MFA Application in Australia:

Cd & P Case studies

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GREETINGS FROM
UNIVERSITY OF N.S.W.
SYDNEY

Overview

- Cadmium in Australia
  - Linking MFA with HHRA
  - Global implications
- Phosphorus in Australia
  - supply and emission issues
  - The Murrumbidgee Irrigation Area
    - Linking P and Cd and biomass energy recovery
  - Sydney
  - Peak P
  - Options for a sustainable future.

Part 1:Cadmium in Australia

Cadmium problems in Australia

Supply of zinc and cadmium to the global economy

Cadmium: why select this substance?
Health & Environmental concerns

- Non-essential bioaccumulative toxic heavy metal
- Acute inhalation: lung edema
- Chronic:
  - Kidney disfunction and disease
  - Itai Itai disease: soft and weak bones, pain
- Prostrate cancer….not now a concern ?
- Bioaccumulative -> kidney disease in animals

Cadmium: intentional uses

Application	*Usage Level (%)*
NiCd battery	79% increasing...
Pigment	11% decreasing...
Coatings	7% decreasing...
Stabilizers	2% decreasing...
Minor Uses (alloys)	1%

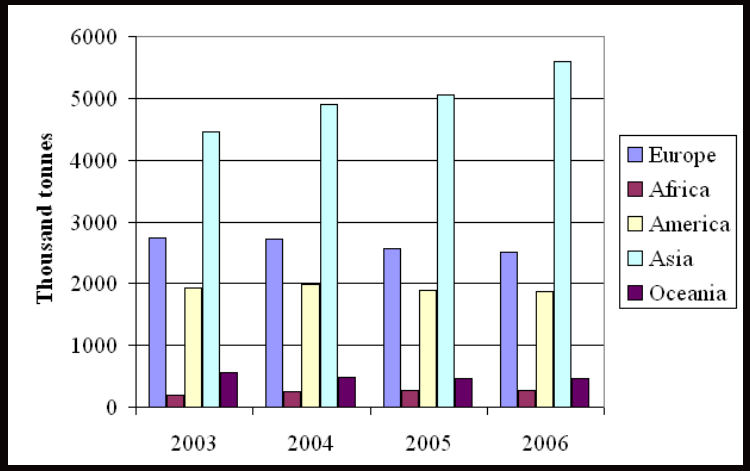
Cadmium: unintentional uses

Sources of exposure to an average non-smoking European 2005

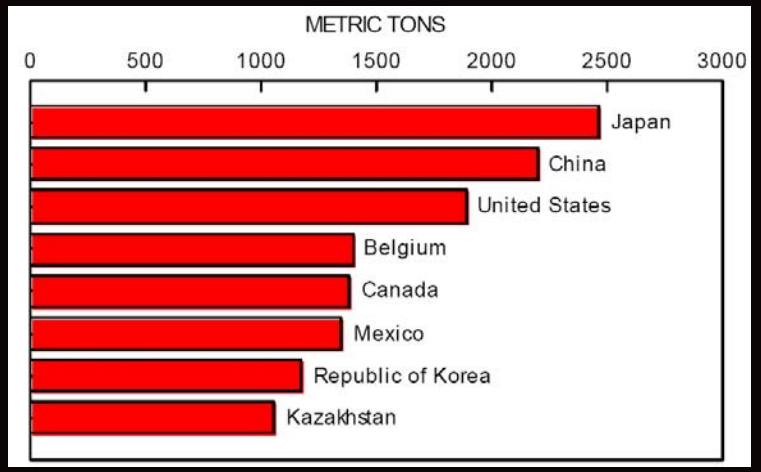
Cadmium source exposed	*Total percentile in the environment*
Phosphate Fertilisers	33 %
Fossil Fuel Combustion	20%
Iron & Steel Production	12%
Natural Sources	20%
Non-Ferrous Metals	4%
Cement Production	6.7%
Cadmium Application	0.3%
Incineration	1.0%

Cadmium: Supply for intentional uses

- Cadmium not intentionally mined as an ore
- Cadmium as a by-product of zinc ore concentration and smelting
- Linked to demand for zinc, increasing at 4%p.a….zinc smelting increasingly in Asia…so supply of Cd increasing at 4% p.a.



Global production of zinc



Cd refining countries…related to zinc smelting

Cadmium: Supply related to unintentional uses

- **Phosphate fertilizers:**
  - EU < 60..40..20mg Cd/Kg P_2O_5
  - (EU <25..17..8.5 mg Cd/kg P)
  - Australia < 300mg Cd/Kg P, generally < 100mg Cd/kg P
  - USA : 85 mg Cd/kgP
  - Japan < 8mg Cd/kg P
  - China? Proposed…8mg Cd/kg P… actual??
  - Thailand?
  - When low Cd phosphate rock depleted?
- **Coal fired electricity production:**
  - OECD (not USA)….reduce ..Kyoto
  - China, India…increase
- **Iron and Steel:**
  - OECD…constant
  - China…increasing
- **Cement production:**
  - OECD…constant, reducing
  - China…increasing

Cadmium source exposed	*Total percentile in the environment to non-smokers in EU*
Phosphate Fertilisers	33 %
Fossil Fuel Combustion	20%
Iron & Steel Production	12%
Natural Sources	20%
Non-Ferrous Metals	4%
Cement Production	6.7%
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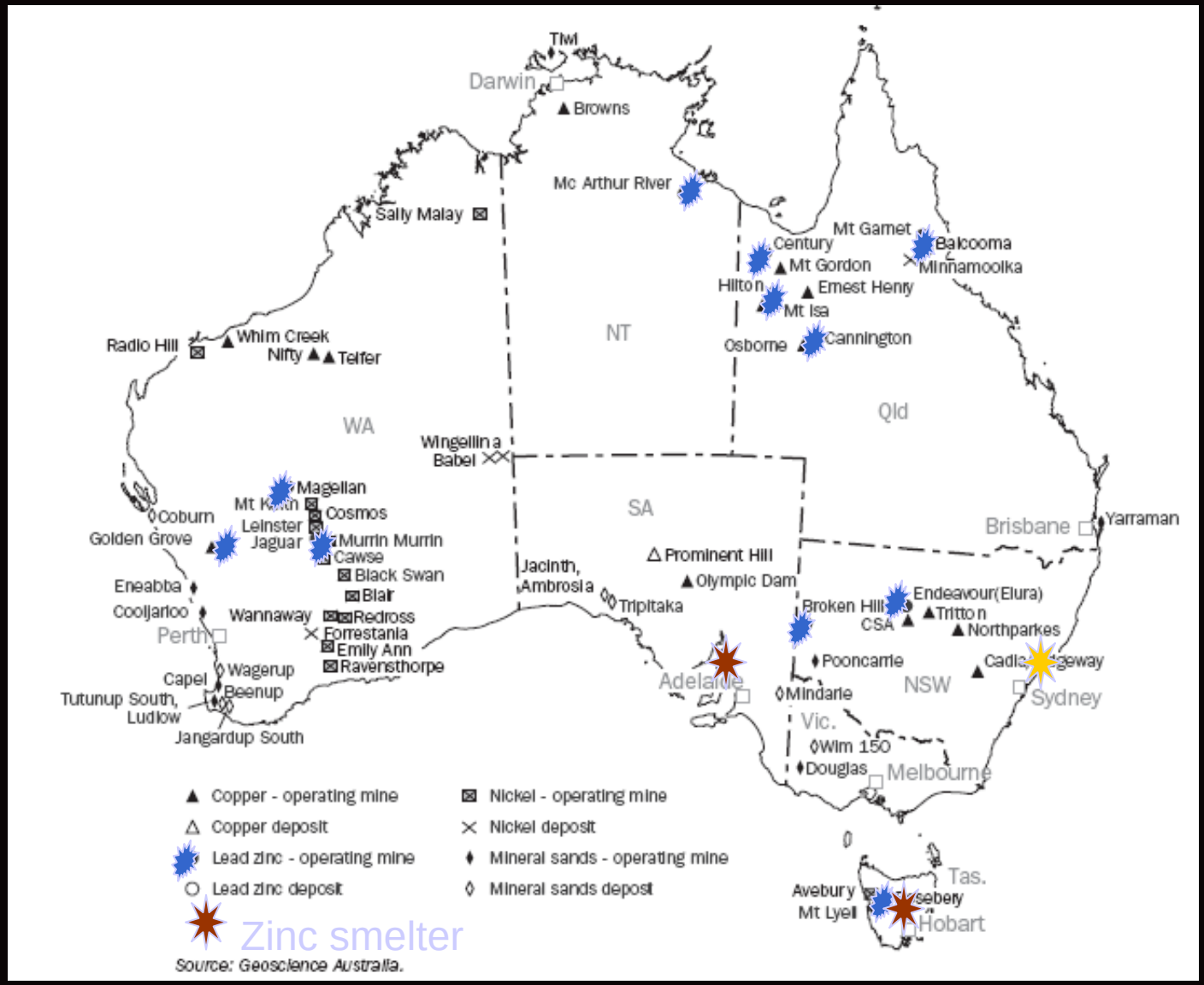

TIM
Darwin
Browns
Mc Arthur River
Sally Malay
Mt Garnet
Century
Balcooma
Mt Gordon
Minnamoolka
Hilton
Ernest Henry
Mt Isa
NT
Osborne
Cannington
Radio Hill
Whim Creek
Nifty
Telfer
WA
Qld
Wingellina
Babel
Magellan
Mt Keith
Cosmos
Coburn
Leinster
Golden Grove
Jaguar
Murrin Murrin
Cawse
Black Swan
Blair
SA
Brisbane
Yarraman
Jacinth, Ambrosia
Prominent Hill
Olympic Dam
Eneabba
Tripitaka
Broken Hill
Endeavour(Elura)
Tritton
CSA
Northparkes
Cooljarloo
Wannaway
Redross
Forrestania
Emily Ann
Ravensthorpe
Perth
Pooncarrie
Cadia
Newcrest
Wagerup
Capel
Beenup
Adelaide
Mindarie
NSW
Sydney
Tutunup South,
Ludlow
Jangardup South
Vic.
Wim 150
Douglas
Melbourne
Tas.
Avebury
Mt Lyell
Hobart
Copper - operating mine
Copper deposit
Lead zinc - operating mine
Lead zinc deposit
Nickel - operating mine
Nickel deposit
Mineral sands - operating mine
Mineral sands deposit
Zinc smelter
Source: Geoscience Australia.

Australia: Zinc and cadmium reserves

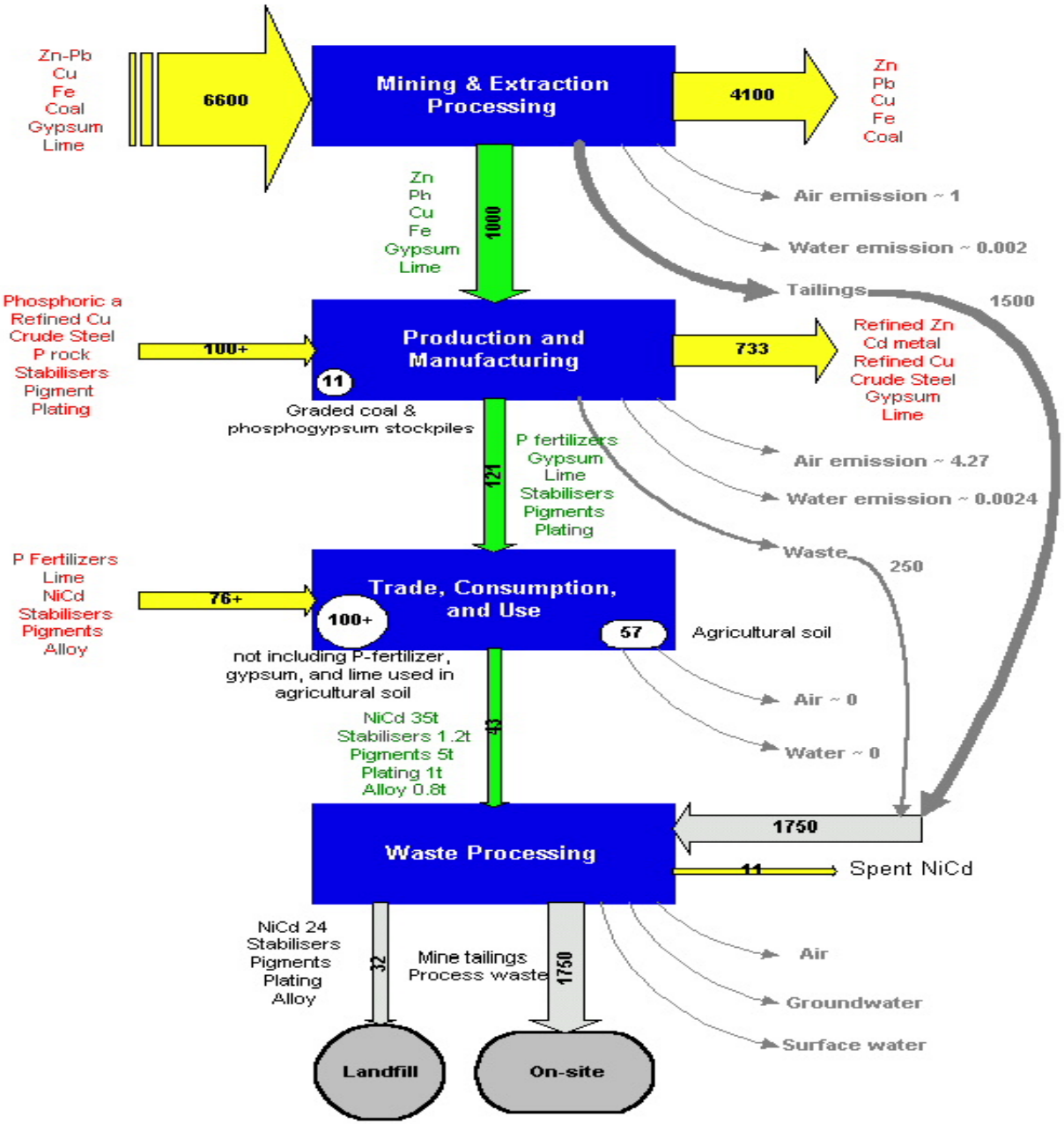
- Cadmium:
  - 18% of global reserves of Cd (& Zn)

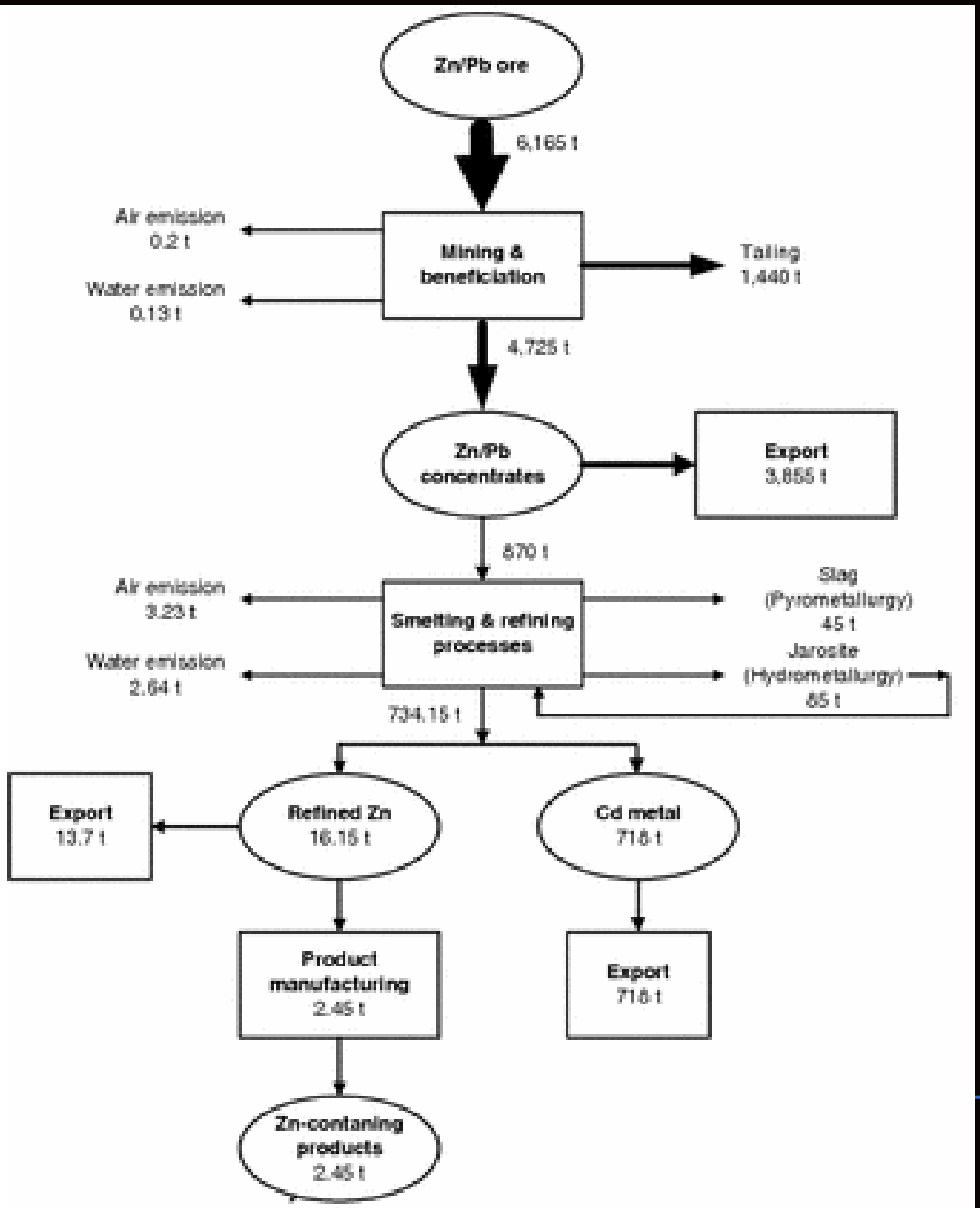
Table 3. Cadmium reserves and reserve base, yearend 2000 [In metric tons, contained cadmium. All data are rounded to two significant digits; because of independent rounding, they may not add to totals shown. Plachy, 2001]

	Reserves	Reserve base
United States	90,000	270,000
Australia	110,000	300,000
Canada	55,000	160,000
China	13,000	35,000
Germany	6,000	8,000
Japan	10,000	15,000
Kazakhstan	25,000	40,000
Mexico	35,000	40,000
Russia	16,000	30,000
Other countries	240,000	330,000
World totals	600,000	1,200,000

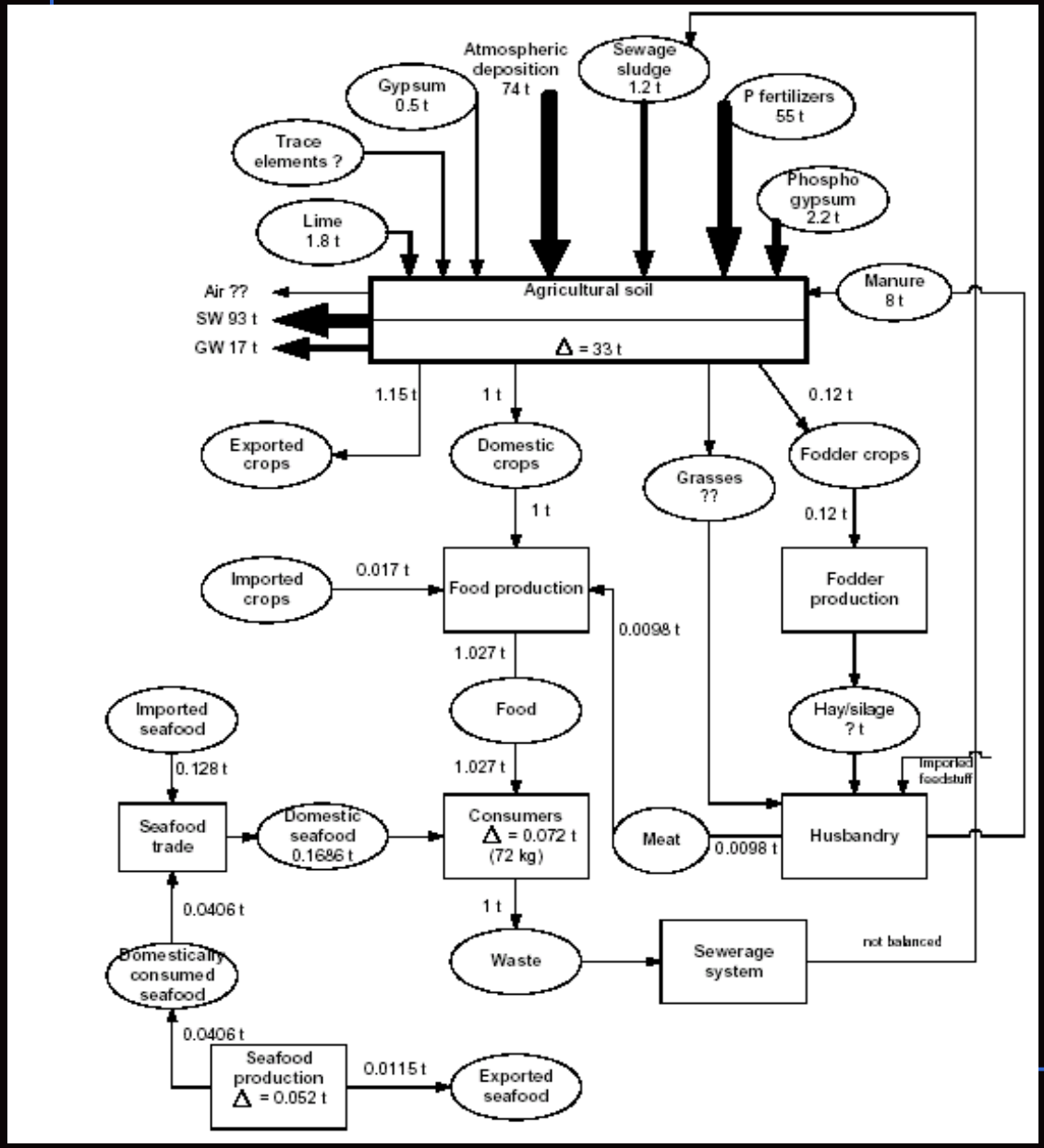
- Zinc Reserves:
  - Australian reserves: 42Mt (18%, highest in world)
  - Global reserves" 228Mt
- World zinc production: 9.6MT
- Australian zinc mine output:
  - 2005: 1.4MT
  - 2011: 1.9MT
  - 15 – 20% of global supply

Cadmium flows in Australian economy, 1998 (tonnes Cd)



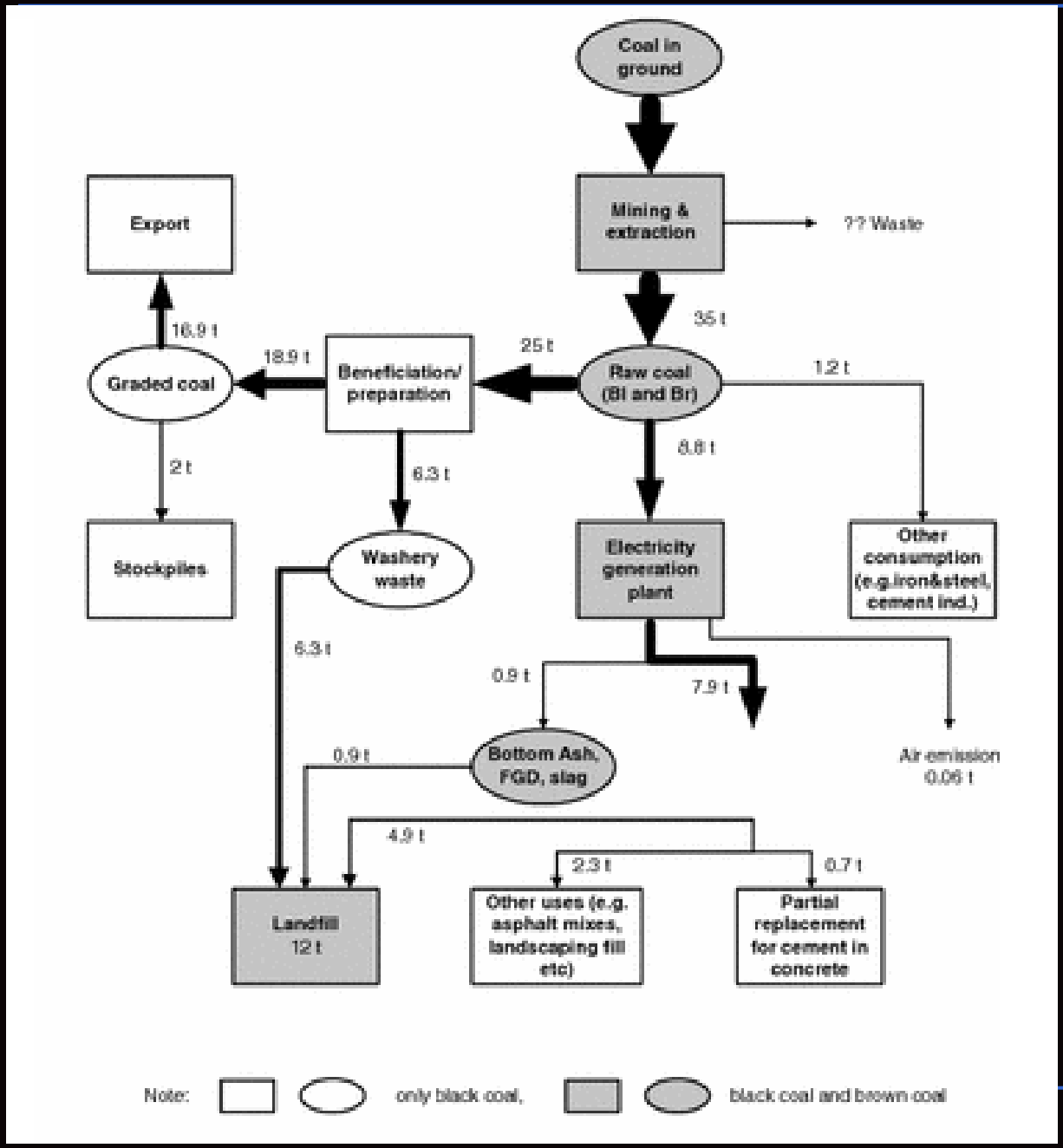


Cadmium flows in zinc mining And smelting



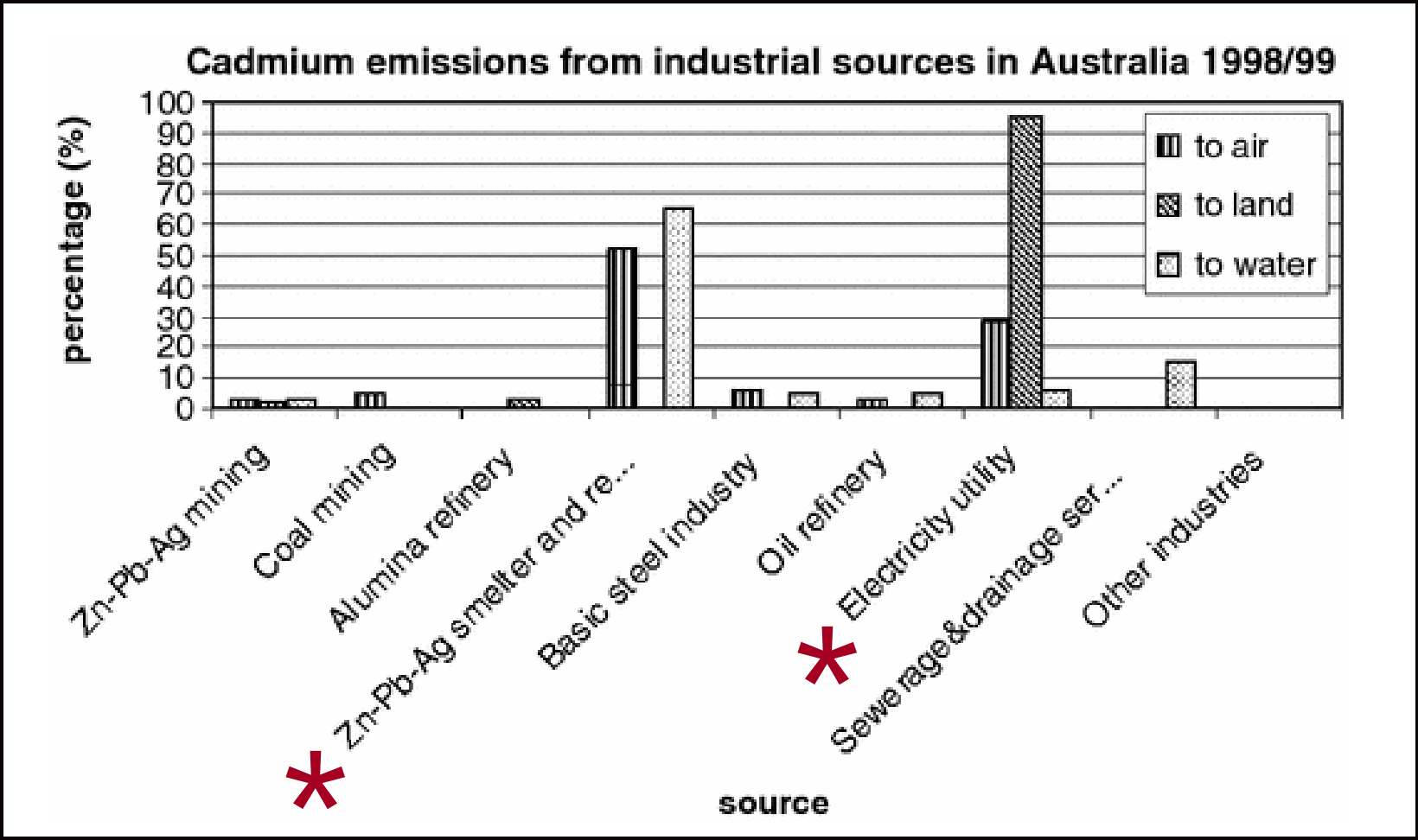
Plus cadmium contaminated
Zinc sulphate trace elements

Cadmium in Agriculture



Cadmium flows in coal Mining and electricity generation

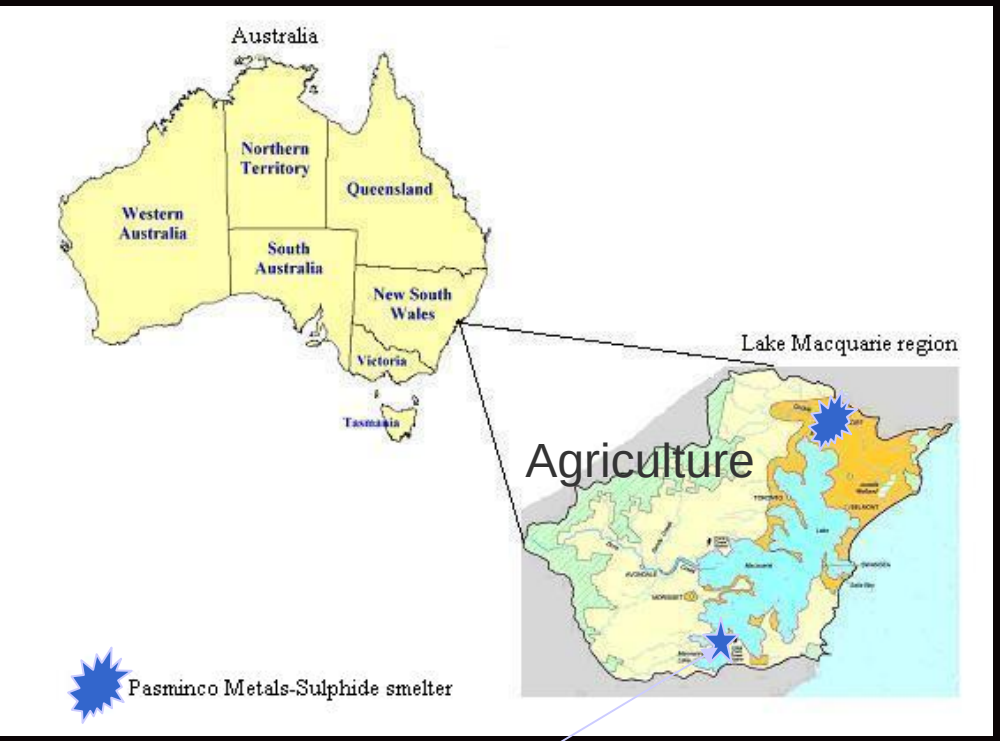
Cadmium emissions:
unintentional use flows included (NPI)



Conclusions

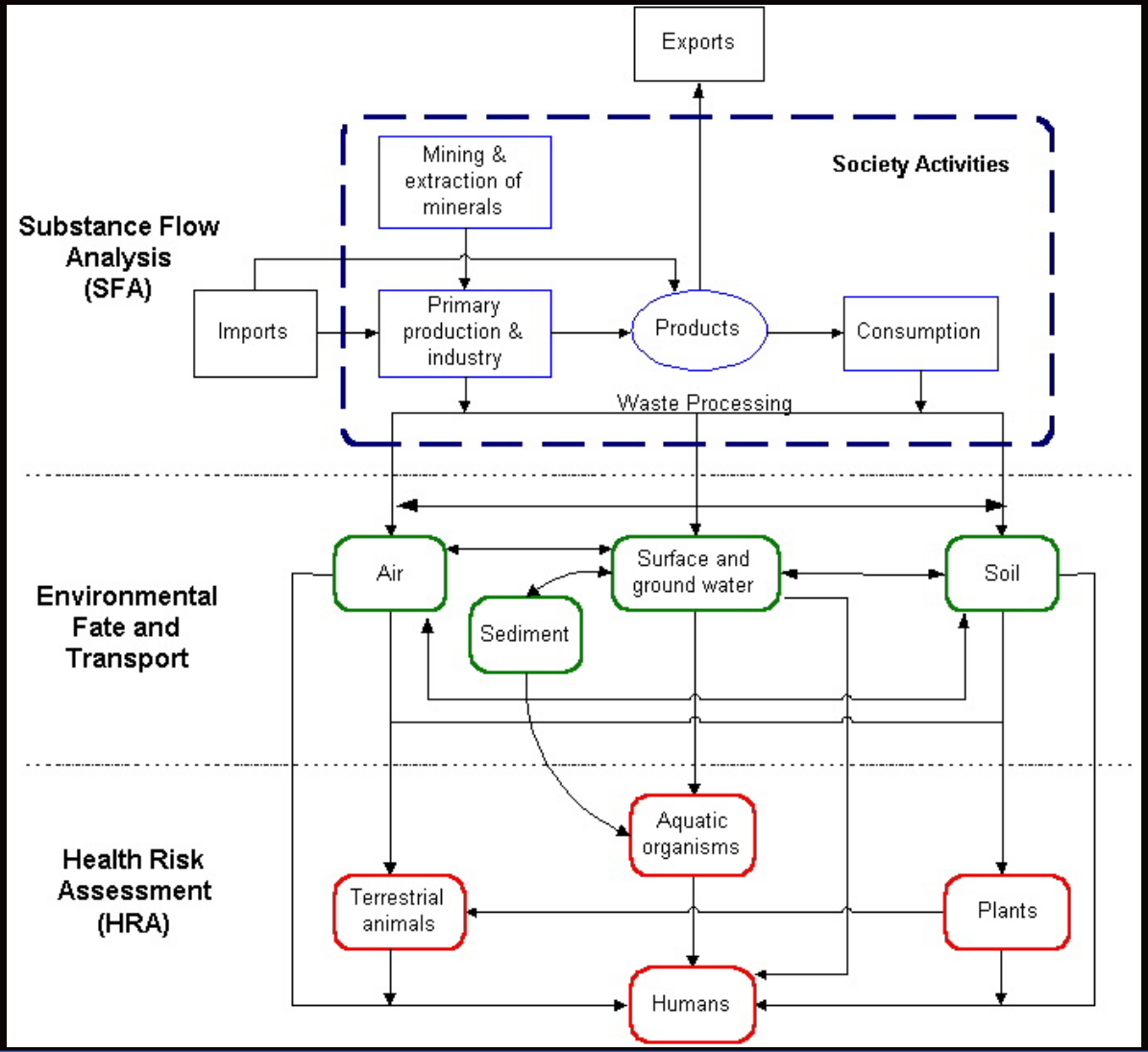
- Exports of cadmium are the major flows
  - Zinc concentrates
  - Coal
    - Where is the sink for Cadmium?
- In Australia, regions associated with:
  - Agriculture,
  - power generation,
  - zinc smelting
    - Any unacceptable health risks?

Region of concern:
Lake Macquarie, 150km north of Sydney



Coal fired power station

Linking MFA with Health Risk Assessment

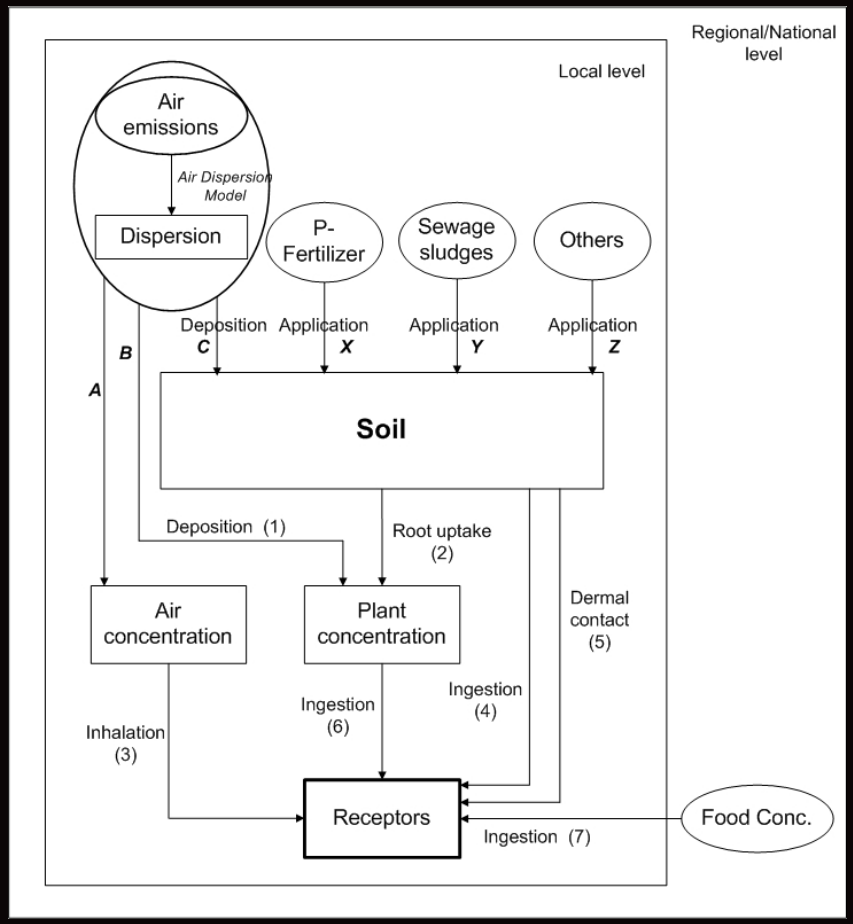


Risk assessment: Speers Point residents

- Conservative, does not include:
  - Coal fired power generation emissions
  - Ingestion of molluscs and fish from Lake Macquarie
- Provisional Tolerable Weekly Intake (FAO/WHO):
- 7ugCd/kg body weight

	Safe daily dose mgCd/d	Actual Daily dose mgCd/d	Multiplier of safe dose
Child	0.018	0.255	14X
Adult	0.07	0.16	2.3X

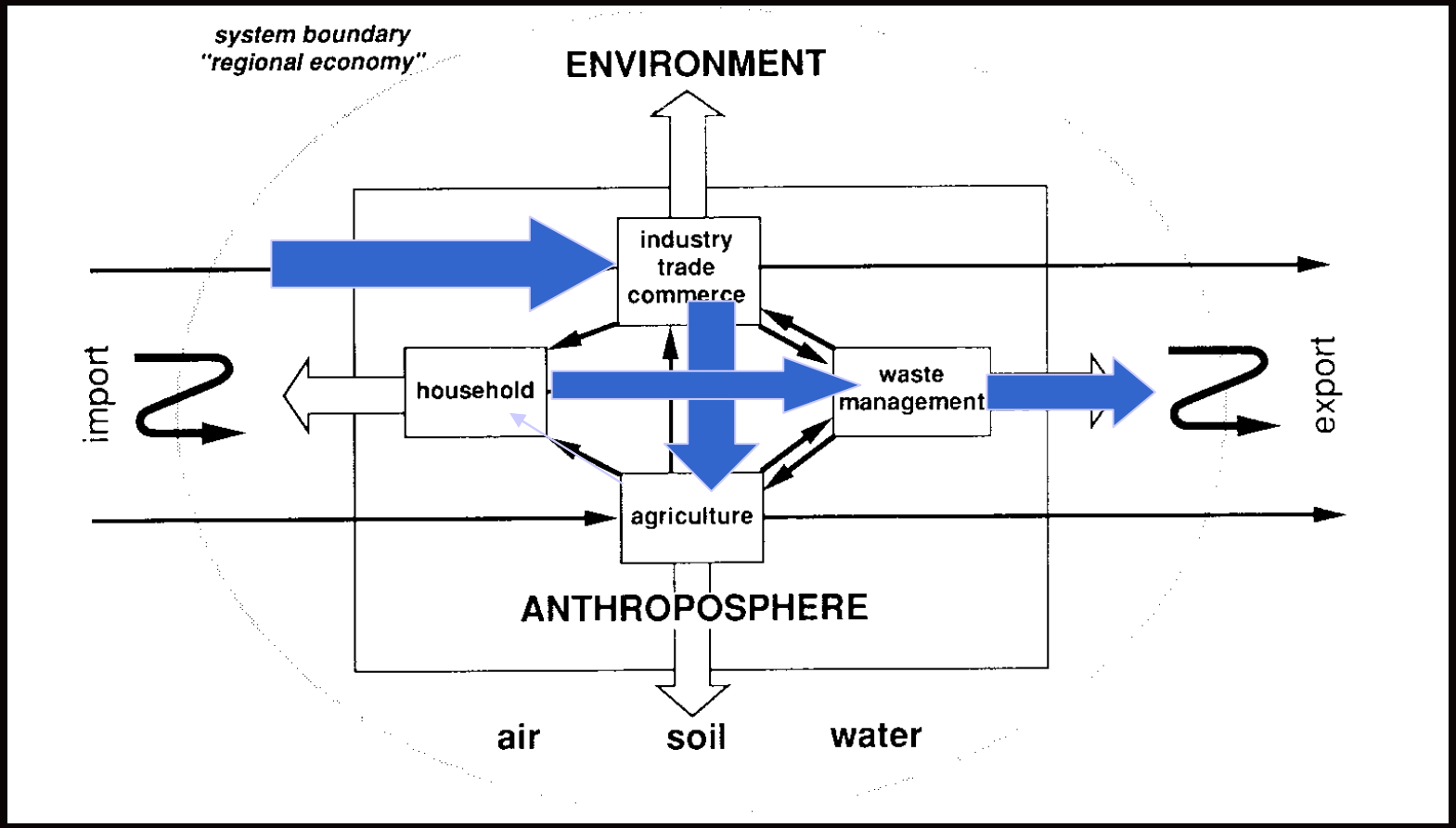
The average values used in EU studies do Not show up these site specific problems



Conclusions

- Integration of MFA with human health risk assessment can identify critical regions of risk prior to observation of chronic damage
- Australia has some regions where risk from chronic kidney disease and cancer related diseases is unacceptable…epidemiological studies should be undertaken here.
- Australia is a major exporter of cadmium, where supply > demand for intentional uses:
  - where is the sink for this cadmium ?
  - is this acceptable ?
  - what management of this substance is necessary?

Part 2: Phosphorus



Why select Phosphorus?

- Inputs
  - Non-renewable resource
  - Essential for nutrition of organisms
  - How long do we have left?
- Outputs:
  - Eutrophication problems
  - Associated contamination with cadmium
- Associated issues:
  - Nutrient cycling v's biomass energy recovery?

Input constraints: Supply of P

Fertilizer 80%, detergents 12%, animal feeds 5%

1996 Table 1: **Global phosphate reserves**

% of total (1996):	Production	Reserves	Potential Reserves	Geological Resources
United States	34	4-10	7-13	25
China	16	2-25	2-10	9
Morocco	16	46-53	63	50
Russia	6	3	7-10	9
South Africa	2	9-22	3-22	3
Tunisia	5	1	1	1-2
Jordan	4	2-3	1-3	1-2
Iraq	–	1	3	2-3
Brazil	3	1-3	1-2	1
Peru	–	1	–	1-2
All other countries	14			
Total P_2O_5 (million tonnes)	**38**	**3,600-8,000**	**11,000-22,000**	**30,000**

Source: United States Geological Survey, International Fertilizer Industry Association and British Sulphur

Australia 1Mt of P_2O_5 per year, 2.5% of global consumption

Fig. 4: **Scenarios of P_2O_5 consumption** Mt/year

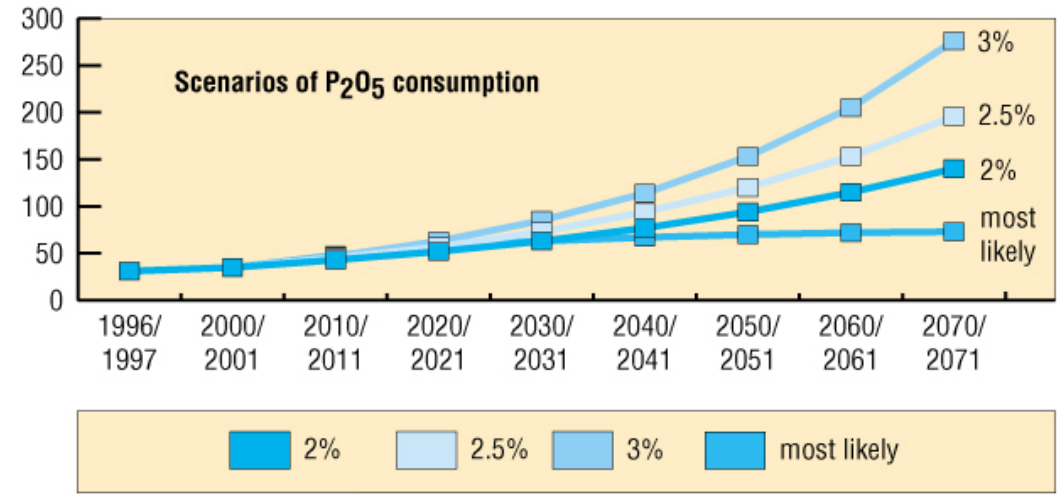
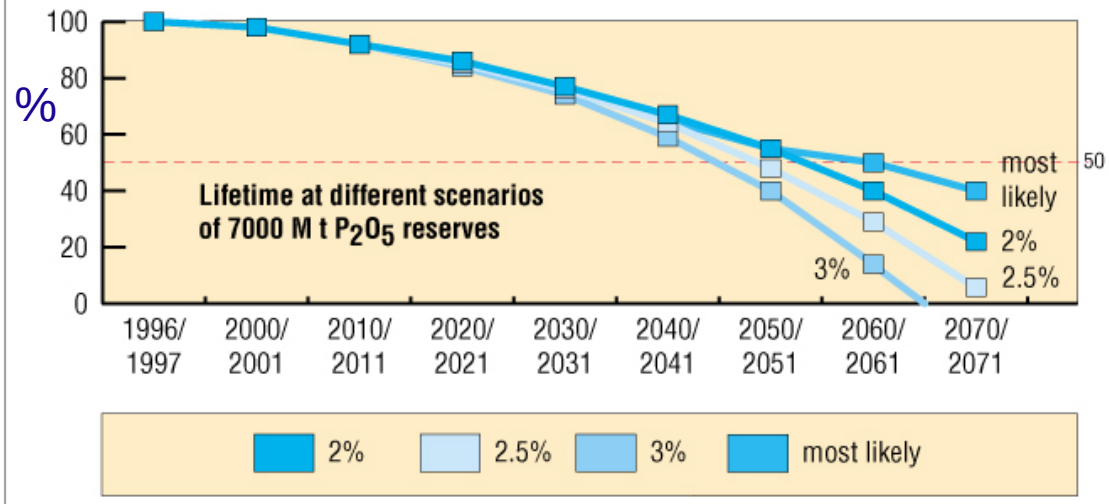


Fig. 5: **Lifetime of reserves**



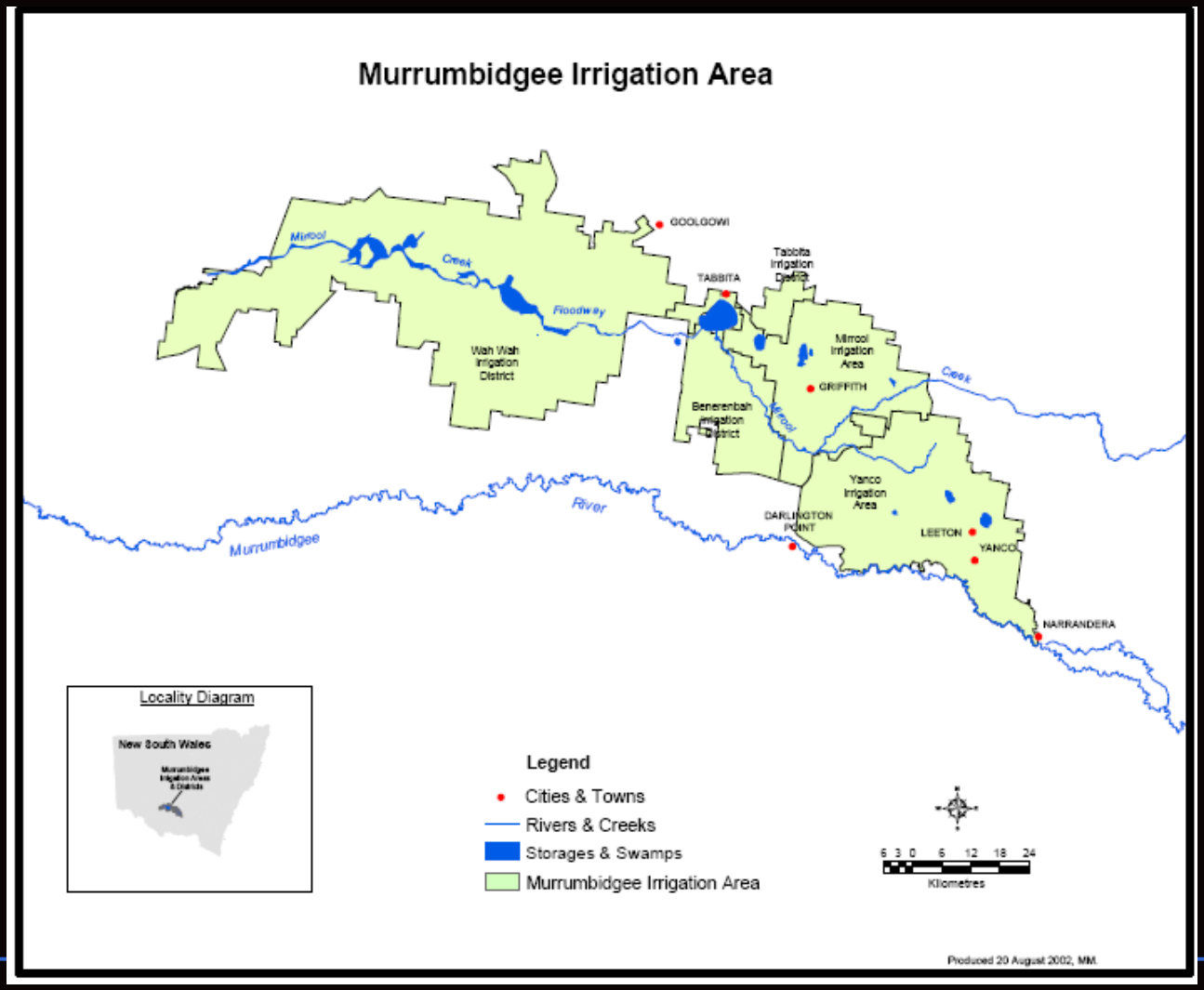
Lifetime

Current reserves:
7 000Mt P_2O_5
60 – 110yrs

Potential reserves:
<22 000Mt P_2O_5
300 years??

Output constraints: eutrophication

Murrumbidgee Irrigation Area (MIA)

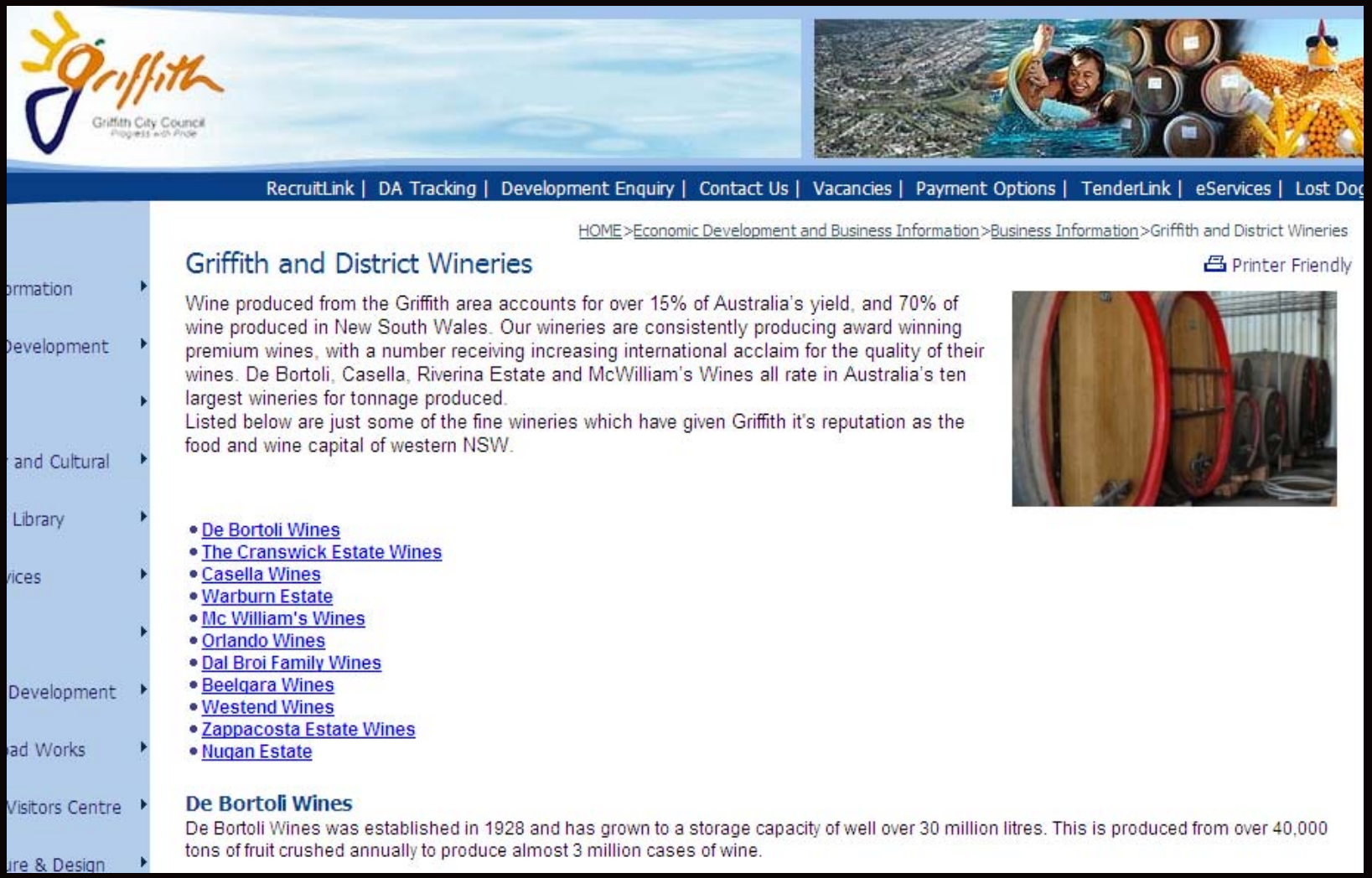


MIA at Griffith
vineyards, orchards, rice

Feedlot cattle and abattoir

Rice 20%, corn…grain export

Wine 20% and fruit juices citrus 35%

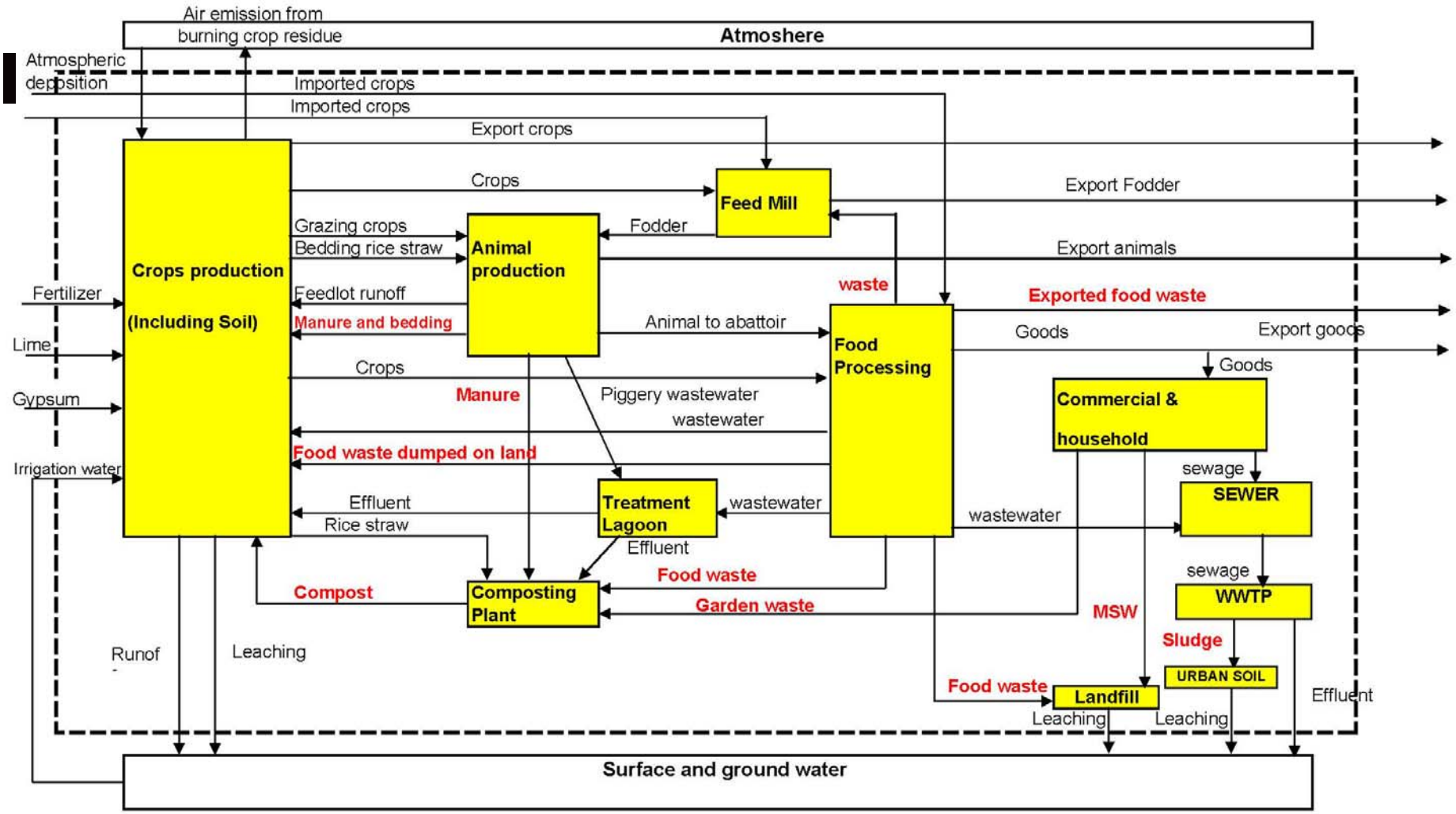


Biowaste:
grape marc from wineries

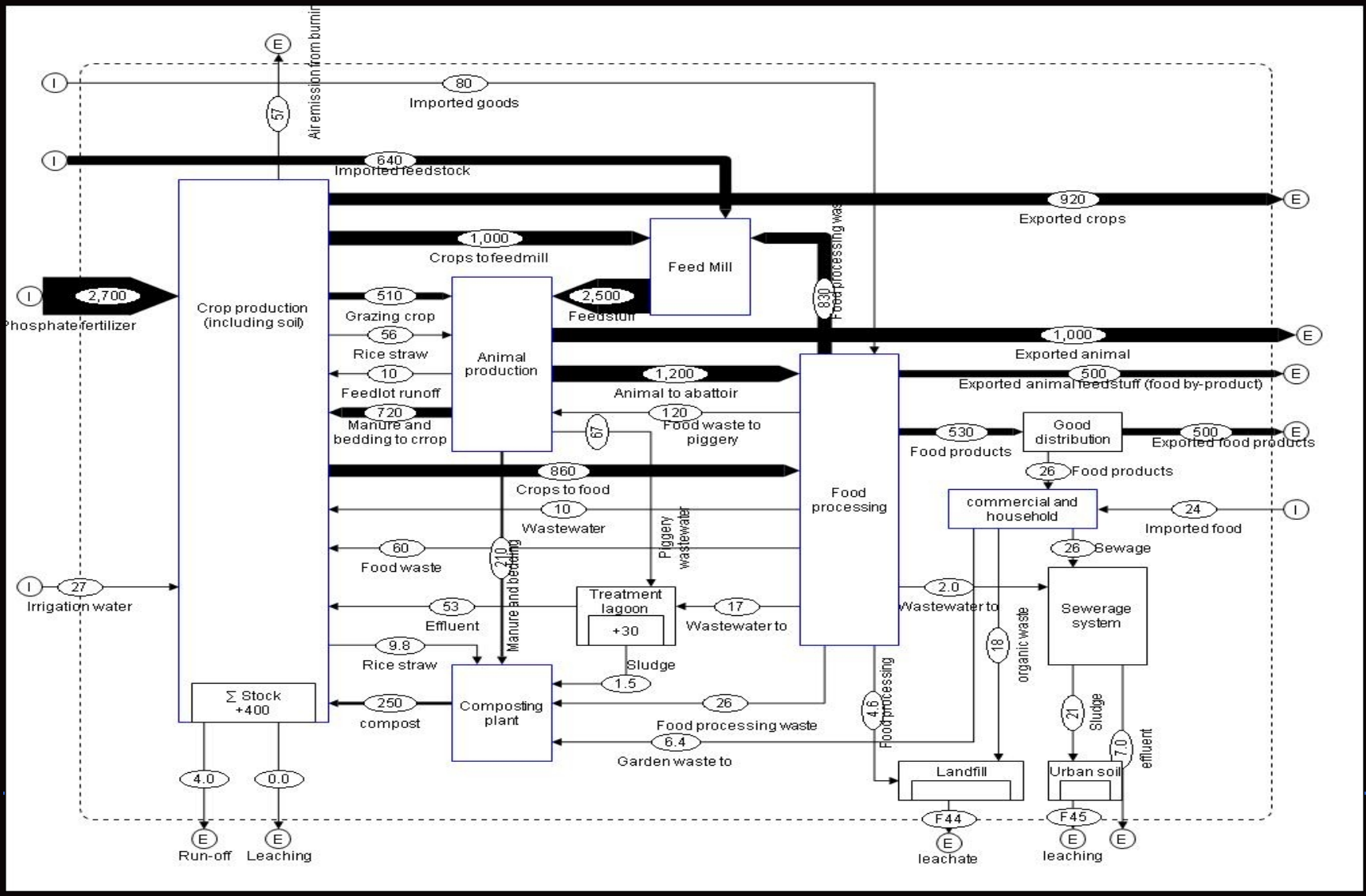
Rice straw bales

Composting of biowaste

Whole system of materials flows containing P

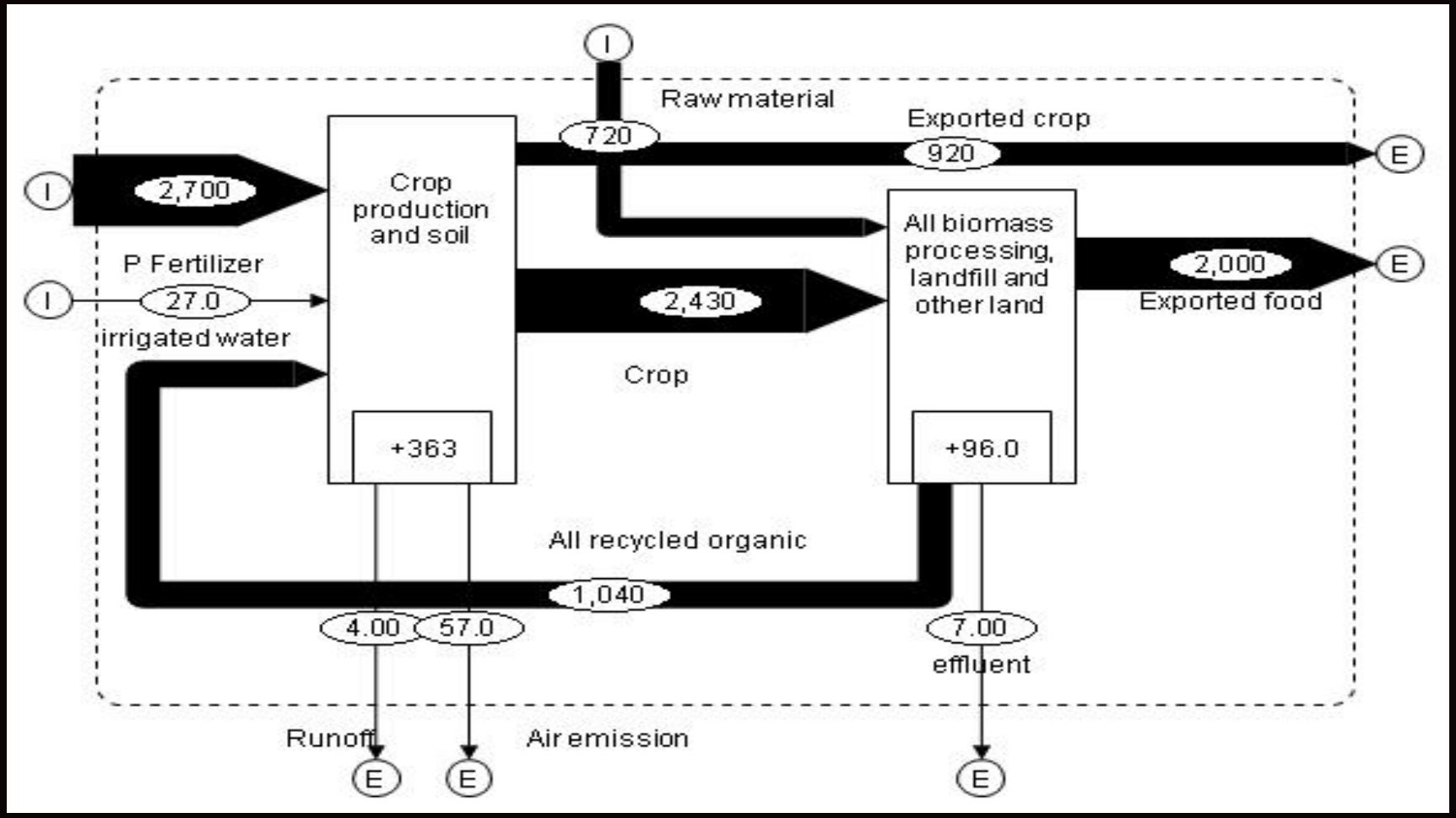


P flows through the MIA 2006



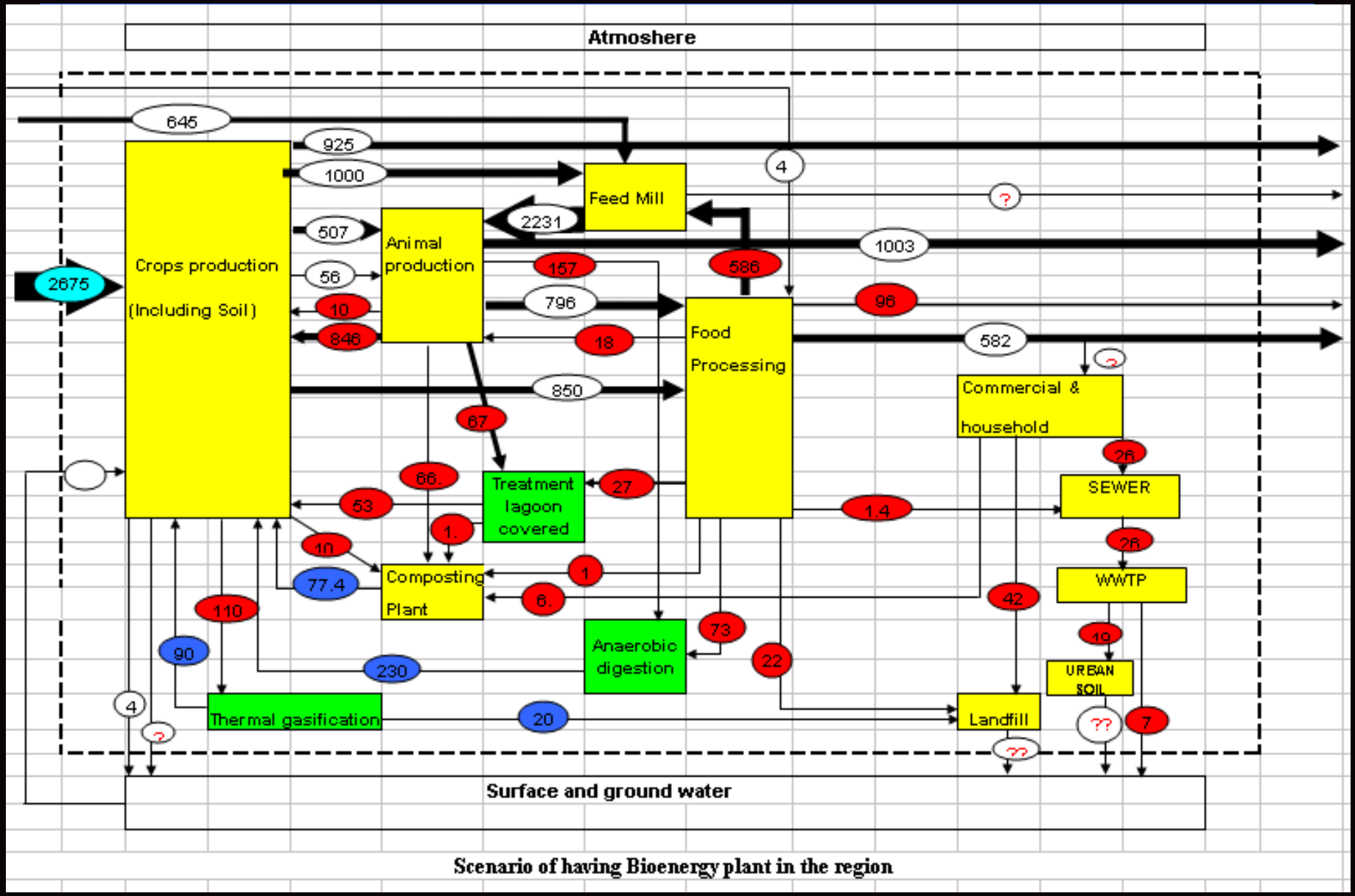
P flows through the MIA 2006

rounded off



Summary of P flows MIA 2006

- Inputs: 3471 t P 100%
- Outputs:
  - Food goods: 2920t P 84%
  - Emissions to environment: 112t 3%
- Stock accumulation: (mostly soil) 483t 13%



Scenario of having Bioenergy plant in the region

P flows after bioenergy and gasification of Biomass waste

Soils I = 519kg/y o = 223kg/yr Stock (soils) = +296kg/y (57% of input)

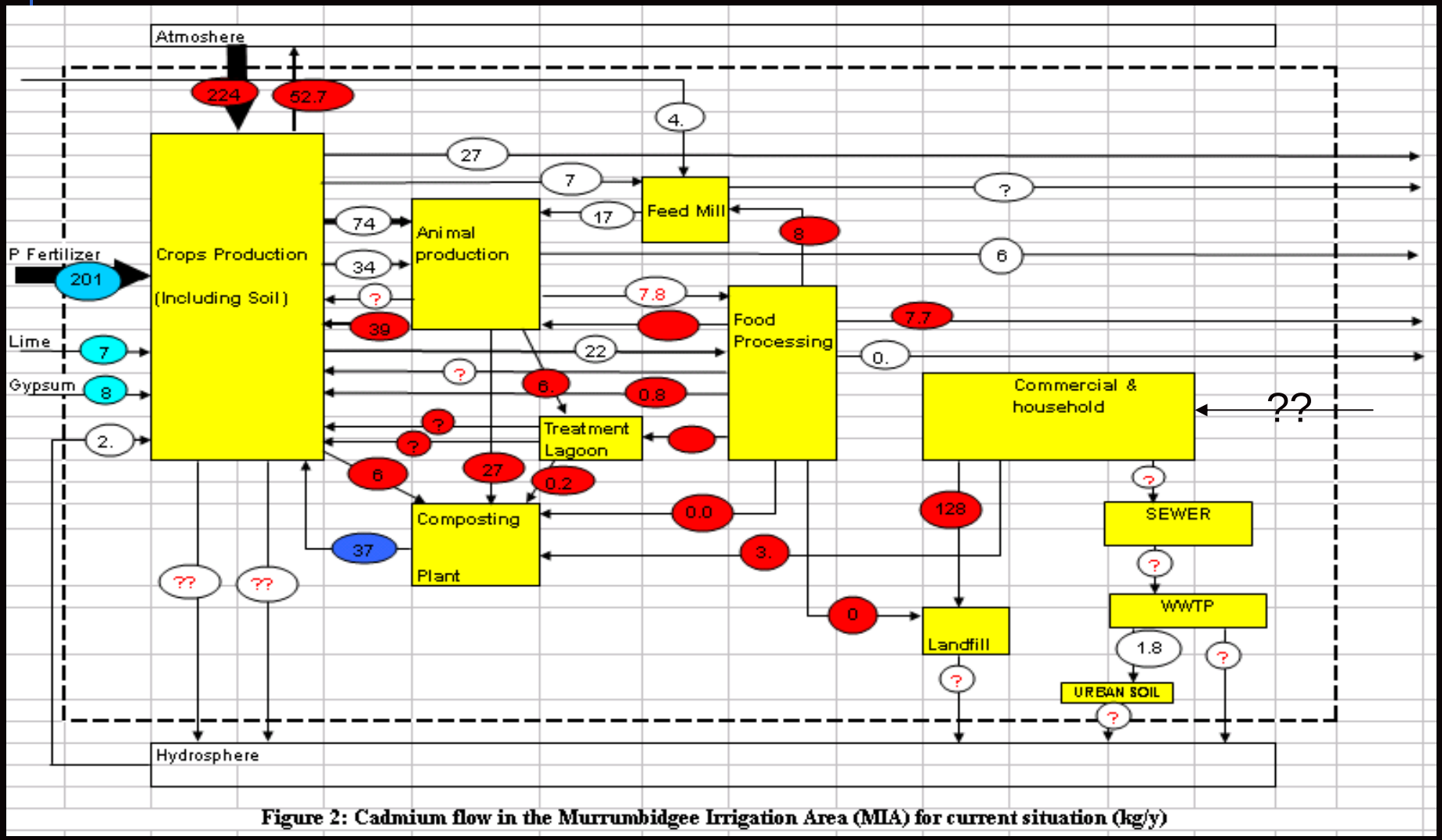
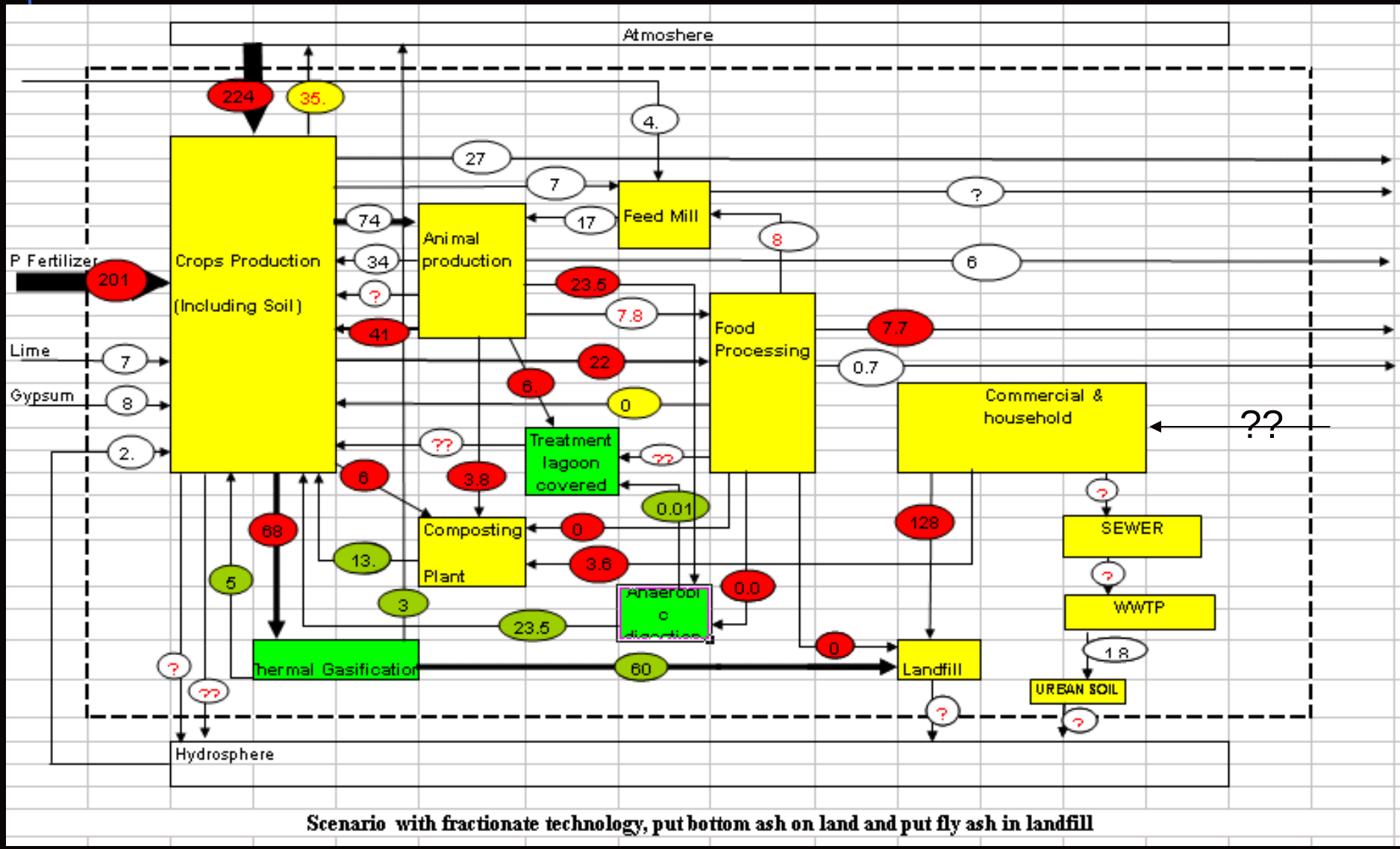


Figure 2: Cadmium flow in the Murrumbidgee Irrigation Area (MIA) for current situation (kg/y)

Current Cd flows kg/y 2006



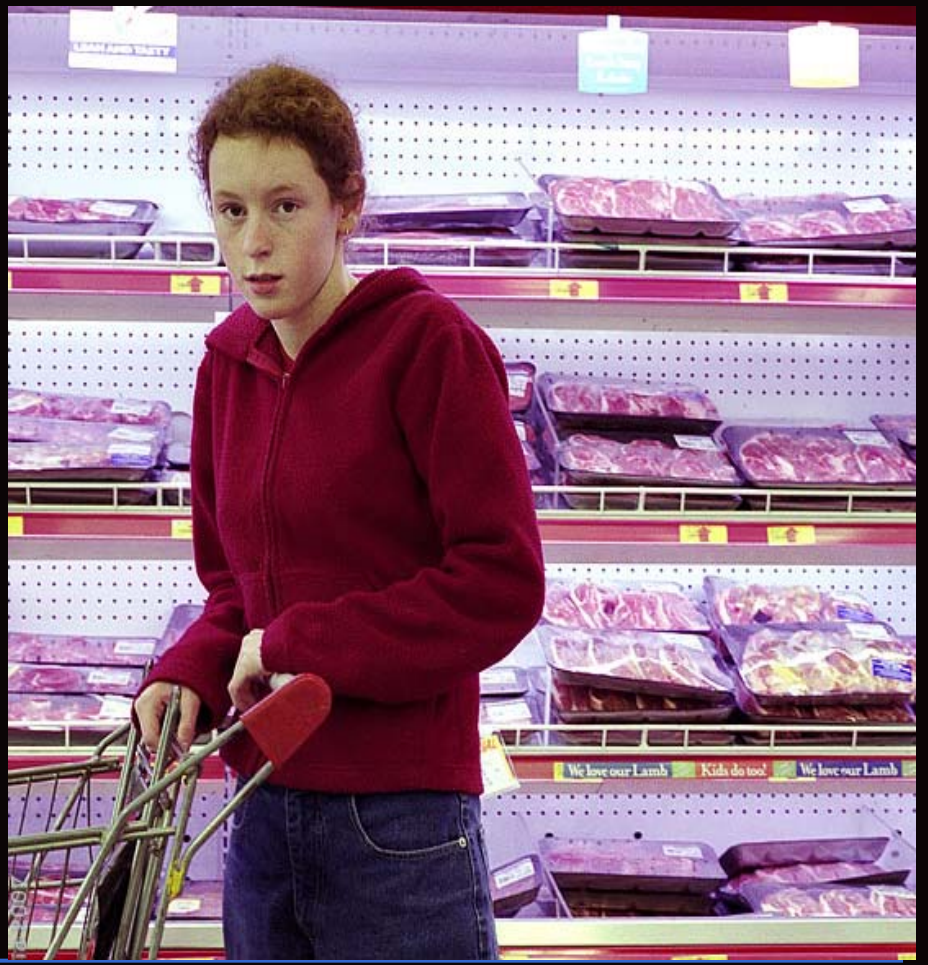
Scenario with fractionate technology, put bottom ash on land and put fly ash in landfill

Cd flows after bioenergy and gasification of Biomass waste

Conclusions on MIA study

- Phosphorus:
  - >75% of P flows out with agricultural goods
    - **Need to track and return these P flows**
  - High level of P cycling from biowaste in current situation…drought effects
  - Energy recovery via anaerobic digestion (CH_4) and pyrolysis gives extra 2.5% of input P returned to soils.
- Cadmium:
  - High accumulation of input into soils…associated with mineral P fertilizer, 60% of input builds up in soils.
  - Use of pyrolysis on biowaste returns P, diverts Cd to Landfill…but only for the 2.5% of input P to region.
- Biowaste from towns in the region are insignificant in terms of P and Cd, and bioenergy resources…except for NiCd batteries.

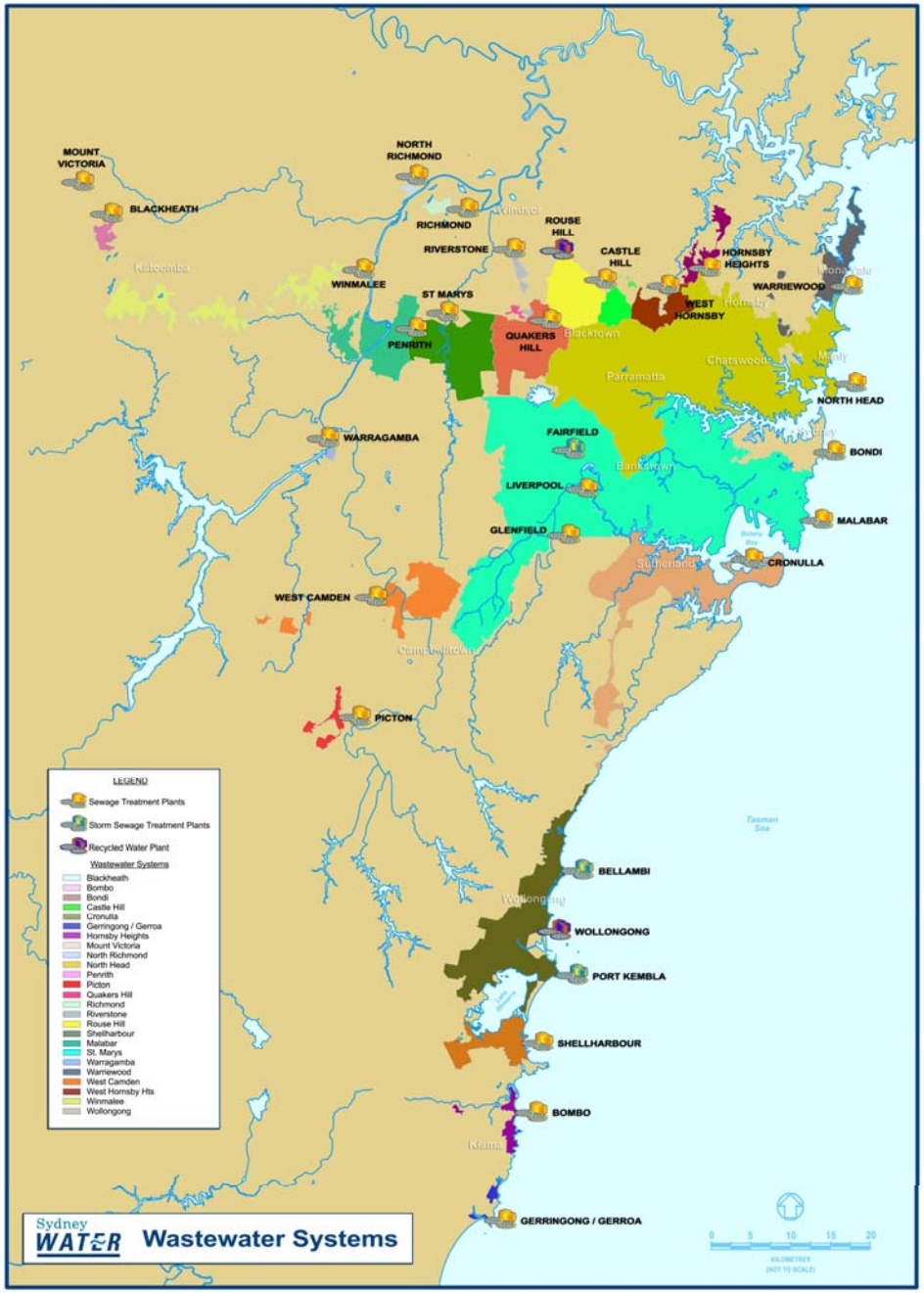
Sydney department stores



Sydney households

Domestic waste to disposal: LF

some garden waste to composting…little food waste



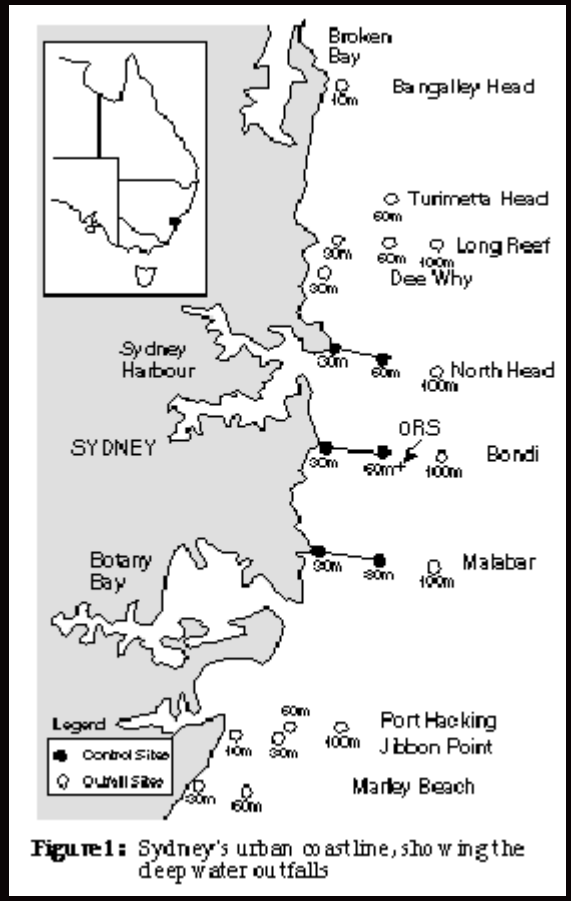
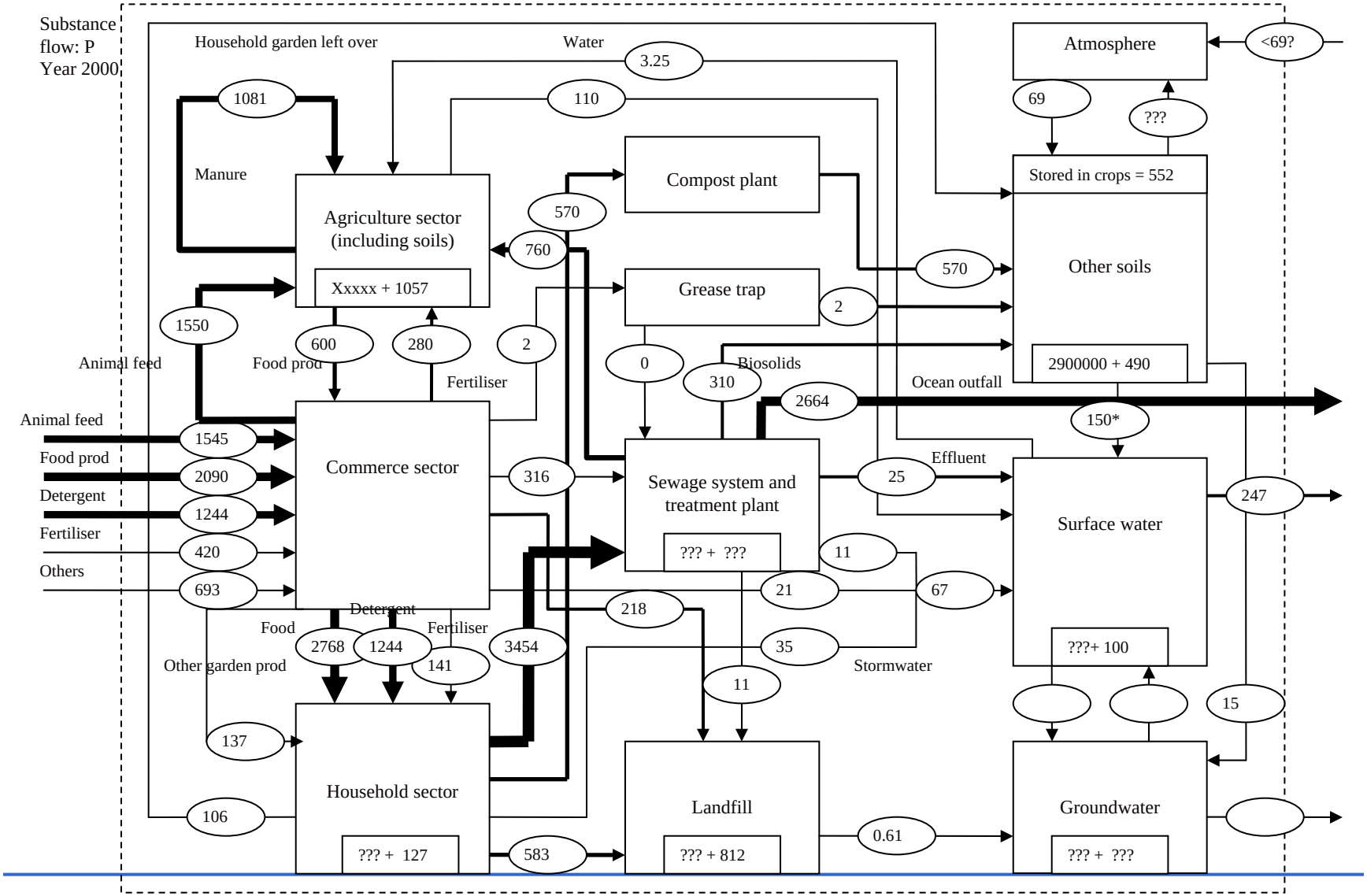


Figure 1: Sydney's urban coastline, showing the deep water outfalls

Cronulla STW: sludge to compost

P flows through Sydney 2000



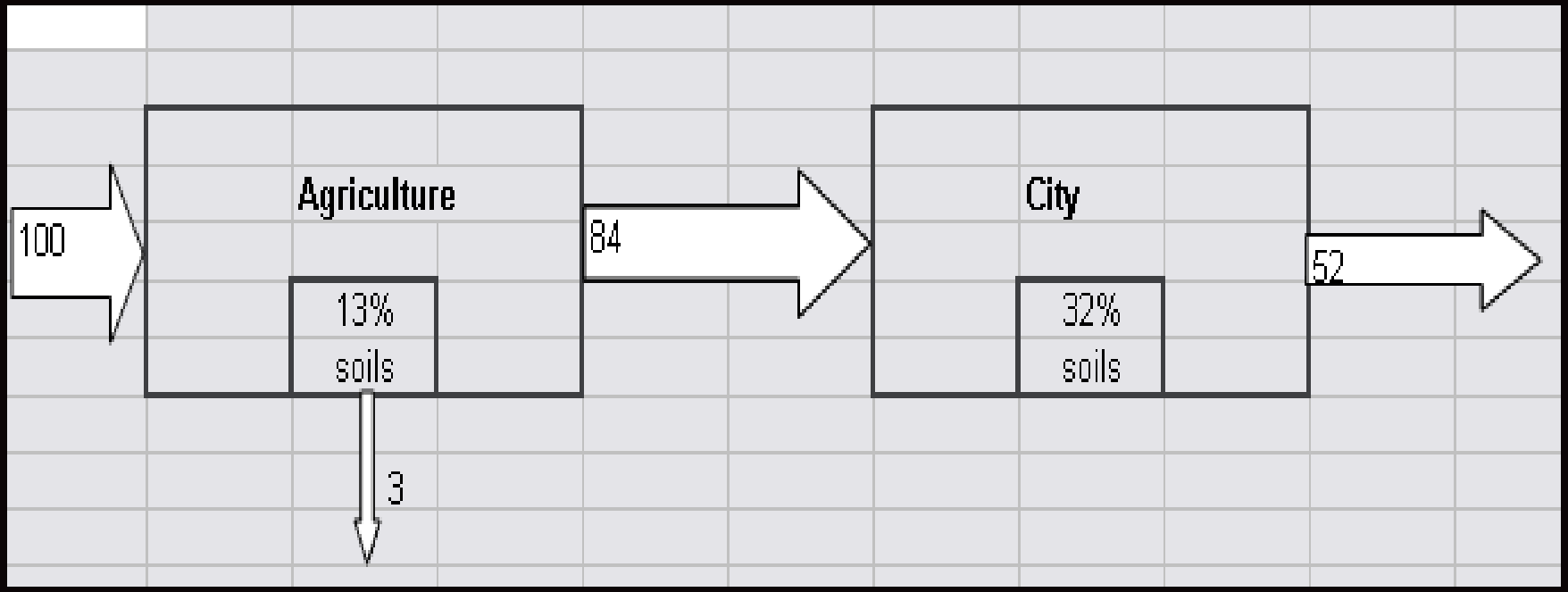
Summary of P flows Sydney 2000

- Input: 5992t
- Output:
  - Effluent to ocean: 2911t 48%
  - Solid waste to landfill: 801t 13%

61%

- Stock accumulation in soils (and then some to food goods): 2280t 39%

Overall P flows



What happens when the P runs out?

Peak P and beyond

- 1830 – 1870: depletion of natural fertility of soils in Europe and North America
- 1835: 100t guano from Peru to England
- 1847: 220,000t imported to England
  - …”guano imperialism”

Synthetic fertilizers…

- 1840: Liebig…importance of NPK to soil fertility
- 1843: Laws invented “superphosphate” fertilizer, from phosphate rock (sedimentary and igneous)
- 2008: after 165 years, have 100 – 300 years of phosphate rock remaining...approaching Peak P
- ….what will our great grandchildren do…??

In the 1800s The Europeans raided the Napoleanic battlefields for bones..

What options do we have??

Our cities…

P in food waste and garden waste to LF

11% of the original P into Agriculture

No organic solid waste to landfill

Retain biomass waste P at household

Or

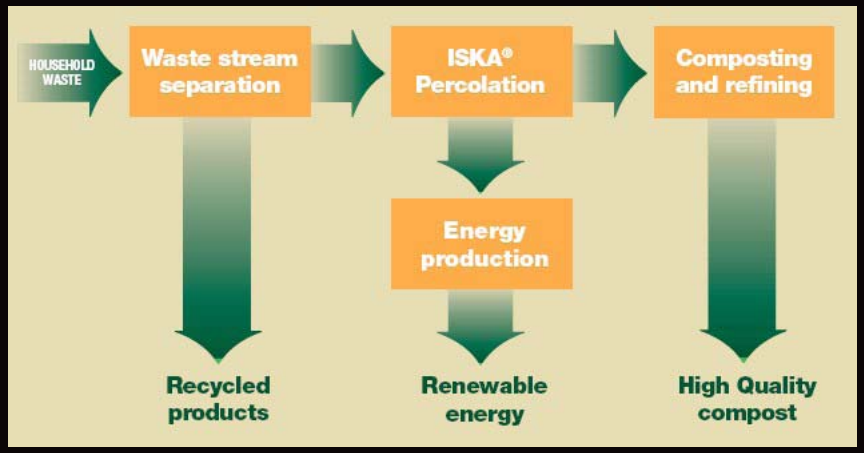
Central treatment of source separated solid biomass waste

Neighbourhoods

Cities

Or

mechanical biological treatment of residual waste to disposal….???



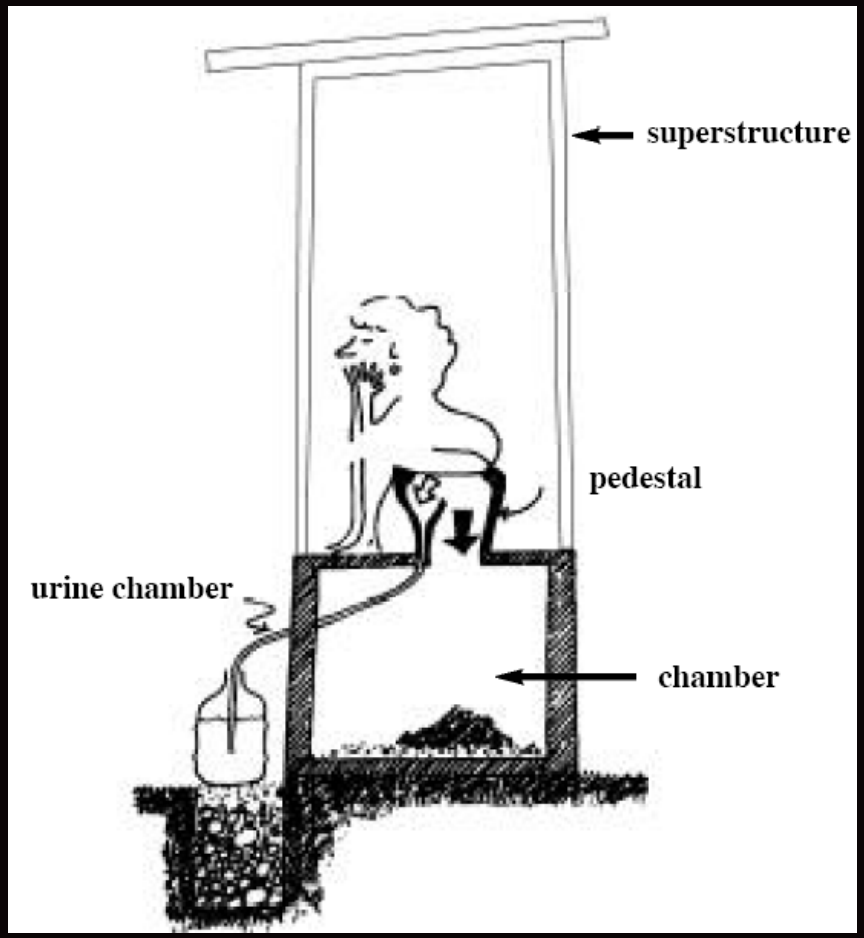
Our cities

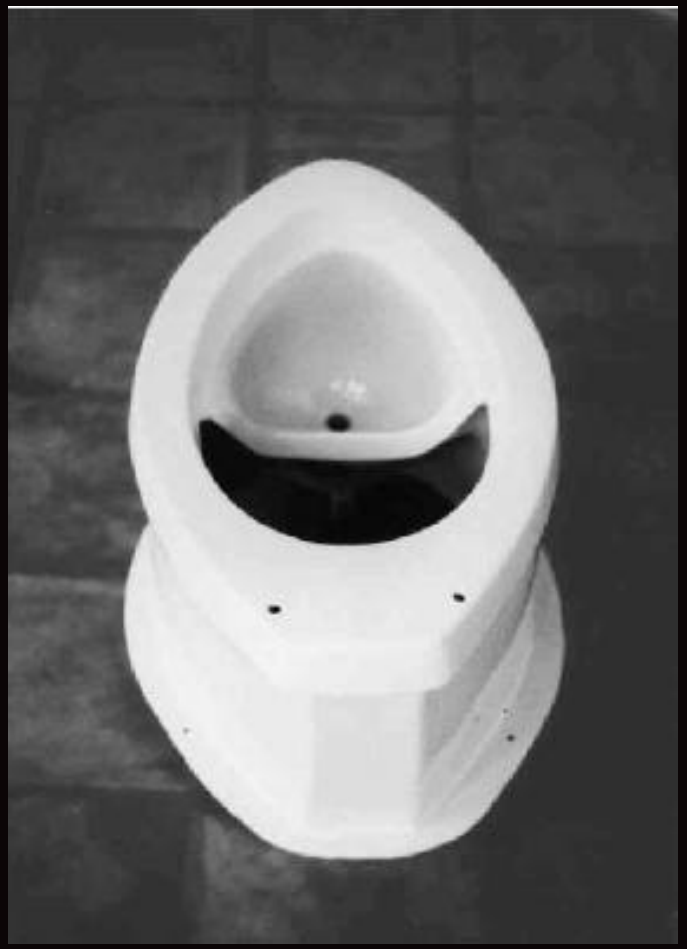
P in wastewater

40% of the original P into agriculture

Urine separating toilets

50% of P in household wastewater from urine
(20% of original P to agriculture that is lost to the ocean)





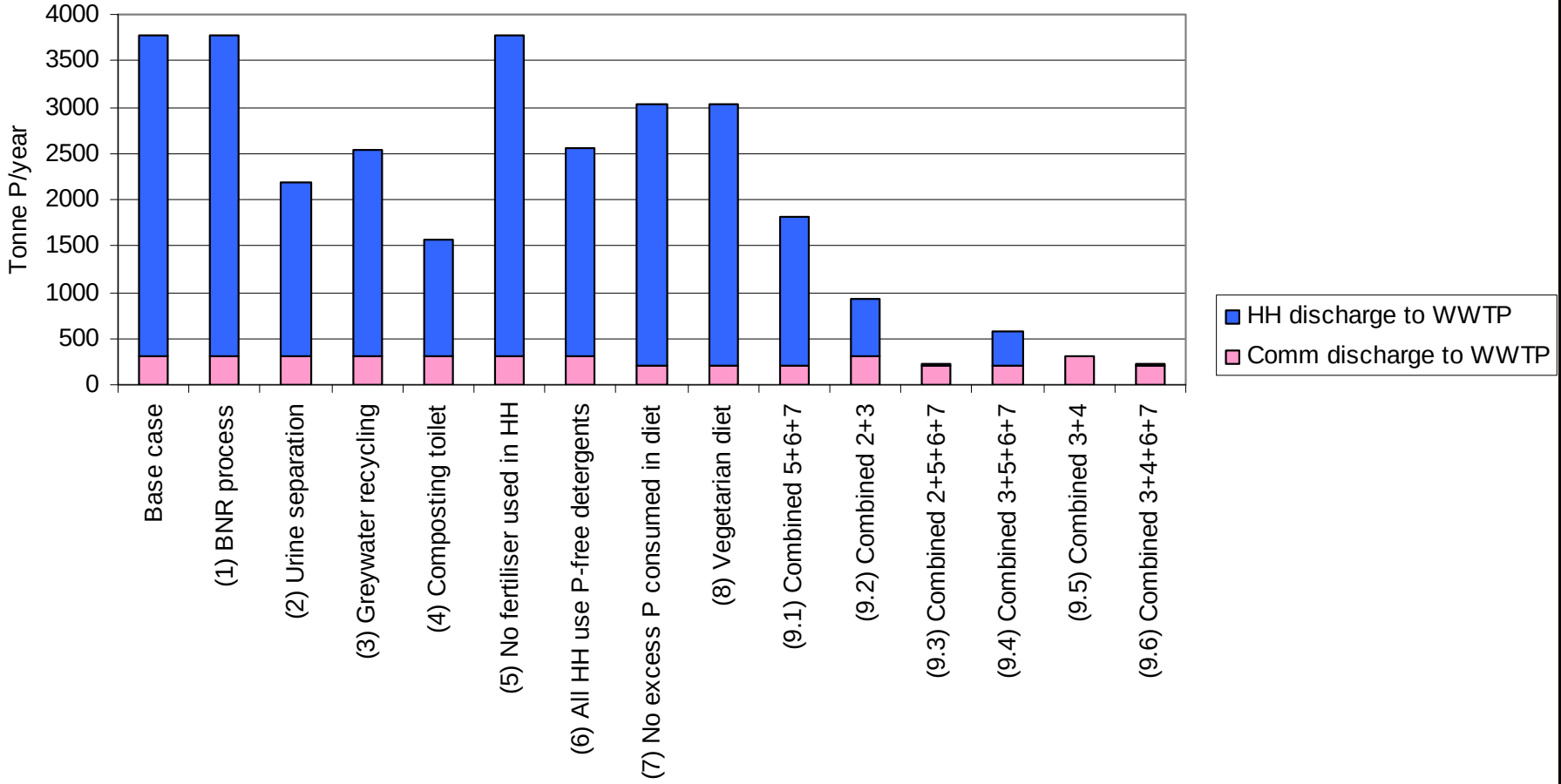
Biosolids from STW

- Heavy metal contamination???
  - Need to look at load on soil from all inputs, not just concentrations in biosolids (sludge)
- Alternative sewerage systems ??
  - Especially for cities with infrastructure being newly established.
- Where is the P coming from??
  - Efficiency of animal protein: Cereal to meat ratio
    - Poultry: 3:1
    - Pigs: 4.5:1
    - Cattle: 6:1

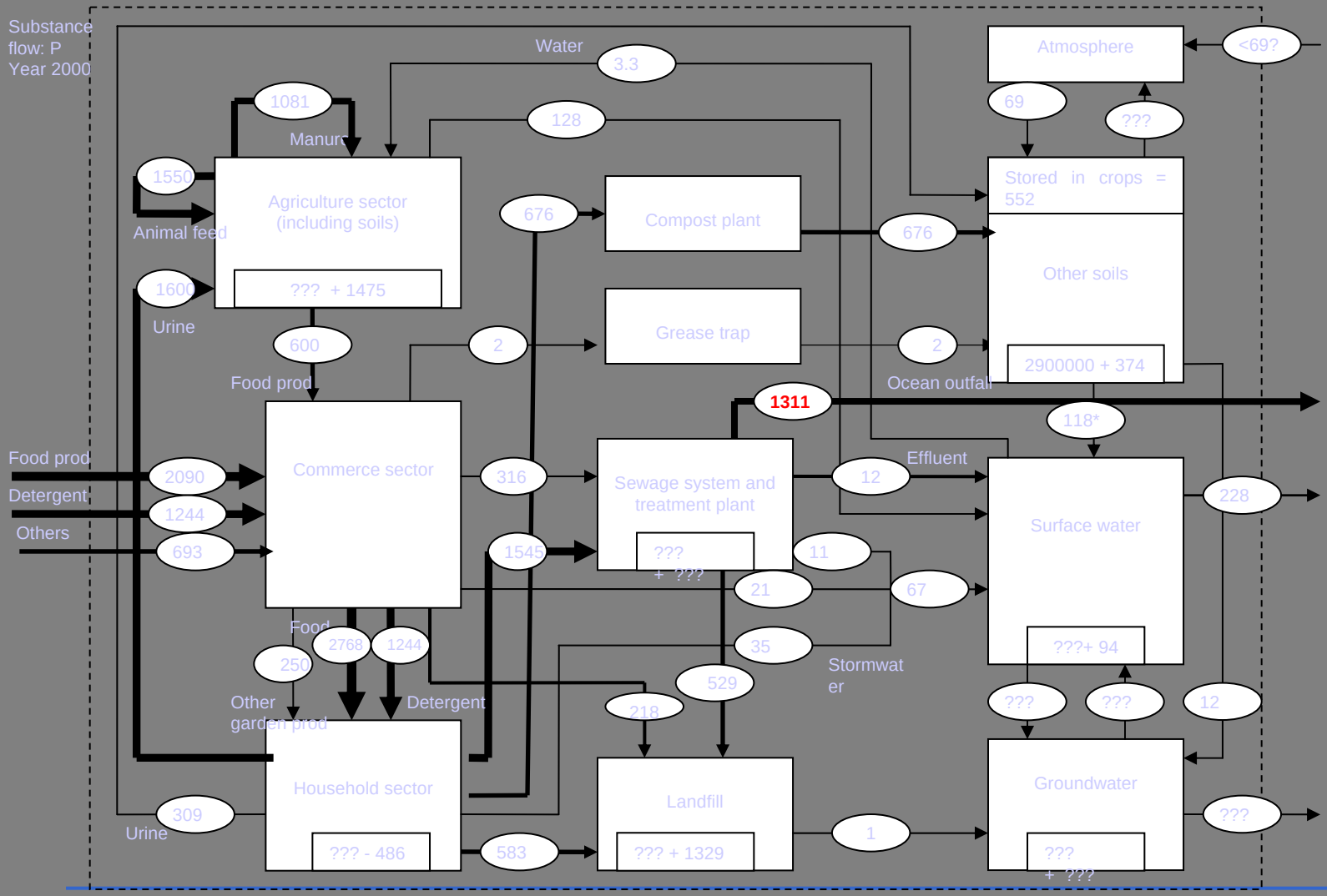
Water recycling and P recovery options

- 1) Maximum water recycling with additional Biological Nutrient Removal (BNR) at all ocean plants in Sydney,
- **2) Install urine separation in all households in Sydney,**
- **3) Install greywater treatment and recycling systems in all households in Sydney,**
- **4) Install composting toilets in all households in Sydney,**
- **5) No household fertilisers used,**
- **6) All households move to use of P-free detergents,**
- **7) All households consume no excess phosphorus in diet (following the current dietary pattern),**
- 8) All households consume no excess phosphorus in diet and everyone adopts a vegetarian diet,
- 9) Combined scenarios[1]
  - 9.1) Combined scenarios 5, 6, and 7,
  - 9.2) Combined scenarios 2 and 3,
  - 9.3) Combined scenarios 2, 5, 6, and 7,
  - 9.4) Combined scenarios 3, 5, 6, and 7,
  - 9.5) Combined scenarios 3 and 4,
  - 9.6) Combined scenarios 3, 4, 6, and 7.
- [1] These combined scenarios are chosen to show the effects of different degrees of changing human behaviour together with changing the wastewater management systems.

P loading on the wastewater treatment system as a result of different scenarios



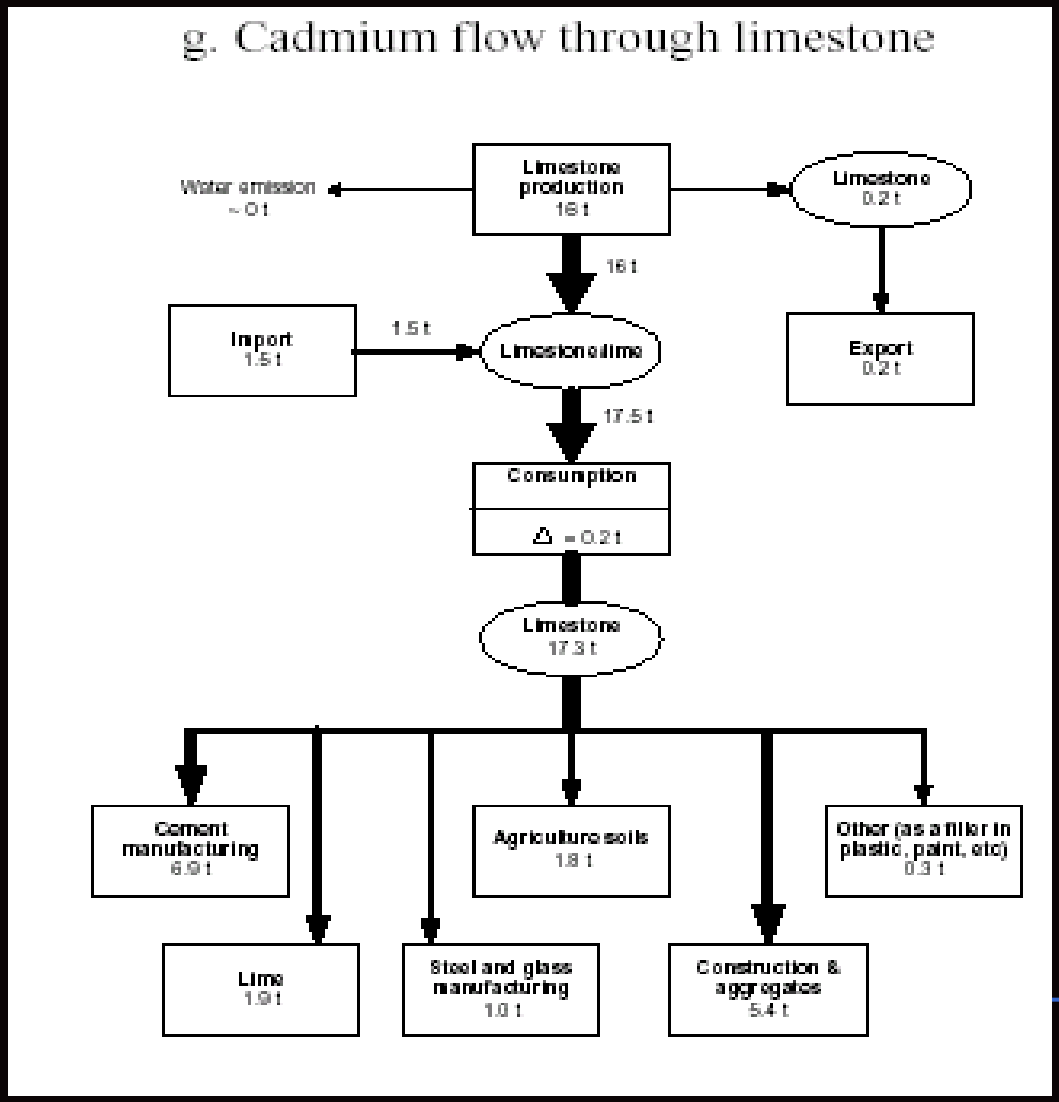
Phosphorus balance in the Sydney region when optimal phosphorus-containing products recycling is imposed (Tonnes P/yr)



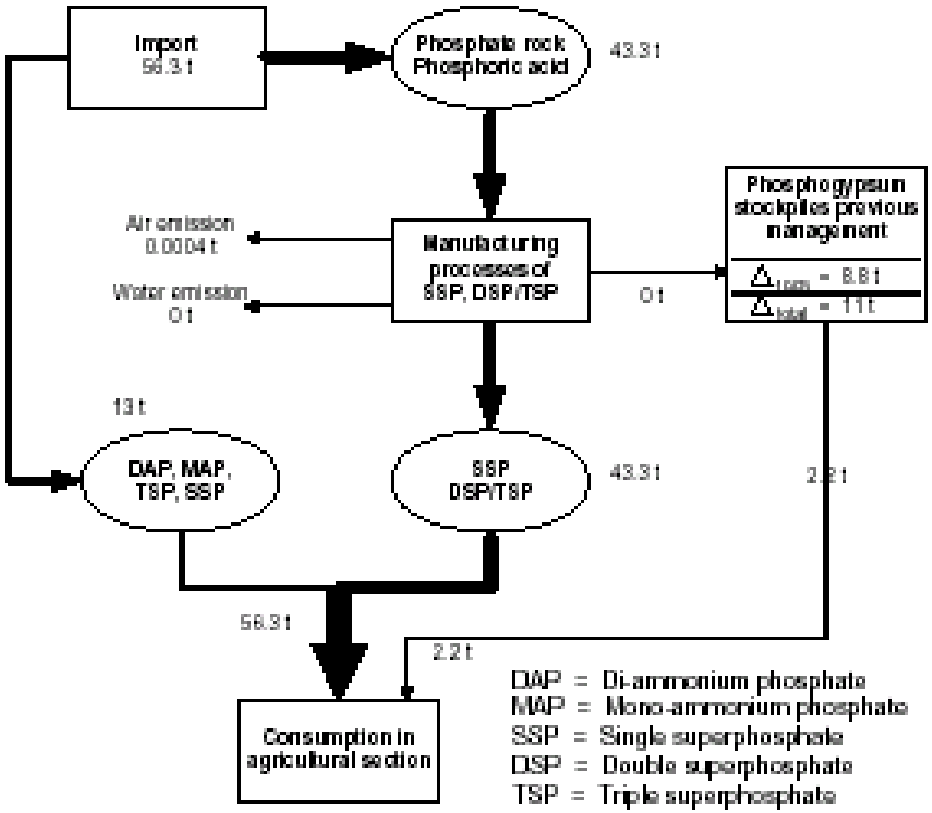
Conclusions

- Peak P is as important as Peak oil
  - Or more so….there are no “solar” options for P
- Need detailed material flow analysis studies of agriculture and consumption in cities, to identify opportunities to more efficiently use P
  - Optimise related to biomass energy use and non-concentration of cadmium in recycled nutrients.
- Need to better design our sewerage and solid waste systems….not only health protection.

Cadmium in Agriculture:
component goods and associated processes



e. Cadmium flow through phosphate fertilisers



Note: Phosphoric acid ceased in early 1990, 2 remaining by-product gypsum stockpiles in eastern Australia and being used to remedy sodic soils