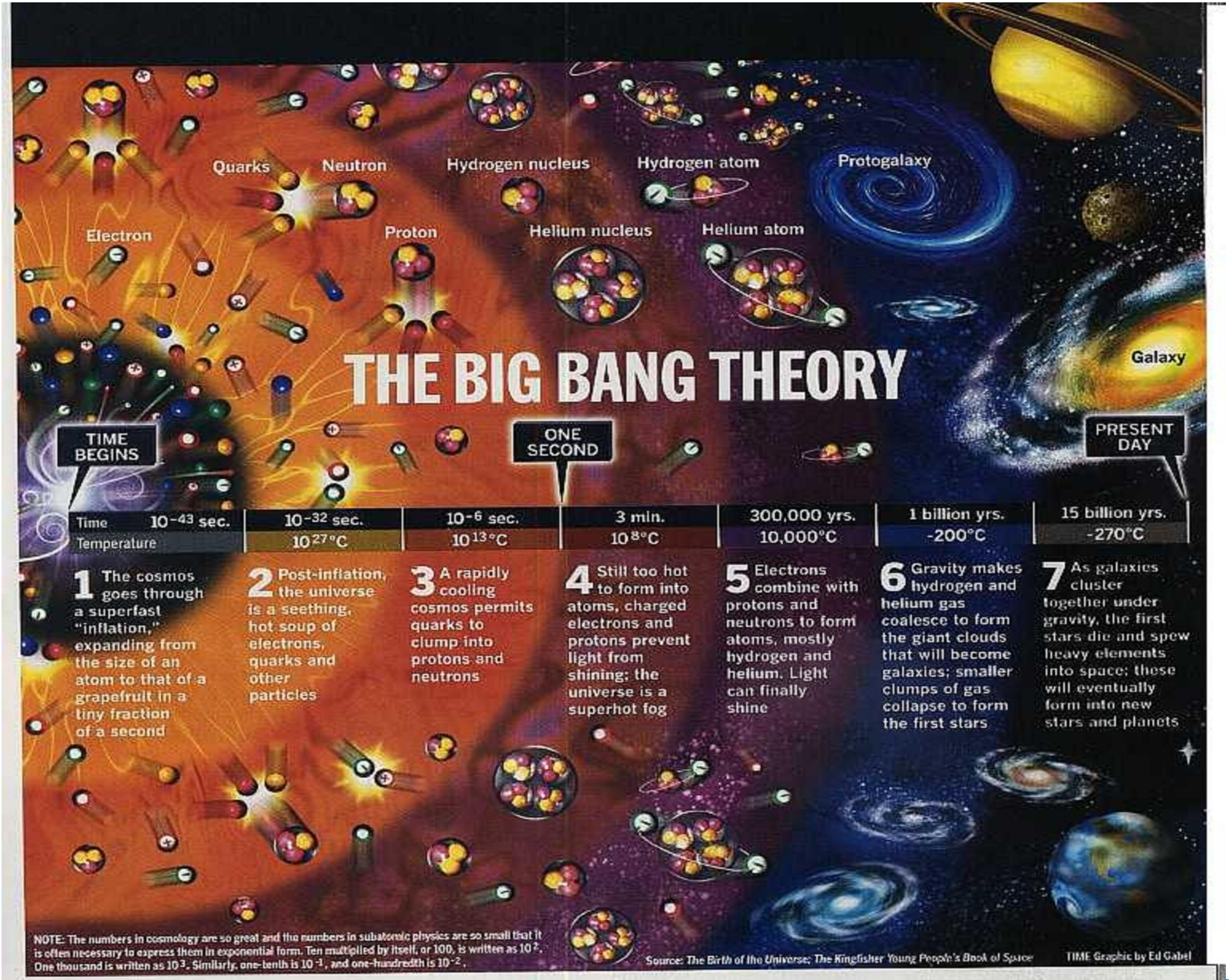

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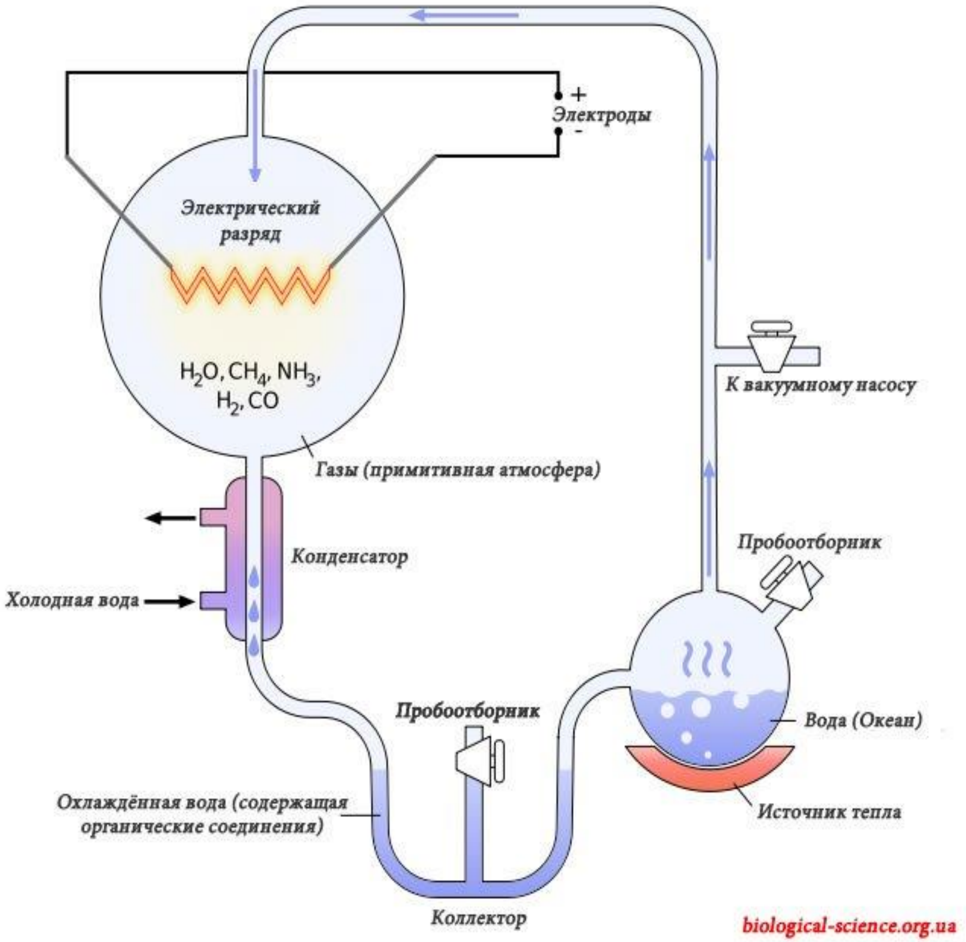
Life on Earth

In the 1950s, Stanley Miller and Harold Urey, scientists at the University of Chicago, exposed a sealed flask full of the inorganic chemicals that may have been present in the atmosphere of the early Earth to an electrical current.

Amino acids, the organic chemical precursors to proteins, were generated and detected in that experimet.



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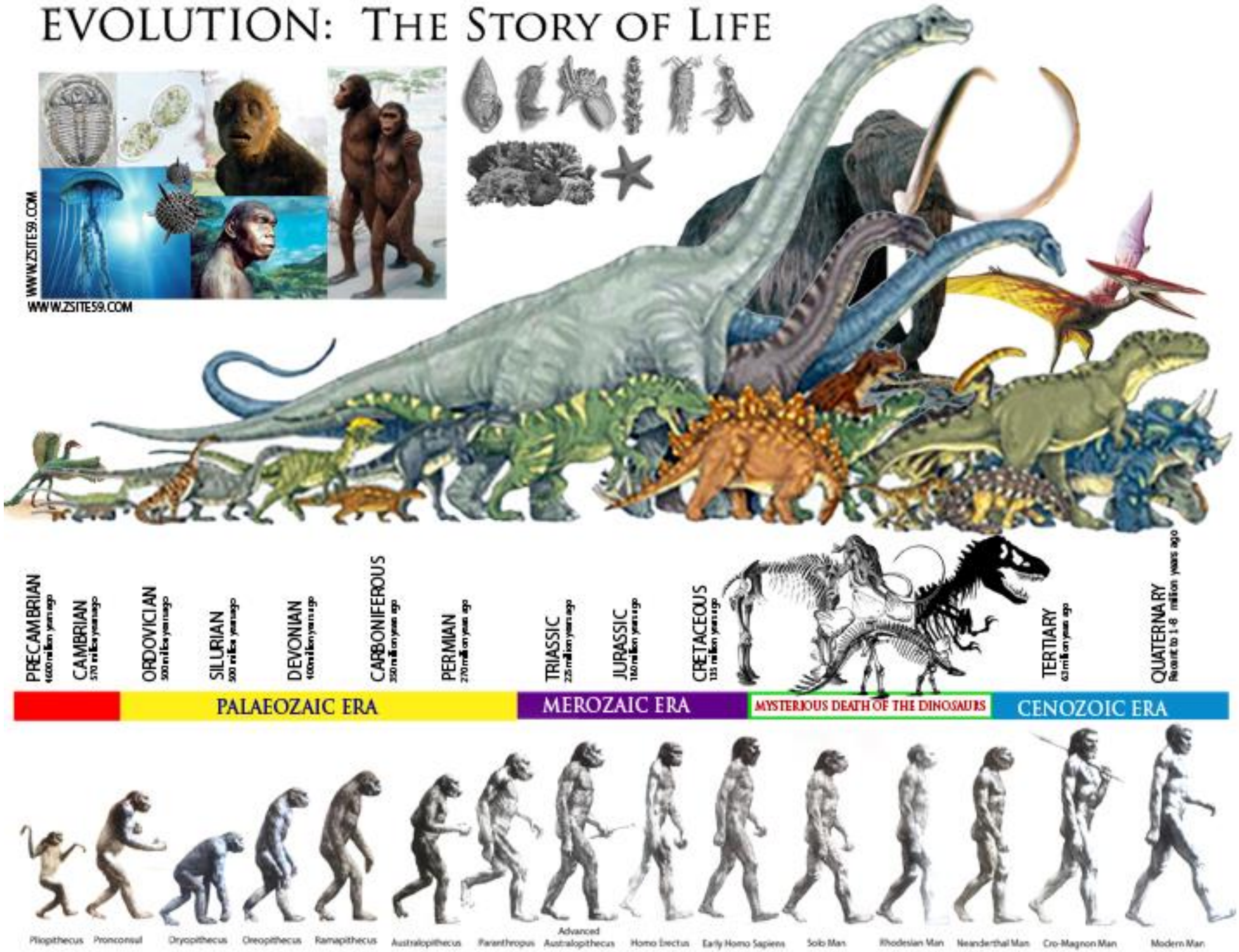

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Prehistoric survivors

Adaptation is key for survival

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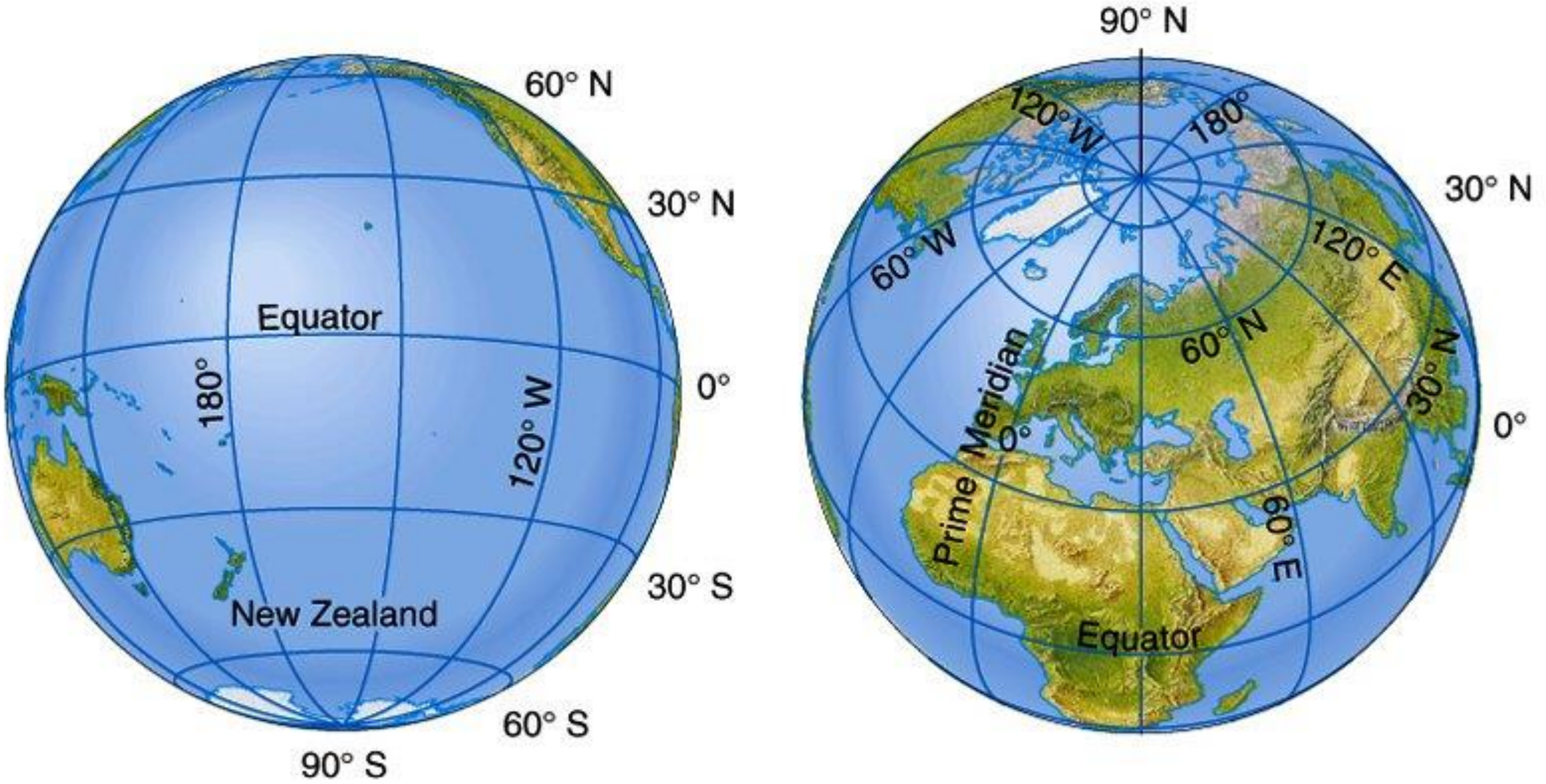
Water

Water distribution



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Water

Water distribution

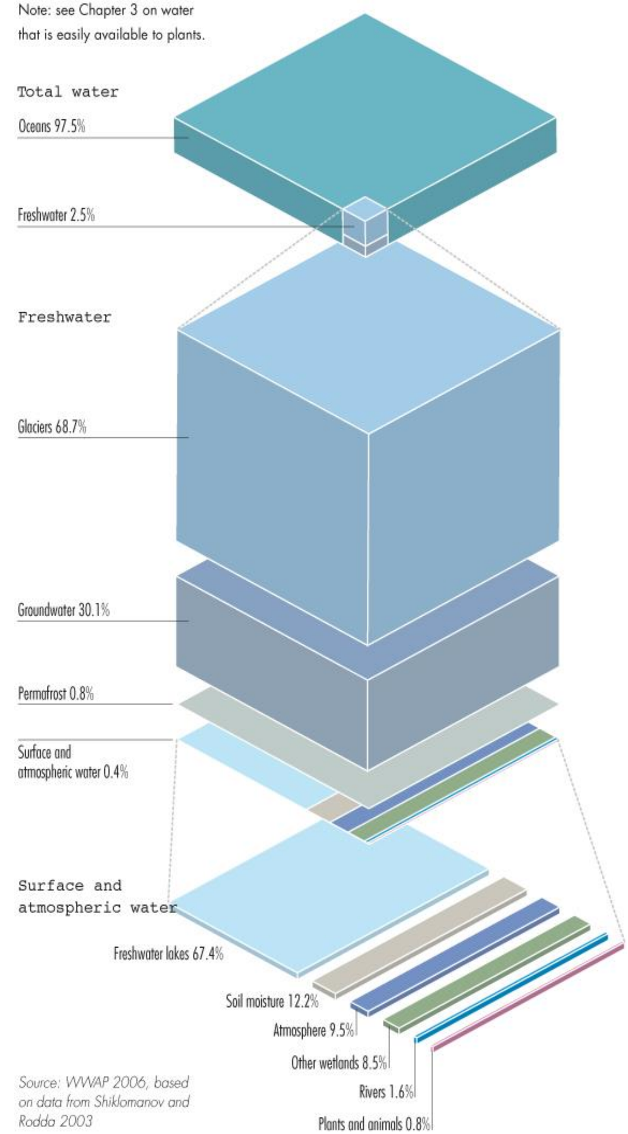
- Less than 3% of the world's water is fresh – the rest is seawater and undrinkable.
- Of this 3%, over 2.5% is locked up in Antarctic and Arctic glaciers, and not available to humankind.
- Thus humanity must rely on this 0.5% for all man's and ecosystem's freshwater needs.

10,000,000 km³ of water is stored in underground aquifers. Since 1950 there has been a rapid expansion of ground water exploitation providing:

- **50% of all drinking water**
- **40% of industrial water**
- **20% of irrigation water**

Figure 4.1 Global distribution of the world's water

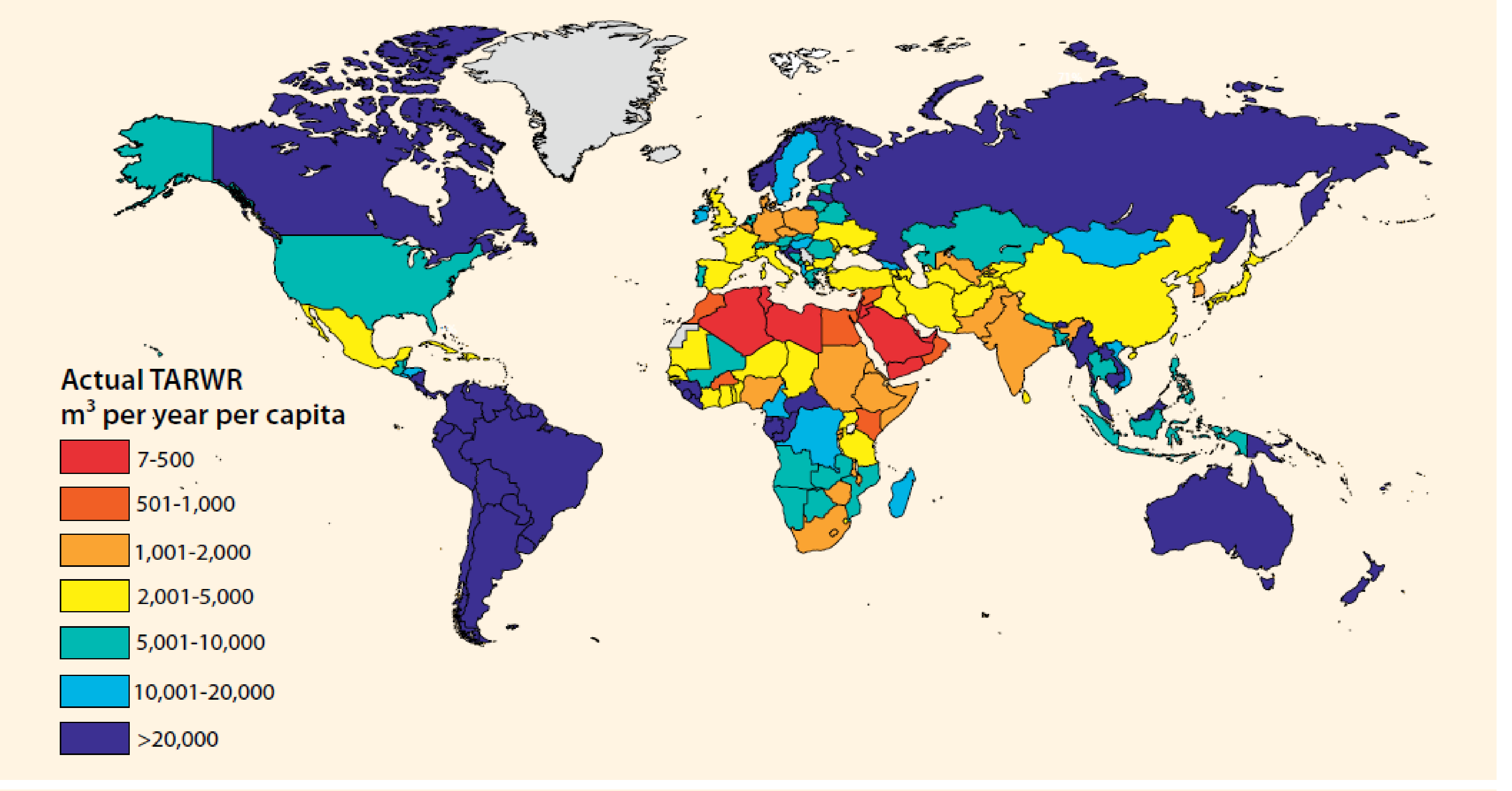
Note: see Chapter 3 on water that is easily available to plants.



Source: WWAP 2006, based on data from Shiklomanov and Rodda 2003

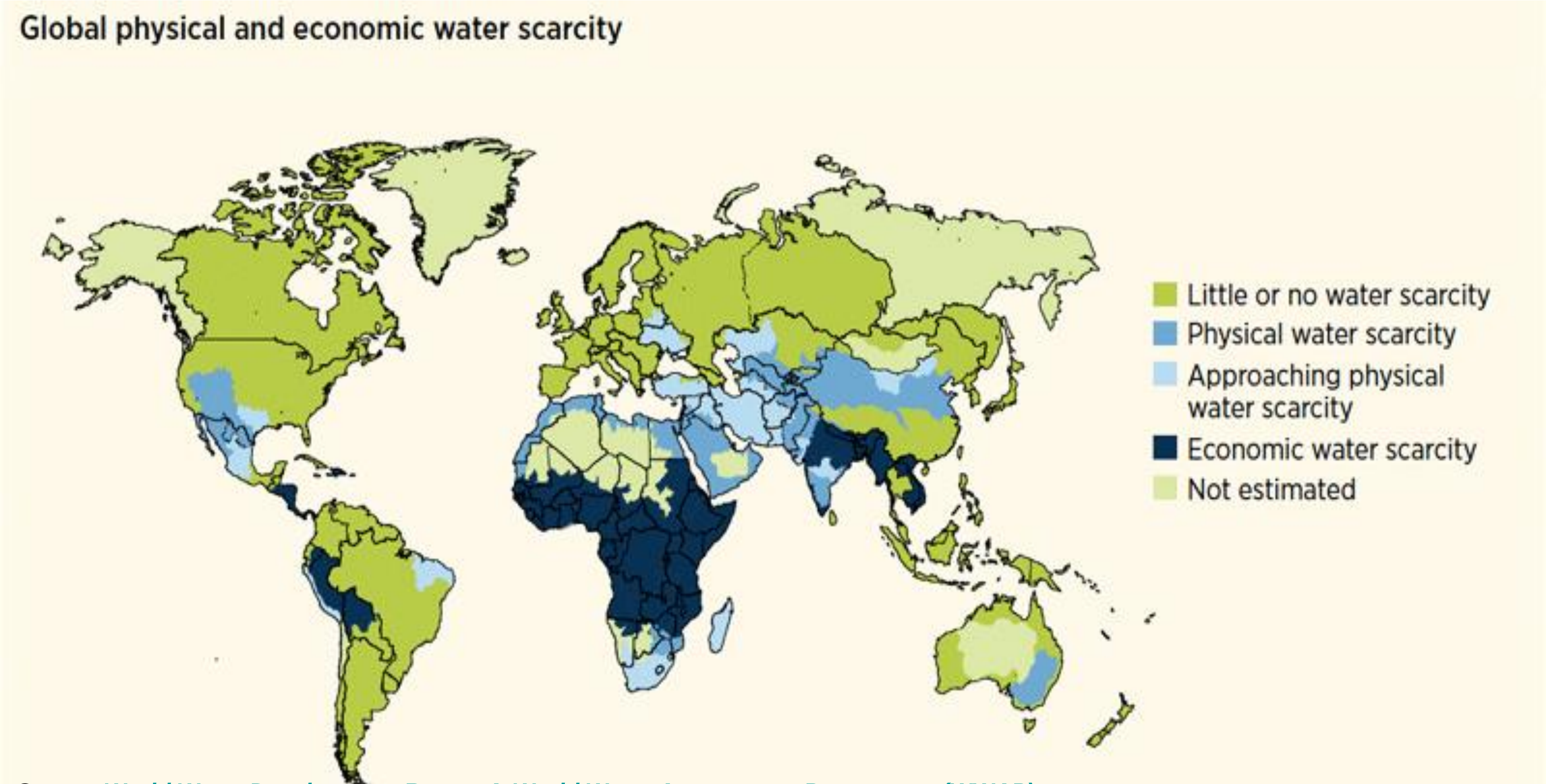
Freshwater distribution

Per capita total annual renewable water resources (TARWR) by country – population data from 2009



Source: FAO AQUASTAT database (http://www.fao.org/nr/aquastat, accessed in 2011).

Water scarcity (<1,000 m³ pppa)



Source: ***World Water Development Report 4. World Water Assessment Programme (WWAP), March 2012.***

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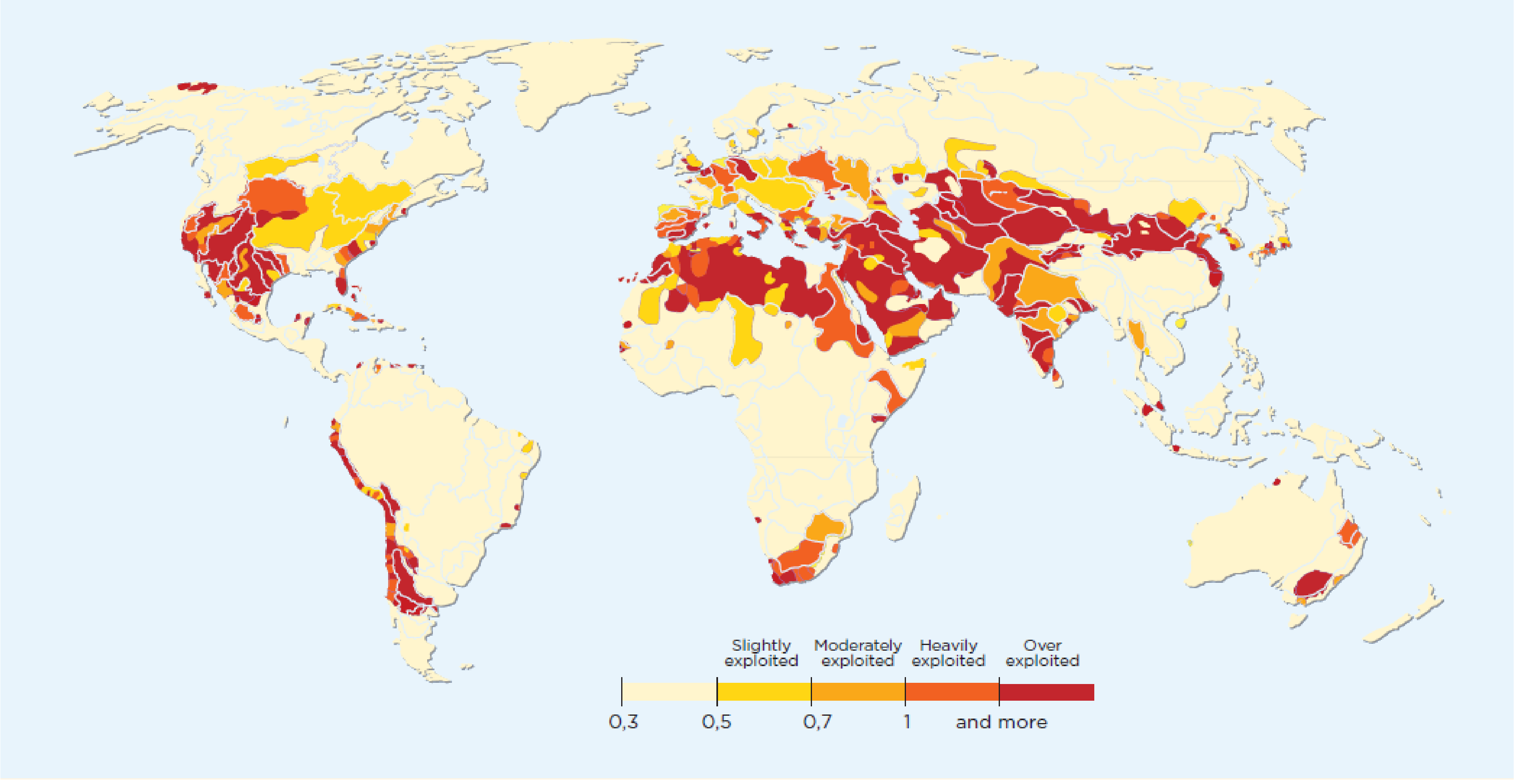
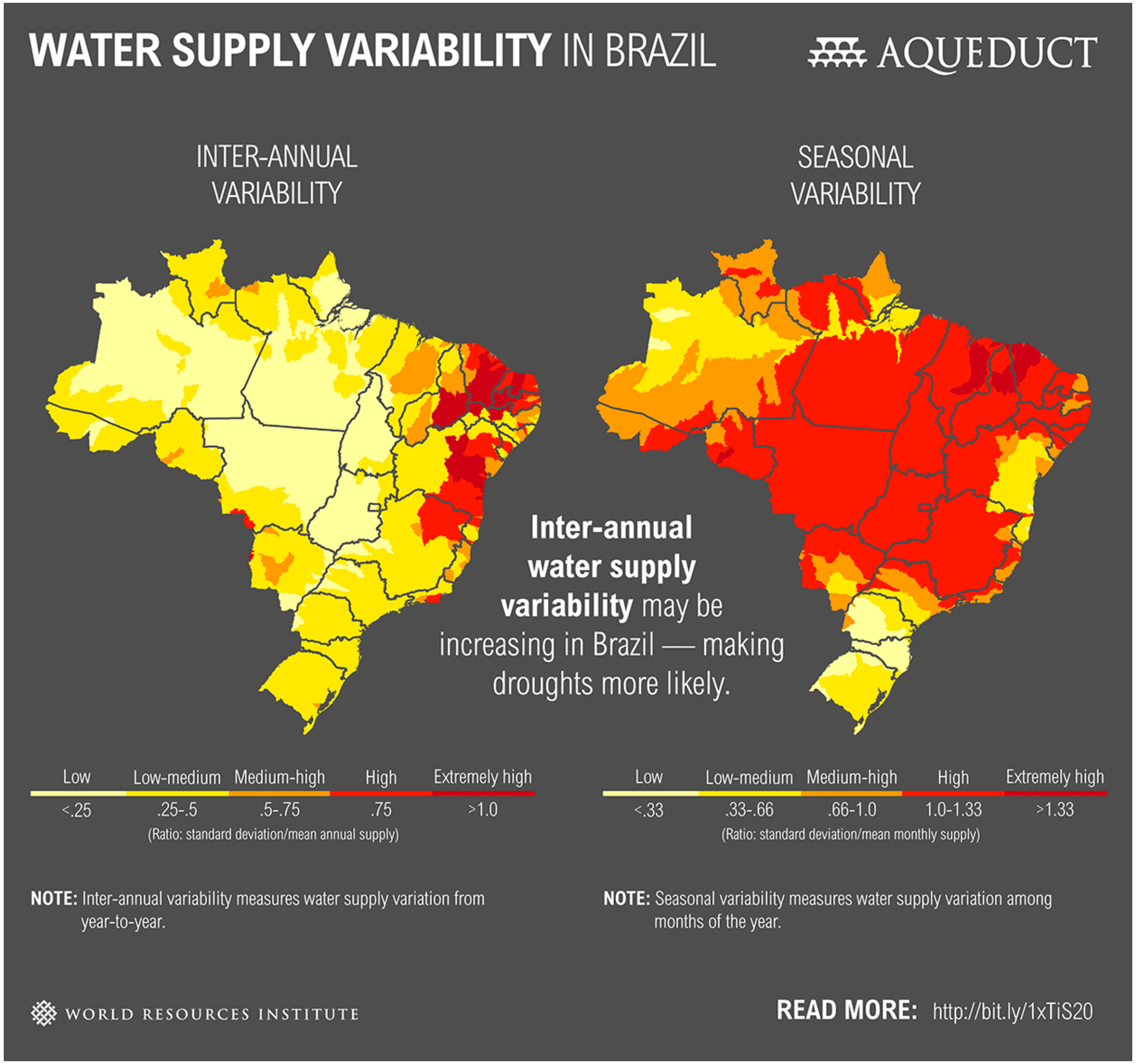
Water stressed countries (<1,700 m³ pppa)

Global Water Stress Indicator (WSI) in major basins



Source: UNEP/GRID-Arendal (2008) (http://maps.grida.no/go/graphic/water-scarcity-index, P. Rekacewicz [cartographer], with sources Smakhtin, Revenga and Döll [2004]).

Extreme weather conditions affect everyone



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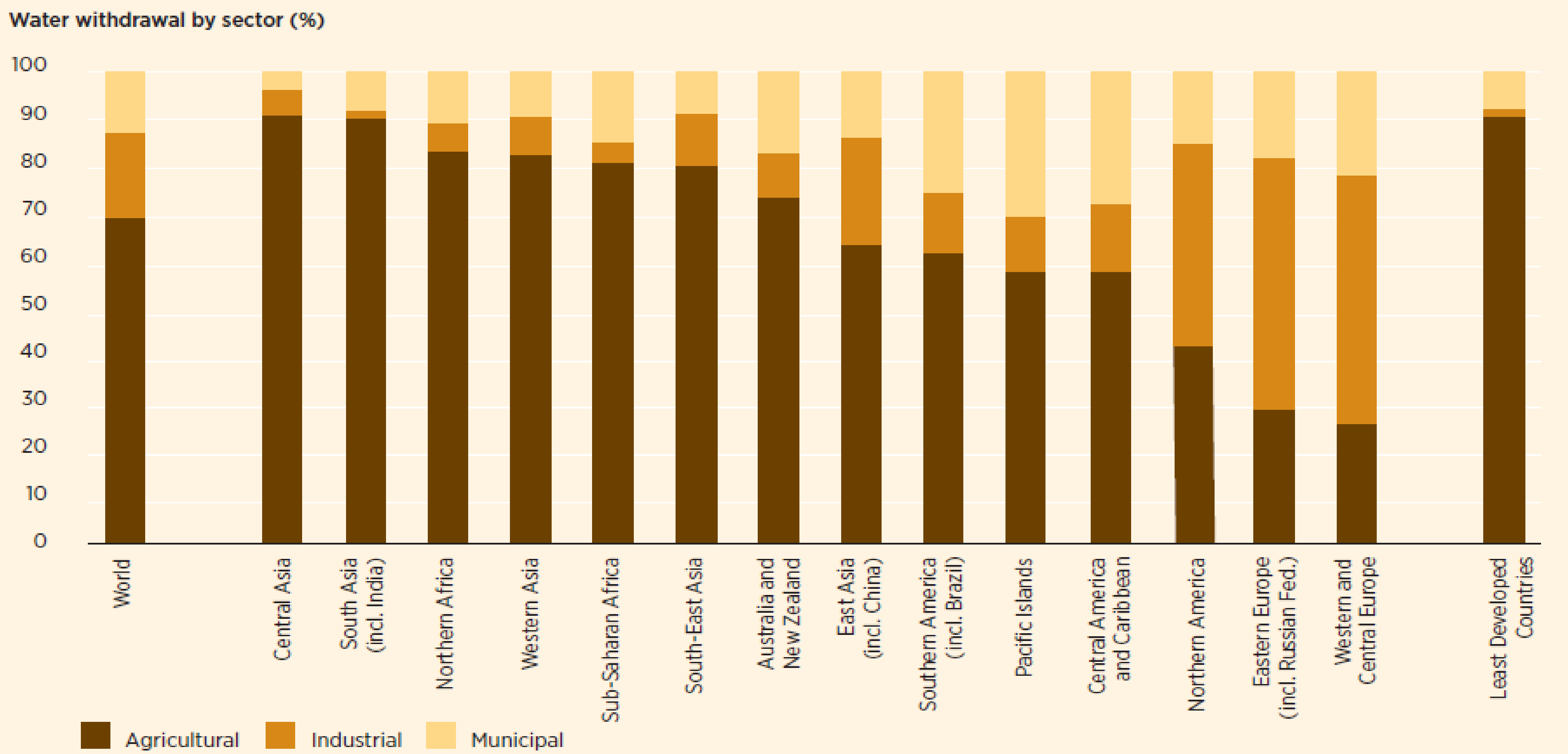
Fresh water withdrawal / consumption

Water withdrawal by sector by region (2005)



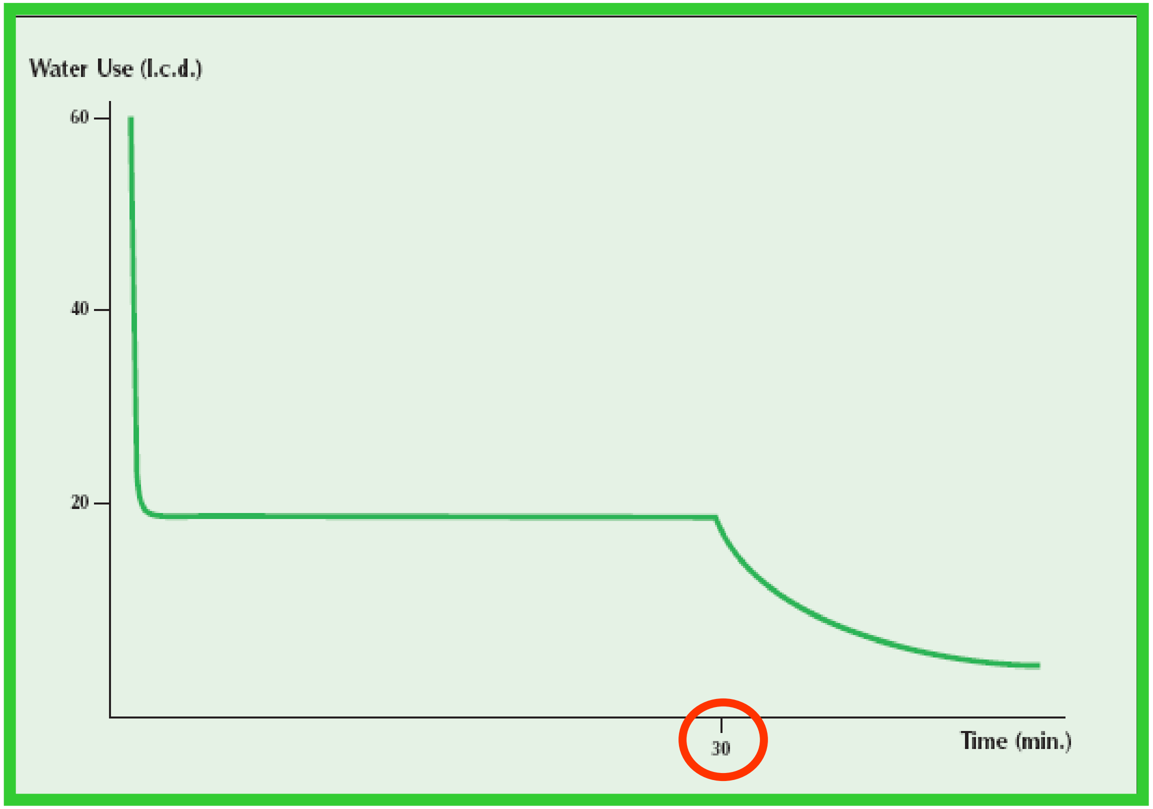
Source: FAO AQUASTAT (http://www.fao.org/nr/water/aquastat/main/index.stm, accessed in 2011).

Basic human water requirements

1. Minimum Drinking Water Requirement: Data from the National Research Council of the National Academy of Sciences was used to estimate the minimum drinking water requirement for human survival under typical temperate climates with normal activity is about *5 liters per person per day*.
2. Basic Requirements for Sanitation: Taking into account various technologies for sanitation worldwide, the effective disposal of human wastes can be accomplished with little to no water if necessary. However, to account for the maximum benefits of combining waste disposal and related hygiene as well as to allow for cultural and societal preferences, a minimum of *20 liters per person per day* is recommended.
3. Basic Water Requirements for Bathing: Studies have suggested that the minimum amount of water needed for adequate bathing is *15 liters per person per day* (Kalbermatten et al., 1982; Gleick 1993).
4. Basic Requirement for Food Preparation: Taking into consideration both developed and underdeveloped countries, the water use for food preparation to satisfy most regional standards and to meet basic needs is *10 liters per person per day*.

Basic human water requirements

Water supply: Water use and time spent collecting the water



Water and Sanitation

Environmental classification of water-related diseases

I. Faeco-oral diseases

- high infective dose (e.g., typhoid)
- low infective dose (e.g., viral diseases)

II. Water-washed non-faeco-oral diseases

- eye infections (e.g., trachoma)
- skin infections (e.g., scabies)

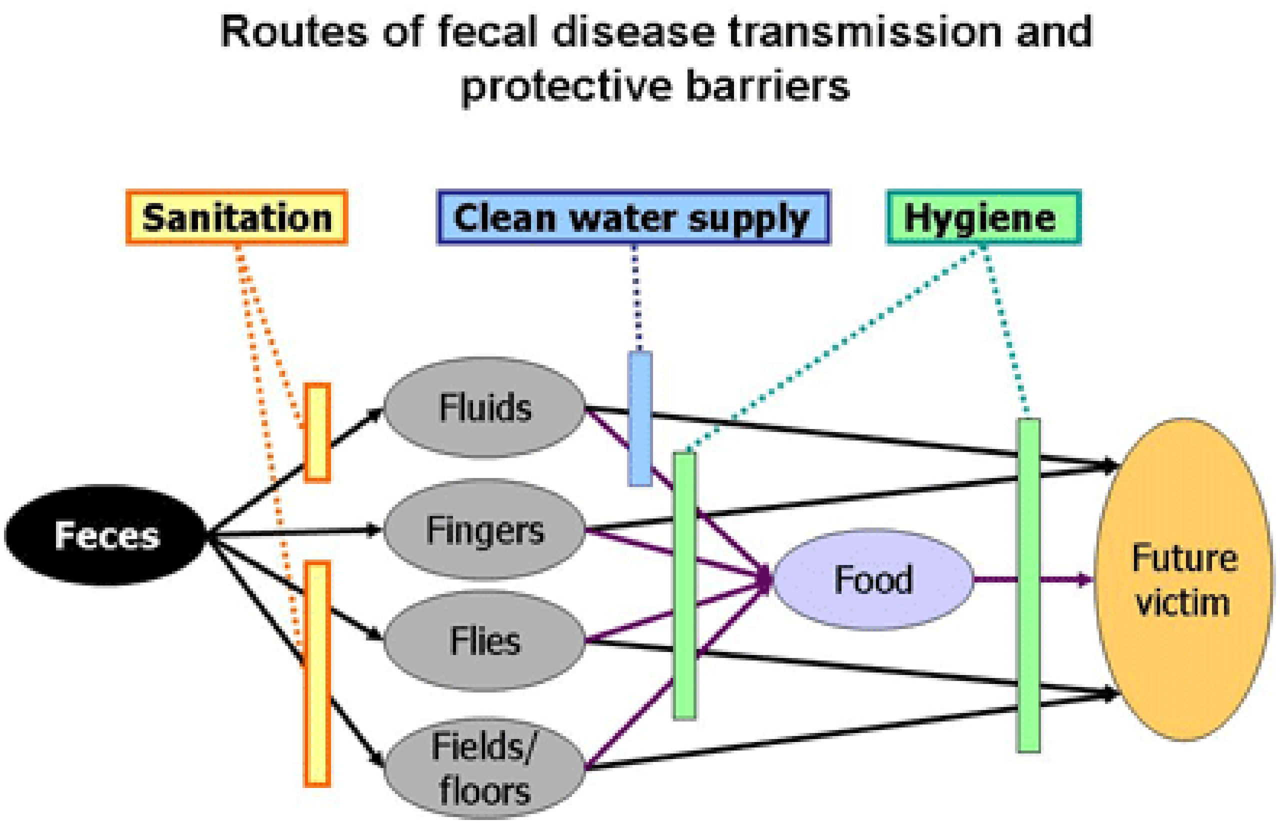
III Water-based diseases

- Percutaneous (e.g., schistosomiasis)
- Ingested (e.g., clonorchiasis)

IV Water-related insect vector diseases

- biting near water (e.g., trypanosomiasis)
- breeding in water (e.g., malaria)

Water and Sanitation



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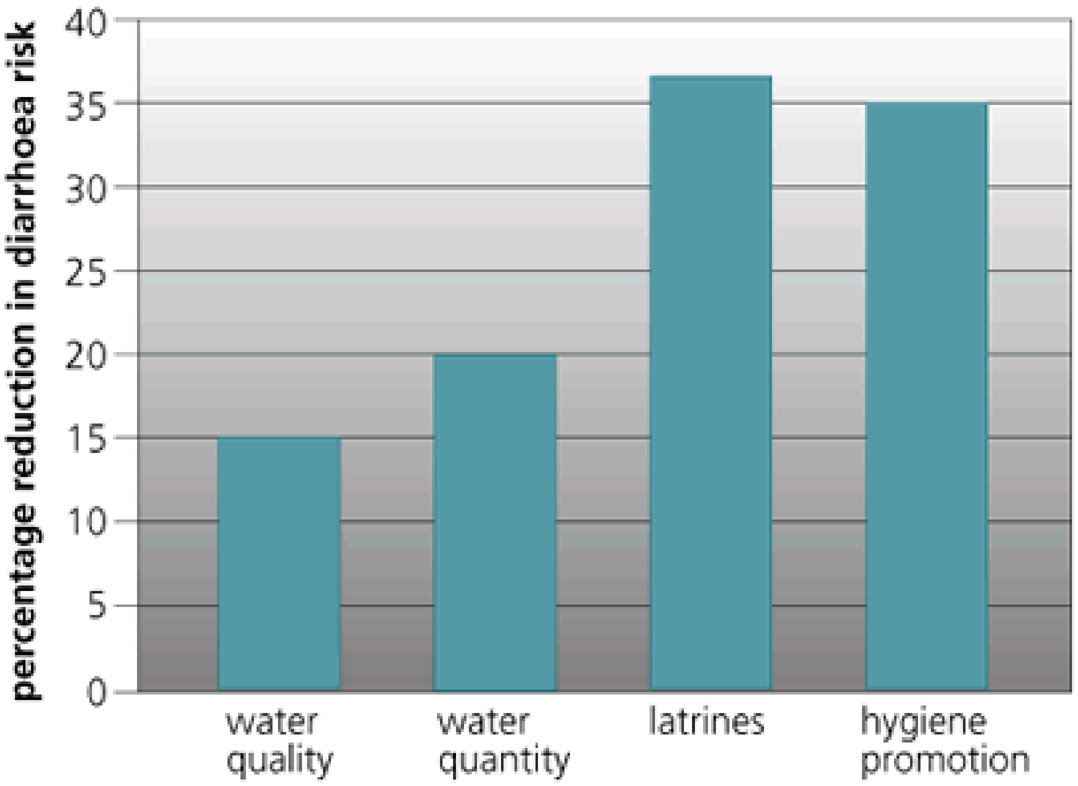
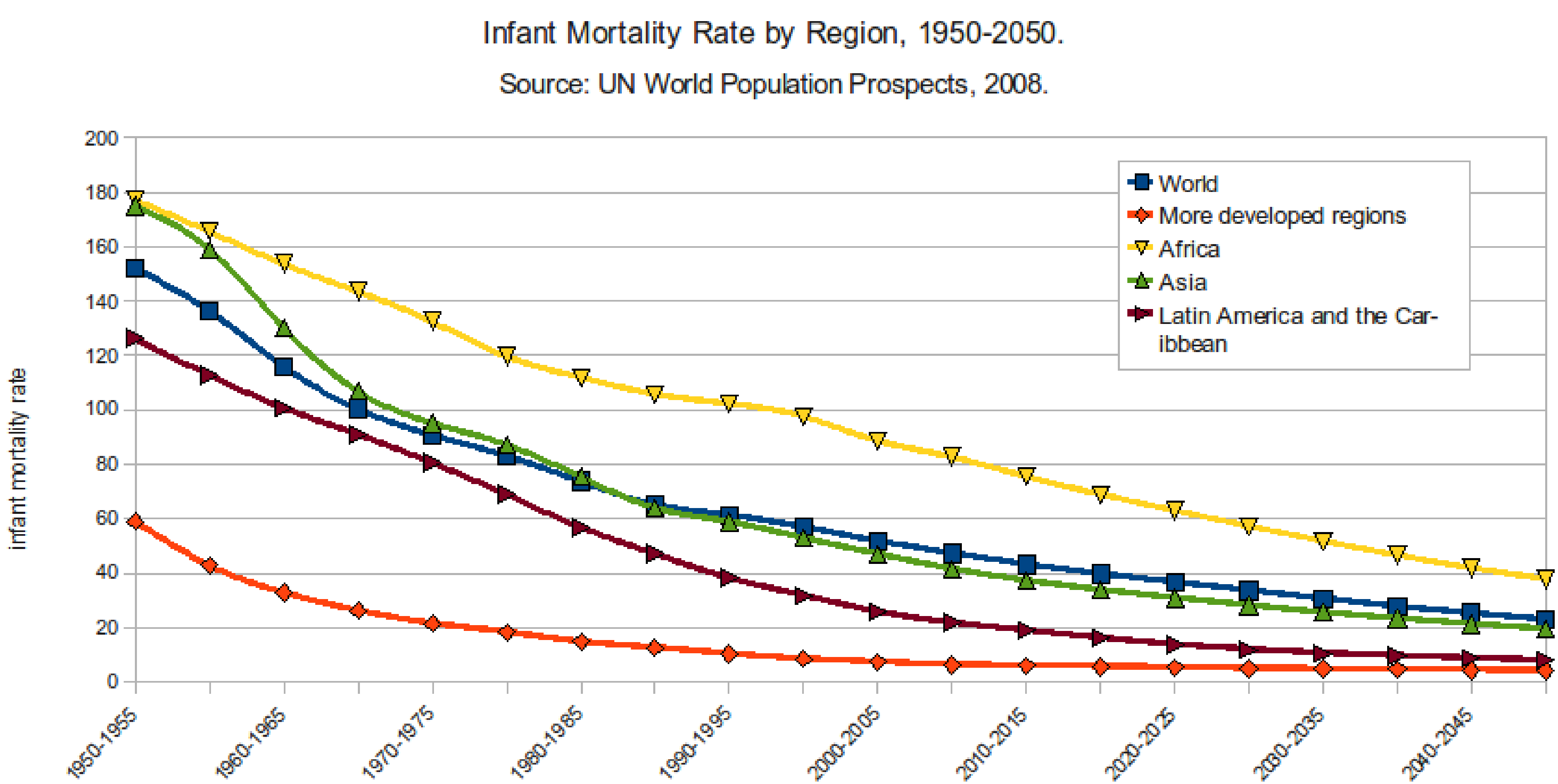
Water and Sanitation

Sanitation: Diarrhoea control



Source: Val Curtis (2003), *id21 Insights* #45

Water and Sanitation



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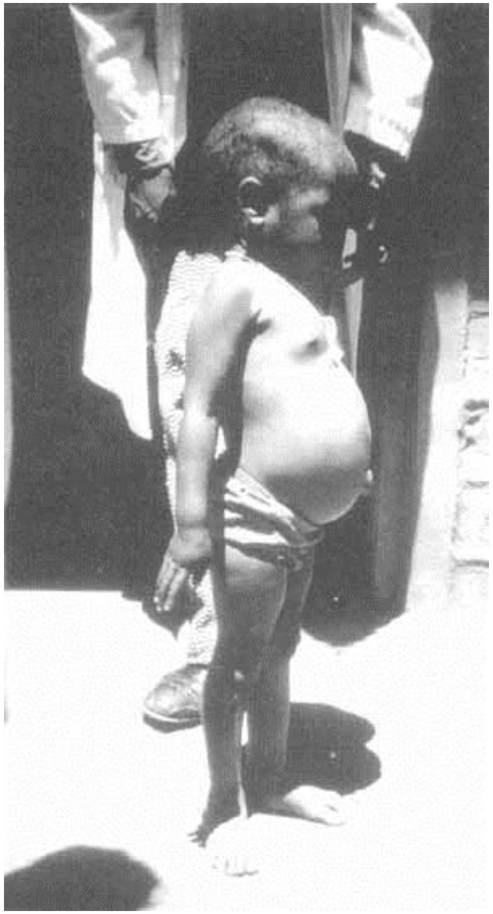
Water and Sanitation

Sanitation: effect on cognition

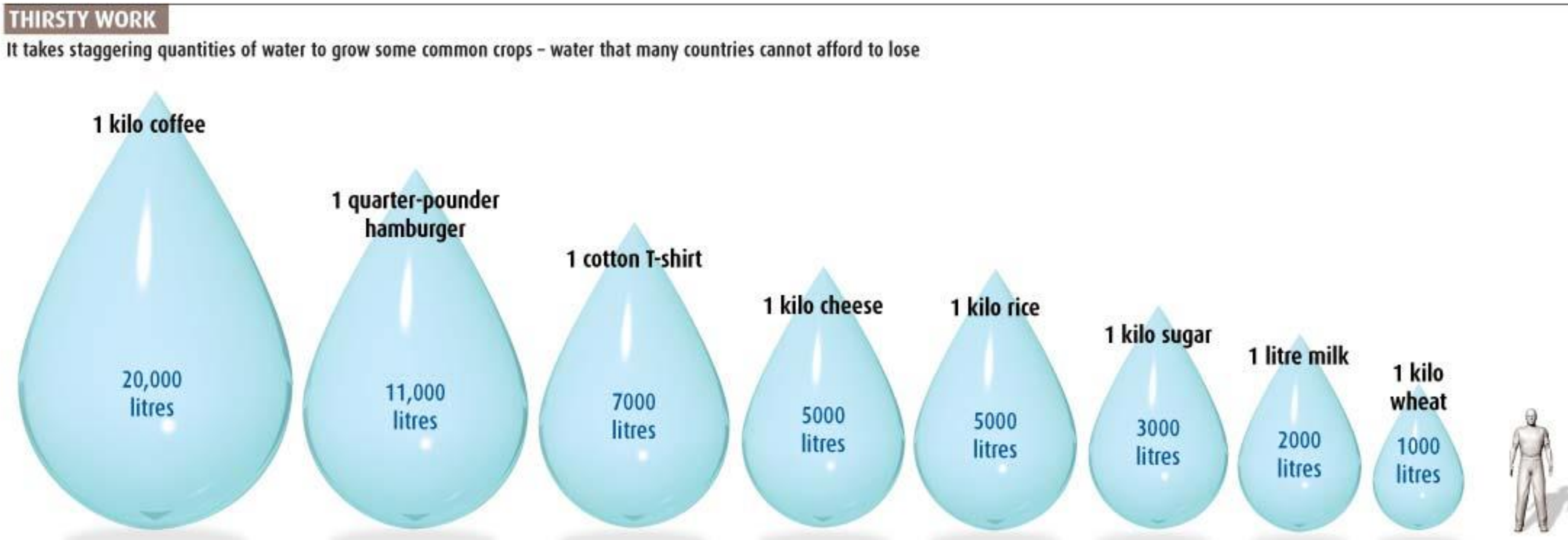


Repeated diarrhoea (and heavy parasitic infection) in infancy leads to stunting (low weight-for-age) and, very importantly, to:

poor cognition in later childhood

Source: Berkman et al, *The Lancet*, 16 Feb. 2002

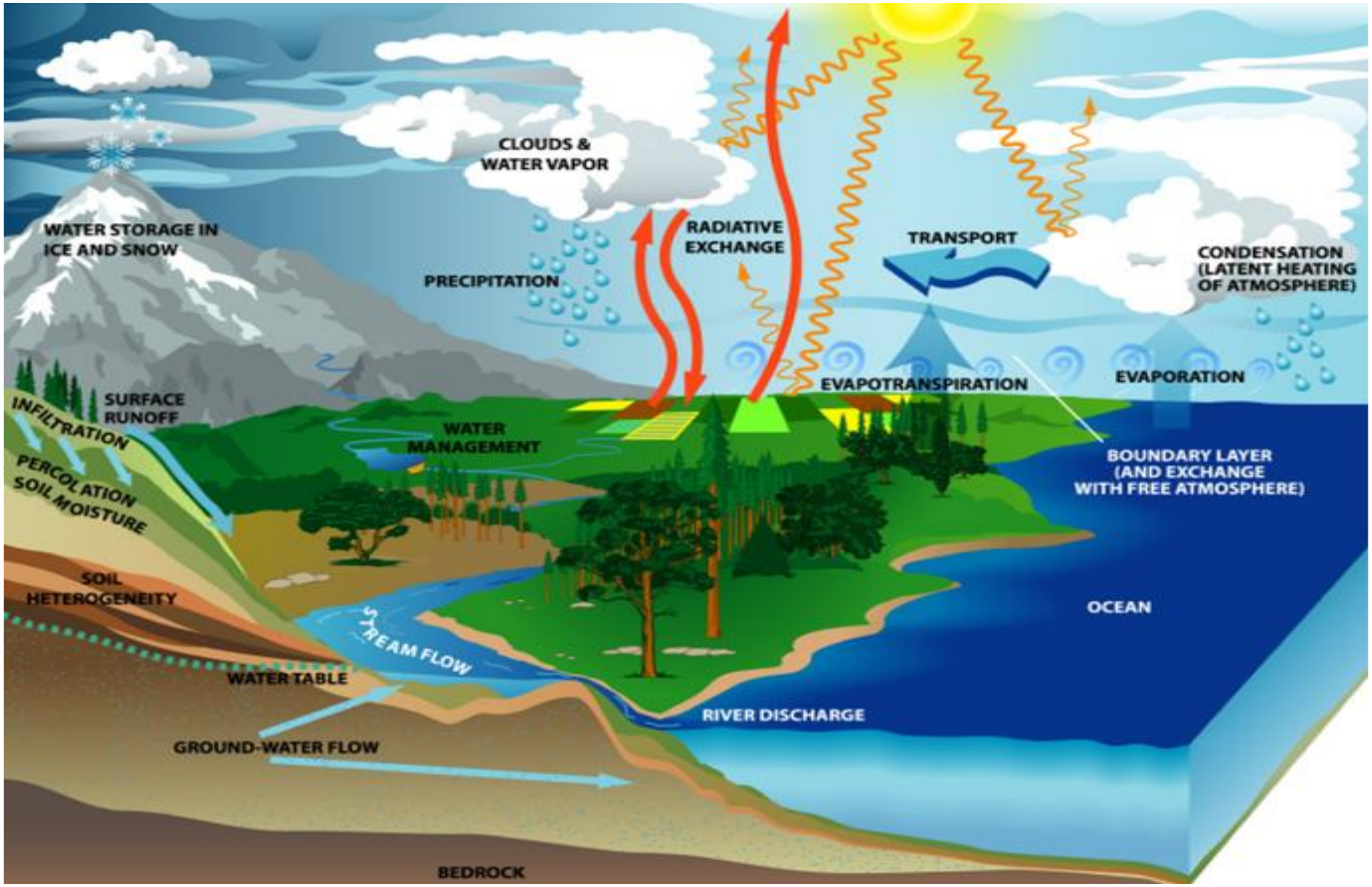
Virtual water



Water consumption :

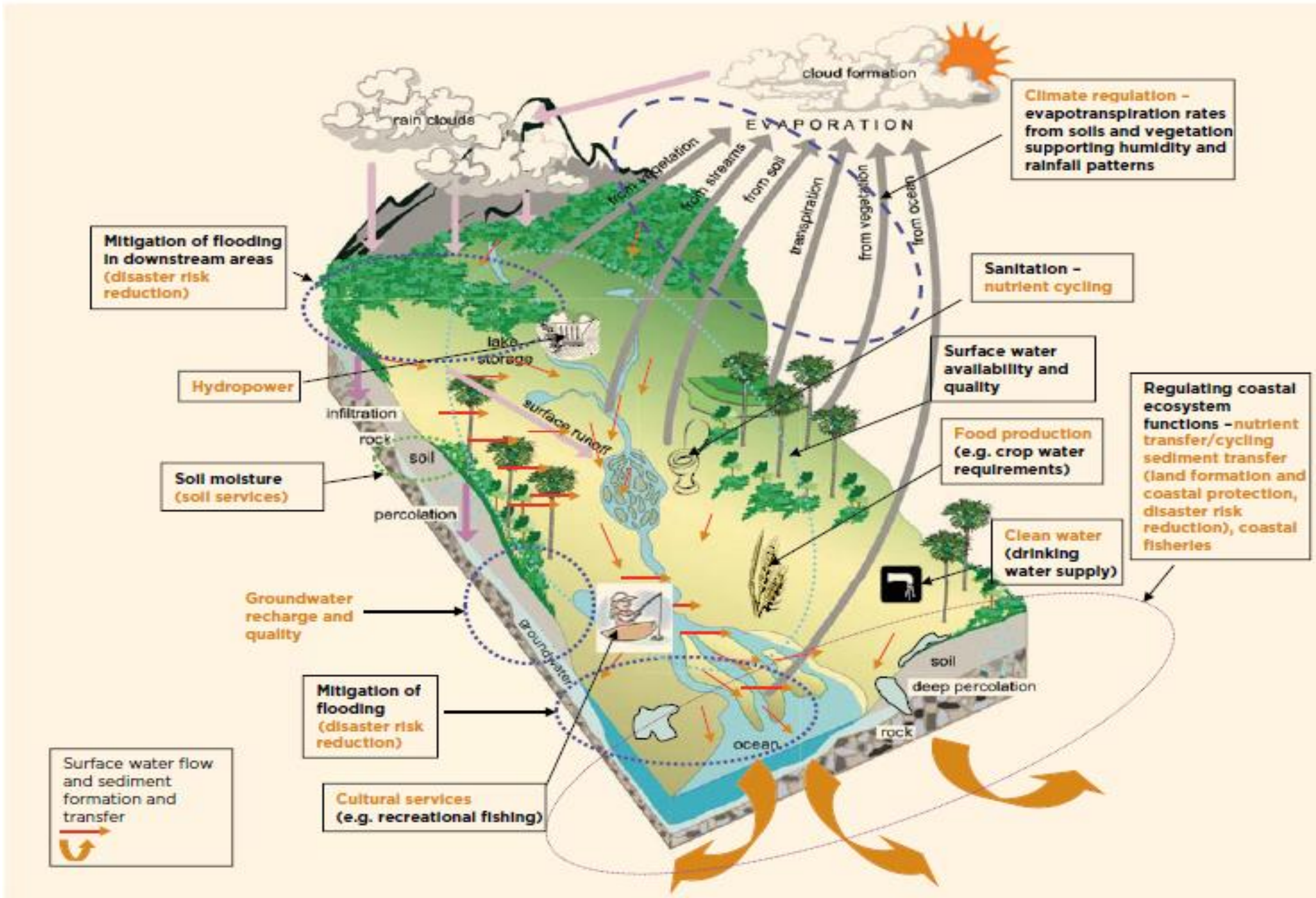
- 2 litres of drinking water per person per day (pppd)
- 100-300 litres pppd for water supply.
- 2,000 – 3,000 litres pppd of water for food production

Water as a renewable resource

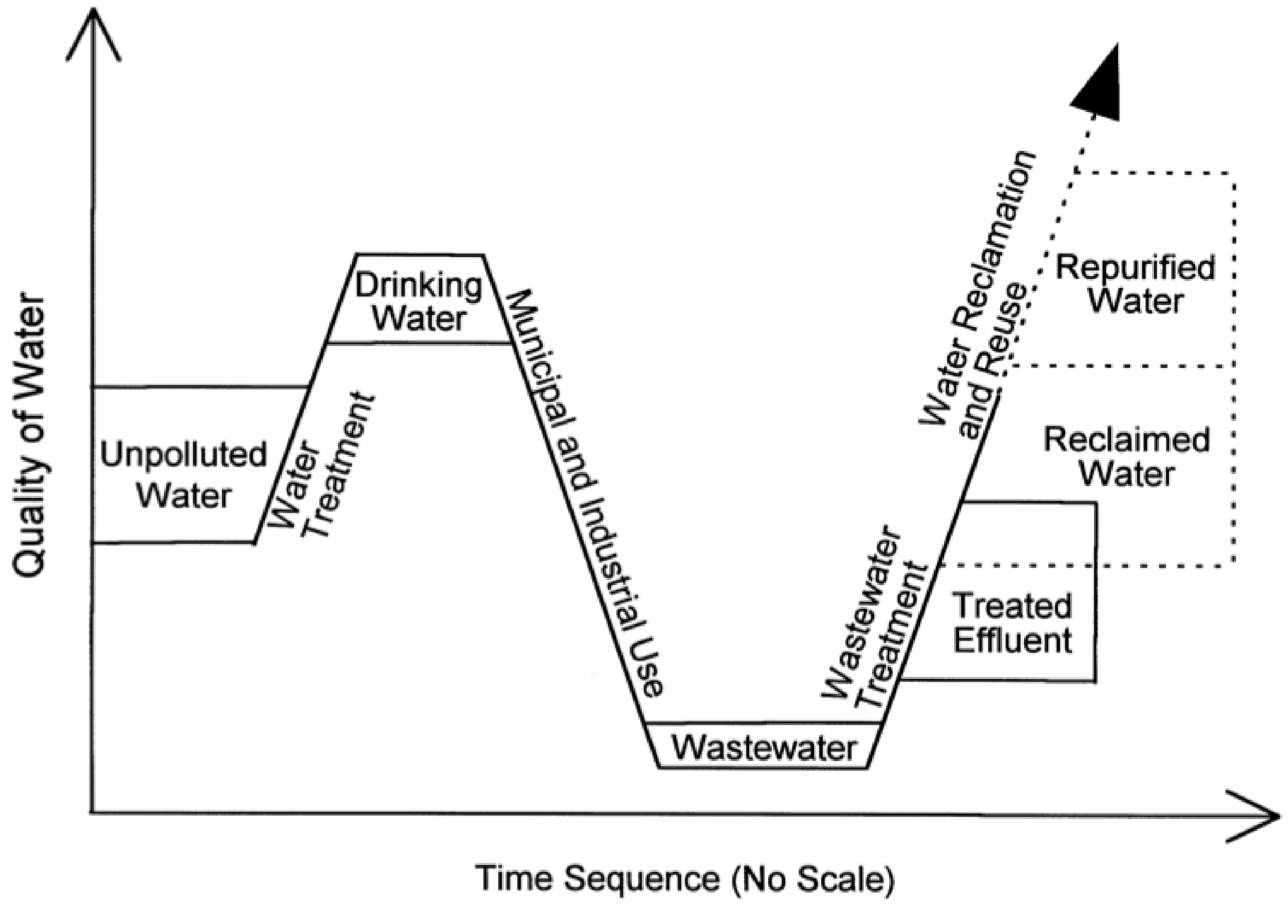


Water as a renewable resource

A simplified conceptual framework illustrating the role of ecosystems in the water cycle



Water as a non-renewable resource



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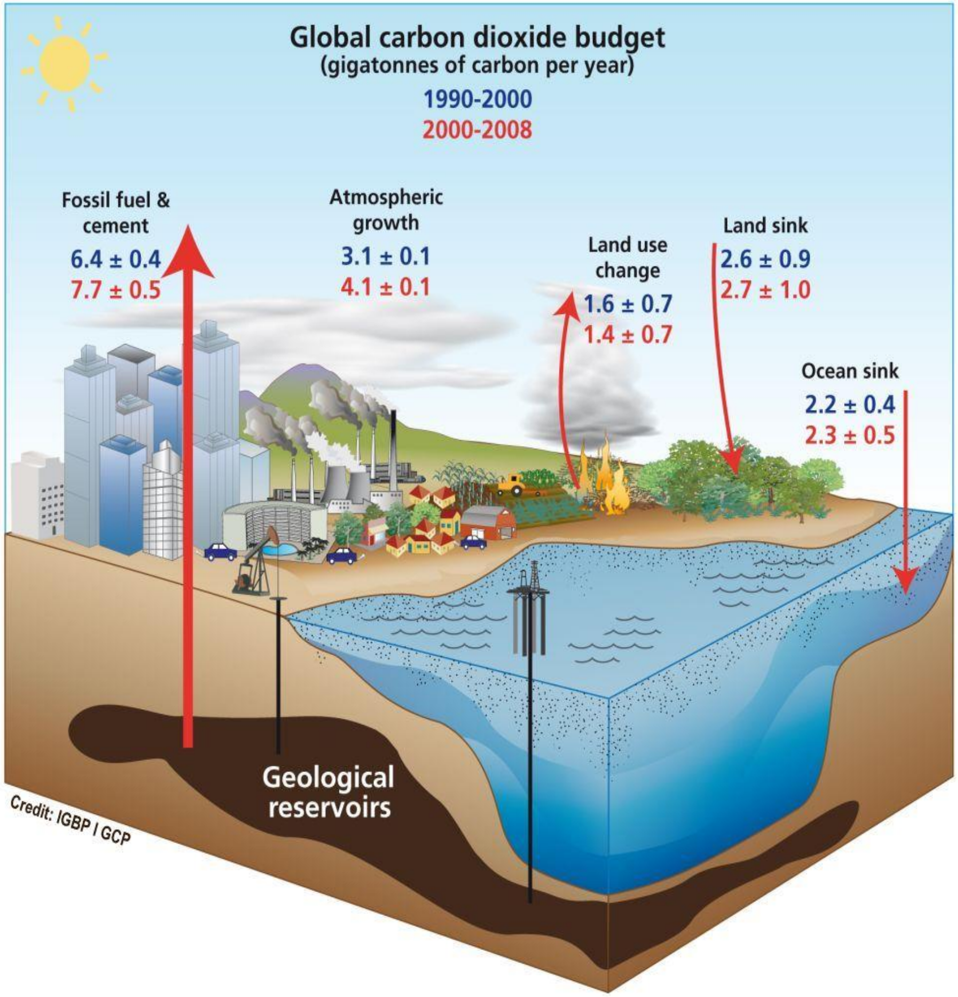
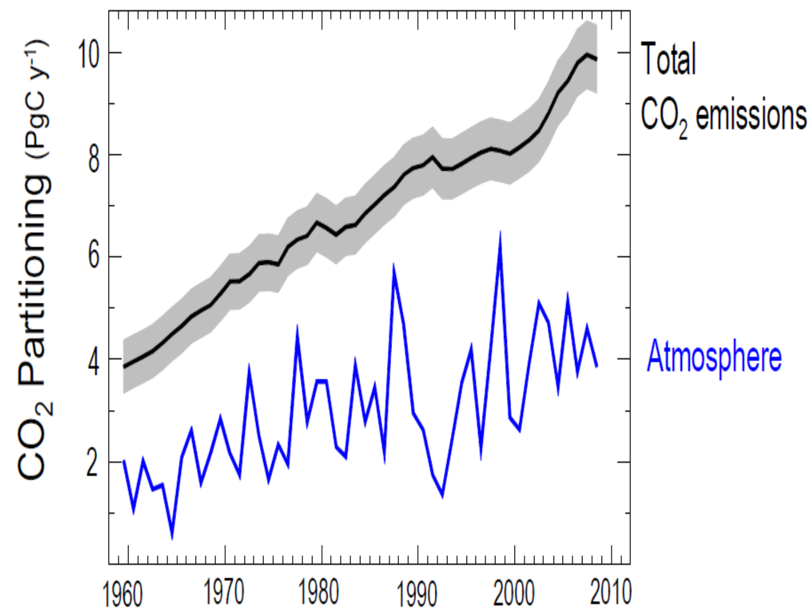
Water security

Future water security?

Carbon cycle and climate change



Evolution of the fraction of total emissions that remain in the atmosphere



Growth rate of CO_2 emissions

2000-2008 = 3.4% per year

1990-2000 = 1.0% per year

Source: Budget 08, GCP-Global Carbon Budget Consortium (2009)

[1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = 1×10^{15}g]

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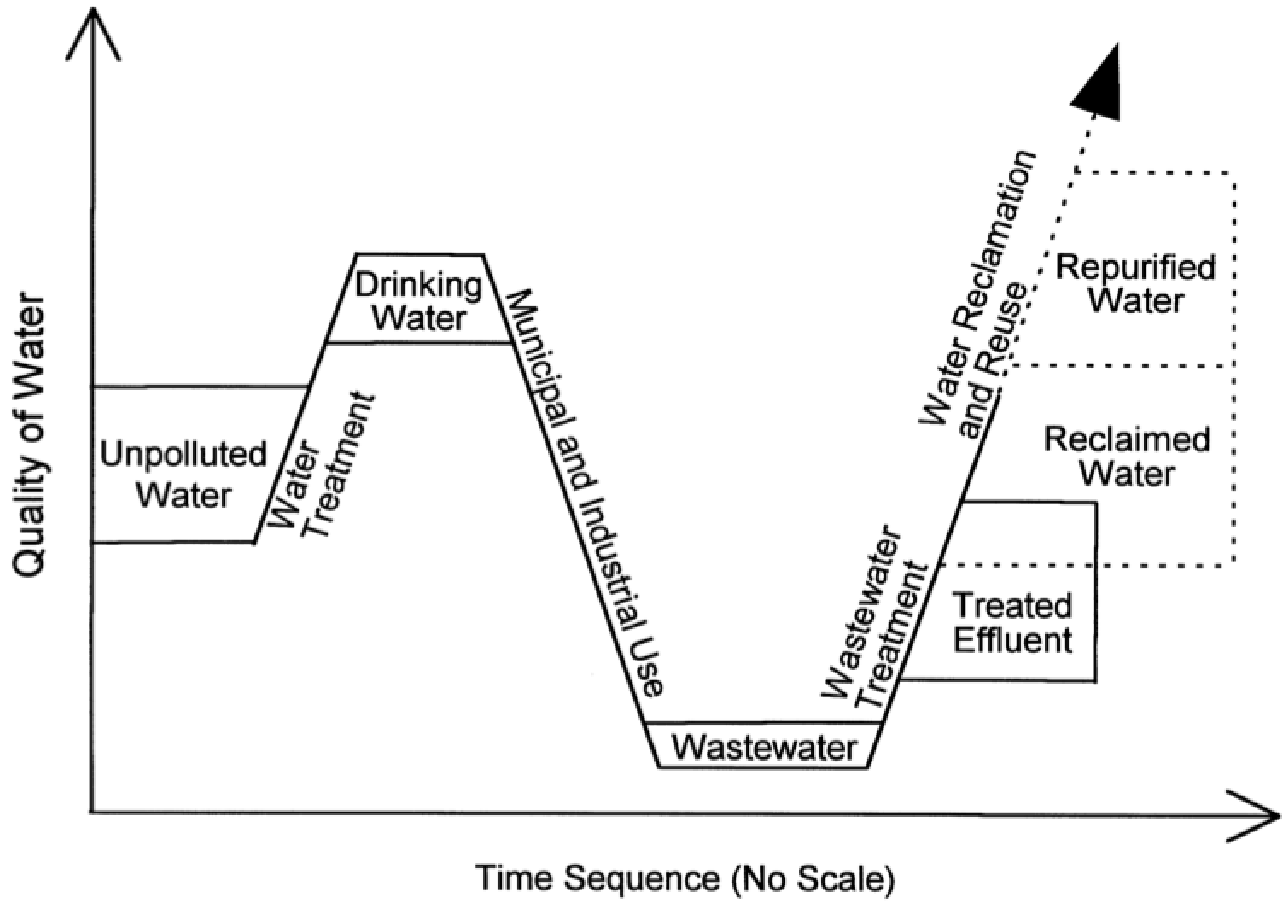
Water as a non-renewable resource



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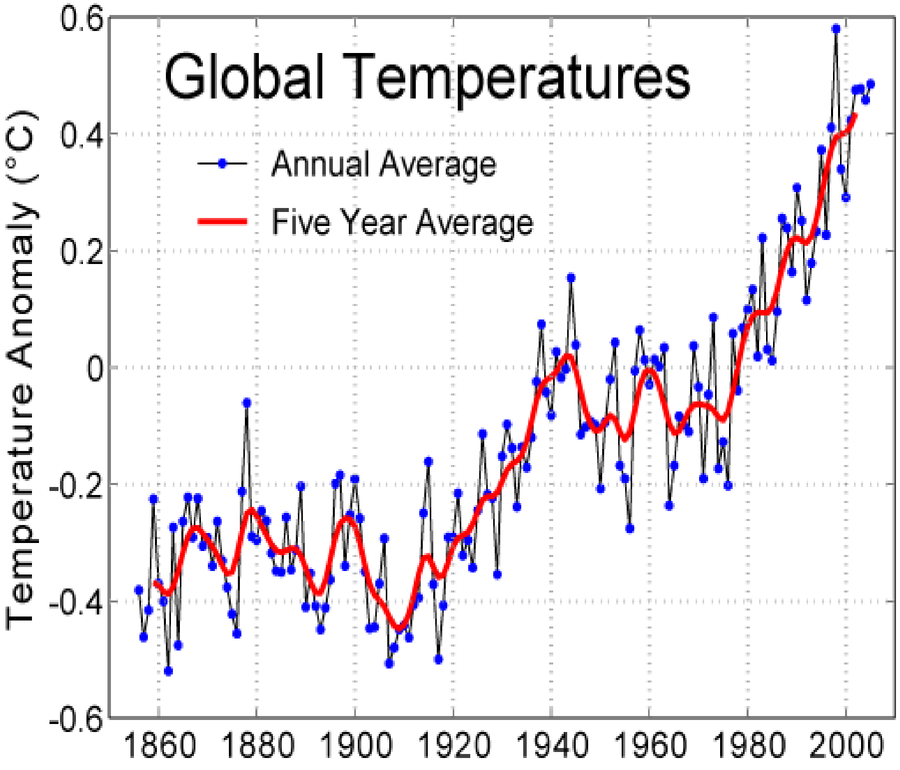
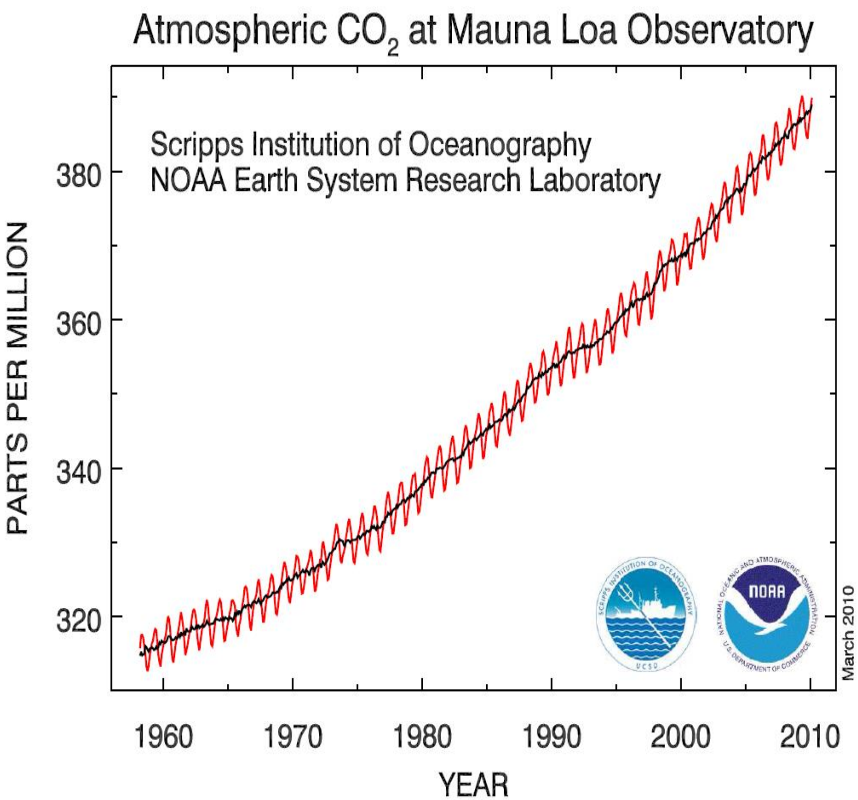
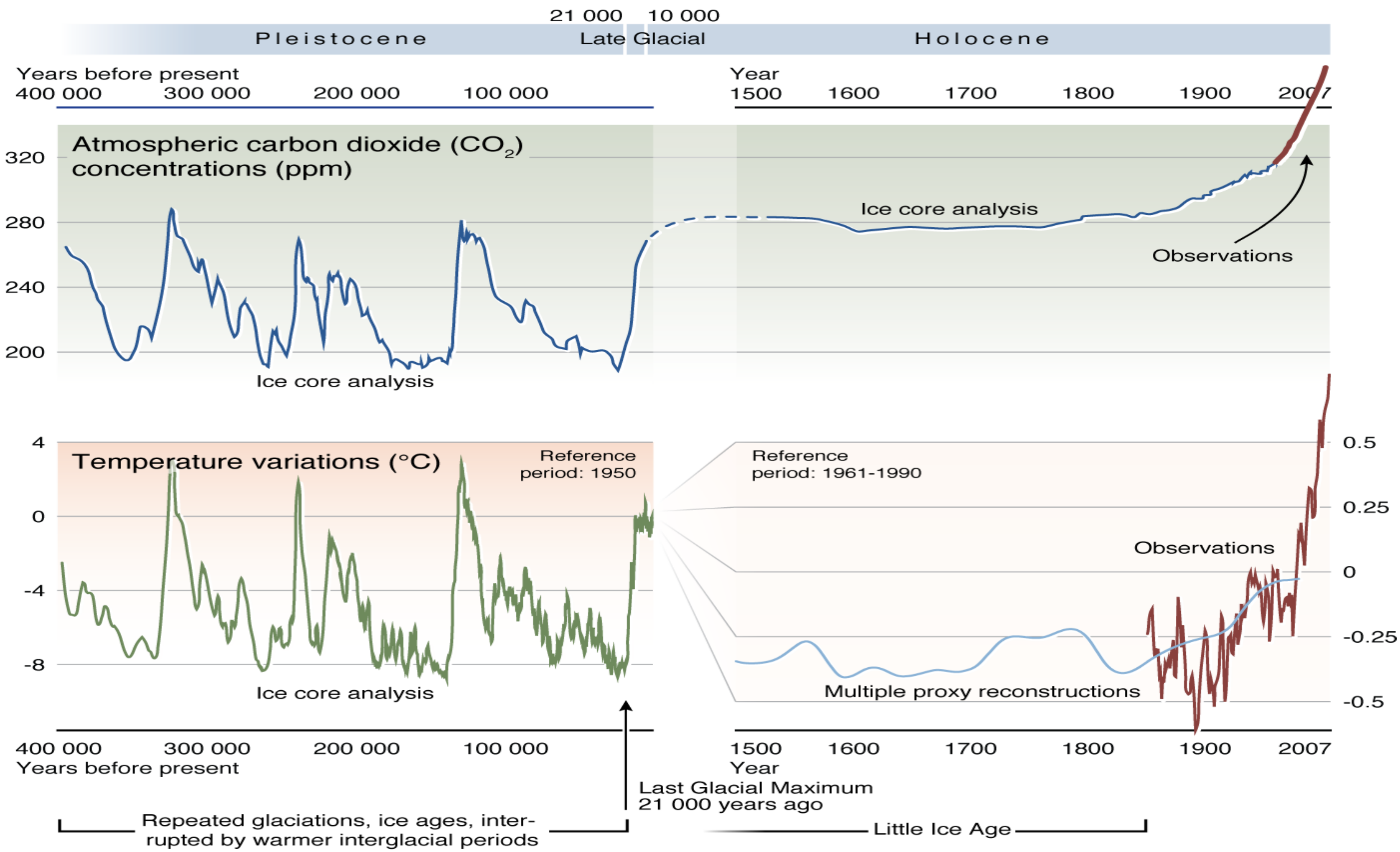
Carbon cycle – climate change





The accumulation of CO_2 (and other greenhouse gases) in the atmosphere has been identified as the main cause of the increase in global temperatures.

Carbon cycle – climate change



Source: United Nations Environment Programme (UNEP).

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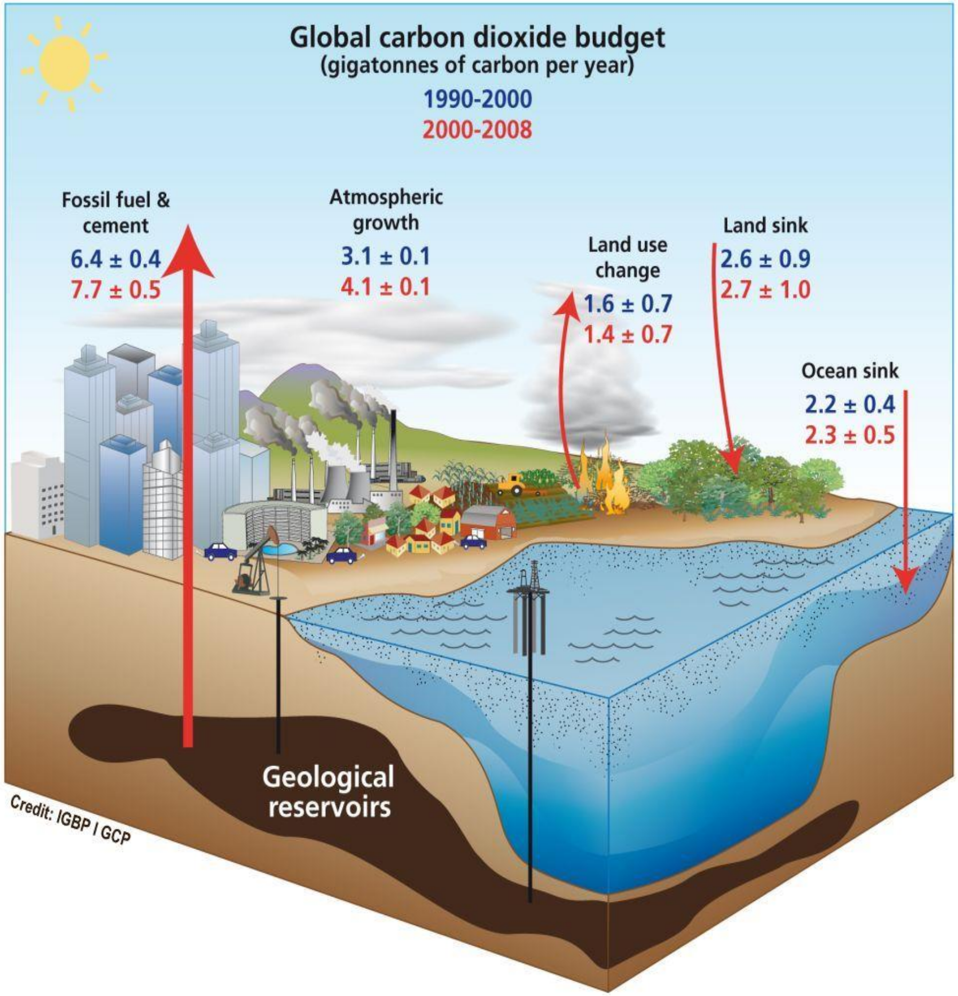
Carbon cycle and climate change



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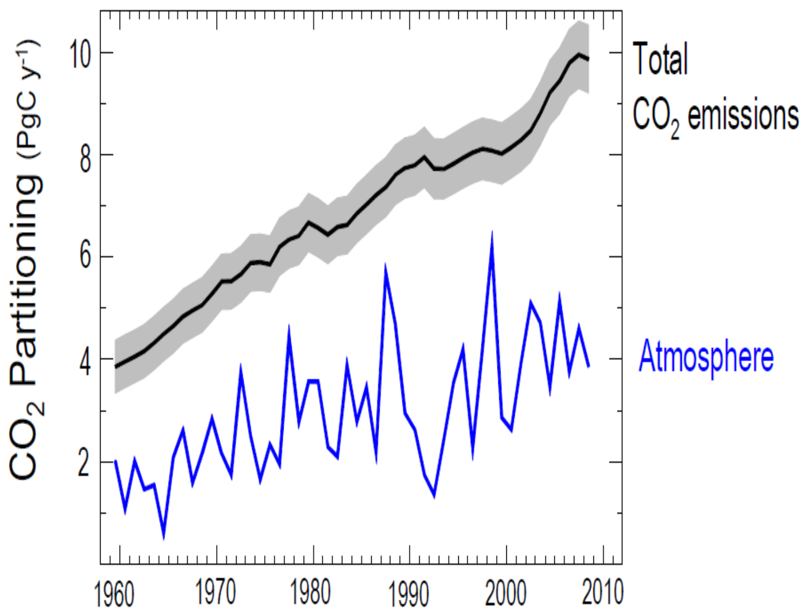

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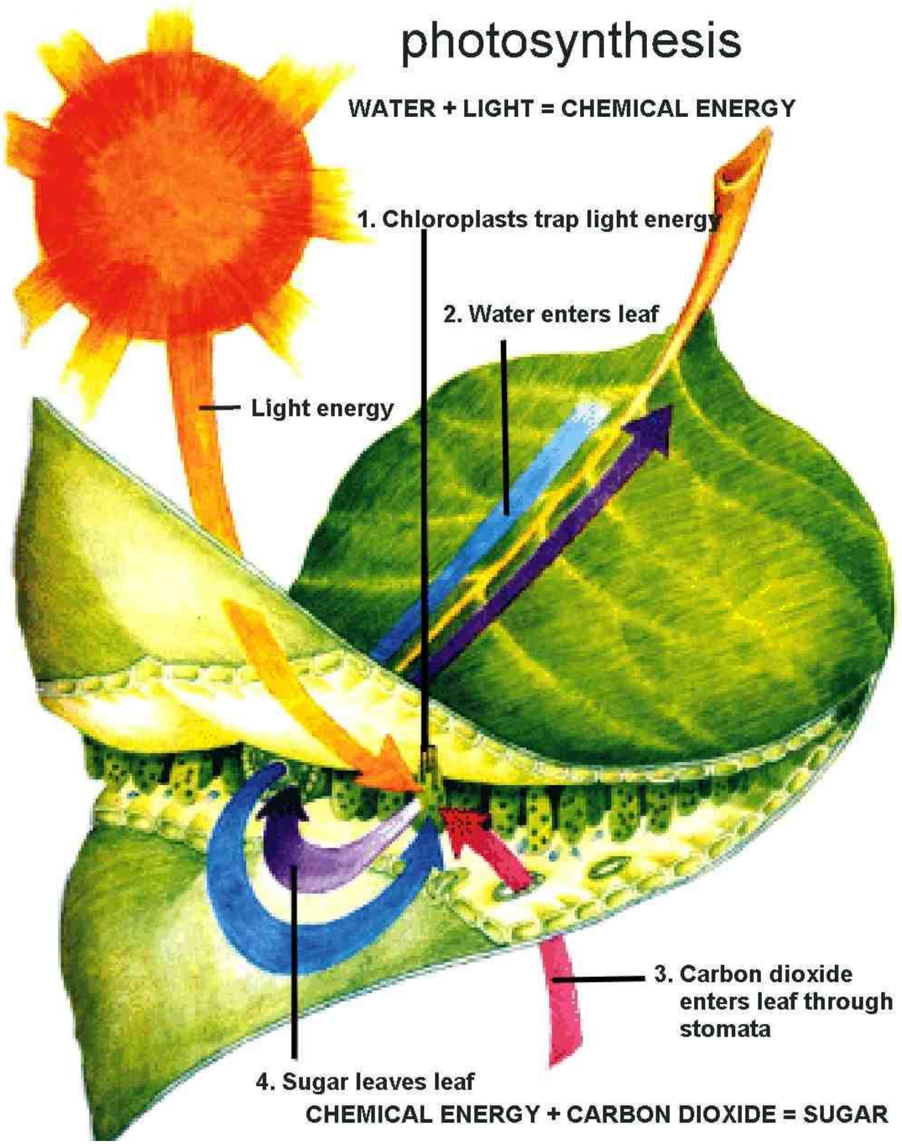
[1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = 1×10^{15}g]

Natural carbon fixation through photosynthesis



Light energy

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

chlorophyll

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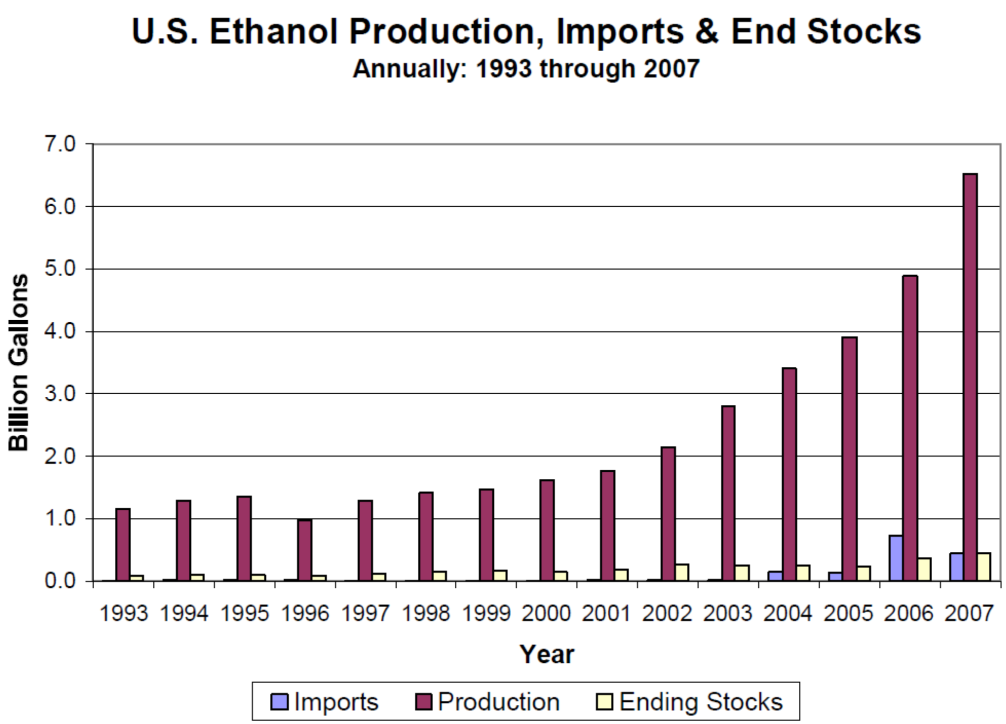
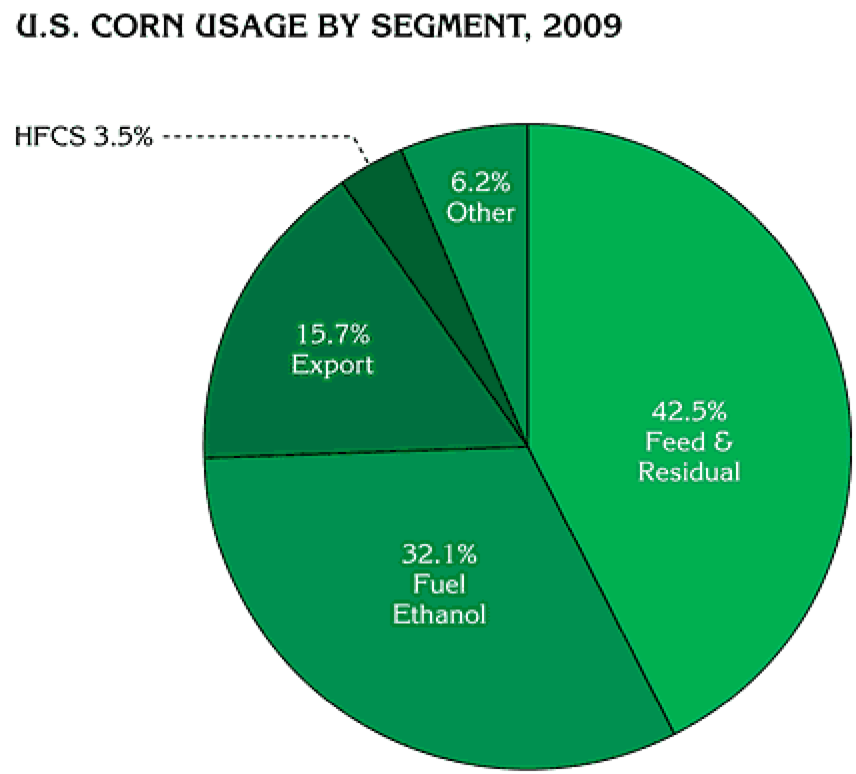
Natural carbon fixation through photosynthesis

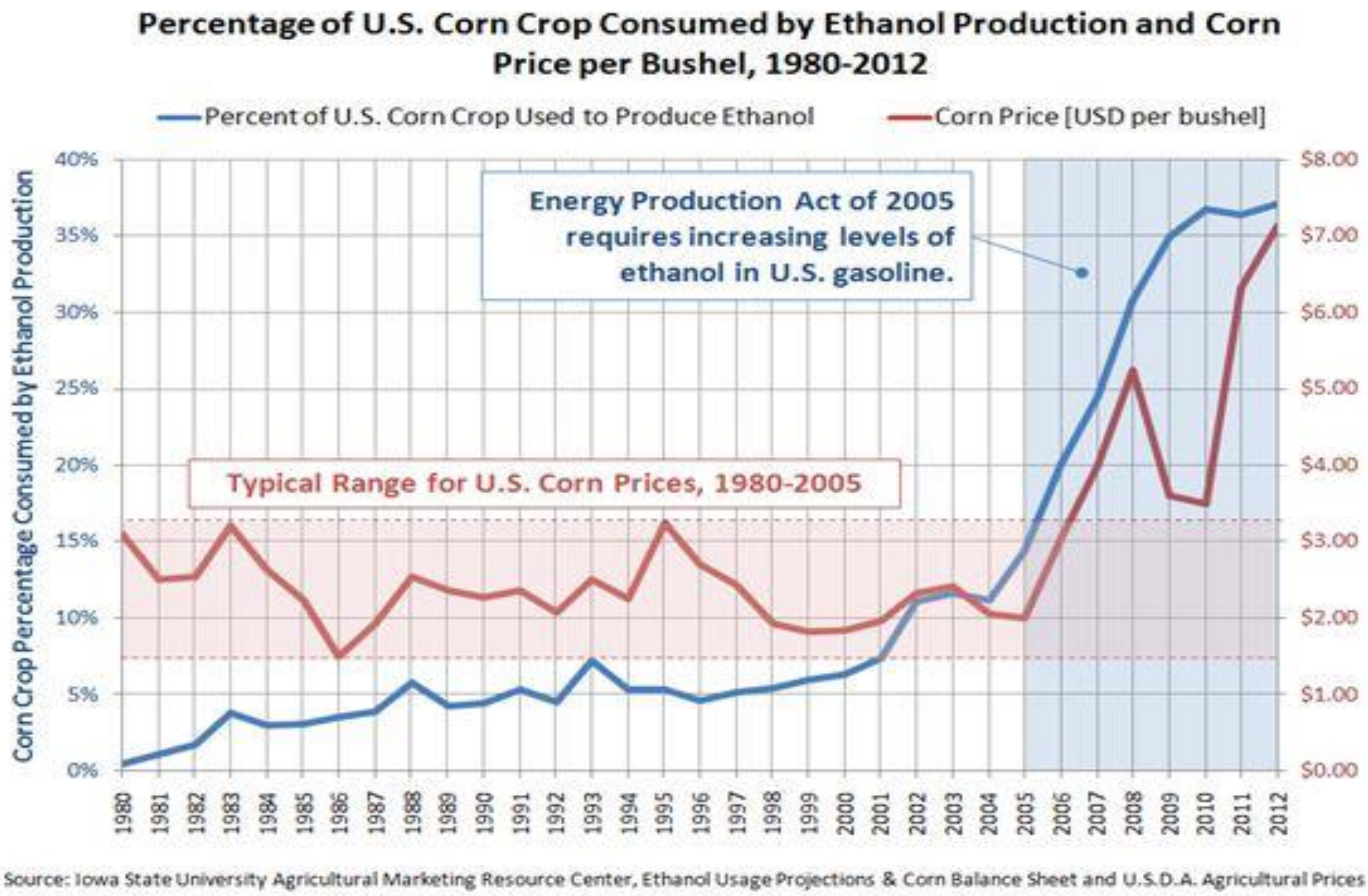
…. and biofuel production





2009 – 10.7b US Gal

Natural carbon fixation through photosynthesis

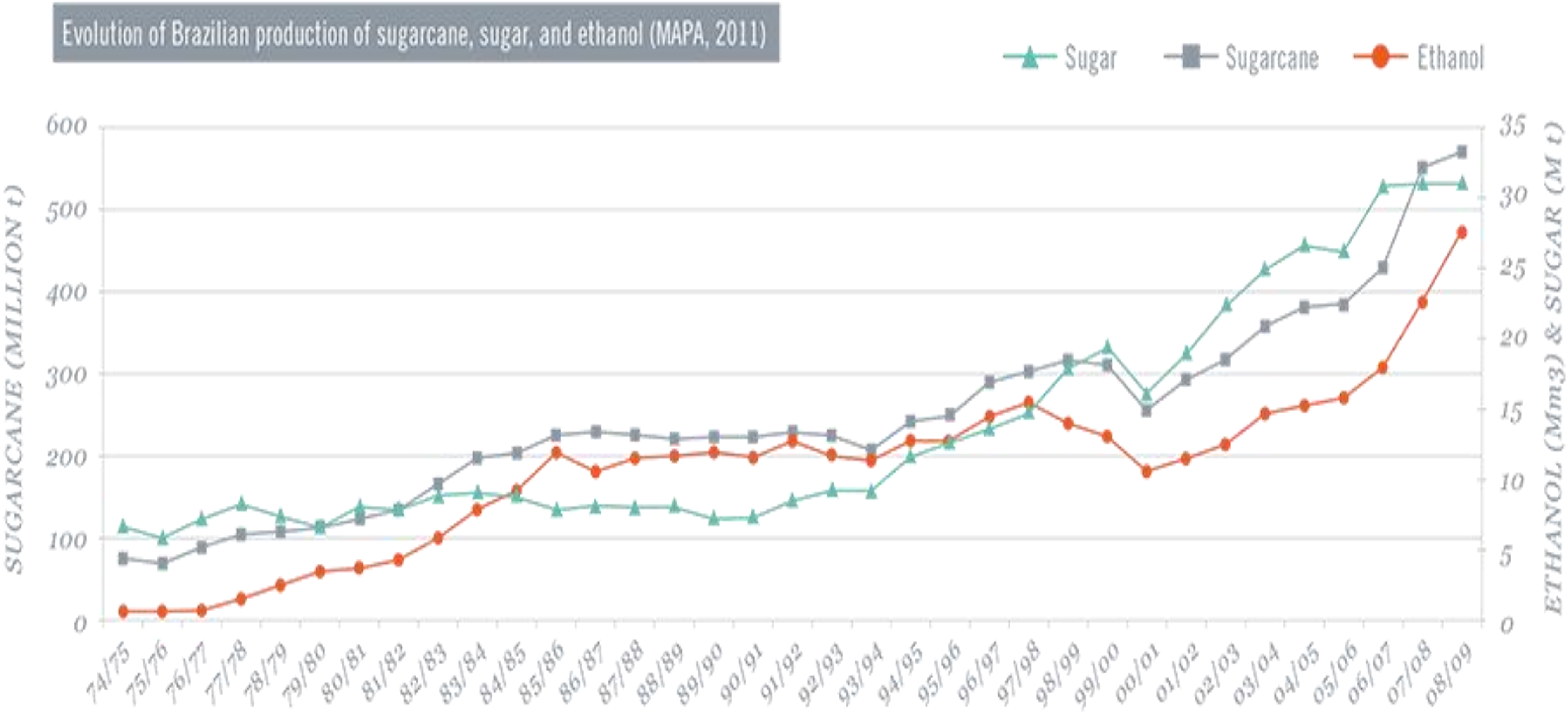


Natural carbon fixation through photosynthesis

……. and biofuel production

Natural carbon fixation through photosynthesis

…… and biofuel production



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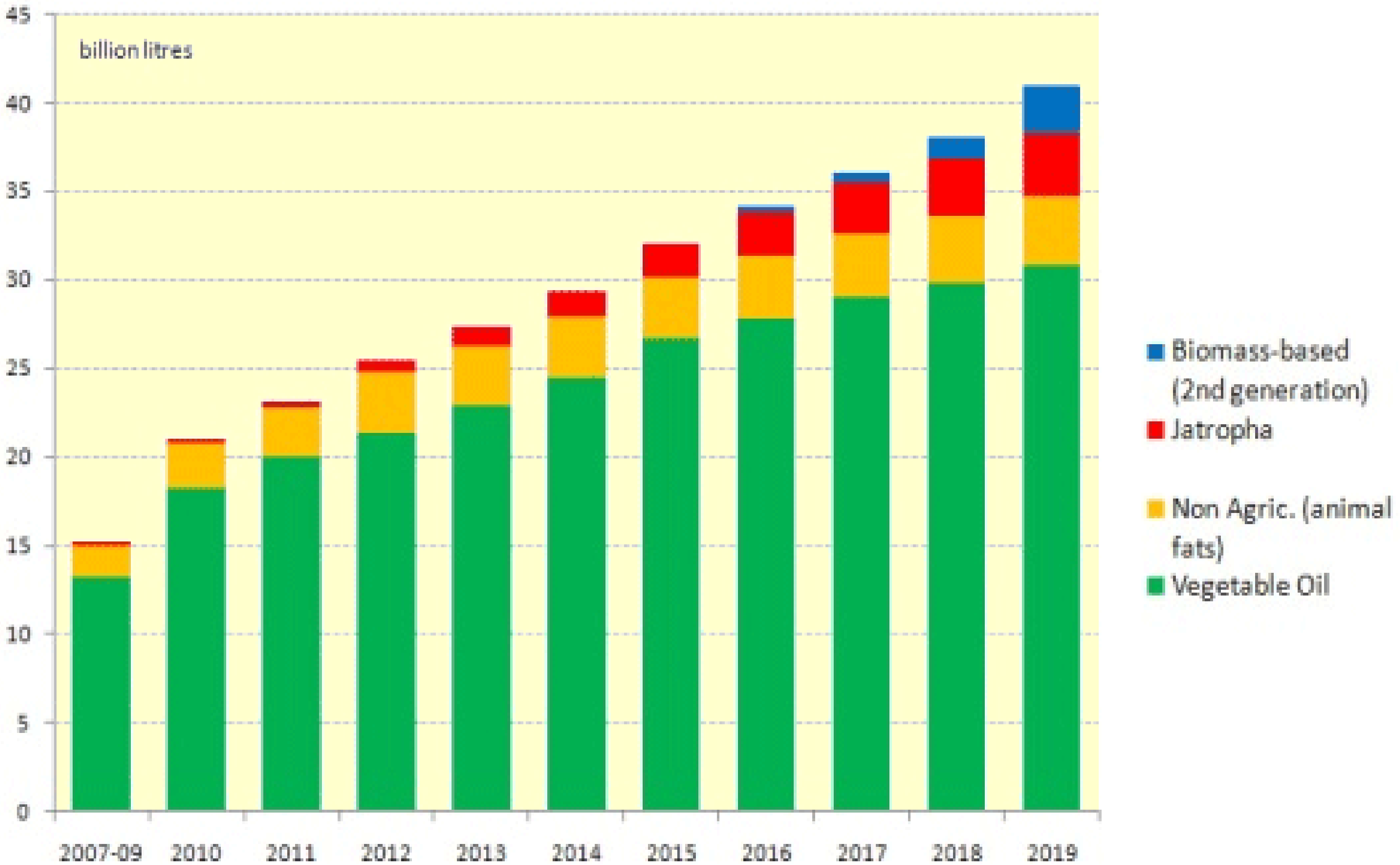
Global biodiesel production by feedstock



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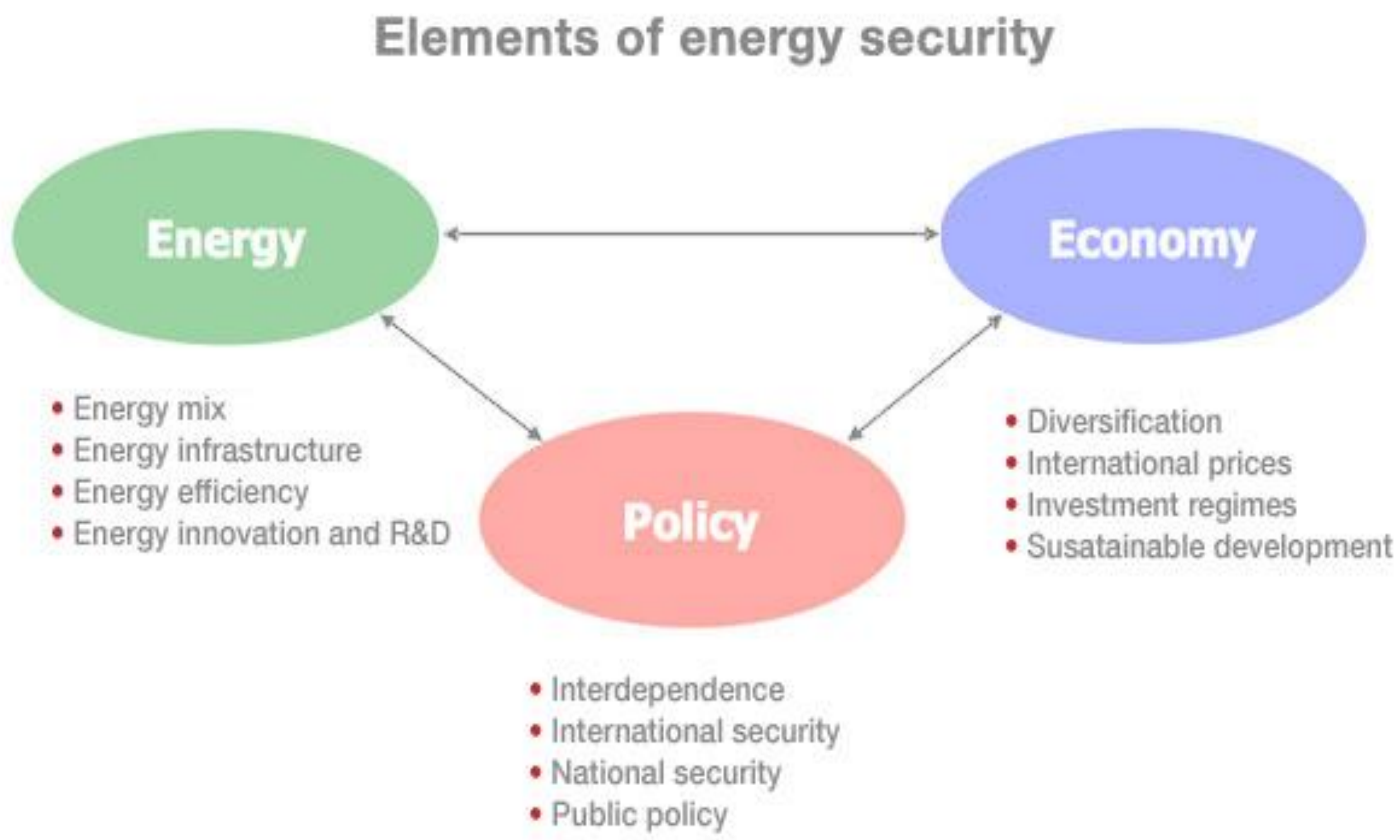
Energy security



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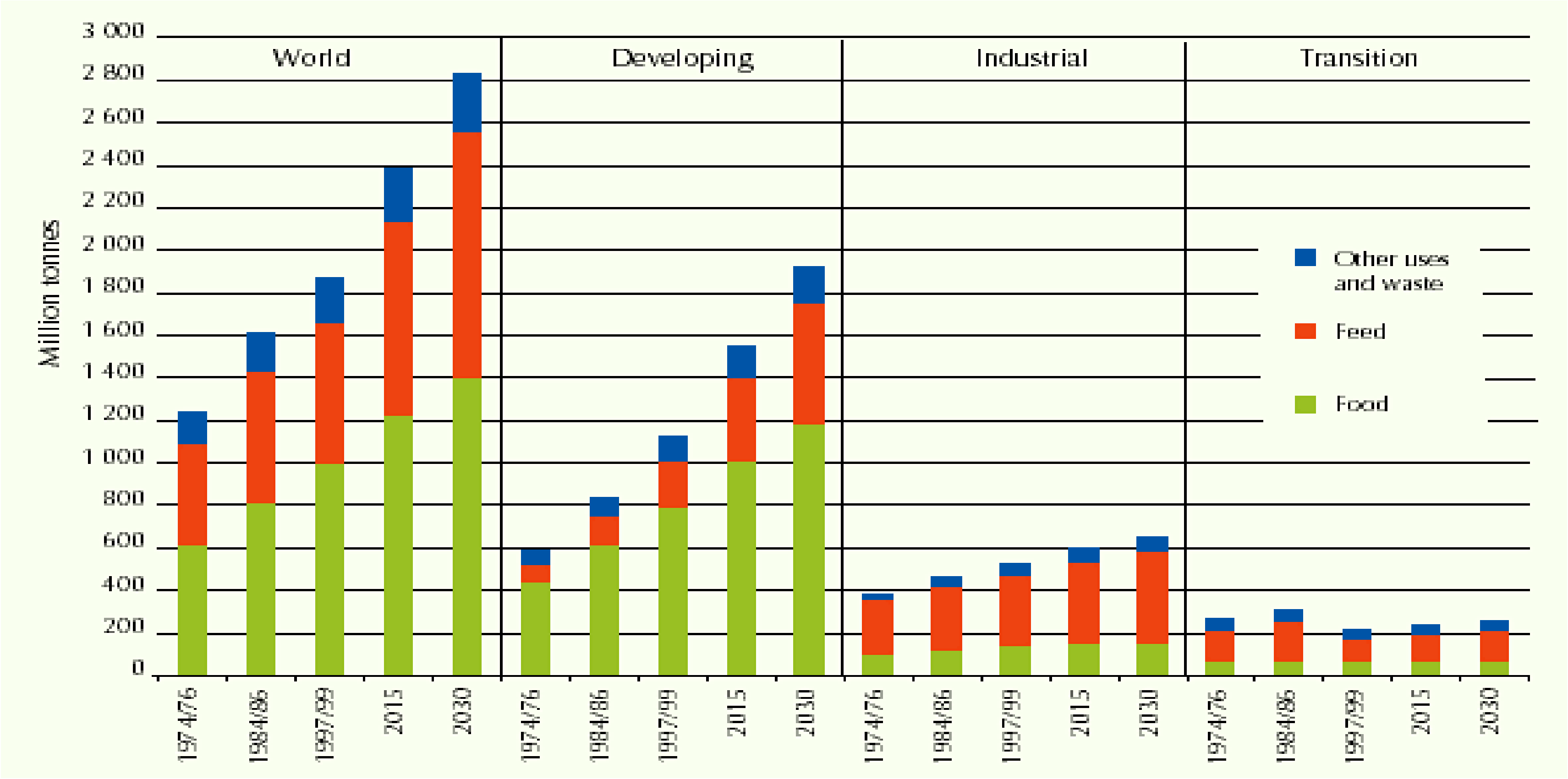
Food supply

Increasing food demand:

Aggregate consumption of cereals, by category of use (FAO, 2003)



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ALTERNATIVE
FUELS
WORLD
FOOD SUPPLY
HAITI

Water – energy – food nexus

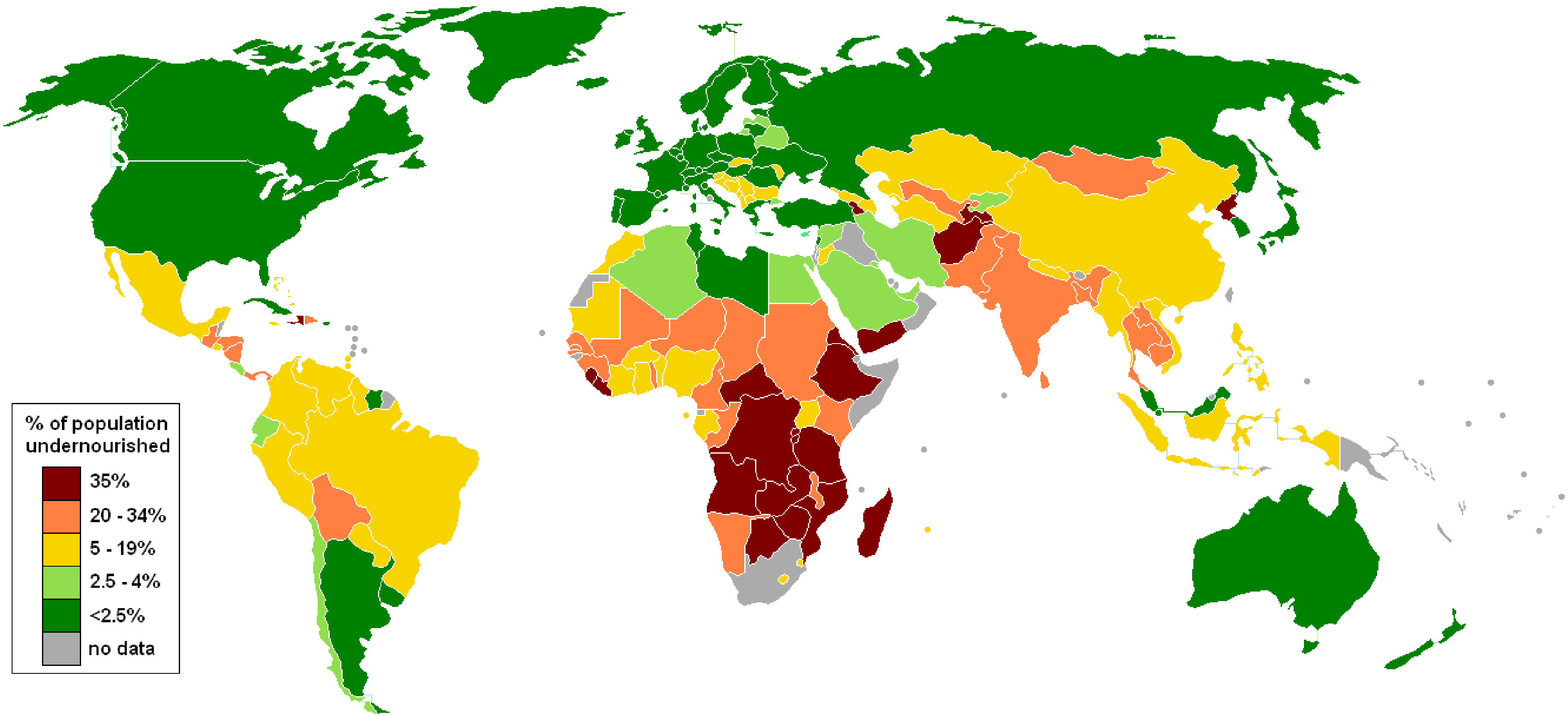
Biofuel v. food production

Water requirements for biofuel crops

Crop	Annual obtainable fuel yield	Energy yield	Evapo-transpiration equivalent	Potential crop evapo-transpiration	Rainfed crop evapo-transpiration	Irrigated crop water requirement	
	(L/ha)	*(G/ha)*	*(L/litre fuel)*	*(mm/ha)*	*(mm/ha)*	*(mm/ha)**	*(L/litre fuel)*
Sugar cane	6 000	120	2 000	1 400	1 000	800	1 333
Maize	3 500	70	1 357	550	400	300	857
Oil palm	5 500	193	2 364	1 500	1 300	0	0
Rapeseed	1 200	42	3 333	500	400	0	0

** On the assumption of 50% irrigation efficiency.*
Source: FAO (2008a).

Water – energy – food nexus

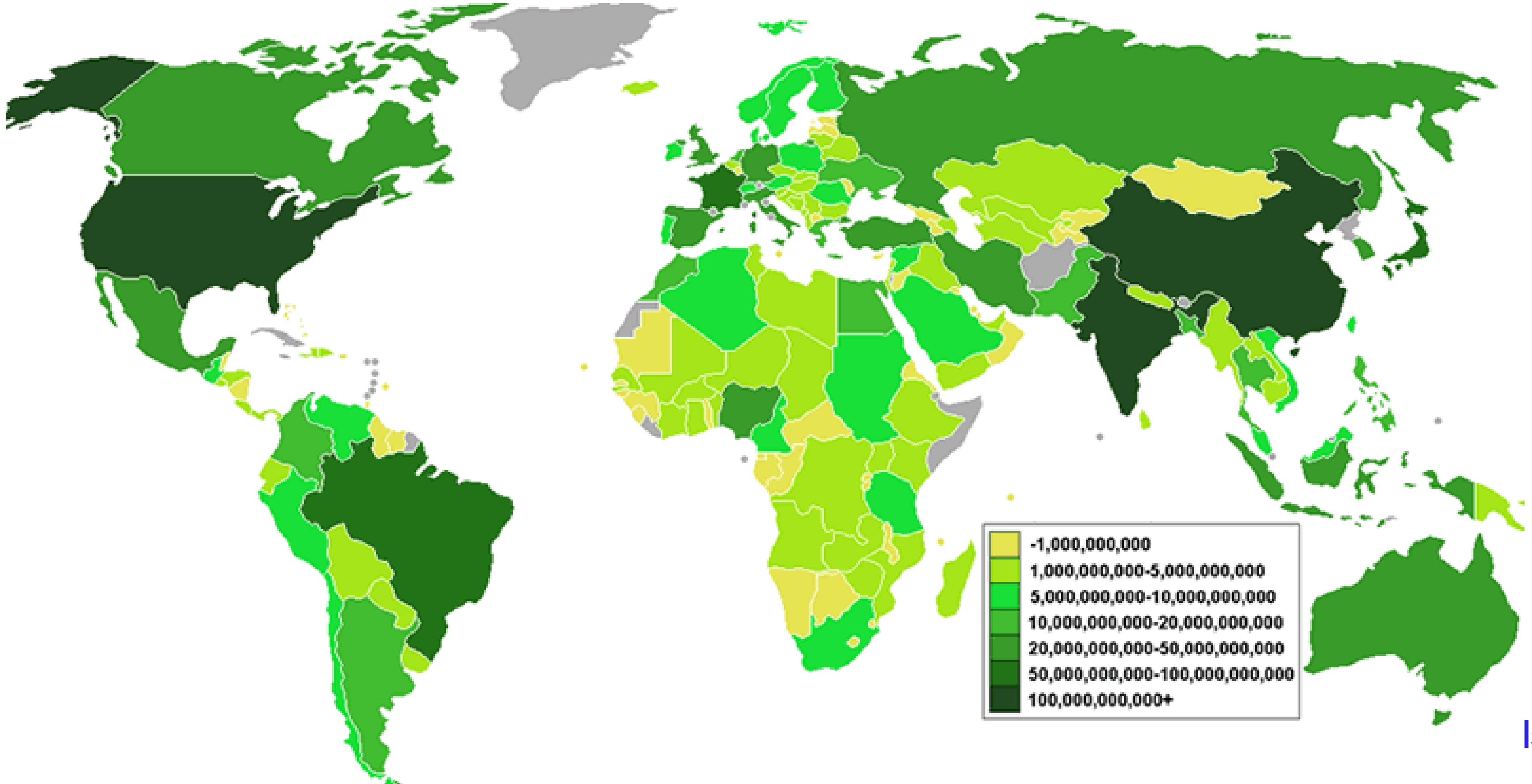


Population undernourished

Water – energy – food nexus

Agricultural production

The graphic below is depicting countries by USD value of their agricultural output, as of 2006.



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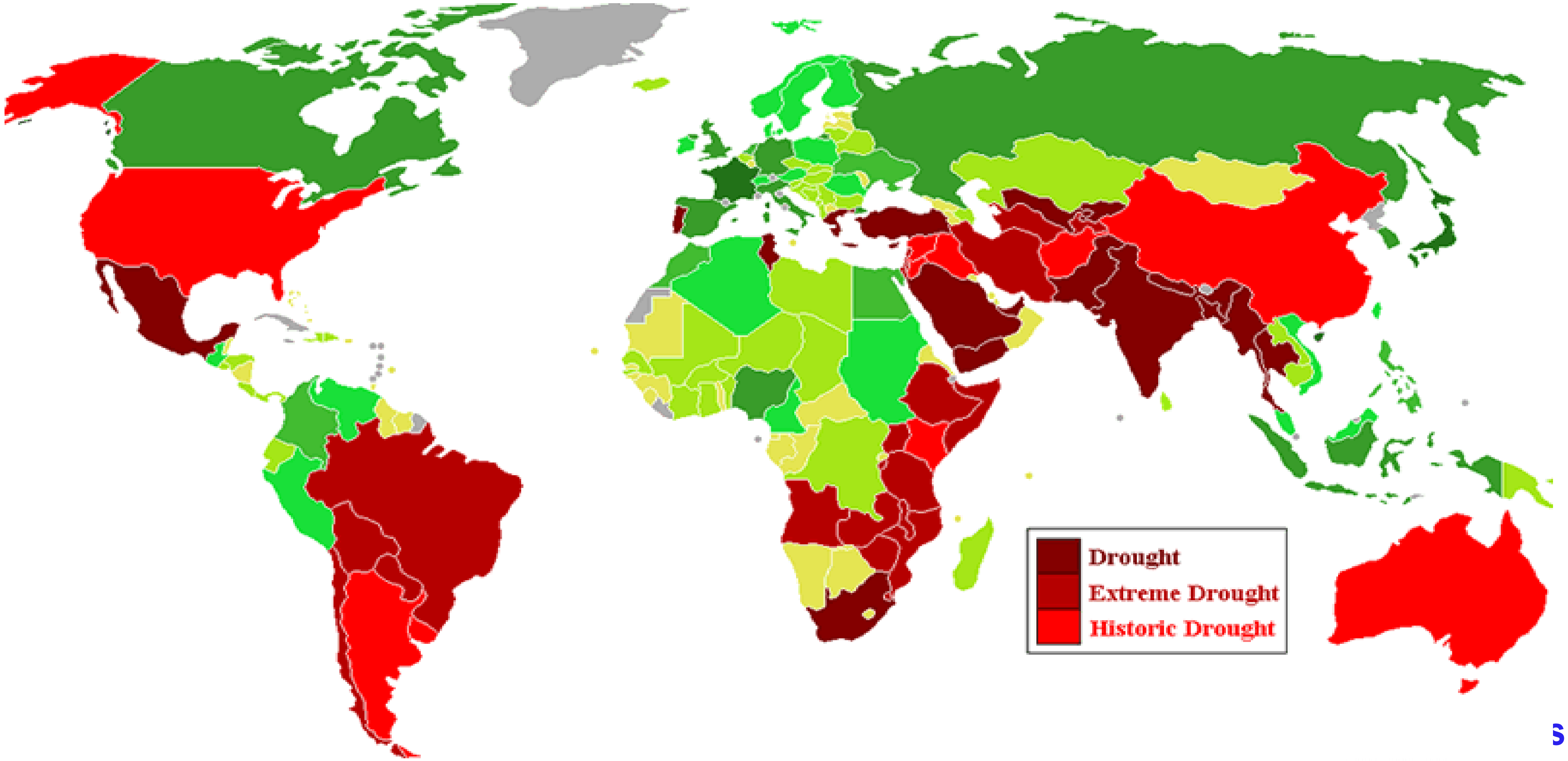
Water – energy – food nexus

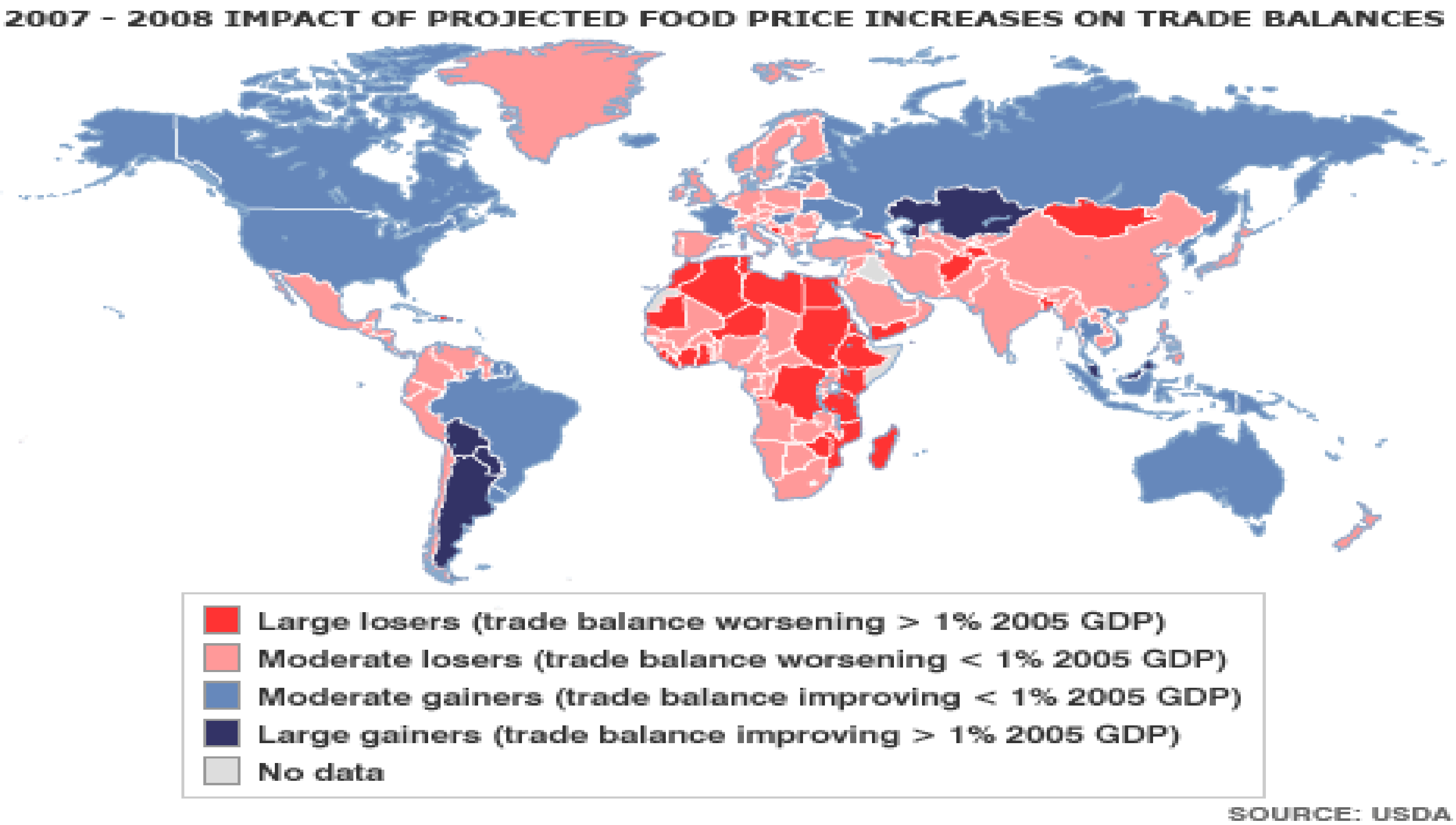
Food production – extreme weather

The countries that make up two thirds of the world's agricultural output are experiencing drought conditions.



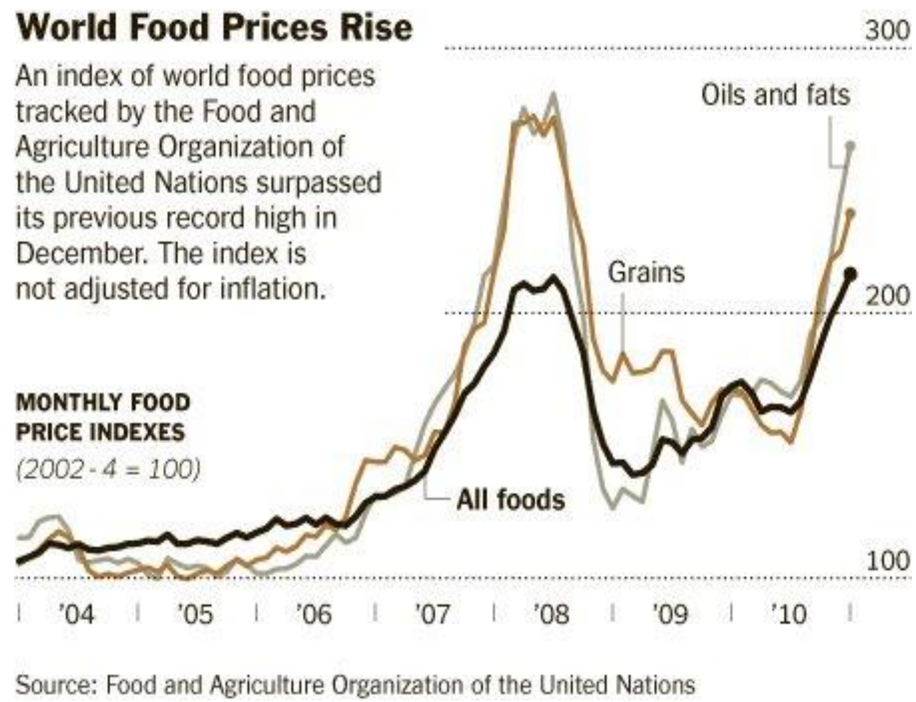
Water – energy – food nexus

Biofuel v. food production



Food supply

Food security: According to the Commission on Growth and Development, there are many potential causes for the steep food price increases. Contributing factors include rising demand, shifting diets, droughts, increased costs of agricultural inputs (such as fertilizers) and policies that encourage the use of agricultural land and output for bioenergy production.



Although there is no consensus yet on the relative importance of these factors, many believe that policies favouring bioenergy over food need to be reviewed.

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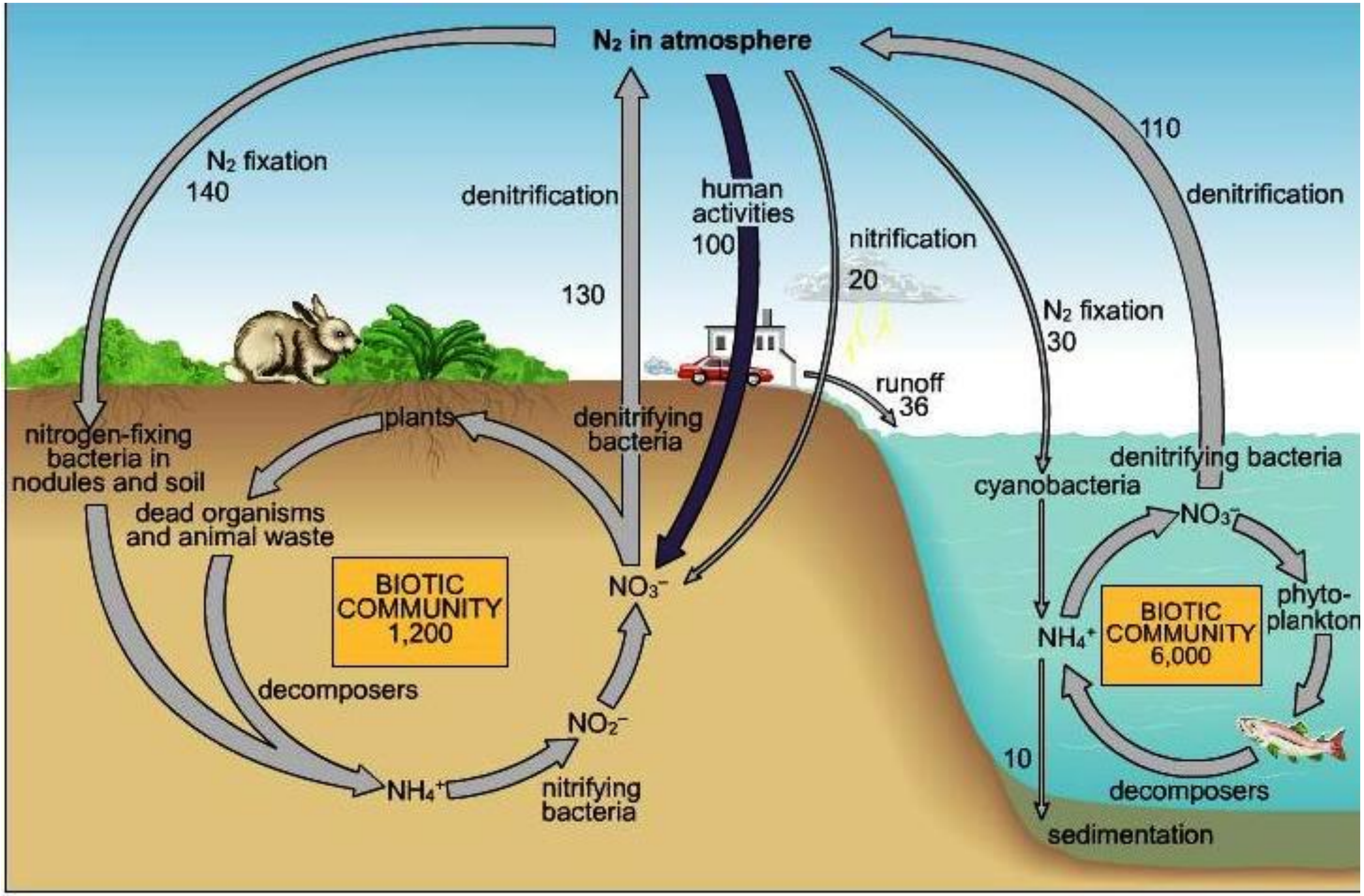
Nitrogen cycle



*Figures in Tg N/y [1000 Tg = 1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = 1x1015g]

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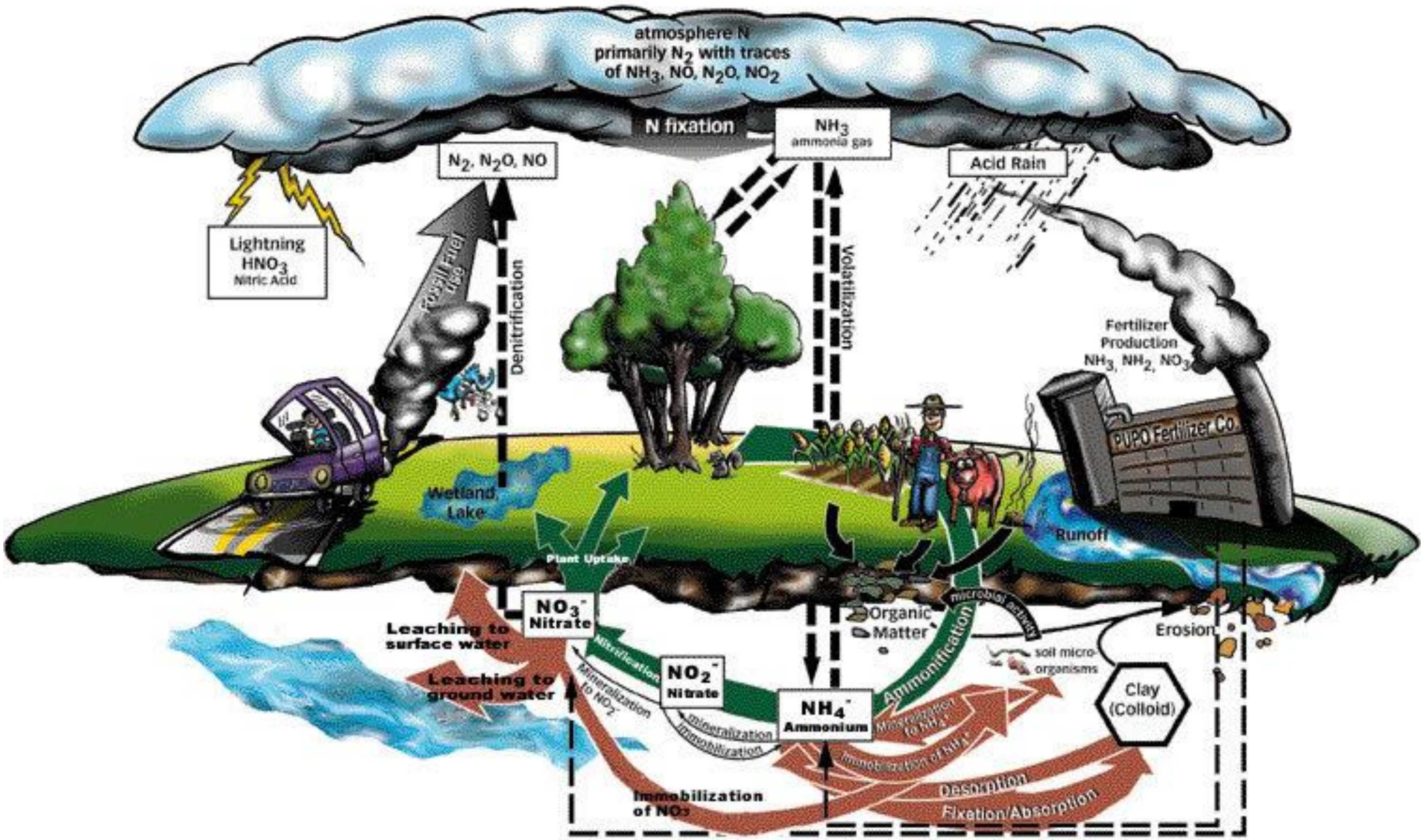
The nitrogen cycle is out of balance



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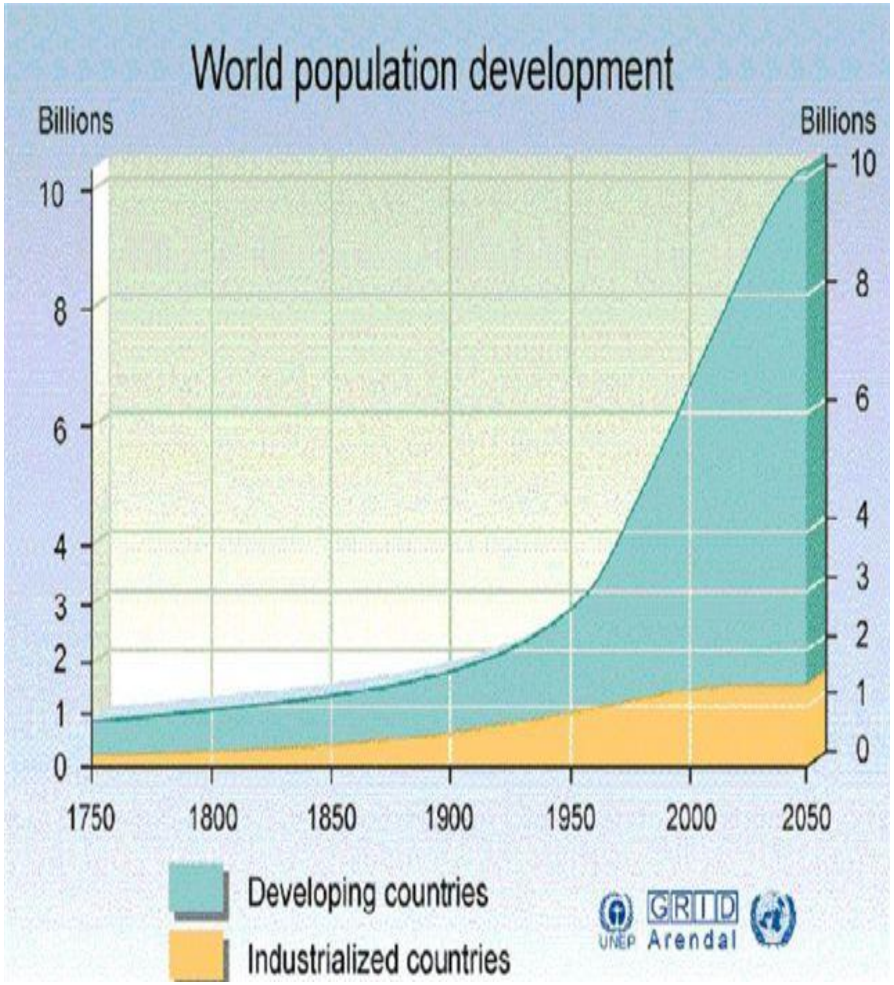
Demographic drivers

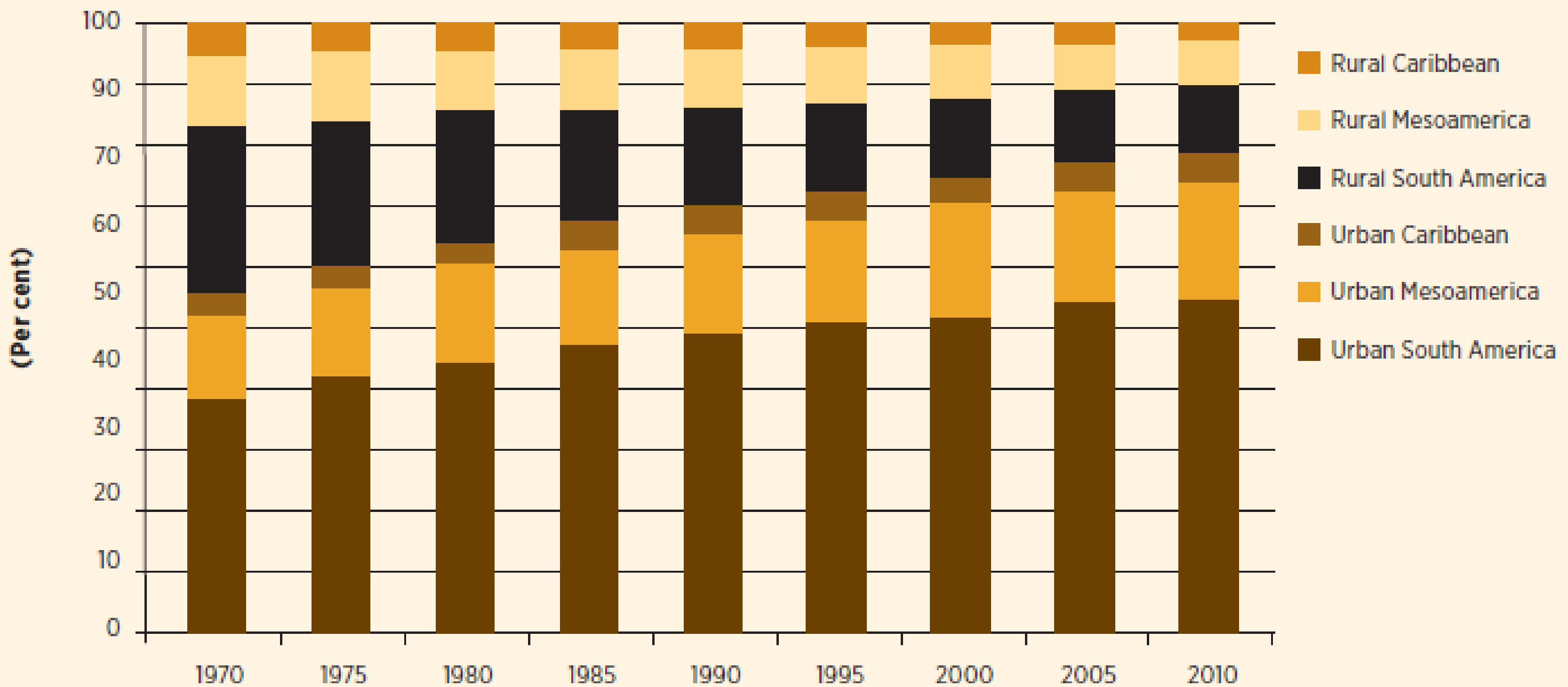
Population growth: The world's population is growing by about 80 million people a year, implying increased freshwater demand of about 64 billion cubic metres a year.

An estimated 90% of the 3 billion people who are expected to be added to the population by 2050 will be in developing countries, many in regions where the current population does not have sustainable access to safe drinking water and adequate sanitation.



Demographic drivers: urbanization in LATAM&C

Increase in urban populations between 1970 and 2010



Source: UNEP (2010a, p. 28, with statistics from the CEPAL STAT database [http://www.pnuma.org/geo/geoalc3/ing/graficosEn.php]).

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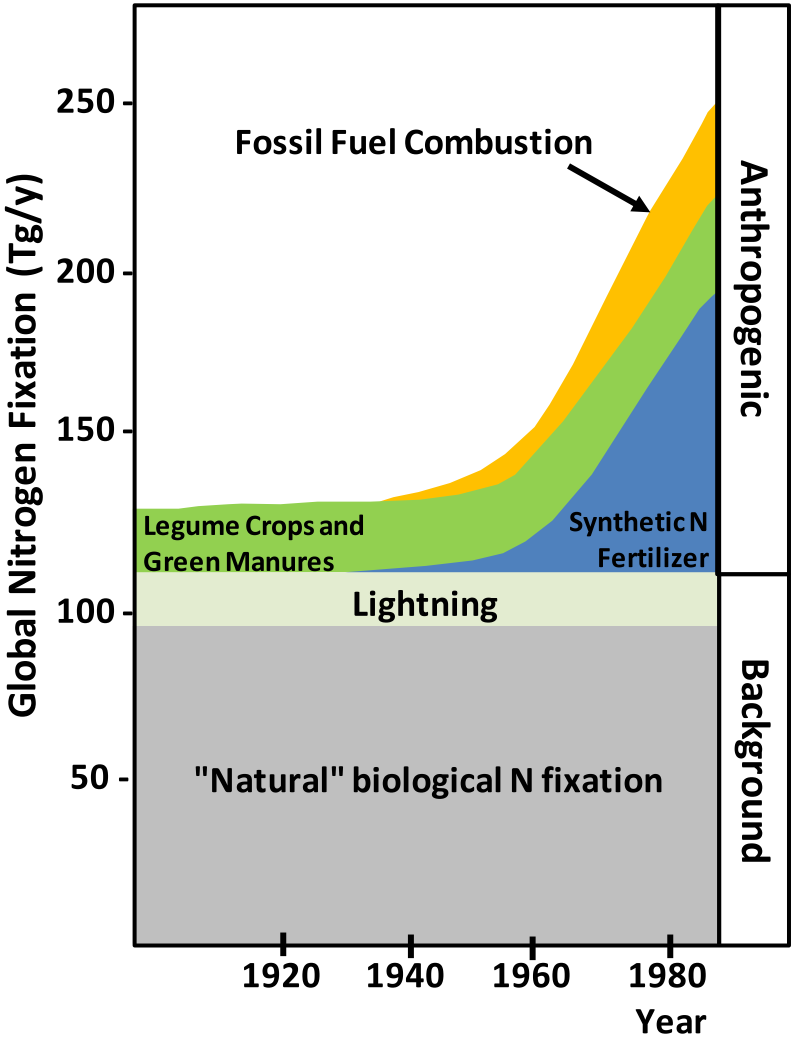
The nitrogen cycle is out of balance



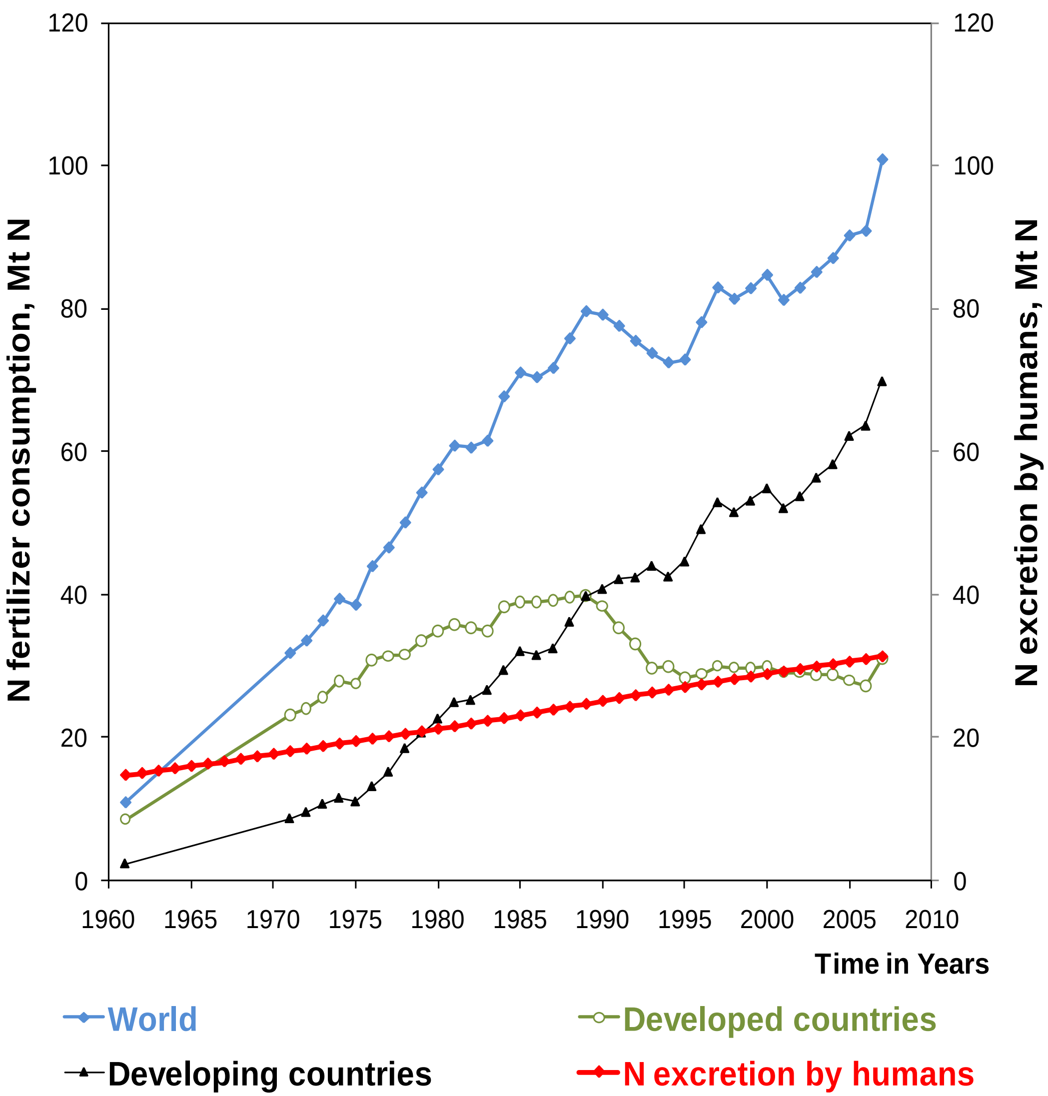
Reactive forms of nitrogen in terrestrial and marine environments (Tg N/y)*

1860	Early – 1990's	2050
125	163	221

*Galloway *et al.*, 2004. *Biochemistry*, **70**, 153-226

The reactive forms of nitrogen are accumulating in the environmental reservoirs

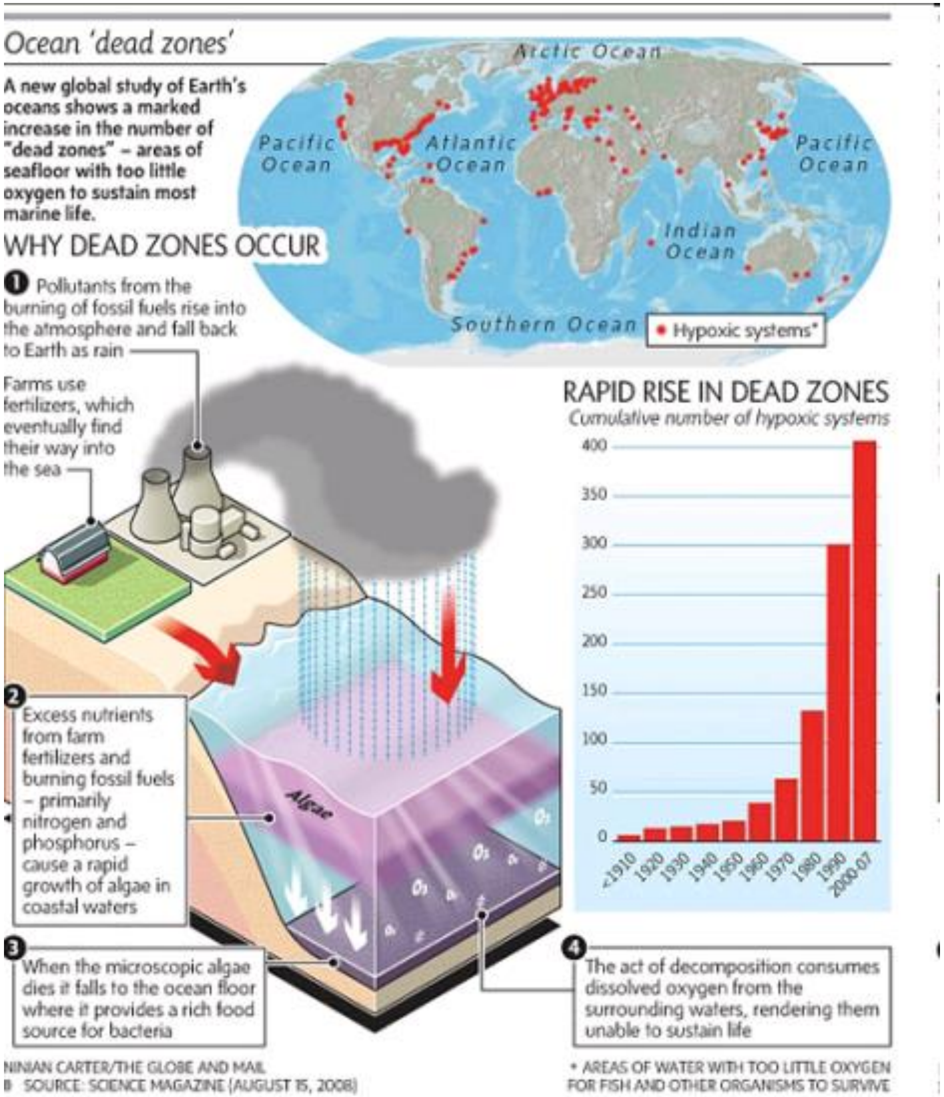
The nitrogen cycle is out of balance



The industrial production of nitrogen fertilizers has increased almost tenfold in the past seven decades.

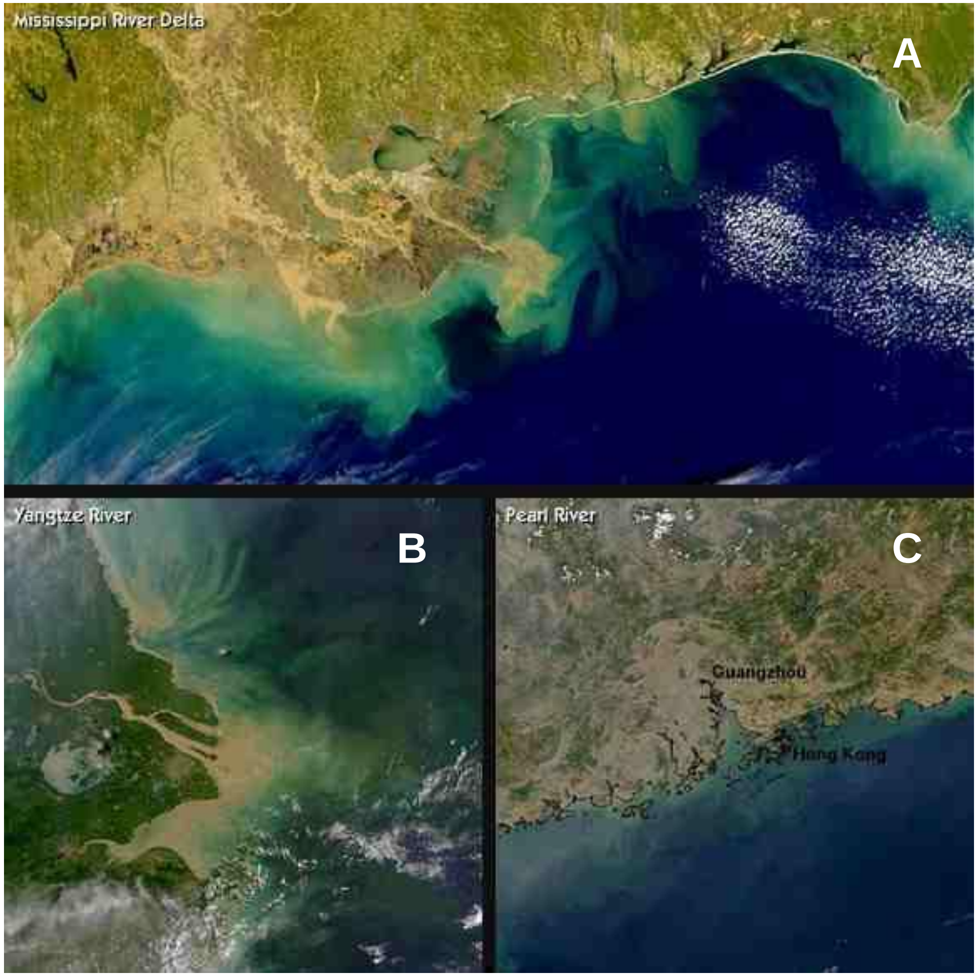
Developing countries are more likely to suffer the consequences of nitrogen discharges in water bodies.

The nitrogen cycle is out of balance



Ocean 'dead zones' have increased rapidly over the last 50 years; in fact there were only ten documented cased of hypoxia in 1960. Diaz and Rosenberg report in the 15 August 2008 issue of *Science*, that 'dead zones' have now been reported from more than 400 systems, affecting an area of 245,00 km^2

The nitrogen cycle is out of balance



SeaWiFS* observations

A - Mississippi River delta
B - Yangtze River mouth in China
C - Pearl River mouth in China, near Hong Kong

*Sea-viewing Wide Field-of-view Sensor (SeaWiFS)

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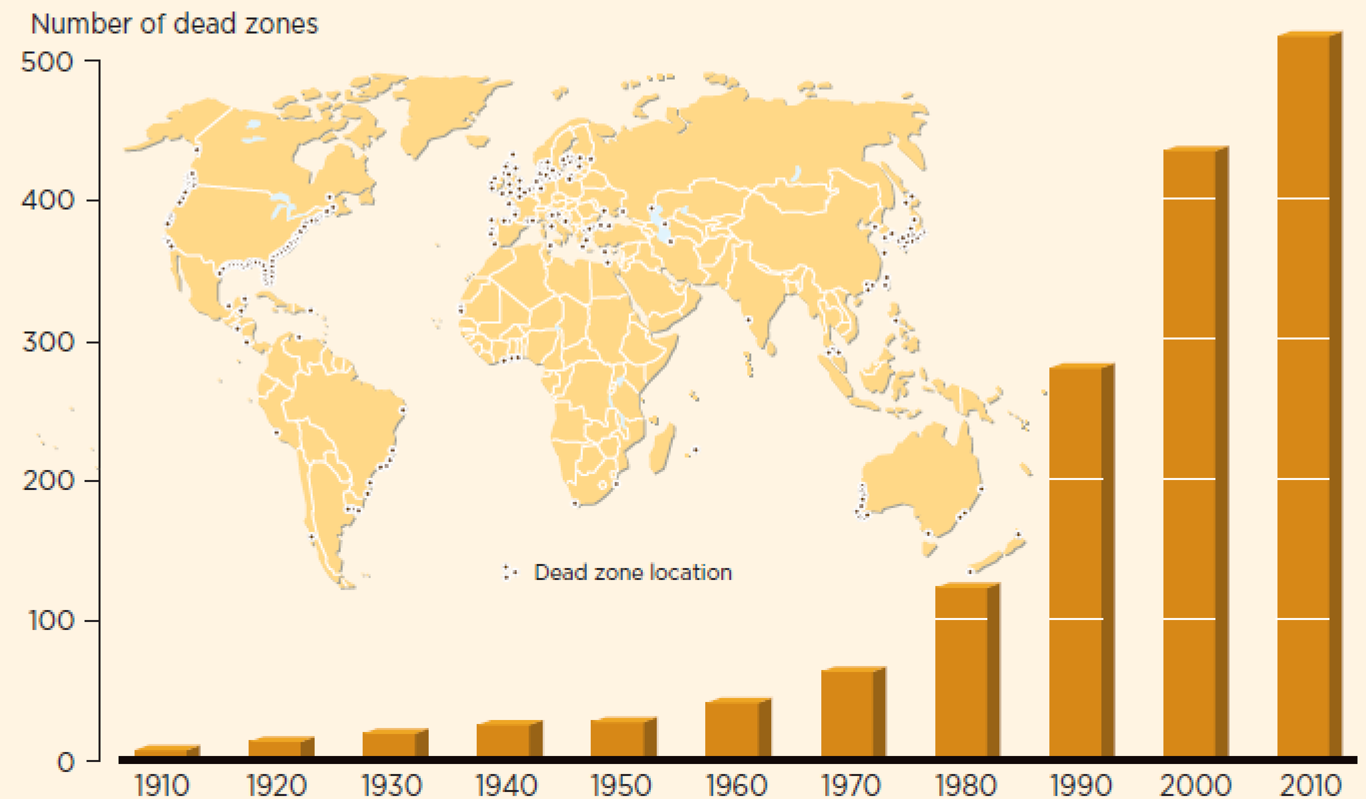
Economic drivers: development v. pollution

Nutrient loading in inland and coastal waters



Note: The number of observed 'dead zones', coastal sea areas where water oxygen levels have dropped too low to support most marine life, has roughly doubled each decade since the 1960s. Many are concentrated near the estuaries of major rivers, and result from the buildup of nutrients, largely carried from inland agricultural areas where fertilizers are washed into watercourses. The nutrients promote the growth of algae that die and decompose on the seabed, depleting the water of oxygen and threatening fisheries, livelihoods and tourism.
Source: CBD (2010a, fig. 15, p. 60).

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The nitrogen cycle is out of balance

•Denitrification Contributes to Greenhouse Gas Emissions

- Nitrous oxide (N_2O) is a long-lived greenhouse gas (atmos-pheric lifetime ≈114 years) and over a 100-year period, each molecule of N_2O has a direct global warming potential 298 times that of a single molecule of CO_2.
- Emissions of N_2O primarily result from bacterial breakdown of nitrogen in soils and in the earth's oceans. Globally, soils covered by natural vegetation are estimated to produce 6.6 Tg of N_2O /year and oceans, rivers and estuaries are thought to add around 5.4 Tg of N_2O annually to the atmosphere*.

Source: US EPA (2010), *EPA 430-R-10-001*, Washington, April

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The nitrogen cycle is out of balance

- **Eutrophication** is the excessive growth of aquatic plants…

… which is produced by uncontrolled discharges of **nitrogen** and phosphorus

The nitrogen cycle is out of balance

 

The presence of **ammonia**, together with high **phytoplanktonic activity** in rivers and lakes, may cause toxic effects on fish population

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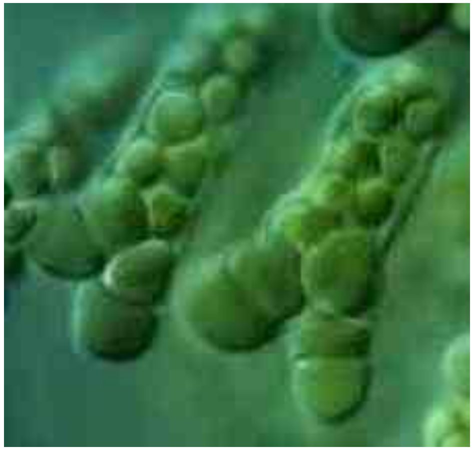
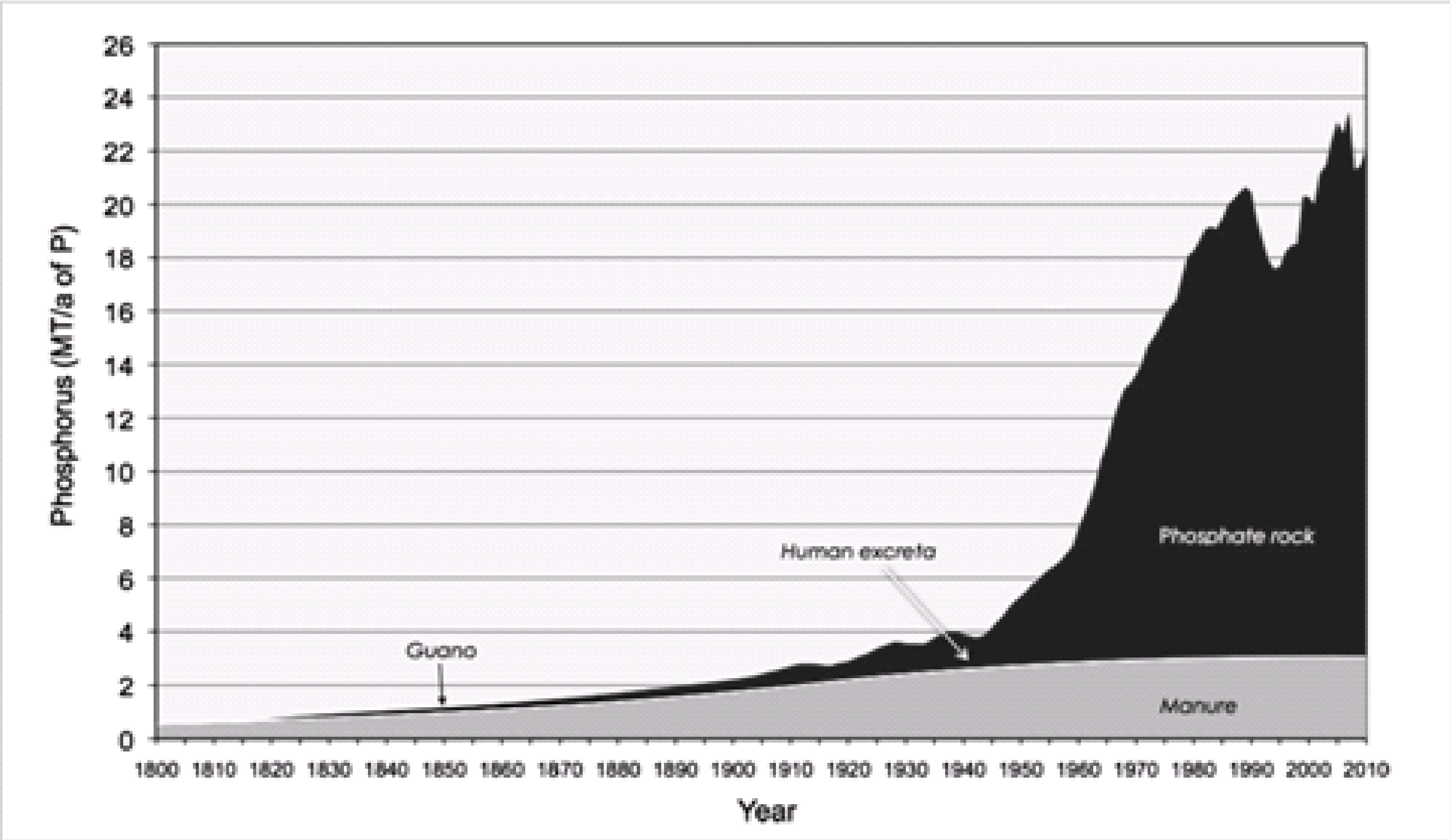
The nitrogen cycle is out of balance

Microcystin-LR, a toxin produced by cyanobacteria or blue-green algae. They occur widely in lakes, reservoirs, ponds and slow-flowing rivers. Many species are known to produce toxins, or "cyanotoxins", which are of concern for health.

There is wide variation in the toxicity of recognized cyanotoxins (including different structural variants within a group, such as microcystins), and it is likely that further toxins remain unrecognized, so control of blooms is the preferred control option.



Phosphorus is a non-renewable resource



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Phosphorus is a non-renewable resource

Table 2 World phosphate rock reserves, reserve bases and production

Country	Mine production, tons 2010	Mine production, tons 2011	Reserves, tons
United States	25,800	28,400	1,400,000
Algeria	1,800	1,800	2,200,000
Australia	2,600	2,700	250,000
Brazil	5,700	6,200	310,000
Canada	700	1,000	2,000
China	68,000	72,000	3,700,000
Egypt	6,000	6,000	100,000
India	1,240	1,250	6,100
Iraq	—	—	5,800,000
Israel	3,140	3,200	180,000
Jordan	6,000	6,200	1,500,000
Mexico	1,510	1,620	30,000
Morocco and Western Sahara	25,800	27,000	50,000,000
Peru	791	2,400	240,000
Russia	11,000	11,000	1,300,000
Senegal	950	950	180,000
South Africa	2,500	2,500	1,500,000
Syria	3,000	3,100	1,800,000
Togo	850	800	60,000

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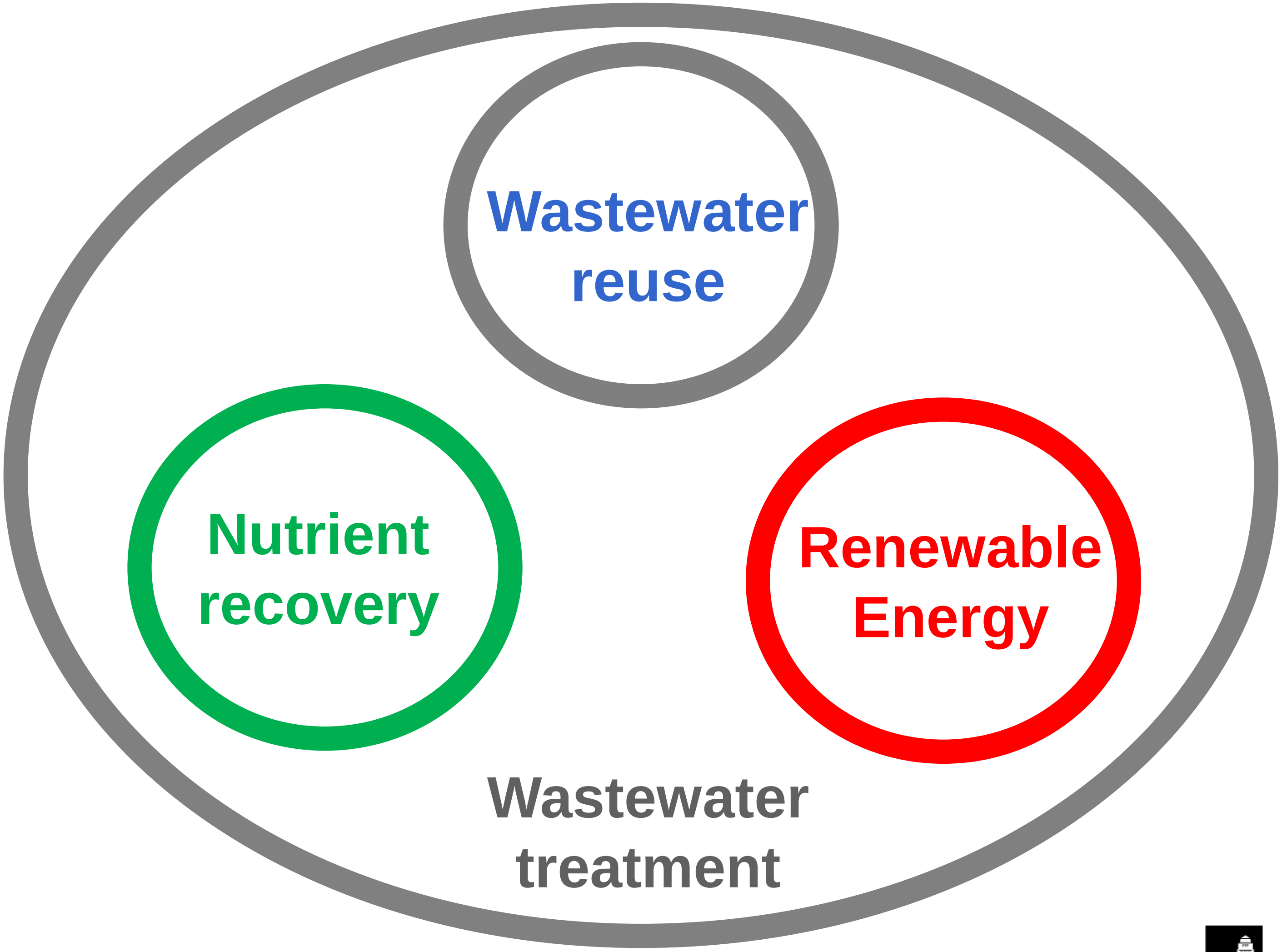
Sustainable wastewater treatment



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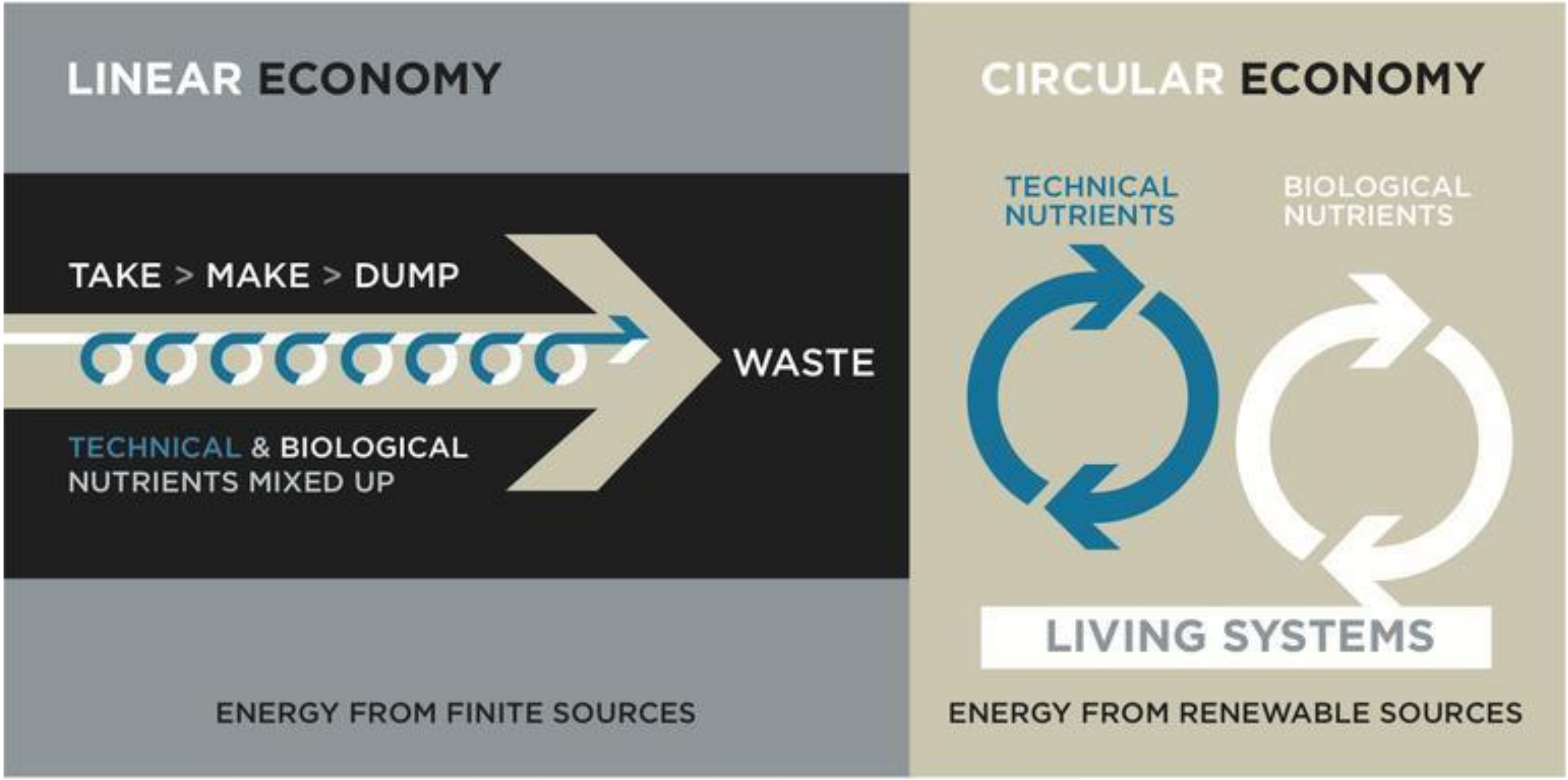
Sustainable urban metabolism



http://circulareconomy.wikispaces.com/file/view/Circular%20linear%20economy.jpg/344676144/800x413/Circular%20linear%20economy.jpg

Four dimensions of value in a circular economy context

Environmental metrics

Technical metrics

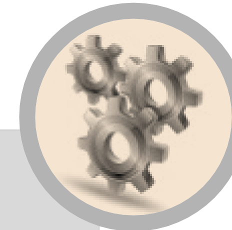
Social metrics

Economic metrics

Four dimensions of value: CVORR project - Leeds

Environmental dimension

- Life Cycle Assessment
- Eco-efficiency analysis
- Environmental Impact Assessment
- Strategic Environmental Assessment



Technical dimension

- Materials mechanical performance
- Green design
- Risk Assessment
- Eco-efficiency analysis

Social dimension

- Life Cycle Costing
- Risk Assessment

Economic dimension

- Cost-benefit analysis
- Value-chain analysis
- Eco-efficiency analysis
- Systems of provision

CVORR project: http://sure-infrastructure.leeds.ac.uk/cvorr/

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“Cogito ergo sum”

“I think, therefore I am”

Rene Descartes

“Cacō ergo sum”

Anus-nymus

“I shit, therefore I am”

Anus-nymous

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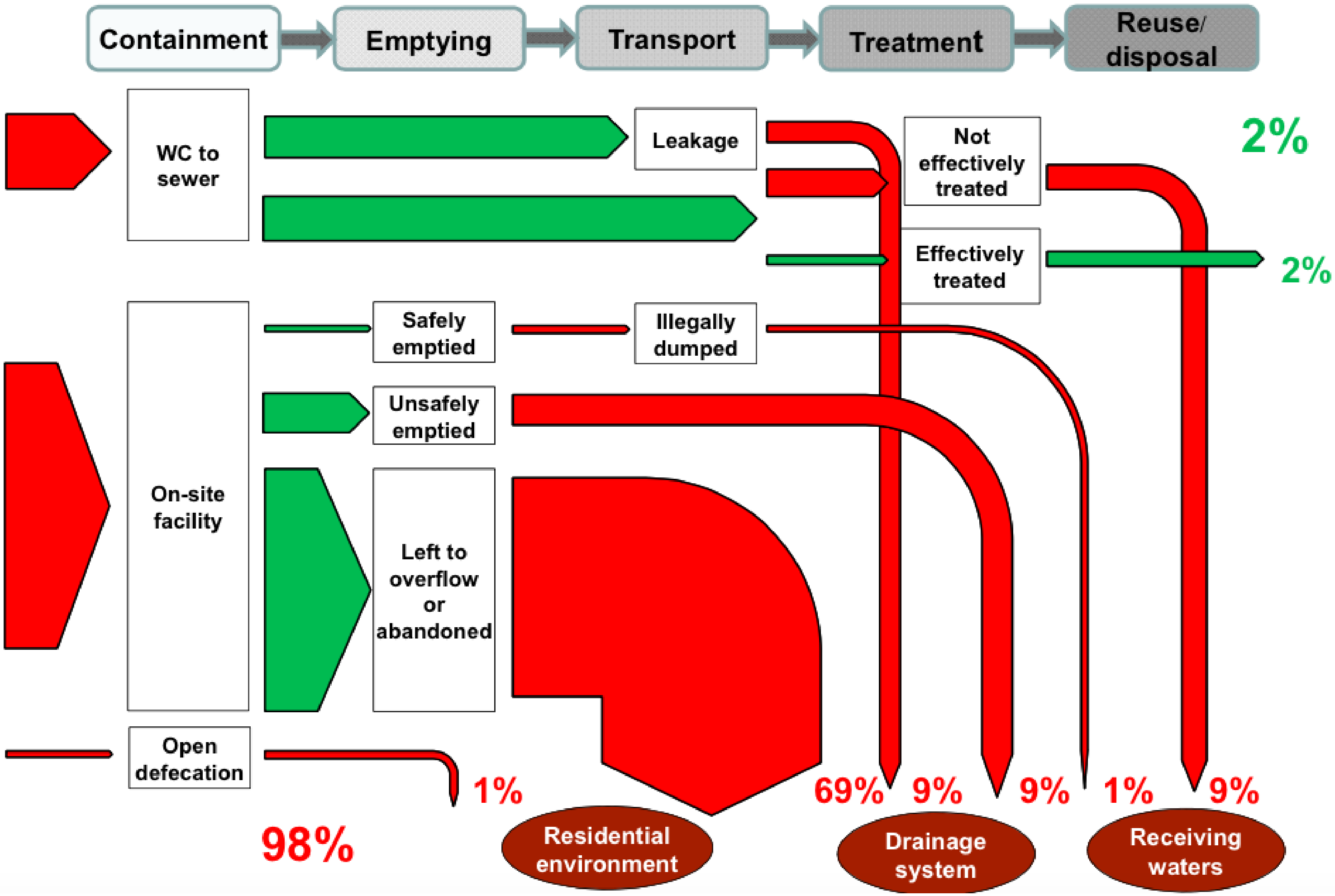
Energy, nutrients and water

Resource recovery from wastewater

CNPK in wastewater streams

kg/person yr:		Brown	Yellow	Grey
N	~4–5	~10%	**~87%**	~3%
P	~0.75	~40%	**~50%**	~10%
K	~1.8	~12%	**~54%**	~34%
COD	~30	~47%	**~12%**	~41%

Resource recovery according to local needs



Bangladesh

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Resource recovery from faecal sludge

Pit latrines in Bangladesh






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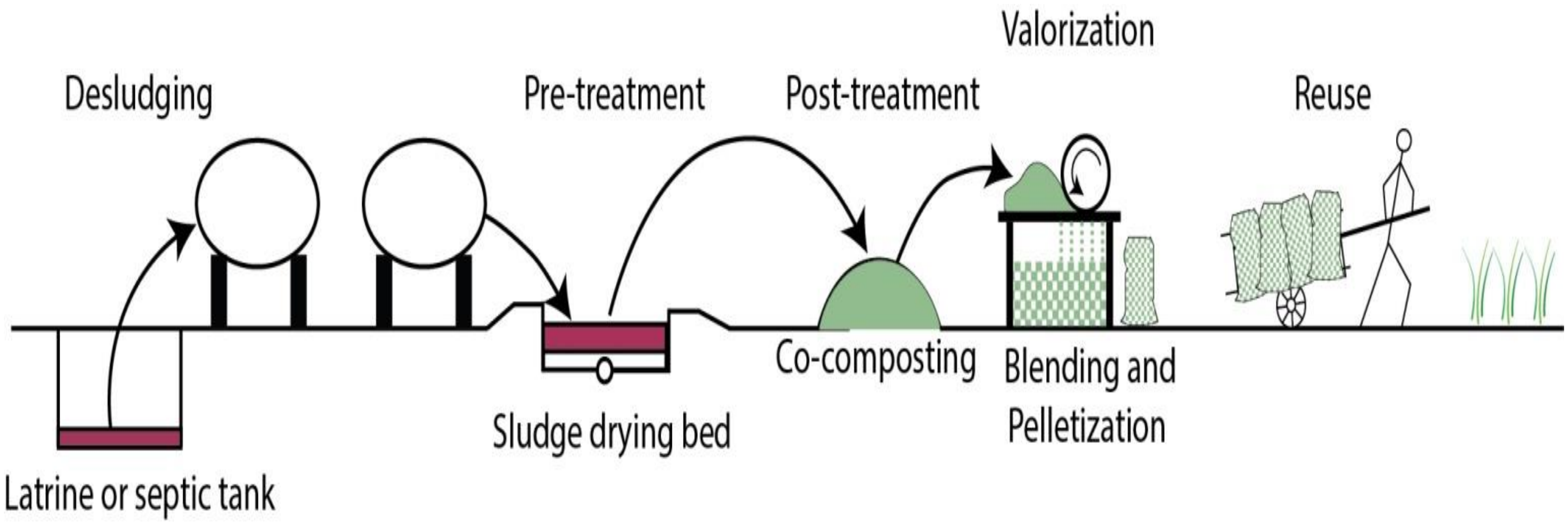
VeSV: Sanitation Value Chain



VeSV: Sanitation Value Chain

WP 4: Pit emptying

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VeSV: Sanitation Value Chain

(a) Gulper pump

(b) Electric pump

(c) Diesel pump

(e) Diaphragm pump

Figure 2 Different types of pumps tested for pit emptying practices.

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VeSV: Sanitation Value Chain

Table 4 Physical and chemical characteristics of FS samples from single pit latrines

District	Moisture (wt%)	pH	Conductivity (mmho/cm)	TVS (wt%)	TOC (wt%)	TN (wt%)	C/N	PO_4-P (wt%)
Gazipur	83.68	7.35	3.34	68.56	36.38	3.70	9.52	2.10
Noakhali	88.10	7.08	5.02	68.65	37.23	3.91	10.09	2.13
Khulna	91.34	7.94	4.76	74.37	39.32	3.66	10.91	2.25
Mymengsingh	90.54	7.73	3.51	68.09	54.34	3.15	12.83	1.67
Feni	90.54	7.81	4.58	77.88	41.19	3.98	11.12	2.49
Mean	88.84	7.58	4.24	71.51	41.69	3.68	10.89	2.13

TVS = Total volatile solids; TOC = Total organic carbon; TN = Total nitrogen; C/N = carbon to nitrogen ratio

VeSV: Sanitation Value Chain

Table 5 Microbiological characteristics of FS samples from single pit latrines

District	Total coliforms, cfu/g	E. coli, cfu/g	Helminth eggs egg/g	Helminth eggs Group
Gazipur	5.2E+06	3.5E+06	20	*Ascaris lumbricoides*
Noakhali	7.9E+04	2.3E+04	119	*Ascaris lumbricoides, Trichuris trichiura, Enterobius vermicularis, Hymenolepis nana*
Khulna	1.4E+05	9.8E+04	32	*Ascaris lumbricoides, Hymenolepis nana,*
Mymengsingh	1.9E+05	9.0E+04	13	*Enterobius vermicularis, Taenia spp*
Feni	1.8E+06	7.6E+05	23	*Enterobius vermicularis, Ascaris lumbricoides,*
Mean	1.5E+06	9.0E+05	41	

VeSV: Sanitation Value Chain

(a) Drying beds – masonry work

(b) Drying beds – plastering work

(c) Drying bed 1 with plastic cover

(d) Drying bed 2 with rigid cover

Figure 5 Sand drying beds at Purbapara, Gazipur

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VeSV: Sanitation Value Chain

WP 5: Drying and composting

VeSV: Sanitation Value Chain

WP 5: Drying and composting

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VeSV: Sanitation Value Chain

WP 5: Drying and composting

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VeSV: Sanitation Value Chain

WP 5: Drying and composting

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VeSV: Sanitation Value Chain

Potential use as energy source

VeSV: Uganda

Lubigi, sewage treatment work, Kampala, Uganda

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VeSV: Uganda

Pumping station

Inlet discharge

Screens

Grit removal + Parshall flume

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VeSV: Uganda

Tanker with faecal sludge and septage

Drying beds

WSP system

(co)-composting

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Wastewater reuse for food and energy crops

Calado-Araujo *et al.*, 2015
Federal University of Rio Grande do Norte, Natal, Brazil

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Wastewater reuse for food and energy crops

Maturation ponds for pathogen control and nutrient recycle

Calado-Araujo *et al.,* 2015
Federal University of Rio Grande do Norte, Natal, Brazil

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Wastewater reuse for food and energy crops

Elephant grass for the production of briquettes

Calado-Araujo *et al.,* 2015
Federal University of Rio Grande do Norte, Natal, Brazil

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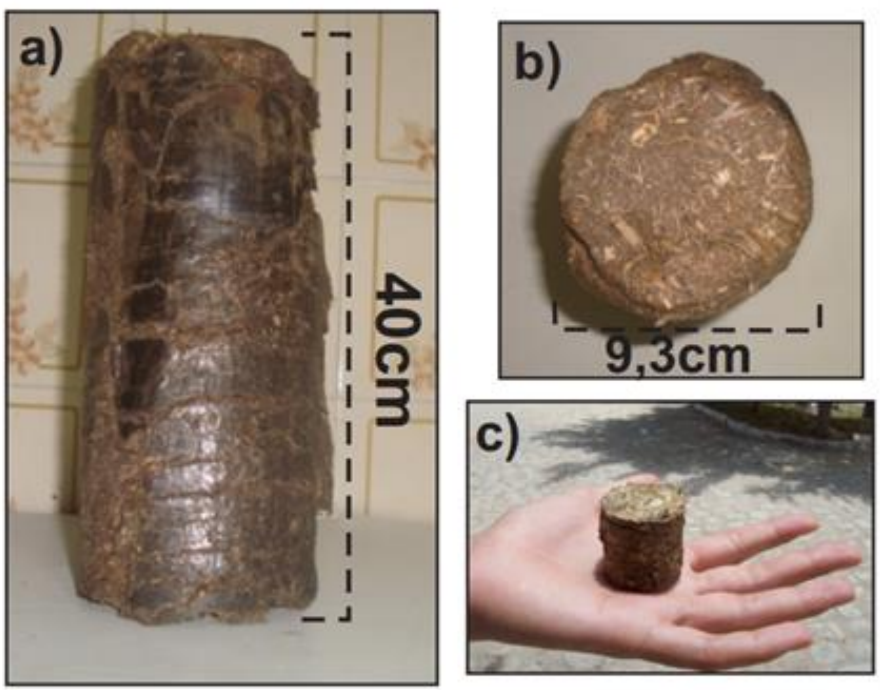
Analysis of ecological wood: the briquette

Briquette	Experiment		
	E1-5	E2-5	E3-3
Moisture content (%)	7.3	10.0	7.0
Calorific power (Kcal/kg)*	4,130	4,090	4,170

***Expected values = 4100 – 4500 Kcal/kg**

*** Native firewood = 3,300 Kcal/kg**



Other kinds of biomass largely produced in the northeast of Brazil, such as sugarcane bagasse, can also be used as raw material for briquette making.

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WSP systems for bioenergy production

All-gas project, FCC Aqualia

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Wastewater reuse and nutrient recovery

Wastewater for agriculture

- 20 million ha of land are irrigated with wastewater worldwide (1.3m ha in China)
- By 2025, 3.5 billion people (48% of the projected population) will reside in river basins considered to be water stressed (<1700 m^3/person/yr)*
- Nearly a billion people are employed in urban and peri-urban farming and related enterprises

*World Resources Institute, 2000

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Wastewater reuse and nutrient recovery

Positive effects	Negative effects
• Conserves water • Low-cost method for sanitary disposal of municipal wastewater • Reduces pollution of rivers, canals and other surface water resources • conserves nutrients, reducing the need for artificial fertilizer • increases crop yields • provides a reliable water supply to farmer	• Health risks for irrigators and communities with prolonged contact with untreated wastewater and consumers of vegetables irrigated with wastewater • Contamination of groundwater • Build-up of chemical pollutants in the soil • Creation of habitats for disease vectors • Excessive growth of algae and vegetation in distribution canals

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Wastewater reuse and nutrient recovery

SUMMARY OF RECOMMENDATIONS IN THE GUIDELINES

The 2006 WHO Guidelines make the following recommendations, either explicitly or implicitly:

- To protect the health of those working in wastewater-irrigated fields against excessive risks of viral, bacterial and protozoan infections, there should be a 3–4 log unit pathogen reduction, which is to be achieved by wastewater treatment.
- To protect the health of those consuming wastewater-irrigated food crops against excessive risks of viral, bacterial and protozoan infections, there should be a 6–7 log unit pathogen reduction, which is to be achieved by wastewater treatment (a 3–4 log unit reduction, as for restricted irrigation) supplemented by post-treatment health-protection control measures providing together a further 2–4 log unit pathogen reduction.
- To protect the health of those working in wastewater-irrigated fields and those consuming wastewater-irrigated food crops against excessive risks of helminthic infections, the treated wastewater should contain ≤1 human intestinal nematode egg per litre.

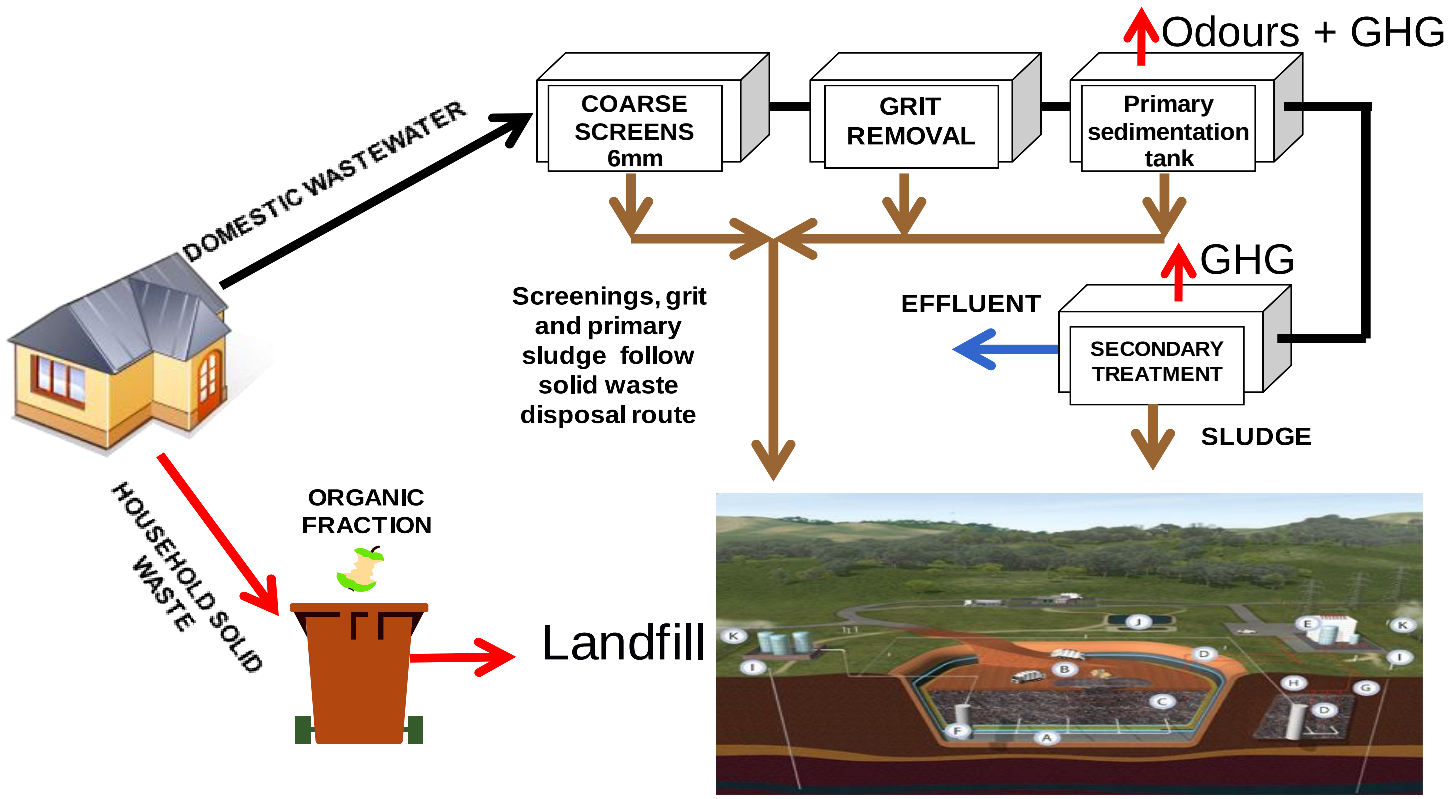
WHO

Guidelines for the Safe use of Wastewater, Excreta and Greywaters
(WHO, 2006)

*Source: Mara D. and Bos R. (2010). Risk analysis and epidemiology: The 2006 WHO guidelines. In Wastewater Irrigation and Health: Assessing and Mitigating Risks in Low-income Countries (ed. P. Drechsel, C. A. Scott, L. Raschid-Sally, M. Redwood and A. Bahri), pp. 51−62. London: Earthscan.

Waste management in the 20th century

Liquid and solid waste management :



Renewable energy generation from sewage

Conventional Wastewater Treatment System are very expensive in terms of energy consumption and sludge treatment.

In the UK, over 11 billion litres of wastewater are produced and transported through sewer networks to about 9,000 wastewater treatment plants.

In order to achieve discharge consent, wastewater treatment in the UK requires ≈663 kWh per Ml (8,290GWh of electricity annually, ≈3% of the country's total energy consumption)

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Renewable energy generation from sewage

Conventional Wastewater Treatment System are very expensive in terms of energy consumption and sludge treatment.

In the UK, over 11 billion litres of wastewater are produced and transported through sewer networks to about 9,000 wastewater treatment plants.

As a whole, the UK water industry consumes ≈663 kWh per Ml (8,290GWh of electricity annually, ≈3% of the country's total energy consumption)

GHG emission: 5 million ton of CO_2 equivalent /year
(56% total UK water sector)

Meeting EU WFD standards would increase CO_2 emissions by 3% a year

UK water industry is committed to reduce its carbon outputs by 26-32% of the 1990 level, by 2020 and 60% by 2050. Also, It must ensure that at least 20% of its energy use is from renewable resources by 2020 (present figure is 6.5%).

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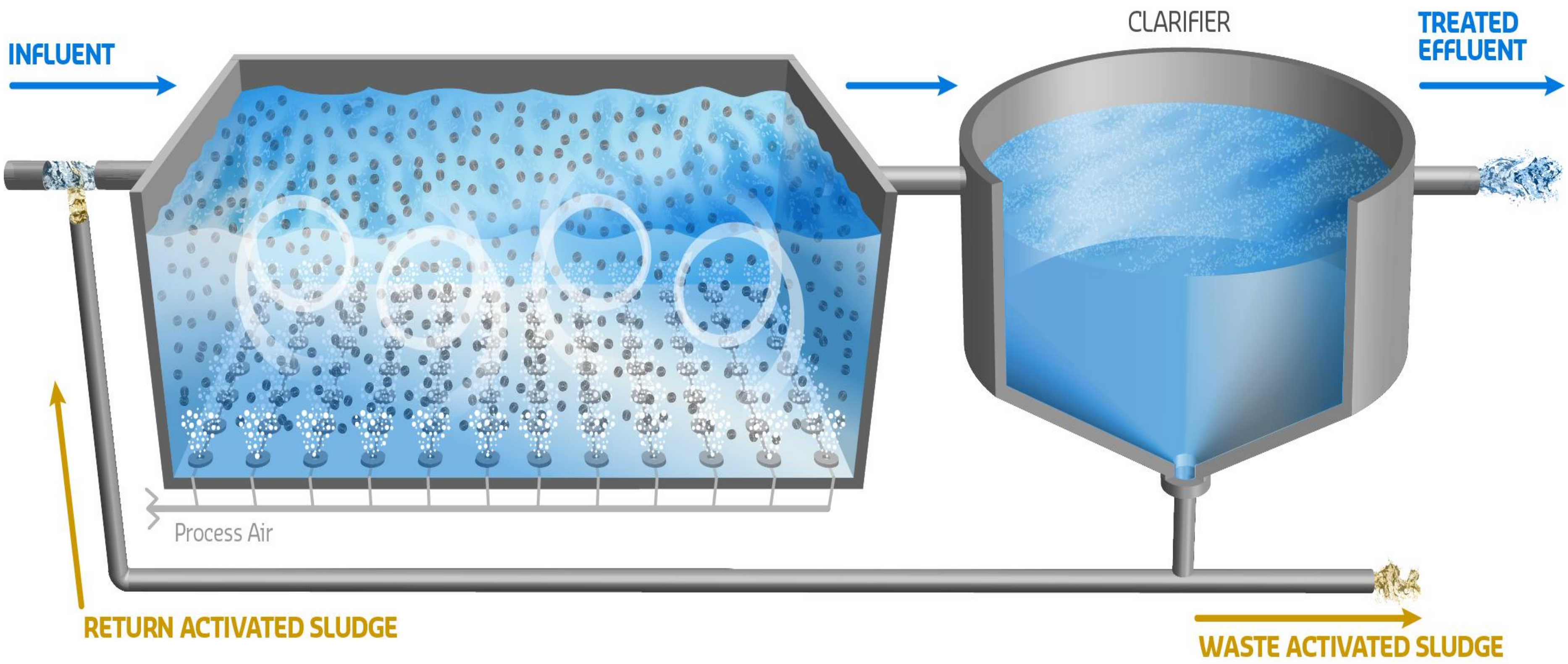
The activated sludge process

The activated sludge process (Edward Ardern and W.T. Lockett, 1913)



But it’s a sewage treatment is very efficient!

- Uses 2,800 GWh of energy to treat the sewage
- For a population of 60 million people – a daily energy use of just 120W per person to treat 150 L of sewage to a very high standard.

- **Much less than a lightbulb …… high energy?**

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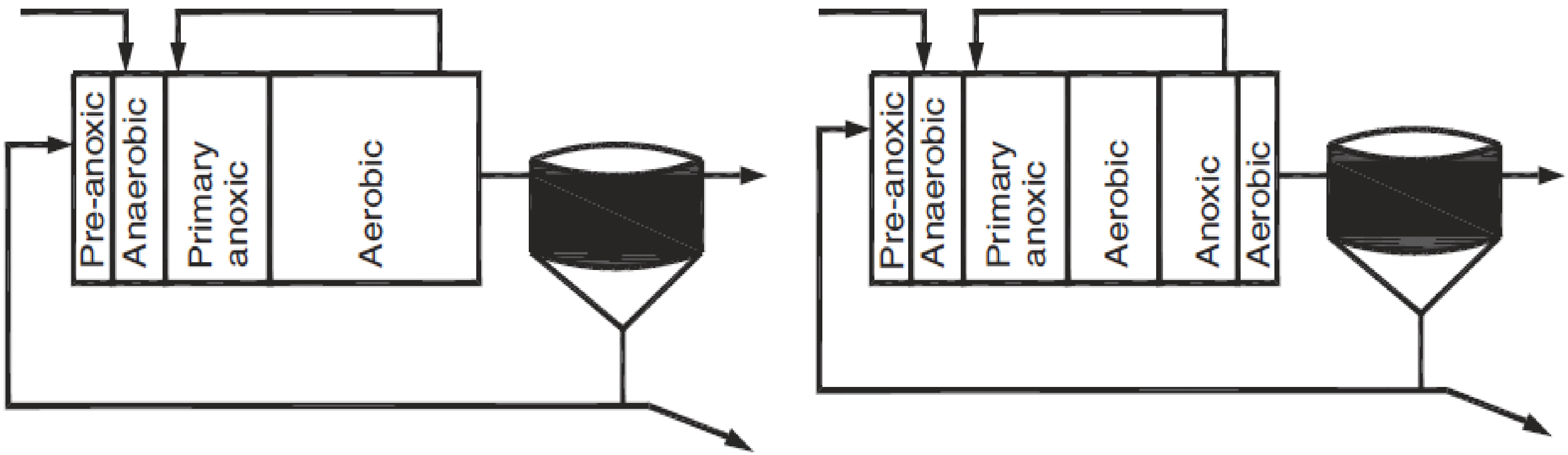
Nutrient control in large WWTWs

Most popular biological nutrient removal configurations



(a) Johannesburg (JHB)

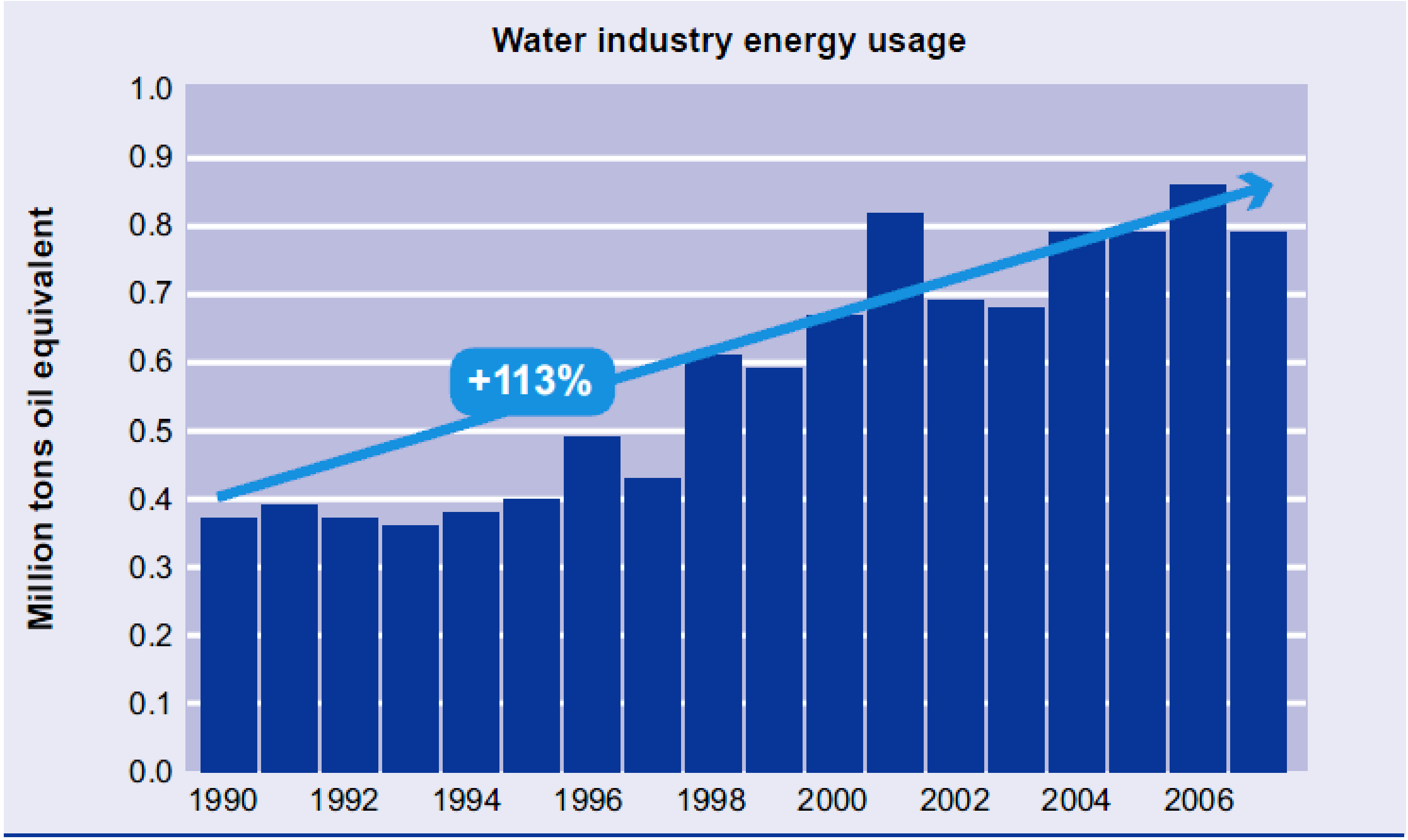
(b) JHB+ five-stage

- Nitrogen removal: nitrification/denitrification and bacterial uptake
- Phosphorus removal: bacterial uptake

Source: Manyumba et al., 2008. Meeting the phosphorus consent with biological nutrient removal under UK winter conditions. *Water and Environmental Journal*, **23**, 83-90.

Wastewater Engineering in the UK

Wastewater treatment in the UK: Changing the course



Source: Severn Trent Water, 2010

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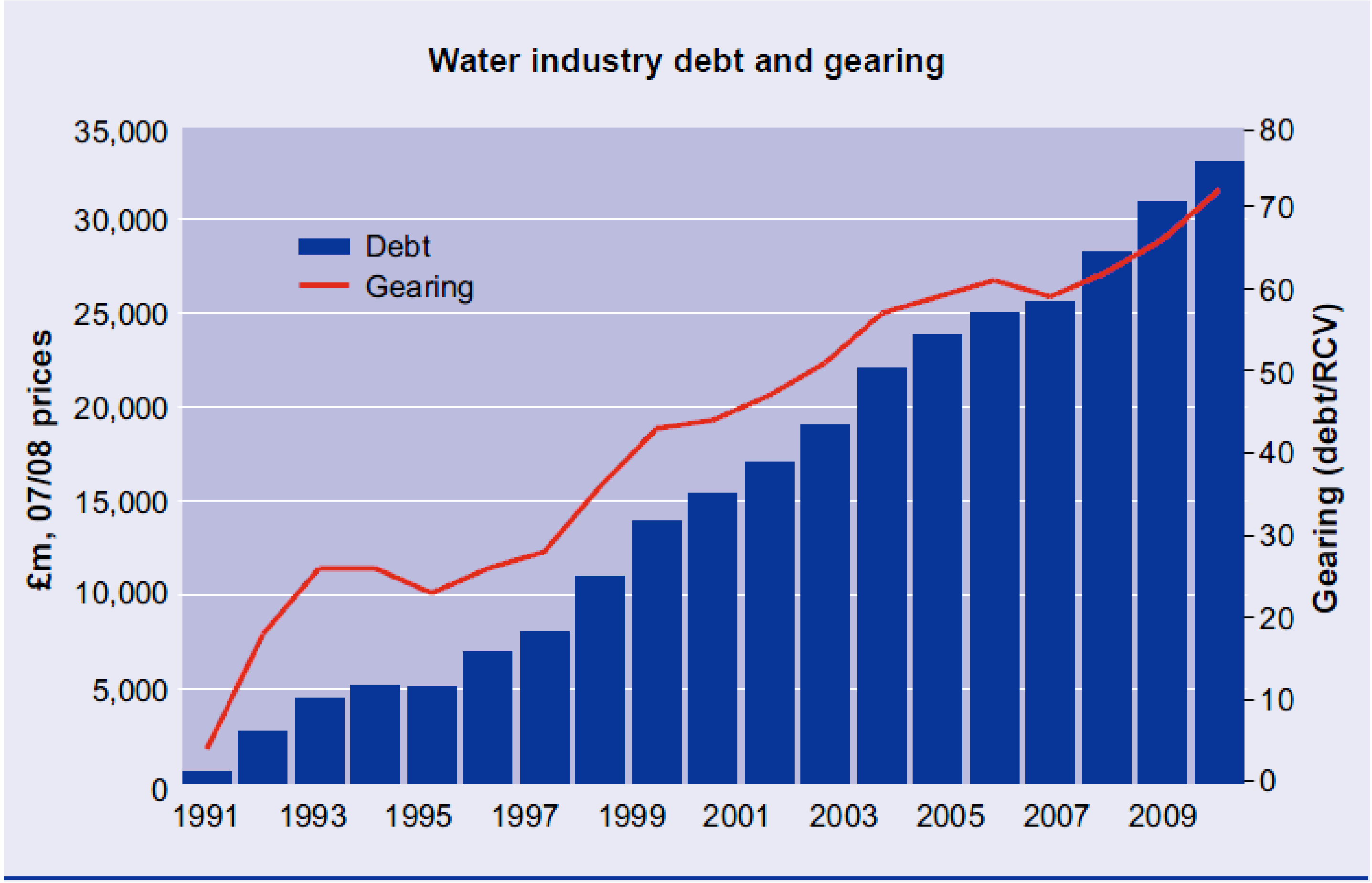
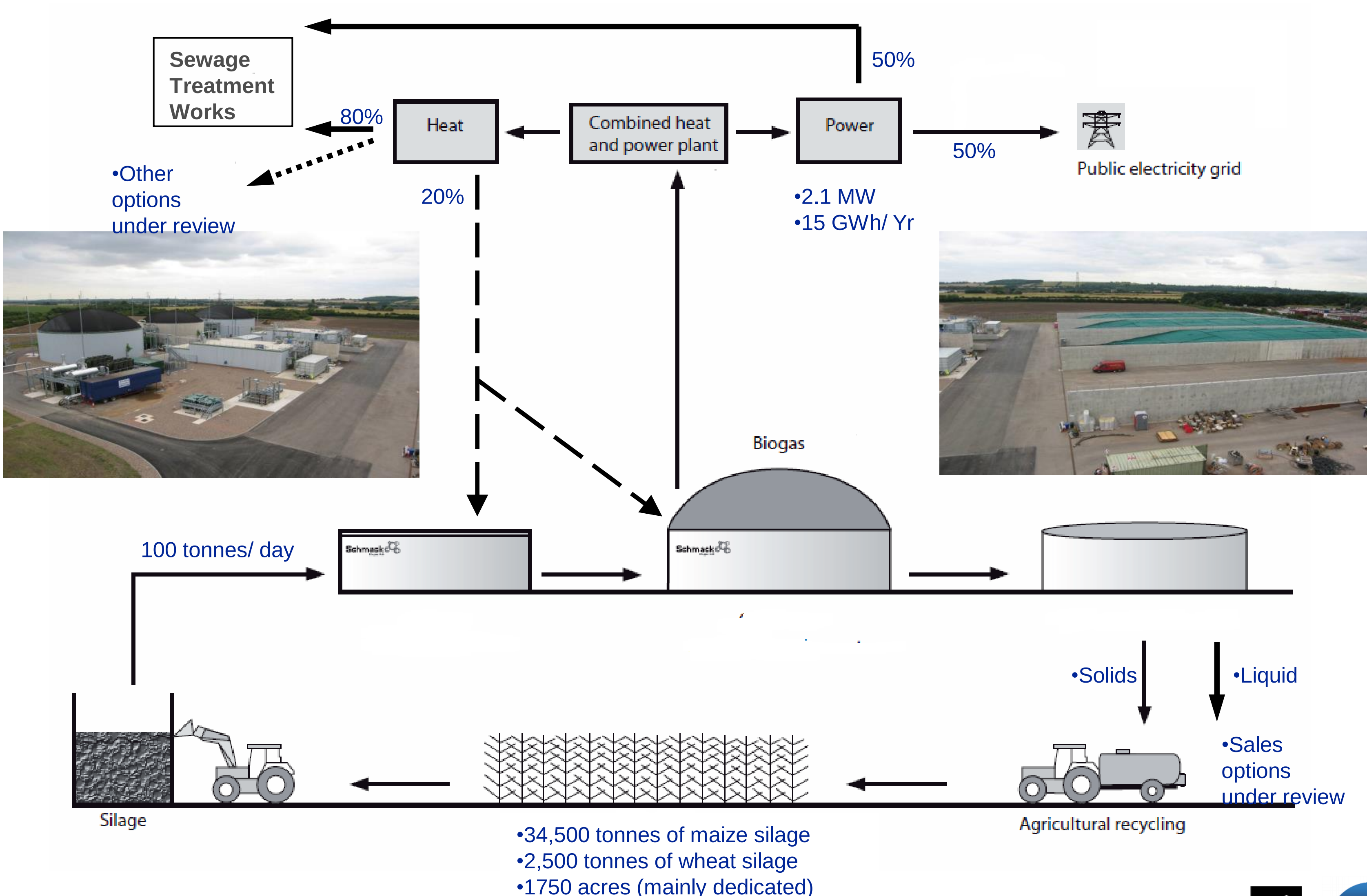
Wastewater Engineering in the UK

Wastewater treatment in the UK: Changing the course



Source: Severn Trent Water, 2010

Wastewater Engineering in the UK



Nutrient control in modern, large WWTWs

Wastewater treatment: costs

Screens → Primary sedimentation → Biological process → Secondary sedimentation → Final effluent

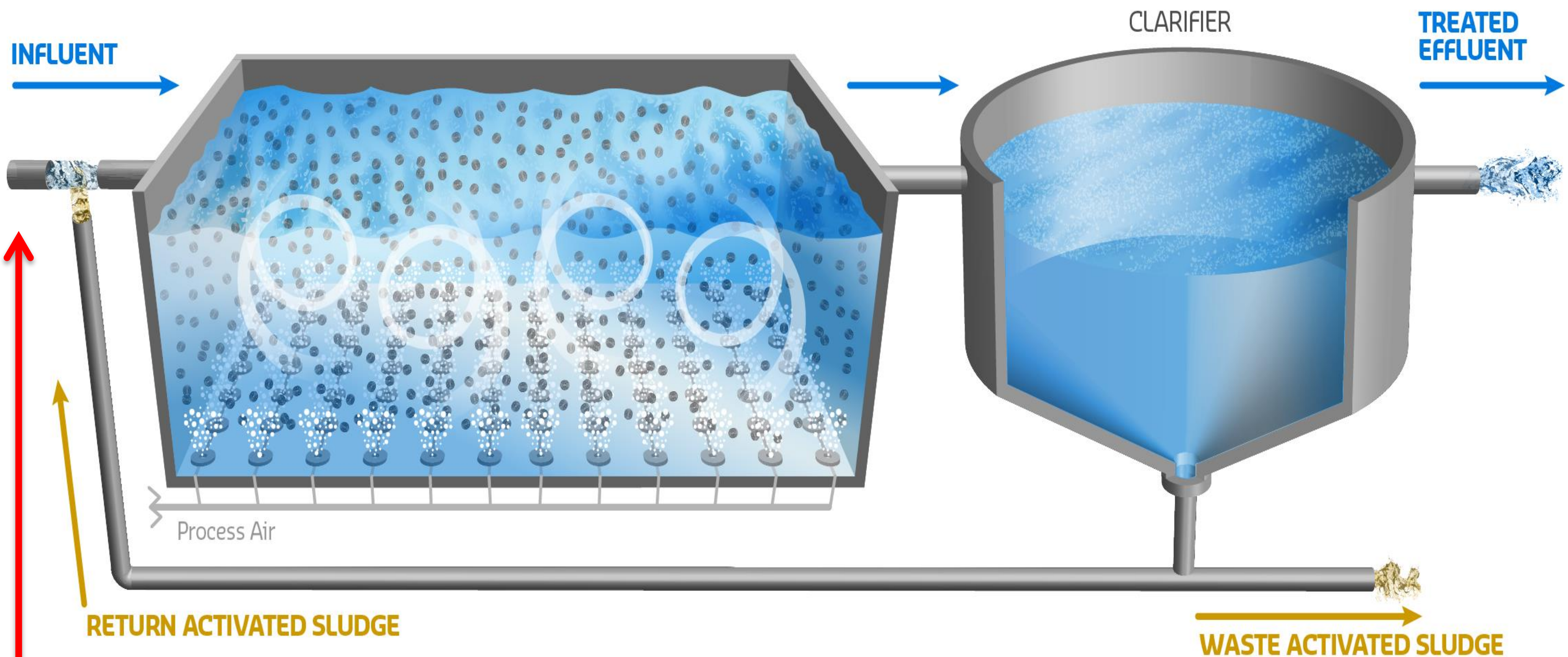
Sewage sludge treatment: income/savings

Sewage sludge → Hydrothermal process → Anaerobic digestion → Combined Heat and Power →

- Power
- Low-grade heat
- Digestate sludge
- Digestate liquor

Re-Engineering the activated sludge process

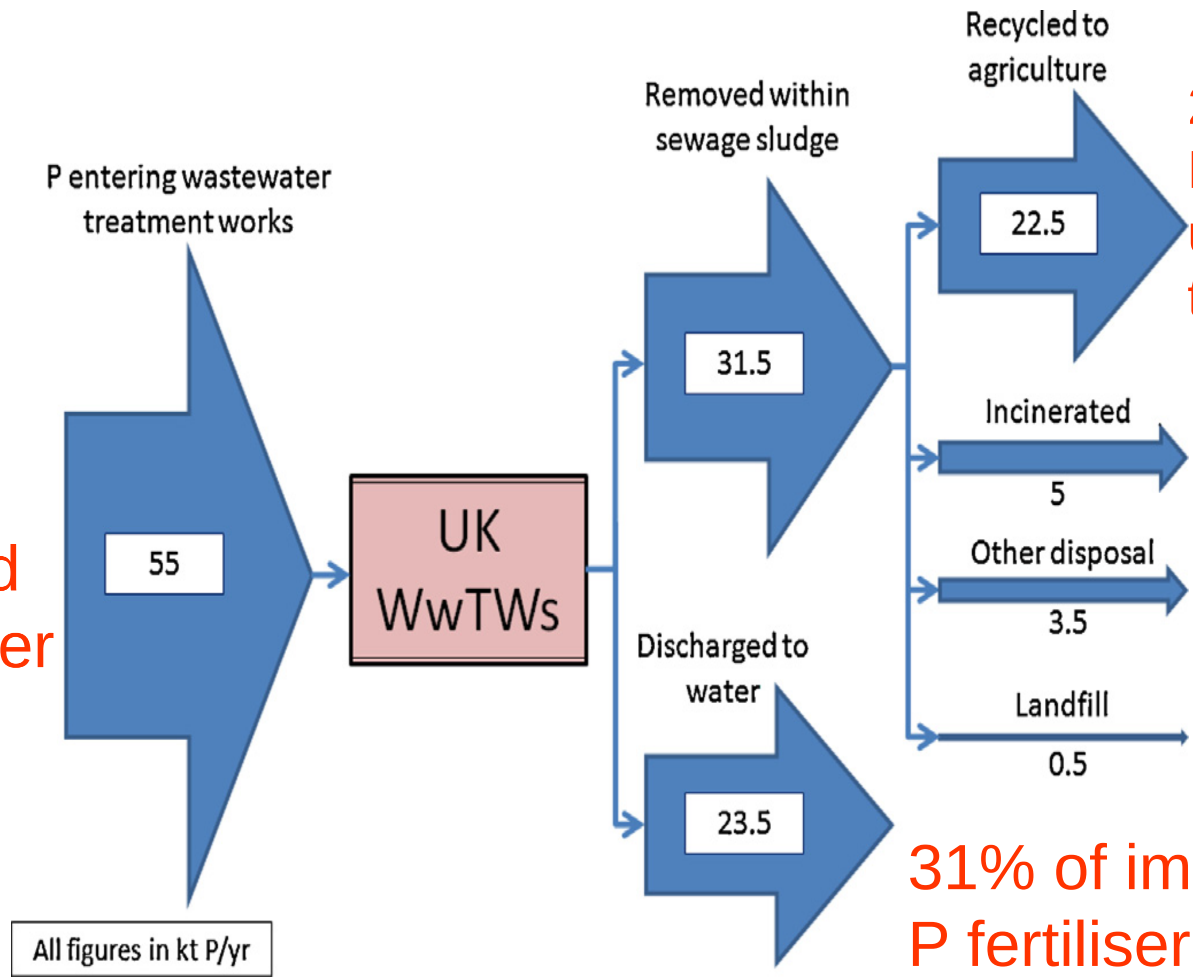
The activated sludge process (Edward Ardern and W.T. Lockett, 1913)



Return of digestate liquor from AD reactors

Potential for P recovery from sewage

71% of imported P fertiliser



29% of imported P recovered, but used in <1% of total arable land

31% of imported P fertiliser

Cooper J and Carliell-Marquet C (2013). A substance flow analysis of phosphorus in the UK food production and consumption system. *Resources, Conservation and Recycling*, 74, 84-100.

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The nitrogen budget in GB (1974 – 2004)

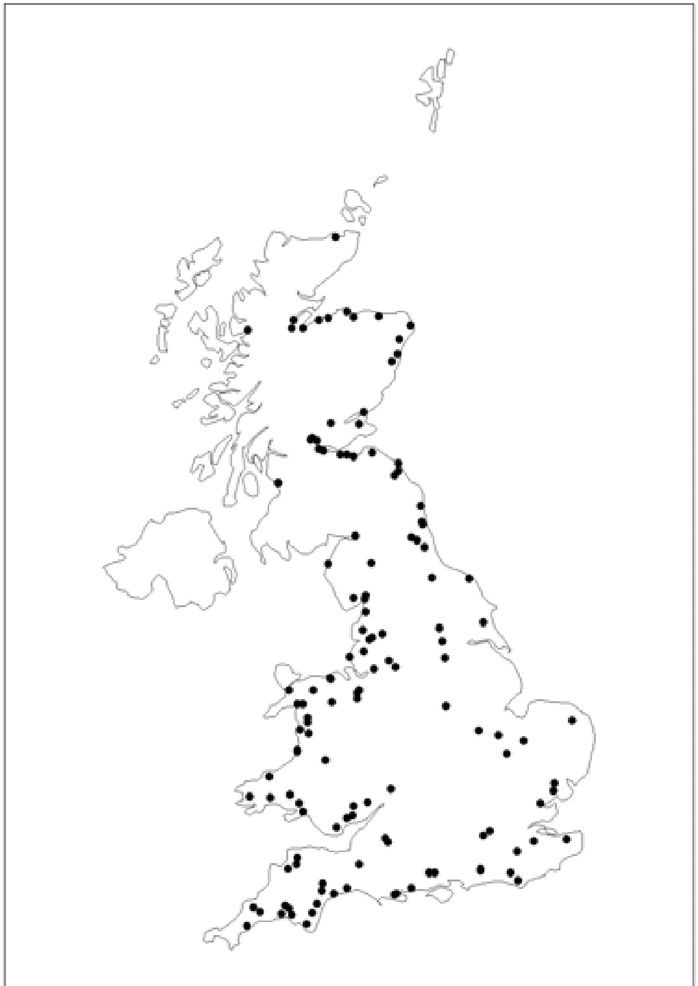

Figure 1. Location of the Harmonised Monitoring Scheme sampling sites

The Harmonised Monitoring Scheme (HMS) was established in 1974 to measure important hydrochemical fluxes to the North Atlantic and to allow their trends to be monitored. These measurements met the UK's commitment to a series of international agreements and treaties.

There are 56 HMS sites in Scotland and 214 sites in England and Wales. Monitoring sites were placed at the tidal limits of all rivers with an average annual discharge of over 2 $m^3 s^{-1}$.

Worrall et al., 2009. Global Biogeochemical Cycles, 23, GB3017

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The nitrogen budget in GB (1974 – 2004)

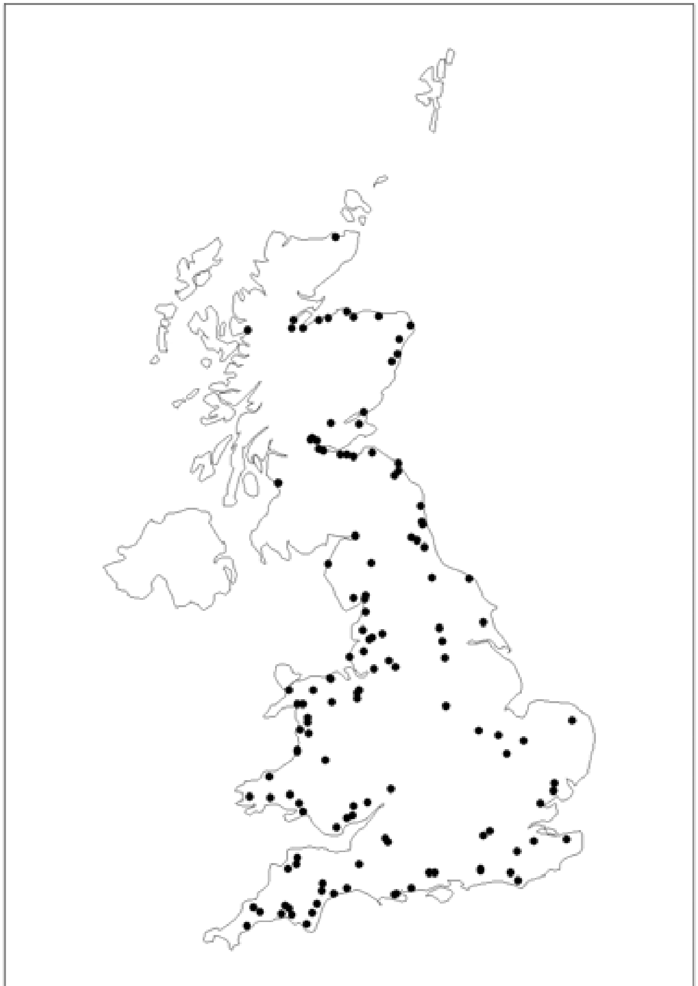

Figure 1. Location of the Harmonised Monitoring Scheme sampling sites

(1) the total dissolved nitrogen flux varied from 470 to 980 kt N year^{-1} (69% nitrate N; 26% dissolved organic N; 4% ammoniacal N; and 1% nitrite N)
(2) the total particulate organic nitrogen (PON) flux varied from 34 to 24 kt N year^{-1}
(3) the flux of ammoniacal N shows a significant decline over the study period, but significant increases in both nitrate N and dissolved organic N mean that the total dissolved nitrogen flux still shows a significant increase at a rate of 6.3 kt N year^{-1}

Worrall et al., 2009. Global Biogeochemical Cycles, 23, GB3017

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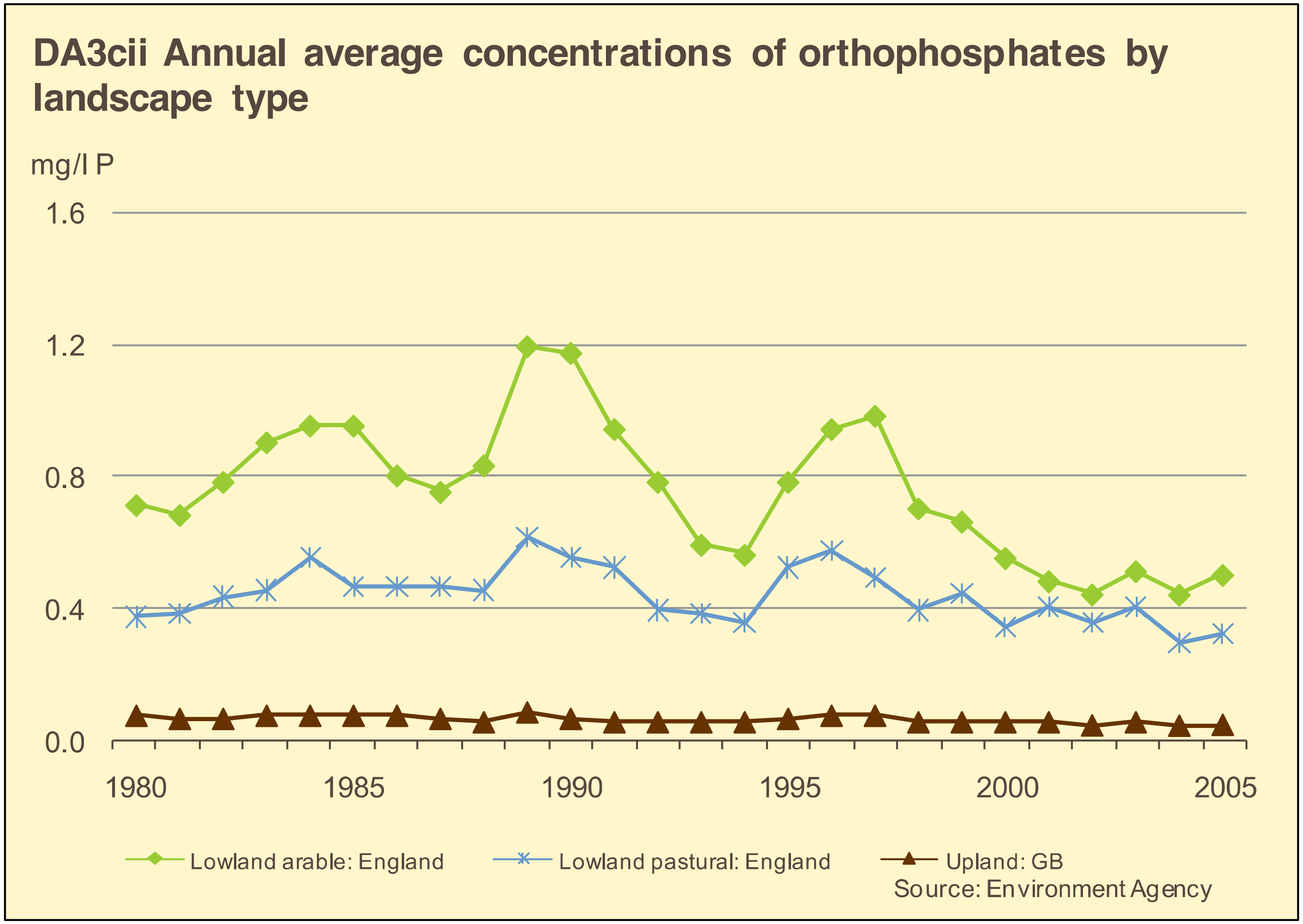
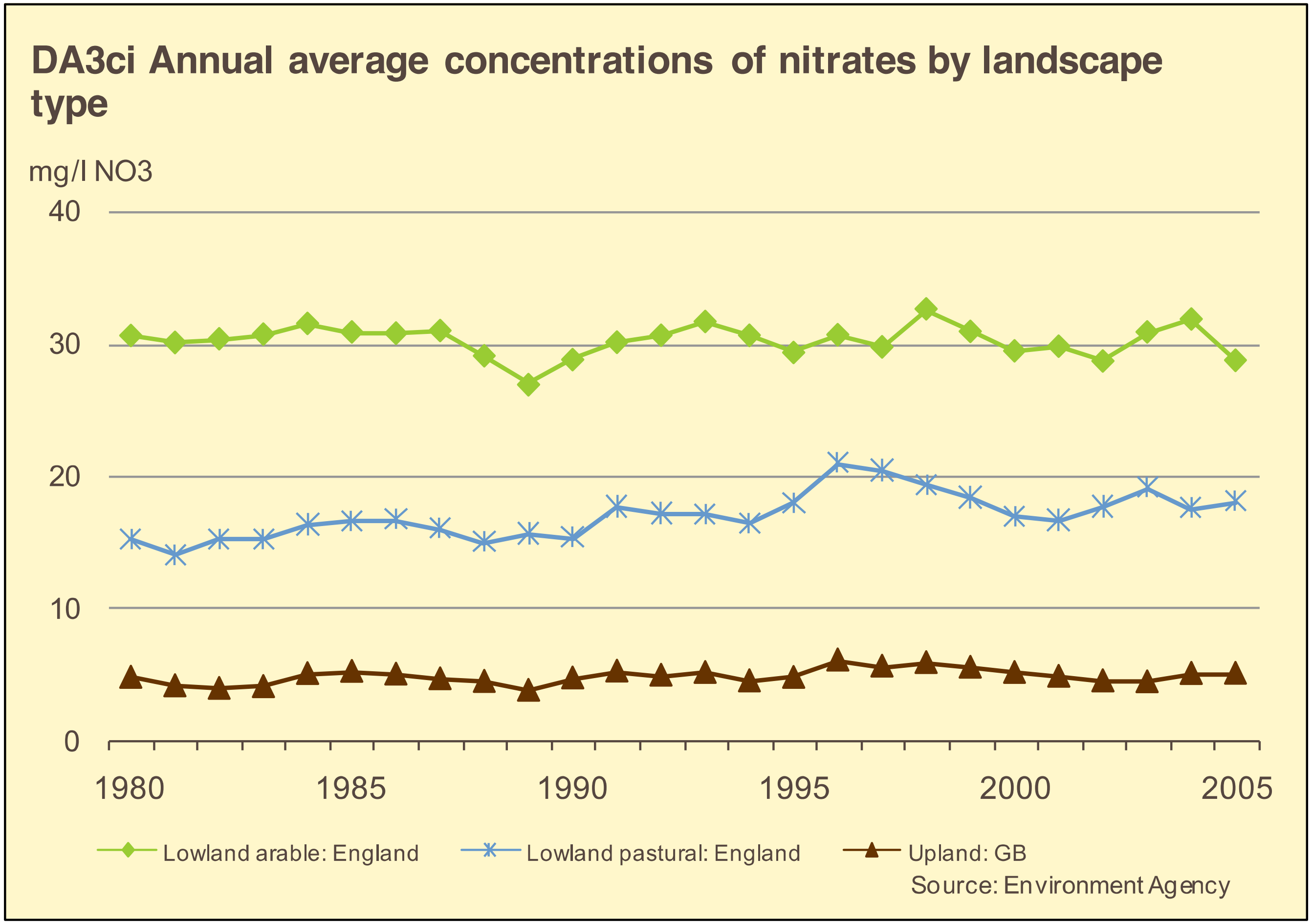
Environmental impact



Environmental impact



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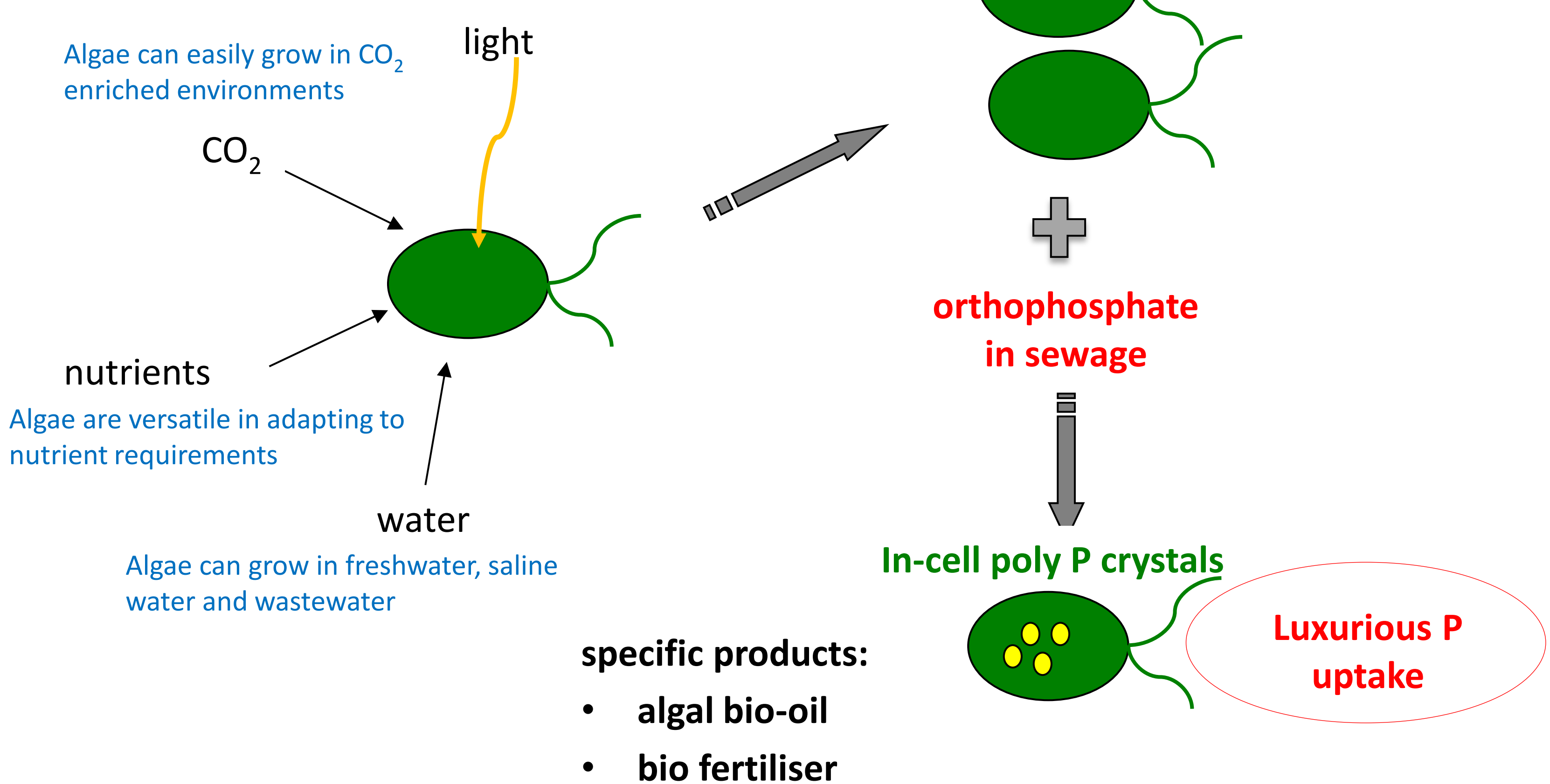
P recovery through biological algal uptake

Typical level of in-cell P in algae = 1% P (dry-weight)

Luxury P uptake = accumulation of poly P (>1% P)



Source: Yulistyorini A., Camargo-Valero M. A. and Horan N. J. (2015)

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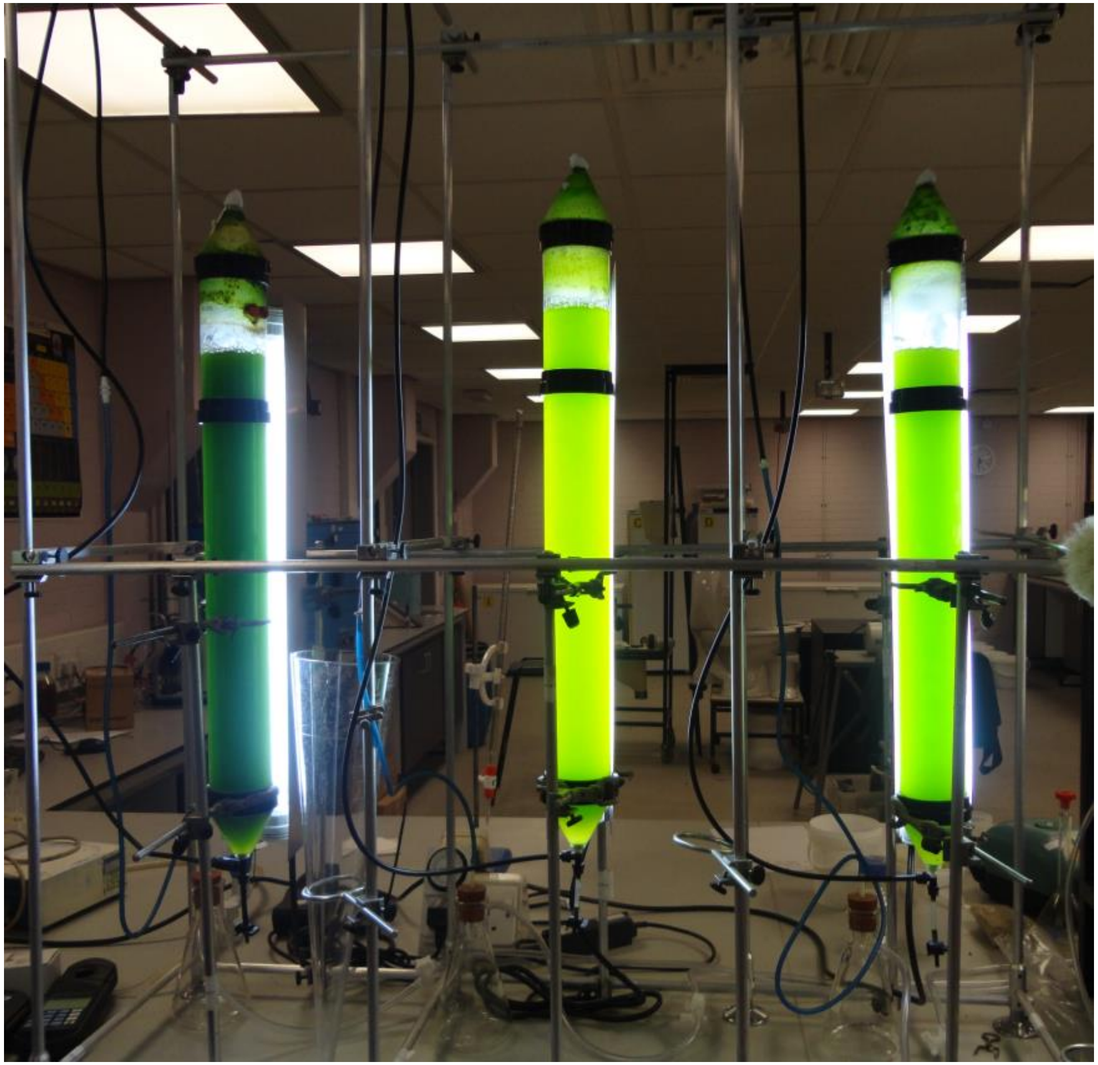
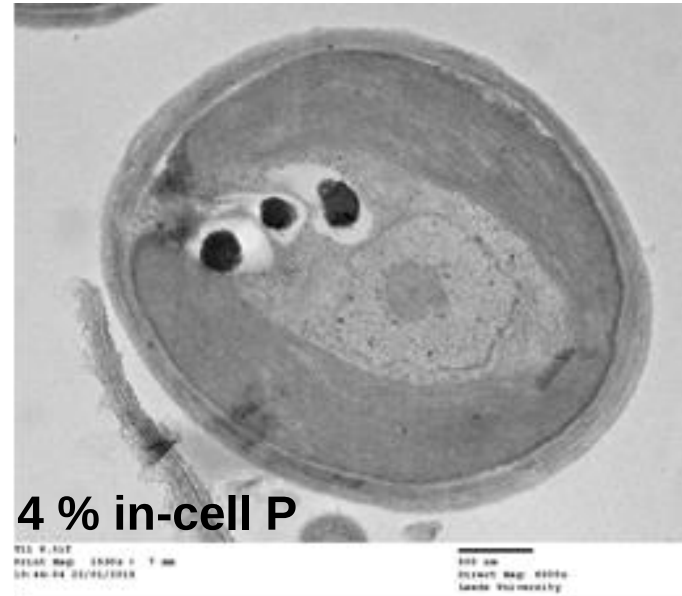
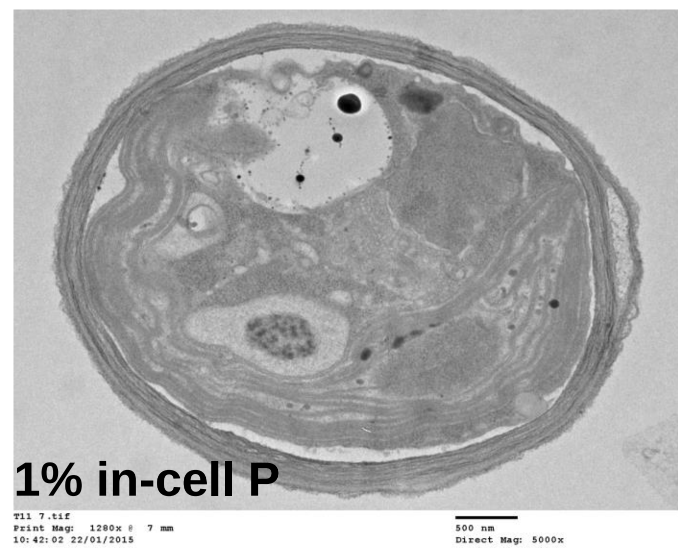
Biological nutrient recovery using microalgae

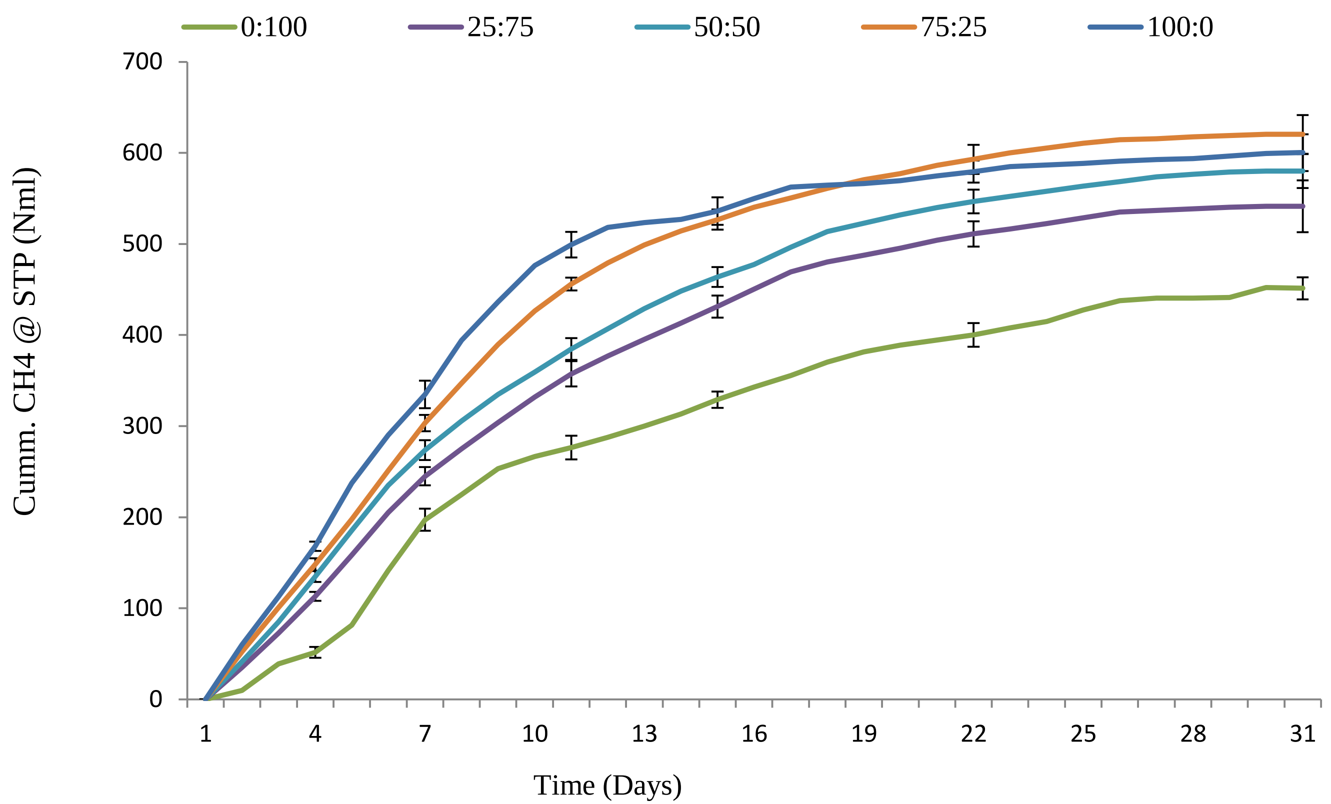






Yulistyorini A., Camargo-Valero M. A. and Horan N. J. (2015)

Bioenergy generation from algal biomass



Cumulative methane yield from a blend of thermally hydrolysed algae and sewage sludge.

Source: Adewale O., Camago-Valero M. A. and Horan H. (2015)

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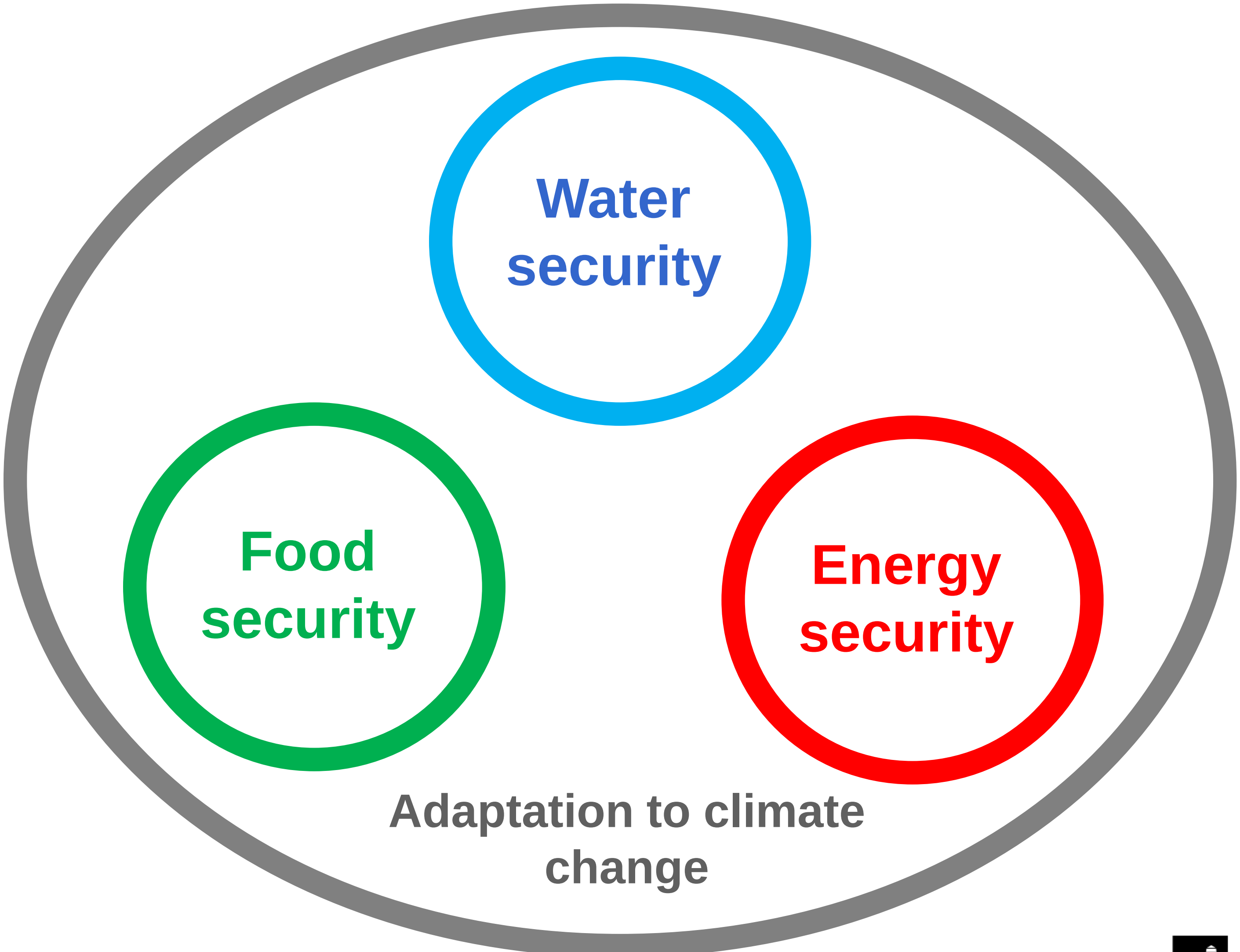
Current global challenges



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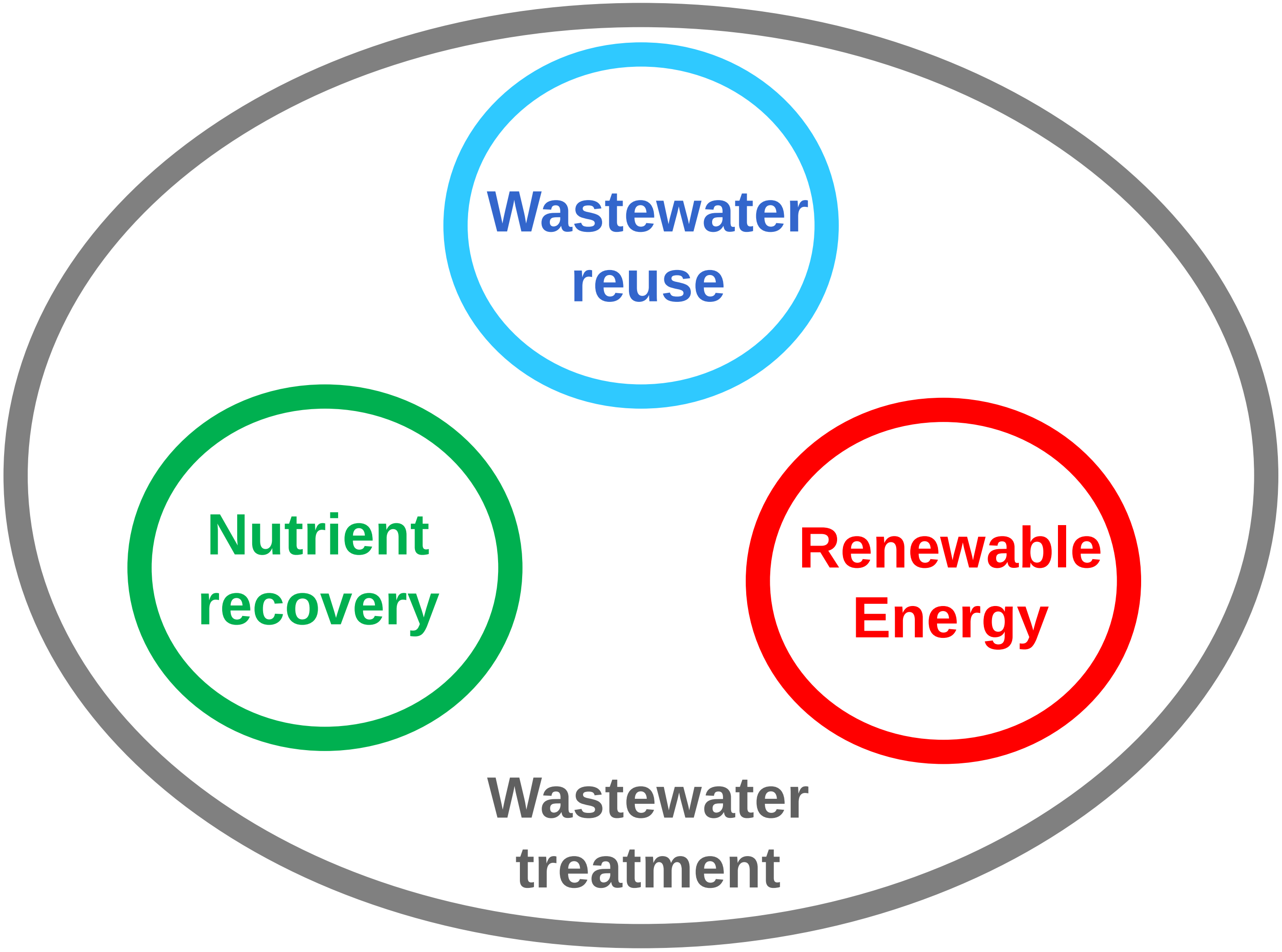
Resource recovery and reuse from wastewater



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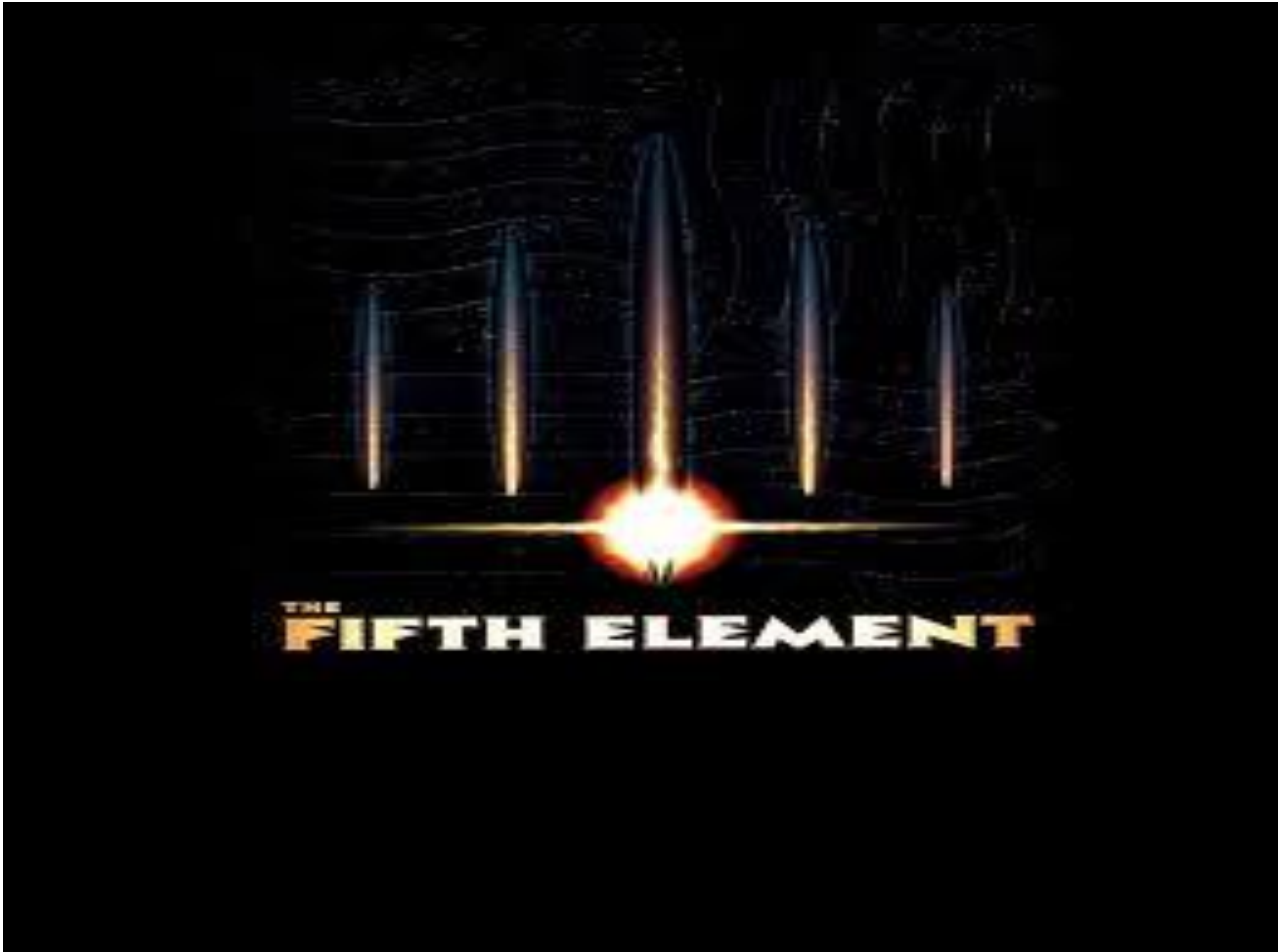
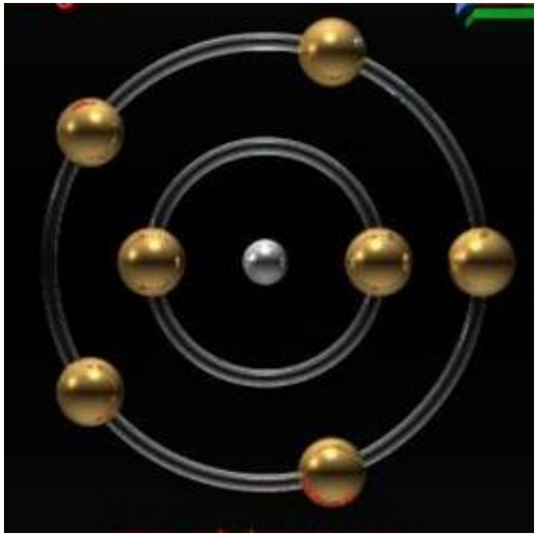

THE
FIFTH ELEMENT

Wastewater, Carbon, Nitrogen, Phosphorus



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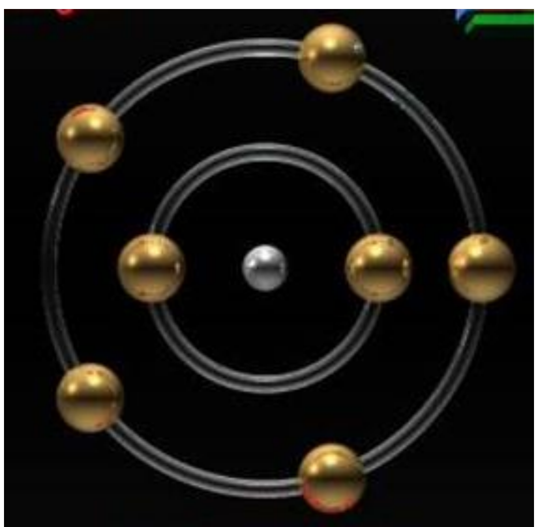
Wastewater, Carbon, Nitrogen, Phosphorus

us



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Message to take home

Water for life

Message to take home

Sanitation for dignity

Message to take home

Renewable energy for development

Message to take home

Resource recovery for sustainable economic growth

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