Fertilisers

vital for food, fibre and carbon capture but increasingly scarce, especially phosphate

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Scanning the agricultural horizon to 2050
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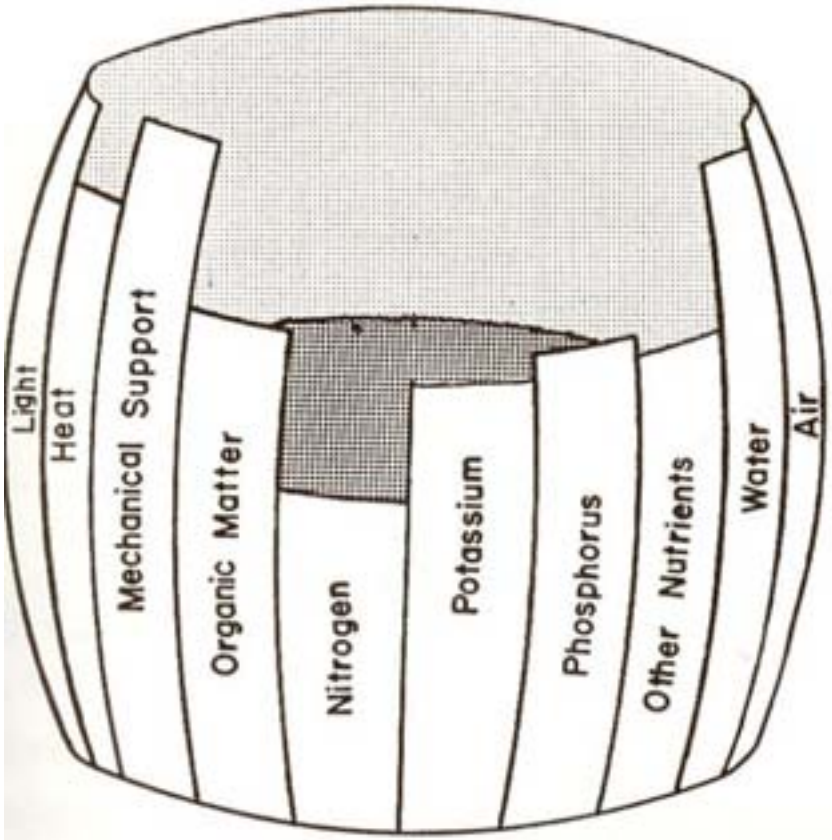
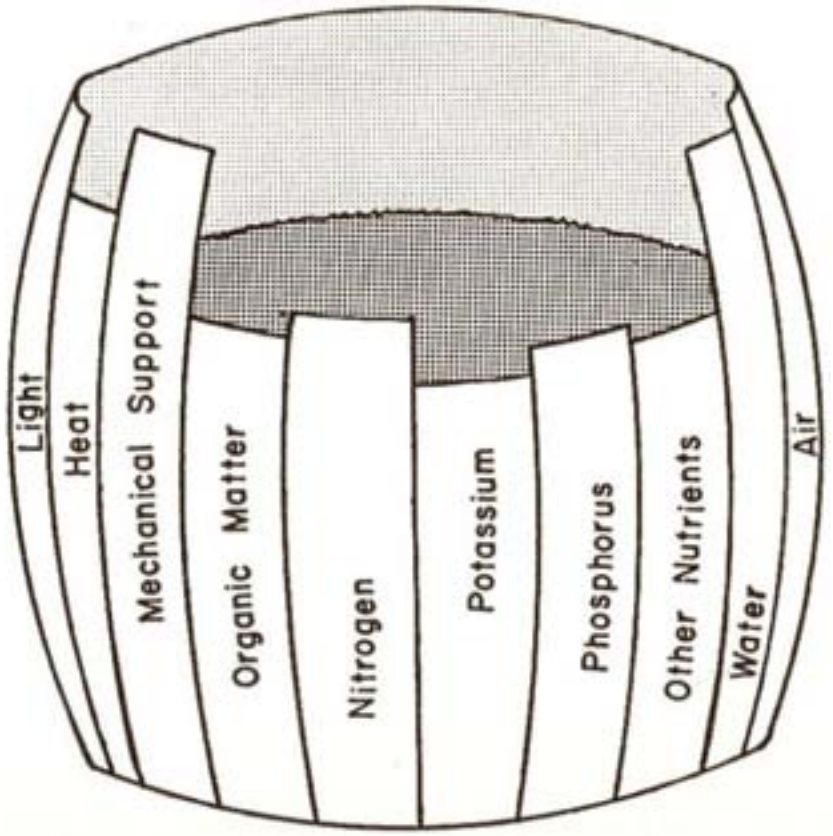
Quick reminder

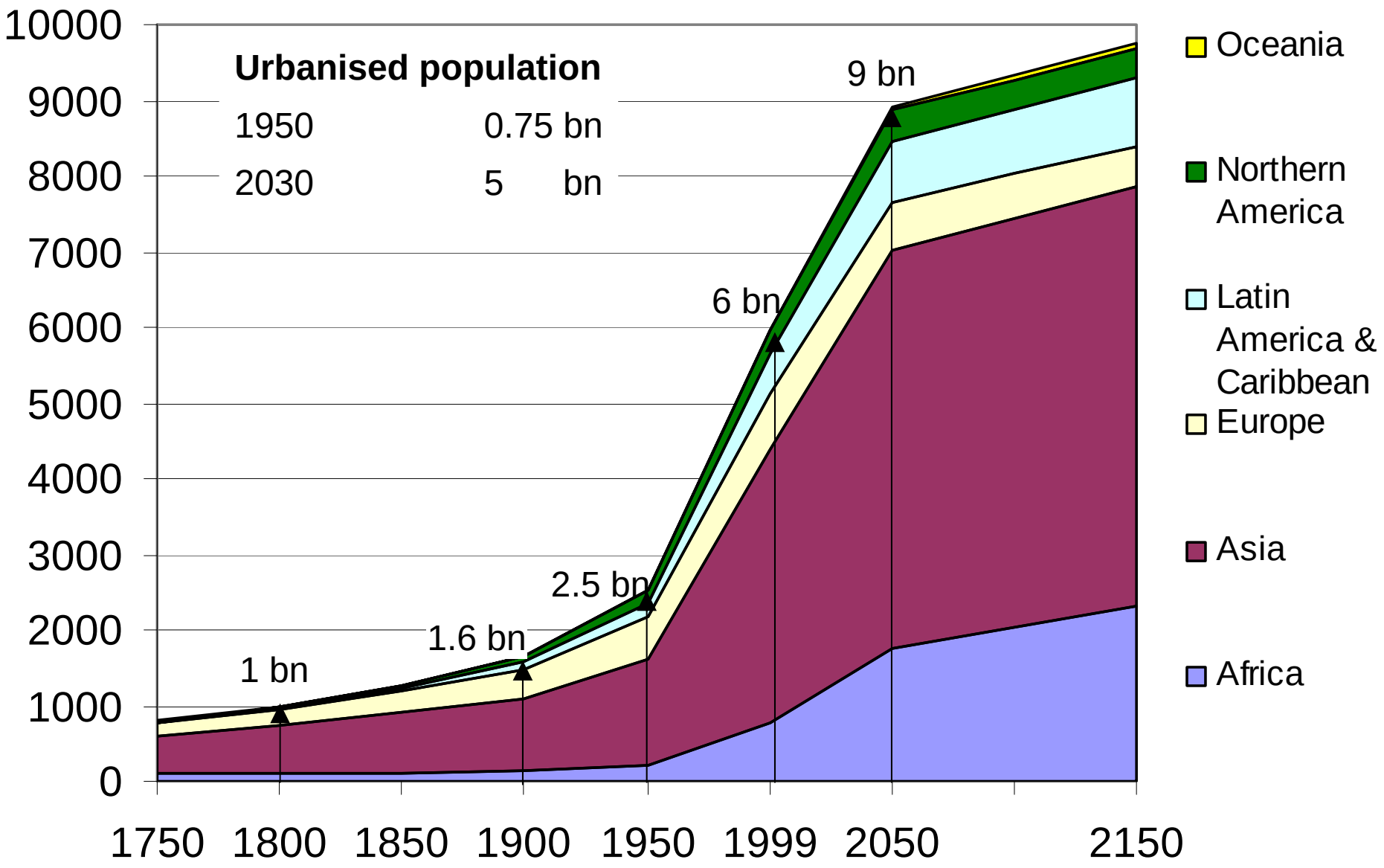
Liebig's Law of the Minimum (1840)

yield cannot exceed the most limiting principle





World human population - millions (UN, 2004)



Fertilisers [green revolution and opposition to birth control] fed population growth

- Farming didn't use inorganic fertilisers before **1850** and we [barely] fed 1.2 bn people
  - Farm manure and town manure were treasured and recycled
- **1900** – 850 Mha and not much fertiliser fed 1.6 bn people [accumulated fertility in New World soils]
- **2000** – 1500 Mha – pro-rata this would feed 2.8 bn but population is 6.5 bn

An 8t grain (DM) cereal crop removes (kg)

	Grain	Straw	G+S
N	160	56	216
P_2O_5	**74**	**6**	**80**
K_2O	54	64	118
CaO	6	39	45
MgO	20	7	27
SO_3	30	8	38

It's got to come from somewhere!

The atmosphere is 80% N_2

There's lots of water, albeit much is saline

Potassium is reasonably abundant

But phosphorus is scarce:

It is too precious to squander

Element		%
Oxygen	O	46.500
Silicon	Si	28.200
Aluminium	Al	8.230
Iron	Fe	5.630
Calcium	Ca	4.150
Sodium	Na	2.360
Magnesium	Mg	2.330
Potassium	K	2.090
Sub-total		*99.5%*
Hydrogen	H	0.140
Phosphorus	P	0.105
Manganese	Mn	0.095
Sulphur	S	0.035
Carbon	C	0.020

Cheap fertilisers are history

- For 30 years from 1970s there was oversupply of fertilisers
- Some manufacturers wanted hard currency, some had cheap/stranded natural gas
- Fertiliser companies were for sale but nobody was buying
- ∴ underinvestment in production
- Increasing demand because of increasing population and wealth
  - Inelastic supply + increased demand = price increase
  - Export restrictions

No more cheap natural gas

- Methane is used 70% for H_2 and 30% for energy

$$CH_4 + H_2O = CO + 3H_2$$
$$CO + H_2O = 2CO_2 + H_2$$
$$N_2 + 3H_2 = 2NH_3$$

- Natural gas was cheap [stranded] at oil fields
- Might as well use it to make N fertiliser
- International gas grids and LNG enable it to be exported
- N-fertiliser price will follow oil prices
- Producers with gas futures stop producing when gas price gets high enough to sell – swing production

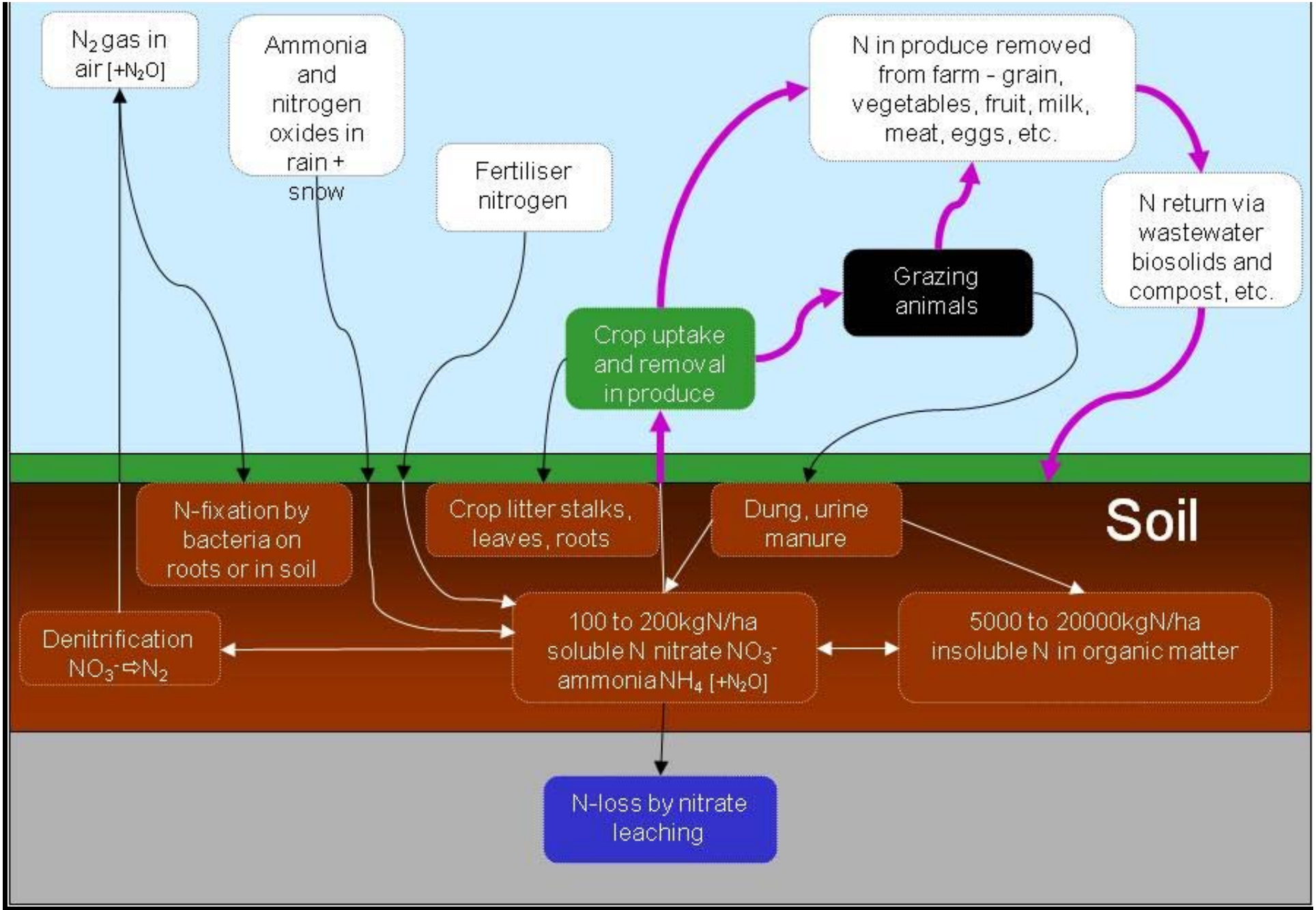
World nitrogen production ktN/y (EFMA, 2004)

Fertiliser year	Chilean nitrate	Guano	Coke-oven ammonium sulphate	Calcium cyanamide	Electric arc Ca nitrate	Synthetic ammonia	Total
1850	5	-	-	-	-	-	5
1860	10	70	-	-	-	-	80
1870	30	70	-	-	-	-	100
1880	50	30	-	-	-	-	80
1890	130	20	-	-	-	-	150
1900	220	20	120	-	-	-	360
1910	360	10	230	10	-	-	610
1920	410	10	290	70	20	150	950
1930	510	10	425	255	20	930	2,150
1940	200	10	450	290	-	2,150	3,100
1950	270	-	500	310	-	3,700	4,780
1960	200	-	950	300	-	9,540	10,990
1970	120	-	950	300	-	30,230	31,600
1980	90	-	970	250	-	59,290	60,600
1990	120	-	550	110	-	76,320	77,100
2000	120	-	370	80	-	85,130	85,700

Dominance of ‘synthetic ammonia’ (99% in 2000)

Nitrogen fertiliser

- ~40% of human dietary protein is fertiliser N
- Cereals engineered to fix N symbiotically are unlikely because feeding rhizobia has large yield penalty
- N-fertiliser won’t run out but it won’t be cheap [until civil nuclear fusion?]
- Increasing price will increase pressure for efficiency and reducing losses



Simplified representation of the nitrogen cycle

Phosphate

"…life can multiply until all the phosphorus is gone, and then there is an inexorable halt which nothing can prevent…. We may be able to substitute nuclear power for coal, and plastics for wood, and yeast for meat, and friendliness for isolation - but for phosphorus there is neither substitute nor replacement."

Isaac Asimov, "Asimov on chemistry" (June 1974)
ISBN 0385041004, Doubleday Company, New York

- 85% of rock phosphate is used in agriculture
- At the current rate of extraction, today's mines will be exhausted by the end of the century
- Wastewater, biosolids and organic resources have a major part to play in the stewardship of this essential resource.
- The phosphate crisis is on a par with climate change as a threat to the human population

Global phosphate resources and depletion – Mt P_2O_5

U.S. Geological Survey, Mineral Commodity Summaries, January 2009

	production		Reserves	Reserve base	
	2007	2008			
Morocco and Western Sahara	27	28	5,700	21,000	44.7%
China	45	50	4,100	10,000	21.3%
United States	30	31	1,200	3,400	7.2%
South Africa	3	2	1,500	2,500	5.3%
Other countries	8	11	890	2,200	4.7%
Jordan	6	6	900	1,700	3.6%
Australia	2	2	82	1,200	2.6%
Russia	11	11	200	1,000	2.1%
Israel	3	3	180	800	1.7%
Syria	4	4	100	800	1.7%
Egypt	2	3	100	760	1.6%
Tunisia	8	8	100	600	1.3%
Brazil	6	6	260	370	0.8%
Canada	0.7	0.8	25	200	0.4%
Senegal	0.6	0.6	50	160	0.3%
Togo	0.8	0.8	30	60	0.1%
World Total (rounded)	**156**	**167**	**15,000**	**47,000**	
Years at 2008 production			90	281	

Morocco 80 mg Cd /kg P_2O_5

Namibia-offshore reserve base 282 Mt P_2O_5

Phosphate balance

- Humans and farm animals use dietary-P inefficiently

adults excrete 98% of P in diet = 1.2-1.4 gP/capita.day

+ other household & urban sources = 1.3-1.8 gP/capita.day

sum = **1** kgP/capita.year

Even at 2mgP/litre in effluent ~0.3 kgP/capita.year goes out in effluent

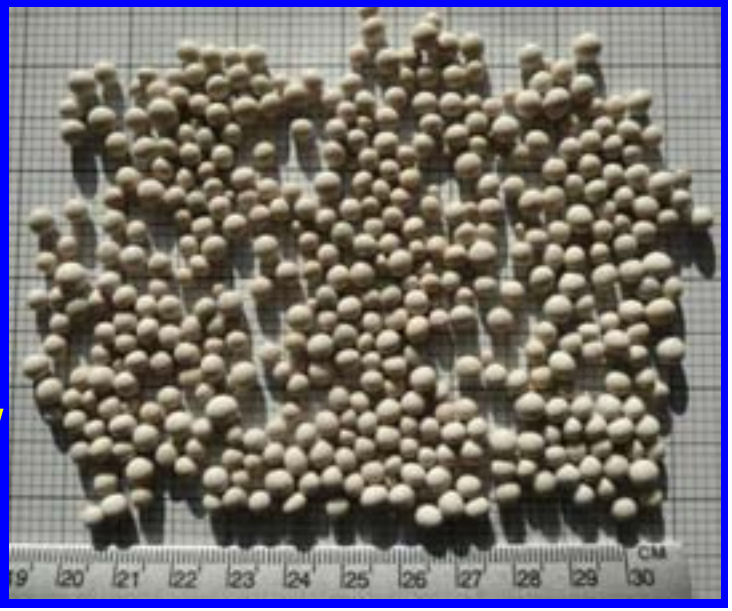
P in farm animal manure in UK = **1.6** kgP/capita.year

P fertiliser use in UK (2008) = 1.5 kgP/capita.year

(1988) = 3.1 kgP/capita.year

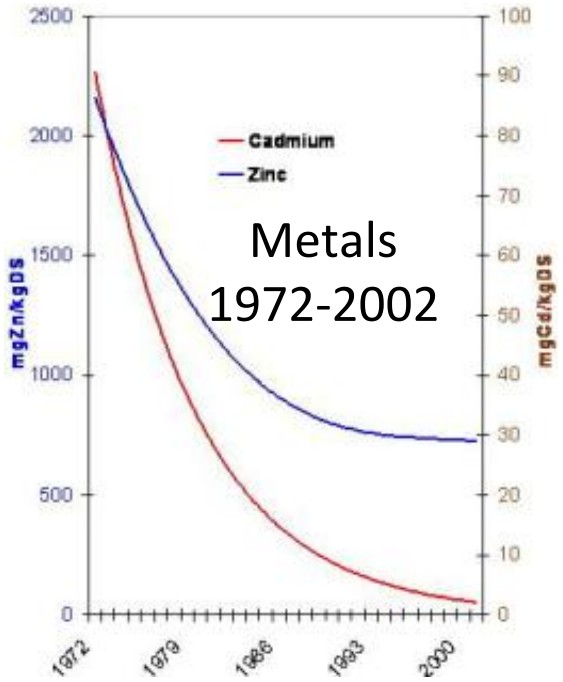
New paradigm for wastewater treatment

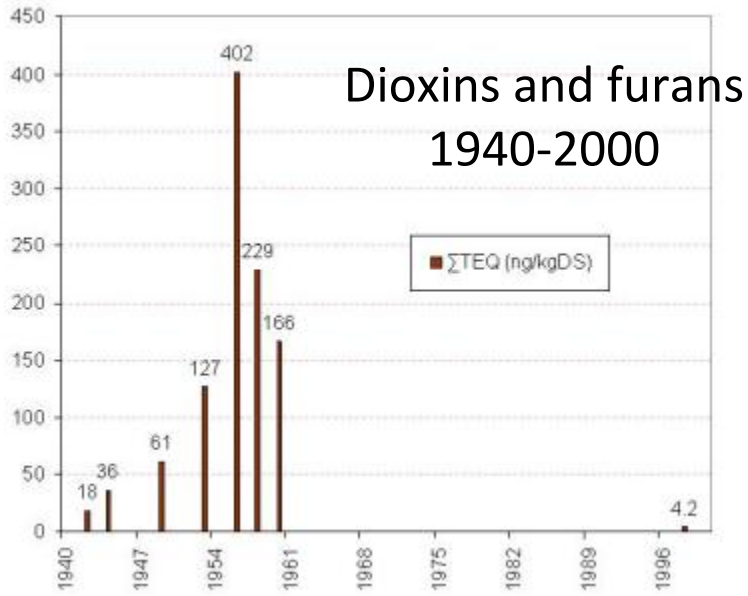
- Wastewater treatment has done a fantastic job
  - Public health and pollution prevention
  - Using energy (GWP) to prevent negatives
  - Compensated by emphasis on maximising biogas:
    66% of UK sewage sludge treated by AD in 2005 – 85% in 2015
- In future additional requirement to recover P?
  - Sweden has target to recycle 60% of P in wastewater by 2015
  - EU next?
  - First struvite ($MgNH_4PO_4.6H_2O$) plant in UK (Slough) operational in 2012 more will follow



We have a P crisis – comparable to climate change

- capturing and using the P in wastewater (and food) is important
- biosolids (sewage sludge) recycling is understood, controlled and SAFE
- shame on anybody who stands in the way of biosolids recycling without good scientific cause; it is important for P conservation

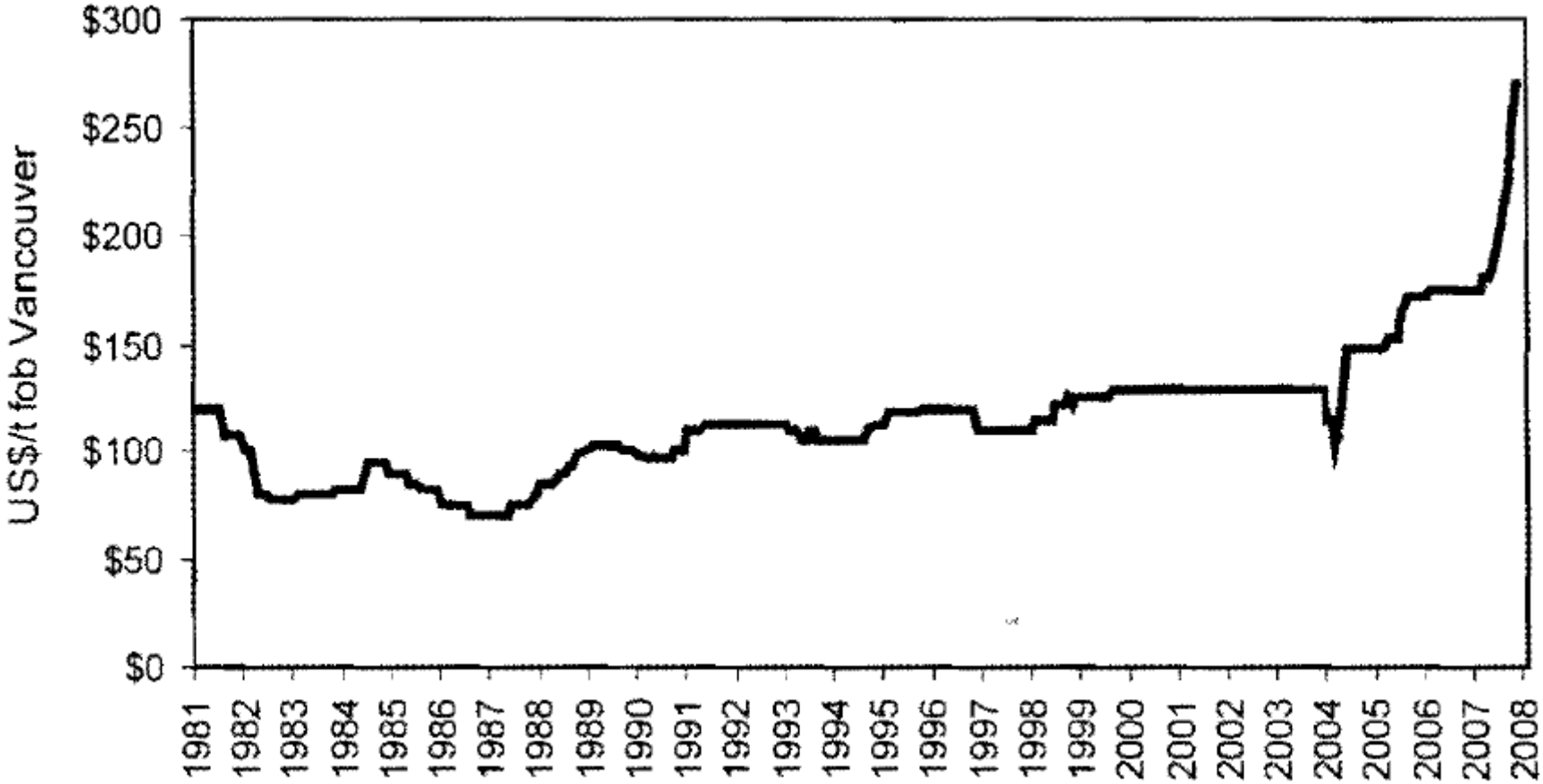




Morocco 80 mg Cd /kg P_2O_5

Biosolids 40 mg Cd /kg P_2O_5

Potash prices 1981-2007 fob Vancouver US$ (Fertecon)



- Marketing potash is in few hands
- High cost of developing new capacity ($2 bn for 2 Mt/y mine)
- Demand strong
- Suppliers found price sensitivity low

Global potash resources and depletion – Mt K_2O

U.S. Geological Survey, Mineral Commodity Summaries, January 2009

	Mine production		Reserves	Reserve base	
	2007	2008			
Canada	11.1	11.0	4,400	11,000	61.1%
Israel	2.2	2.4	540	5,580	31.0%
Jordan	1.1	1.2	540	5,580	31.0%
Russia	6.6	6.9	1,800	2,200	12.2%
Belarus	5.0	5.1	750	1,000	5.6%
Germany	3.6	3.6	710	850	4.7%
Brazil	0.4	0.4	300	600	3.3%
China	2.0	2.1	8	450	2.5%
United States	11.1	11.2	90	300	1.7%
Chile	0.5	0.6	10	50	0.3%
Spain	0.6	0.6	20	35	0.2%
Ukraine	0.0	0.0	25	30	0.2%
United Kingdom	0.4	0.5	22	30	0.2%
Other countries	—	—	50	140	0.8%
World total (rounded)	**35**	**36**	**8,300**	**18,000**	
Years at 2008 production			231	500	

- Potash is held on cation exchange sites and clay interlayer spaces in soil
- If there’s no phosphate it doesn’t matter that there’s loads of potash!

conclusions

- We must have science [evidence] based policies
- We shall have to balance environmental ideals with demands of excessive population and climate change
- Fertilisers are essential for feeding the world
- Cheap fertiliser is history
- Precise, targeted use of fertilisers
  - Soil analysis; spectral sensing; variable application
- GM [is wheat nearing its genetic yield potential?] and chemical protection so we feed crops (not weeds and disease) and exploit soil nutrients better
- P is the most limited – stewardship is essential

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