The Bio-Economy
Where Do Materials Fit?

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Head of Materials
NNFCC

June 2013

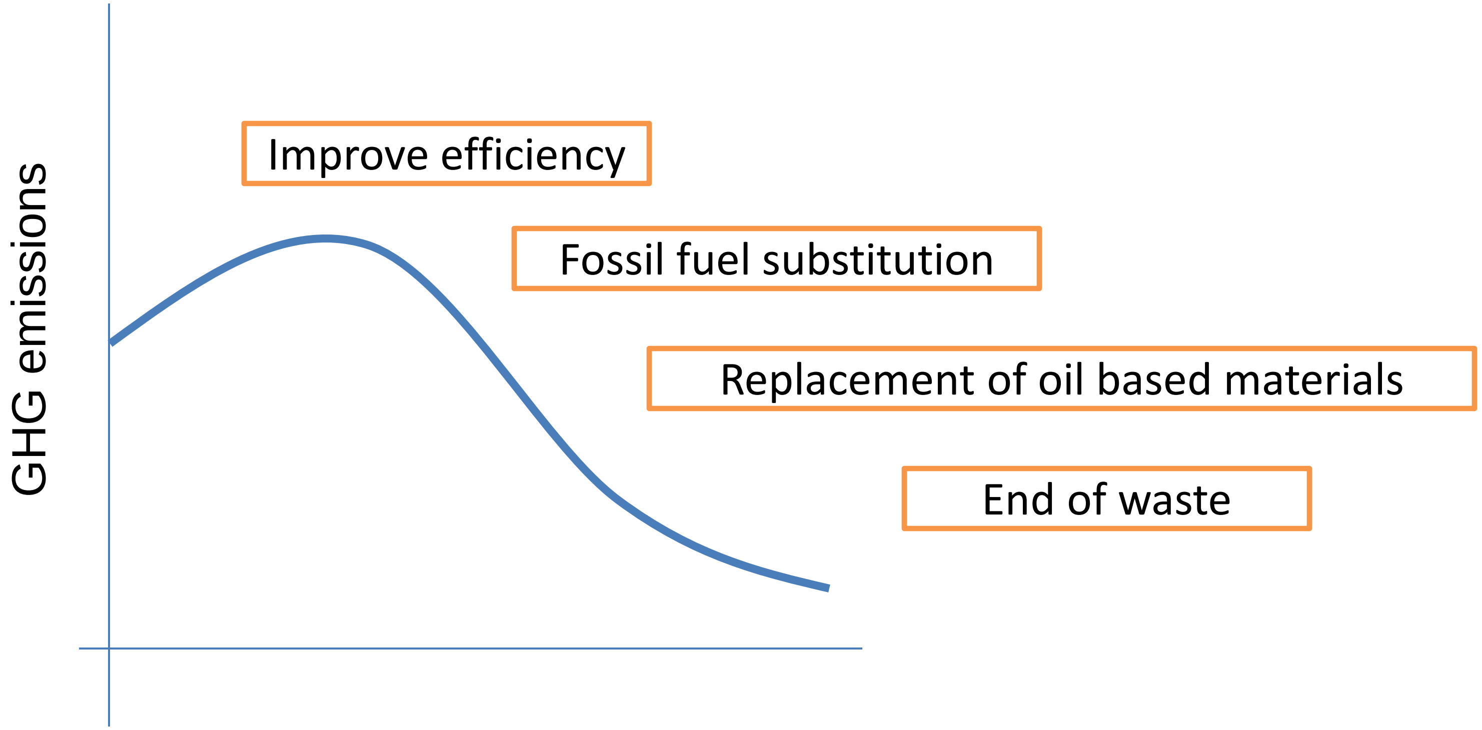
The Bio Economy

The aggregate set of economic operations in a society that use the latent value incumbent in biological products and processes to capture new growth and welfare benefits for citizens and nations.

These benefits are manifest in product markets through productivity gains, enhancement effects and substitution effects, additional benefits derive from more eco-efficient and sustainable use of natural resources to provide goods and services to an ever growing global population.

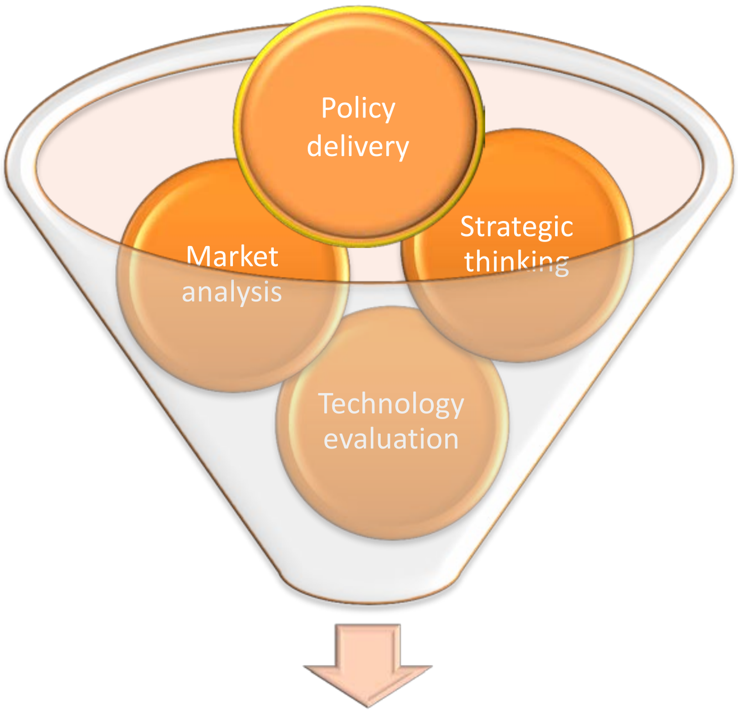
Source: OECD

Towards a low carbon economy



Source: Adapted from 'GHG Emission reductions with Industrial Biotechnology': Assessing the Opportunities, WWF & Novozymes

The UK's national centre for renewable energy, fuels, chemicals and materials

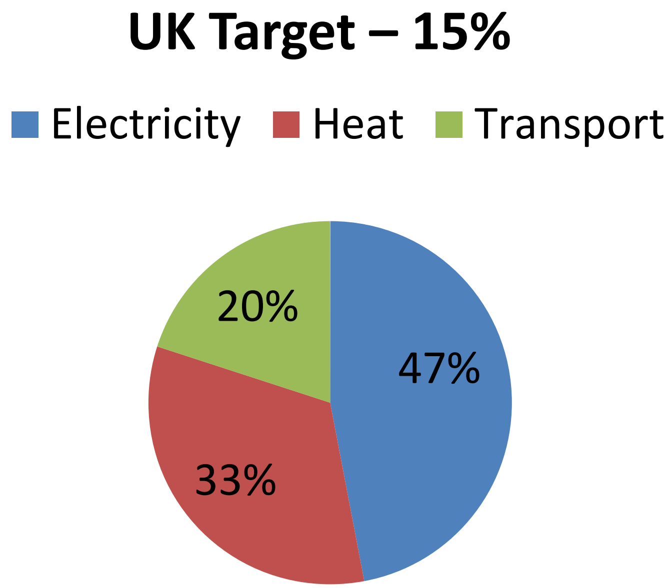


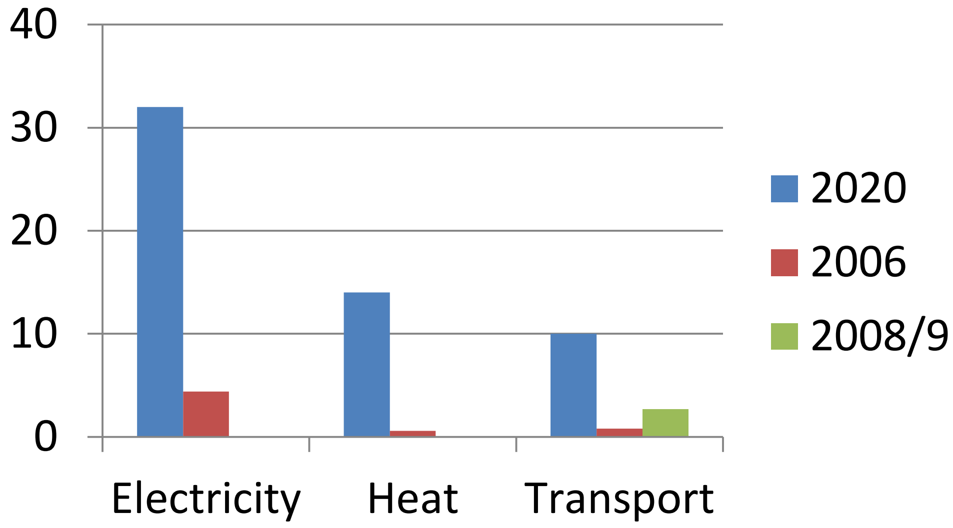
bio-economy development

EU Renewable Energy Directive

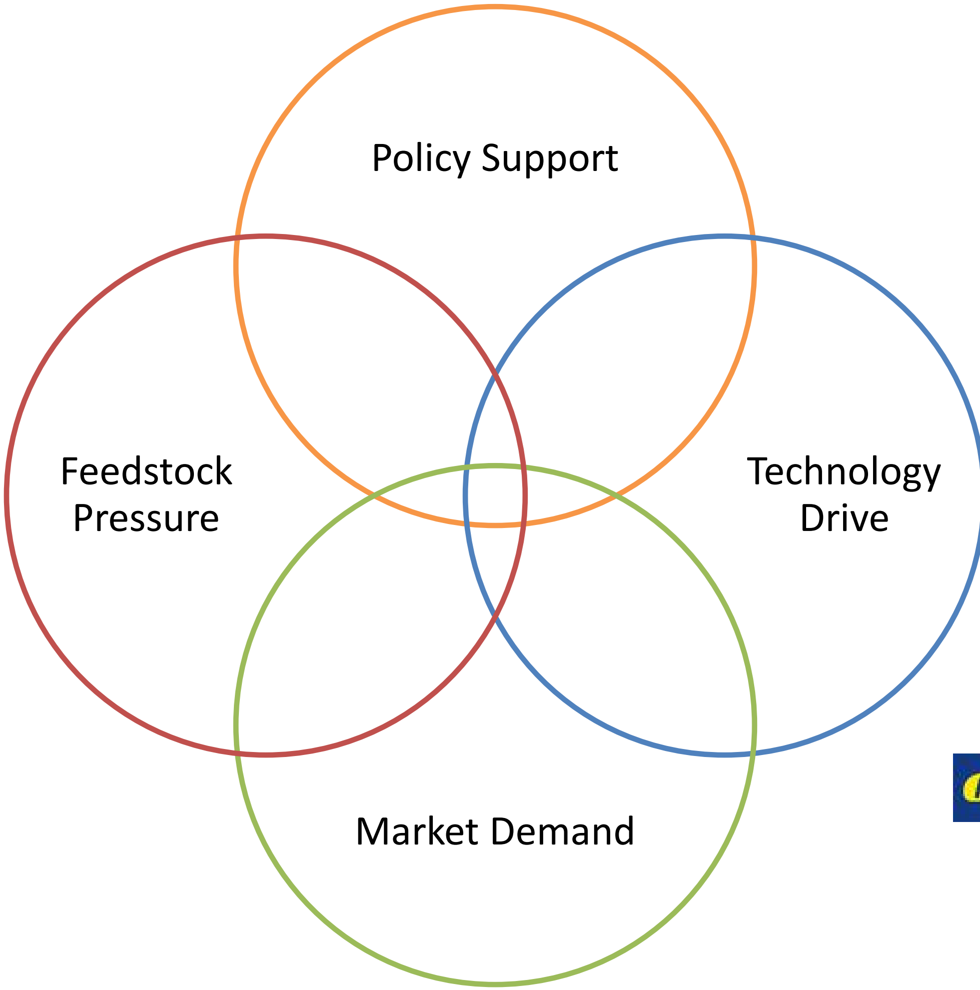
European Governments focussed on Bioenergy

Mandatory EU target of 20% renewable energy in overall energy consumption by 2020





Interest in bio-based chemicals - Why now?



DOW

DSM

BASF The Chemical Company

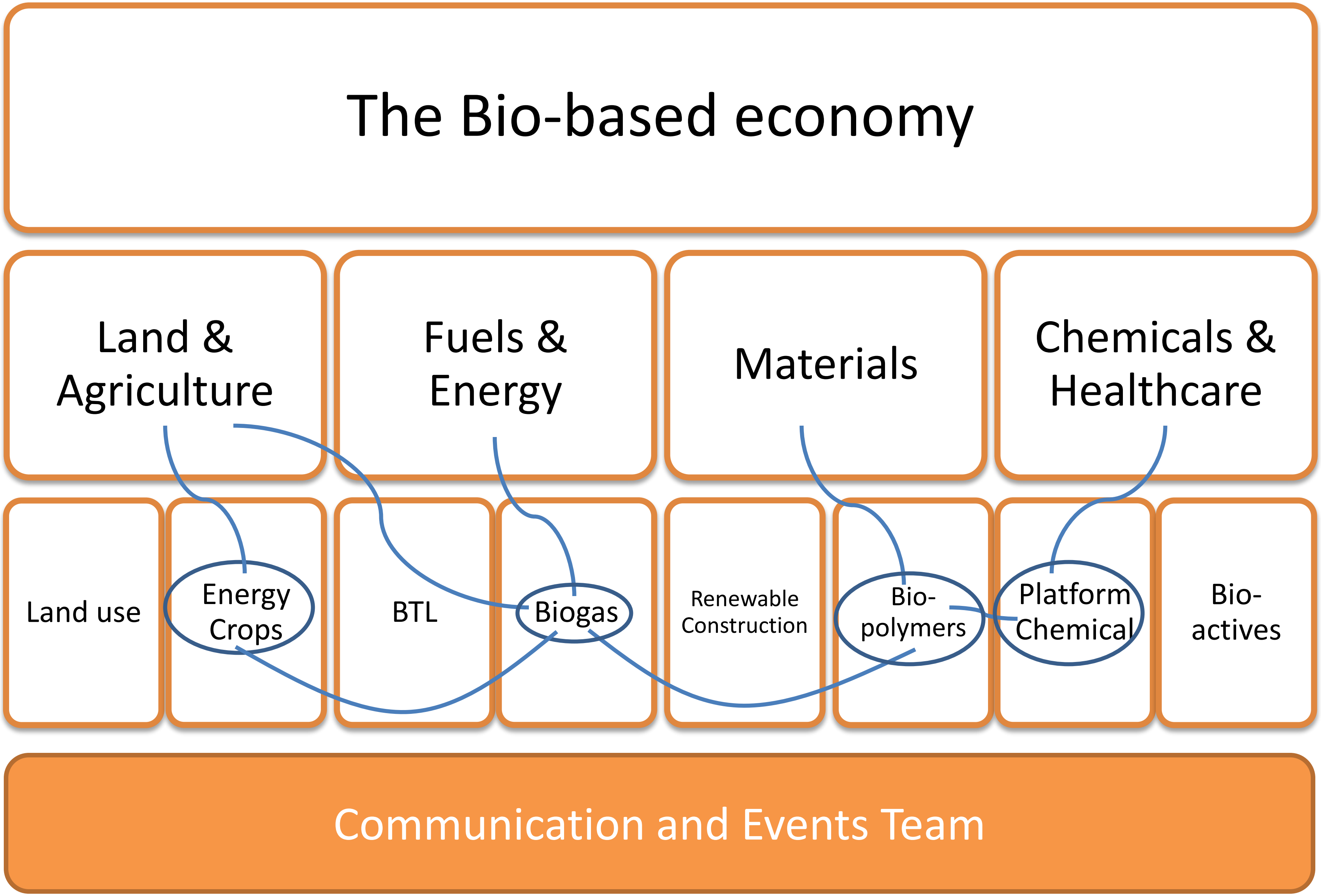
Braskem

PURAC biomaterials

DUPONT

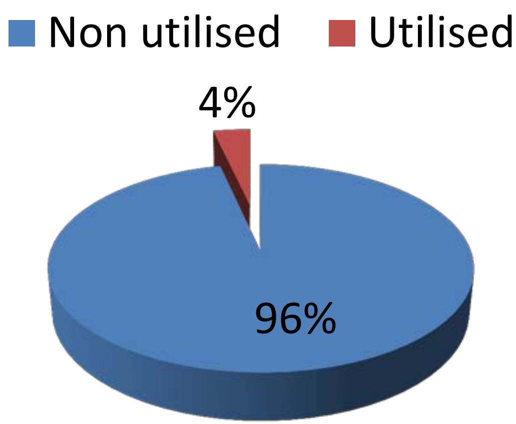
GOODYEAR

SOLVAY


The Bio-based economy
Land & Agriculture
Fuels & Energy
Materials
Chemicals & Healthcare
Land use
Energy Crops
BTL
Biogas
Renewable Construction
Bio-polymers
Platform Chemical
Bio-actives
Communication and Events Team

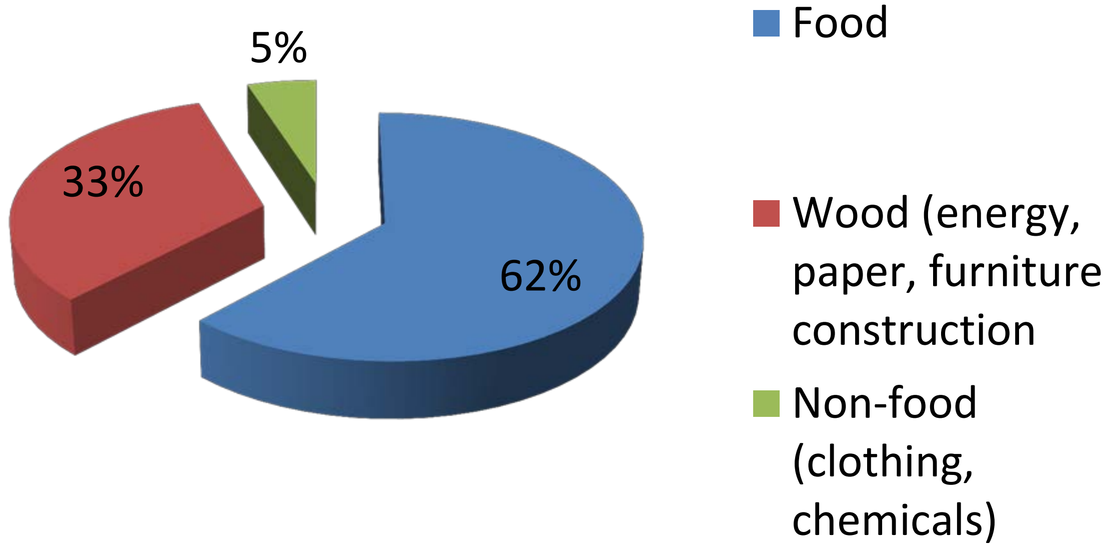
World biomass production

170 trillion tonnes



Biomass utilised by humans

6 billion tonnes



Source: Product overview and market projection of emerging bio-based plastics PRO-BIP 2009, Utrecht University

Ecosystem Services

- Provisioning
  - Food, water, energy, chemicals
- Regulating
  - Control of climate, control of disease
- Amenity/cultural
  - Recreation, spiritual
- Supporting
  - Biogeochemical cycles – C and N, Crop pollination, biodiversity

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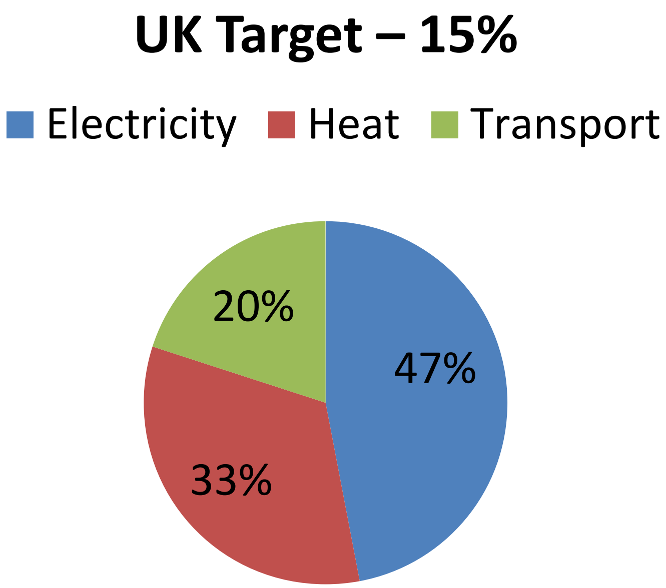
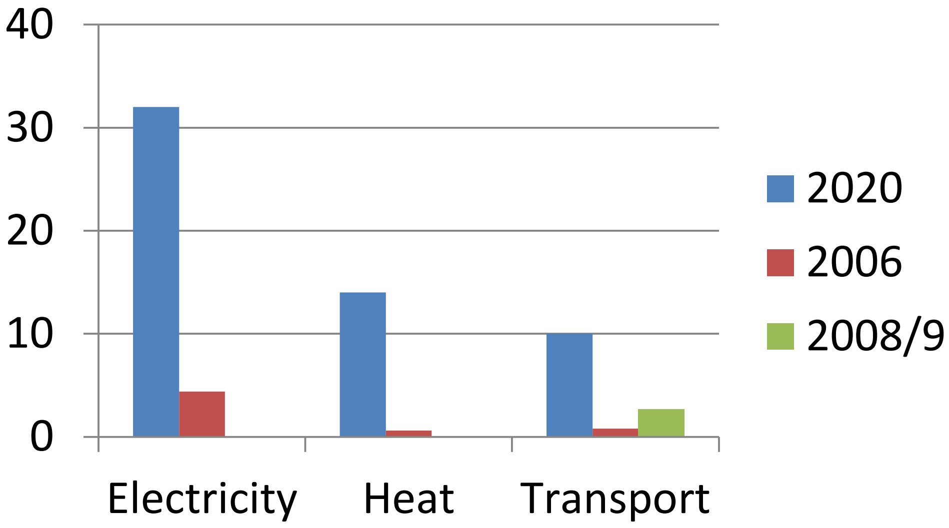
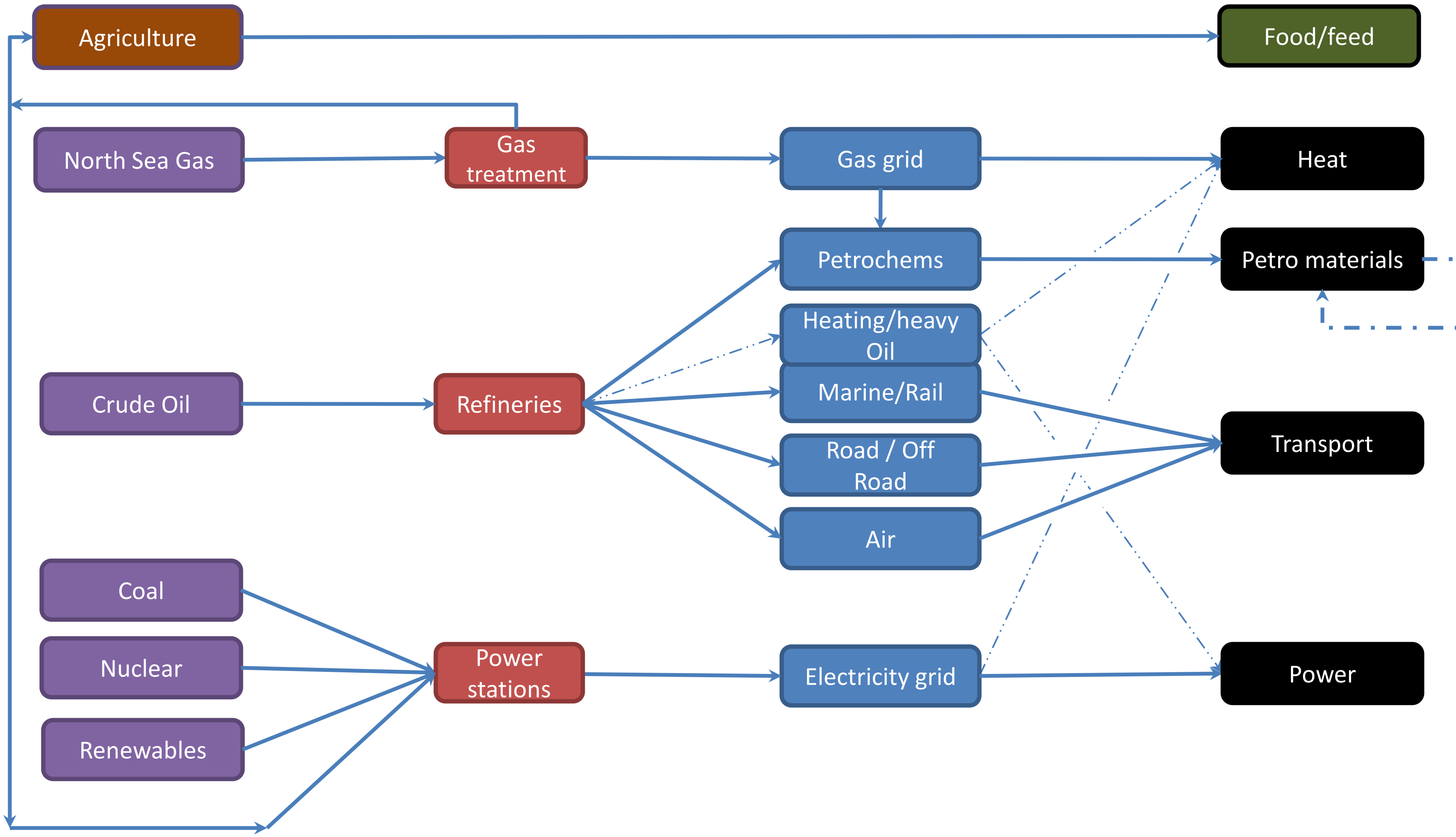
Renewable Energy Directive

Mandatory EU target of 20% renewable energy in overall energy consumption by 2020

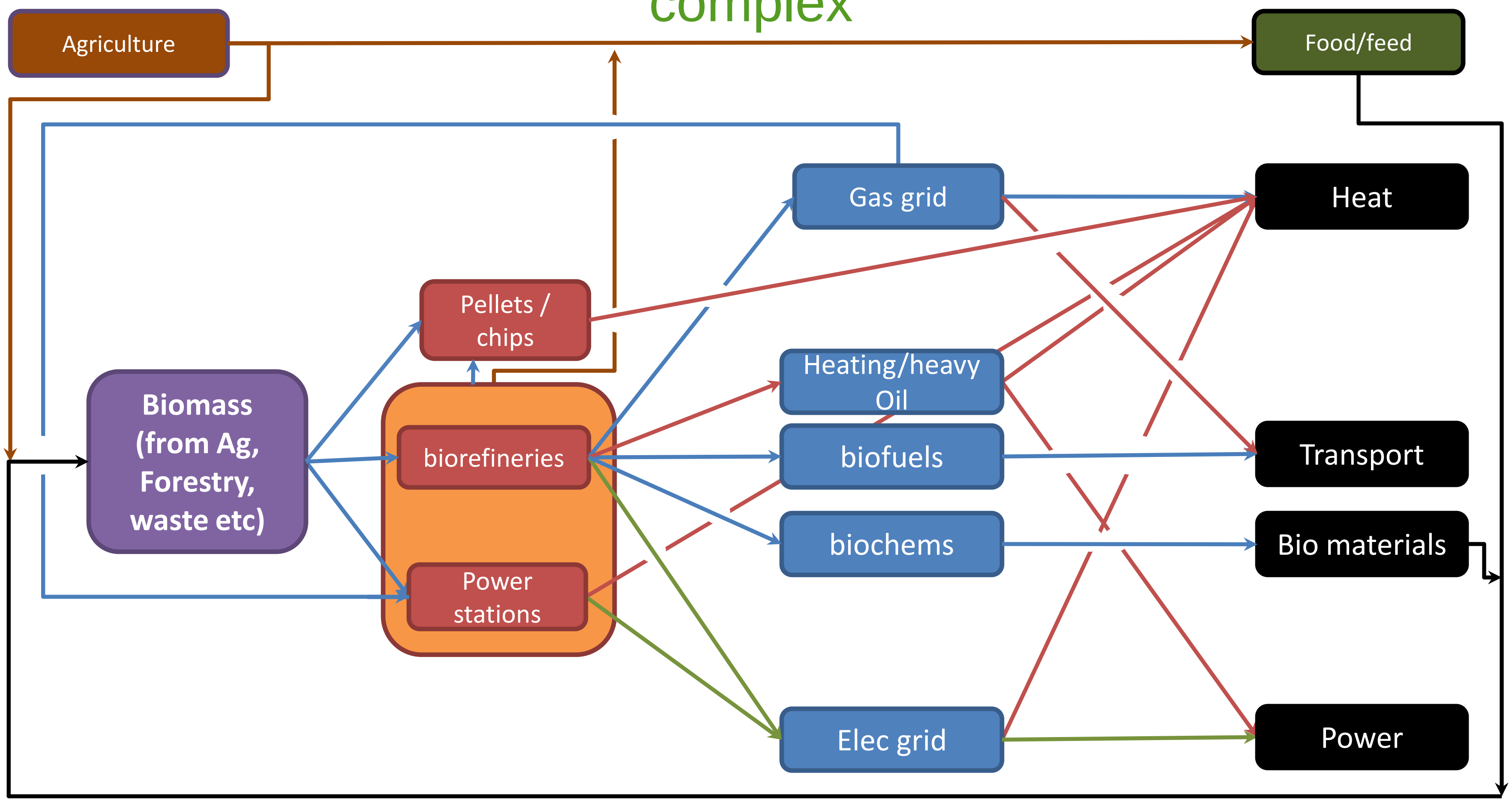




Current energy supplies are compartmentalised – very little integration across sectors

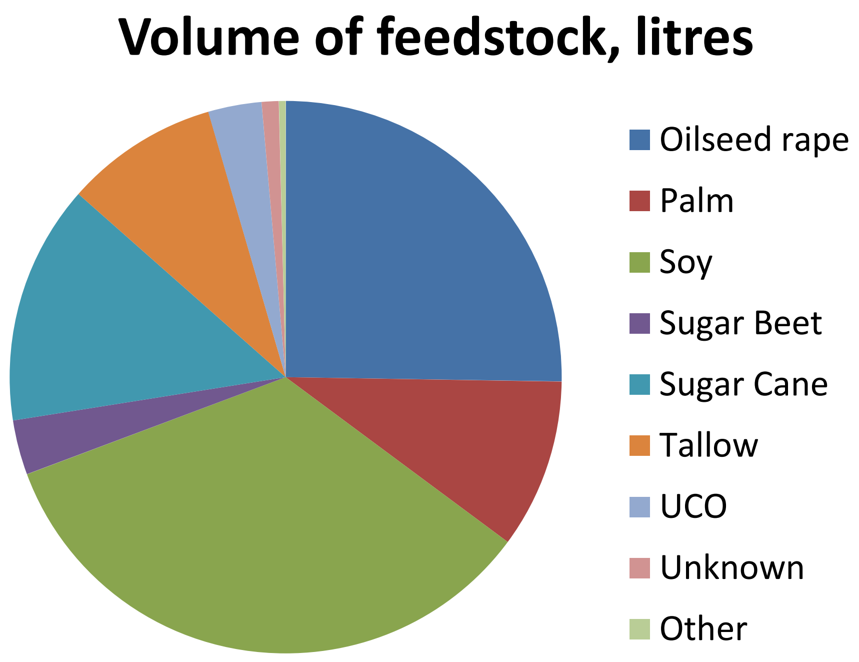


Biomass can serve all sectors – integrated production of heat, power, fuels, and chemicals including recyling of bio-based chemicals and food/feed wastes. System is complex



RTFO Year 1

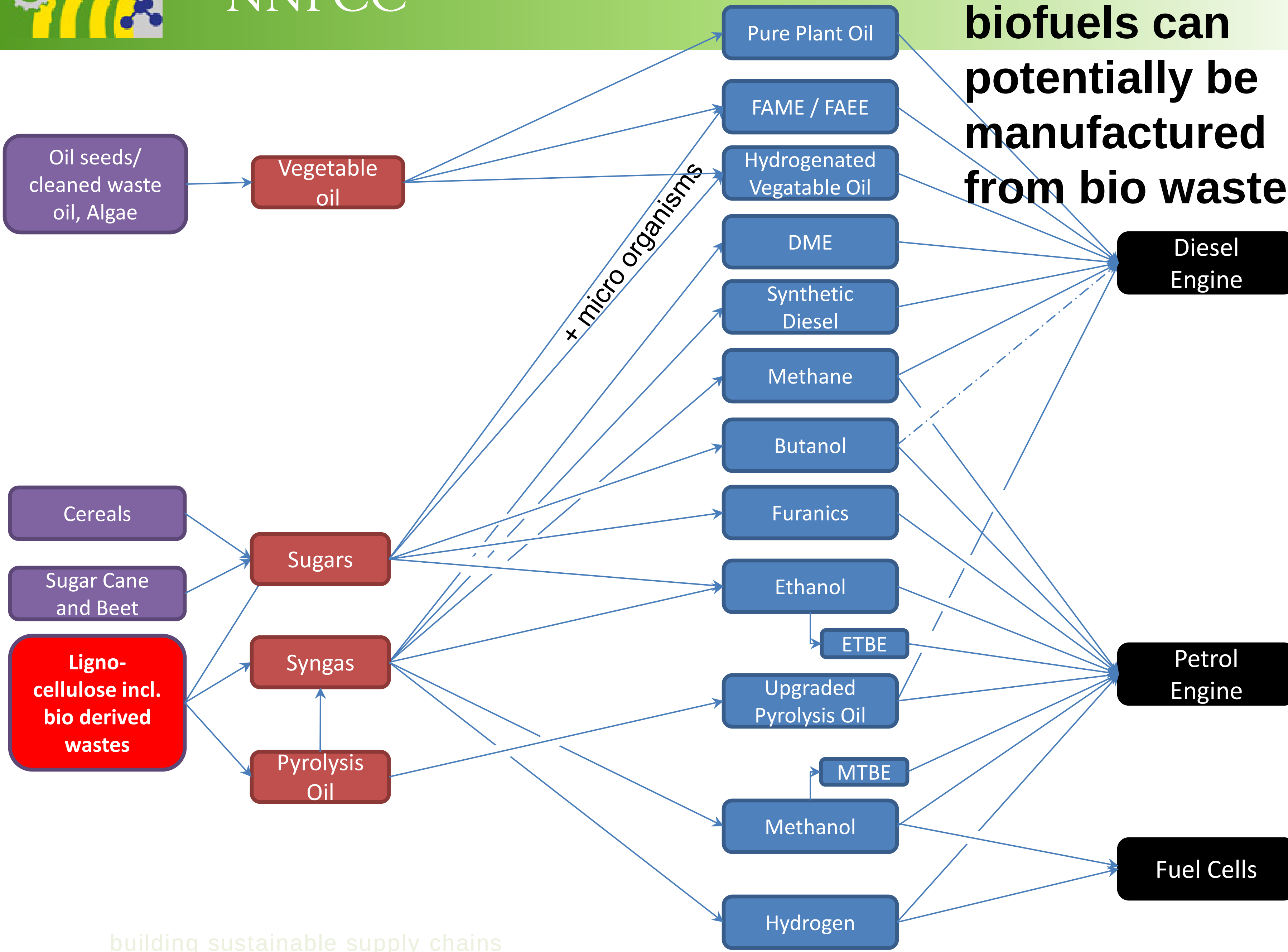
Biofuel supplied - 1,284m litres of fuel, 46% average GHG savings



Diesel Blend - Fatty acid methyl ester (FAME)

Petrol Blend - Ethanol

A wide range of biofuels can potentially be manufactured from bio wastes

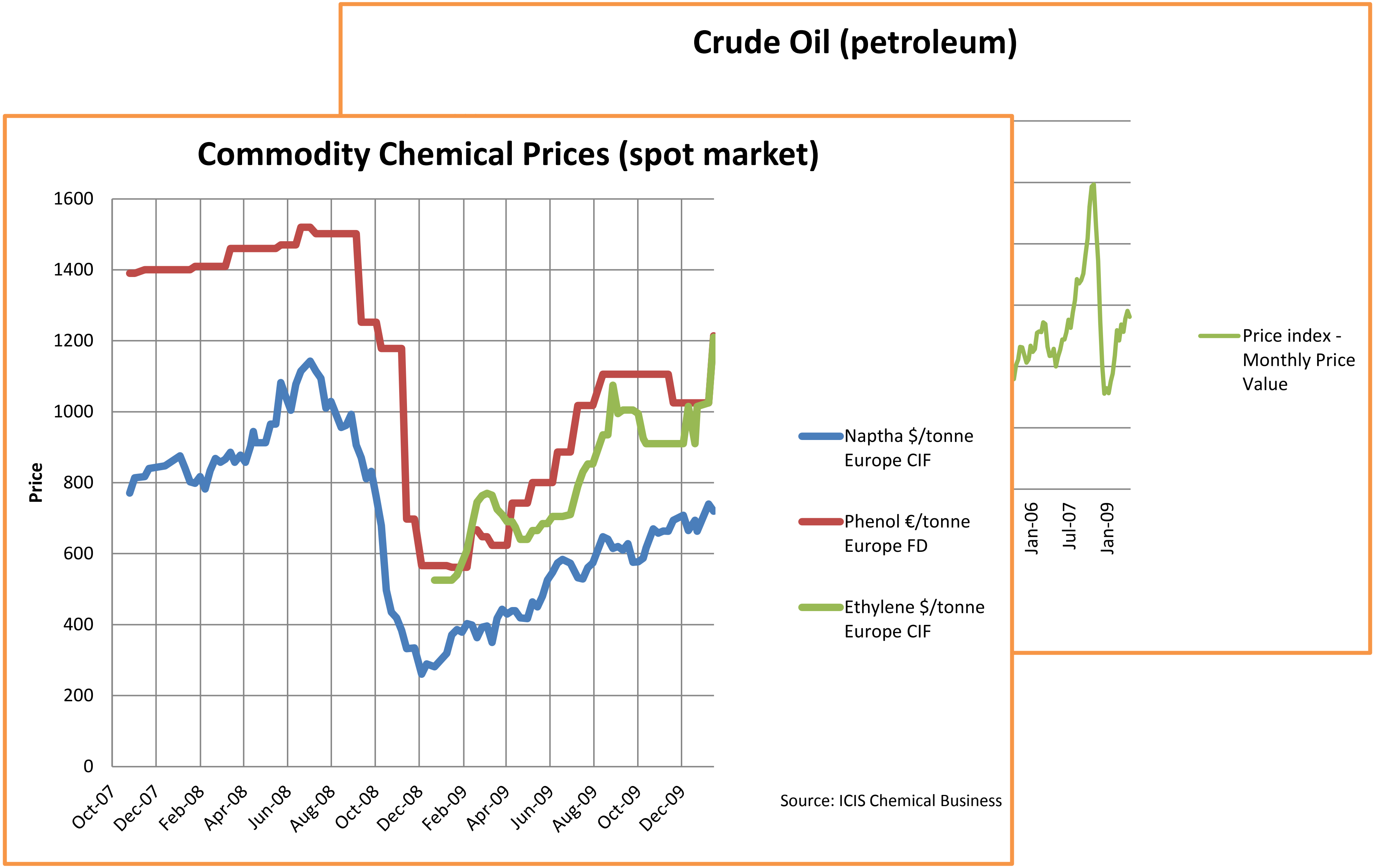


Bio-materials

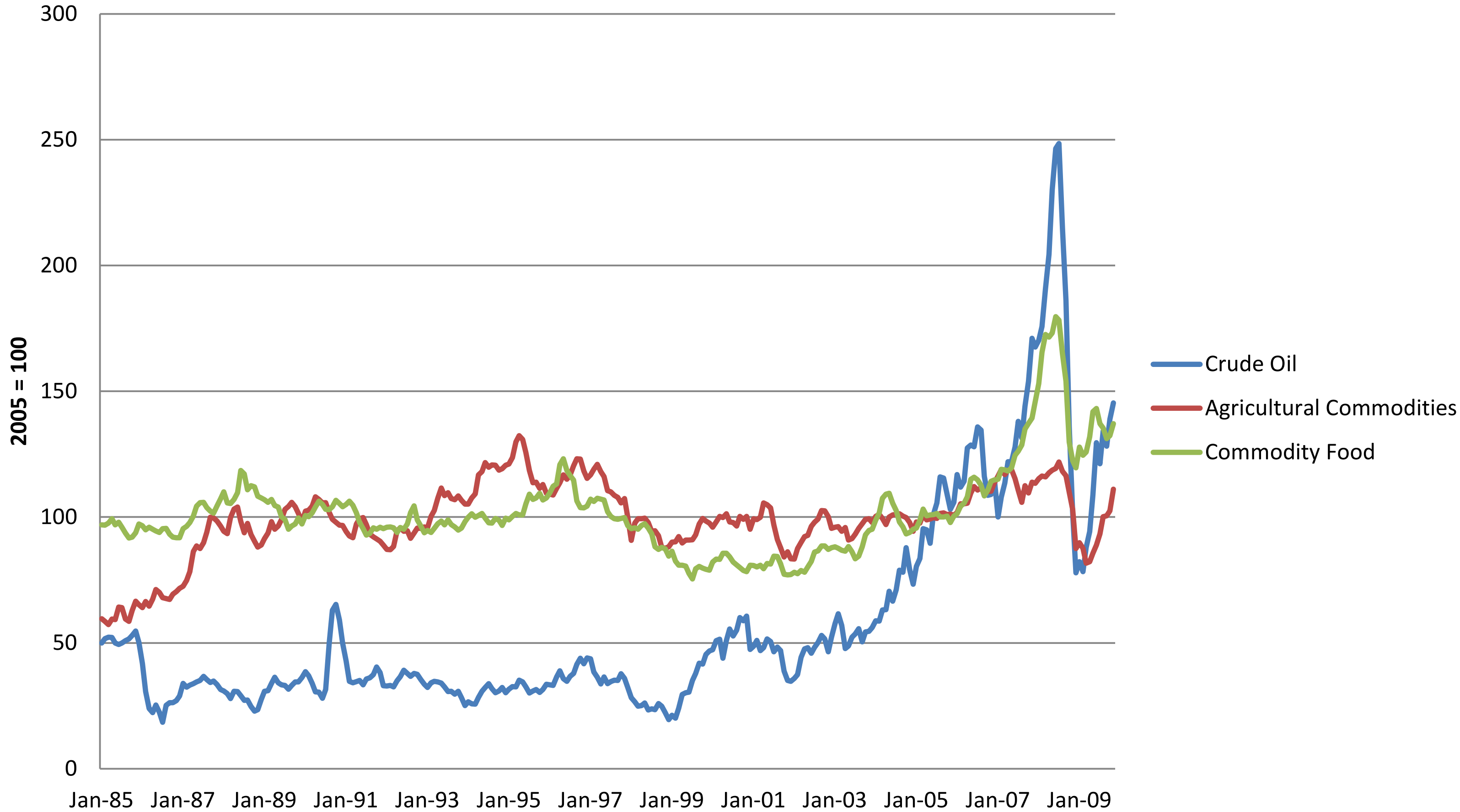
- Global biofuel markets supported by subsidies or mandated targets
- No financial market support schemes for bio-materials
- Therefore
  - Evidence for sector interest?
  - Evidence for sector activity?
  - What factors are driving the development of bio-materials?

Interest from chemical producers

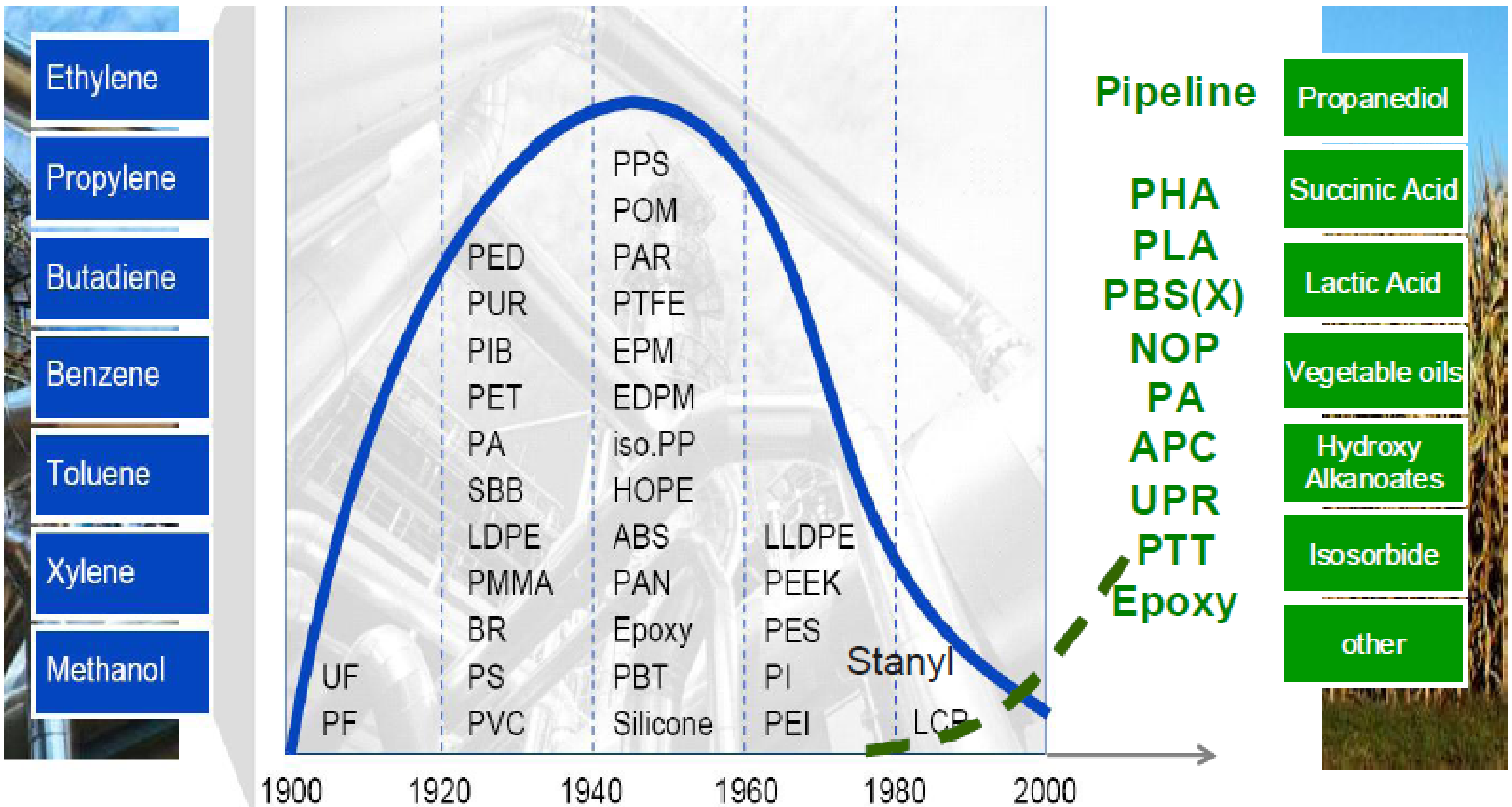
- Reduce exposure to crude oil prices
- Reduce process energy costs (industrial biotechnology)
- Potential for novel functionality
- Reacting to supply chain demands
- Green premium???


Crude Oil (petroleum)
Jan-06
Jul-07
Jan-09
Price index - Monthly Price Value
Commodity Chemical Prices (spot market)
Price
1600
1400
1200
1000
800
600
400
200
0
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Aug-08
Oct-08
Dec-08
Feb-09
Apr-09
Jun-09
Aug-09
Oct-09
Dec-09
Naptha $/tonne Europe CIF
Phenol €/tonne Europe FD
Ethylene $/tonne Europe CIF
Source: ICIS Chemical Business

Crude oil (petroleum) and Agricultural Commodity , Price index

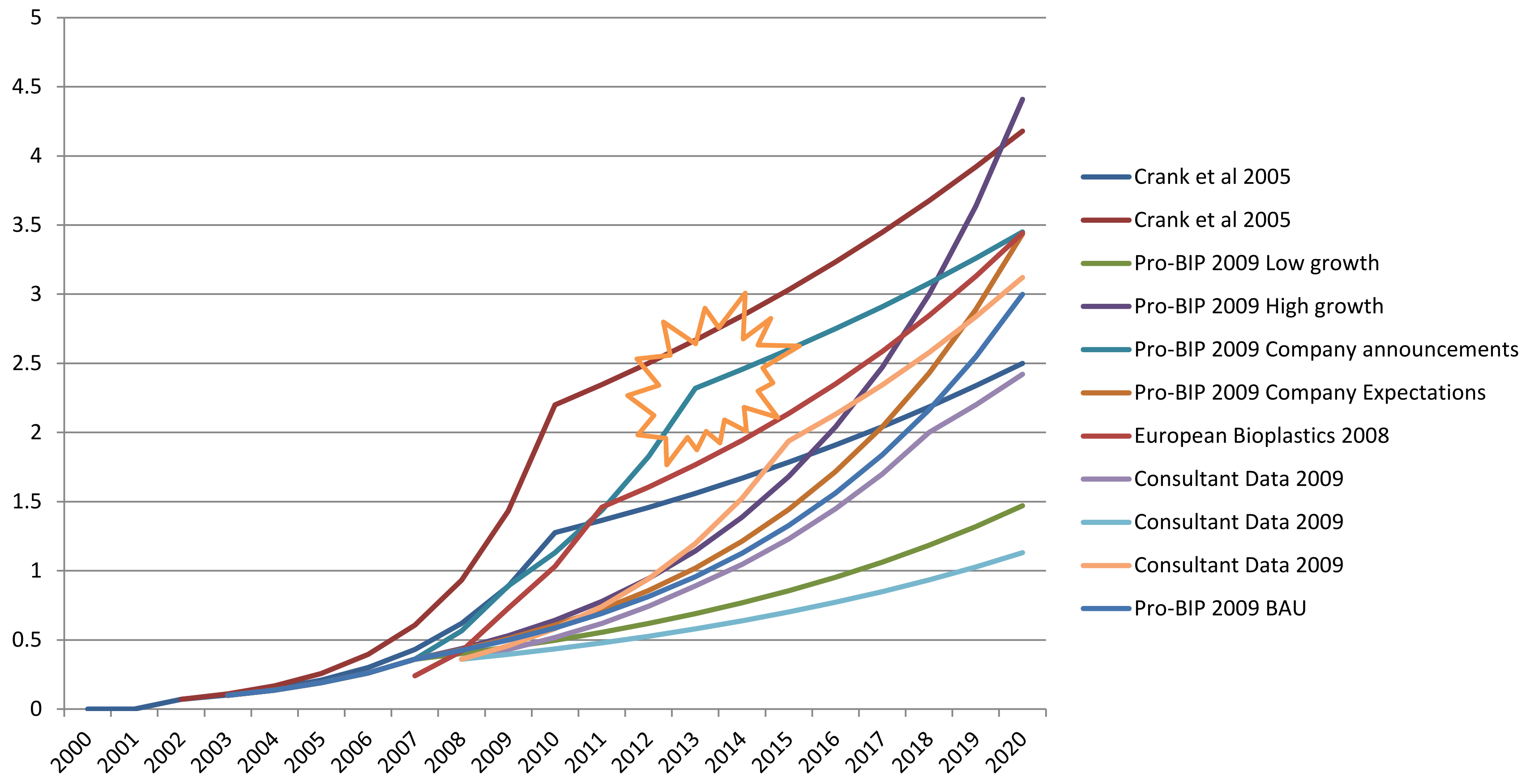


Source: International Monetary Fund

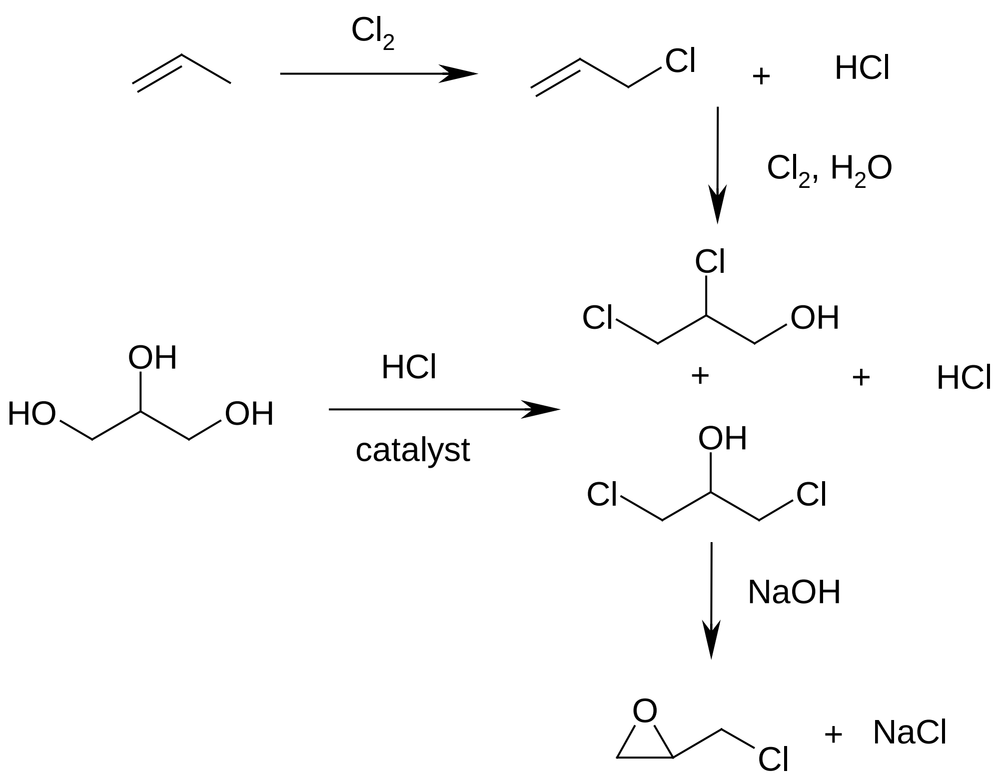


Biobased will take a significant part of oil based chemistry

Global Bio-based plastic Capacity Growth



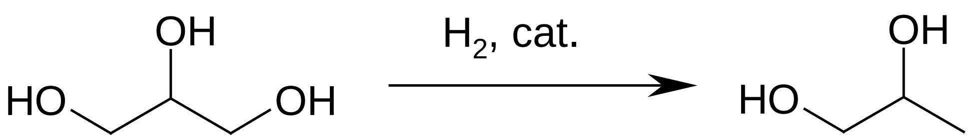
Epichlorohydrin from glycerol



- Solvay Epicerol® process
- Demonstration - Tavaux, France

- Commercial
- Plant location - Map Ta Phut
- Capacity 100,000 tonnes
- Glycerine demand – 120,000 tonnes
- Start Up - Q1 2012

Propylene glycol from glycerol



- ADM – Propylene glycol
- Plant location – Decatur US
- Capacity 100,000 tons

DOW Chemical Company - Status unknown
Huntsman Corporation – Status unknown
Cargil/Ashland – Capacity 65,000 tonnes, location Europe

Growth in US ethanol

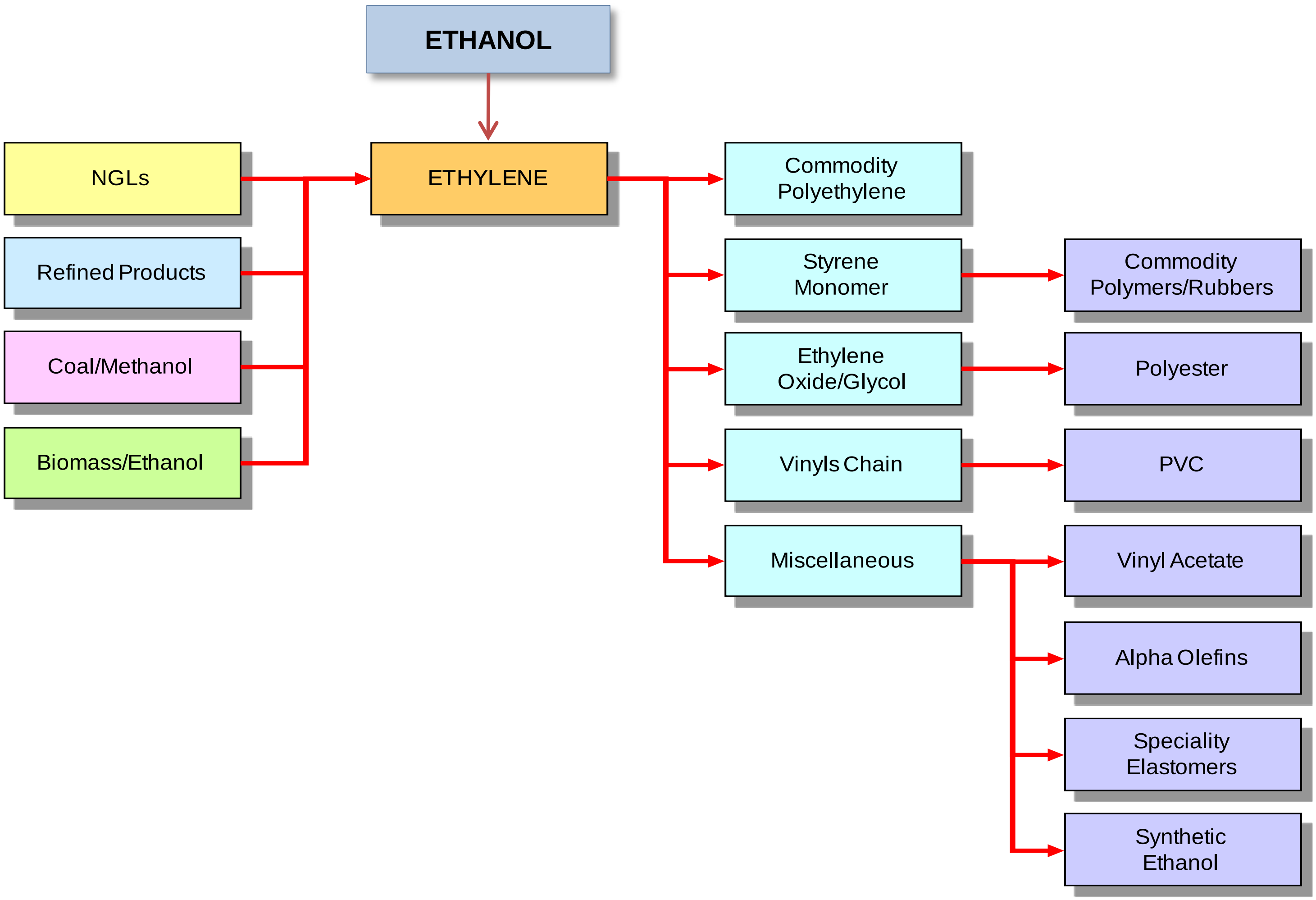
Year	January 1999	January 2000	January 2001	January 2002	January 2003	January 2004	January 2005	January 2006	January 2007	January	January
Total Ethanol Plants	50	54	56	61	68	72	81	95	110		
Ethanol Production Capacity	1701.7 mgy	1748.7 mgy	1921.9 mgy	2347.3 mgy	2706.8 mgy	3100.8 mgy	3643.7 mgy	4336.4 mgy	5493.4 mgy	7	
Plants Under Construction/ Expanding	5	6	5	13	11	15	16	31	76		
Capacity Under Construction/Expanding	77 mgy	91.5 mgy	64.7 mgy	390.7 mgy	483 mgy	598 mgy	754 mgy	1778 mgy	5635.5 mgy		
States with Ethanol Plants	17	17	18	19	20	19	18	20	21		

* operating plants
** 12,475.4 mgy capacity including idled capacity

Country	Millions of Gallons
USA	9000.0
Brazil	6472.2
European Union	733.6
China	501.9
Canada	237.7
Other	128.4
Thailand	89.8
Colombia	79.29
India	66.0
Australia	26.4
Total	**17,335.2**

Source: RFA, F.O. Licht 2008 Estimates

Ethylene Value Chain

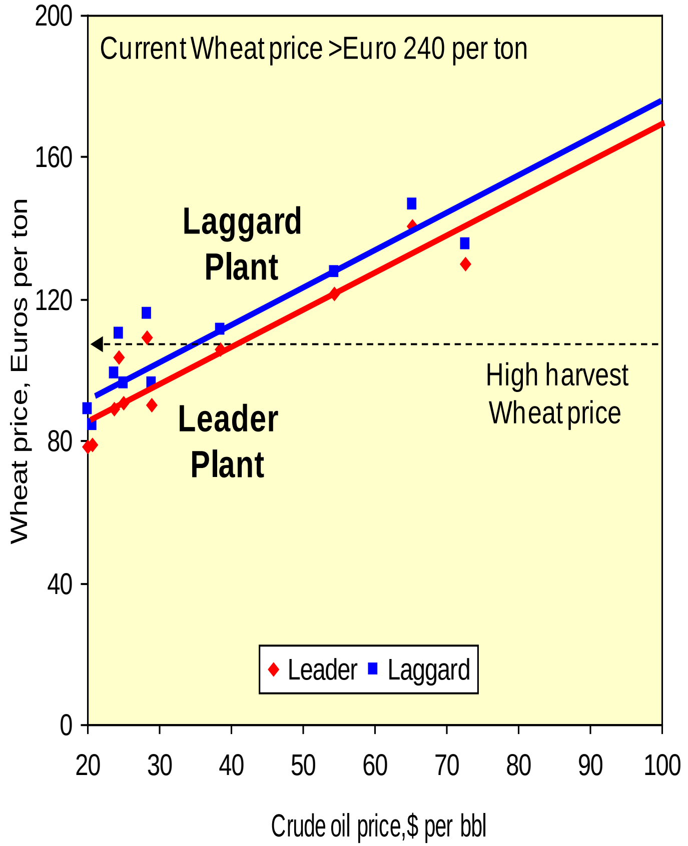


Bio-ethylene near market activity

- No technical hurdles for the production ethylene from biomass
- Braskem (Brazil)
    - Planned HDPE production
    - Capacity 250,000 tonnes/year Q4 2010
        - 1Mt end of 2012
- Dow/Crystalsev (Brazil)
    - Planned Polyolefin production 2011
    - Capacity 350,000 tonnes/year
- Solvay (Brazil)
    - Planned PVC and PVA

- Same economic considerations as fossil based production, feedstock cost and availability, construction and operating costs, access to market etc

Ethylene Economics

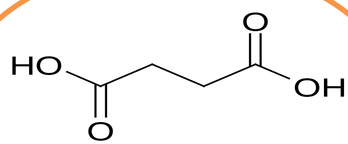


For a wheat price, typical of a balanced to long market, ethylene derived from bioethanol makes green polyethylene competitive with petrochemical derived routes in a high crude oil price world

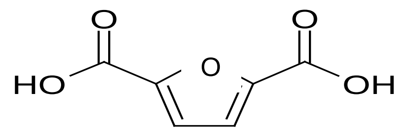
Current wheat price ~ £110/tonne

Current crude oil price ~ $75/bbl

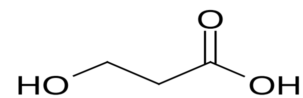
DOE's Top 12 Bio-derived building blocks



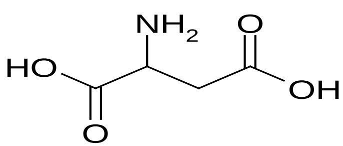
Succinic acid



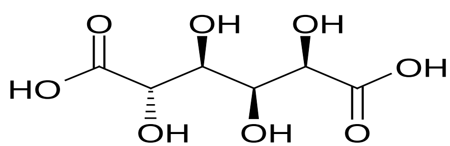
2,5-Furandicarboxylic acid



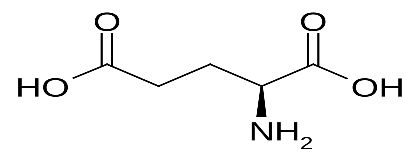
3-Hydroxypropionic acid



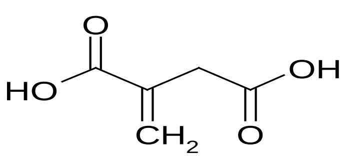
Aspartic acid



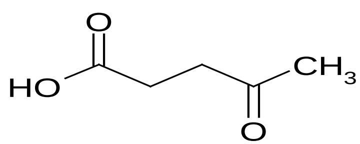
Glucaric acid



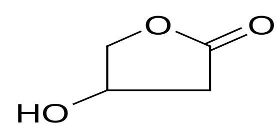
Glutamic acid



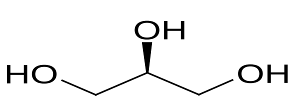
Itaconic acid



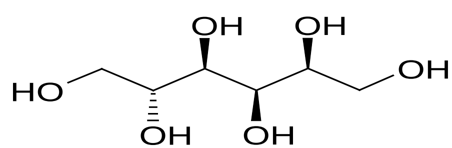
Levulinic acid



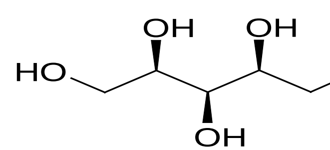
3-Hydroxybutyrolactone



Glycerol

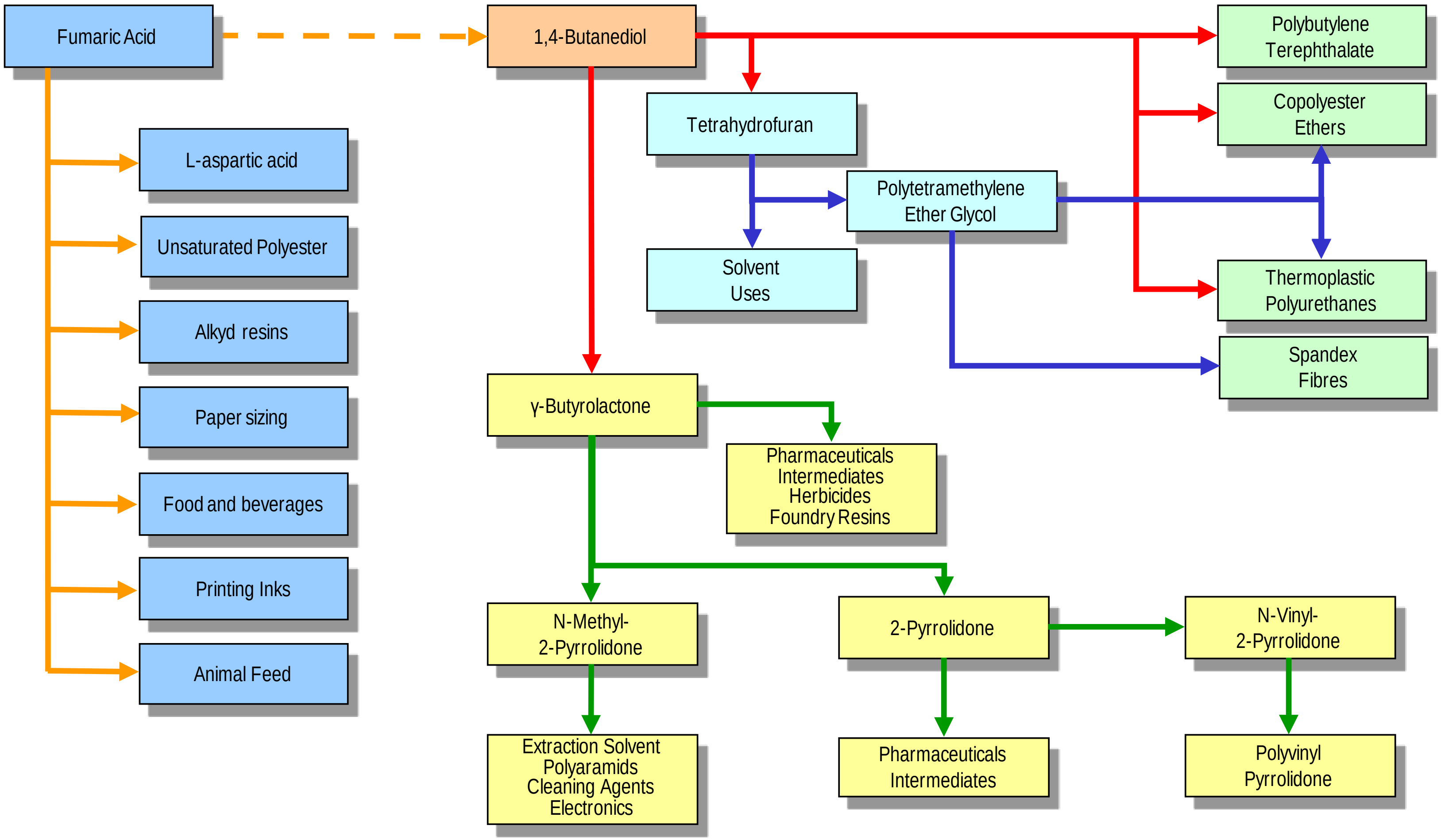


Sorbitol

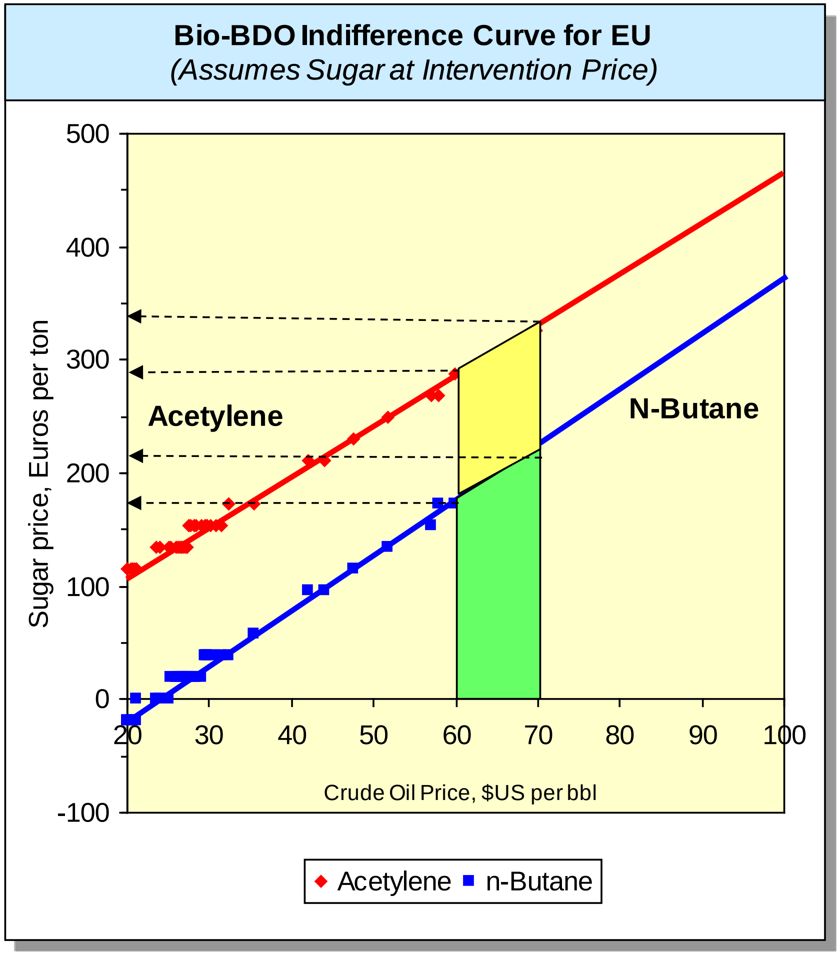


Xylitol

Fumaric & succinic acid downstream potential



Butanediol economics



Brazilian sugar - €150-200

Wet milling of wheat and corn is limited in Europe with most sugar being sugar beet-derived. With a sugar beet price of circa €30 per ton then on an integrated basis it may be possible to support captive fumaric acid and butanediol production.

The race to commercial industrial bio-succinic acid

BASF and CSM announce joint production development of biobased succinic acid

2009-09-30
P-09-395

LUDWIGSHAFEN , GERMANY, and DIEMEN, NETHERLANDS – September 30, 2009 – BASF SE and CSM nv today announced the cooperation between their respective subsidiaries BASF Future Business GmbH and PURAC for the development of the production of biobased succinic acid. Both partners have been working on the development of the industrial fermentation and down-stream processing of biobased succinic acid and will start production of commercial quality and volumes in the second quarter of 2010.

Bio amber

PRESS RELEASE

Bioamber Commissions World's First Renewable Succinic Acid Plant

Pomacle, France, January 20th, 2010: Bioamber, a joint venture between US-based DNP Green Technology and France-based ARD (Agro-industrie Recherches et Développements), announces the successful start-up and commissioning of the world's first bio-based succinic acid plant. Since December 2009, the plant has been producing renewable succinic acid from wheat derived glucose.

DSM and ROQUETTE to commercialize bio-based succinic acid as of end 2009

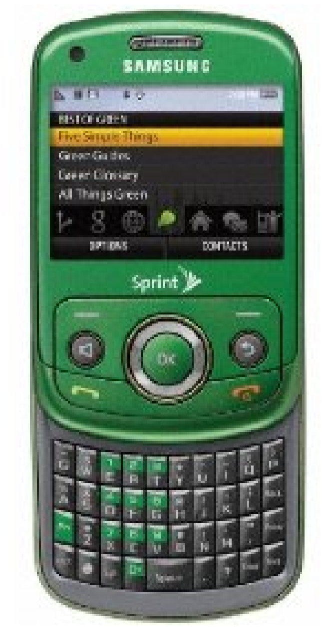
Heerlen, NL, 09-Mar-2009 08:15 CET

Royal DSM N.V., the global Life Sciences and Materials Sciences company headquartered in the Netherlands, and the French starch and starch-derivatives company ROQUETTE confirmed during the international Life Sciences Forum, BioVision, that its bio-based succinic acid demonstration plant in Lestrem (France) will be operational by the end of 2009. The pilot scale production has proven that this biological route for producing succinic acid can be commercially viable. The first tests for customers are already underway with this 'green' succinic acid.

Lactic acid

- Polylactic acid - Worlds leading bio-based synthetic polymer
- European demand predicted to rise from 25,000 per year to 650,000 tonnes by 2025
- Global lactic acid production capacity > 400,000 tonnes
- Expanding number of additive packages increasing application areas
- Compostable packaging to textile fibres

Market confusion – bio means biodegradable



Samsung Reclaim M560 Phone, Earth Green (Sprint)

Contains 40% polylactic acid

According to the blogosphere - A biodegradable phone!

What is bio ?

Origin of material	Biodegradability	Example	The meaning of the prefix “bio-”
Renewable	Biodegradable	Polyhydroxyalkanoate (PHA)	Biodegradable and bio-based
Non-renewable	Biodegradable	Polycaprolactone (PCL)	Biodegradable
Renewable	Non-biodegradable	Polyethylene (PE) from sugar cane	Bio-based
Non-renewable	Non-biodegradable	Polyetheretherketone (PEEK) for biomedical applications	Biocompatible

Adapted from: Taking bio-based from promise to market, EU Commission

Relevance of biodegradability?

DECEMBER 2, 2009 - COPENHAGEN DELEGATES WALK ON ECO2PUNCH® INGEO™ CARPET MADE FROM PLANTS, NOT OIL

Manufacture of this innovative performance carpet emits less greenhouse gas, reduces energy consumption, and demonstrates a new model for recycling

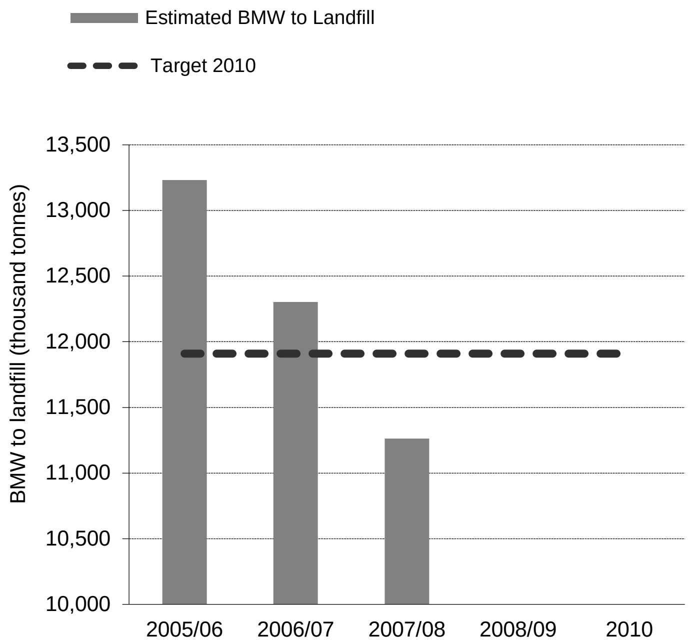
COPENHAGEN, Denmark., December 2, 2009 - At the Bella Center where the United Nations global conference on climate change will be held, every one of the 15,000 dignitaries will stand, walk, and rest their feet on an ultra low carbon footprint Eco2punch® carpet made with Ingeo™ fibers from plants not oil.

Image courtesy of Natureworks

PLA provides end of life flexibility compost, incineration or recycling

LOOPLA® BY GALACTIC

Food packaging

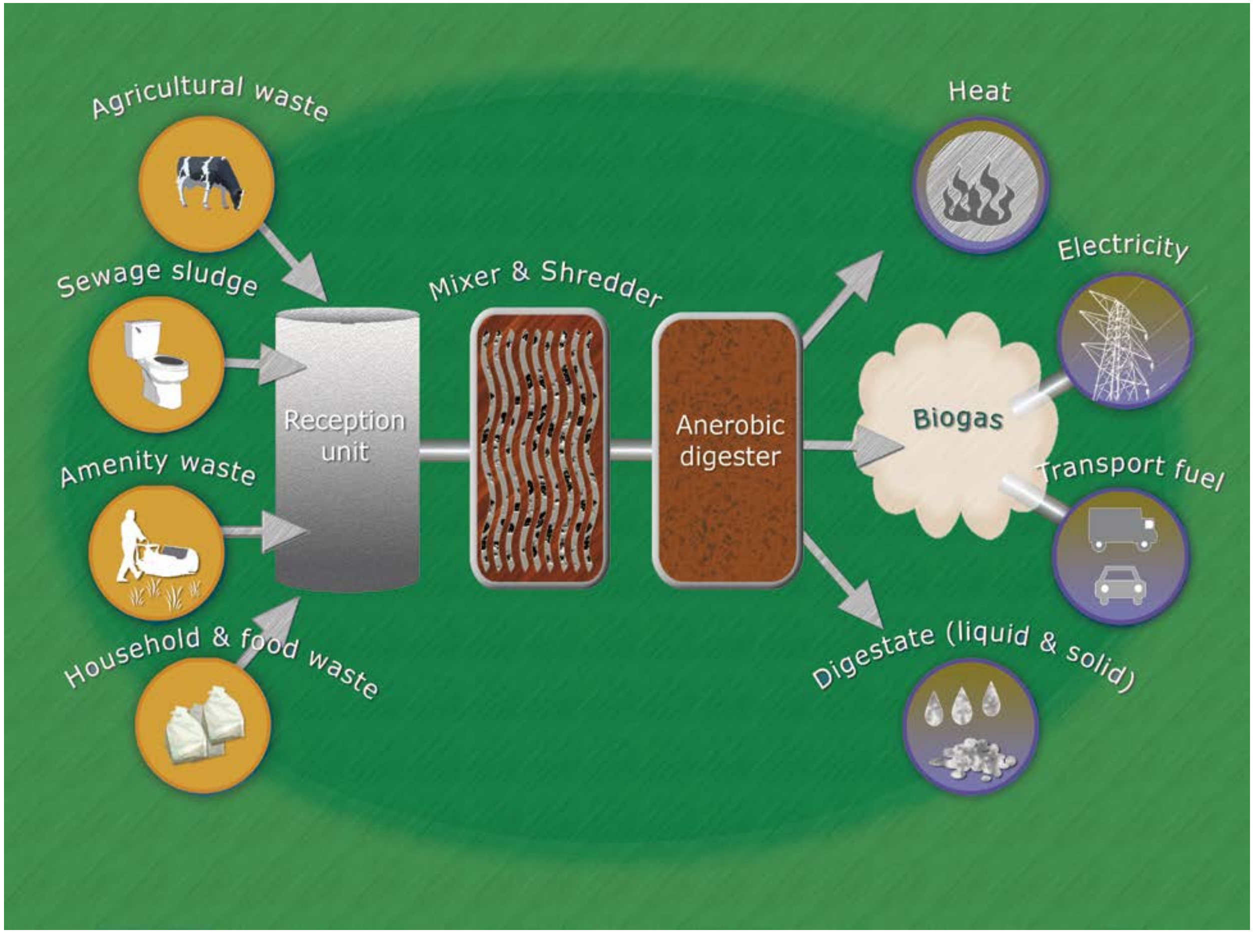


Source: Defra

Source: totals from Environment Agency annual report on landfill allowances produced from data provided by Local Authorties on WasteDataFlow

- An estimated 8.3 million tonnes of household food waste is produced each year in the UK (source WRAP)
- Large quantities of food waste are packaged
- Packaging increases the shelf life of products and reduces waste
- Need an efficient system to deal with food waste

The role for biodegradable packaging



England's Official Information Portal on

ANÆROBIC DIGESTION

www.biogas-info.co.uk

defra
Department for Environment Food and Rural Affairs

DEPARTMENT OF ENERGY & CLIMATE CHANGE

NNFCC

European Lead Market Initiative

- Standards, labels and certification
- Legislation promoting market development
- Product specific legislation
- Legislation related to biomass
- Encourage Green Public Procurement
- Financing and funding of research

Labels and standards

- Biodegradability - material function
  - Plastic products can provide proof of their compostability by successfully meeting the harmonised European standard, EN 13432
- Is origin of material is important?
- How do we communicate

Value to the supply chain

THE COCA-COLA COMPANY INTRODUCES INNOVATIVE BOTTLE MADE FROM RENEWABLE, RECYCLABLE, PLANT-BASED PLASTIC

plantbottle™
up to 30% plant-based
100% recyclable bottle
redesigned plastic,
recyclable as ever.

TETRA PAK PLANS BIOPLASTIC TRIALS IN 2011

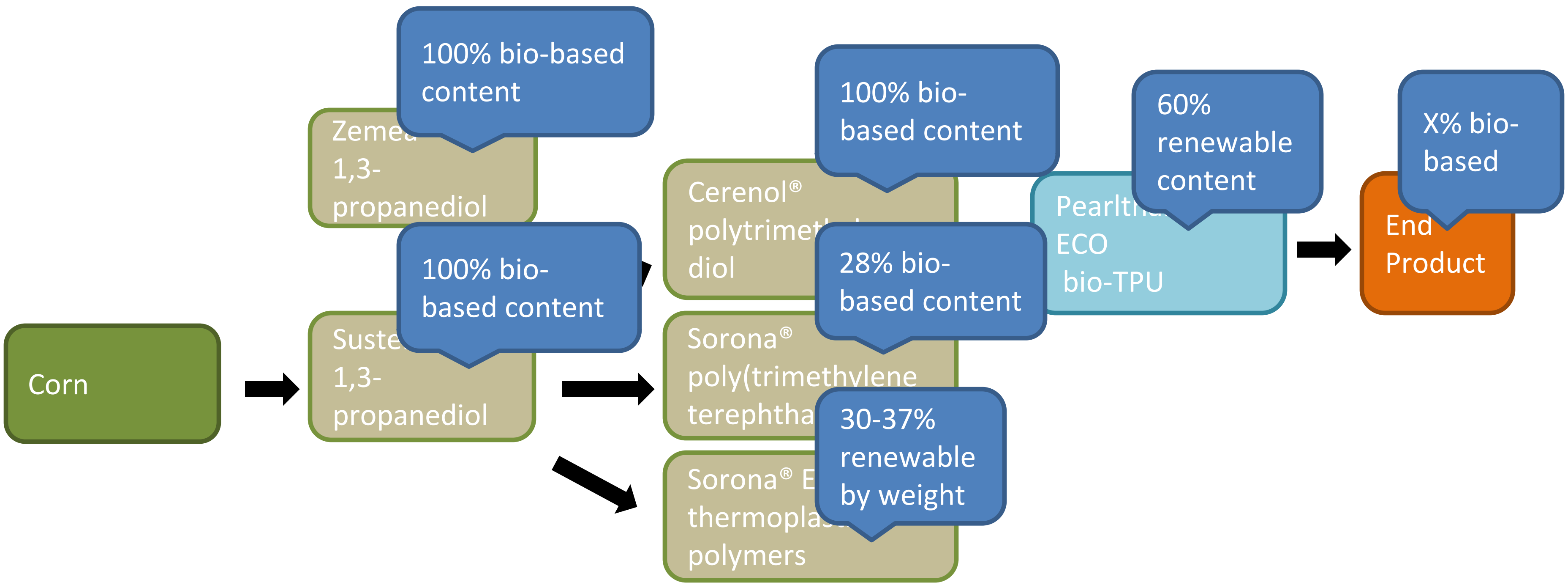
Dupont's Propanediol platform

Zemea™ Propanediol

SmartStrand® Carpet with DuPont™ Sorona® Renewably Sourced Polymer
Photo courtesy of Mohawk Industries

Calvin Klein Golf jacket made with DuPont™ Sorona® polymer.
Photo Courtesy of Calvin Klein Golf

Propanediol Value Chain



Merquinsa

DuPont

ASTM Standard D 6852: Standard Guide for Determination of Biobased Content, Resources Consumption, and Environmental Profile of Materials and Products

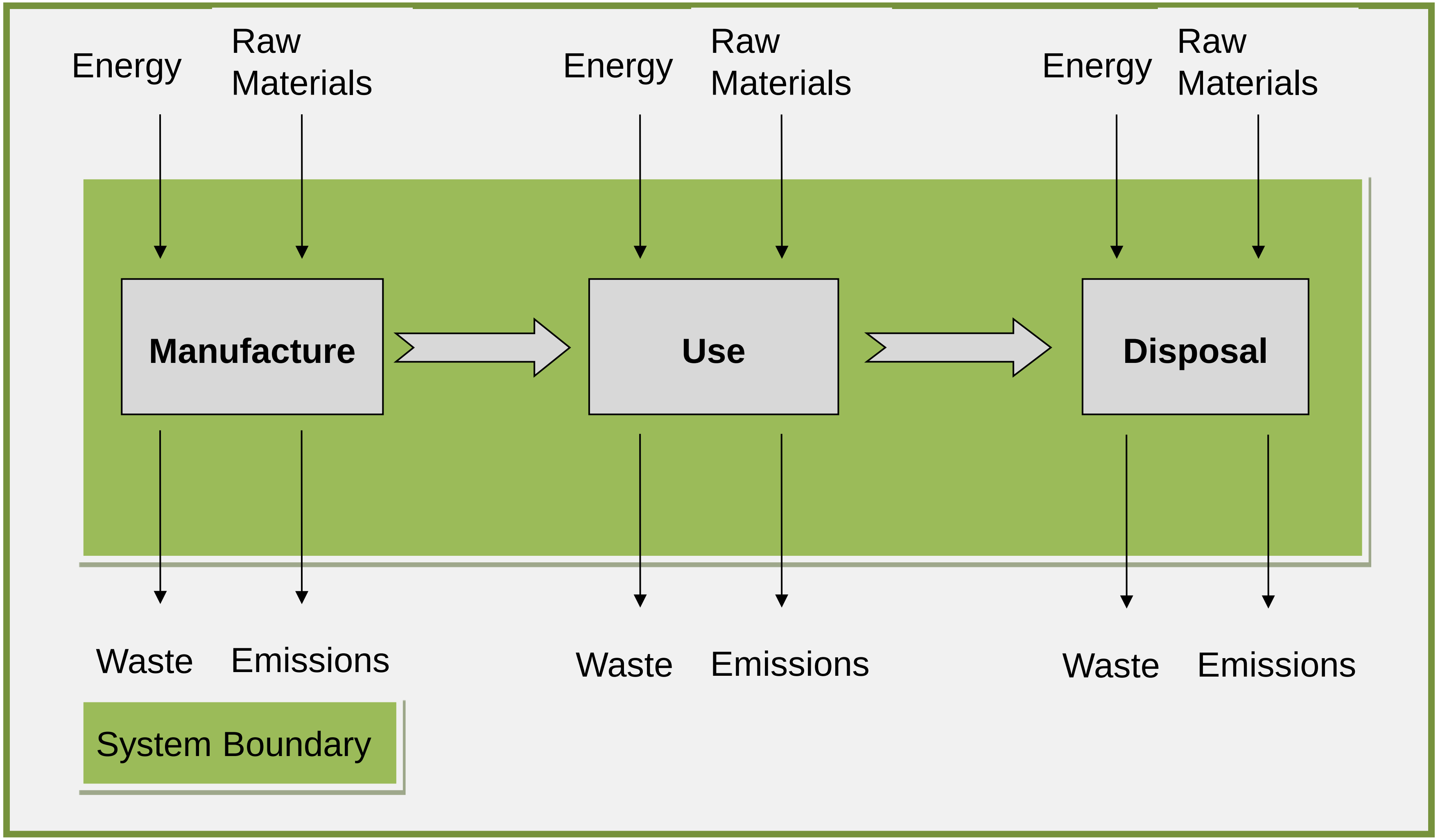
Bio-based content define by C14 levels

Vinçotte announces proudly the first OK biobased certificates of a whole range of raw materials.

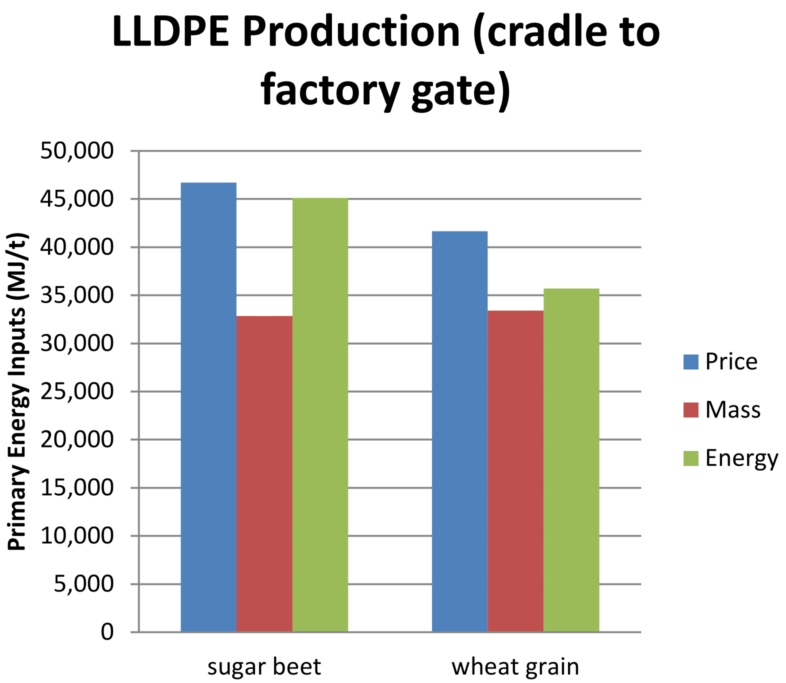
between 20 and 40 % Biobased	between 40 and 60 % Biobased	between 60 and 80 % Biobased	more than 80 % Biobased

IF WE CAN

SHOULD WE?

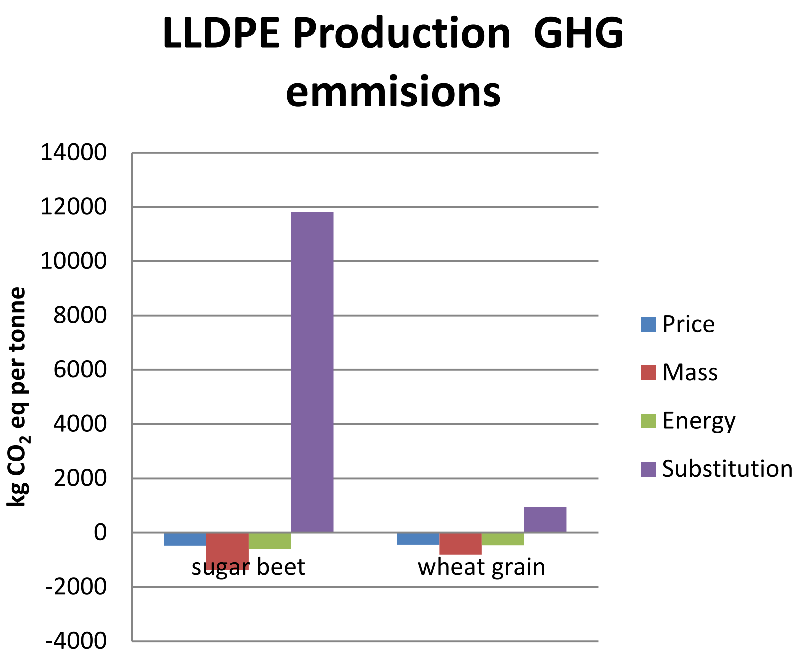

Energy
Raw Materials
Energy
Raw Materials
Energy
Raw Materials
Manufacture
Use
Disposal
Waste
Emissions
Waste
Emissions
Waste
Emissions
System Boundary

Significant fossil energy savings



Sugar Beet	**Price**	**46,709**
	Mass	**32,852**
	Energy	**45,110**
Wheat Grain	**Price**	**41,659**
	Mass	**33,421**
	Energy	**35,699**
Petro (Plastics*Europe*)		**72,300**

Significant GHG emissions savings



Sugar Beet	Price	-481
	Mass	-1,372
	Energy	-595
	Substitution	11,815
Wheat Grain	Price	-446
	Mass	-812
	Energy	-470
	Substitution	944
Petro (Plastics*Europe*)		1,890

Comparison with fuel ethanol

Production Option	Energy requirement	GHG emissions	GHG emissions Petro equiv	% savings
Bioethanol from wheat grain	0.597 (MJ/MJ)	0.044 (kg CO_2 eq./MJ)	0.081 (kg CO_2 eq./MJ)	46%
LLDPE from wheat grain	41,659 (MJ/tonne)	-446 (kg CO_2 eq./tonne)	1,890 (kg CO_2 eq./tonne)	124%

Findings of the Gallagher Review

- **There is probably sufficient land for food, feed and biofuels**
- The review has examined both the likely levels of future demand for agricultural land and how much land might be available. There remains much uncertainty.
- At present, feedstock for biofuel occupies just 1% of cropland but the rising world population, changing diets and demand for biofuels are estimated to increase demand for cropland by between 17% and 44% by 2020.
- However, the balance of evidence indicates there will be sufficient appropriate land available to 2020 to meet this demand......
- The review has not examined the situation beyond 2020 when current trends are anticipated to continue and climate change will affect land productivity. The long-term potential of bioenergy using land suited for agricultural production therefore requires further consideration.

GHG savings per unit of land

	Land unit	Output	GHG savings
Bioethanol from wheat	1 ha	66801 MJ 3181 litres	2,472 kg CO_2 eq.
LLDPE from wheat	1 ha	1.4 tonnes	3,270 kg CO_2 eq.

Using wheat grain for polyethylene delivers an additional 32% GHG saving over fuel ethanol

	Land unit	Output	GHG savings
LLDPE from sugar beet	1 ha	2.7 tonnes	6,402 kg CO_2 eq.

Product	GHG savings tCO_2 eq. per t	Land Use (ha per tonne)	GHG savings tCO_2 eq. per ha
acetic acid	0.3	0.14	2 (-2 – 6)
acrylic acid	1.6	0.18	9
adipic acid	2.8	0.28	10
butanol	3.4	0.32	10
caprolactam	5.1	0.33	15
ethanol	2.7	0.27	9
ethyl lactate	1.4	0.30	5
ethylene	2.4	0.45	5
succinic acid	4.0	0.15	27
1,3-propanediol	1.4	0.36	9
PLA	2.9	0.18	12

NB: Production from corn starch

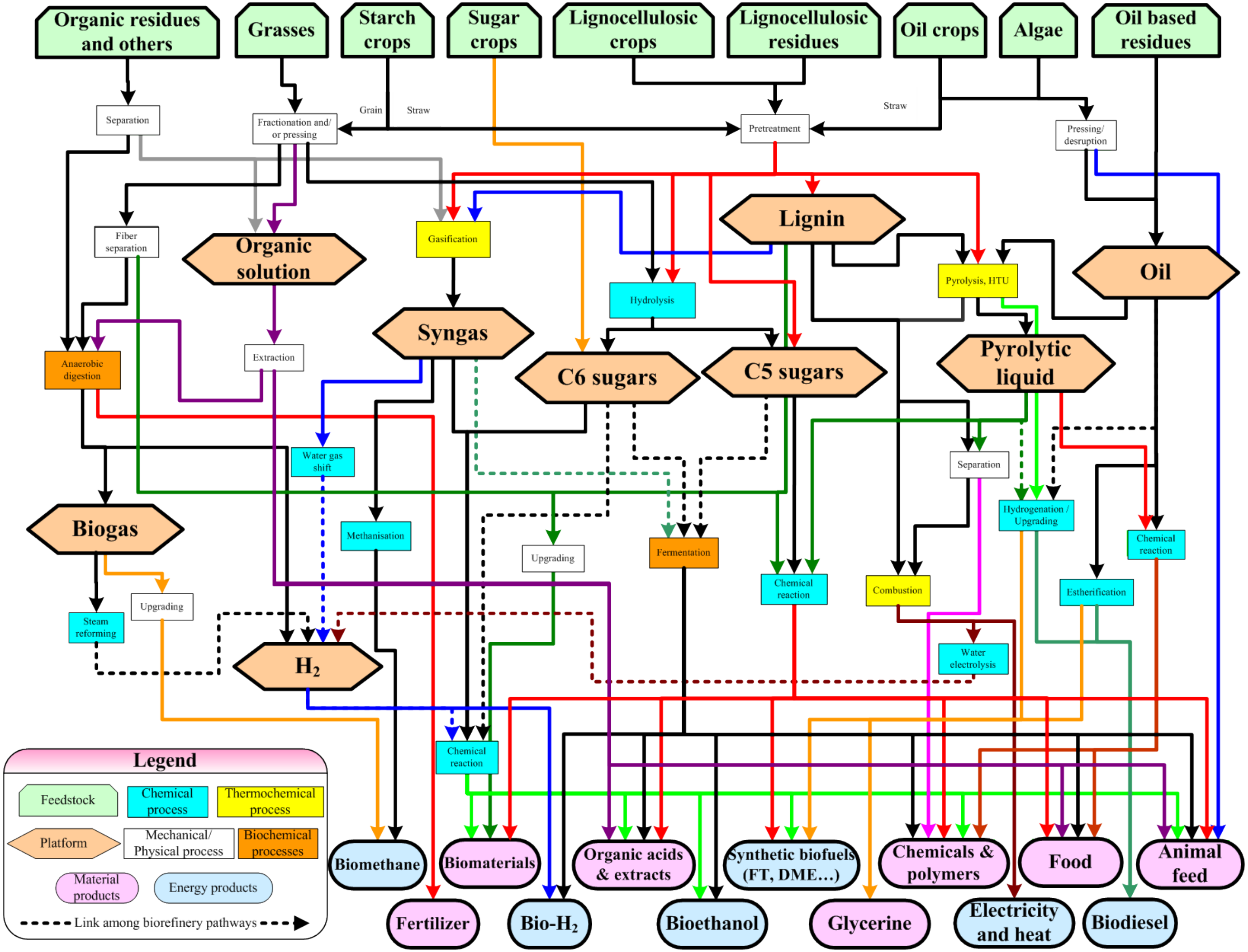
Adapted from: Medium and Long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources, Utrecht University 2006.

Potential for high land productivity

- Ethanol $C_6H_{12}O_6 \rightarrow 2\ C_2H_6O + 2\ CO_2$
- Lactic Acid $C_6H_{12}O_6 \rightarrow 2\ C_3H_6O_3$
- Succinic Acid $C_6H_{12}O_6 + 2\ CO_2 + 2\ H_2 \rightarrow 2\ C_4H_6O_4 + 2\ H_2O$

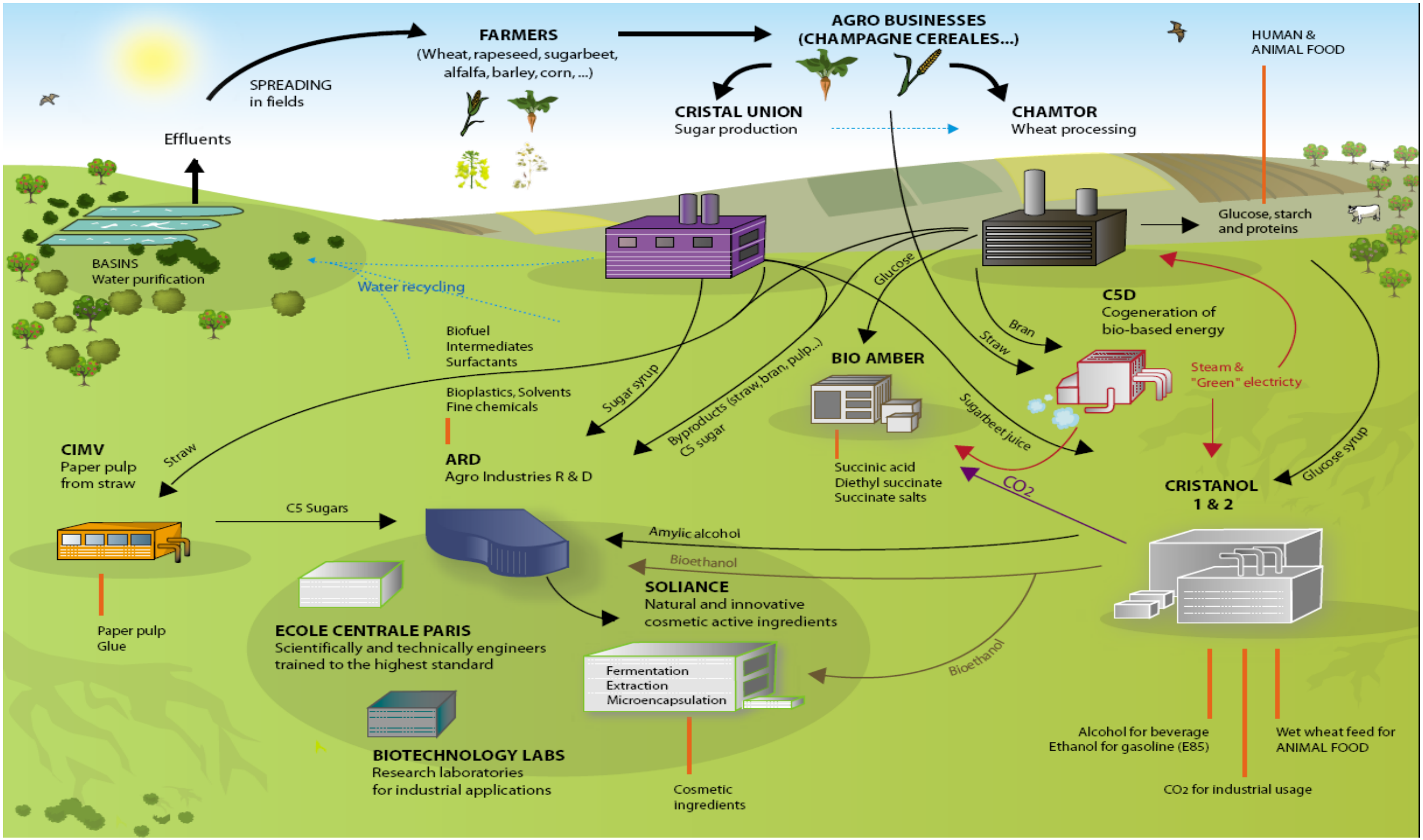
NNFCC

IEA Bioenergy | Task 42 Biorefinery

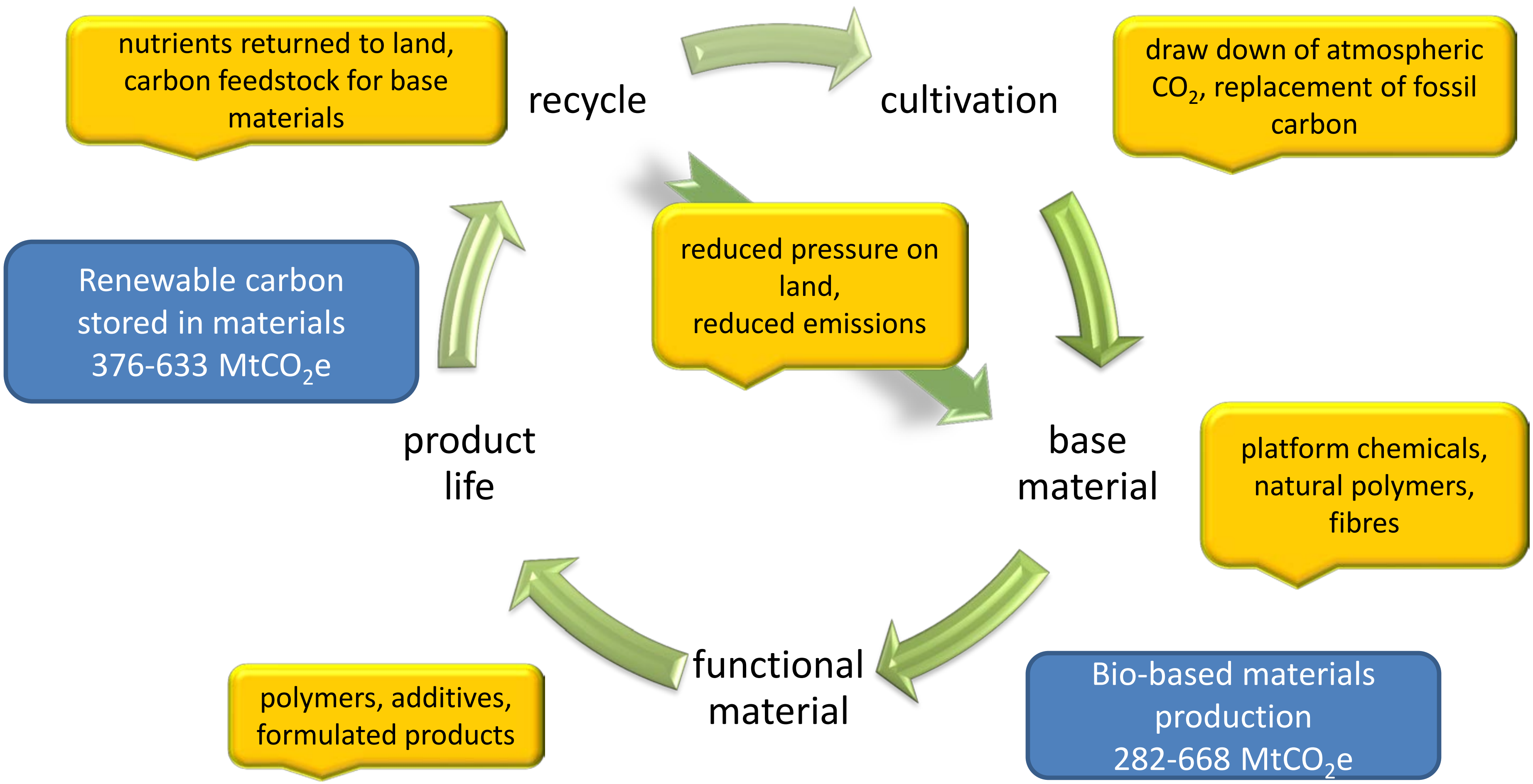


building sustainable supply chains

French Biorefinery Development



Potential biobased material economy 2030

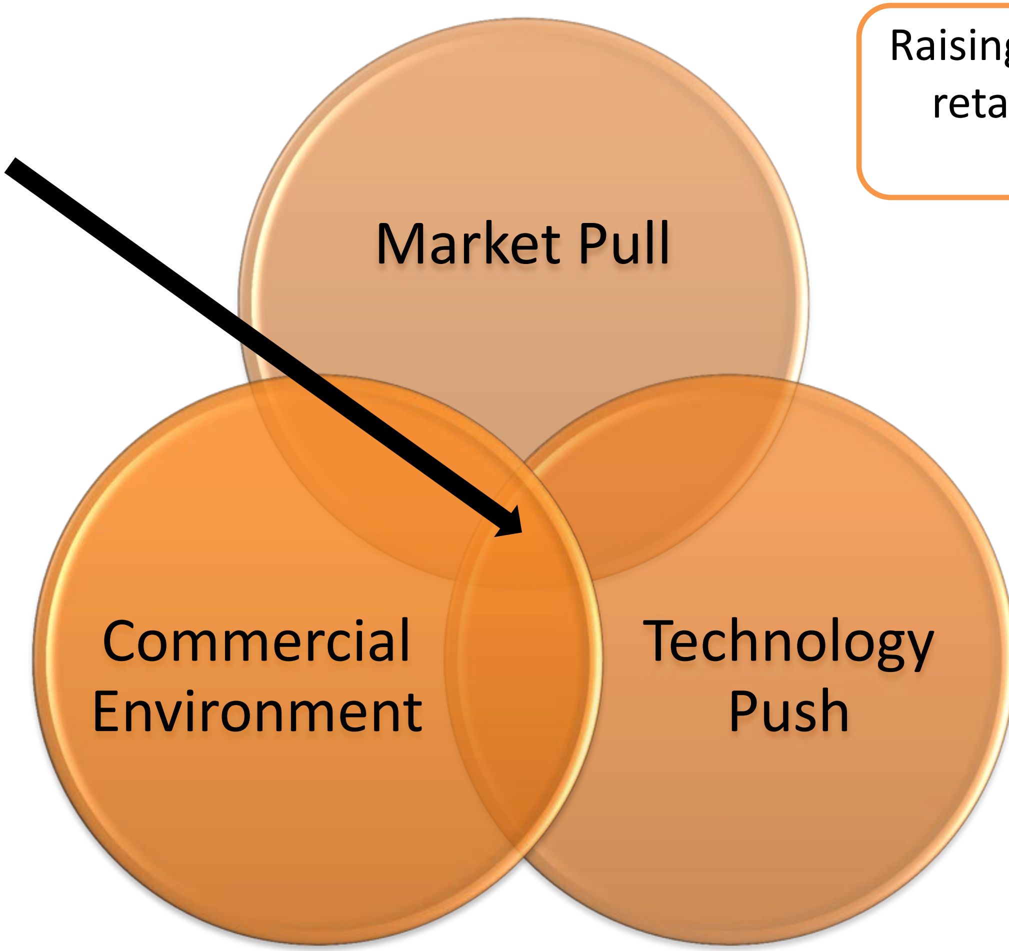


Source: NNFCC & 'GHG Emission reductions with Industrial Biotechnology': Assessing the Opportunities, WWF & Novozymes

NNFCC's role in development

The right conditions

Raising awareness of retailers and the public



Engaged with UK and EU policy makers

Supporting UK R&D

NNFCC

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building sustainable supply chains