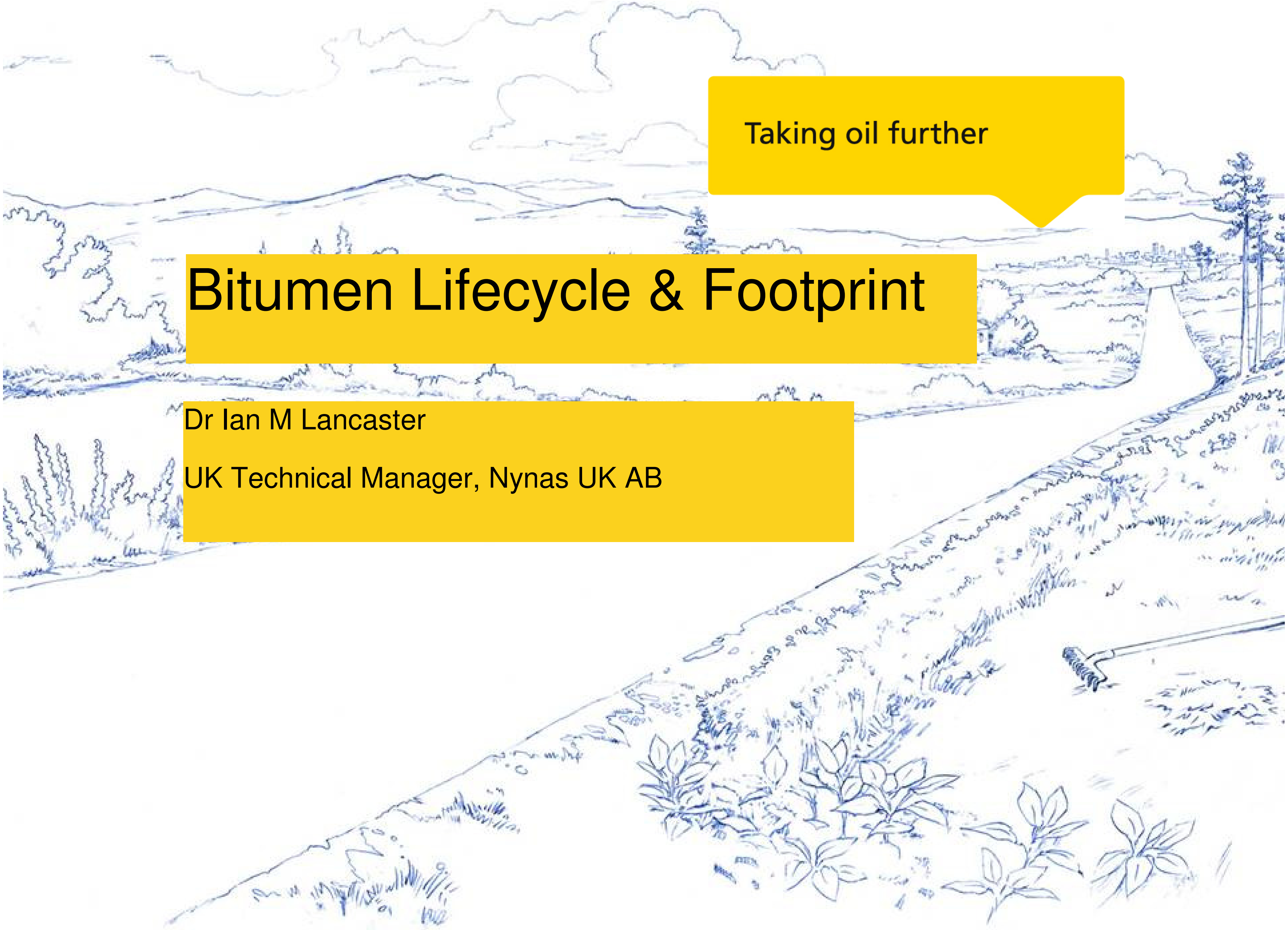

Taking oil further

Bitumen Lifecycle & Footprint

Dr Ian M Lancaster

UK Technical Manager, Nynas UK AB

Summary

- Definitions, Data and Models
- Current position on LCI & Carbon Footprint
- Joint Research

"All men, by nature, desire knowledge"
Aristotle

"A little knowledge is a dangerous thing"
Alexander Pope

"Knowledge is power"
Francis Bacon

"Power corrupts, absolute power corrupts absolutely"
Lord Acton

"Before giving an answer, it helps to know the question"
Ian Lancaster

From the web ("information" superhighway)

Greenpeace Forum (forum.greenpeace.org)
I am concerned with what i see going on in the road building industry.The asphalt(oil) industry lobbiest control almost every State. Why are we building our roads out of oilbased materials that don't hold up and are not enviromentally friendly.I read an article that we use 500k barrels of oil per day across the USA just for asphalt roadways. Our nieghbors to the north have an interesting study that they recently completed. It is called the Athena Study. It shows just how much difference between an asphalt road and concrete road in regards to how much fossil fuel is used to produce both. Also visit the website www.pavements4life.com to see about the heat island effect that an asphalt road has.

What about the oil in the roadway, where is it going? Right into our environment doing harm to our wildlife. But yet we keep using it, why is that?

Aggregateresearch.com
I read in an article that recycling 1Te of asphalt will save 60Te of CO_2. This is absurd; how can I refute it?

Yahoo.com/answers
Is it possible that carbon dioxide retains heat as long as BLACK ASPHALT PAVING?

Mb-soft.com blog
There are over 100,000 square miles of black asphalt pavement and roofs in the USA.
If those areas could be made white instead of black, they could REFLECT a lot of sunlight back out to space rather than absorbing it.
This relatively minor change could help combat Global Warming.

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Definitions

- Carbon footprint is:
  - The amount of CO_2 emitted due to your daily activities
  - A methodology to estimate the total emissions of greenhouse gases (GHG) in carbon equivalents across its life-cycle
  - A technique for identifying and measuring the individual GHG emissions from each activity within a supply chain and the framework for attributing this to each output product
  - The full extent of direct & indirect CO_2 emissions caused by your business
  - The impact human activities have on the environment
  - The demand on biocapacity required to sequester (through photosynthesis) the CO_2 emissions from fossil fuel combustion
  - A measure of the amount of CO_2 emitted through the combustion of fossil fuels
  - The total amount of CO_2 and other GHG's emitted over the full life cycle of a process or product

It's all about the carbon – or is it?

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Greenhouse gases

- Relation of all emissions to carbon or CO_2 equivalent
  - Using GWP (global warming potential)

Gas	GWP	GWP_{100}
Carbon Dioxide	1	1
Methane	21	25
Nitrous Oxide	310	298
HFC's	124-14800	124-14800
Sulphur hexafluoride (SF6)	23900	22800

Factors for Process Emissions				
Emission	Amount Emitted per Year in tonnes	x	Conversion Factor	Total kg CO_2 equivalent
CO_2		x	1,000	
Methane		x	21,000	
Nitrous Oxide		x	310,000	
HFC - 125		x	2,800,000	
HFC - 134		x	1,000,000	
HFC - 134a		x	1,300,000	
HFC - 143		x	300,000	
HFC - 143a		x	3,800,000	
HFC - 152a		x	140,000	
HFC - 227ea		x	2,900,000	
HFC - 23		x	11,700,000	
HFC - 236fa		x	6,300,000	
HFC - 245ca		x	560,000	
HFC - 32		x	650,000	
HFC - 41		x	150,000	
HFC - 43 - l0mee		x	1,300,000	
Perfluorobutane		x	7,000,000	
Perfluoromethane		x	6,500,000	
Perfluoropropane		x	7,000,000	
Perfluoropentane		x	7,500,000	
Perfluorocyclobutane		x	8,700,000	
Perfluoroethane		x	9,200,000	
Perfluorohexane		x	7,400,000	
SF_6		x	23,900,000	
Total				0

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Tools

- “Footprint” depends on amount of GHGs generated and lifecycle
- Amount of GHG can be measured
  - Directly or indirectly
  - Calculation of equivalent CO_2 or carbon equivalent
- Lifecycle is a matter of opinion
  - When is a product “born”
  - At what point do we declare it “dead”
  - Studies from “cradle to grave” or “cradle to gate”
- European commission has over 50 tools for calculation / estimation of life-cycle

http://lca.jrc.ec.europa.eu/lcainfohub/directory.vm

Simple calculations

CO_2 produced from combustion: (simple model)
Assuming ideal combustion occurs:

$$C_xH_y + (x+y/4)O_2 = xCO_2 + (y/2)H_2O$$

One mole methane = 16g

Assuming ideal combustion 1 mole methane produces 1 mole CO_2

One mole CO_2 = 44g therefore every 1g of methane produces 2.75g CO_2

Similar calculations hold for other alkanes / fuels

If the consumption of fuel is known, the mass of CO_2 produced can be calculated

Dividing CO_2 produced / crude processed indicates efficiency

Ideal combustion rarely occurs:
Carbon monoxide, hydrocarbons, NOx & SOx will be present

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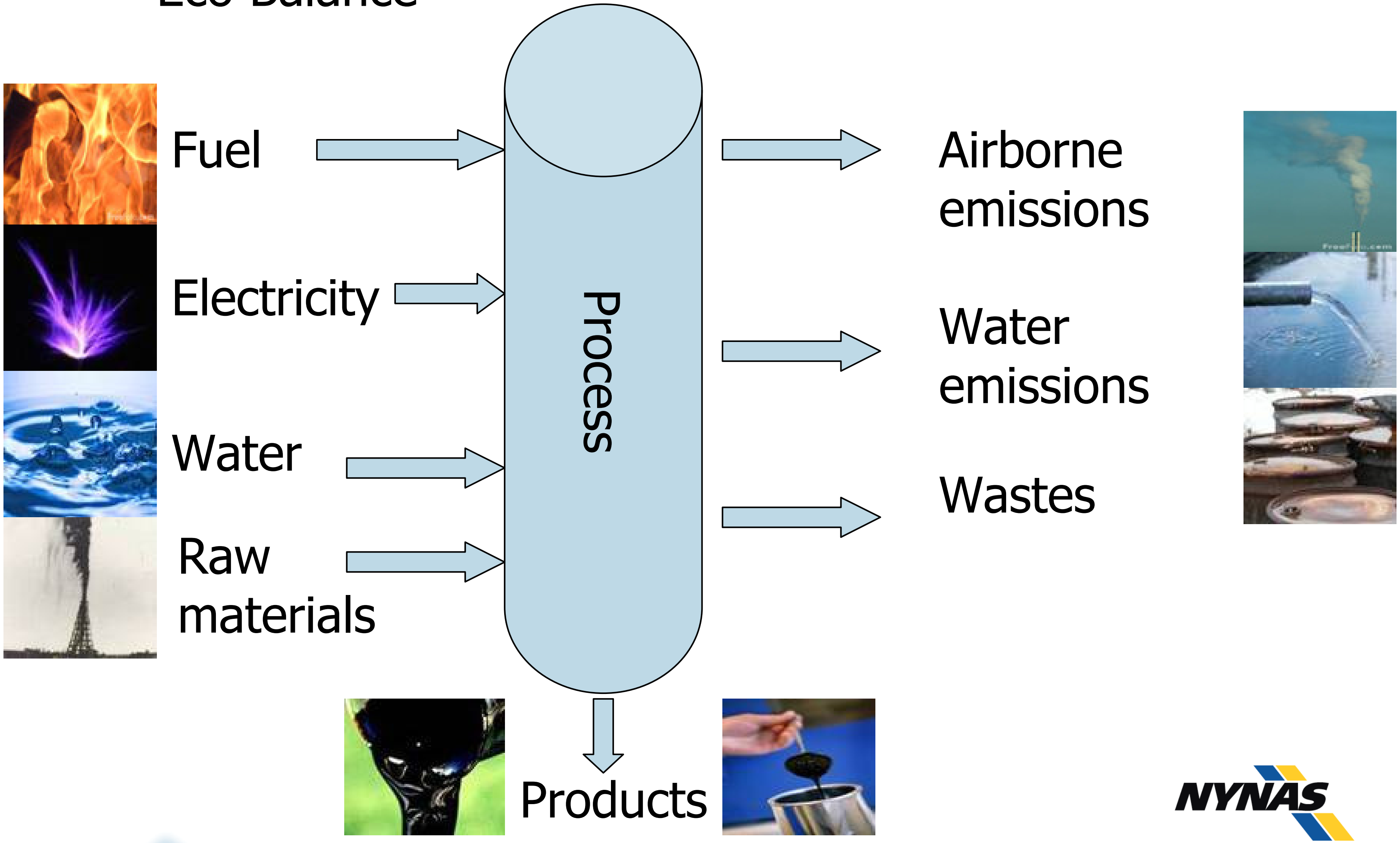
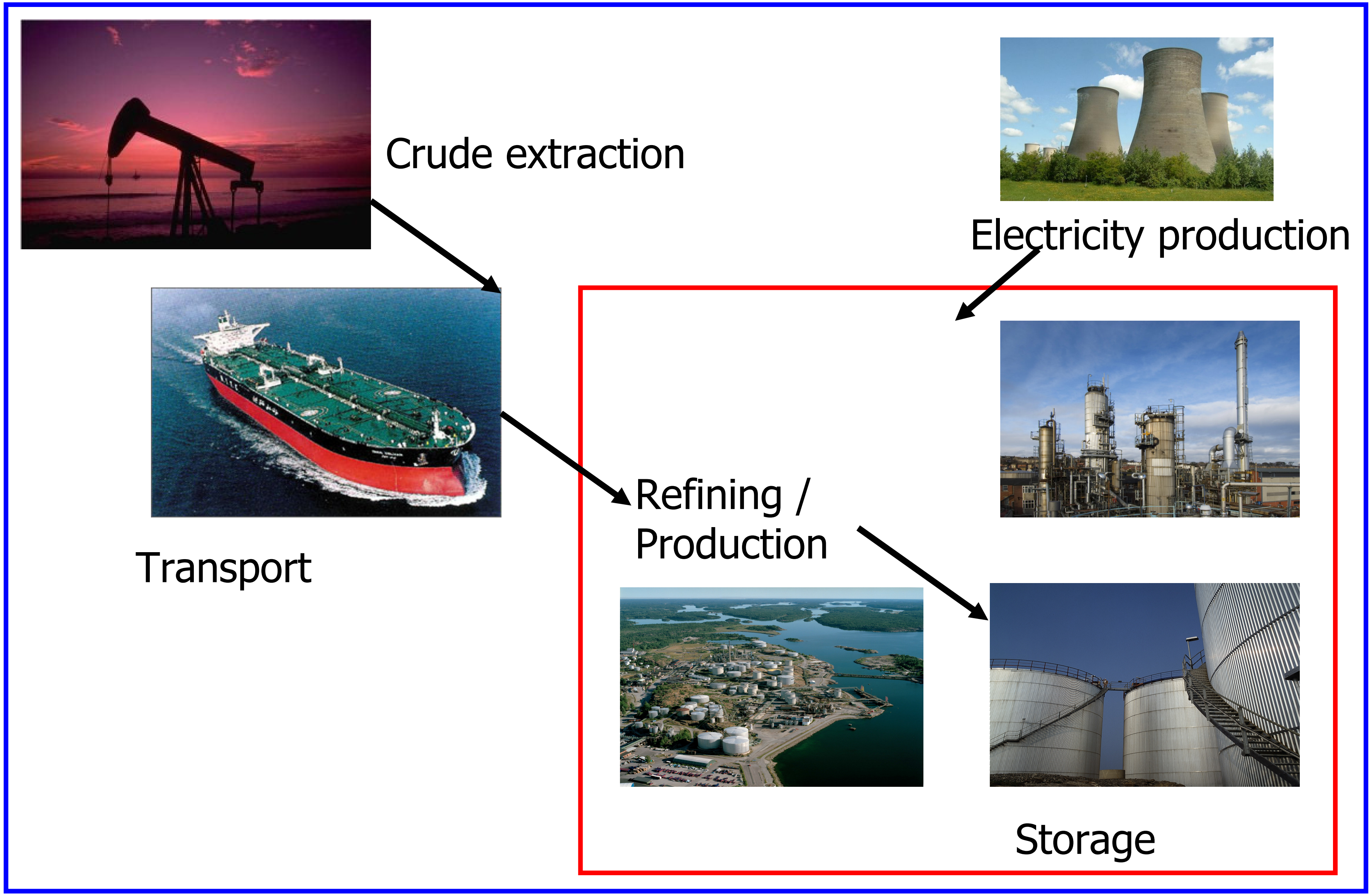
Converting fuel types to CO_2				Net CV Basis [5]			Gross CV Basis [6]	
Fuel Type	Amount used per year	Units	x	kg CO_2 per unit	Total kg CO_2	x	kg CO_2 per unit	Total kg CO_2
Electricity		See Annex 3					See Annex 3	
Natural Gas		kWh	x	0.206		x	0.185	
		therms	x	6.023		x	5.421	
Gas Oil		tonnes	x	3190		x	3190	
		kWh	x	0.265		x	0.252	
		litres	x	2.674		x	2.674	
Diesel		tonnes	x	3164		x	3164	
		kWh	x	0.263		x	0.250	
		litres	x	2.630		x	2.630	
Petrol		tonnes	x	3135		x	3135	
		kWh	x	0.252		x	0.240	
		litres	x	2.315		x	2.315	
Fuel Oil		tonnes	x	3223		x	3223	
		kWh	x	0.282		x	0.268	
Burning Oil [1]		tonnes	x	3150		x	3150	
		kWh	x	0.258		x	0.245	
		litres	x	2.518		x	2.518	
Industrial Coal [2]		tonnes	x	2457		x	2457	
		kWh	x	0.347		x	0.330	
Domestic Coal [3]		tonnes	x	2523		x	2523	
		kWh	x	0.313		x	0.298	
Wood Pellets [4]		tonnes	x	132		x	132	
		kWh	x	0.026		x	0.025	
Coking Coal		tonnes	x	2810		x	2810	
		kWh	x	0.349		x	0.332	
LPG		kWh	x	0.225		x	0.214	
		therms	x	6.608		x	6.277	
		litres	x	1.495		x	1.495	
Aviation Spirit		tonnes	x	3128		x	3128	
		kWh	x	0.250		x	0.238	
		litres	x	2.233		x	2.233	
Aviation Turbine Fuel [1]		tonnes	x	3150		x	3150	
		kWh	x	0.258		x	0.245	
		litres	x	2.518		x	2.518	
Other Petroleum Gas		tonnes	x	2894		x	2894	
		kWh	x	0.217		x	0.206	
Naphtha		tonnes	x	3131		x	3131	
		kWh	x	0.250		x	0.237	
Lubricants		tonnes	x	3171		x	3171	
		kWh	x	0.263		x	0.250	
Petroleum Coke		tonnes	x	3410		x	3410	
		kWh	x	0.361		x	0.343	
Refinery Miscellaneous		kWh	x	0.258		x	0.245	
		therms	x	7.562		x	7.184	
Total					0			0

Eurobitume Partial LCA

- Originally published 1999
  - Carbon footprint concept?
- Adopts a cradle to gate approach
  - Delivery beyond refinery gate not considered
- Covers crude extraction, transport, production & storage
- Idealised, hypothetical refinery
  - Western Europe
  - Restricted crude diet

Eco Balance


Fuel
Electricity
Water
Raw materials
Process
Airborne emissions
Water emissions
Wastes
Products


Crude extraction
Electricity production
Transport
Refining / Production
Storage

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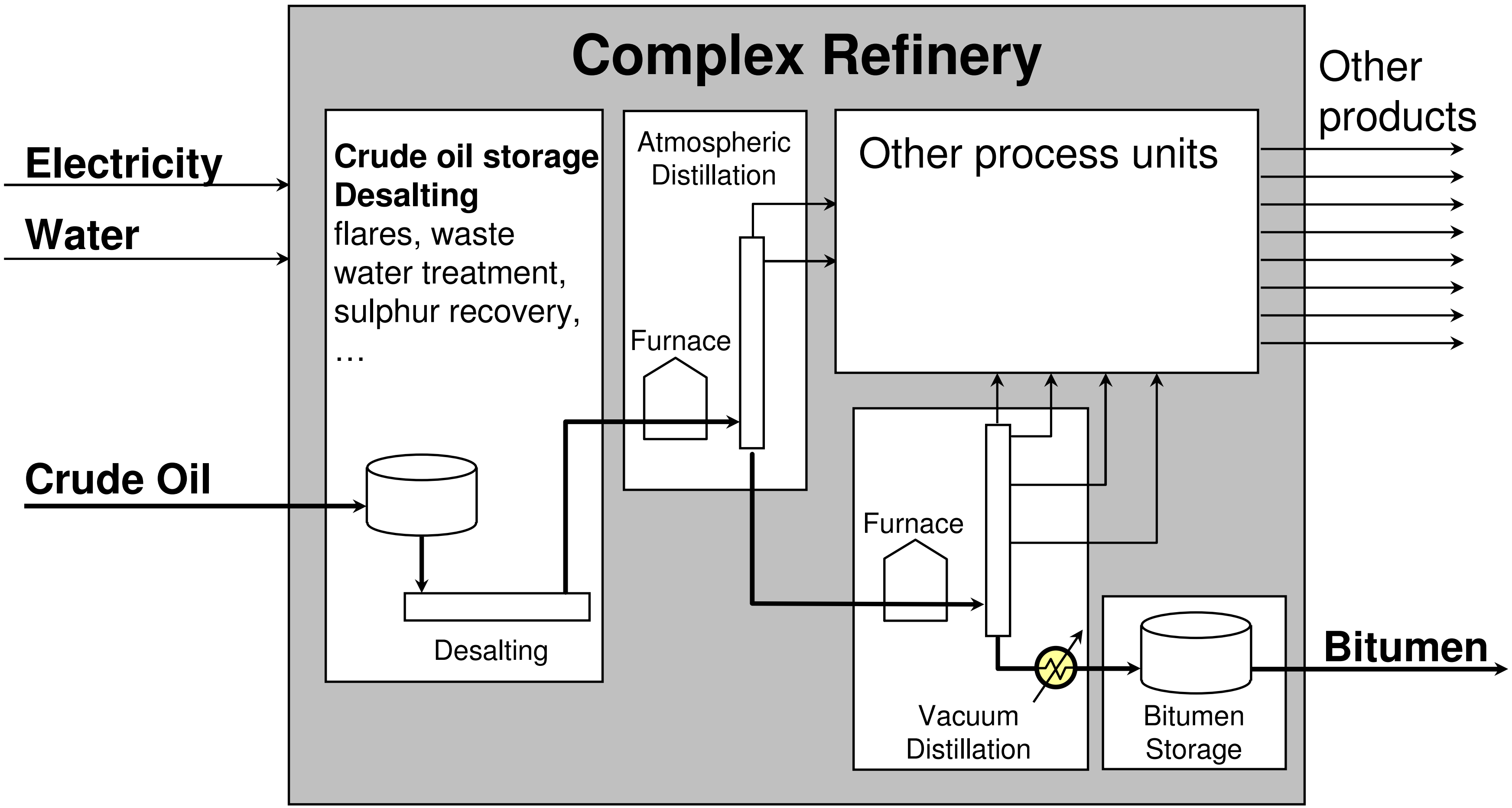
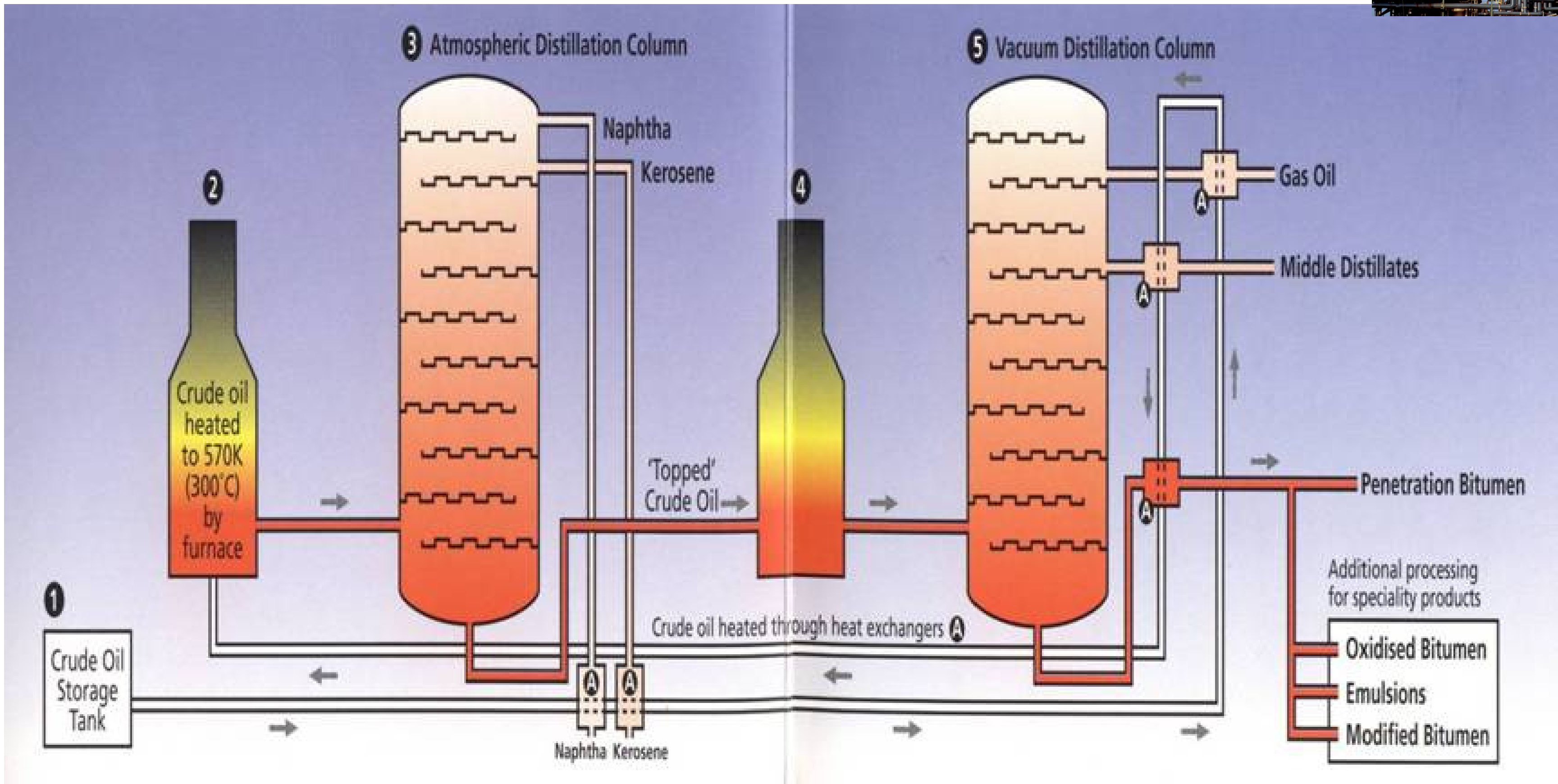

Complex Refinery
Electricity
Water
Crude Oil
Crude oil storage
Desalting
flares, waste
water treatment,
sulphur recovery,
…
Desalting
Atmospheric
Distillation
Furnace
Other process units
Other
products
Furnace
Vacuum
Distillation
Bitumen
Storage
Bitumen

This bit does the bitumen!

Bitumen Production



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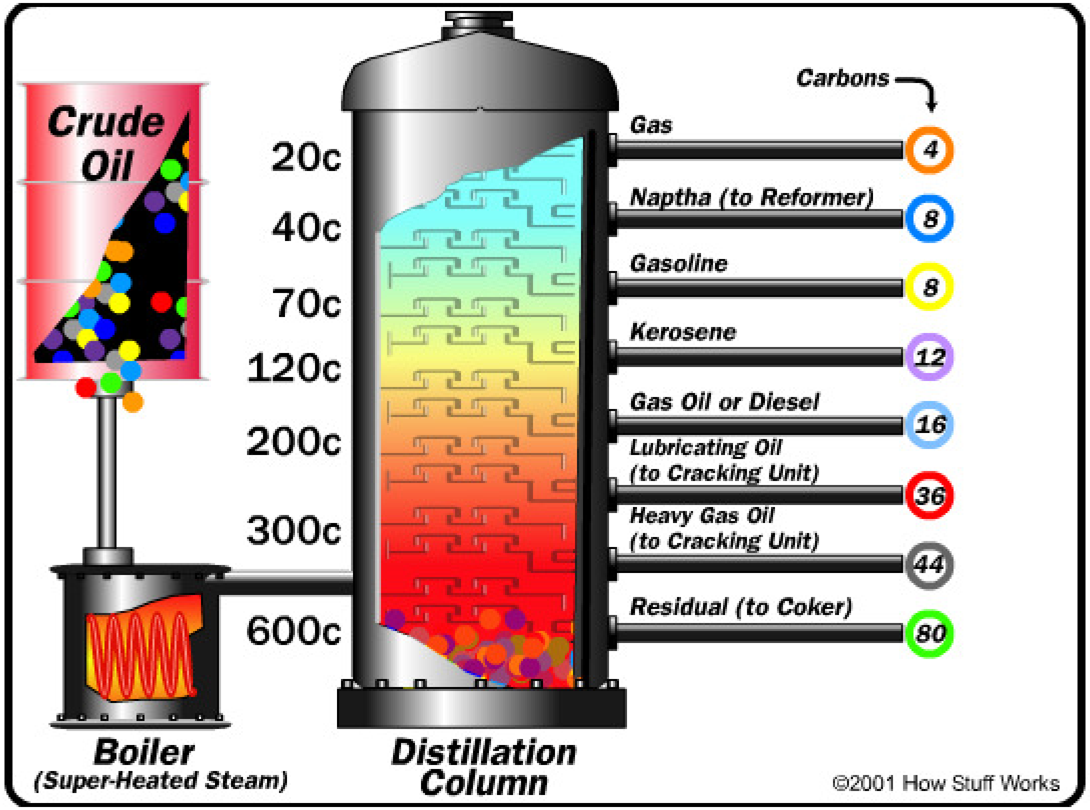
Where to apportion carbon?



Some streams can be/ are used as internal fuel

Partial LCA Assumptions

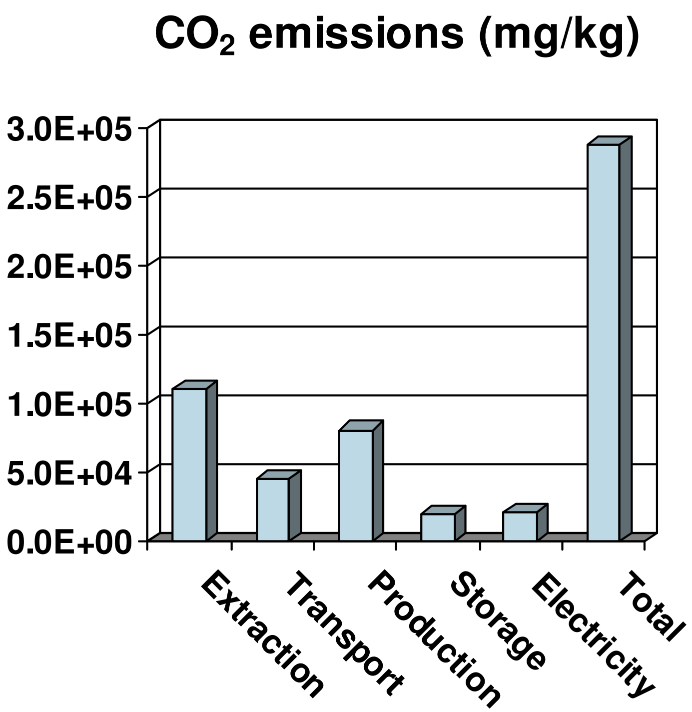
- Single "average" grade in common use
- Straight-run distillation
- Mix of Middle Eastern & South American crudes (70:30)
- Optimised Nautical Cargo (105kTe)
- Notional Yield
  - Middle Eastern 35%
  - South American 70%
- Coastal, West European Refinery
  - Capacity 40kTe.a
- Flows balanced according to product
- Bitumen 100% recyclable

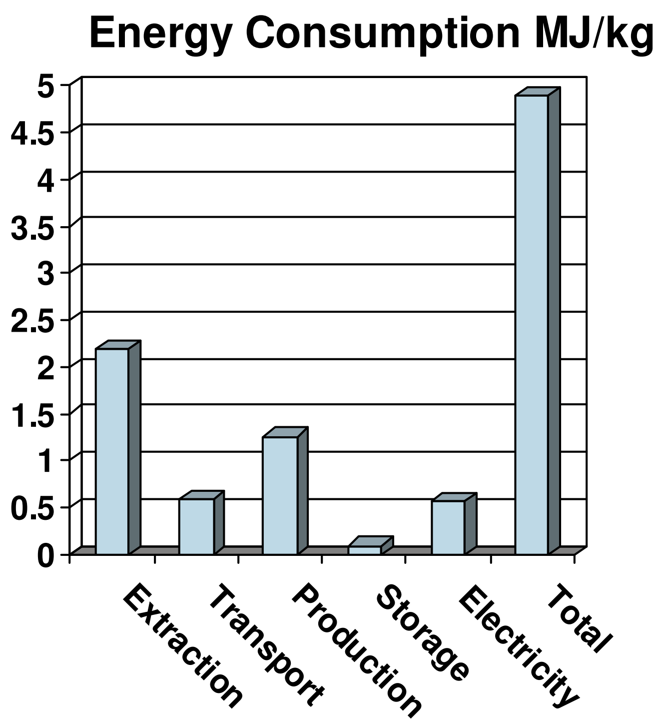
		Crude oil extraction	Transport to Europe	Bitumen production	Bitumen storage	Electricity production	Total from crude oil to bitumen in a storage tank [3]
Energy							
Gas	MJ/kg	2.196		0.855	0,.01		3.061
Oil	MJ/kg		0.588	0.404	0.096		1.088
Electricity	MJ/kg			(0.14)	(0.033)		
Primary energy [1]	MJ/kg					0.561	0.561
Air emissions							
SO_2	mg/kg	0,324	914	655.7	122.1	108.5	1 800
NO_x	mg/kg	658	1 219	137	32.4	44.5	2 090
CO_2	mg/kg	109 918	45 941	81 062	19 114	20 609	277 000
CO	mg/kg	3.24	130.6	0.06	0.01	3.81	138
HC	mg/kg	1 163	36.24	12.7	4.6	61.6	1 280
Dust	mg/kg	154		33.3	7.9	24.6	220
Metals	mg/kg			2.8	0.6	1.04	4.44
HCl	mg/kg			0.9	0.2		1.1
Water emissions			(2)		(2)		
Oil	mg/kg	40		2.0		2.08	44.1
Acid as H^+	mg/kg	30					30
Phenol	mg/kg			<0.1			<0.1
Phosphorus	mg/kg			0.3		0.17	0.47
Sulphate	mg/kg					98.3	98.3
Chloride	mg/kg	10				96.0	106
Mineral salts	mg/kg					79.2	79.2
Dissolved organics	mg/kg	20					20
Nitrogen	mg/kg			10.8		0.17	11
Chemical Oxygen Demand	mg/kg	1		54		0.17	55.2
Biological Oxygen Demand	mg/kg			16			16
Metals	mg/kg	5				22.5	27.5
Solids	mg/kg	80		29		6.75	116
Solid wastes	mg/kg	1480	(2)	3350	(2)	3 157	7 987
Raw materials							
Water	g/kg	23.1		325		89.4	438
Bauxite/limestone/iron ore	g/kg	0.728					0.728
Bitumen	g/kg			1 000			1 000

[1] European average data used. [2] Included in the bitumen production data. [3] The values are given with three significant figure

Energy		4.9	MJ/kg
Air emissions	SO_2	1.8×10^3	mg/kg
	NO_x	2.1×10^3	mg/kg
	CO_2	2.8×10^5	mg/kg
	CO	140	mg/kg
	HC	1.3×10^3	mg/kg
	Dust	220	mg/kg
	Metals	4.4	mg/kg
	HCl	1.1	mg/kg
			mg/kg
Water emissions	Oil	44	mg/kg
	Acid as H+	30	mg/kg
	Phenol	<0.1	mg/kg
	Phosphorus	0.5	mg/kg
	Sulphate	98	mg/kg
	Chloride	110	mg/kg
	Mineral salts	79	mg/kg
	Dissolved organics	20	mg/kg
	Nitrogen	11	mg/kg
	C.O.D	55	mg/kg
	B.O.D	16	mg/kg
	Metals	28	mg/kg
	Solids	120	mg/kg
Solid Wastes		8×10^3	mg/kg
Raw materials	Water	440	g/kg
	Bauxite / limestone / iron ore	0.7	g/kg
	Bitumen	1000	g/kg

Summary Data





Limitations of the current LCA

- Crude “diet”
  - Based on mix of Middle East / South American crude oils
  - Increase in supply from Russia
- Shipping
  - Assumption based on fuel demand in 1999
    - Engines are more efficient
    - Fuel is cleaner
    - Cargos are heavier
- Refineries
  - Are more efficient
  - Recover more heat
  - Fuel / power use
  - Location
  - Production methods
- Deals with pen bitumen only
  - Idealised single grade
- Transport
  - Delivery to asphalt plant / customer not included
- Does not consider lifetime / recycling

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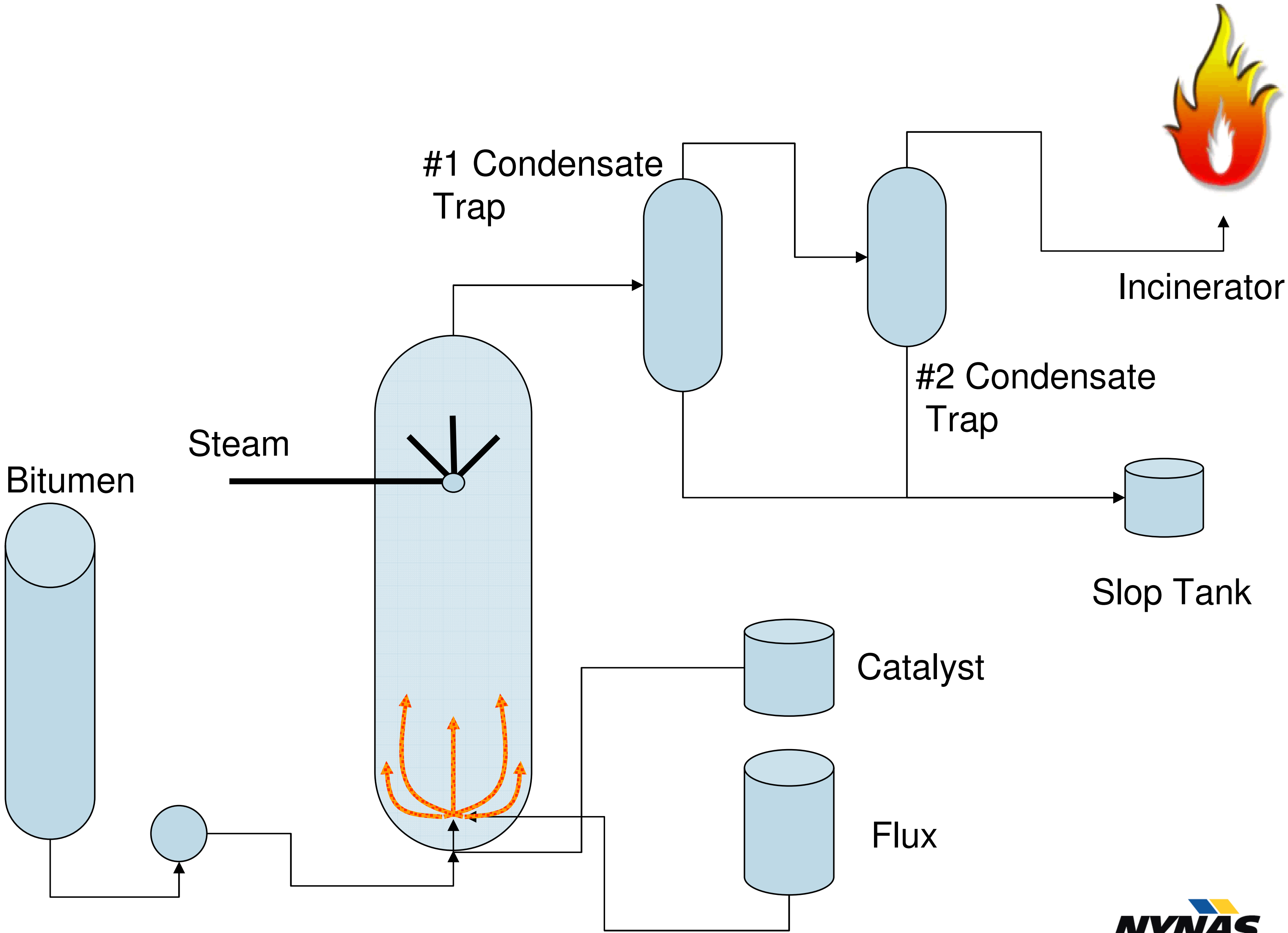
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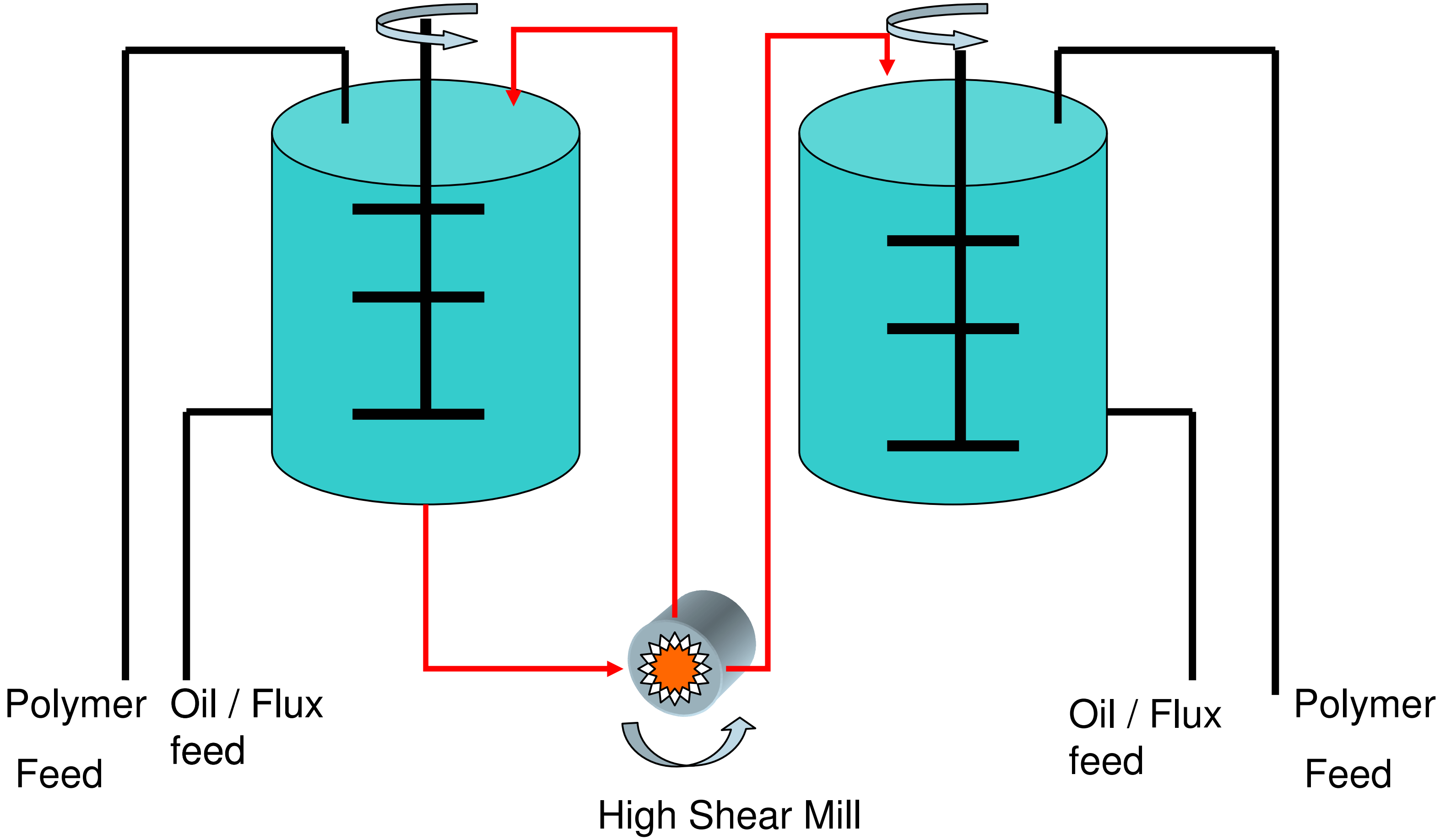
Incinerator
#2 Condensate Trap
Steam
Bitumen
Slop Tank
Catalyst
Flux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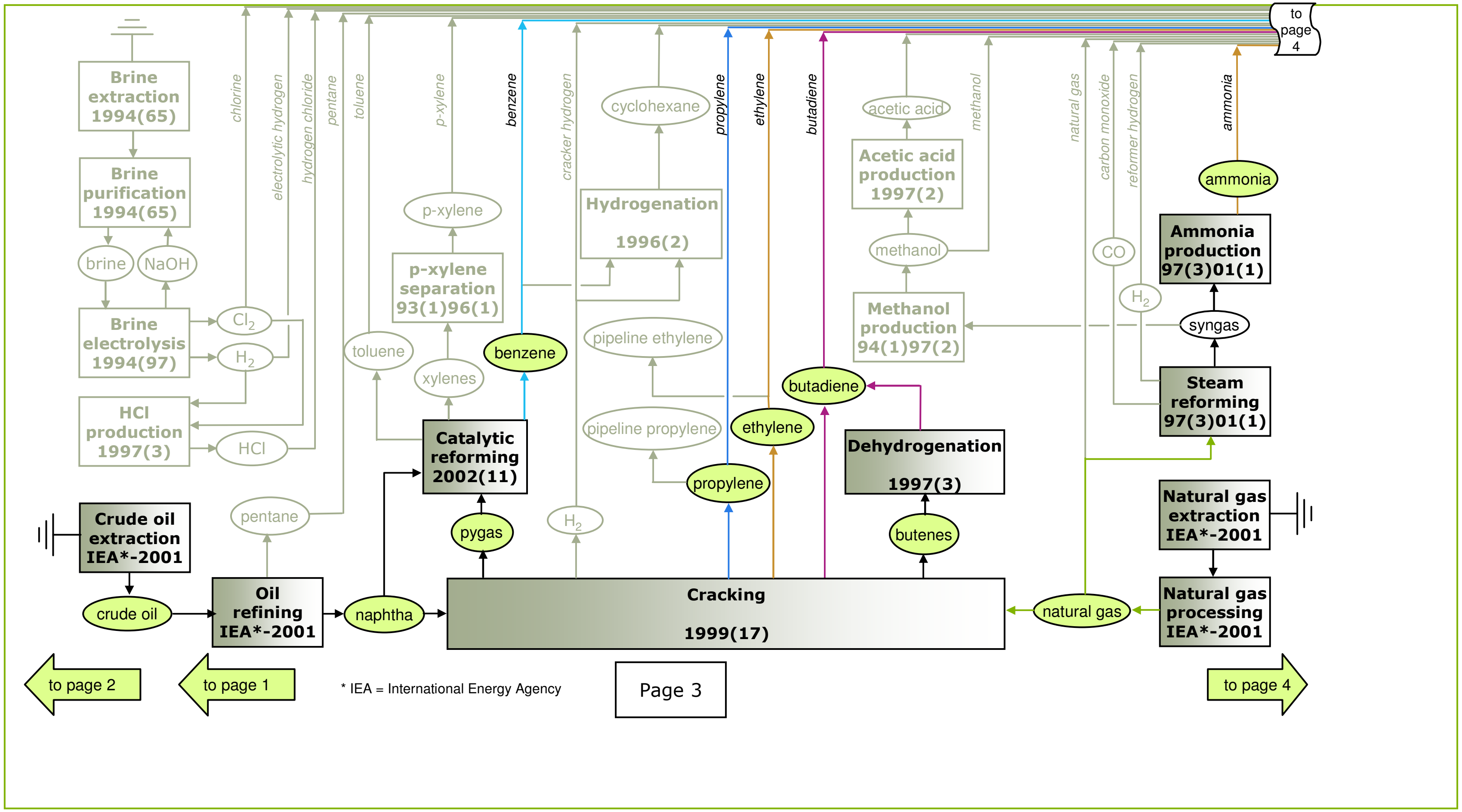
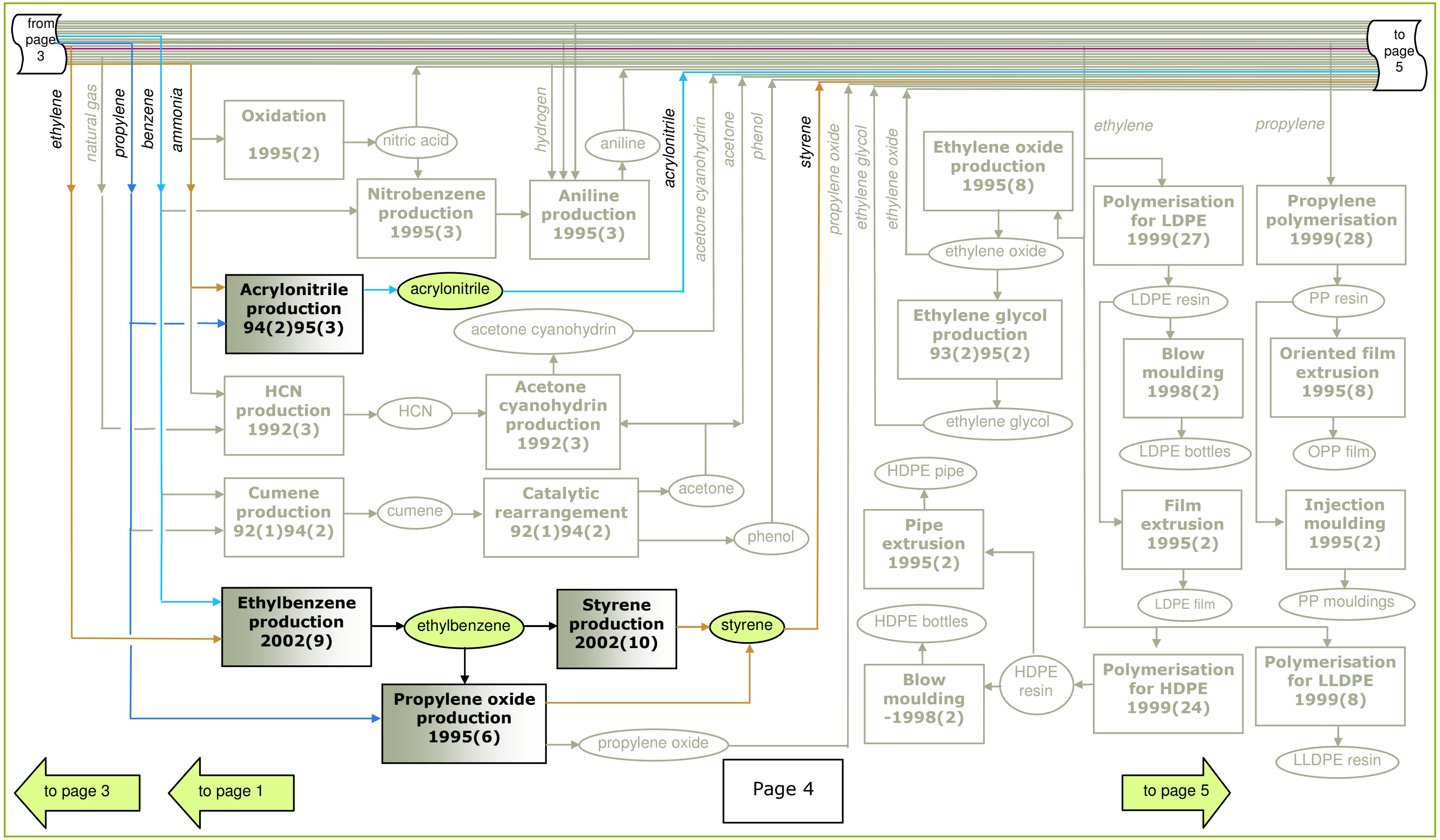
Feed
Oil / Flux
feed
High Shear Mill
Oil / Flux
feed
Polymer
Feed



* IEA = International Energy Agency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to page 5
ethylene
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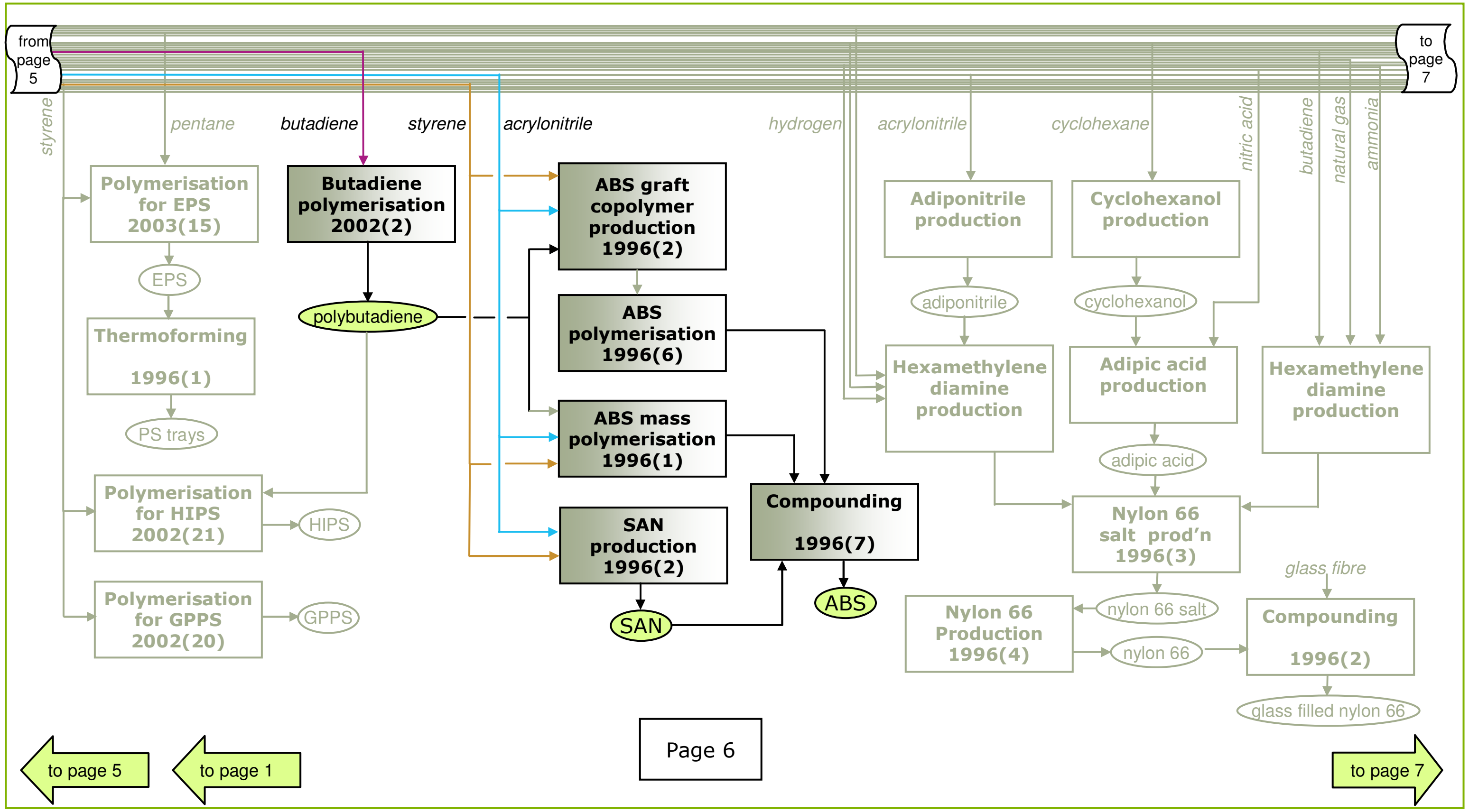
propylene
benzene
ammonia
Oxidation 1995(2)
nitric acid
Nitrobenzene production 1995(3)
hydrogen
aniline
Aniline production 1995(3)
acrylonitrile
acetone cyanohydrin
acetone
phenol
styrene
propylene oxide
ethylene glycol
ethylene oxide
Ethylene oxide production 1995(8)
ethylene
propylene
Polymerisation for LDPE 1999(27)
Propylene polymerisation 1999(28)
Acrylonitrile production 94(2)95(3)
acrylonitrile
acetone cyanohydrin
HCN production 1992(3)
HCN
Acetone cyanohydrin production 1992(3)
Ethylene glycol production 93(2)95(2)
LDPE resin
PP resin
Blow moulding 1998(2)
Oriented film extrusion 1995(8)
ethylene glycol
LDPE bottles
OPP film
HDPE pipe
Cumene production 92(1)94(2)
cumene
Catalytic rearrangement 92(1)94(2)
acetone
phenol
Pipe extrusion 1995(2)
Film extrusion 1995(2)
Injection moulding 1995(2)
LDPE film
PP mouldings
Ethylbenzene production 2002(9)
ethylbenzene
Styrene production 2002(10)
styrene
HDPE bottles
Blow moulding -1998(2)
HDPE resin
Polymerisation for HDPE 1999(24)
Polymerisation for LLDPE 1999(8)
Propylene oxide production 1995(6)
propylene oxide
LLDPE resin
to page 3
to page 1
Page 4
to page 5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to page 7
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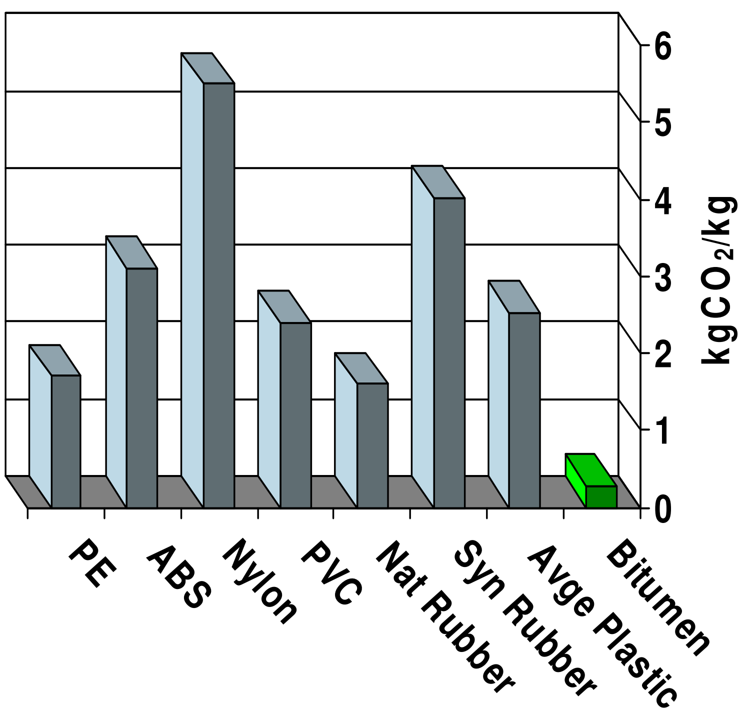
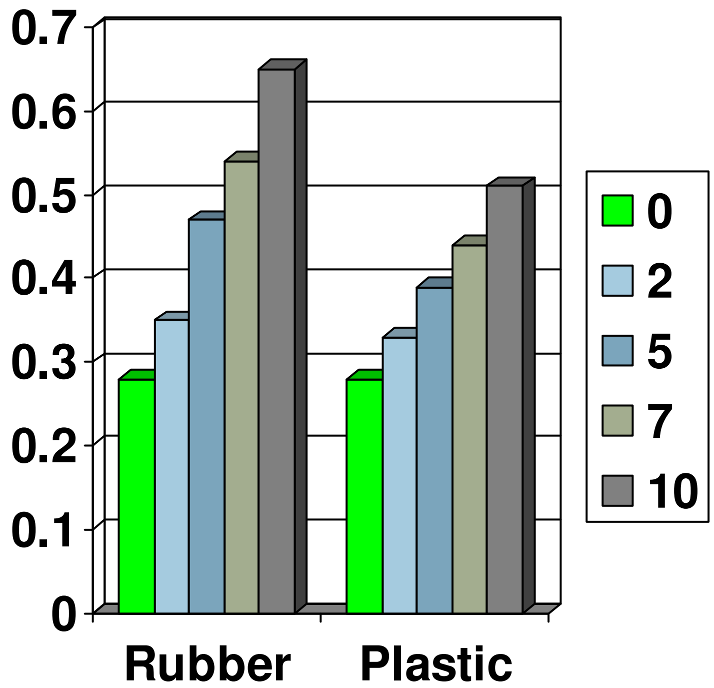
butadiene
styrene
acrylonitrile
hydrogen
acrylonitrile
cyclohexane
nitric acid
butadiene
natural gas
ammonia
Polymerisation for EPS 2003(15)
EPS
Thermoforming 1996(1)
PS trays
Polymerisation for HIPS 2002(21)
HIPS
Polymerisation for GPPS 2002(20)
GPPS
Butadiene polymerisation 2002(2)
polybutadiene
ABS graft copolymer production 1996(2)
ABS polymerisation 1996(6)
ABS mass polymerisation 1996(1)
SAN production 1996(2)
SAN
Compounding 1996(7)
ABS
Adiponitrile production
adiponitrile
Cyclohexanol production
cyclohexanol
Hexamethylene diamine production
Adipic acid production
adipic acid
Hexamethylene diamine production
Nylon 66 salt prod'n 1996(3)
nylon 66 salt
Nylon 66 Production 1996(4)
nylon 66
glass fibre
Compounding 1996(2)
glass filled nylon 66
to page 5
to page 1
Page 6
to page 7

Impact of Polymer





Consider life cycle.
PmB = greater flexibility, durability, longer life

Emulsion Production

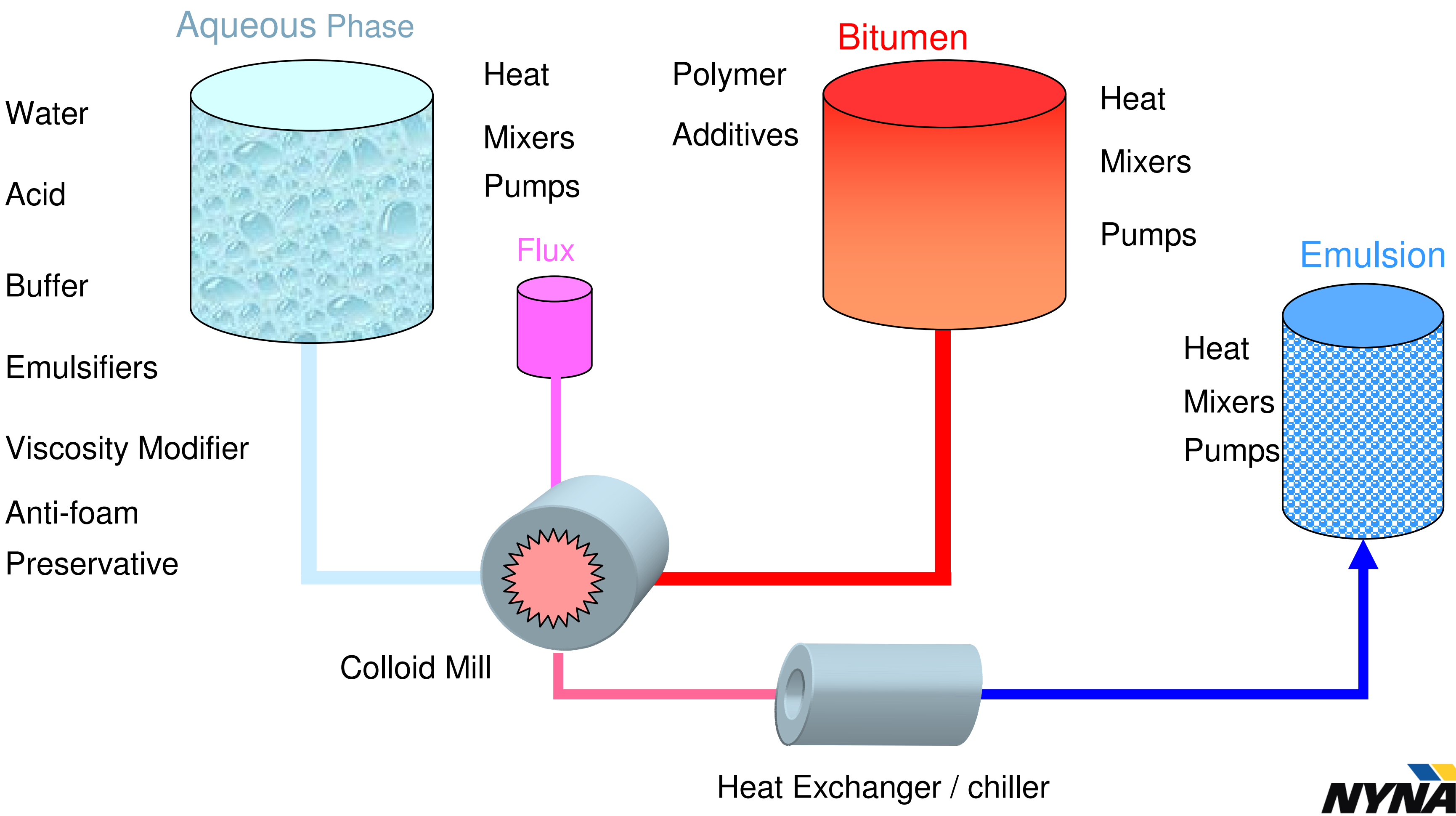


Table 5b

Standard road transport fuel conversion factors					
Fuel used	Total units used	Units	x	kg CO_2 per unit	Total kg CO_2
Petrol		litres	x	2.3154	
Diesel		litres	x	2.6304	
Compressed Natural Gas (CNG)		kg	x	2.7278	
Liquid Petroleum Gas (LPG)		litres	x	1.4951	
Total					0

Sources: UK Greenhouse Gas Inventory for 2005 (produced for Defra by AEA Energy & Environment)
Digest of UK Energy Statistics (DTI)
Carbon factors for fuels (UKPIA, 2004)

Notes: 1 imperial gallon (UK) = 4.546 litres

Table 12a

Van/Light Commercial Vehicle Road Freight Mileage Conversion Factors: Vehicle km Basis					
Type of van	Gross Vehicle Weight (tonnes)	Total vehicle km travelled	x	kg CO_2 per vehicle km	Total kg CO_2
Petrol	up to 1.25t		x	0.224	
Diesel	up to 3.5t		x	0.272	
LPG or CNG	up to 3.5t		x	0.272	
Average	*up to 3.5t*		x	0.266	
Total					0

Table 12b

Van/Light Commercial Vehicle Road Freight Mileage Conversion Factors Based on UK Average Vehicle					
	Gross Vehicle Weight (tonnes)	Total tonne km travelled	x	kg CO_2 per tonne km	Total kg CO_2
Petrol	up to 1.25t		x	0.449	
Diesel	up to 3.5t		x	0.272	
LPG or CNG	up to 3.5t		x	0.272	
Average	*up to 3.5t*		x	0.283	
Total					0

Sources: Factors developed by AEA Energy & Environment and agreed with Department for Transport (2008)

Notes: Emission factors for vans in tonne km were calculated from the emission factors per vehicle km provided in Table 8 and an average load factor of 50%. The average cargo capacity was taken to be 0.5 tonnes for vans up to 1.25 tonnes gross vehicle weight, and 2 tonnes for vans up to 3.5 tonnes gross vehicle weight.

Table 13a

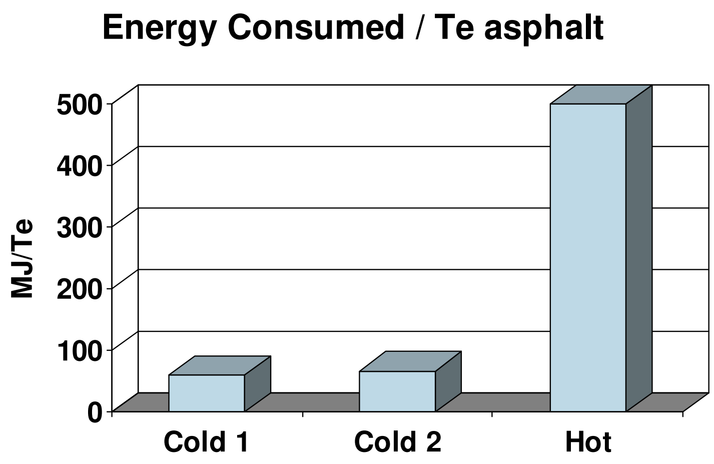
Diesel HGV Road Freight Mileage Conversion Factors: Vehicle km Basis							
	Gross Vehicle Weight (tonnes)	% weight laden		Total vehicle km travelled	x	kg CO_2 per vehicle km	Total kg CO_2
Rigid	>3.5-7.5t	0%			x	0.525	
		50%			x	0.571	
		100%			x	0.617	
		41%	*(UK average load)*		x	0.563	
Rigid	>3.5-7.5t	0%			x	0.525	
		50%			x	0.571	
		100%			x	0.617	
		41%	*(UK average load)*		x	0.563	
Rigid	>7.5-17t	0%			x	0.672	
		50%			x	0.768	
		100%			x	0.864	
		39%	*(UK average load)*		x	0.747	
Rigid	>17t	0%			x	0.778	
		50%			x	0.949	
		100%			x	1.119	
		56%	*(UK average load)*		x	0.969	
All rigids	***UK average***				x	0.895	
Articulated	>3.5-33t	0%			x	0.672	
		50%			x	0.840	
		100%			x	1.008	
		43%	*(UK average load)*		x	0.817	
Articulated	>33t	0%			x	0.667	
		50%			x	0.889	
		100%			x	1.111	
		59%	*(UK average load)*		x	0.929	
All artics	***UK average***				x	0.917	
ALL HGVs	***UK average***				x	0.906	

Future Research

- Carbon Footprint is important
- Eurobitume LCA is accurate (but limited)
  - Future work to address limitations
- RBA, HA, MPA & TRL research
  - Building on current data
  - Sustainability management system for asphalt
  - To include maintenance and end-of-life considerations
- Individual figures?

Reducing the footprint

- Asphalt and bitumen are recyclable
- Lower mixing & storage temperatures preserve binder properties
  - Cold, warm & semi-warm technologies
- Higher bitumen content = lower ageing = longer life
- Prevention of moisture ingress = longer life



NYNAS

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Taking oil further

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