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Future Energy: Chemical Solutions

Energy Innovation and policies to
deliver our future energy needs

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Overview

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- Policy challenges for future energy supplies;
- The innovation and commercialisation challenge;
- Barriers to innovation and commercialisation;
- Role of Governments;
- Innovation and commercialisation:
  - 3 examples
- Some conclusions.

Policy challenges

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- tackling climate change by reducing carbon dioxide emissions both within the UK and abroad; and
- ensuring secure, clean and affordable energy as we become increasingly dependent on imported fuel.

Source: Energy White Paper 2007

Relevant trends

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- Energy consumption rising at unprecedented rate – especially in the new economies China, India, Brazil: world consumption expected to rise by >50% by 2025
- Greenhouse gas emissions rising – now >380ppm CO_2 compared with 180-300 ppm CO_2 range over last 650K years;
- More extreme weather events: Hurricane Katrina, floods in EU; summer 2003 heat anomaly; unprecedented forest fires in Australia and Greece; droughts in Africa;
- Security of supply concerns rising – most oil and gas reserves are in less stable parts of the world (except Canada);
- Skills gaps emerging in UK science and engineering;
- UK energy assets 30-50 years old: huge investment required to achieve a low carbon, secure energy economy.

Inter-Governmental Panel on Climate Change – 4th Assessment Report

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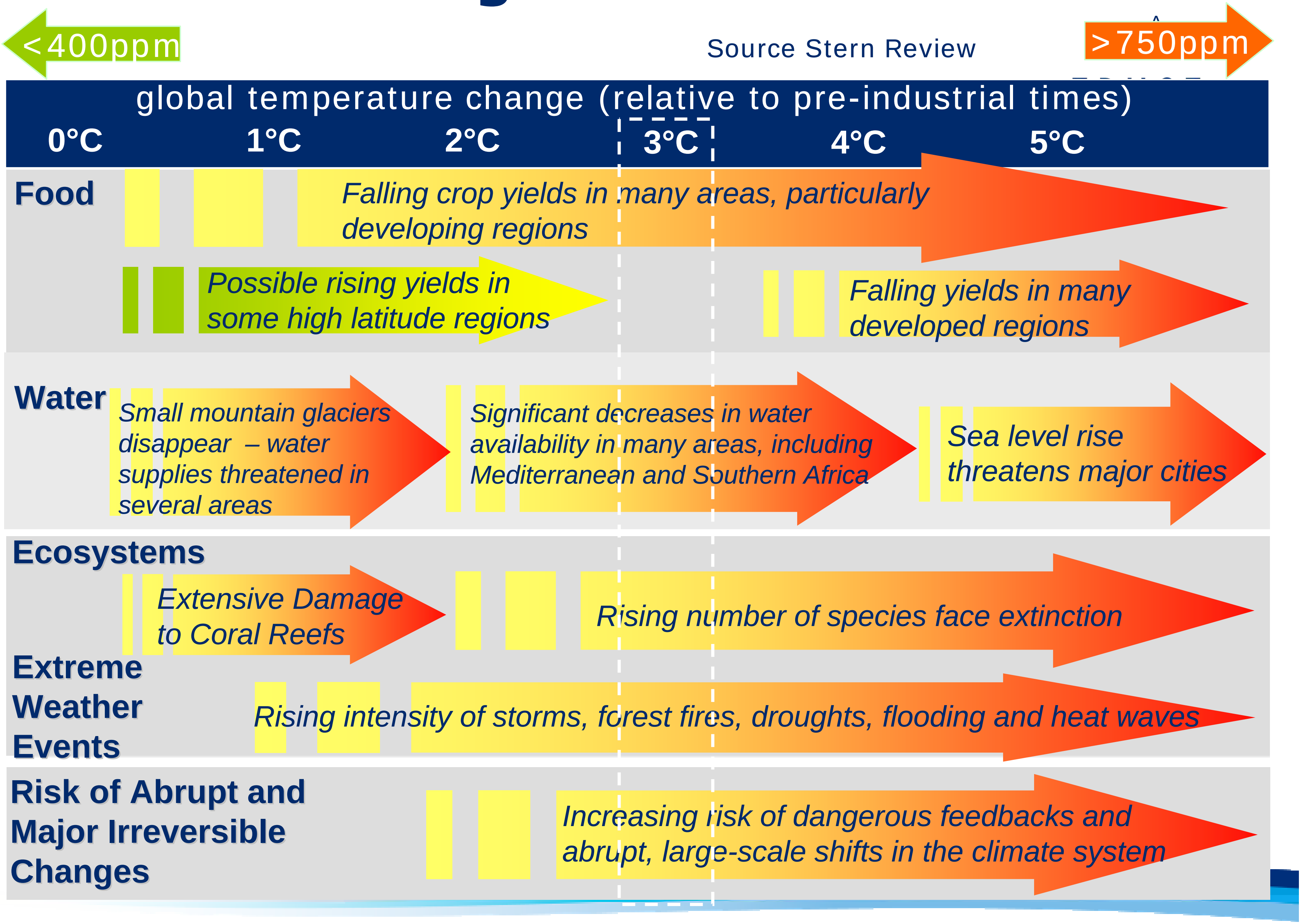
- warming of the climate system is unequivocal: 11 of the last 12 years (1995 -2006) rank among the 12 warmest years since records began in 1850.
- most of the observed temperature increase is *very likely* to be due to the observed rise in greenhouse gas concentrations.
- temperature range is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C; *very unlikely* to be less than 1.5°C.
- *very likely* that heat waves, and heavy precipitation events will continue to become more frequent

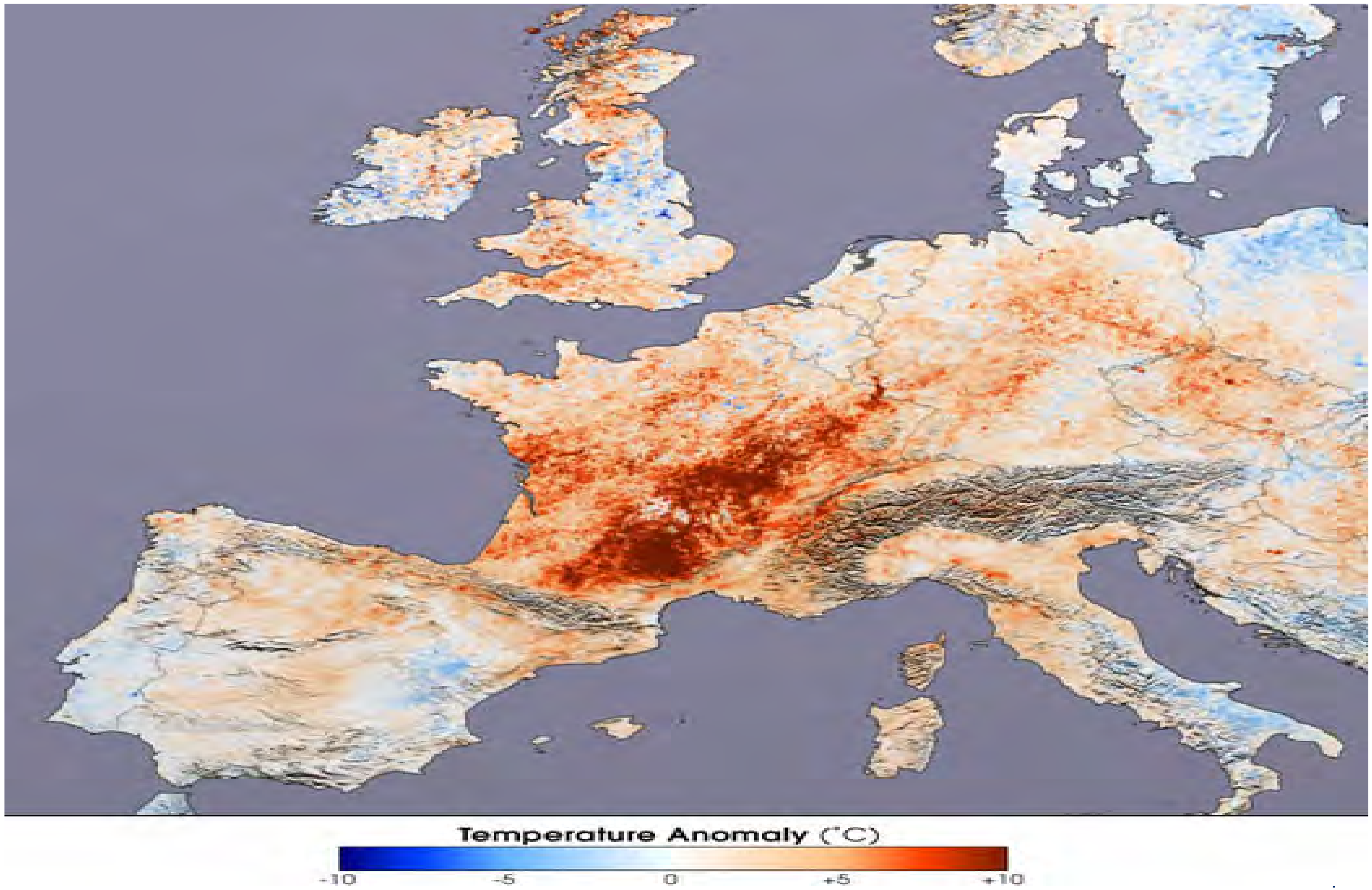
- ice core sample analysis over 650k years shows CO_2 range from 180-300ppm for cold-warm periods 12-20k years cycles.
- Currently CO_2 levels >380ppm and rising 2ppm pa. Mainly man-made
- Glaciers receding and disappearing; western Antarctic ice sheet warming. Larsen B.
- Droughts in Africa, India, China; fresh water stress; growing seasons altering;
- warming of about 0.2°C per decade projected

The challenges and risks we face



Localised temperature anomaly - summer 2003 heat wave: 26,000 deaths

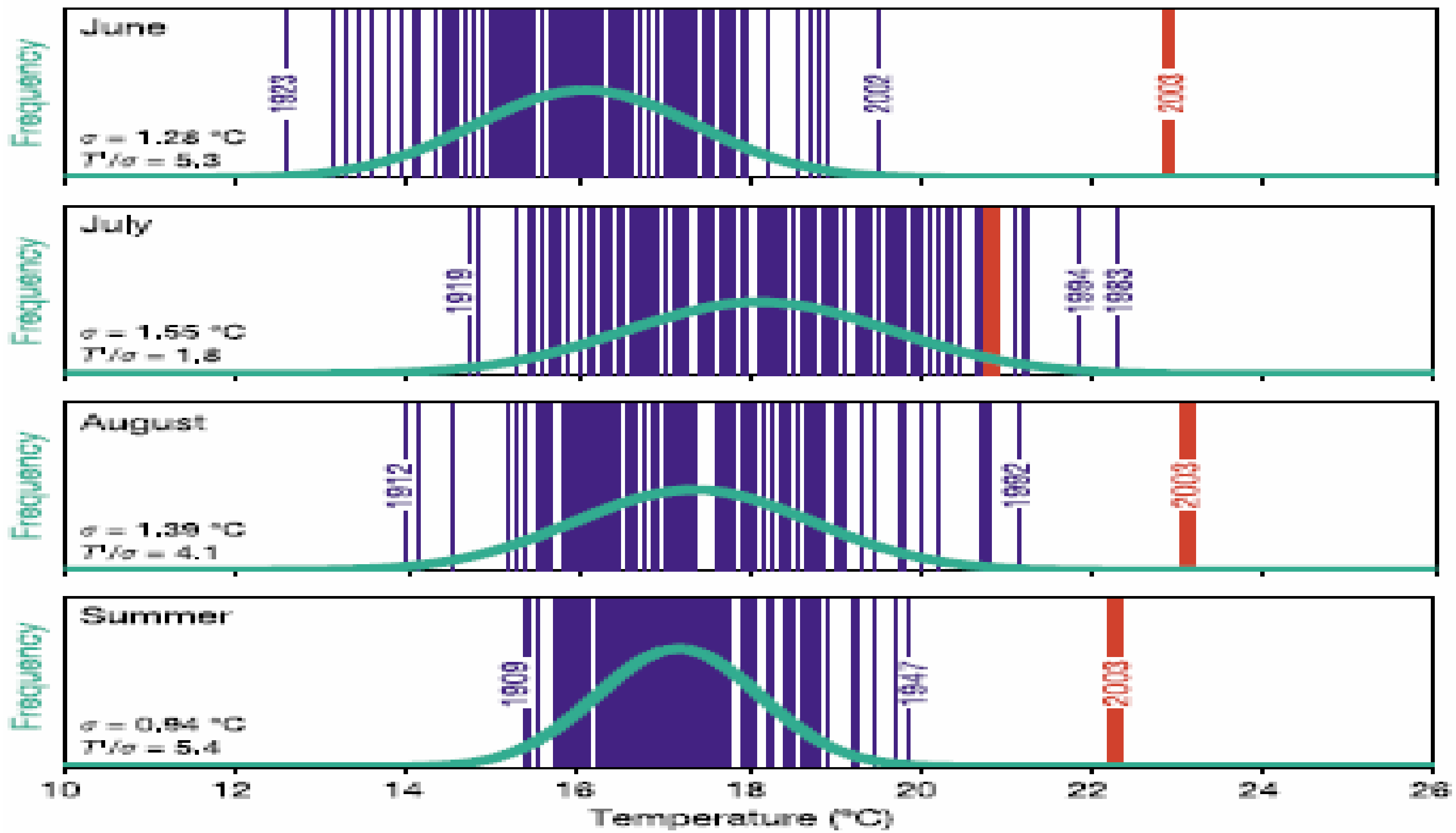
Source: Met Office



Localised temperature anomaly - summer 2003 heat wave. Are these changes "natural"?

Source: Nature Vol 427

Distribution of monthly and seasonal summer temperatures 1864-2003



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The innovation and commercialisation challenge

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- Markets work best when delivering goods and services which are valued by consumers. Consumers demand: the market delivers (more or less);
- Markets work less well (poorly, even) when asked to deliver goods and services which have high societal value but little individual consumer or commercial value.

The challenge is to transform markets to deliver the clean, low carbon energy we need at acceptable prices.

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Barriers to innovation and commercialisation

- Technological and commercial risk – will it work at prices consumers can (or are willing) to pay?
- Lack of funds for demonstration and pre-commercial trials (a "valley of death");
- Poor understanding of the supply chain and weaknesses therein – technology brand reputation is only as strong as the weakest link;
- Inadequate consideration of infrastructure;
- Inadequate consideration of the roles of minimum standards and regulation;
- Investor & business confidence: will policies remain stable?
- Insufficient consumer demand.

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Role of Governments is to transform markets and help make a smooth transition to a low carbon economy

- Reducing CO_2 emissions is a long term, high priority societal good: Governments therefore have a essential role;
- Transition to a low carbon economy requires technological <u>and</u> behavioural change. Not overnight; not easy; not without tears.
- Creating sustained market value for CO_2 is a crucial step: emissions trading is a start but market is immature; price signals are weak and alone are insufficient to deliver low carbon outcomes;
- Scale of the challenge is huge – need cuts of Gtonnes of CO_2 pa across the global economy. Alignment of interests not automatic.
- In countries where energy markets are liberalised, the regulatory regime can be a crucial factor.

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Innovation and commercialisation: example 1 – still cameras

English mahogany camera 19th C

Typical folding sheet film camera 1930s

Kodak Brownie 127 1950s

Canon AE-1 Program 1981

Canon EOS 30D Digital SLR - 2004

Sony T9 digital

Sony Ericsson K550i Digital Camera Phone

Innovation and commercialisation: example 1 – still cameras

- Early photography was mainly chemistry, some physics, a little engineering and no marketing:
  - – no lens or only rudimentary focusing devices;
  - – cameras made of wood (nicely polished)
  - – images were fixed on glass plates – took minutes to hours to take pictures;
  - – cameras and developing technology were carried on carts;
  - – no recognised commercial products – technology for enthusiasts only;
  - – no thought about mass markets and consumers

Innovation and commercialisation: example 1 – still cameras

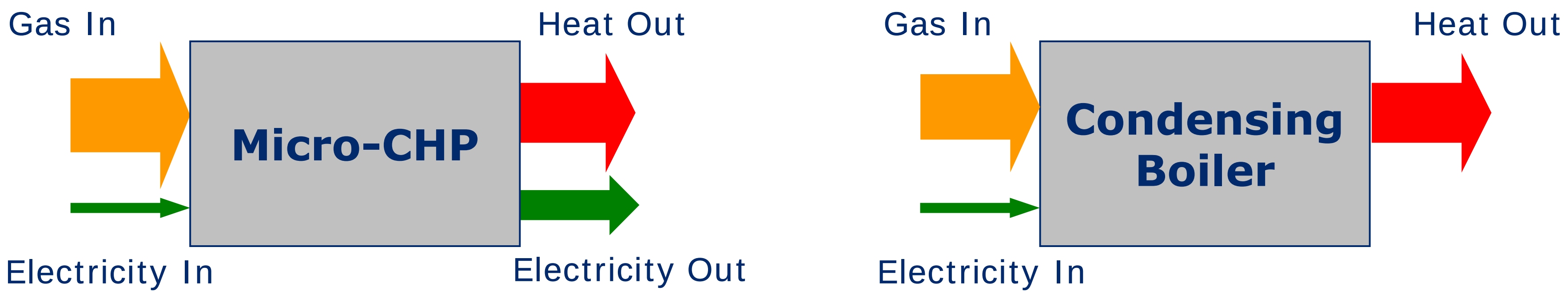
Breakthroughs and co-incident developments:

- cheaper, good quality glass for better lenses; emulsions deposited on rolled film reduced size and weight of cameras;
- cameras made of metal, bakelite, plastic; mass production, handy-sized, emerges from geek world, becomes a popular consumer “fun” product;
- a mass consumer industry is born: pictures taken in seconds, developed locally at the “chemists”. Product segmentation, marketing & branding take over.
- modern developments: digital format, instant gratification, converging camera-phone technology.

This innovation story goes on – consumer pull and business imagination drive innovation.

Innovation and commercialisation: example 2 – micro-combined heat and power

- Micro-CHP and boilers both cause carbon emissions due to the gas and electricity they use;
- However, micro-CHP can potentially save carbon relative to boilers by offsetting local use of grid electricity;



- Micro-CHP carbon-saving potential can vary significantly and depends on the chosen operating environment and usage profile;
- If used in the wrong environments, or badly integrated, micro-CHP emissions may be higher than those from current technology.

Innovation and commercialisation: example 2 – micro-combined heat and power

- Aim is to offer a lower carbon solution for domestic and small scale heat and power customers. However:
  - customers happy with incumbent technology – i.e. efficient boilers plus access to electricity from the national grid;
  - customers don't value the reduced carbon footprint; unwilling to pay extra costs; hassle-averse: hence no mass market pull for new micro-CHP products;
- On the other hand, in the right circumstances, micro-CHP can play a useful role in CO_2 mitigation. Therefore need:
  - to identify the "right circumstances";
  - to help develop the technologies; and then
  - stimulate market pull via Government policy instruments: incentives, regulation, standards, etc

Innovation and commercialisation: example 2 – micro-combined heat and power

Promotional literature

The WhisperGen™ microCHP system – an energy efficient, domestic appliance (no bigger than your average dishwasher) that generates both heat and electricity for use in the home.

Your personal power station

The WhisperGen™ is Micro Combined Heat and Power (or Residential Co-generation) technology that is creating a quiet revolution in energy generation.

It is an effective and clean energy generation system which is poised to replace existing home boilers. Not only can it supply all of the household's water heating demand (with domestic hot water and central heating), but at the same time it generates electricity which can either be used in the home or supplied back to the grid.

Benefits of the WhisperGen™

- Real savings for the customer through the production of their own electricity to supplement grid electricity supply.
- Environmental benefits as fuel is used more efficiently, reducing CO_2 and other emissions.
- Economic benefits for utilities especially in helping to avoid peak-load costs when the network is overloaded.
- Reduces the need for large central power stations and their associated transmission network.
- Allows for rapid introduction of new generation capacity.
- Creates the opportunity for the integration of gas and electricity retailing.

There's more than one reason to choose the WhisperGen™

Clean and Efficient: both in design and performance, which means lower energy costs and with minimal impact on the environment.

Reliable: low maintenance design.

Self Managing: features integrated microprocessor controlled system, which eliminates the need for constant user interaction.

Effective Heat Output: typically 12KW thermal output.

Compact: the WhisperGen™ microCHP system is the size and shape of an average domestic dishwasher.

Quiet: the low vibration and external combustion features of the WhisperGen™ Stirling engine result in noise levels comparable to (and in many cases much quieter than) other household appliances.

Technical Specifications

Model MkV AC Gas fired

Engine 4 Cylinder double acting Stirling cycle

Outputs Electrical: 1000W AC at 220-240V. Thermal: heat output from 7.5-12kW

Fuel 2H - 2nd family natural gas

Power Connection Grid connected 4 pole induction generator, IEC plug and socket connections

Dimensions 480 x 560 x 840 (w x d x h)

Dry Weight 137 kg

Enclosure Floor mounted, free standing, stainless steel front enclosure with built-in control panel

Connections Standard plumbing connections

Environment Ambient: 0-45°C. Humidity: 0-95% non-condensing

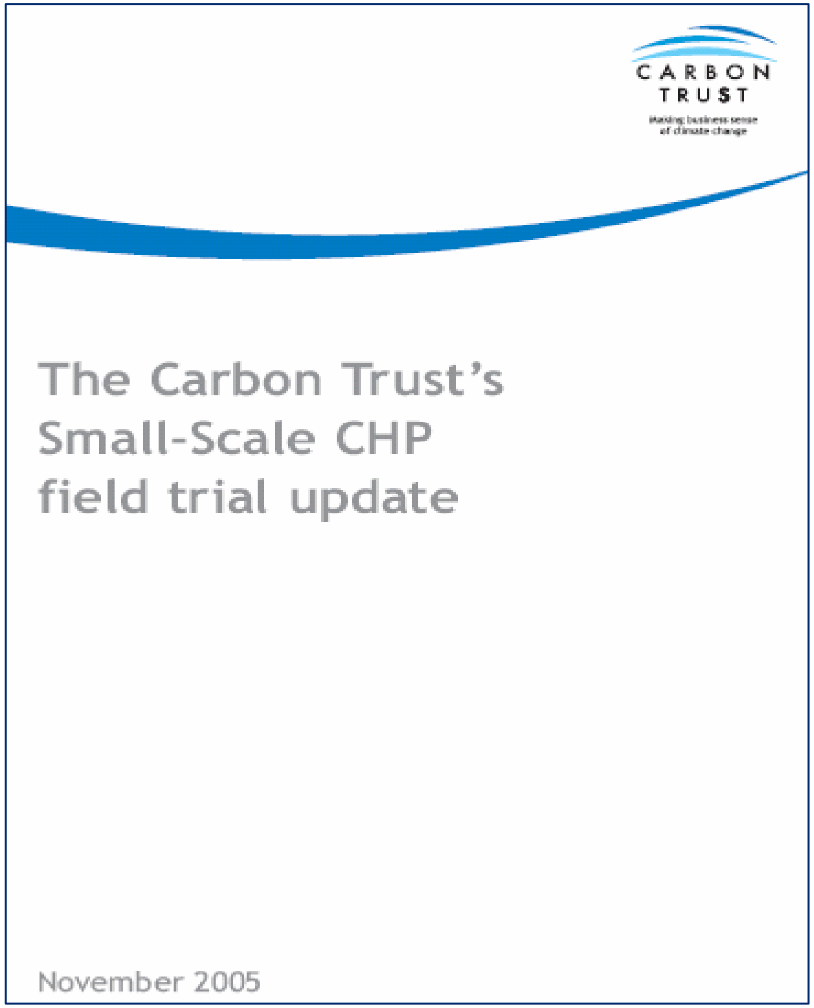
Flue Horizontal or vertical balanced flue

Approvals CE Marked

WHISPERGEN™ microCHP

The Urban Home Power Station

Micro-chp performance monitoring - interim findings from Carbon Trust's independent trials

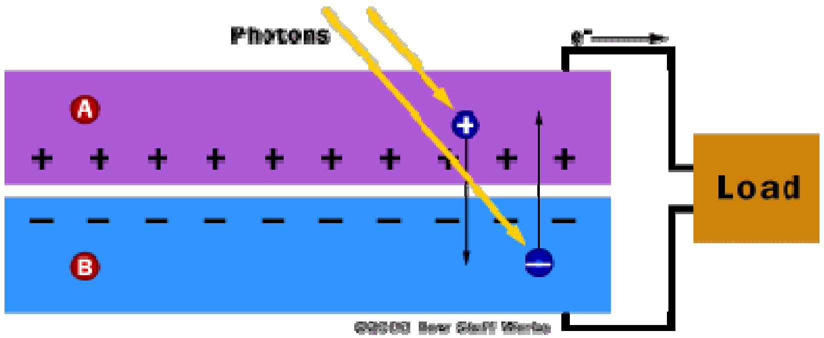


CO_2 saving potential of micro-chp depends on:

- overall thermodynamic efficiency;
- amount of electricity generated;
- carbon intensity of the electricity displaced from the grid.

- Prospects for CO_2 savings in small commercial, multi-residential markets are good
- Domestic applications have mixed prospects, depending on heat needs, installation quality, integration with the dwelling. Trials report said + or – 18%.

Innovation and commercialisation: example 3 – solar photovoltaics



How it Works
- Direct conversion of light to electricity (Becquerel, 1839)
- Crystalline silicon (c-Si)
- Oppositely charged layers form a diode
- Light (photon) absorbed frees electron-hole pair
- Charge separation by p-n diode
- Current flows around circuit
- Typical efficiency ~15%

"First Generation (c-Si)"

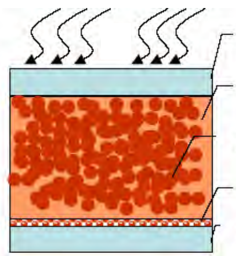
Limits to Efficiency
- Low energy photons pass straight through
- Excess energy from high-energy photons lost as heat
- Poor light absorber (~250μm thick)

Limits to cost reduction
- Energy-intensive (1700°C)
- Wafers sawed from ingot
- Batch processing

Source: Los Alamos National Laboratory

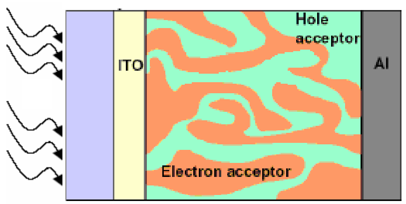
Innovation and commercialisation: example 3 – advanced solar pv

Device concepts



Source: Konarka

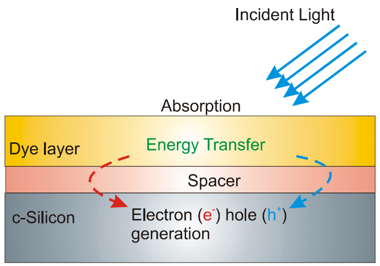
Dye-sensitised solar cells (DSSC)



Source: Konarka

Conducting polymer cells

Luminescent concentrators

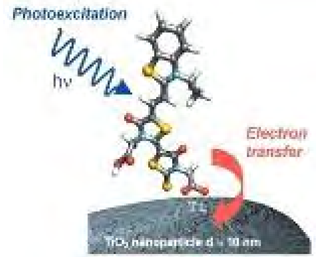


Source: L. Danos, Southampton University

Photosensitised silicon cells

Light capture

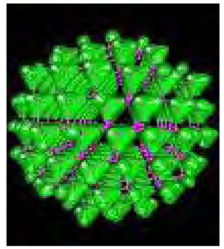
Dyes



Source: University of Frankfurt

Quantum dots

10-50 nm



Source: EPFL

Innovation and commercialisation: example 3 – the project vehicle

Our Special Purpose Vehicle aims to:

- bring together a critical mass of business led research on advanced pv via a partnership comprising business, top R&D groups and the Carbon Trust;
- make a step change in 3rd generation pv: hence the scale of our involvement – a few £M over 3 years or so;
- create intellectual property with commercial potential which can be taken to market by the business partners;
- deliver returns to all partners in the event of commercial success.

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Some conclusions

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Innovation:

- is an essential part of making the transition to a low carbon economy. However, it:
- can make fortunes or damage businesses:
  - fuel cell millionaires;
  - Kodak lost money as film lost ground to digital formats;
  - BG withdrew Microgen Energy Ltd from the micro-CHP market "Microgen unit . . . not in our view capable of making the breakthrough required";
- will have surprises up its sleeve:
  - (Microgen assets "reborn" as Microgen Engine Corporation Ltd. Julian Hughes, CEO: "Microgen Engine Corporation Ltd is ideally positioned to capitalise on the growing momentum currently developed in the micro-CHP sector".)
  - Remember the old quote: "I think there is a world market for maybe five computers." Thomas Watson, chairman of IBM, 1943.

Some more conclusions

- Accelerating investment in low carbon and demand reduction technologies depends on having an attractive value proposition for consumers and suppliers;
- The value proposition is tempered by the impact of policies and instruments on the market;
- Selling the low carbon value proposition is hard: costs and benefits are not well aligned across stakeholders: do we have the will to move to a low carbon economy?
- We have some policy instruments in place but they do not yet form a coherent, consistent and robust set which will enable us to make the transition.

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For further details of the Carbon Trust and its activities, you are invited to look at our website: www.carbontrust.co.uk

Or, call our Advice Line on 0800 085 2005

Biomass, Bioenergy and Biofuels

Prof. Tony Bridgwater
Bioenergy Research Group
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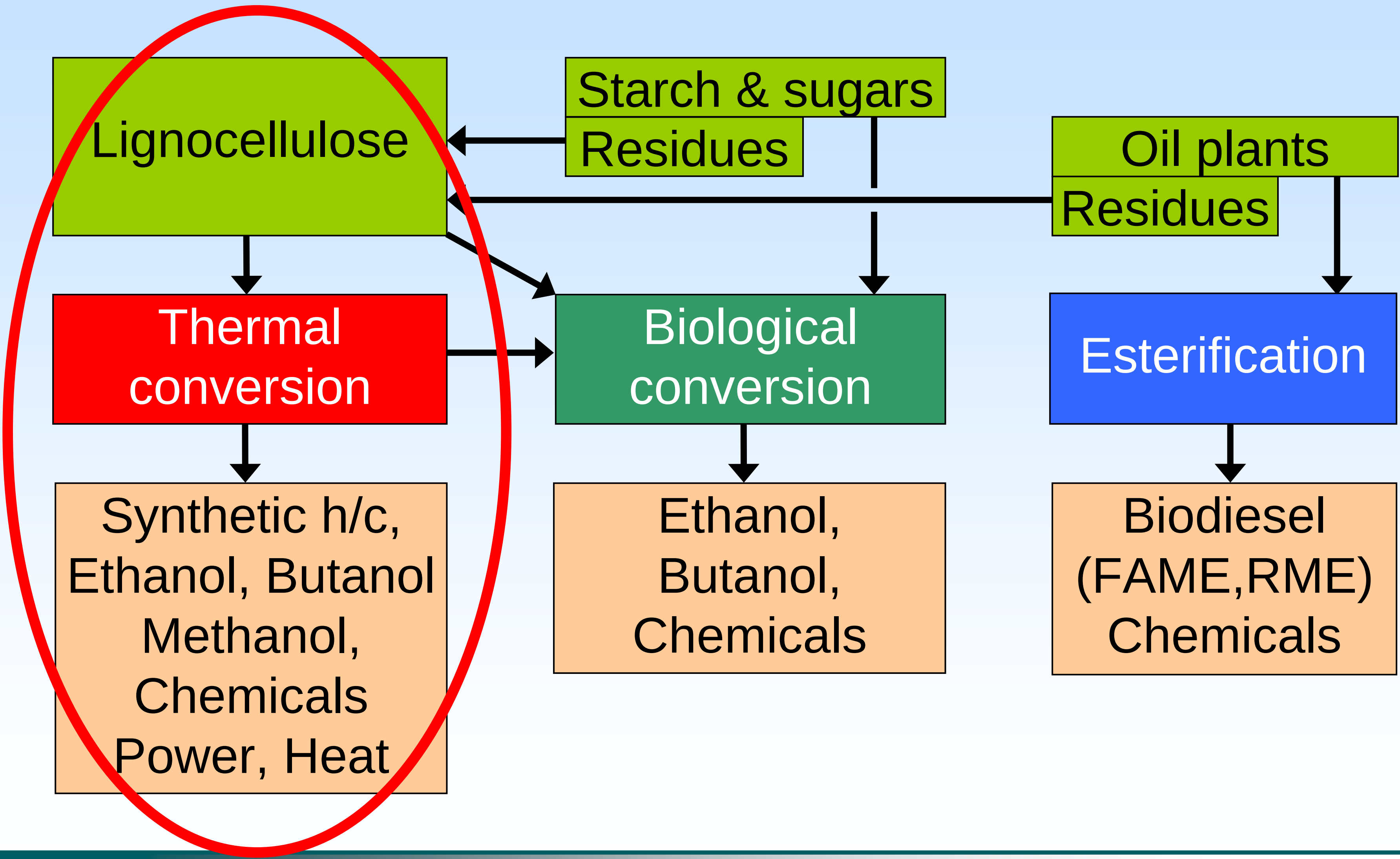
Aston University

Biomass

- Energy crops
- Agricultural and forestry wastes
- Industrial & consumer wastes

- Biomass is widely dispersed, with few sites that can sustainably produce 100,000 dry t/y, about 20-25 MWe,

Feeds, processes, products



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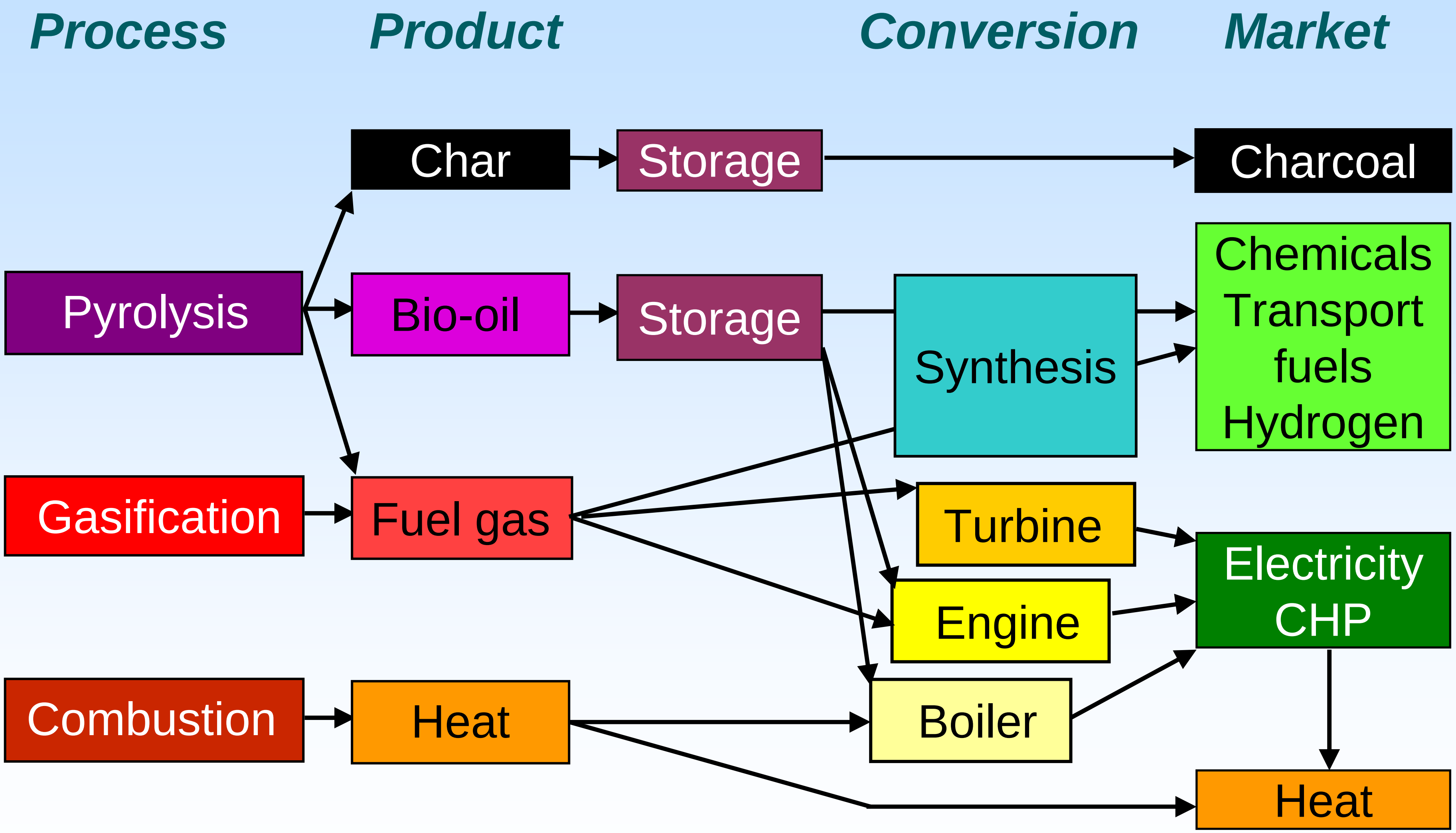
Thermal vs biological

- Thermal conversion
  - Dry feed needed
  - Fast processes
  - Less selective - Mixed products
  - More versatile in range of products and applications
- Biological conversion
  - Wet feed acceptable
  - Slow processes
  - More selective - Single product generally (e.g. ethanol)
  - Less versatile

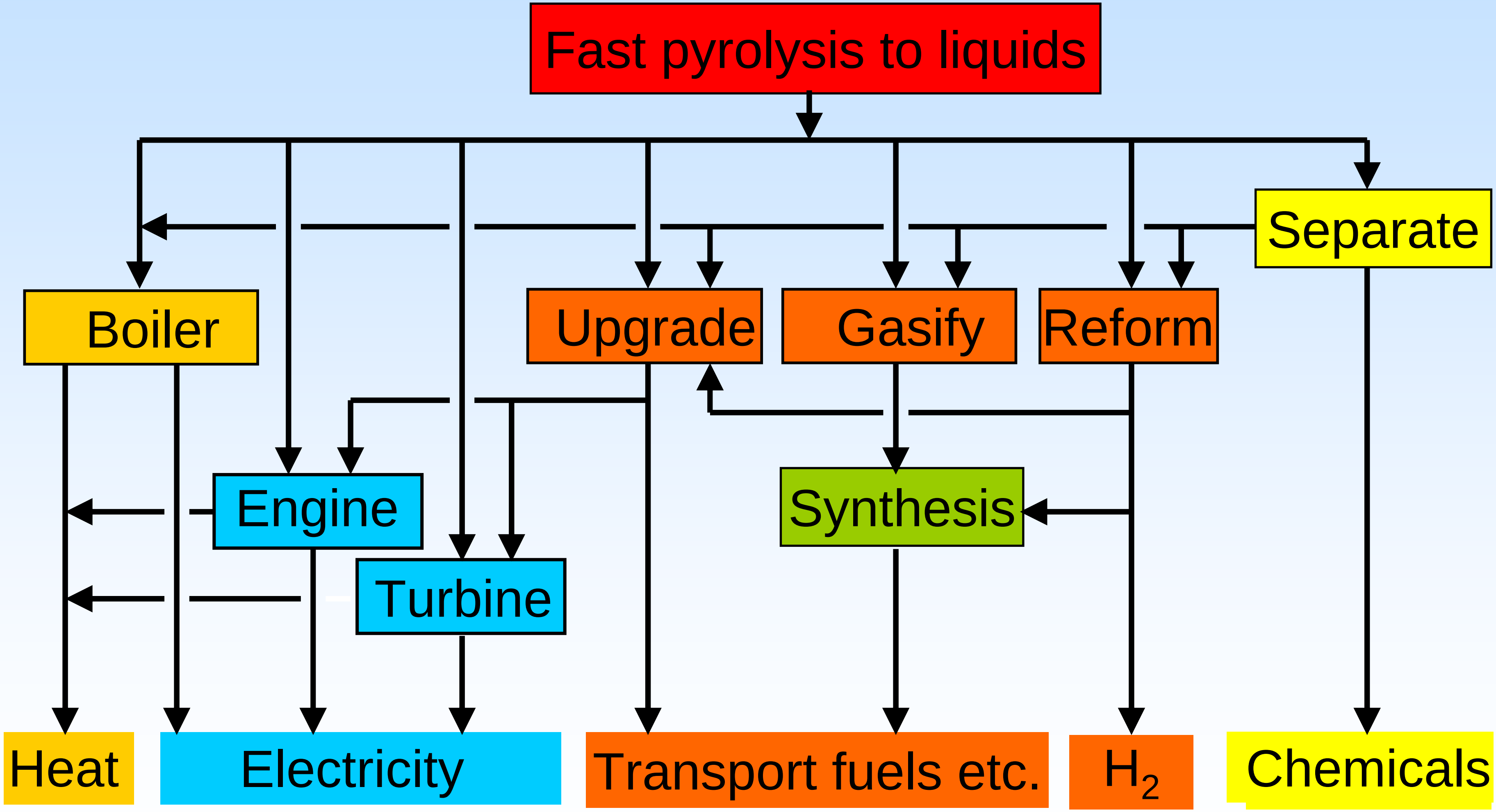
Thermal Biomass Conversion



Pyrolysis

	Liquid	Char	Gas
FAST PYROLYSIS moderate temperature (~500C) short hot vapour residence time (<2 s)	75% **25% water**	12%	13%
INTERMEDIATE PYROLYSIS Low-moderate temperature, moderate hot vapour residence times	50% **50% water**	25%	25%
SLOW PYROLYSIS Low-moderate temperature, long residence times	30% **70% water**	35%	35%
GASIFICATION high temperature (>800C), long vapour residence time	5% (tar) **5% water**	10%	85%

Applications for bio-oil



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Fast pyrolysis for liquids

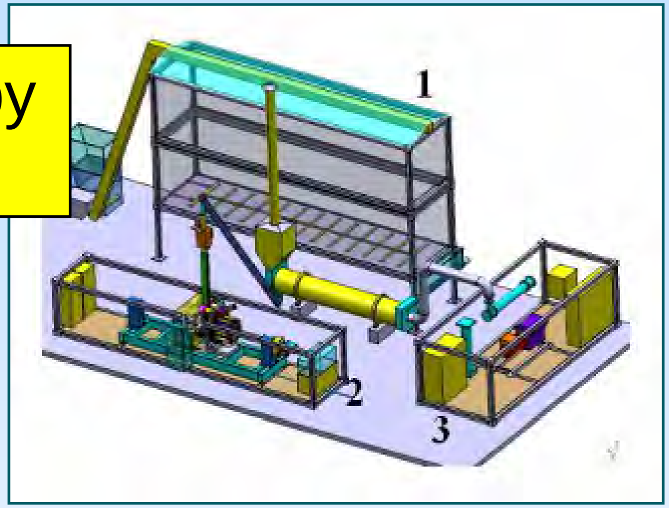
- Biomass is heated as quickly as possible …..
- To a carefully controlled temperature (~500°C)
- Products are cooled as quickly as possible (<2 s)
- The liquid has unique properties
  - Dark brown mobile liquid,
  - Combustible, but not flammable,
  - Heating value ~ 17 MJ/kg,
  - Not miscible with hydrocarbons,
  - Density ~ 1.2 kg/l,
  - Acid, pH ~ 2.5,
  - Pungent odour,

Process requirements

Drying	<10%. Feed and reaction water report to bio-oil
Comminution	-2mm (fluid bed), -6 mm (CFB)
Fast pyrolysis	high heat rate, controlled T, short residence time,
Char separation	Efficient char separation needed
Liquid recovery	By condensation and coalescence.

Pyrolysis examples

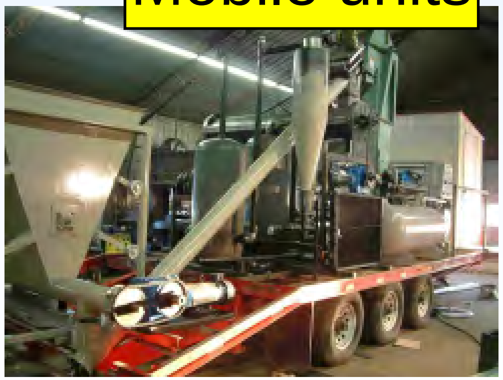
100 & 200 t/d by Dynamotive



50 t/d by Pytec

50 t/d by BTG

Mobile units



50 t/d by Ensyn

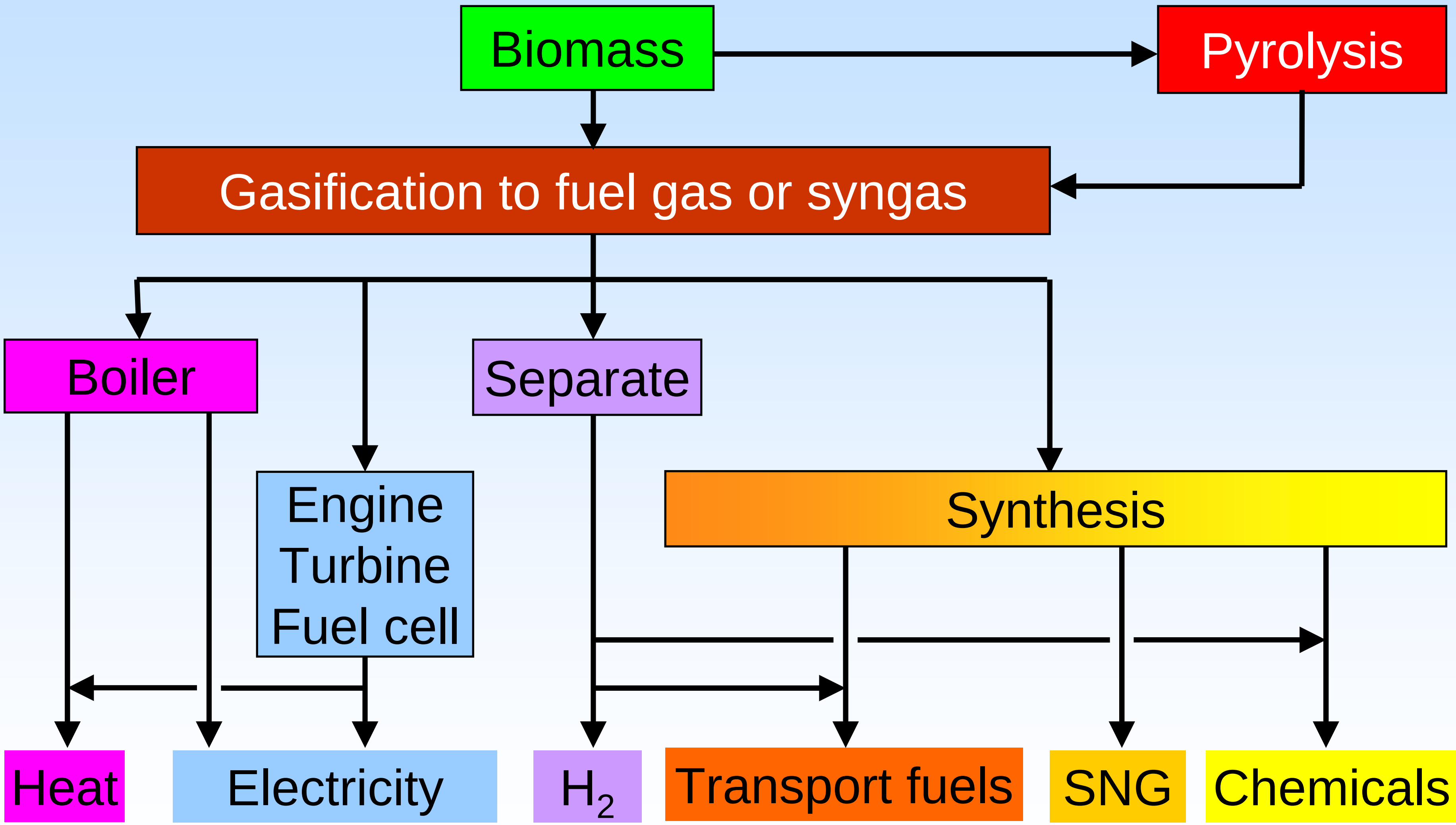
Gasification

- Gasification is the substantial conversion of organic material into a combustible gas.
- This can be thermal:
  - Partial oxidation by incomplete combustion with air or oxygen to give a combustible fuel gas or synthesis gas. This is mostly carbon monoxide, carbon dioxide, hydrogen, and nitrogen if air is used.
  - Steam gasification or pyrolytic gasification using heat derived from combustion of byproduct char, without addition of oxygen or air. The product gas also contains significant quantities of methane.
- Or it can be biological:
  - Anaerobic digestion to methane and carbon dioxide.

Gasification types

Type	*Gas HV*	*Efficiency*	*Comments*
AIR	~ 5 MJ/Nm^3	High	Simple
OXYGEN	~ 10 MJ/Nm^3	Moderate	Costly
STEAM (PYROLYSIS)	~ 15 MJ/Nm^3	Low	Complex process, Endothermic
PRESSURE			Costly, but high IGCC potential
AIR	~ 5 MJ/Nm^3	High	
OXYGEN	~ 10 MJ/Nm^3	Moderate	
BIOGAS	~ 18 MJ/Nm^3	Moderate	
Methane for comparison	35.5 MJ/Nm^3		

Applications for fuel gas or syngas



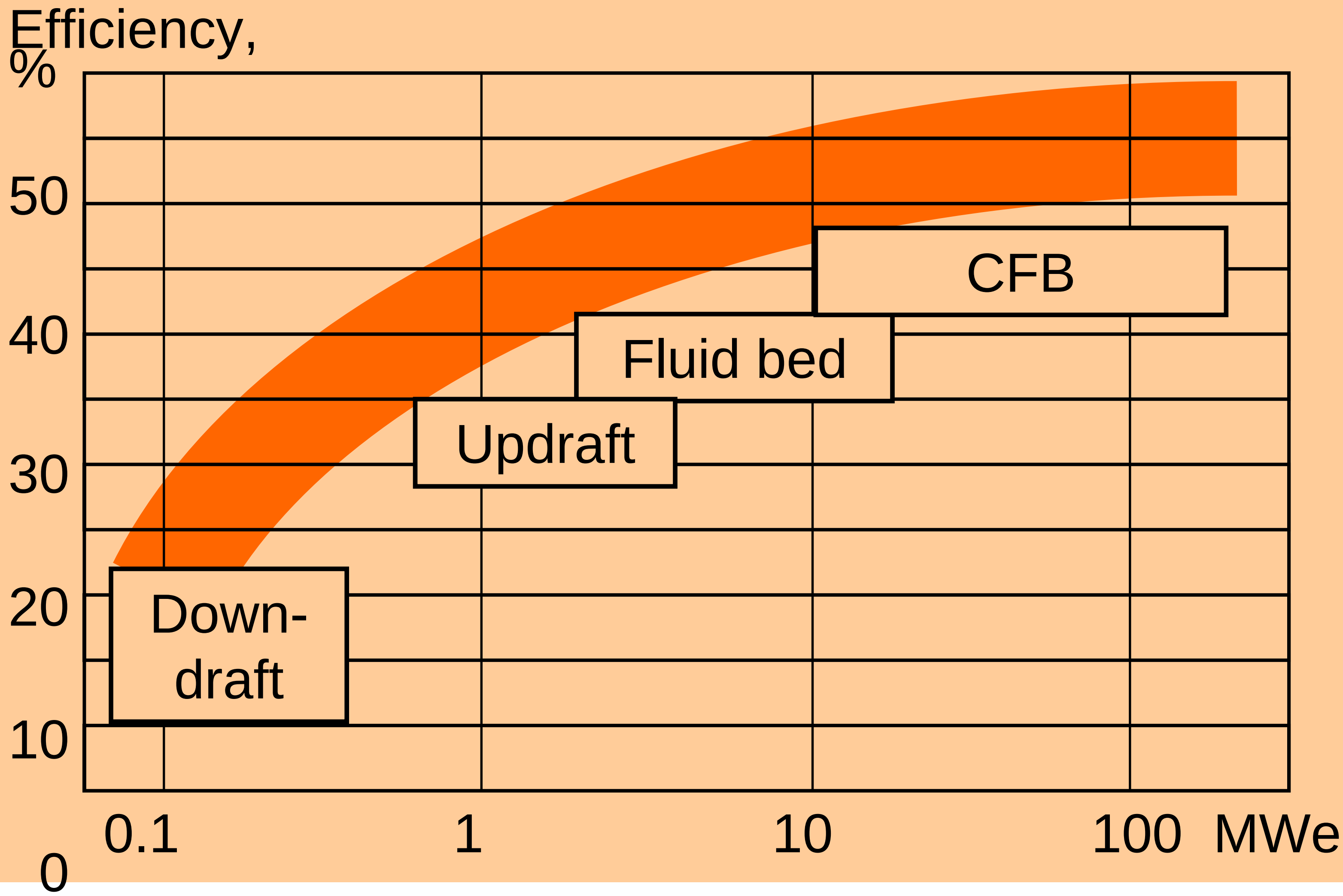
Gasifier examples

2 MWe by Austrian Energy at Guessing

50 kWe by Biomass Eng'g in UK

45 MWe co-firing at Lahti

Efficiency, technology & scale



Main challenge - gas quality

Contaminant	Examples	Problem	Solution
Particulates	Ash, char, fluid bed material	Erosion	Cyclone, barrier filter.
Alkali metals	Na, K compounds	Hot corrosion	Temperature.
Fuel-bound nitrogen	Ammonia, HCN	NOx	Temperature, SCR.
Tars	Refractive aromatics	Clogs filters, Difficult to burn, Deposits.	Cracking, Removal, Combustion.
Sulphur, chlorine	HCl, H_2S	Corrosion Emissions	Capture, Washing.

Renewable transport fuels

Oxygenates	Generation	Process
• Methanol	2°	Thermal
• Ethanol	1° & 2°	Biological or Thermal
• Butanol	1° & 2°	Biological or Thermal
• Mixed alcohols	2°	Thermal
• Dimethyl ether	2°	Thermal
Hydrocarbons		
• Biodiesel	1°	Physical + chemical
• Synthetic diesel	2°	Thermal
• Synthetic gasoline	2°	Thermal
• Methane (CSNG)	1° & 2°	Thermal
Other		
• Hydrogen	1° & 2°	Thermal or Biological

Synthetic hydrocarbons

- Synthetic hydrocarbons are entirely compatible with conventional crude oil–derived fuels in all proportions, but much cleaner. They include diesel, gasoline, kerosene
- The process is biomass or bio-oil gasification to a clean syngas and synthesis of hydrocarbons.
- Concept proven from coal in South Africa and from gas in Far East

- Biomass gasification technology is unproven at large scale. Gas cleaning claimed to not be a problem, but there is no evidence and no large scale experience

Gasification + Fischer-Tropsch

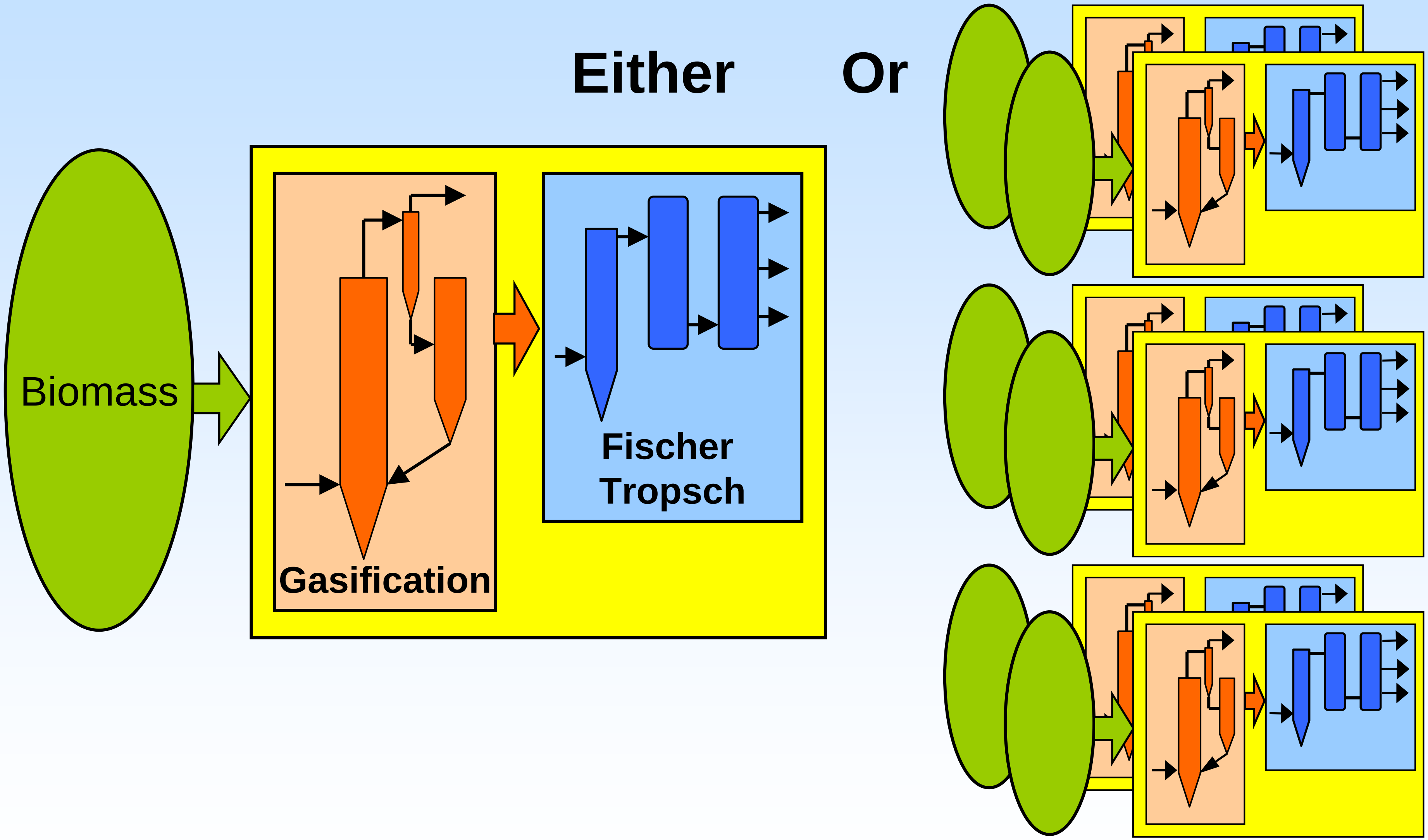
Fischer Tropsch is claimed to require a minimum size of 1 million t/y fuels to be economic

Biomass is a dispersed resource that has to be collected and transported over large distances. There are 2 options:

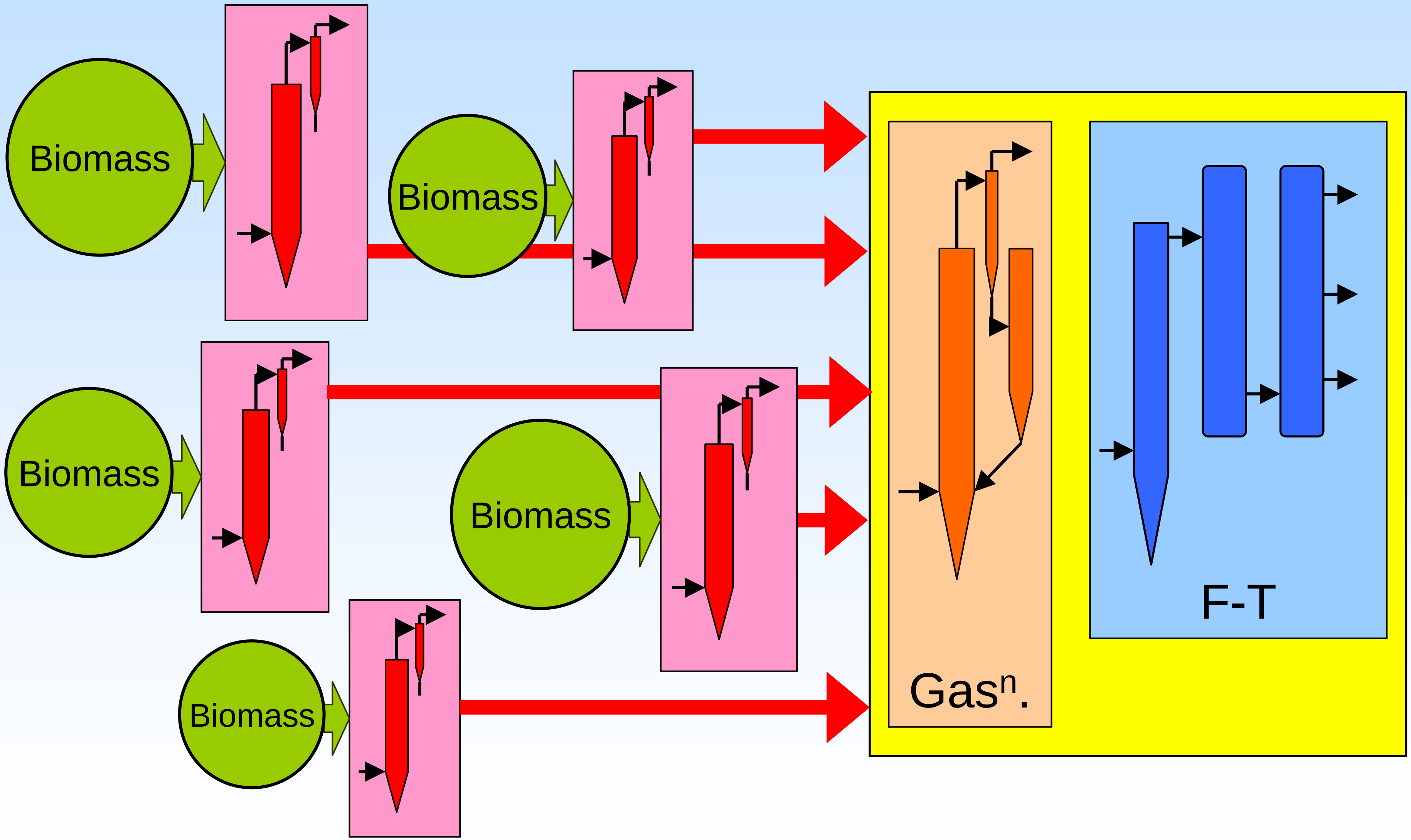
1. Large gasification plants integrated with FT synthesis. This requires delivery of very large quantities of biomass – around 5 million t/y to meet current views on economies of scale for FT plants.
2. Small multiple gasification plants integrated with downscaled Fischer-Tropsch (FT) hydrocarbon synthesis. This is costly due to absence of economies of scale and downscaling is unproven.

Gasification + Fischer-Tropsch

Either Or



Pyrolysis + Fischer Tropsch



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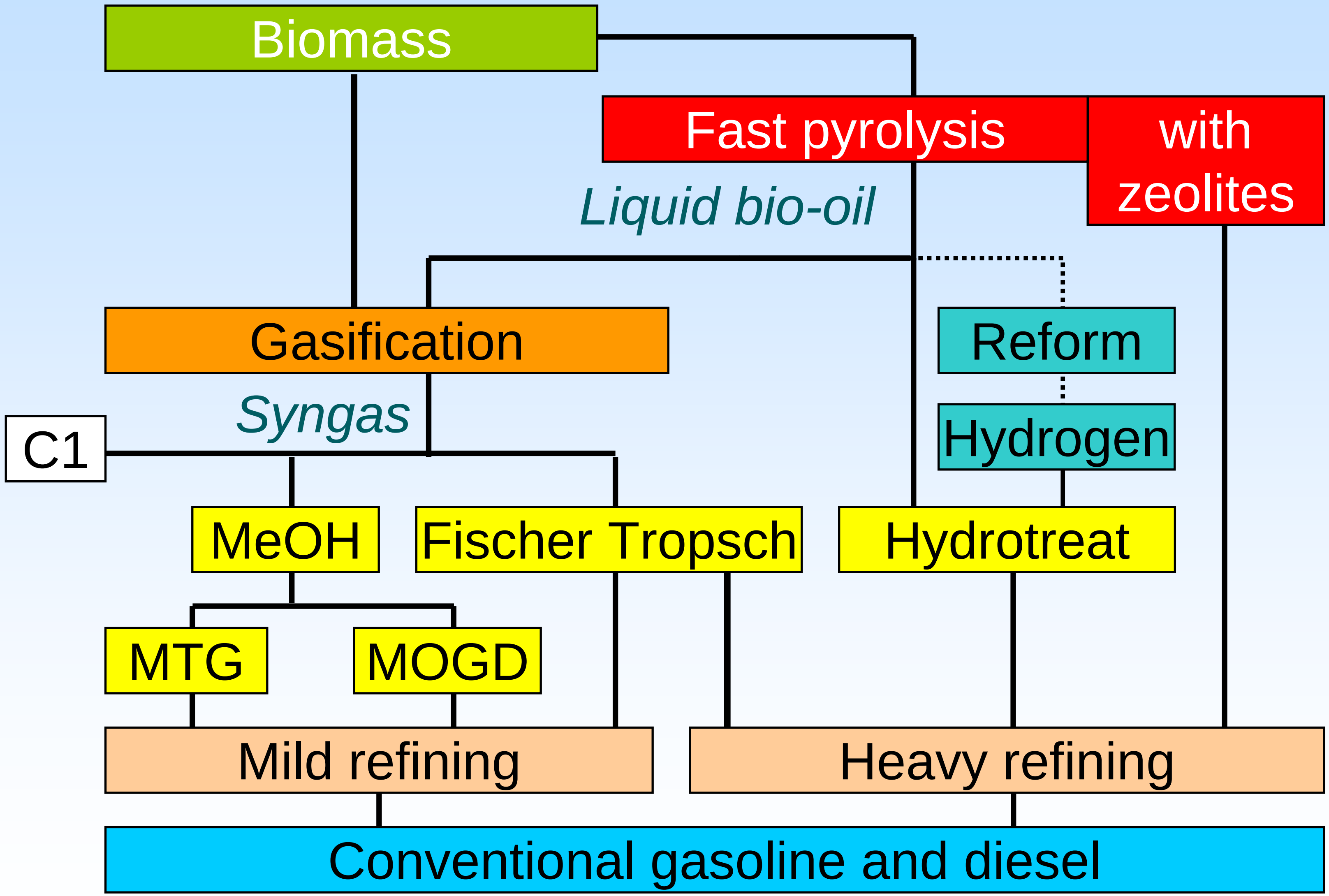
Comparison liquid vs solid feed

- Capital cost **increase** of ~10% due to diseconomies of scale in small pyrolysis plants
- Capital cost **reduction** of ~8% due to lower raw material handling costs
- Capital cost **reduction** of ~12% due to lower gasification costs in feeding a liquid at pressure compared to solid biomass
- Efficiency **loss** of ~6% due to additional processing step

Routes to bio-hydrocarbon fuels

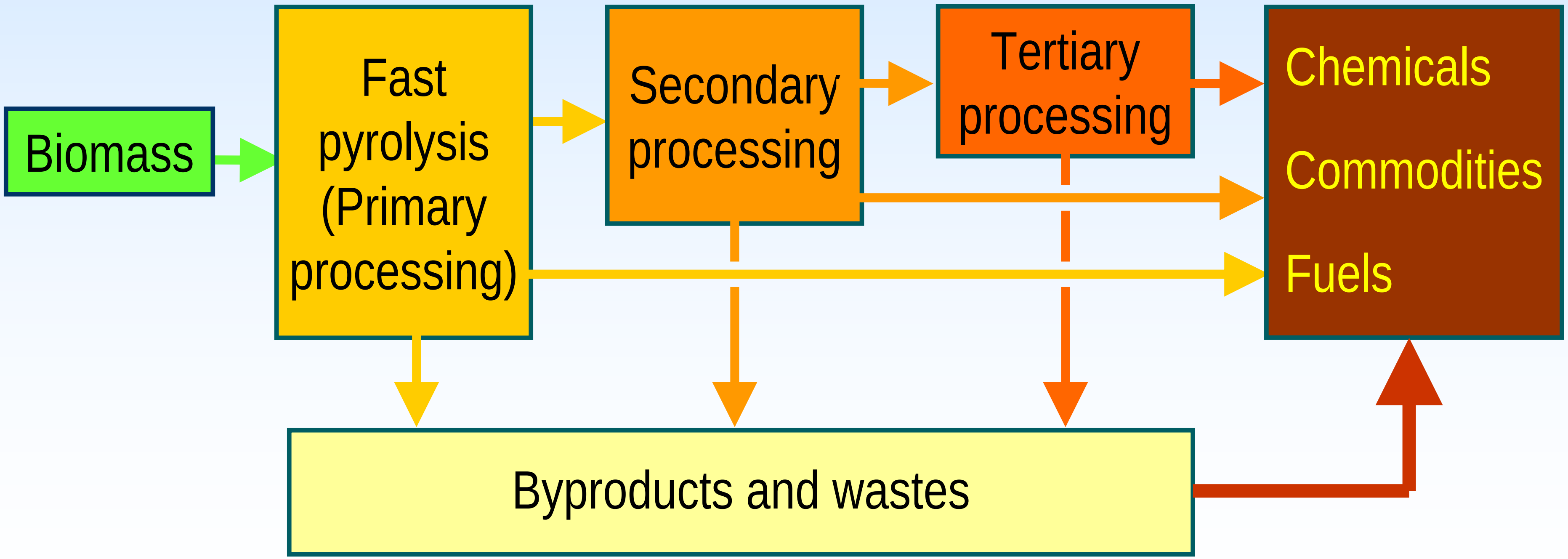
1. Thermal gasification + Fischer Tropsch
   - Solid biomass
   - Pyrolysis liquid as a preparation step
2. Thermal gasification + Methanol synthesis + upgrading by MTG or MOGD
3. Pyrolysis + upgrading by hydro-processing
4. Hydro-processing vegetable oil

Transport fuels from biomass



Biorefinery concept

- Integrate production of higher value chemicals and commodities, as well as fuels and energy,
- Optimise use of resources, maximise profitability, maximise benefits, minimise wastes



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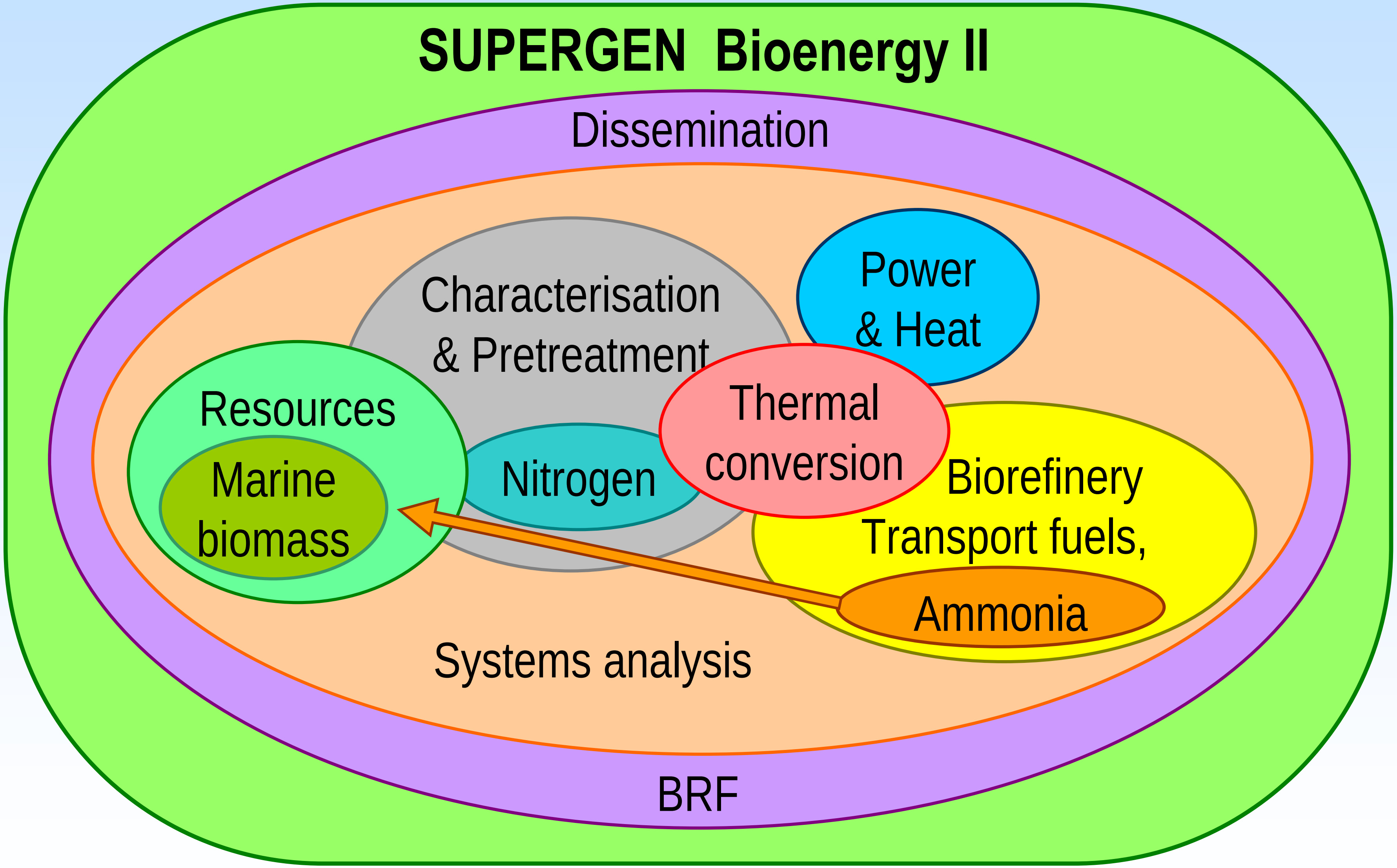
SUPERGEN Bioenergy

- SUPERGEN Bioenergy is one of 13 academically led consortia funded by EPSRC researching renewable energy
- A consortium of 14 research organisations and 11 companies
- Continuation of a 4 year phase 1 project with a second 4 year term and a £6.35 million budget
- Continuation of the focus on interfaces between biomass production, thermal conversion and product utilisation with added activities on:
  - marine biomass as a new resource,
  - nitrogen as a significant component of biomass,
  - second generation biofuels,
  - biorefineries and fertilisers

SUPERGEN Bioenergy structure



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Partners

ACADEMIC

- Aston (Management)
- Cranfield
- Forest Research
- Imperial College
- IGER
- Leeds (Finance)
- Manchester
- Policy Studies Institute
- Rothamsted Research
- Sheffield

ASSOCIATE PARTNERS

- Irish Seaweed Centre, Oxford, SAMS, Ulster

INDUSTRIAL INVITATIONS

- Alstom
- AMEC
- Bical
- BIFFA
- Biomass Engineering
- BP
- Coppice Resources
- E.On
- Johnson Matthey
- RWE
- Rural Generation

Overall conclusions

- Bio-oil from fast pyrolysis:
  - Storable and transportable
  - Successfully used in boilers, gas turbines, diesel engines, and for chemicals,
  - Good economics and efficiency as an energy carrier for synthesis of transport fuels etc.
- Gasification
  - More developed commercially,
  - Successfully used for heat and power production, but has to be close coupled to applications,
- Biorefineries
  - Opportunity to improve costs and performance
- SUPERGEN Bioenergy is contributing to all aspects of the work described here

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Future Energy: Chemical Solutions

RSC, 13 Sept 2007

Simon Bennett

Imperial College

Centre for Energy Policy and Technology

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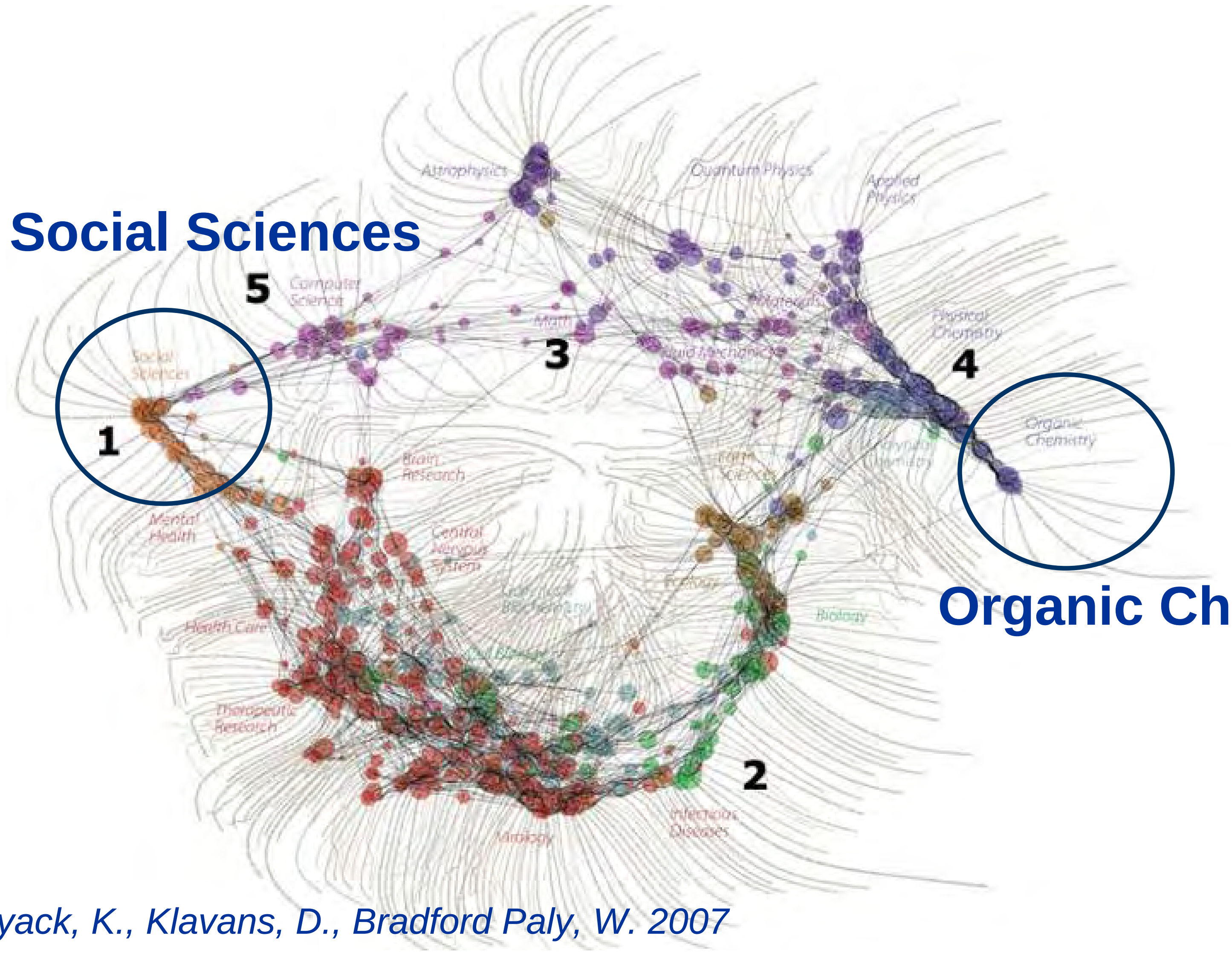
Science's Family Tree



Boyack, K., Klavans, D., Bradford Paly, W. 2007

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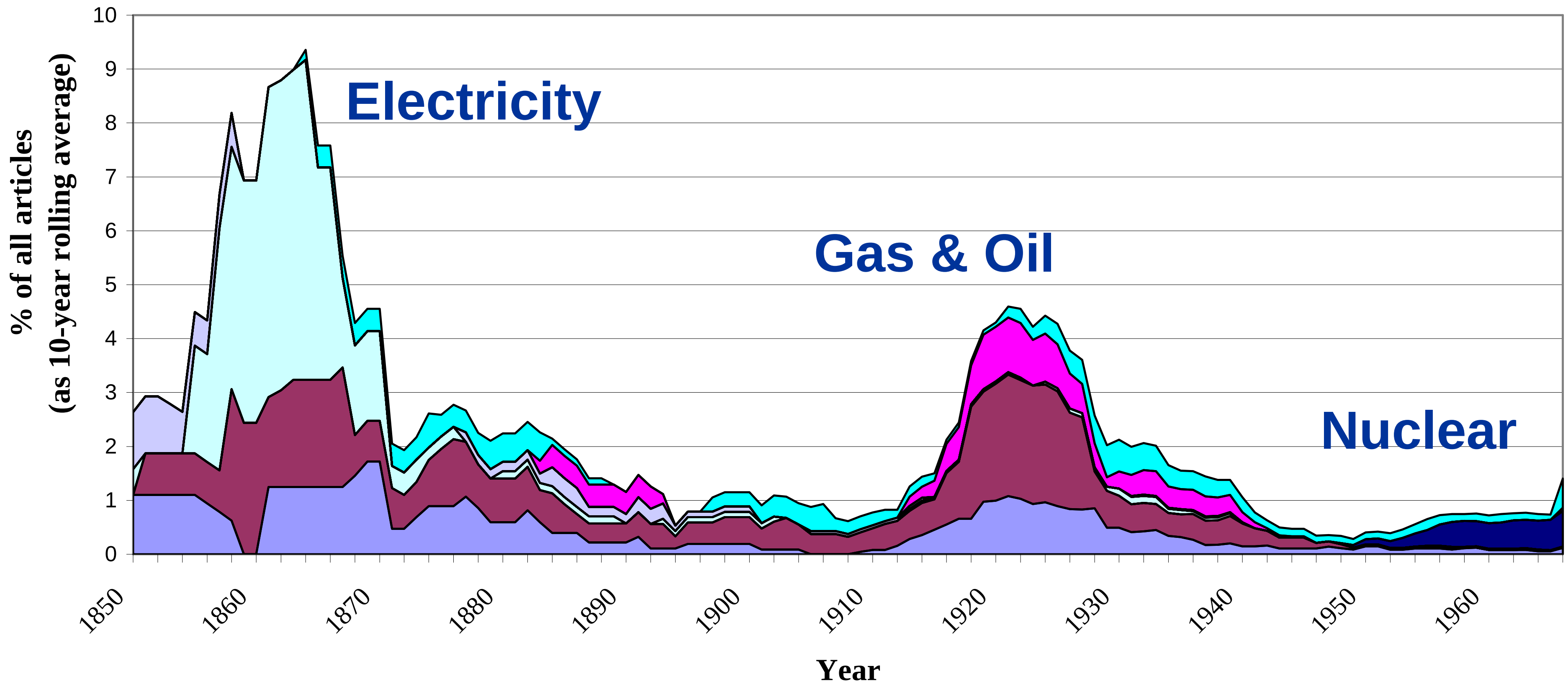
RSC articles relating to energy topics 1850-1960



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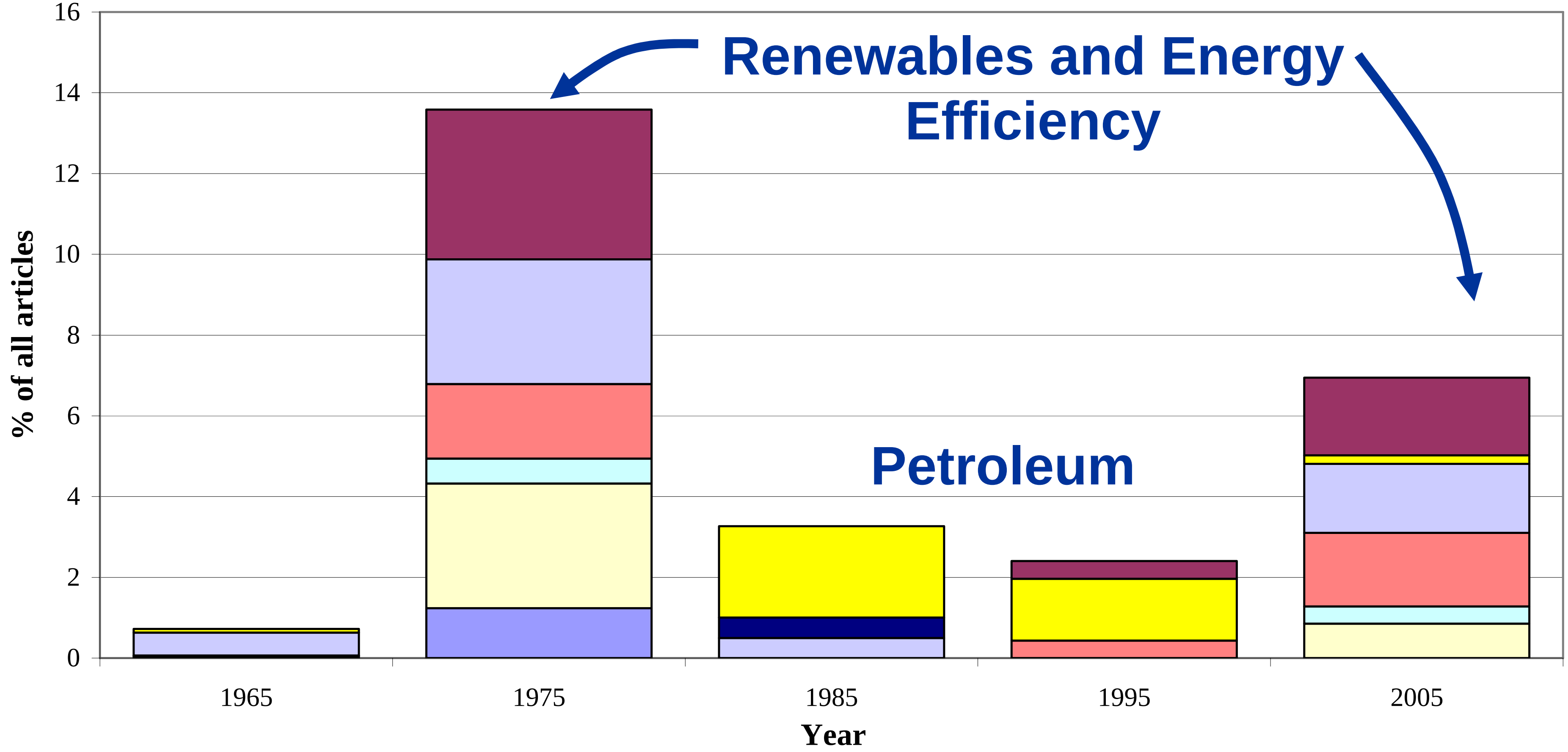
RSC articles relating to energy topics 1965-2005

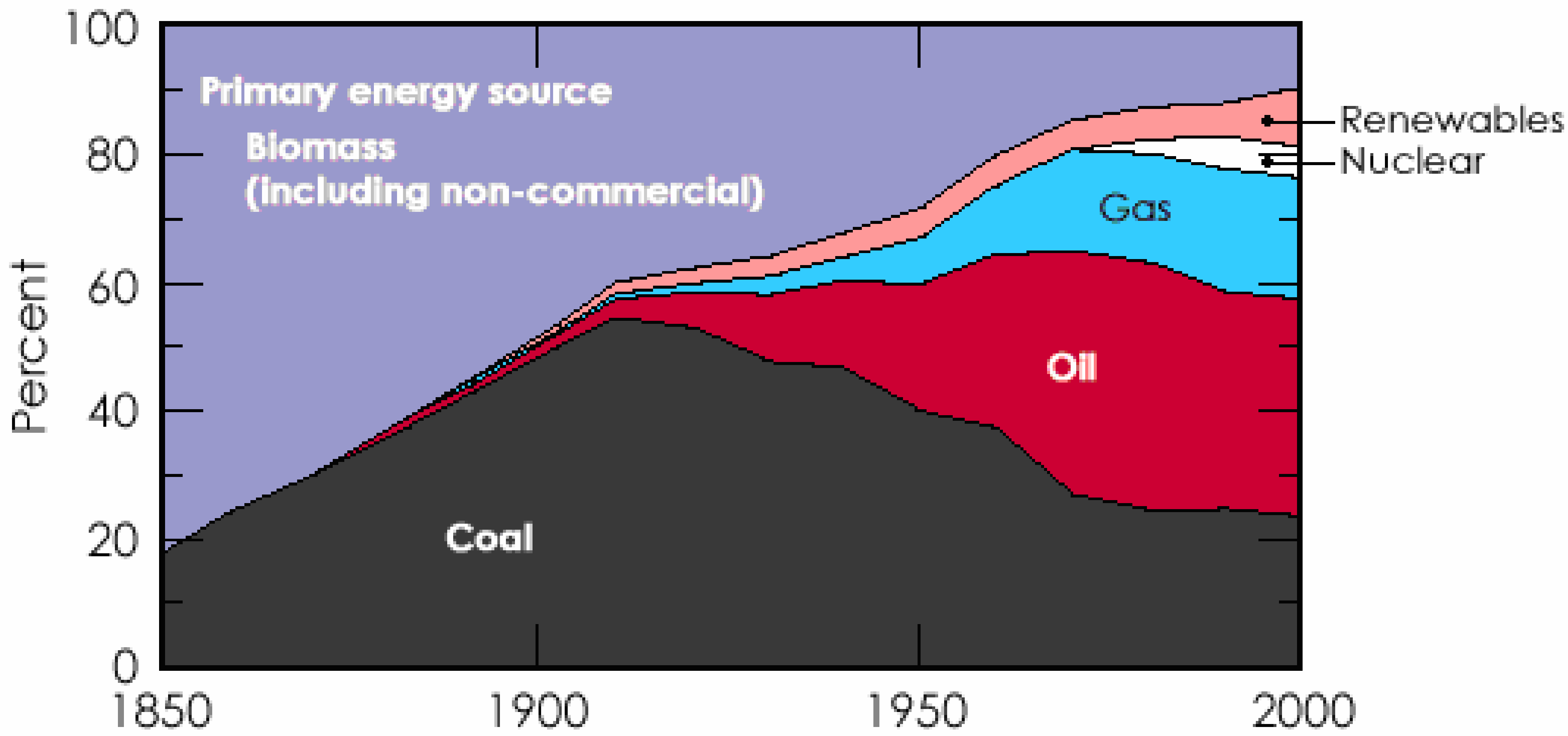


Unlocking the petroleum-chemical complex

The relevance of chemical production in the transition to sustainable energy systems

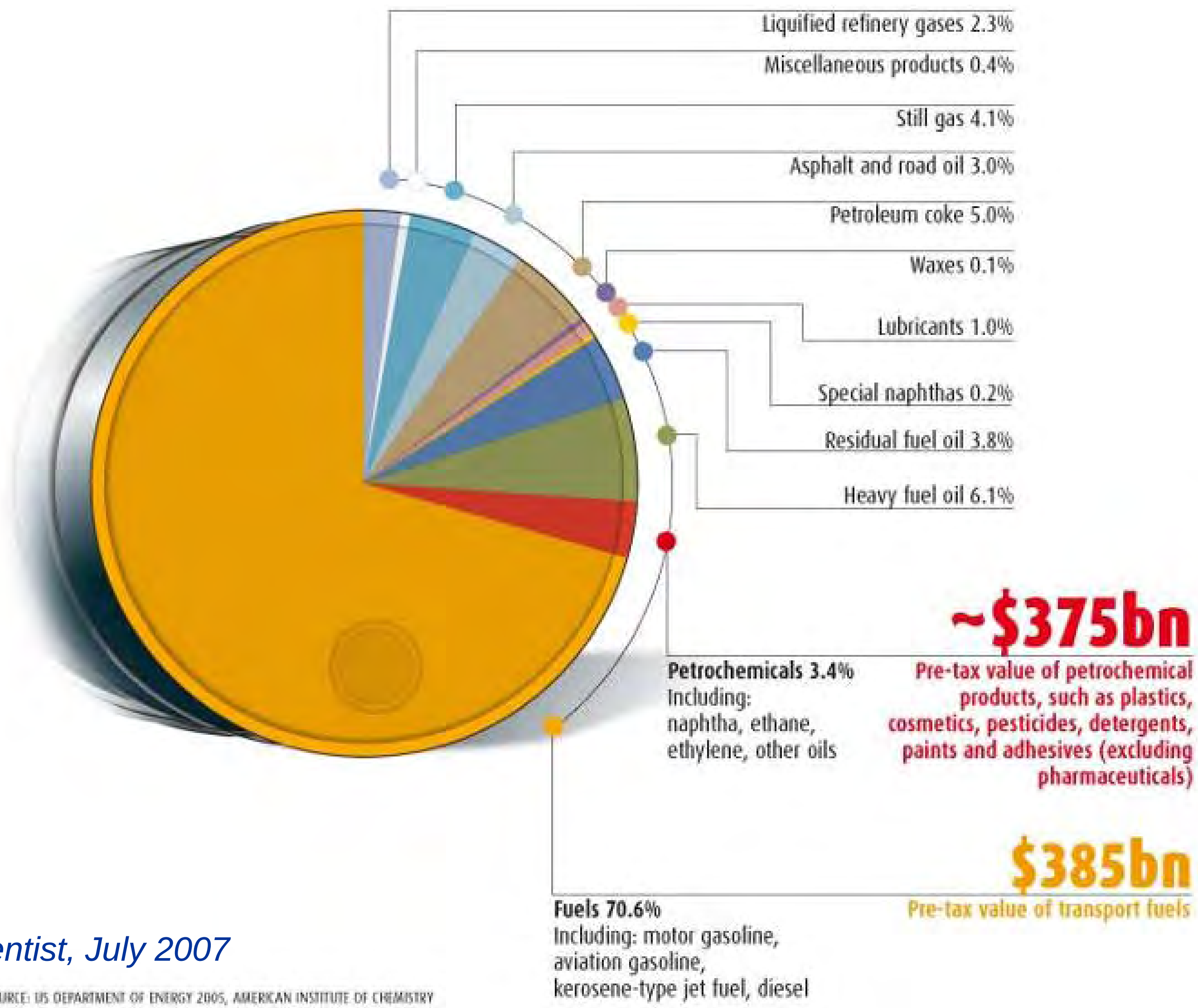
- Transitions – Past & Present
- Co-evolution
- Technological Lock-in
- Policy context

Energy Transitions 1850-2000



IEA

Oil Barrel Breakdown, 2005



SOURCE: US DEPARTMENT OF ENERGY 2005, AMERICAN INSTITUTE OF CHEMISTRY

New Scientist, July 2007

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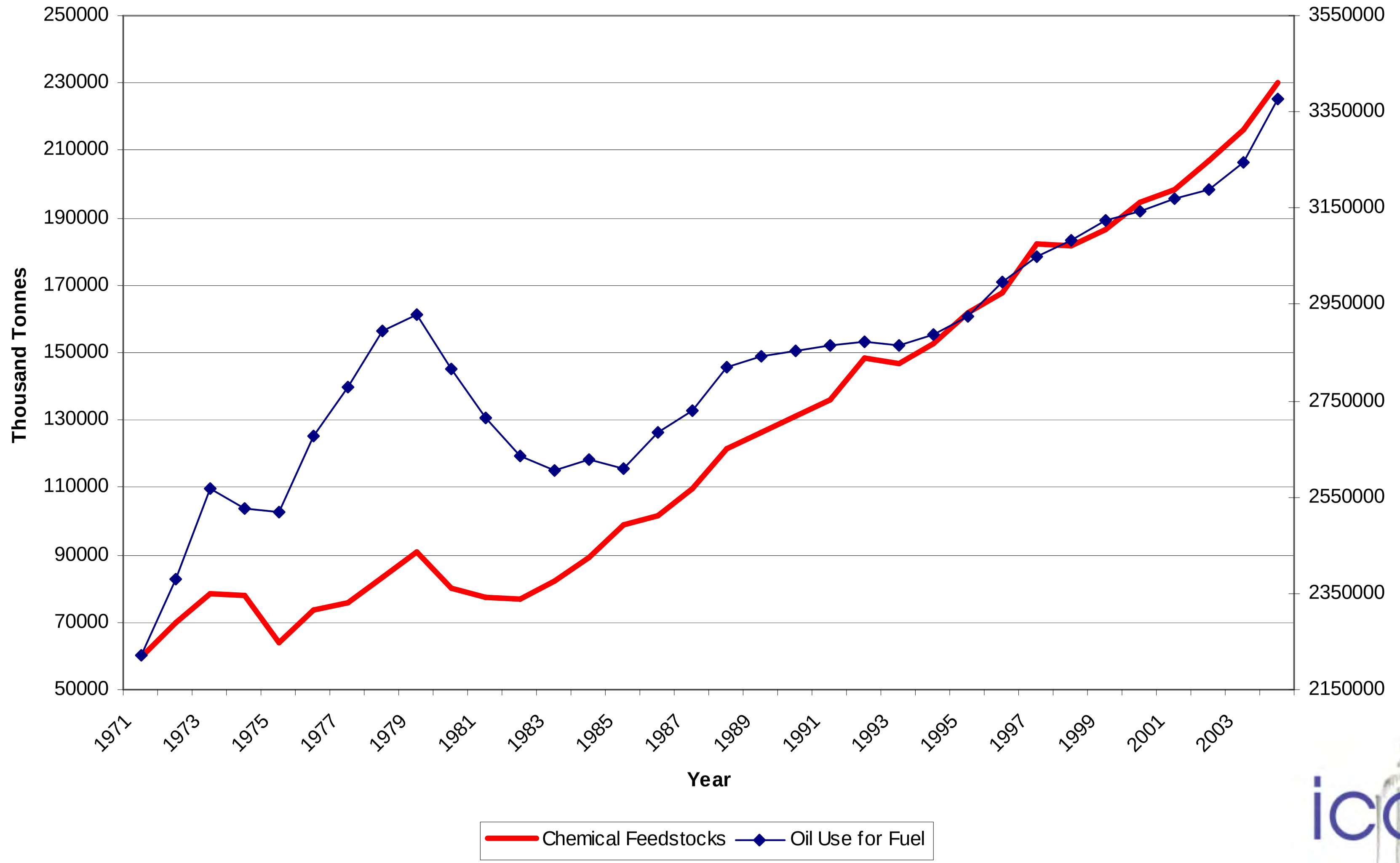
Growth in Global Fuel and Feedstock Demand



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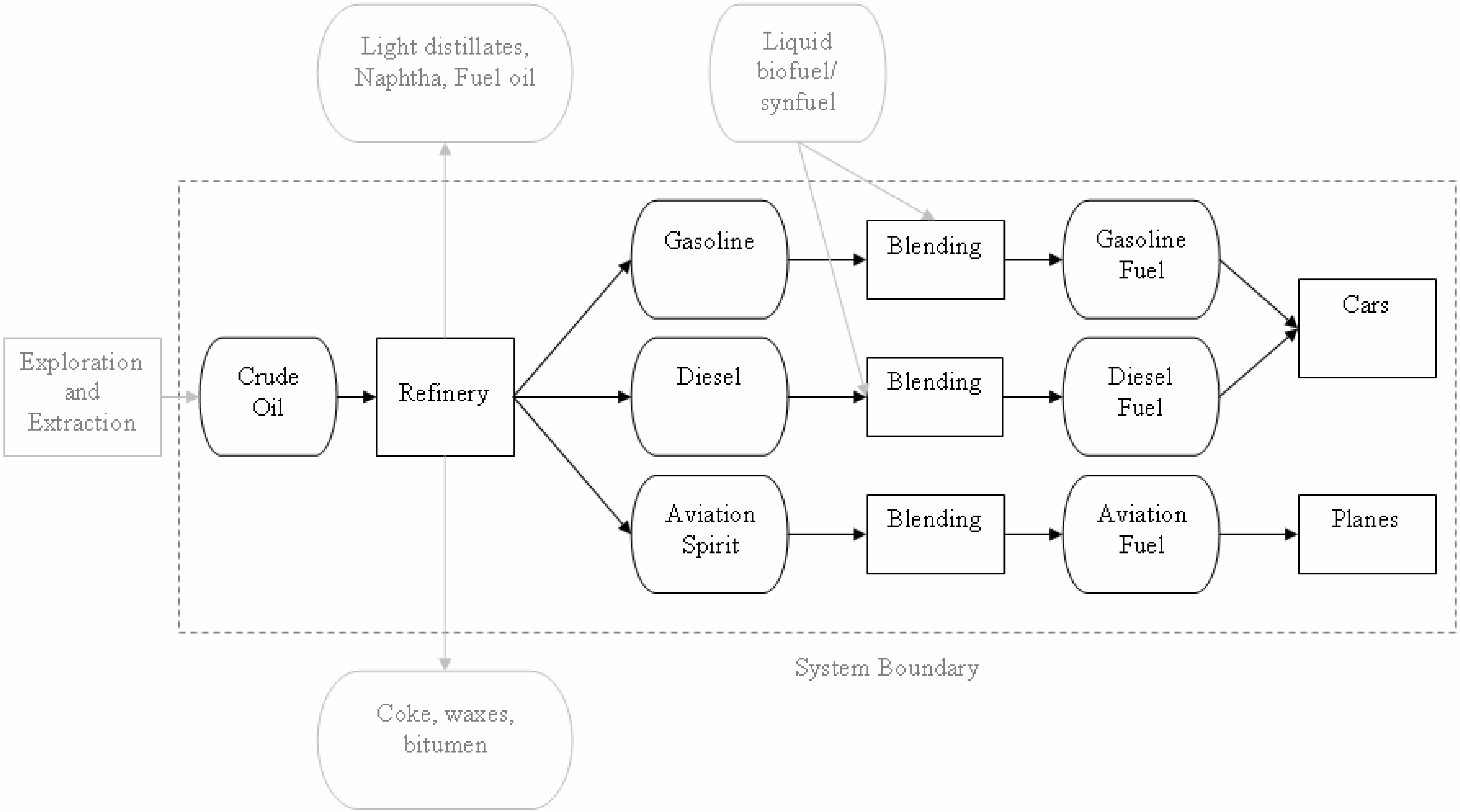
Transport Fuels System – closed view



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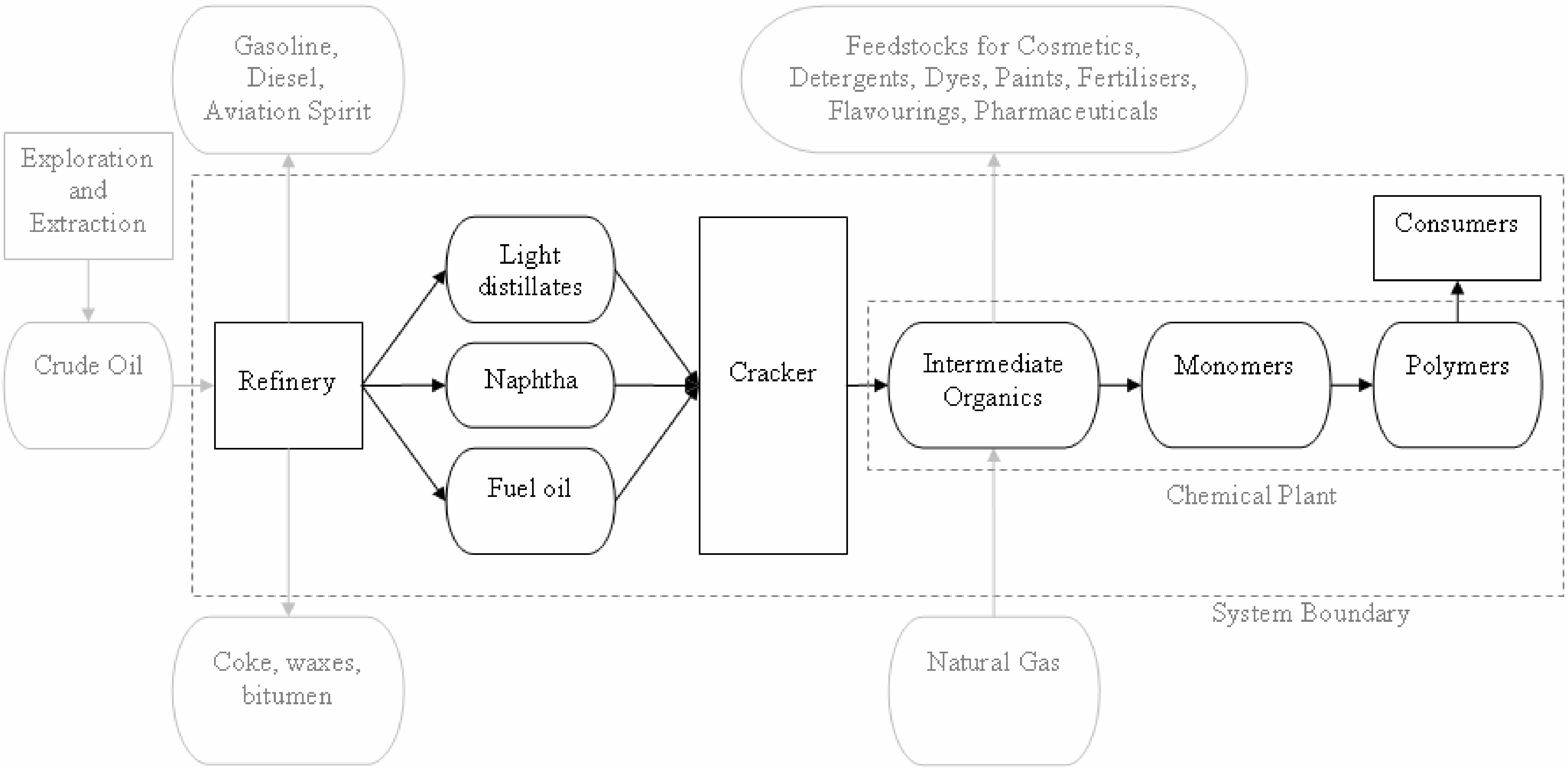
Polymers Production System – closed view



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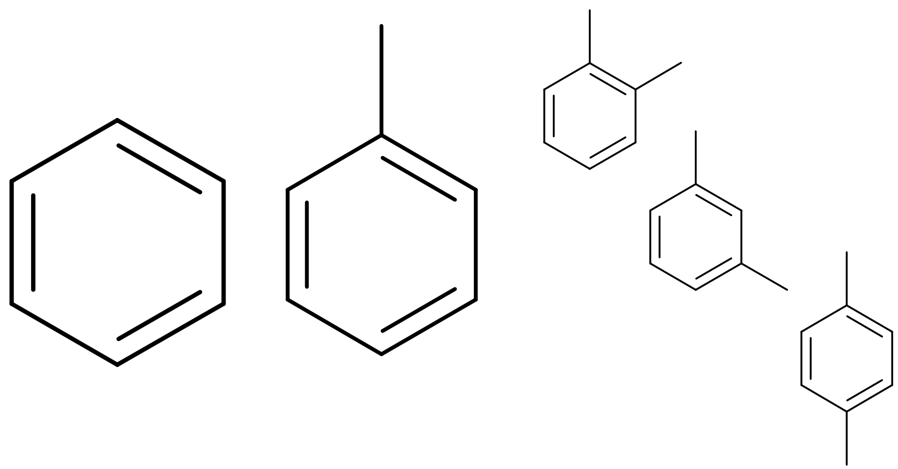
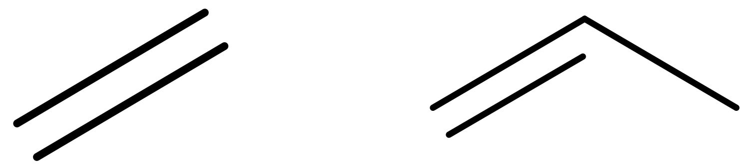
Primary Platform Chemicals





Heavy oil fractions

Coal

Oil & Gas

Bioethanol

Acetylene (coal)

Basis for 95% of all petrochemical products

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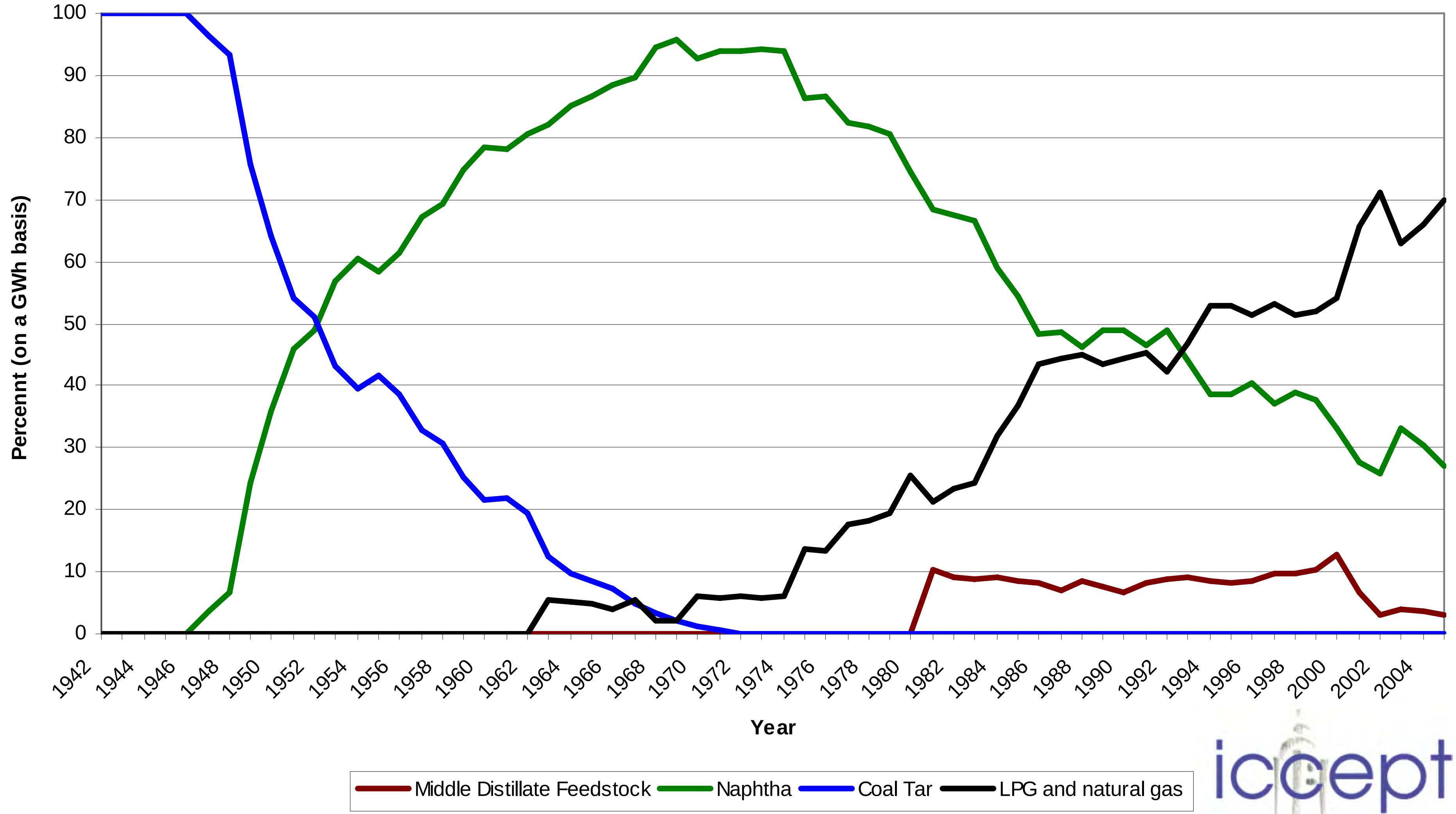
UK Chemical Feedstocks 1942-2004



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Co-evolution

“Each party exerts selective pressures on the other, affecting each others evolution”

- Biological definition

"any feedback processes between two evolving systems &…the reciprocal process of change”

- Economics definition (Noorgard, 1984)

The systems of chemicals and energy provision have co-evolved and are co-evolving

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Technological lock-in

Technological Lock-in

Increasing returns to the adoption of technologies may give rise to 'lock-in' of incumbent technologies, preventing the adoption of potentially superior alternatives.

(Arthur, 1989)

Carbon Lock-in

"industrial economies have become locked into fossil-fuel based energy systems…through combined interactions among technological systems and governing institutions"

(Unruh, 2000)

Interactions between the co-evolving petrochemical and energy regimes contributes to carbon lock-in

Trends in Fuels

Current relevant energy trends:

- Oil price remains high ($80 yesterday)
- Gas demand increasing
- Global move to heavier crudes
- Rising coal use cannot be ignored
- Biofuels are growing rapidly in US & EU
- Uncertainties over security of supply
- Renewable economies still a future dream

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Reminiscent of the 1930s

- Recent warnings of UK 'Peak Coal'
- Middle East oil yet to be discovered
- Lobbying for bioethanol and biochemicals (chemurgy)
- Geopolitical security of supply concerns

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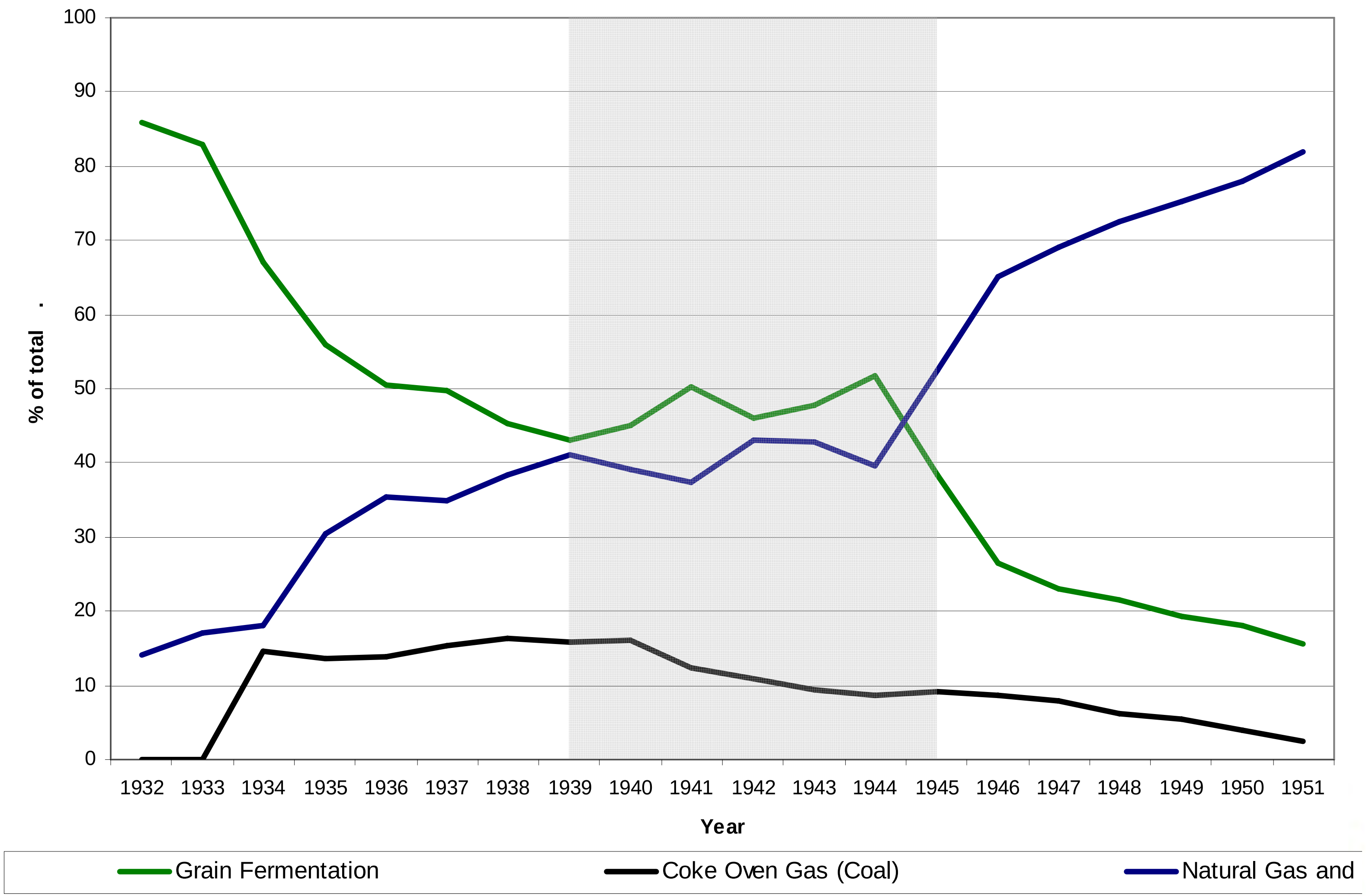
US Ethanol Production 1932-1961



This has now reversed again

Spitz, 1988

Lessons –

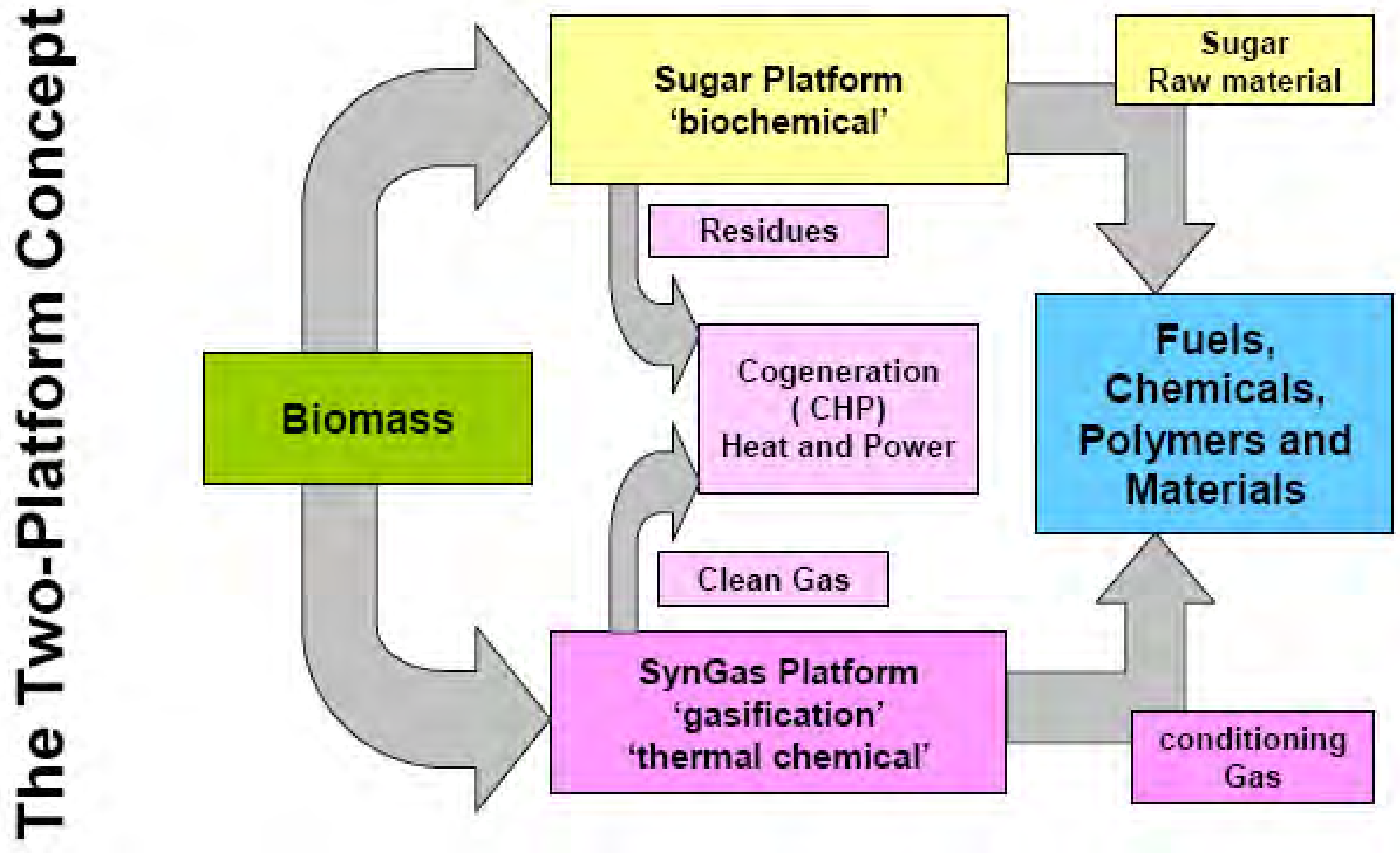
Broad changes can occur quite rapidly under conditions of stress

Lock-in of the petroleum-chemical complex

Need to address all parts of the system

Will there be chemical by-products of sustainable energy?

Biorefineries



Kamm, 2006

Implications for Policy

Current policy focus:

- EU targets for biofuels as a % of all motor fuels ☹
  - 10% by 2020
- Carbon pricing ☺ 😐
- US targets for Renewable Raw Materials 😐
  - 10% by 2020
  - 50% by 2050

Role for chemists to develop bulk materials from the new bioplatforms

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BIOPOL

Assessing the status (technical, socio-economic, environmental, policy, and deployment) of innovative BIOrefinery concepts and the implications for agricultural and forestry POLicy.

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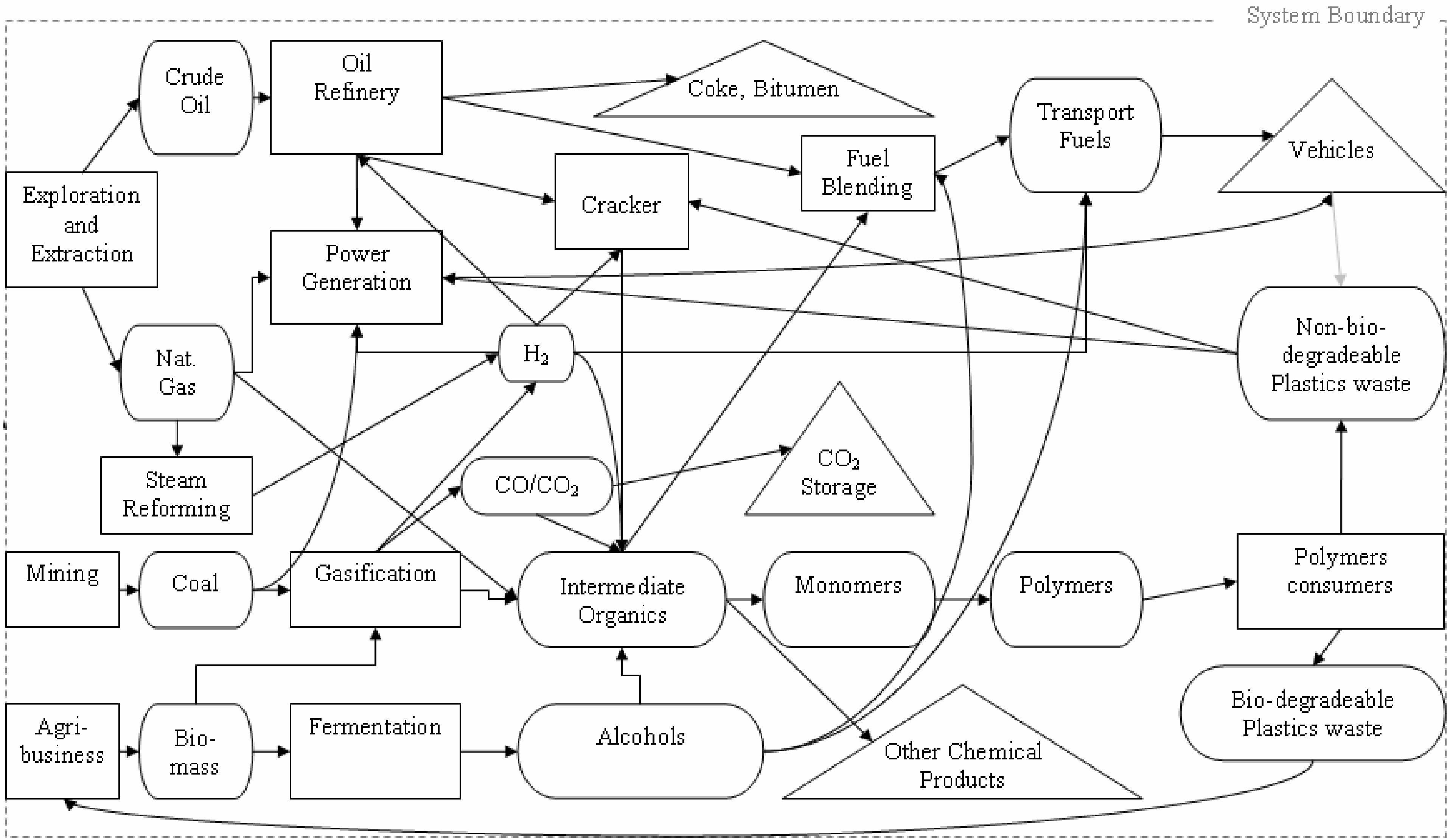
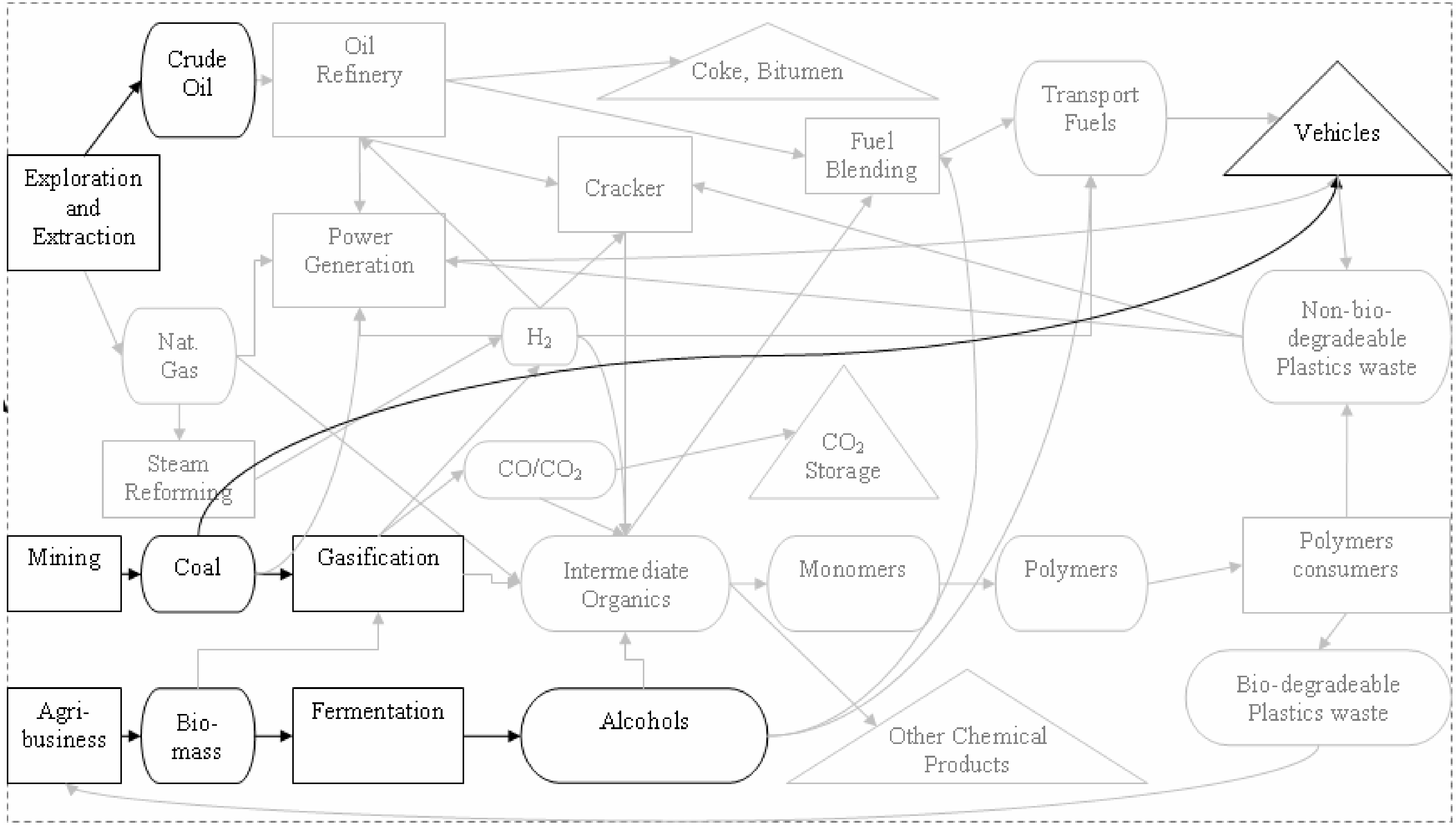
Energy-Chemicals System

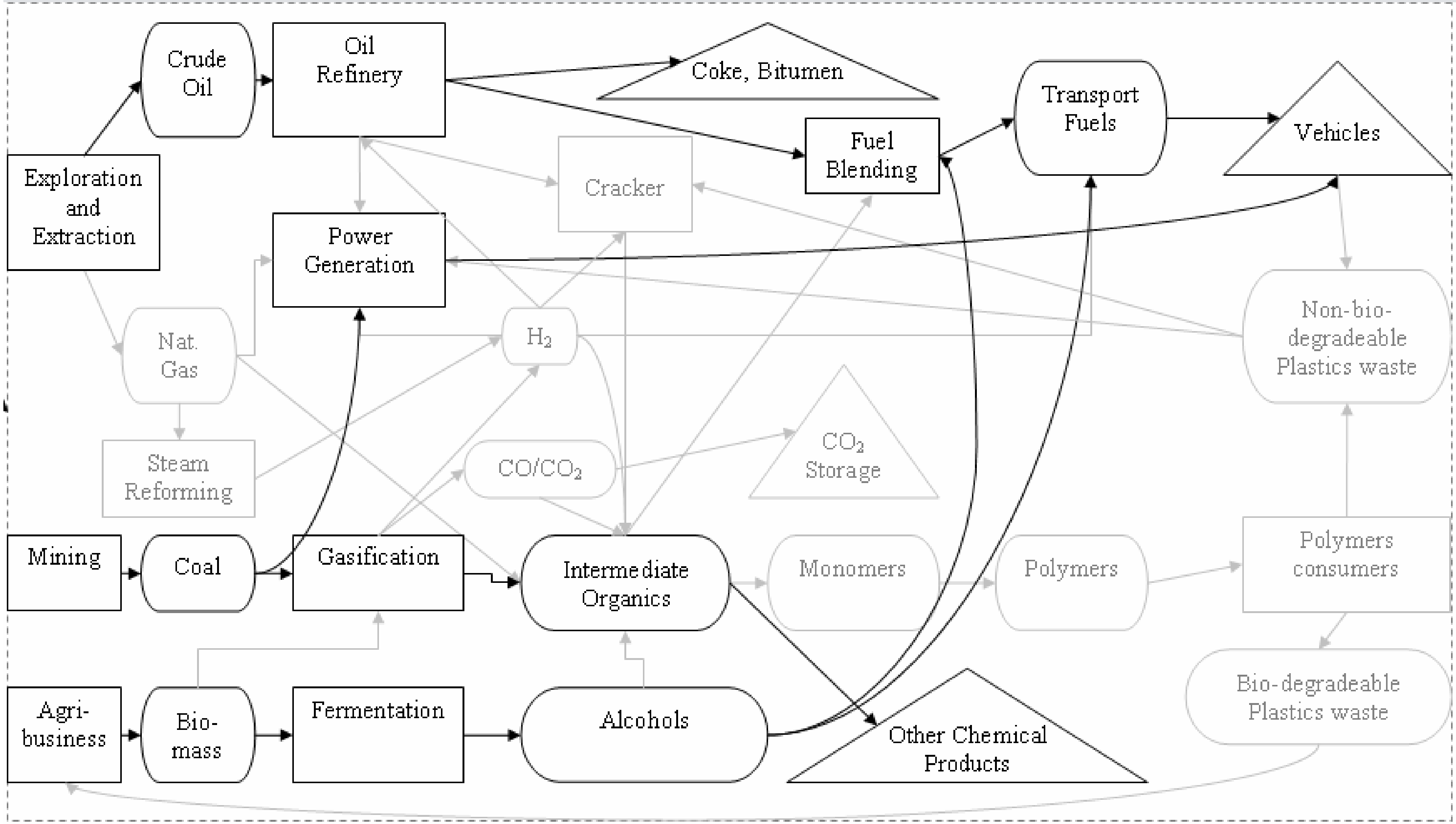


1850



Crude Oil
Oil Refinery
Coke, Bitumen
Transport Fuels
Vehicles
Exploration and Extraction
Cracker
Fuel Blending
Power Generation
Nat. Gas
H_2
Non-bio-degradeable Plastics waste
Steam Reforming
CO/CO_2
CO_2 Storage
Mining
Coal
Gasification
Intermediate Organics
Monomers
Polymers
Polymers consumers
Bio-degradeable Plastics waste
Agri-business
Bio-mass
Fermentation
Alcohols
Other Chemical Products

1900



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Agri-business
Bio-mass
Fermentation
Alcohols
Other Chemical Products
Bio-degradeable Plastics waste

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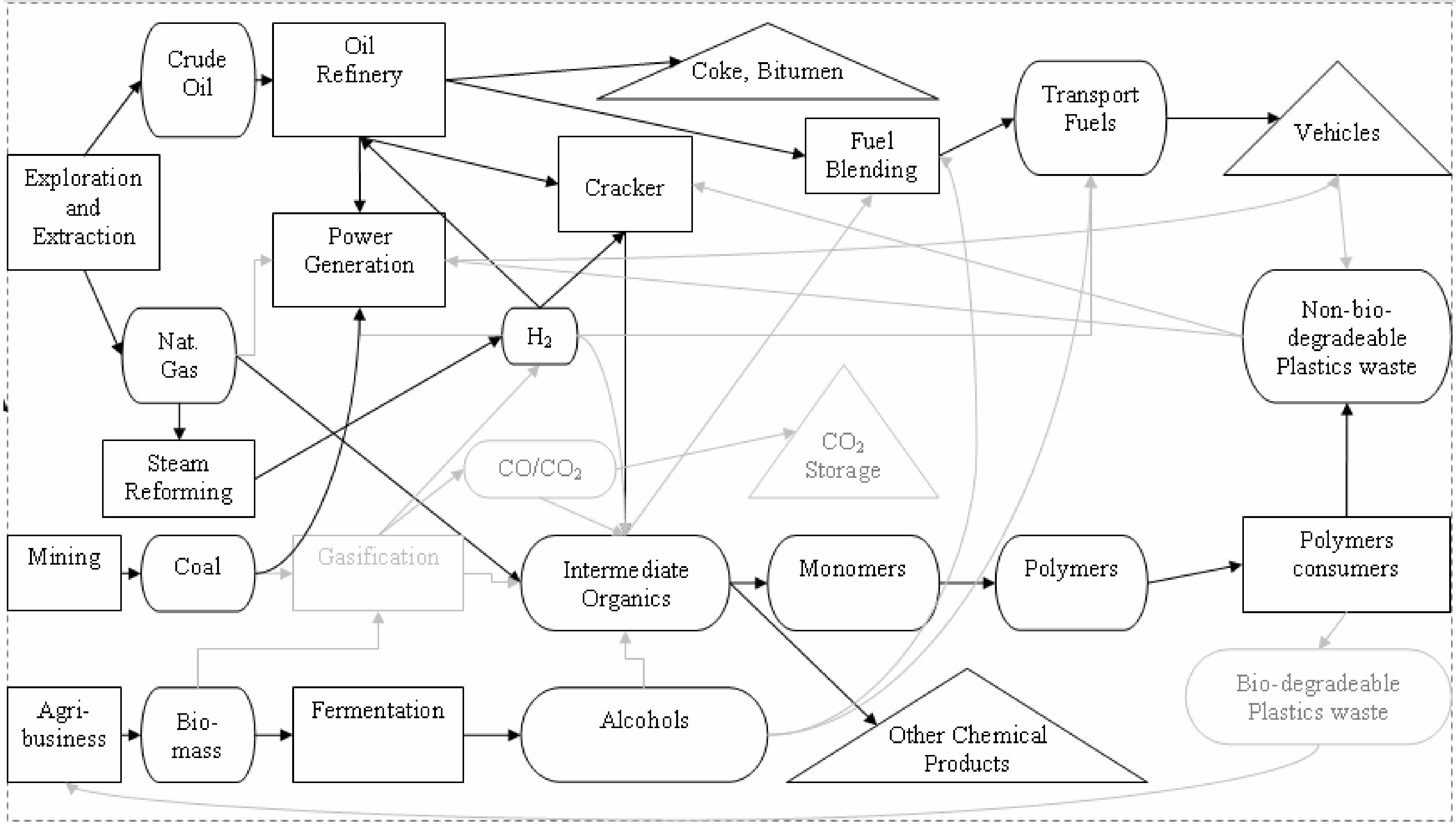
1950



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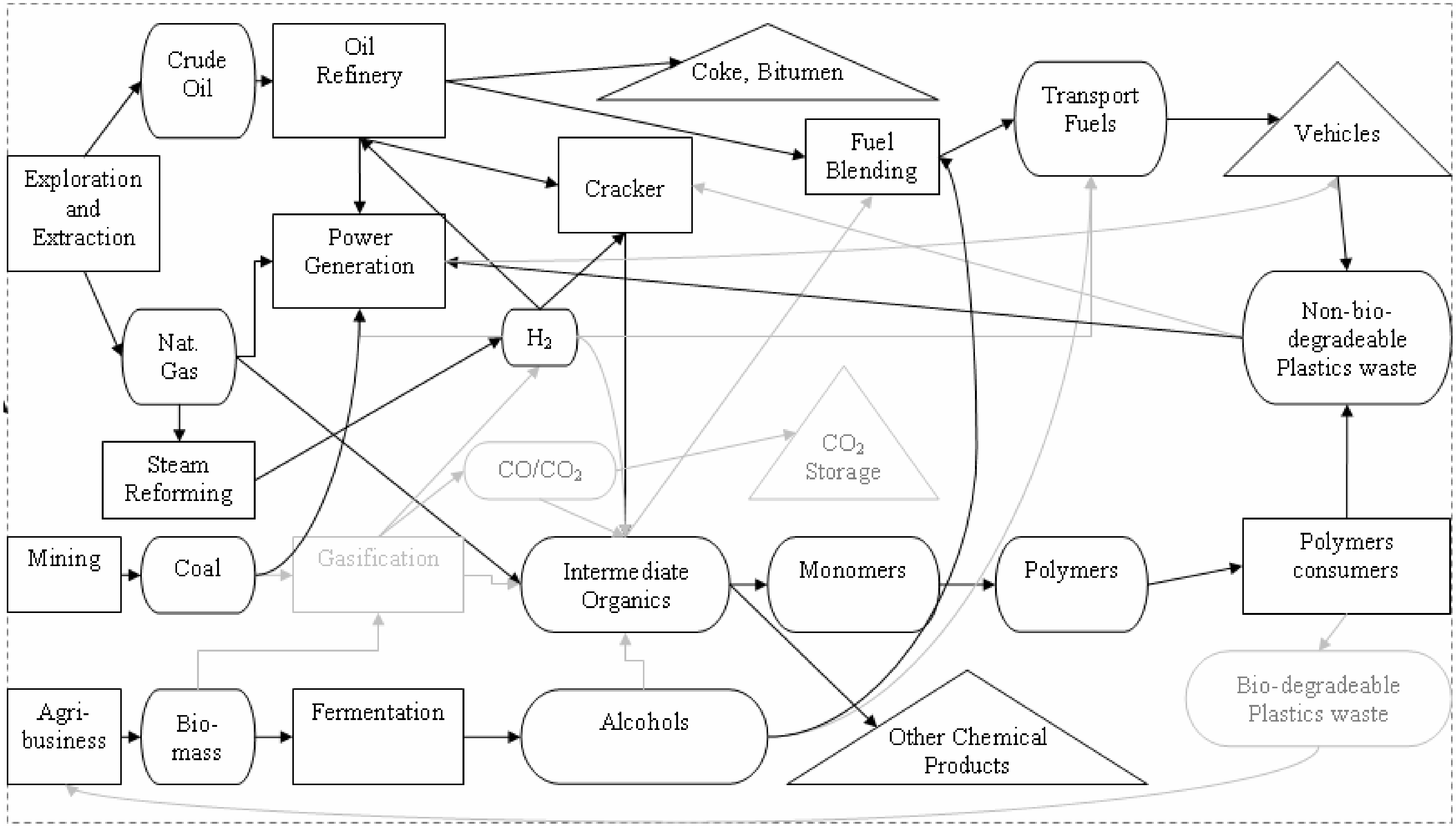
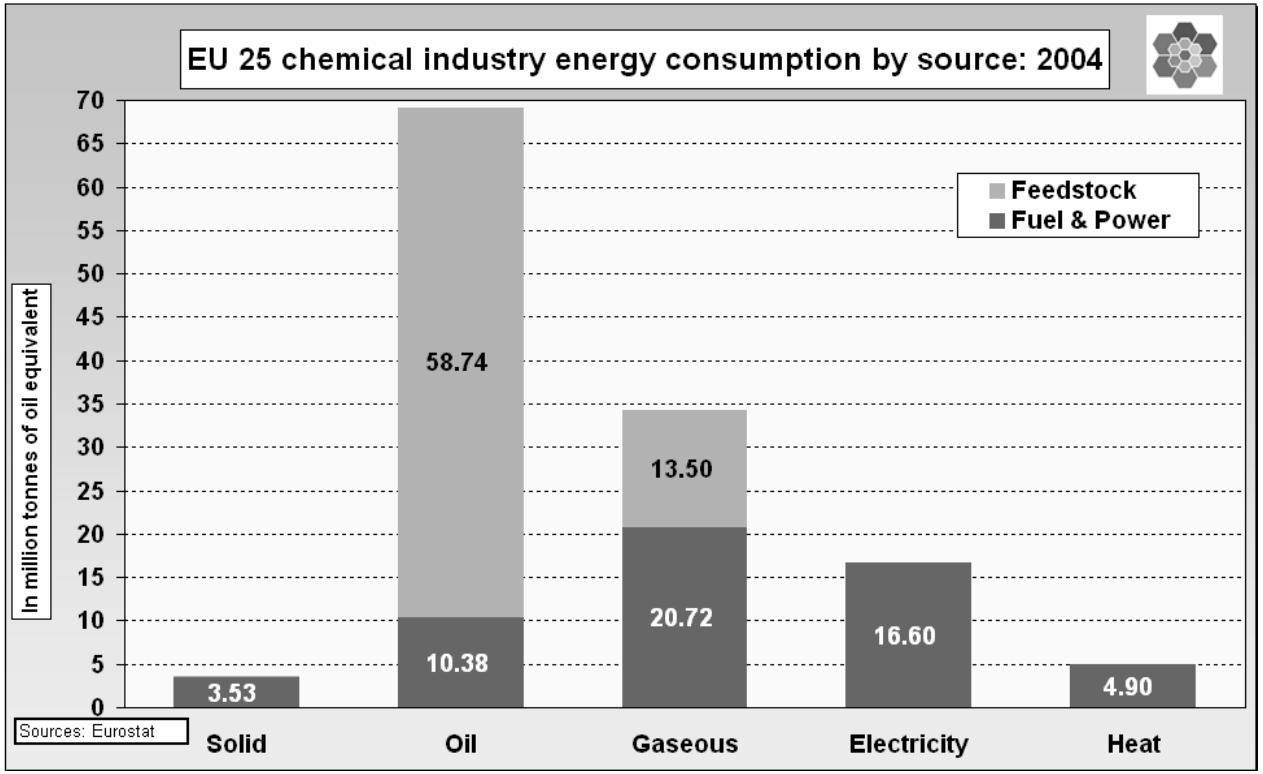
Today



Energy and Non-energy Use

EU Chemical sector is the biggest energy user amongst manufacturing industries



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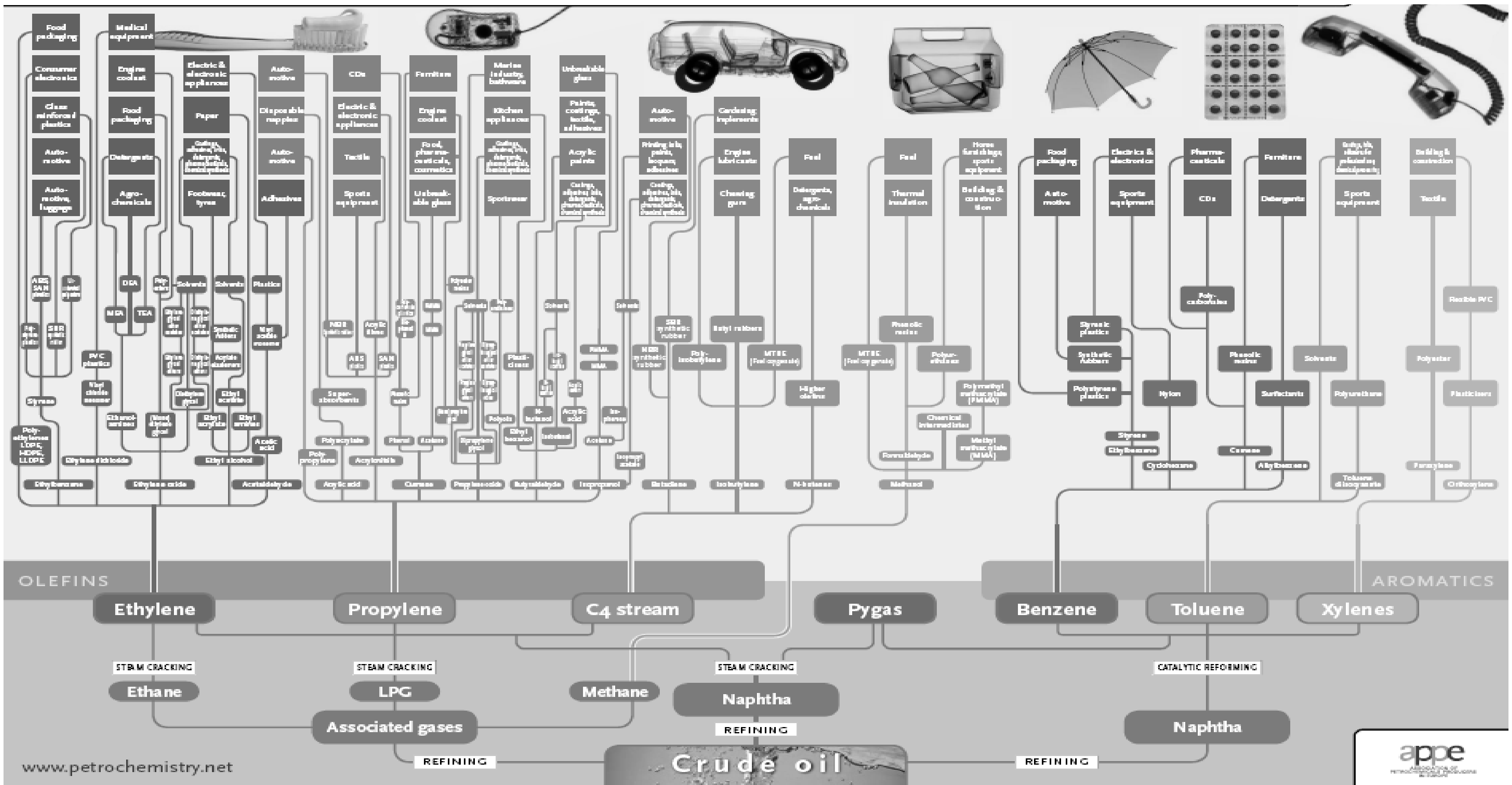
The Bulk Chemical Industry



Highly integrated, little room for small players