Sao Paulo, Brazil, 18-20 May 2011 - Paulista University

3rd International Workshop

"Advances in Cleaner Production"

Organic Waste, Residues and By-Products from Agricultural, Industrial and Urban Systems as Biorefinery Substrates.

Viable Option or Fairie Tales?

An Application of SUMMA (SUstainability Multi-method Multi-scale Assessment)

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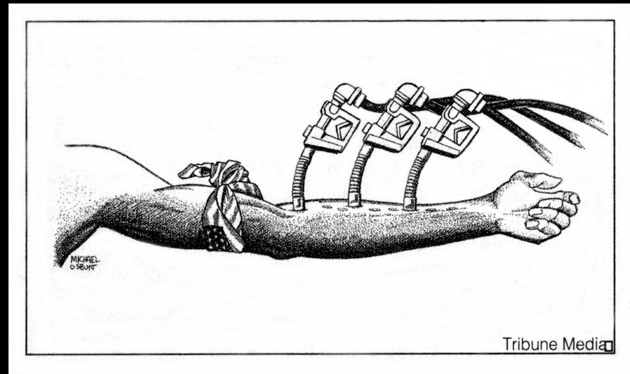
A Problem - Us

- All studies clearly identify human activity as a primary cause of the Earth System Crisis
- The 20th Century has seen exponential growth in human populations, made possible by the industrial-scale exploitation of natural resources and services
- The globalised industrial economy is committed to continuing growth in production and consumption
- Growth demands ever-increasing energy and material inputs
- Growth results in increasing levels of pollution, resource depletion, species loss and ecosystem degradation.

Business-as-usual

Advocates of business-as-usual suggest that what is needed to maintain a growing economy is increased efforts to extract more energy from deeper reservoirs, oil sands, nuclear.

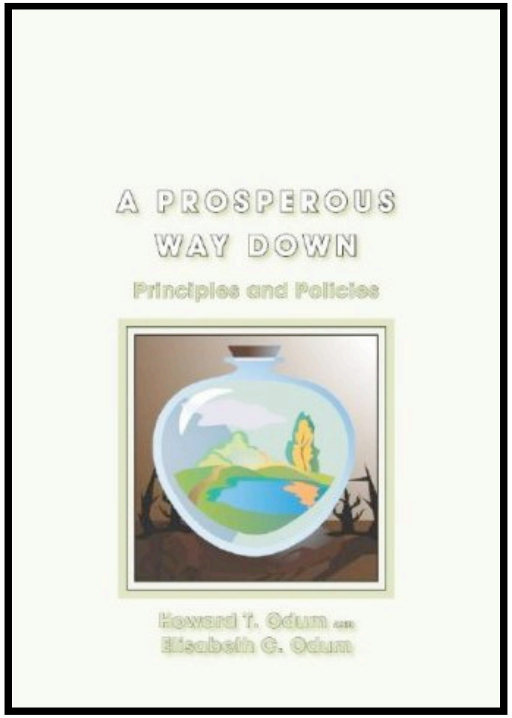


They disregard the declining net return of these sources (increased efforts mean increased energy investment, less net energy, more environmental disturbance).

Business-as-usual is not an option for the future of humankind.

Unlimited growth is impossible in a limited planet and sooner or later every activity is constrained by a limiting factor.

Howard T. Odum (1925-2002):
the impossibility of business-as-usual
and the search for alternatives.



Howard T. Odum and Elisabeth C. Odum (2001)
A Prosperous Way Down: Principles and Policies.
Boulder, Colorado: University Press of Colorado.

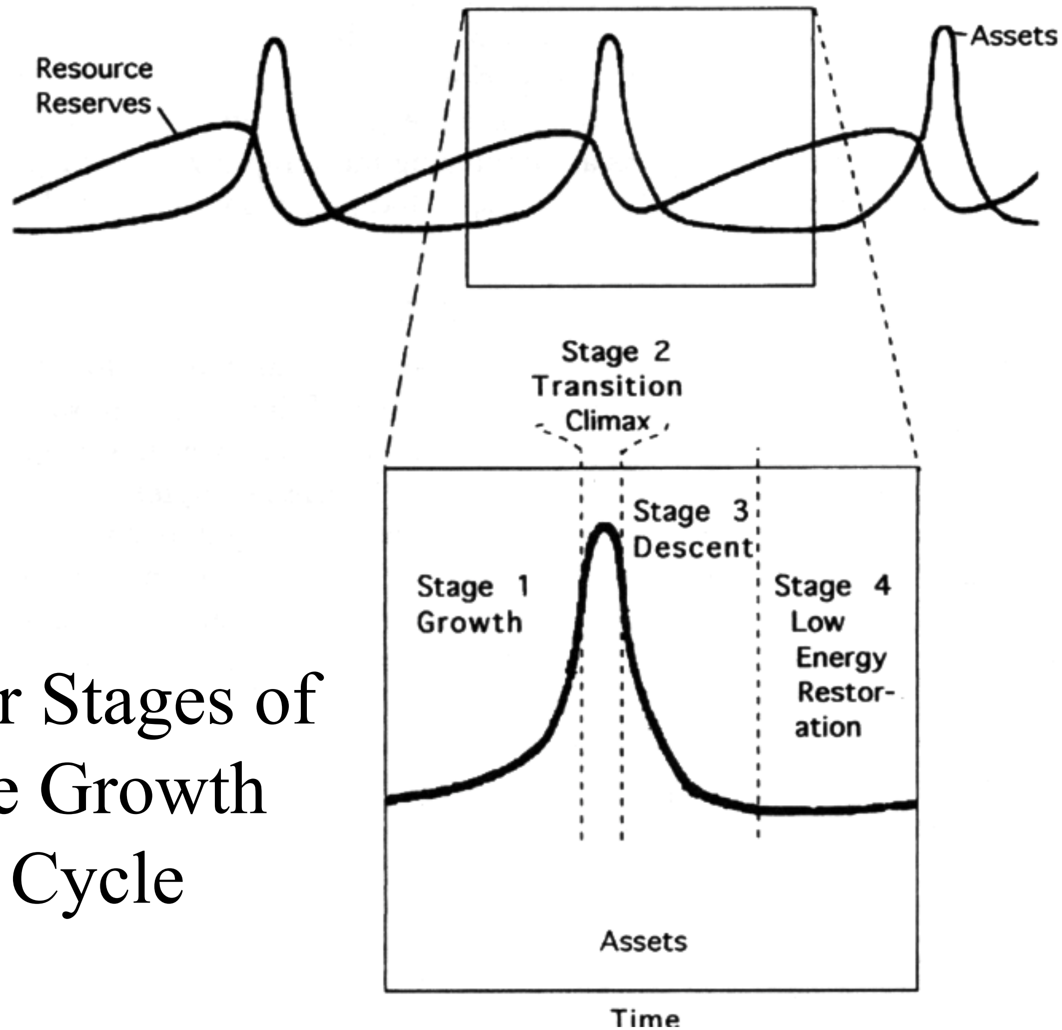
Main premises of cleaner production and sustainable societies:

a) recognizing the stage we are in;

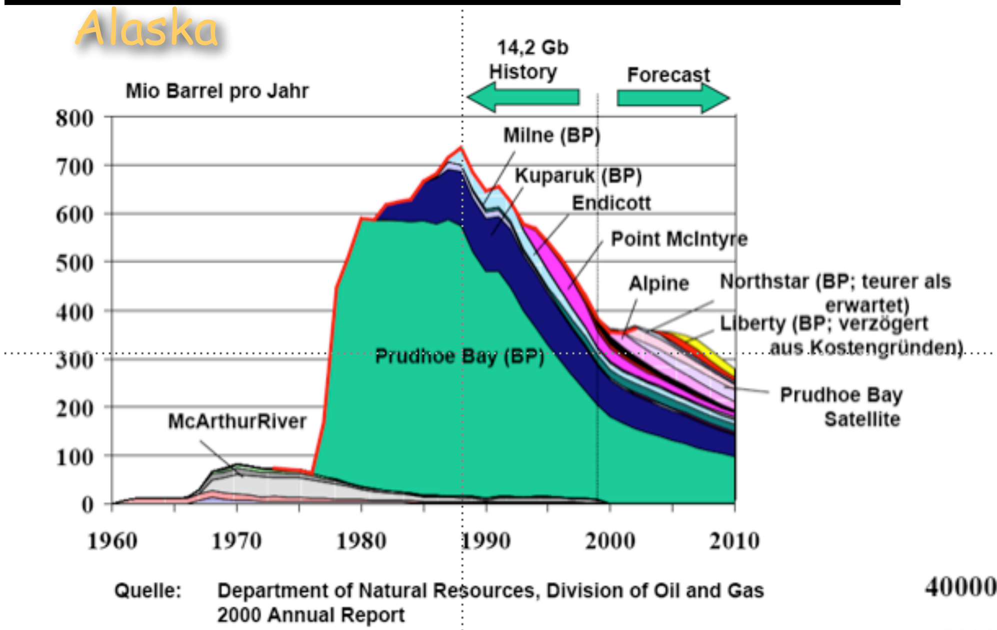
b) Choosing the appropriate policy for that stage.

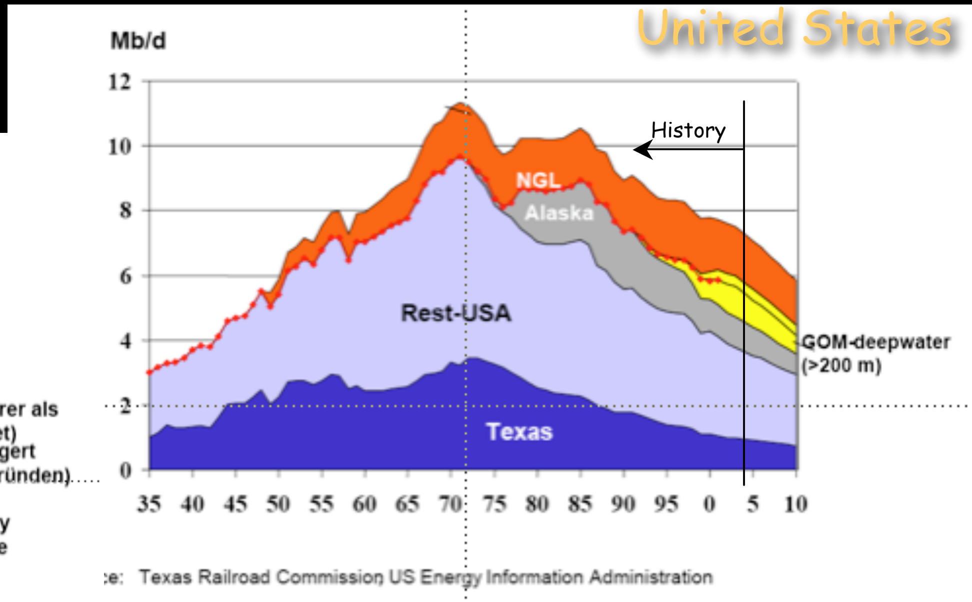
c) Growth policies do not fit descent periods

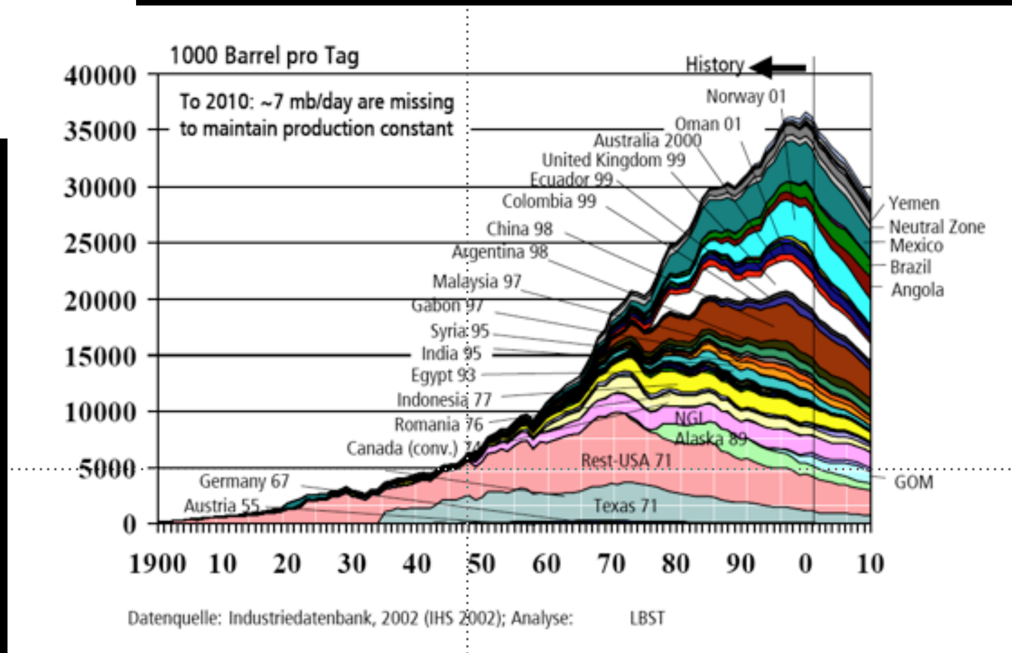
Odum's Pulsing Model



Four Stages of the Growth Cycle

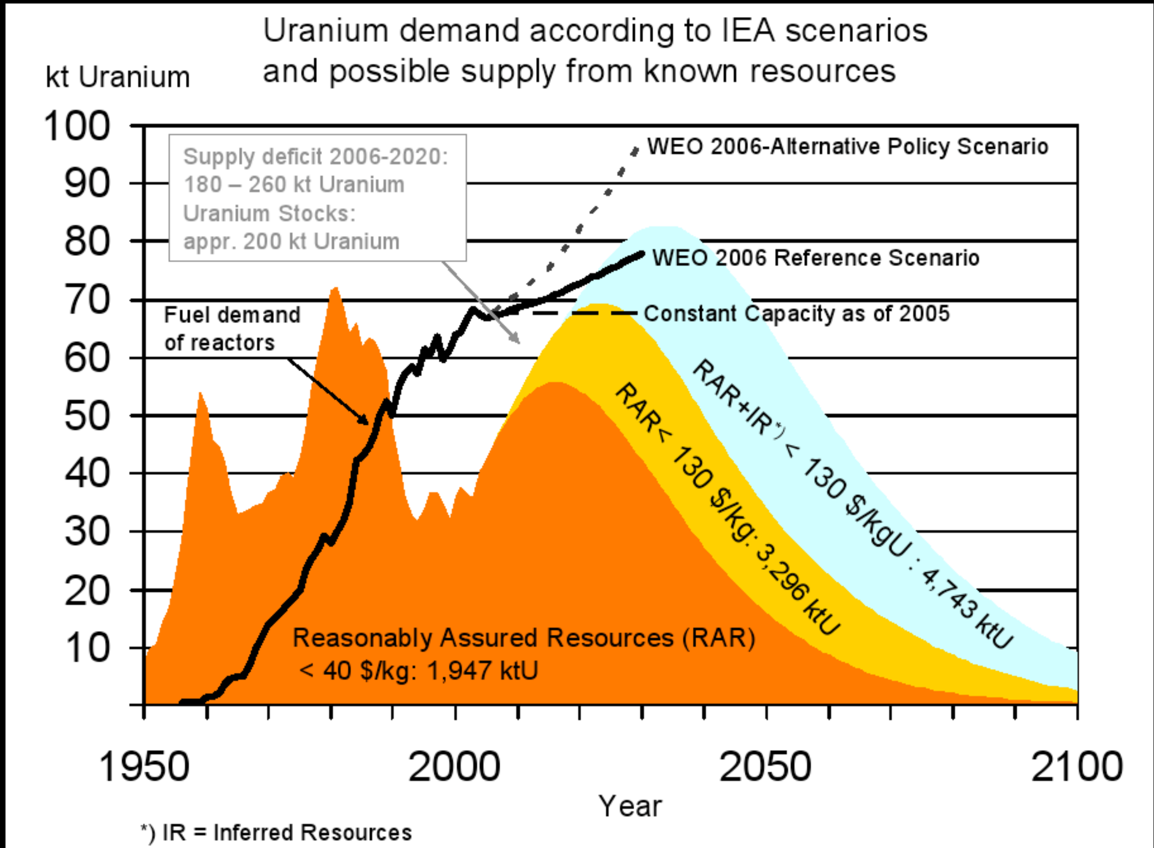






No matter how you cut it…the hydrocarbon age (cheap fossil fuels) is over.

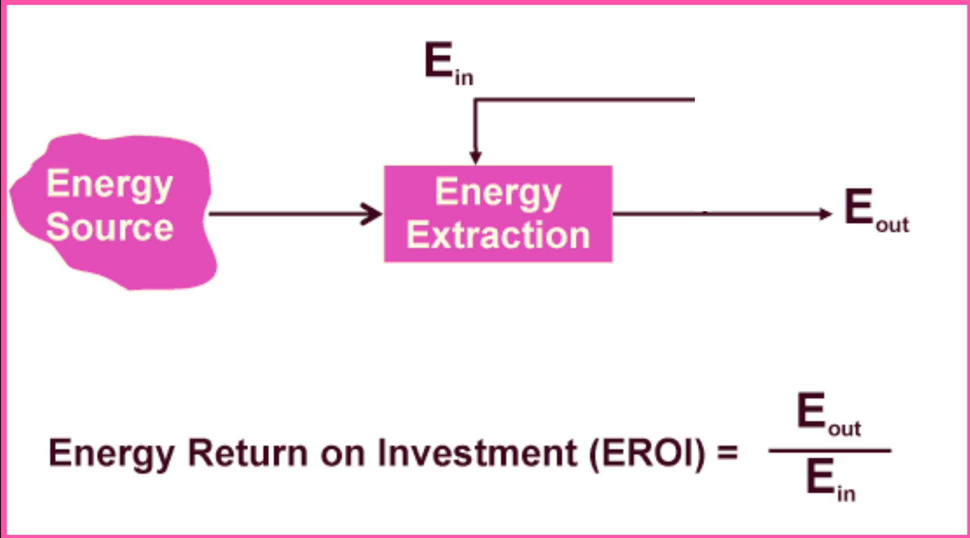
A PEAK FOR (CHEAP) URANIUM ?



Estimates of available uranium stocks at different price compared to the present uranium demand for existing reactors

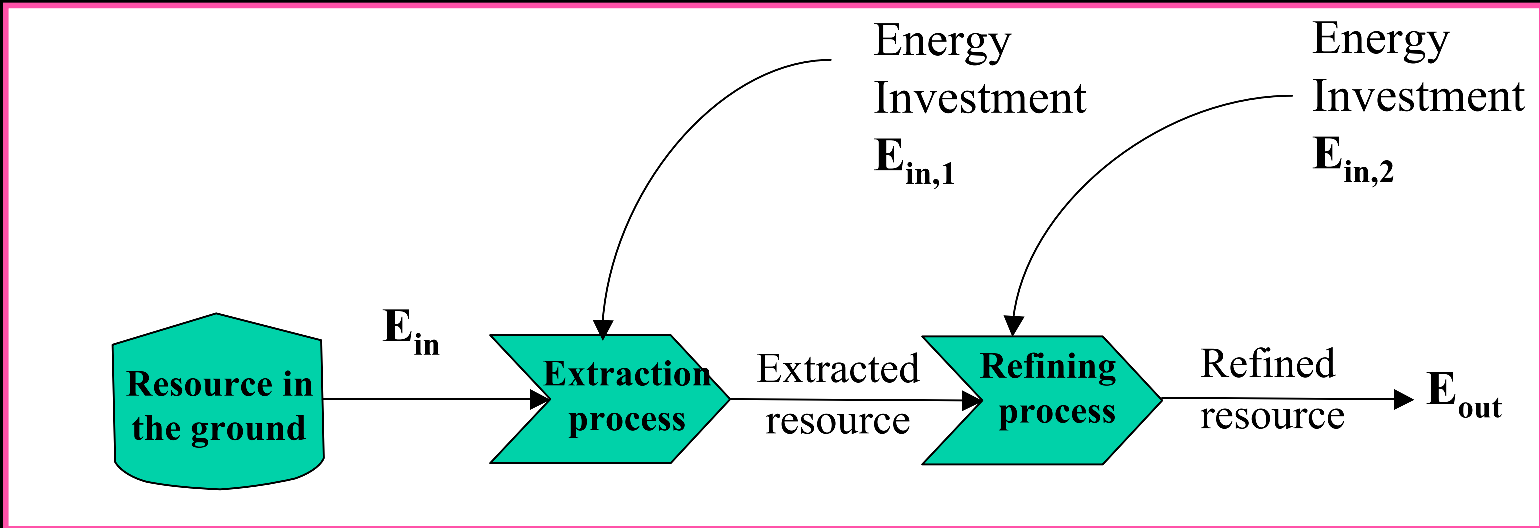
Source: EWG, 2006. URANIUM RESOURCES AND NUCLEAR ENERGY. Energy Watch Group, December 2006. EWG-Series No.1/2006. http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Uranium_3-12-2006ms.pdf.

Net Energy and EROI (Energy Return on Investment)



$$\text{Net Energy} = E_{out} - E_{in}$$

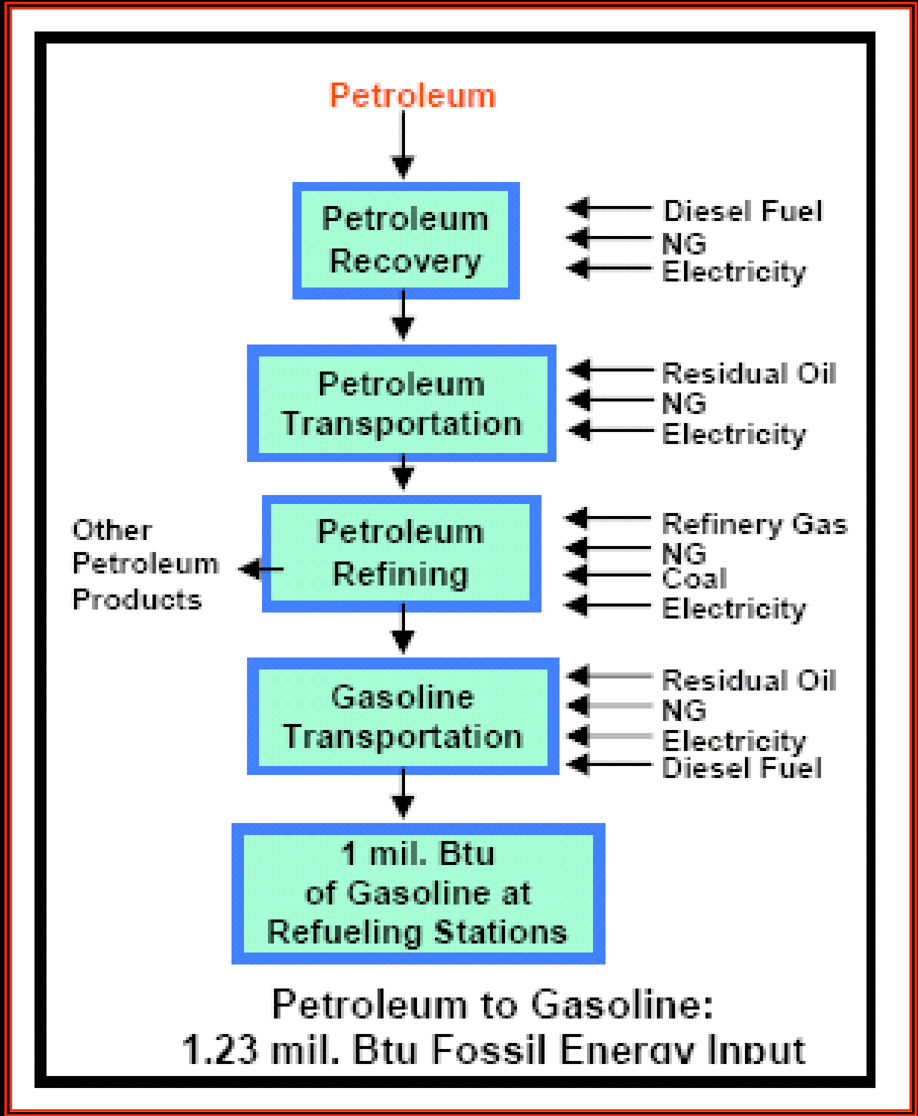
$$\text{EROI} = E_{out} / E_{in}$$



Fossil oil to gasoline process

(Michael Wang, 2005, Ethanol from Corn and Cellulosics, Center for Transportation Research, Argonne National Laboratory)

The EROI of refined fuels is around 5:1



The search for alternatives

Our addiction to fossil fuels results on intensive consumption of petroleum derivatives which, combined with diminishing petroleum resources, causes environmental and political concerns.

Electricity and heat can be provided by a variety of renewable alternatives (wind, sun, hydro, geo, and so on).

Instead, the fossil resource alternative for production of transportation fuels and chemicals is biomass, the only C-rich material source available on the Earth, besides fossils.

Alternatives must be:

A) Environmentally friendly: less, or no loading at all on water, land, air, climate, biodiversity.

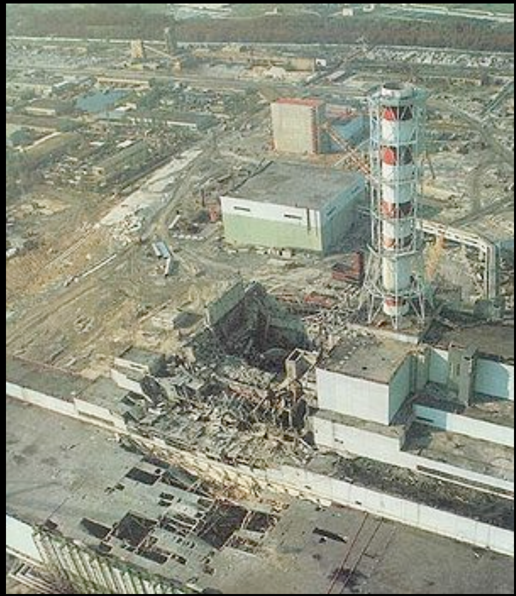
B) Renewable. The age of fossil fuels is over.

C) Complex and integrated: components interact and exchange energy and matter flows in order to decrease emissions and waste.

D) Aiming at wellbeing, not at growth.

E) Sustainable under different points of view: energetic, environmental, economic, and social.

Bio-ethanol production in the contaminated land around Chernobyl (Belarus) ?



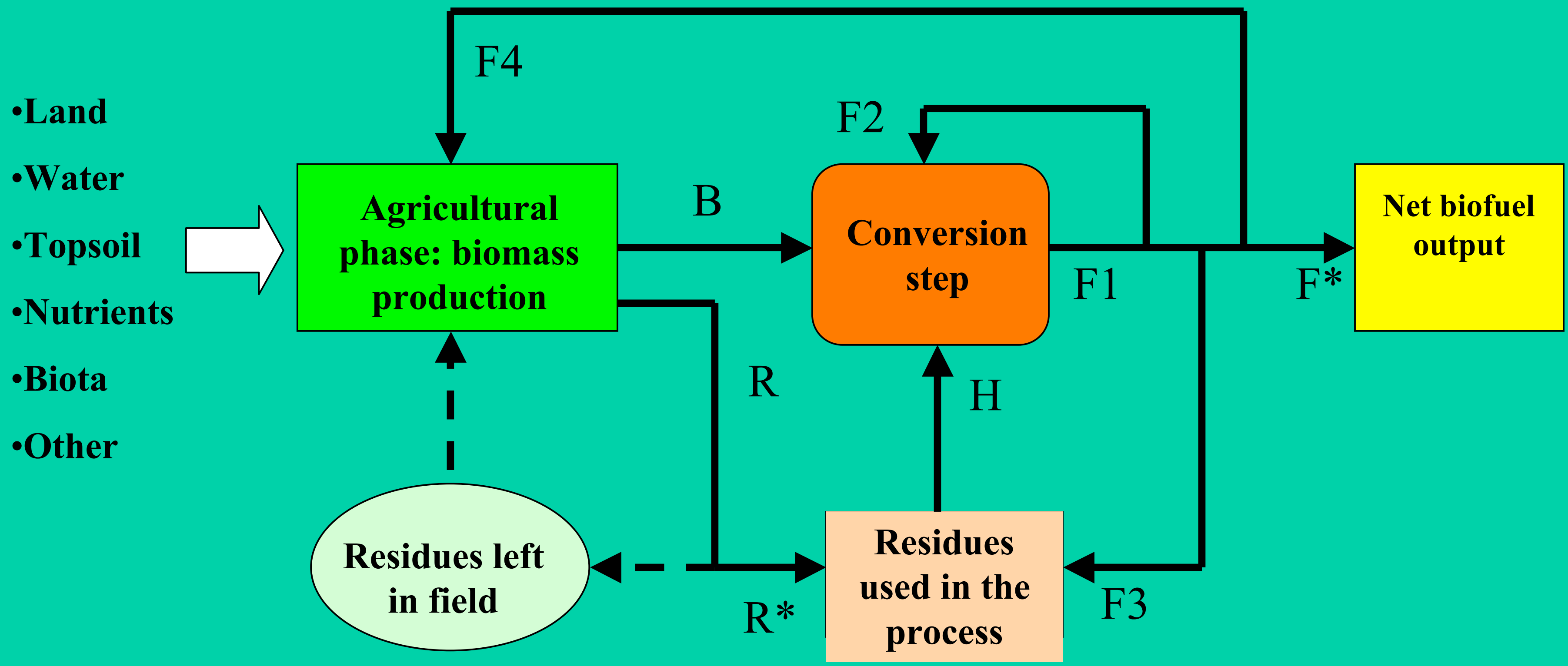
In 2009 an Irish Company (Greenfield Project Management Ltd) planned to use four million ha in Belarus, in the Chernobyl surroundings. The biofuel produced should have been commercialised in Europe. This was a false annoucement to raise money in order to avoid bankrupcy (http://www.facebook.com/note.php?note_id=145364802189057).

On 16 May 2011, PhotoFuels, a Belgian-Ukrainian joint venture, announced to have obtained approval from the Ukraine government to plant several test fields of common millet for biofuels in the Chernobyl area evacuated in the year 1986 after the nuclear power accident. (Deutsche Presse-Agentur)

The failure of Bioenergy from food crops:

corn, wheat, oilseeds,...

Biofuel Production



F1 = Gross biofuel production

F2 = Process energy demand met by biofuels

F3 = Biofuels invested in harvesting of residues

F4 = Biofuel demand for agricultural production

R = Potentially available residues (mass)

R* = Residues used in process (mass)

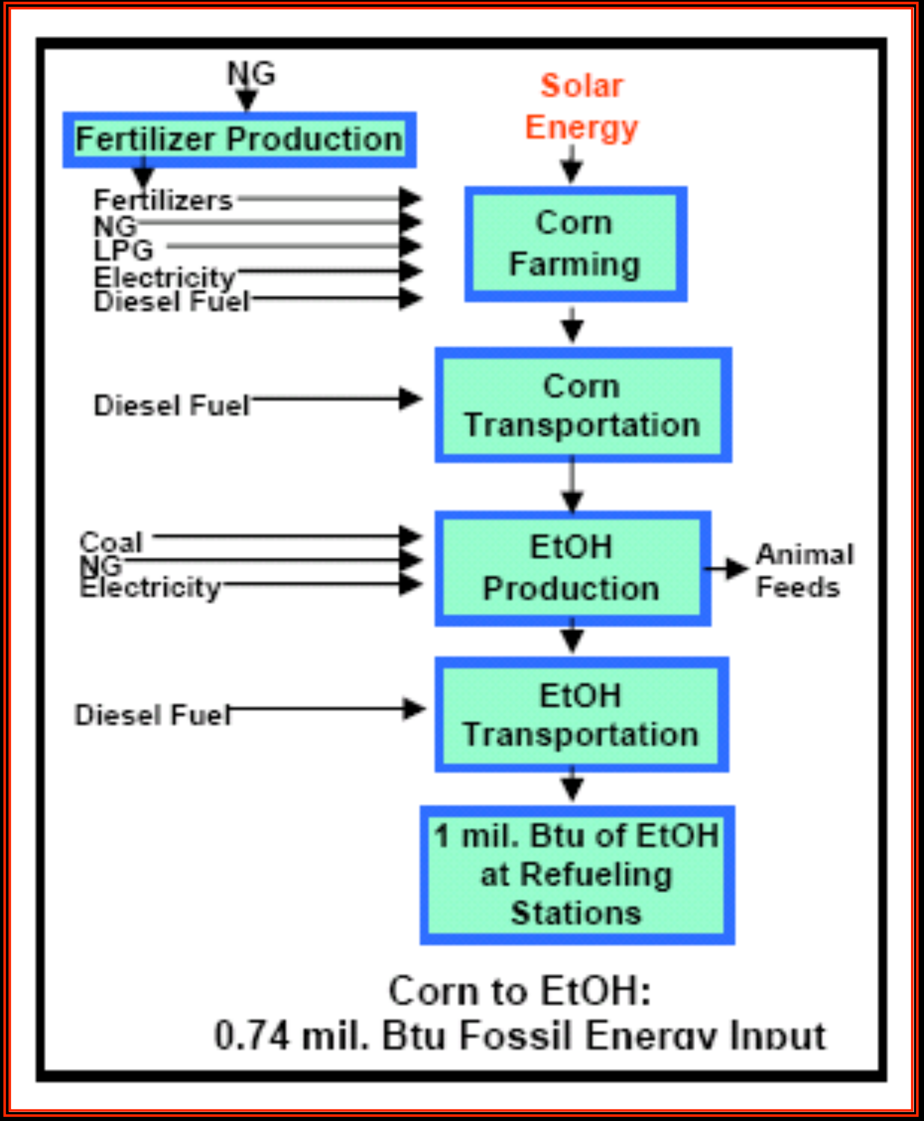
H = Process energy demand met by residues

B = Total biomass produced (mass)

Corn to EtOH process

(Michael Wang, 2005, Ethanol from Corn and Cellulosics, Center for Transportation Research, Argonne National Laboratory)

The EROI of bioethanol from corn is around 1.3:1



	Units	Wheat	Corn
Energy and mass flows			
Total commercial energy invested for grain production	J/ha/yr	2.38E+10	2.92E+10
Total commercial energy invested for bioethanol production	J/ha/yr	3.28E+10	4.92E+10
Grain produced	g/ha/yr	4.30E+06	7.60E+06
Ethanol produced	g/ha/yr	1.20E+06	1.96E+06
Energy content of bioethanol produced	J/ha/yr	3.57E+10	5.84E+10
Net energy yield of bioethanol (energy of ethanol–energy invested)	J/ha/yr	2.89E+09	9.15E+09
Ethanol production			
Energy cost of ethanol	J/g	2.74E+04	2.51E+04
Output/input energy ratio		1.09	1.19
Transformity of ethanol, with labor and services	sej/J	2.77E+05	1.89E+05
Transformity of ethanol, without labor and services	sej/J	1.67E+05	1.24E+05

Energy and eMergy evaluation of bioethanol production from wheat in Henan Province, China

Xiaobin Dong [a], Sergio Ulgiati [b], Maochao Yan [c,d], Xinshi Zhang [a], Wangsheng Gao [c,*]

Energy Policy 36 (2008) 3882– 3892

Second Generation vs First Generation? Maybe…

- ***1st generation biofuels***

  Derived from Biomass harvested for the sugar, starch and oil content, which can be converted using hydrolysis & fermentation

  Technology established

  Major Issues - Crops needed, Food v Fuel, Water Demand, Environmental issues - land clearing, soil degradation.

- ***2nd generation biofuels***

  Produced from lignocellulosic biomass, utilising hydrolysis, fermentation, gasification or pyrolysis

  Can utilise Waste Materials (e.g. waste paper, paper mill waste, wood waste, agricultural crop residues etc)

Table 5 Energy and emergy performance indicators for bioethanol production for each pretreatment system

Item	Unit	Pretreatment system					
		Dilute acid	Controlled pH	Flowthrough	AFEX	ARP	Lime
Energy and mass flows							
Total energy invested for bioethanol production	J	1.93E+13	7.48E+12	4.48E+13	8.31E+12	1.06E+13	2.22E+12
Mass of bioethanol and co-products produced	g	3.57E+08	3.07E+08	3.82E+08	2.56E+08	3.07E+08	2.36E+08
Energy content of bioethanol and co-products produced	J	1.06E+13	9.13E+12	1.14E+13	7.61E+12	9.15E+12	7.02E+12
Net energy yield	J	-8.67E+12	1.65E+12	-3.34E+13	-7.06E+11	-1.44E+12	4.81E+12
Emergy flows							
Locally renewable inputs, R	seJ	4.09E+17	4.09E+17	4.09E+17	4.09E+17	4.09E+17	4.09E+17
Locally nonrenewable inputs, N	seJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
% renewable of purchased inputs, %R_F	seJ	1.04E+16	8.22E+15	1.38E+16	1.02E+16	8.45E+15	1.01E+16
% nonrenewable of purchased inputs, %N_F	seJ	3.21E+18	1.37E+18	5.54E+18	7.13E+18	6.04E+18	1.19E+18
% renewable of Labor and Services, %R_S	seJ	6.32E+16	5.55E+16	6.70E+16	4.76E+16	5.55E+16	4.46E+16
% nonrenewable of Labor and Services, %N_S	seJ	1.80E+17	1.58E+17	1.91E+17	1.35E+17	1.58E+17	1.27E+17
Imported emergy, F = %R_F+%N_F+%R_S+%N_S	seJ	3.47E+18	1.59E+18	5.81E+18	7.33E+18	6.26E+18	1.37E+18
Total emergy inputs, Y = R+N+F	seJ	3.88E+18	2.00E+18	6.22E+18	7.74E+18	6.67E+18	1.78E+18
Bioethanol production							
Output/input energy ratio		0.55	1.22	0.25	0.92	0.86	3.17
Transformity of bioethanol, with co-product	seJ/J	3.65E+05	2.19E+05	5.47E+05	1.02E+06	7.29E+05	2.53E+05
EYR = Y/F		1.12	1.26	1.07	1.06	1.07	1.30
ELR = (N+F)/R		8.48	3.89	14.20	17.91	15.30	3.35
% Renewable = 1/(1+ELR) = R/Y		10.55%	20.47%	6.58%	5.29%	6.13%	23.00%
ESI = EYR/ELR		0.13	0.32	0.08	0.06	0.07	0.39

(Li et al., 2010; Wyman et al., 2005)

What is a biorefinery?

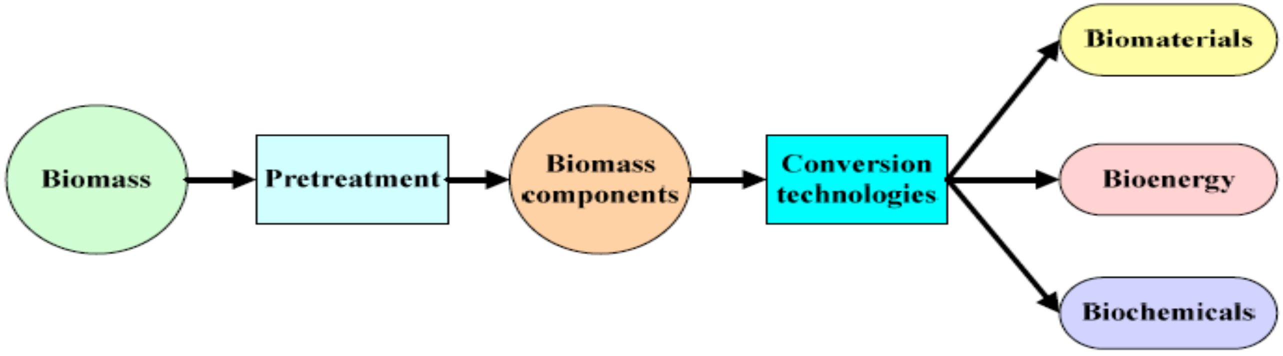
Biorefinery: the sustainable processing of biomass into a spectrum of marketable products and energy"

(IEA Bioenergy Task 42)

The "biorefinery" concept embraces a wide range of technologies able to separate biomass resources (wood, grasses, corn, urban waste) into their building blocks (carbohydrates, proteins, biogas, fats)…

…that can be converted to value added products, biofuels and chemicals.

In short:



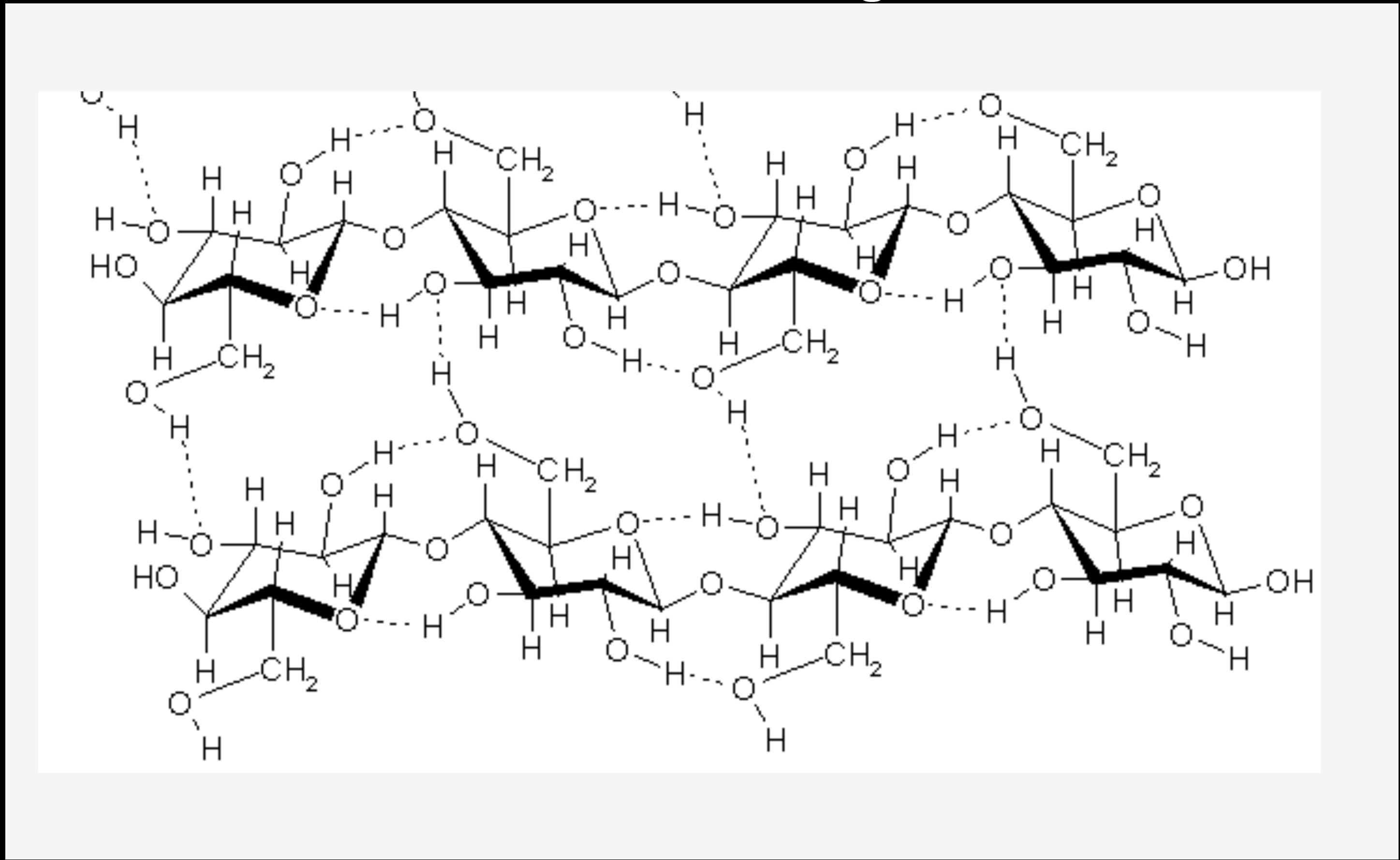
Simplified scheme of biorefinery: conversion of biomass into bioproducts.

Table 1—Most common biorefinery platforms and their major characteristics

Platform	Raw materials	Main processes	Products	Development stage
Sugar (Biochemical)	Lignocellulosic and starch biomass	Chemical and enzymatic hydrolysis, Fermentation, Biotransformation, Chemical and catalytical processes	Added value chemicals (both from sugar and lignin) Building block chemicals Materials (from lignin or lignocellulose) Fuel ethanol. Heat and electricity (from lignin)	Laboratory, large scale pilot plant and commercial (sugarcane and starch based)
Syngas (Thermochemical)	Lignocellulosic biomass but also plastics, rubber etc.	Thermochemical processes : - Gasification - Pyrolysis	Syngas Pyrolysis oil Added value chemicals Gaseous or liquid fuels	Laboratory, large scale pilot plant
Biogas	Liquid effluents Manure	Anaerobic digestion	Methane and carbon dioxide (biogas) Added value chemicals	Large scale pilot plant, commercial
Carbon-rich chains (Oil)	Plant oils such as soybean, rapeseed corn, palm, and canola oils. Animal fat	Transesterification	Fatty acid methyl ester (biodiesel), Glycerin and fatty acids as platform chemicals	Commercial

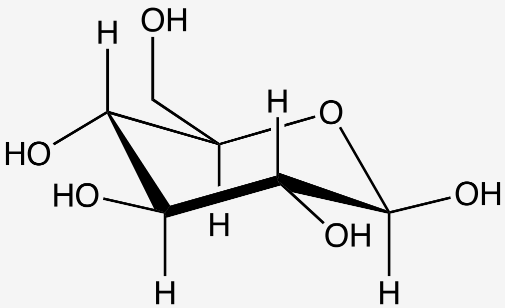
CELLULOSE

- Extensive intramolecular and intermolecular H-bonding
- Insoluble in water and most common organic solvents

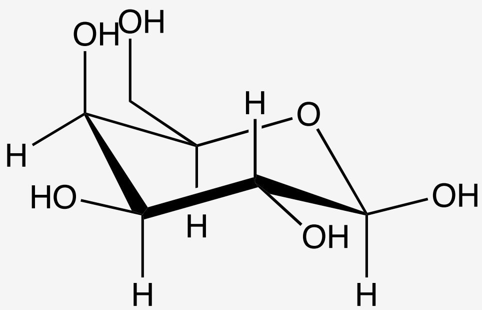


http://www.doitpoms.ac.uk/tlplib/wood/printall.php accessed on 9/03/09

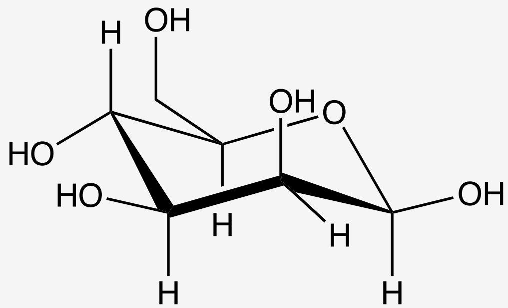
HEMICELLULOSE



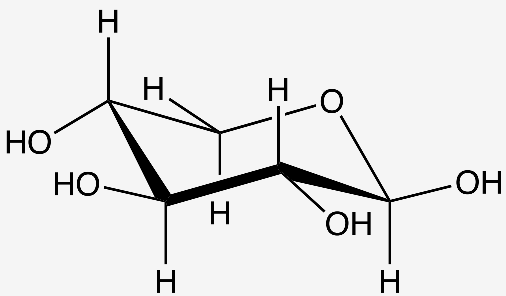
Glucose



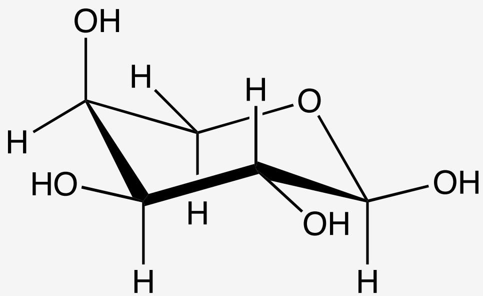
Galactose



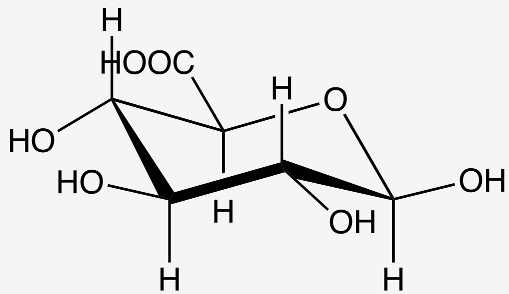
Mannose



Xylose

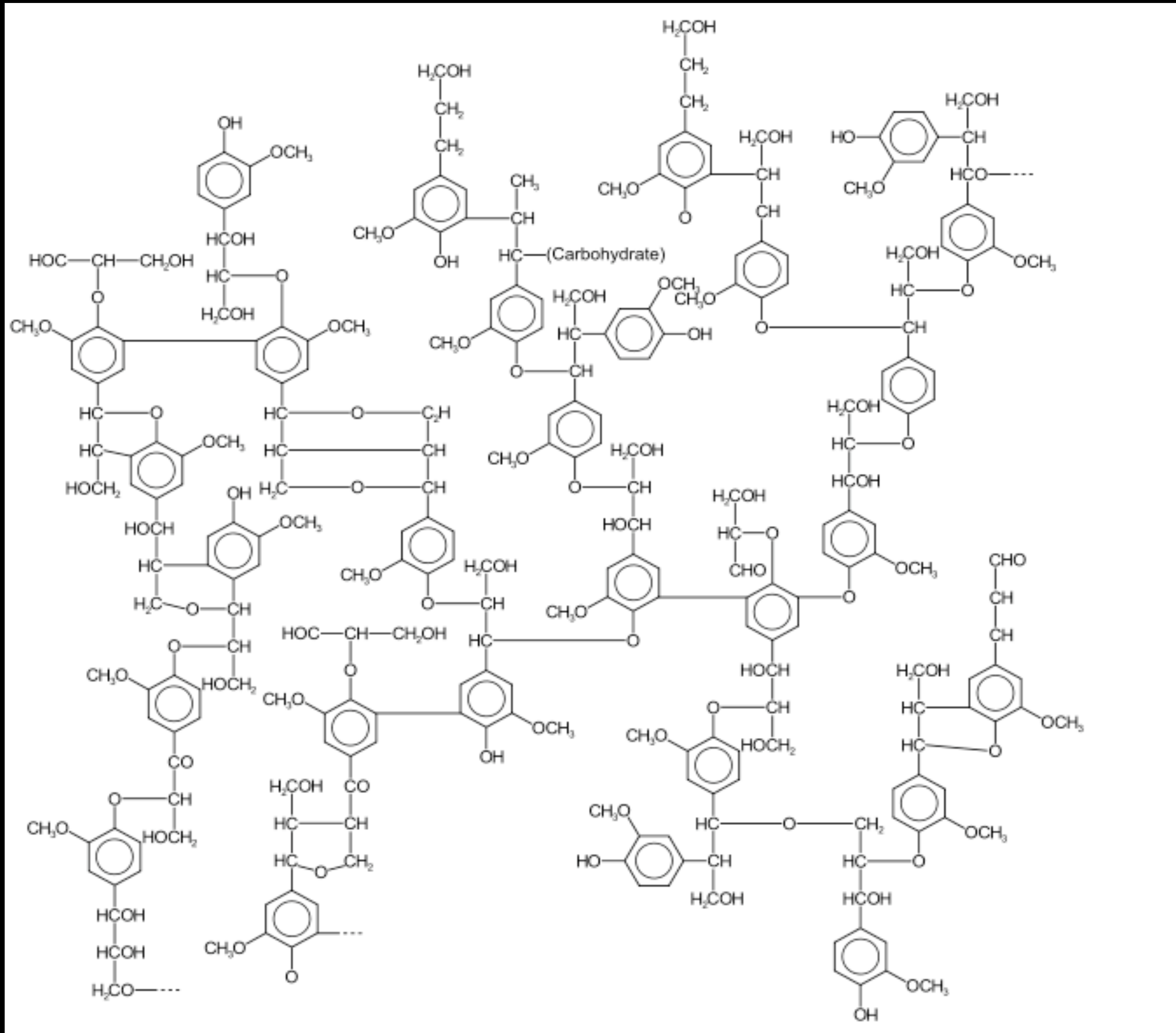


Arabinose



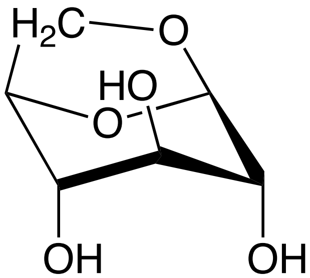
Glucuronic acid

LIGNIN

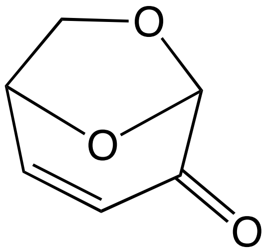


http://commons.wikimedia.org/wiki/Image:Lignin_structure.svg?uselang=ja accessed on 9/03/09

Chemical products from ligno-cellulosic materials



(1)



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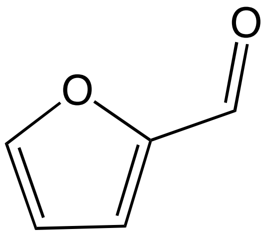

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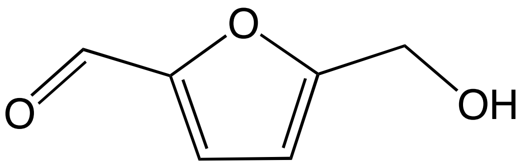

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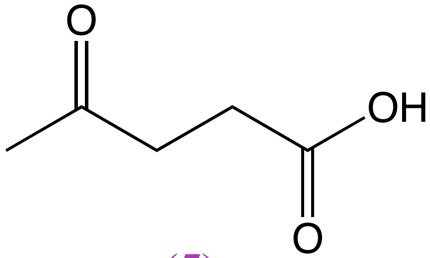
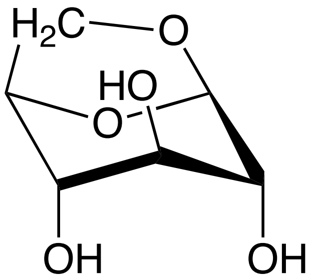


(5)

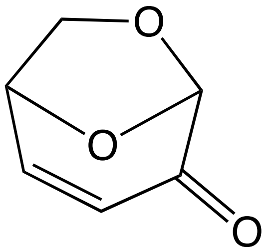
1. Levoglucosan
2. Levoglucosenone
3. Furfural
4. 5-Hydroxymethylfurfural
5. Levulinic acid

F. Shafizadeh and Y. L. Fu, *Carbohydr. Res., 1973,* ***29, 113-122.***
R. Krishna, M. R. Kallury, C. Ambridge and T. T. Tidwell, *Carbohydr. Res., 1986,* ***158, 253-261***
J. Horvat, B. Klaic, B. Metelko and V. Sunjic, *Tetrahedron Lett., 1985,* ***26, 2111-2114***

Chemical products from ligno-cellulosic materials



(1)



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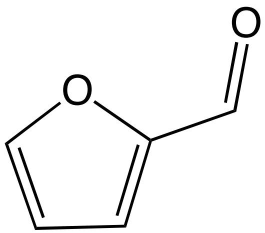
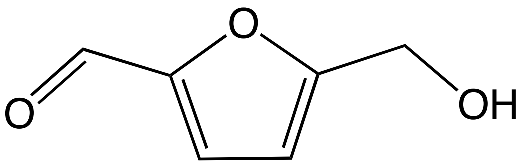


(3)

Ethyl levulinate



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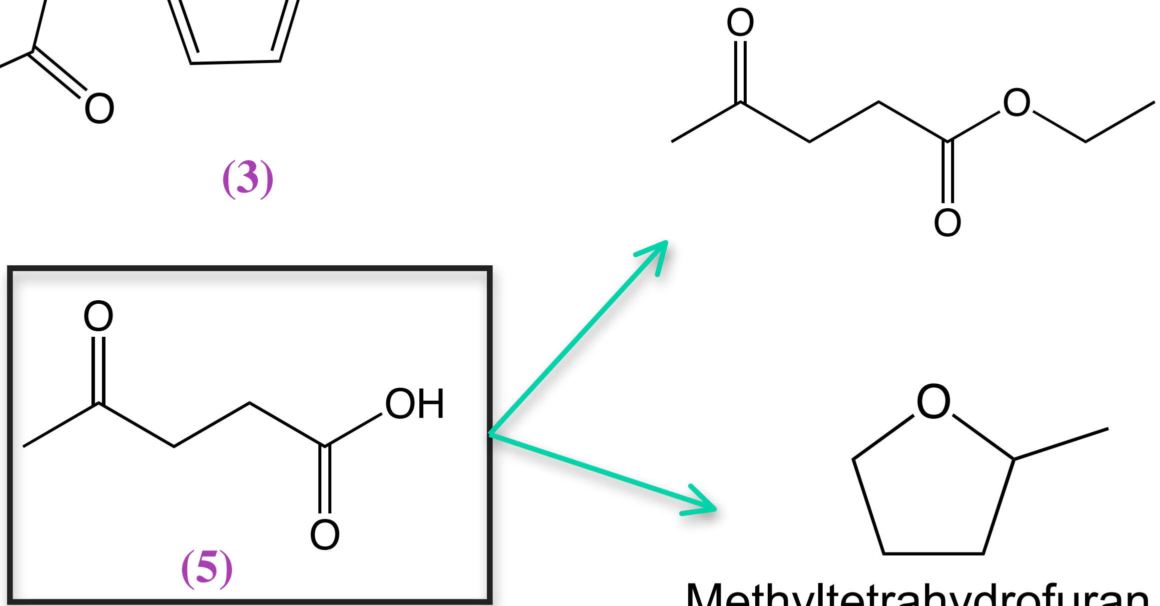
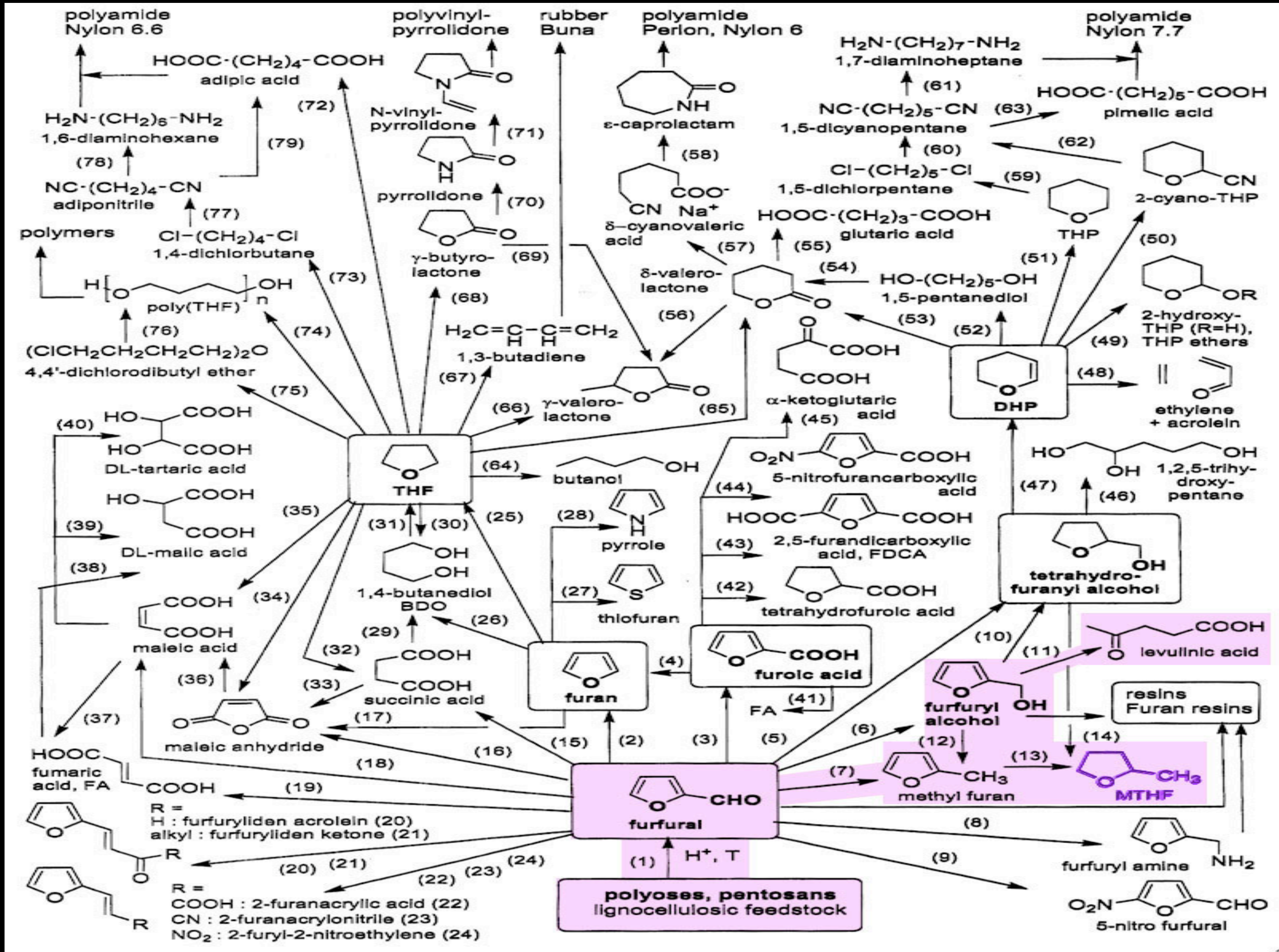


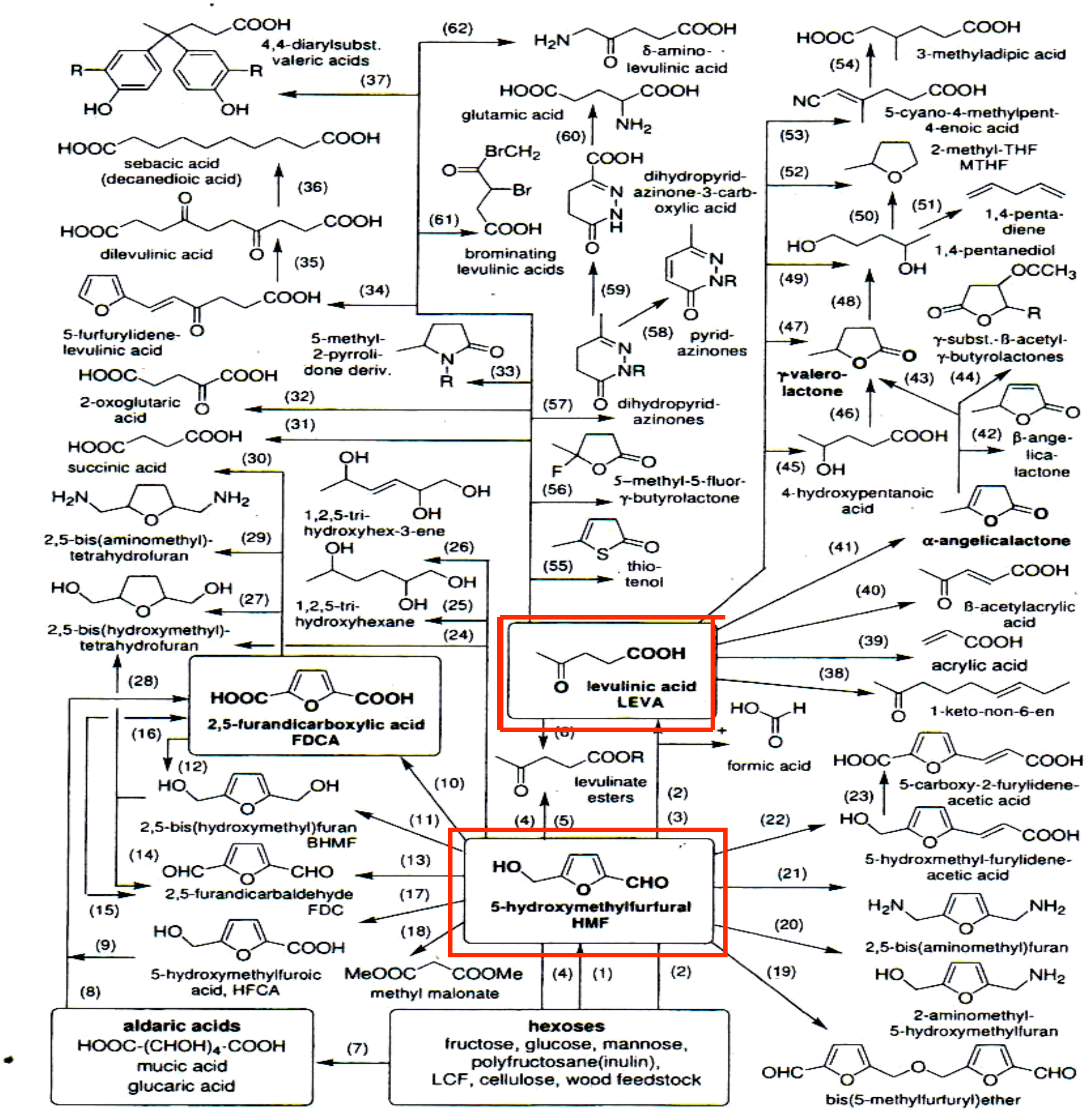
Methyltetrahydrofuran
(fuel additive)

T. Werpy and G. Petersen, U.S Department of Energy, 2004, p. 76



polyamide Nylon 6.6
HOOC-(CH2)4-COOH
adipic acid
H2N-(CH2)6-NH2
1,6-diaminohexane
NC-(CH2)4-CN
adiponitrile
Cl-(CH2)4-Cl
1,4-dichlorbutane
polymers
poly(THF)
(ClCH2CH2CH2CH2)2O
4,4'-dichlorodibutyl ether
polyvinyl-pyrrolidone
N-vinyl-pyrrolidone
pyrrolidone
γ-butyrolactone
rubber Buna
H2C=C-C=CH2
1,3-butadiene
polyamide Perlon, Nylon 6
ε-caprolactam
δ-cyanovaleric acid
δ-valerolactone
γ-valerolactone
H2N-(CH2)7-NH2
1,7-diaminoheptane
polyamide Nylon 7.7
HOOC-(CH2)5-COOH
pimelic acid
NC-(CH2)5-CN
1,5-dicyanopentane
Cl-(CH2)5-Cl
1,5-dichlorpentane
HOOC-(CH2)3-COOH
glutaric acid
HO-(CH2)5-OH
1,5-pentanediol
THP
2-cyano-THP
2-hydroxy-THP (R=H), THP ethers
α-ketoglutaric acid
DHP
ethylene + acrolein
DL-tartaric acid
DL-malic acid
maleic acid
maleic anhydride
THF
butanol
1,4-butanediol BDO
succinic acid
pyrrole
thiofuran
furan
5-nitrofurancarboxylic acid
2,5-furandicarboxylic acid, FDCA
tetrahydrofuroic acid
furoic acid
FA
1,2,5-trihydroxypentane
tetrahydrofuranyl alcohol
levulinic acid
furfuryl alcohol
resins Furan resins
methyl furan
MTHF
fumaric acid, FA
R = H : furfuryliden acrolein (20)
alkyl : furfuryliden ketone (21)
furfural
H+, T
polyoses, pentosans
lignocellulosic feedstock
R = COOH : 2-furanacrylic acid (22)
CN : 2-furanacrylonitrile (23)
NO2 : 2-furyl-2-nitroethylene (24)
furfuryl amine
5-nitro furfural

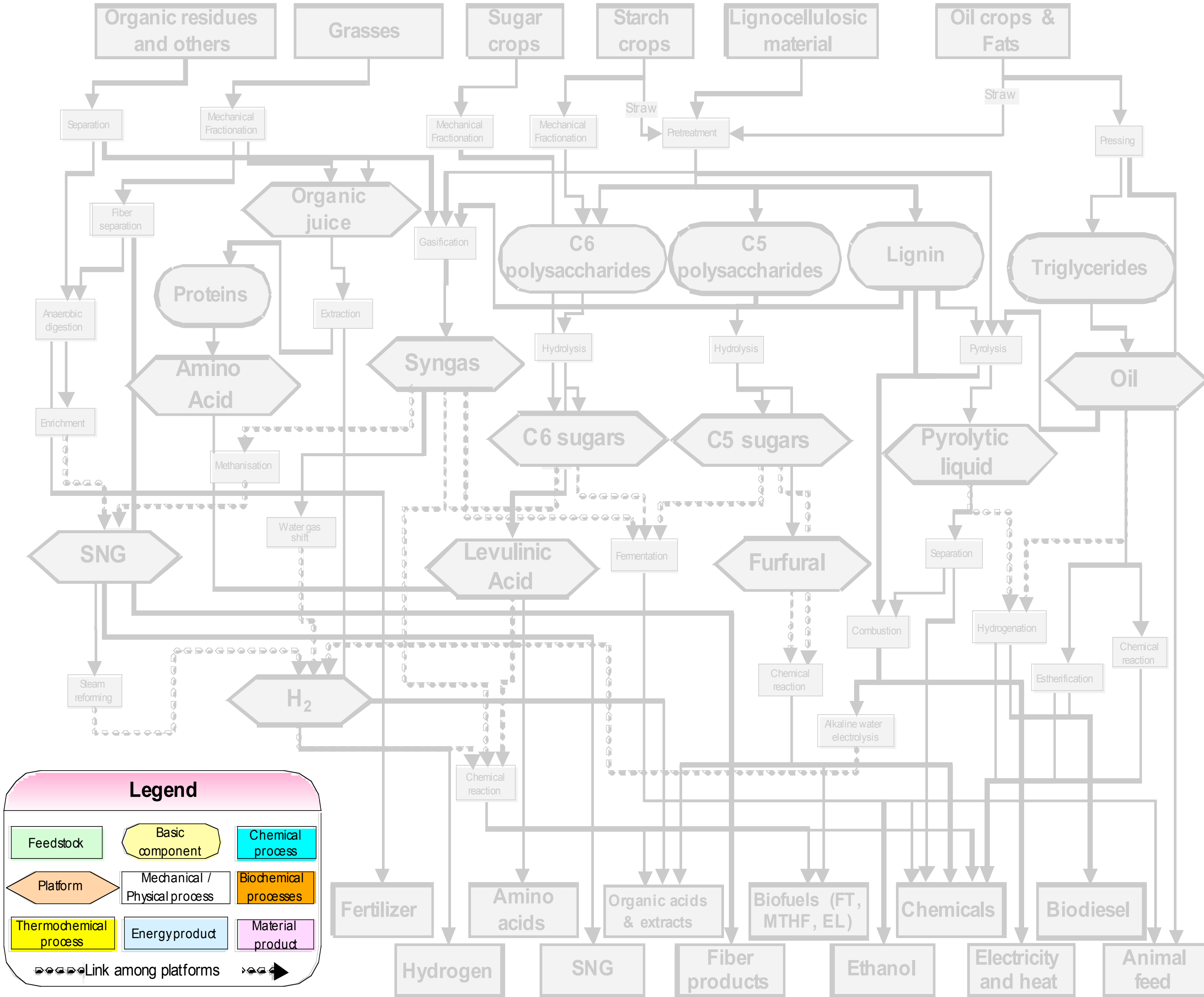
Levulinic Acid Derivatives



P.R. Gruber & M Kamm (Editors), "Biorefineries – Industrial Processes and Products, Status Quo and Future Directions, Vols 1 & 2, 2006, Wiley-VCH

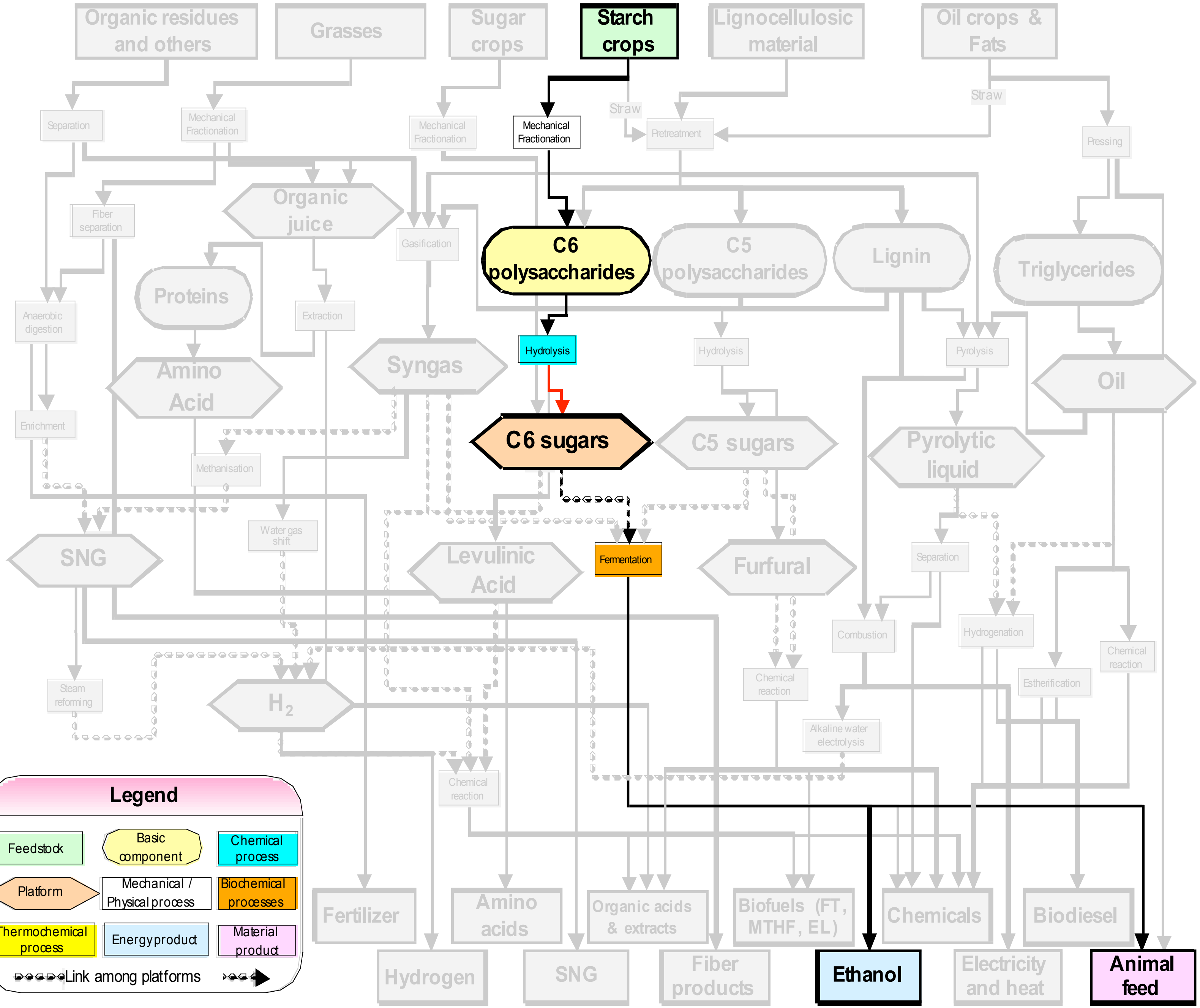
Step No. 1:

Identifying substates, intermediate products, and technological pathways

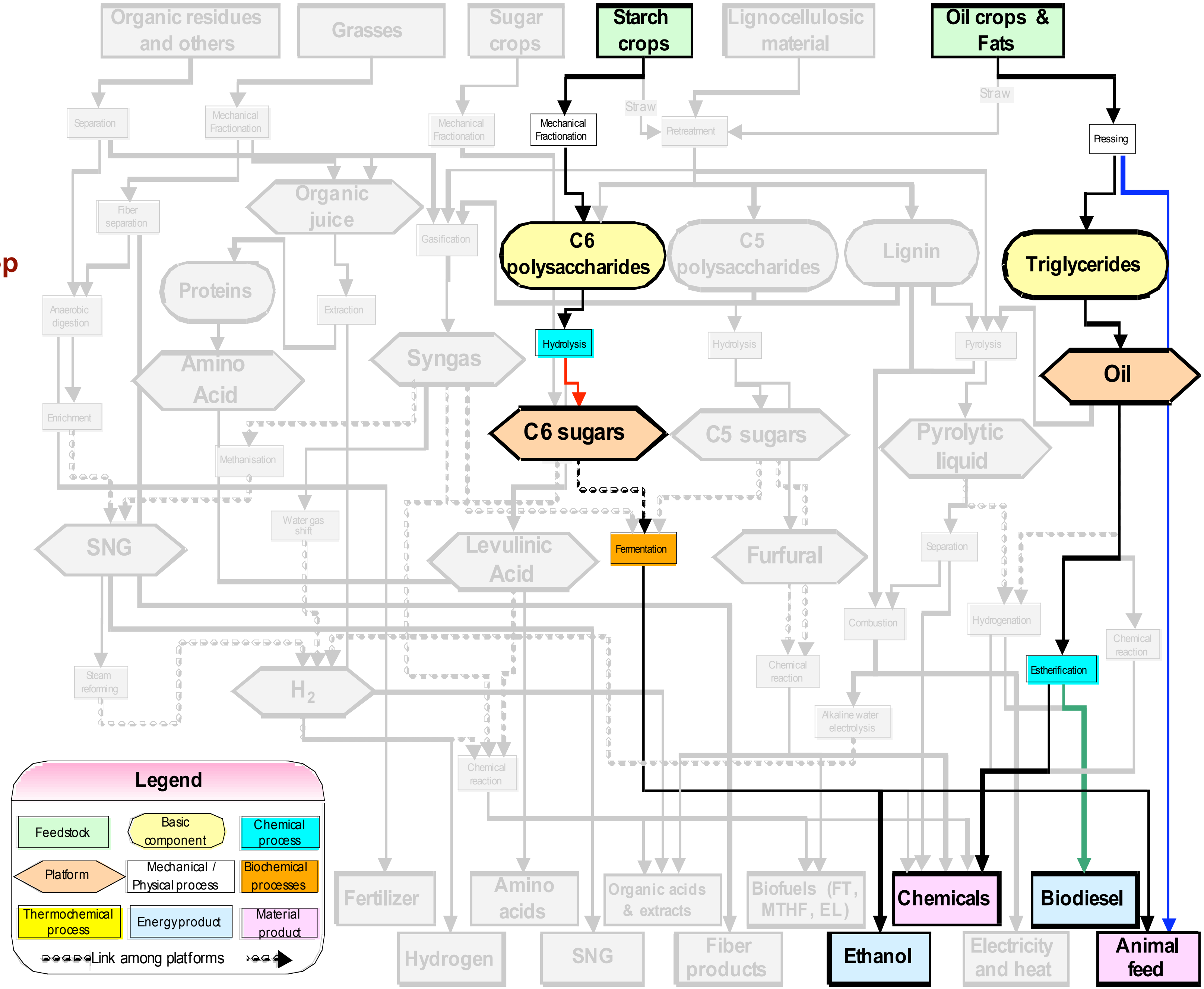


Organic residues and others
Grasses
Sugar crops
Starch crops
Lignocellulosic material
Oil crops & Fats
Separation
Mechanical Fractionation
Mechanical Fractionation
Mechanical Fractionation
Straw
Pretreatment
Straw
Pressing
Fiber separation
Organic juice
Gasification
C6 polysaccharides
C5 polysaccharides
Lignin
Triglycerides
Proteins
Extraction
Anaerobic digestion
Amino Acid
Syngas
Hydrolysis
Hydrolysis
Pyrolysis
Oil
Enrichment
Methanisation
C6 sugars
C5 sugars
Pyrolytic liquid
Water gas shift
SNG
Levulinic Acid
Fermentation
Furfural
Separation
Combustion
Hydrogenation
Chemical reaction
Esterification
Chemical reaction
Steam reforming
H2
Alkaline water electrolysis
Chemical reaction
Legend
Feedstock
Basic component
Chemical process
Platform
Mechanical / Physical process
Biochemical processes
Thermochemical process
Energy product
Material product
Link among platforms
Fertilizer
Amino acids
Organic acids & extracts
Biofuels (FT, MTHF, EL)
Chemicals
Biodiesel
Hydrogen
SNG
Fiber products
Ethanol
Electricity and heat
Animal feed

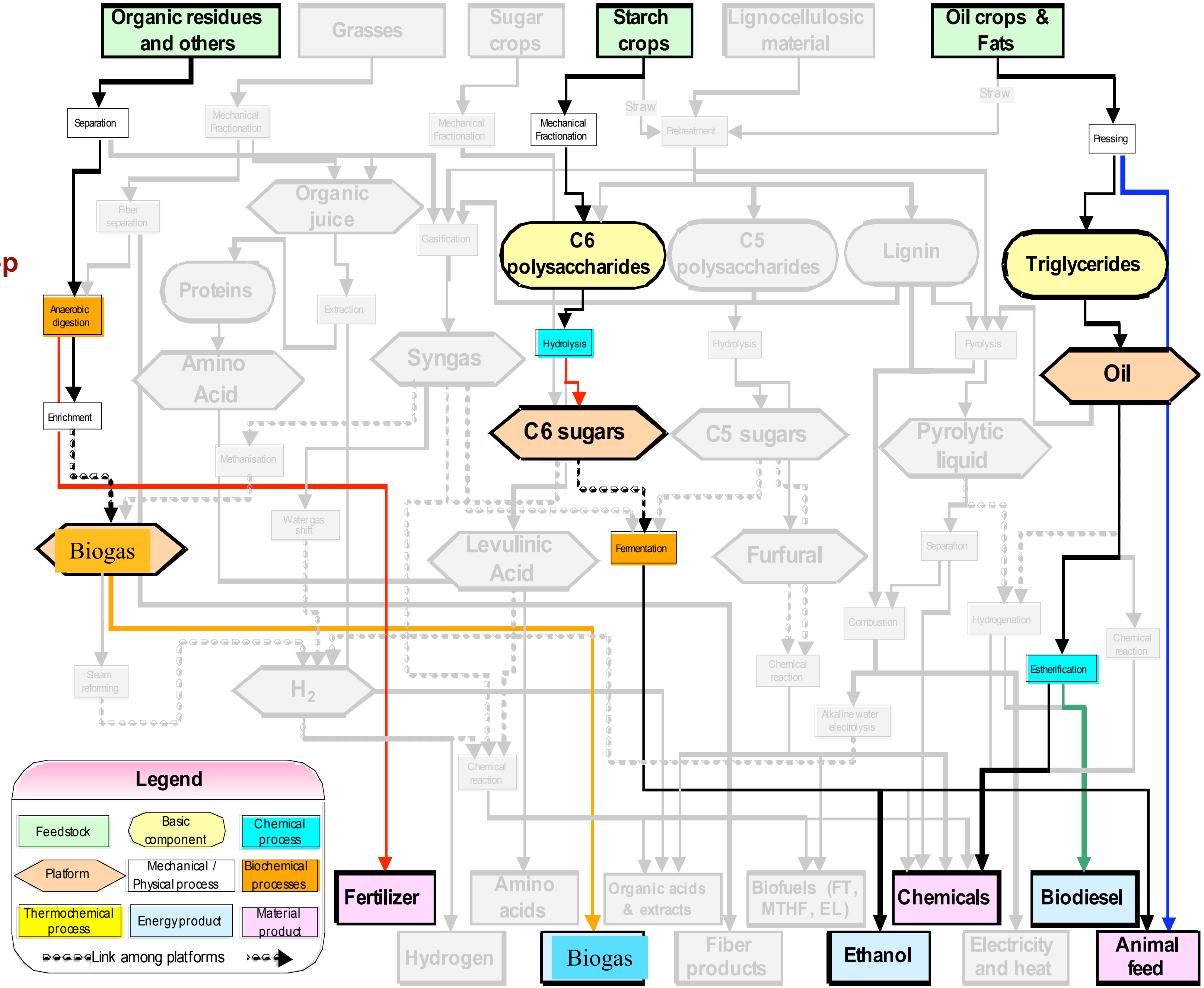
1. Bioethanol from starch



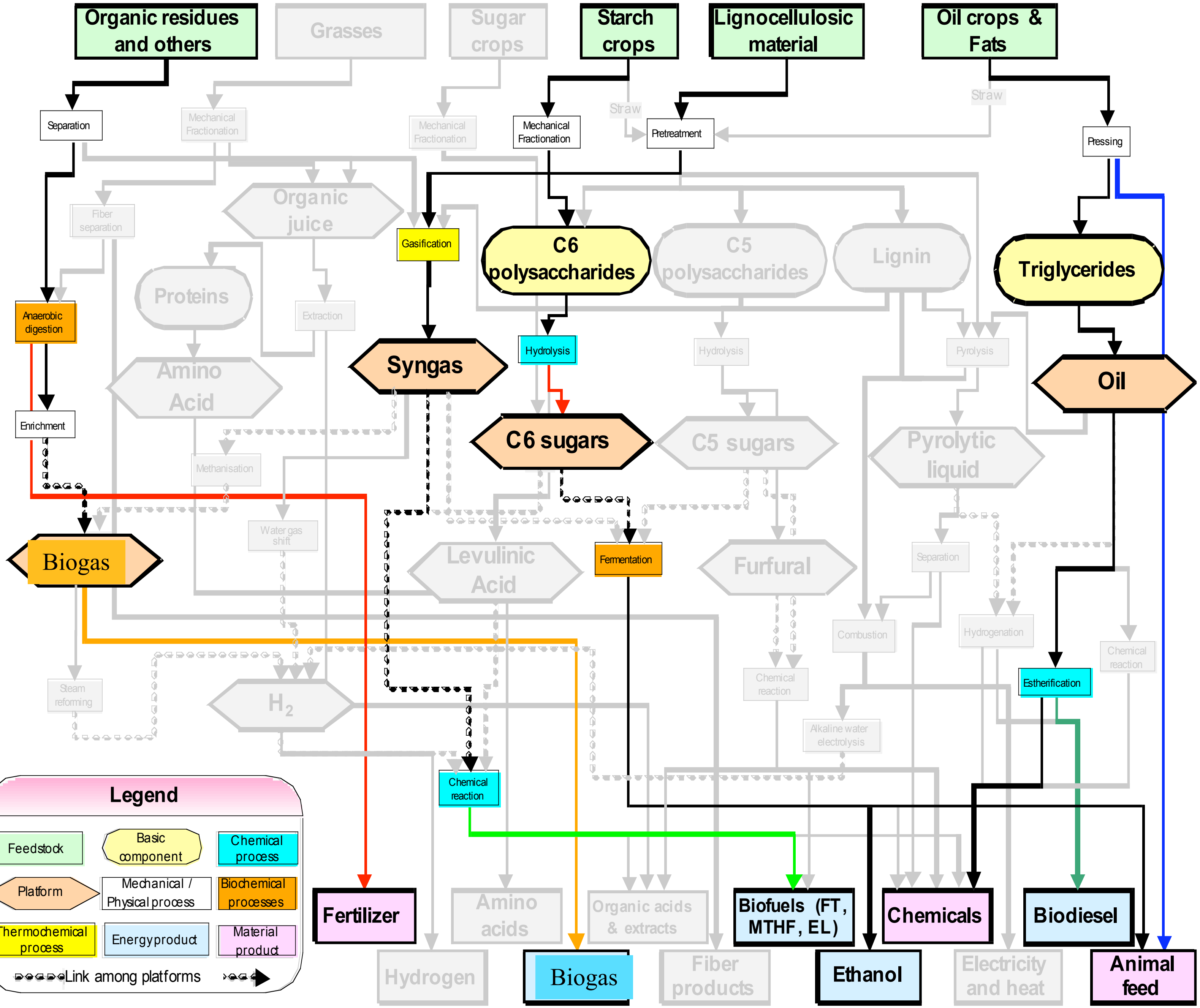
1. **Bioethanol from starch**
2. **Biodiesel from oil crop**



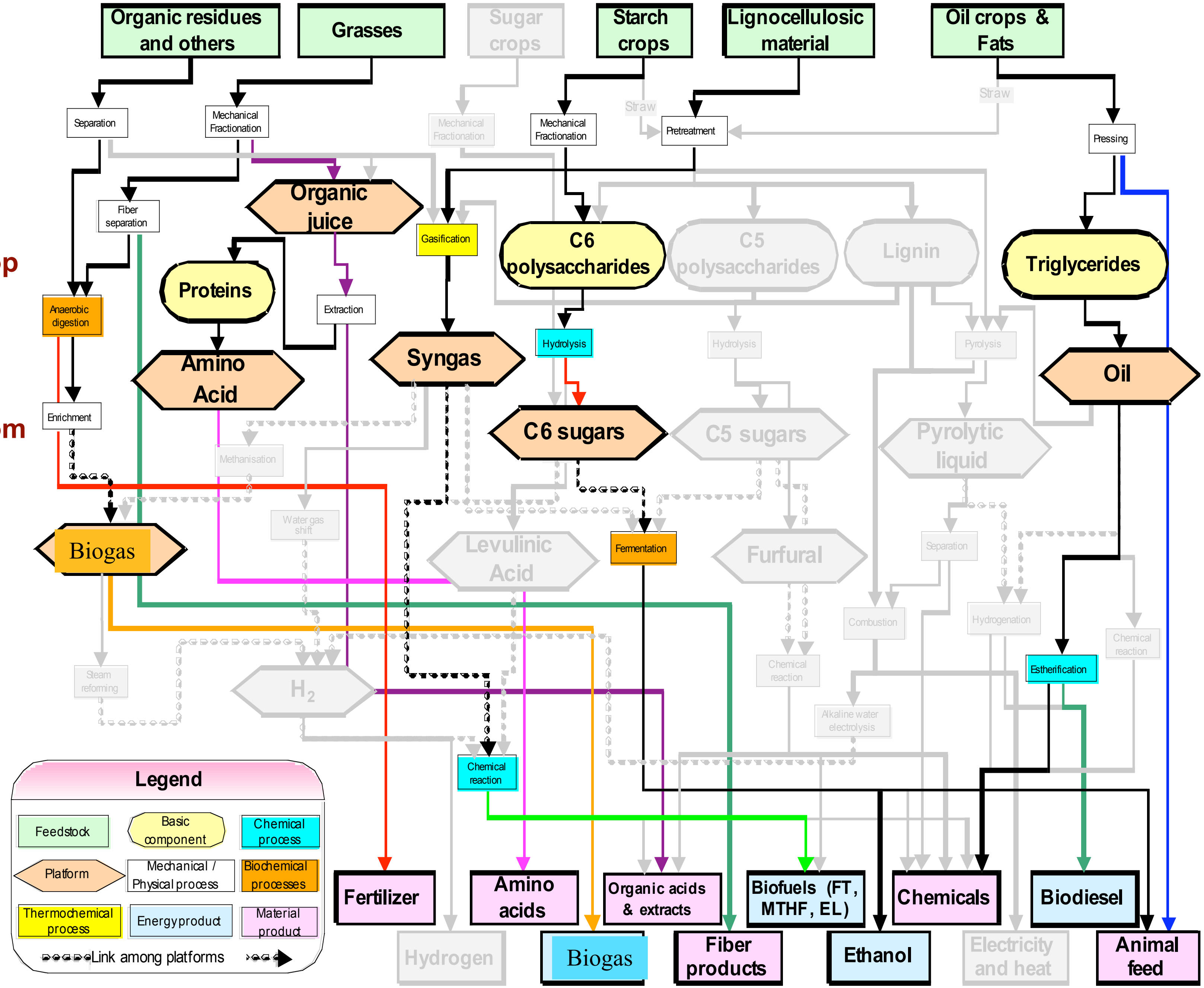
1. **Bioethanol from starch**
2. **Biodiesel from oil crop**
3. **SNG from organic residues**



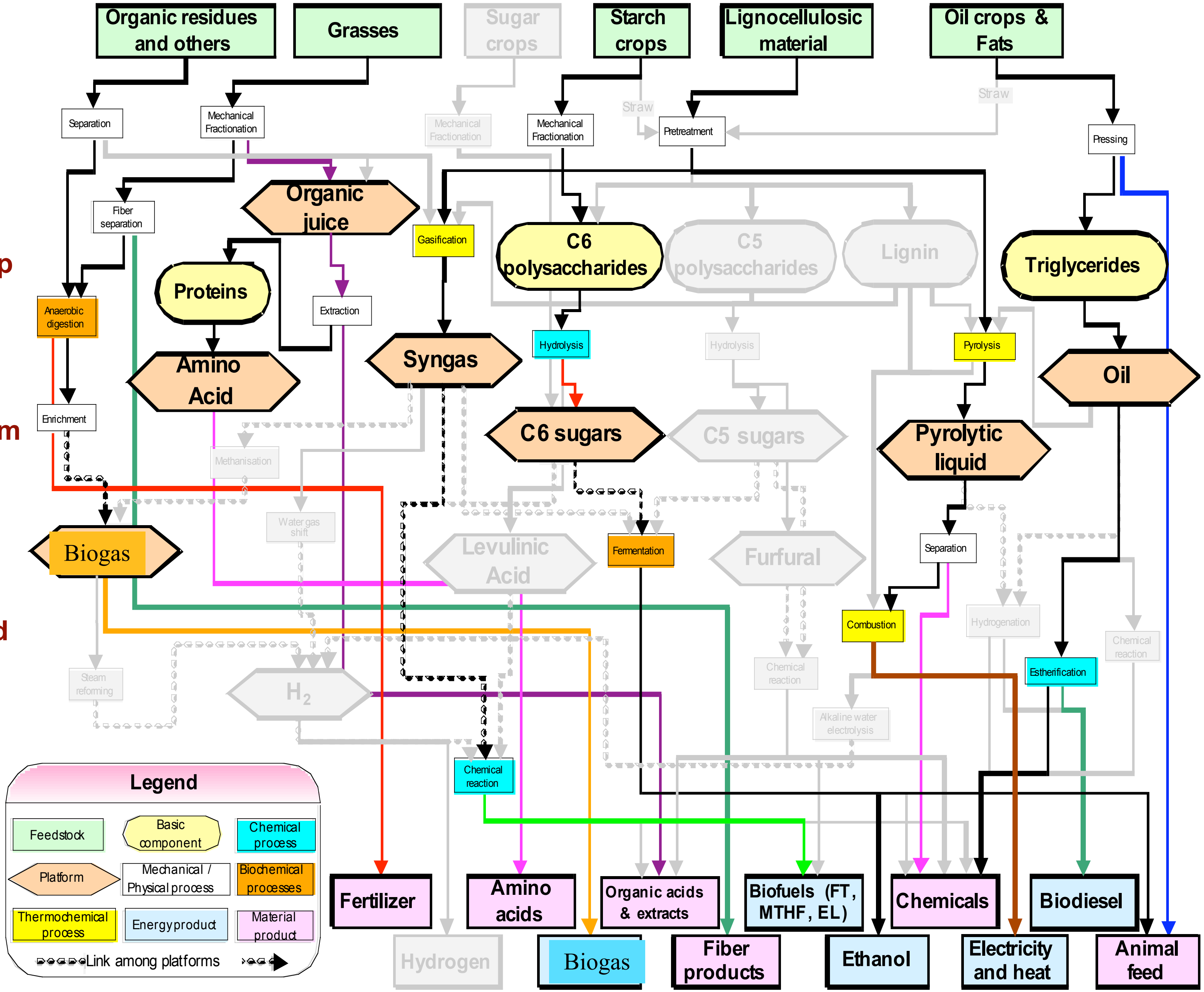
1. **Bioethanol from starch**
2. **Biodiesel from oil crop**
3. **SNG from organic residues**
4. **FT-fuels from forest residues**



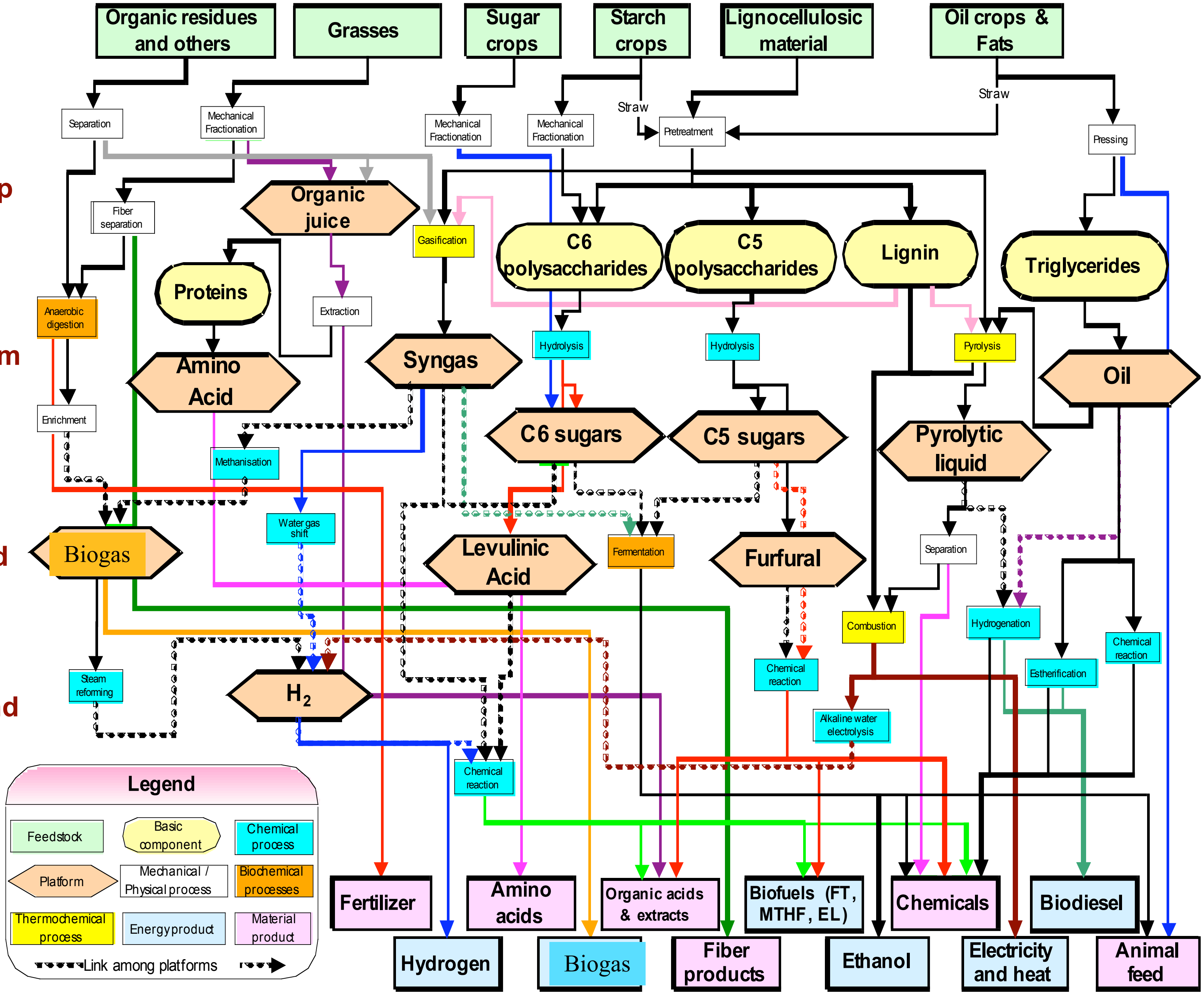
1. Bioethanol from starch
2. Biodiesel from oil crop
3. SNG from organic residues
4. FT-fuels from forest residues
5. Green Biorefinery



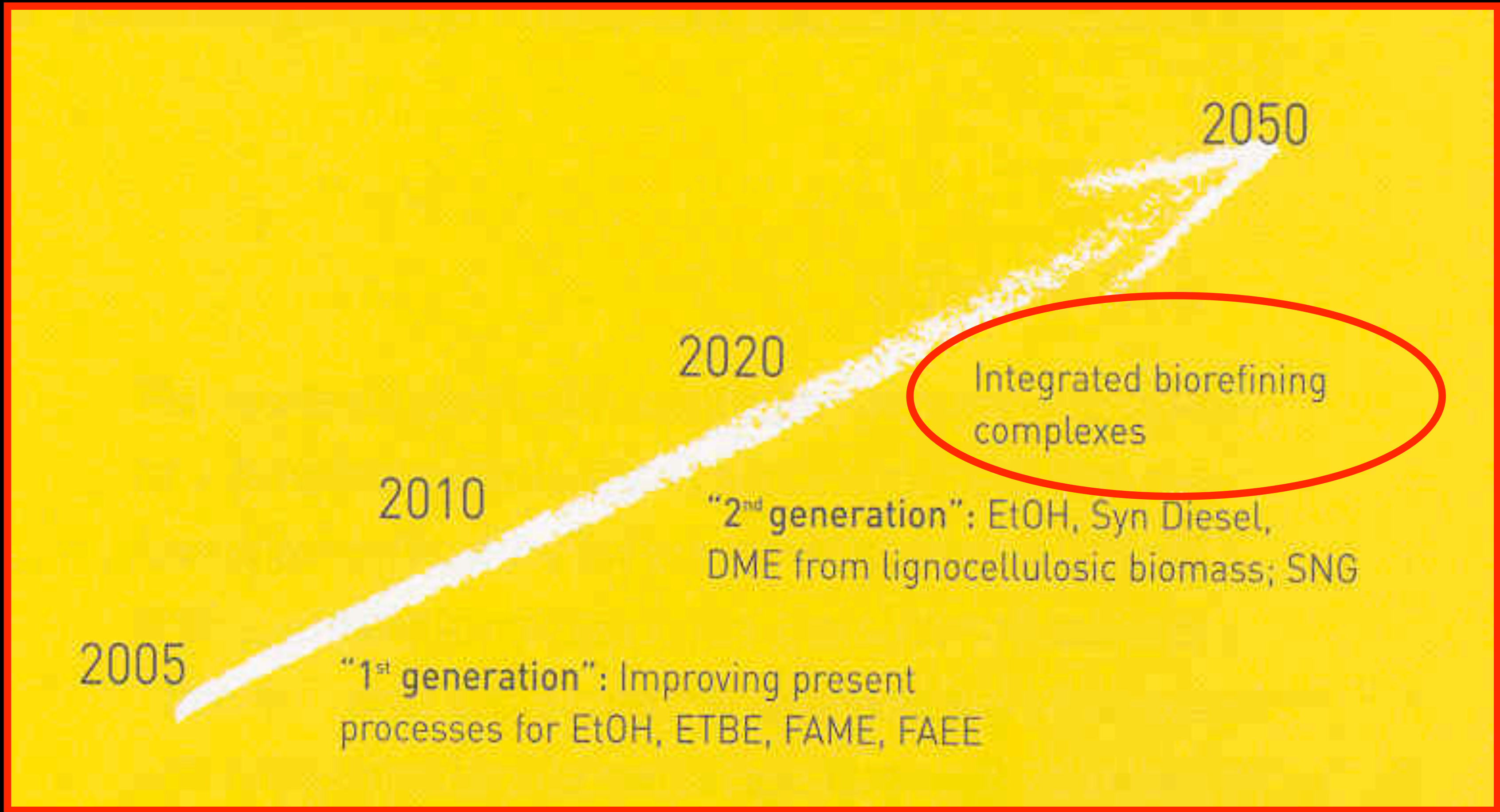
1. **Bioethanol from starch**
2. **Biodiesel from oil crop**
3. **SNG from organic residues**
4. **FT-fuels from forest residues**
5. **Green Biorefinery**
6. **Phenols and power from wood pyrolysis**



1. Bioethanol from starch
2. Biodiesel from oil crop
3. SNG from organic residues
4. FT-fuels from forest residues
5. Green Biorefinery
6. Phenols and power from wood pyrolysis
7. Hydrogen and chemicals from sugar crops



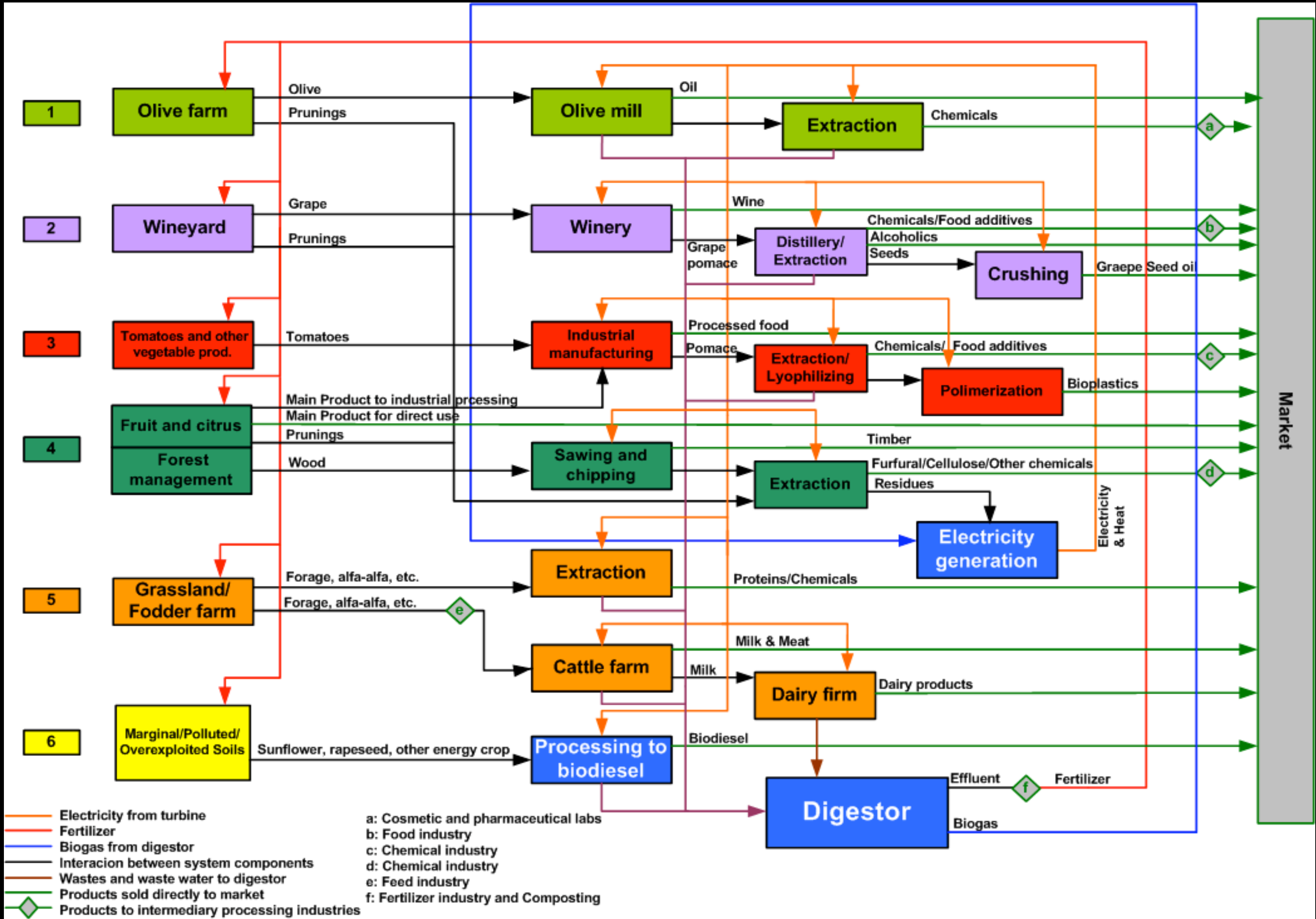
The European Union roadmap to Biorefineries (huge investments for research, 7th RTD program)



Source: Biofuels in the European Union – A vision for 2030 and beyond, Final report of the Biofuels Research Advisory Council, June 2006

Step No. 2:

Designing an integrated system



Agro-Industrial Integrated System “Parthenope” - Napoli, Italy

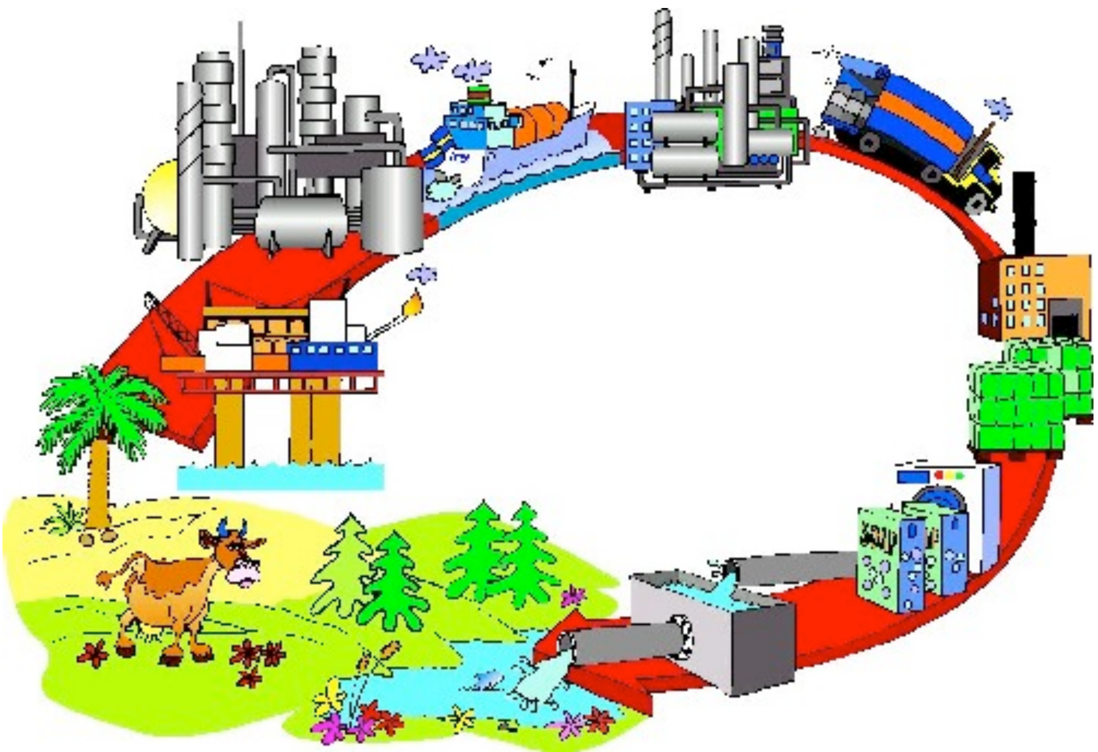
Step No. 3:

Assessing the profitability and environmental friendliness of biorefineries

A case study with LCA

Life Cycle Assessment- LCA

Life Cycle Assessment (LCA) is a technique for assessing the potential environmental aspects associated with a product (or service), by:



- **compiling an inventory of relevant inputs and outputs**
- **evaluating the potential environmental impacts associated with those inputs and outputs**
- **interpreting the results of the inventory and impact phases in relation to the objectives of the study**

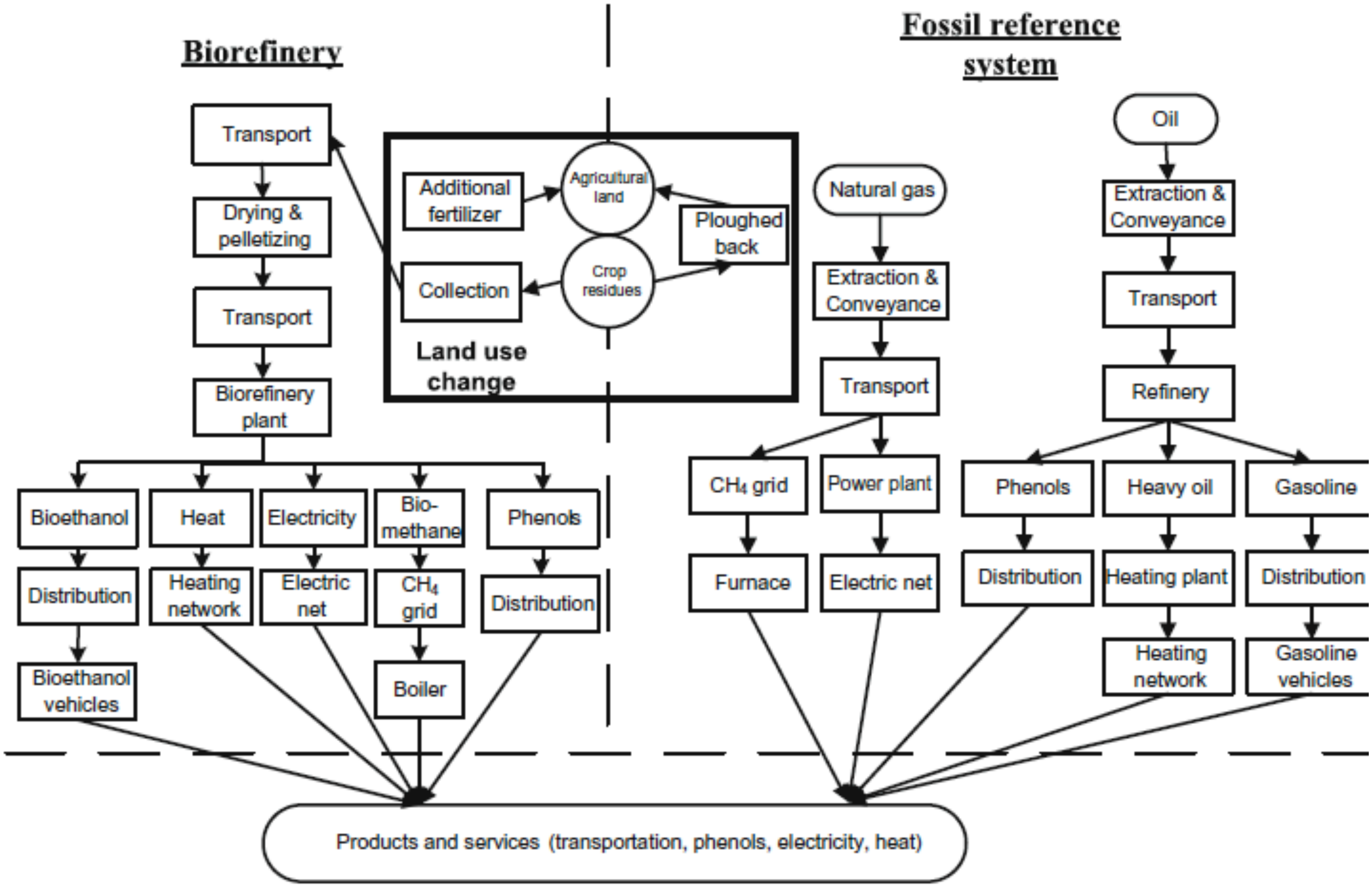


Fig. 1. Comparison between the production chains of the biorefinery and the fossil reference systems.

[redacted]

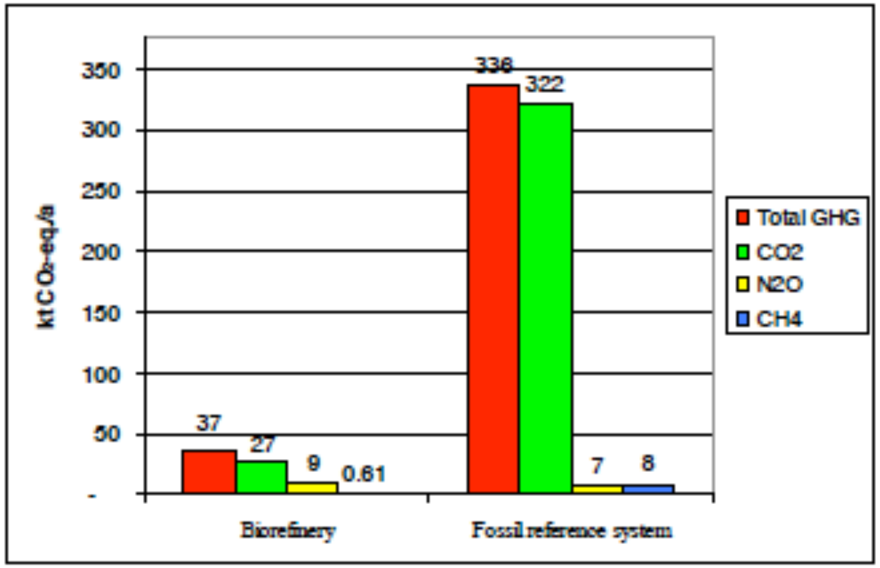
Table 4
Final products produced from the biorefinery using corn stover or wheat straw as raw materials.

Product	Unit/a	Biorefinery-Corn stover	Biorefinery-Wheat straw
Bioethanol	10^6 km	1208	1083
Heat (from biomethane)	TJ	243	350
Electricity (from CHP)	TJ	183	90.2
Heat (from CHP)	TJ	2.17	3.74
Phenols	kt	1.75	1.46

[redacted]

Table 6. Quantities of final products, GHG emissions and primary energy demand of biorefinery system and fossil reference system.

Birefinery System			Fossil Reference System		
Product/service:			Product/service:		
Transportation (bioethanol)	1,082	Mio km	Transportation (gasoline)	1,204	Mio km
Transportation (MTHF)	122	Mio km			
Furan resins	2.91	kt	Epoxy resins (from fossil)	2.91	kt
FUMA	3.34	kt	FUMA (from fossil)	3.34	kt
Electricity	333	TJ	Electricity (from natural gas)	333	TJ
Heat	224	TJ	Heat (from oil)	224	TJ
Biomethane	261	TJ	Natural gas	261	TJ
H2	13.7	TJ	H_2 (from natural gas)	13.7	TJ
O_2	7.07	kt	O_2 (conventional, from air)	7.07	kt
Fertilizer (no benefit)	36.9	kt_{dry}			
Environmental impacts:			Environmental impacts (including heat):		
Total GHG emissions	36.8	kt CO_2-eq./a	Total GHG emissions	336	kt CO_2-eq./a
CO_2	27.0	kt CO_2-eq./a	CO_2	322	kt CO_2-eq./a
N_2O	9.22	kt CO_2-eq./a	N_2O	7.27	kt CO_2-eq./a
CH_4	0.61	kt CO_2-eq./a	CH_4	7.69	kt CO_2-eq./a
Primary energy demand	10,858	TJ/a	Primary energy demand	4,772	TJ/a
Fossil	208	TJ/a	Fossil	4,736	TJ/a
Renewable (biomass)	10,495	TJ/a	Renewable	7	TJ/a
Others	16	TJ/a	Others	25	TJ/a
GHG and energy savings					
With heat credits			Environmental impacts (excluding heat):		
GHG emissions saved	300	kt CO_2-eq./a	Total GHG emissions	313	kt CO_2-eq./a
	0.66	t CO_2-eq./$t_{drywood}$	CO_2	299	kt CO_2-eq./a
Fossil energy saved	4,527	TJ/a	N_2O	6.76	kt CO_2-eq./a
	10.05	GJ/$t_{drywood}$	CH_4	7.15	kt CO_2-eq./a
Excluding heat credits					
GHG emissions saved	276	kt CO_2-eq./a	Primary energy demand	4,474	TJ/a
	0.61	t CO_2-eq./$t_{drywood}$	Fossil	4,440	TJ/a
Fossil energy saved	4,231	TJ/a	Renewable	6	TJ/a
	9.39	GJ/$t_{drywood}$	Others	24	TJ/a



Comparison between GHGs of biorefinery and fossil reference system.

Table 5
GHG emissions and savings of the biorefinery systems in comparison with their respective fossil reference systems.

	Unit/a	Corn stover	Fossil reference system	Wheat straw	Fossil reference system
GHG emissions					
Total	kt CO_2-eq.	137	296	130	255
CO_2	kt CO_2-eq.	107	280	113	242
N_2O	kt CO_2-eq.	26.3	6.51	13.3	5.79
CH_4	kt CO_2-eq.	3.89	10.5	3.88	7.7
GHG savings					
Per year	kt CO_2-eq.	159		125	
Per year	%	53.7		49.0	
Per t_{dry} feedstock	t CO_2-eq./t_{dry}	333		262	
Per hectare	t CO_2-eq./ha	3.01		1.82	

Table 6
Results of the CML impact assessment method.

Impact category	Unit	Biorefinery corn stover	Fossil reference system	Biorefinery wheat straw	Fossil reference system
Abiotic depletion	kt Sb eq	0.30	2.09	0.35	1.78
Global warming (GWP100)	kt CO_2-eq	137	296	130	255
Ozone layer depletion (ODP)	kg CFC-11 eq	8.31	29.7	8.86	26.9
Human toxicity	kt 1,4-DB eq	24.7	192	25.6	167
Fresh water aquatic ecotox.	kt 1,4-DB eq	2.54	17.4	2.90	14.8
Marine aquatic ecotoxicity	Mt 1,4-DB eq	17.7	51.2	20.1	44.5
Terrestrial ecotoxicity	kt 1,4-DB eq	0.22	0.60	0.28	0.54
Photochemical oxidation	kt C_2H_4	0.06	0.28	0.05	0.25
Acidification	kt SO_2 eq	0.93	1.16	0.78	1.03
Eutrophication	kt PO_4-eq	0.52	0.17	0.39	0.15

Step No. 4

Expanding the focus of the assessment:

a) thermodynamic efficiency (exergy),
b) demand for environmental support (eMergy), and
c) economic feasibility.

An extended LCA

Multidimensional Life Cycle Assessment

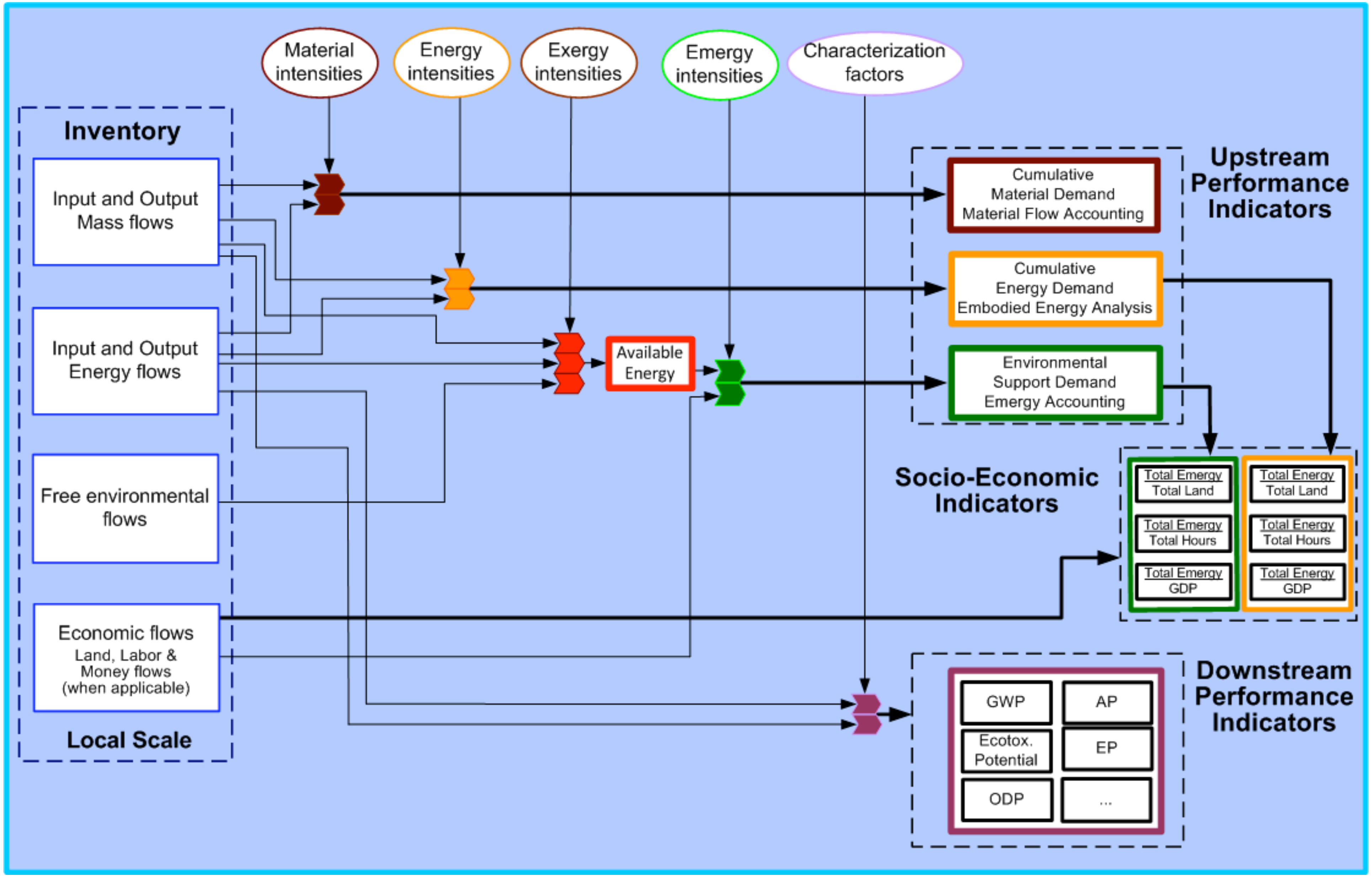
1. LCA → Matter and energy flows

2. Extended LCA: SUMMA

SUstainability Multimethod Multiscale Approach

SUMMA → LCA + process efficiency + environmental support + embodied time + money flows

SUstainability Multimethod Multiscale Approach



Step No. 5: Marginal and polluted land (GIS - Geographical Information System)

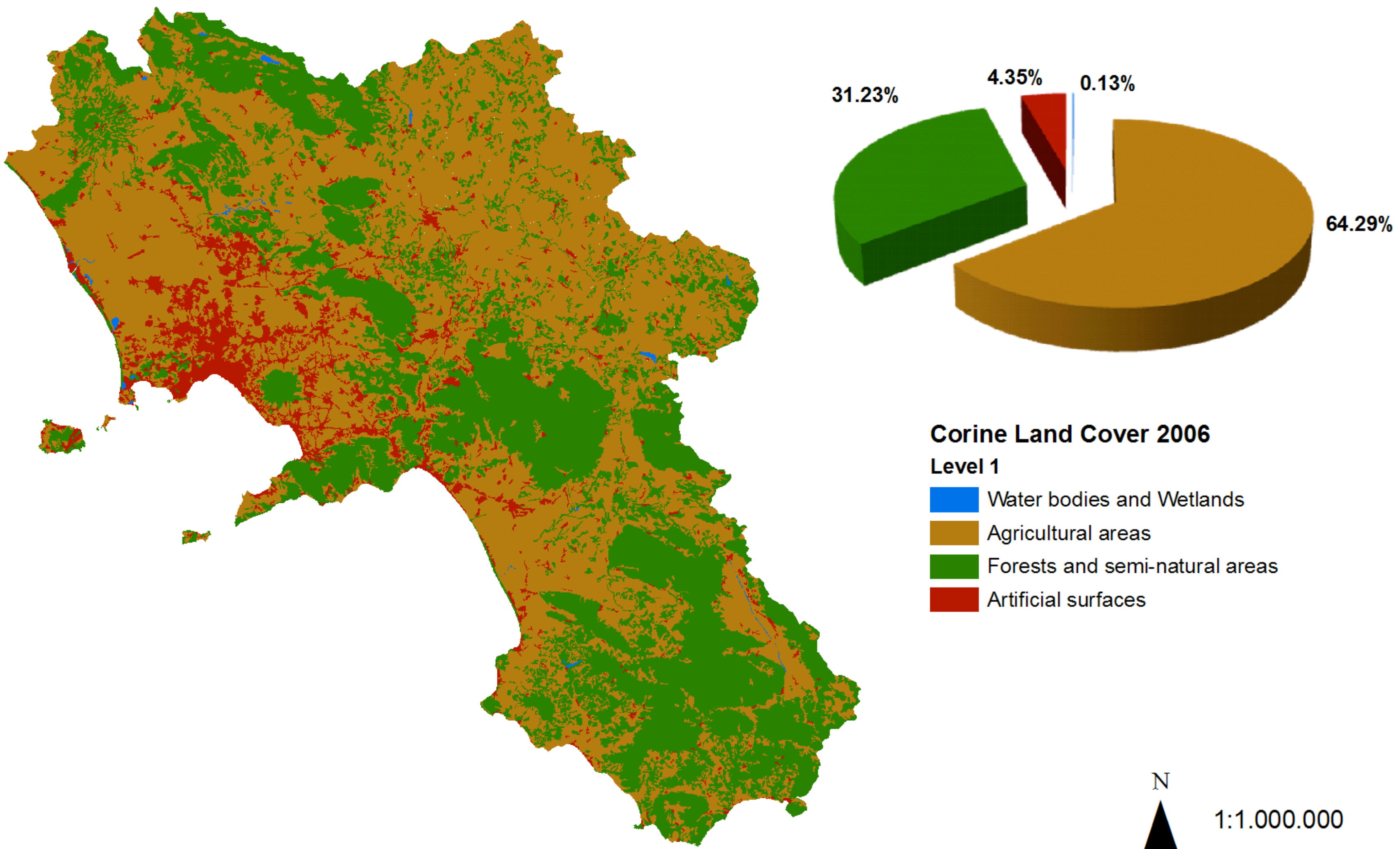
Case study:

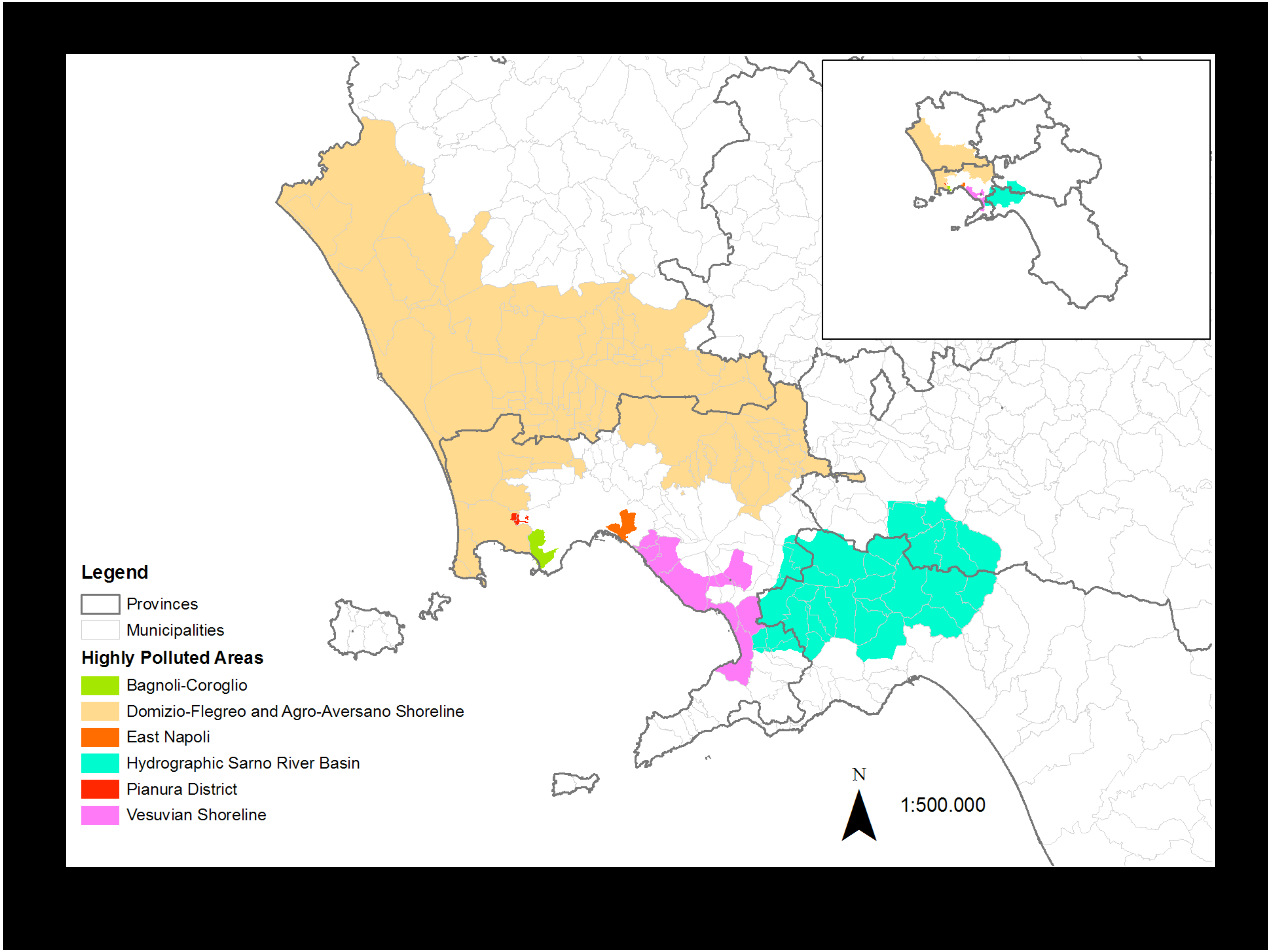
Non-food crops on land unsuitable for agriculture.

a) Cropping for energy

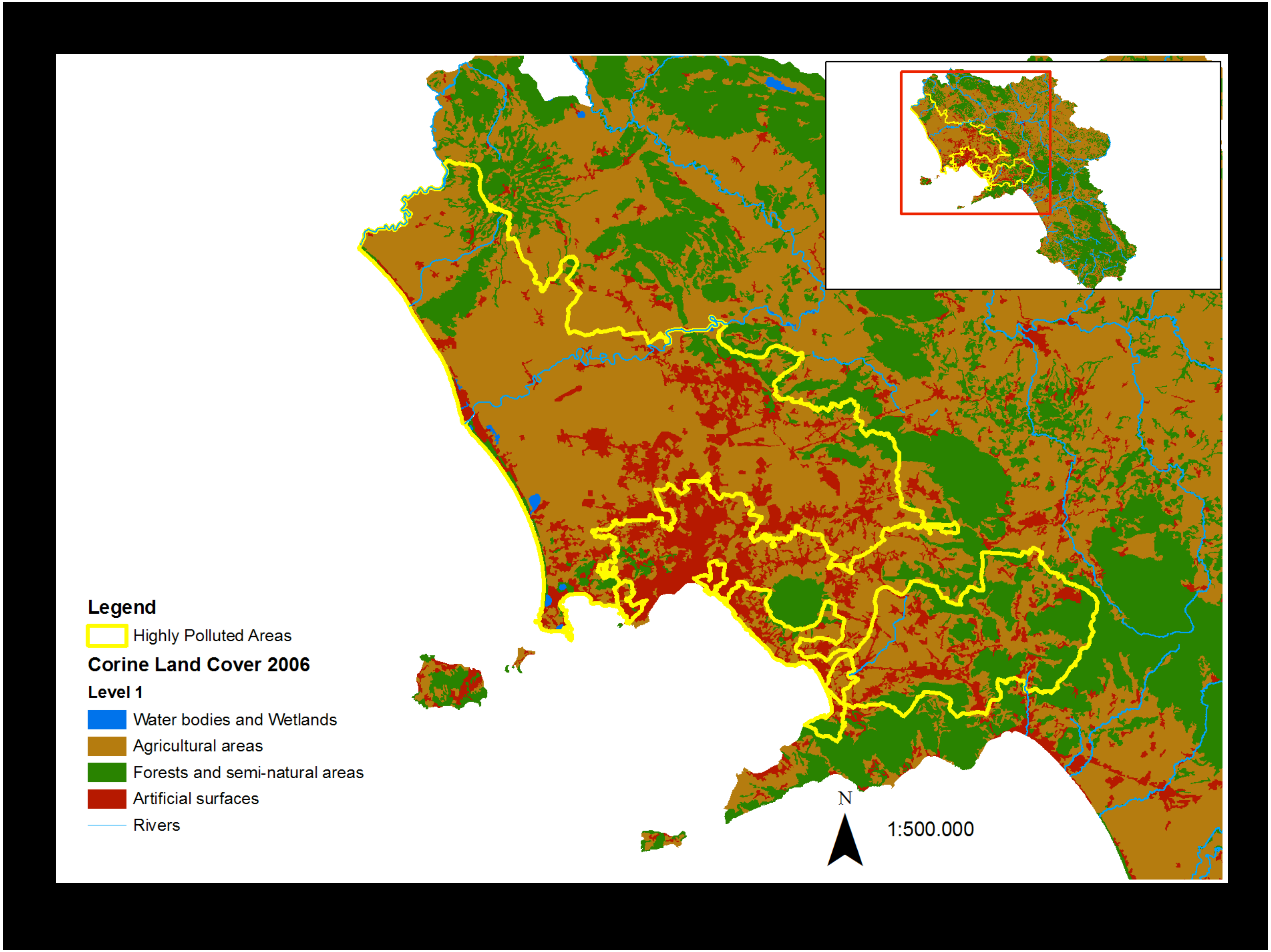
b) Biorefinery, the Biofine process

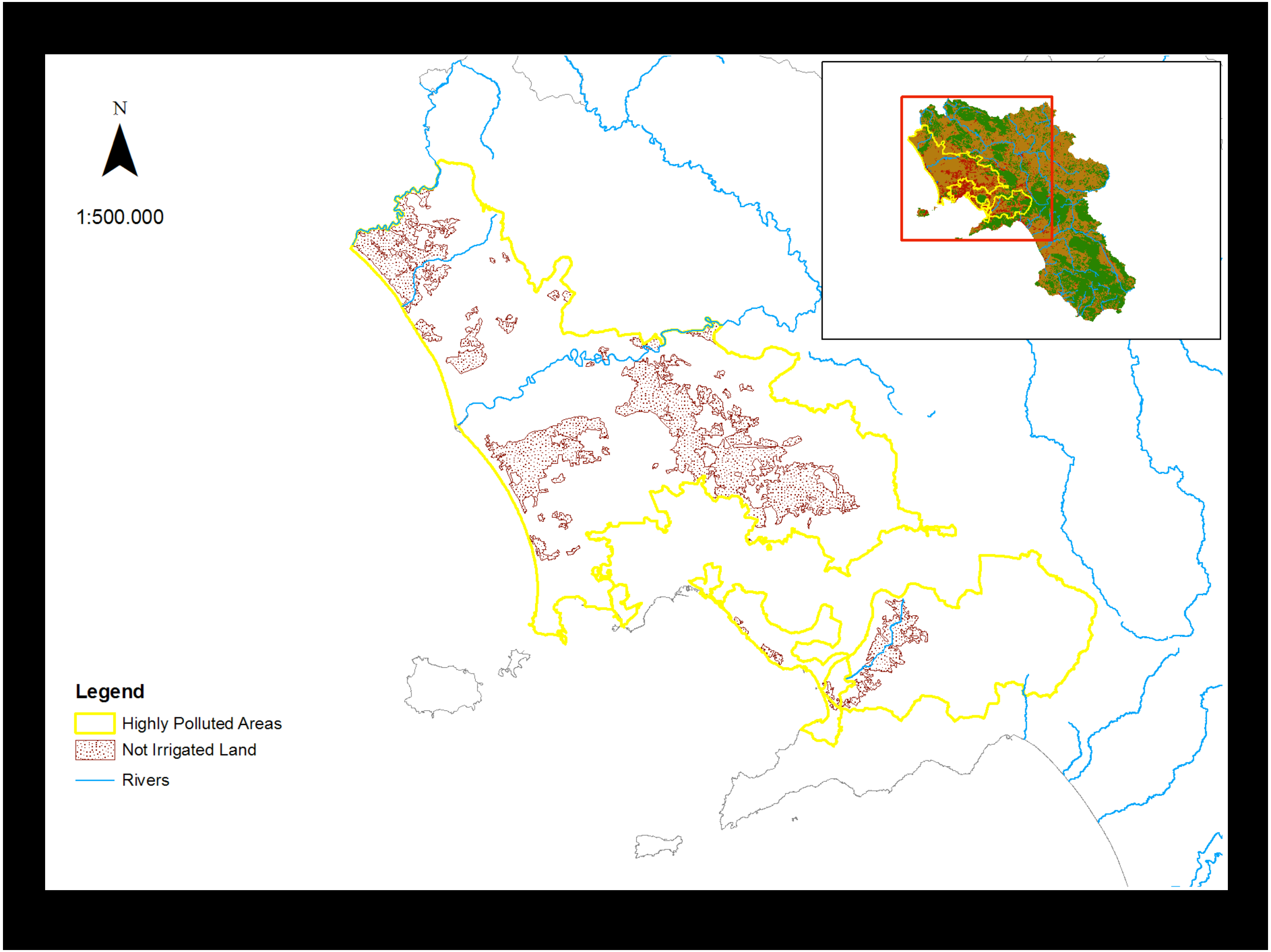
Land Use in Campania Region





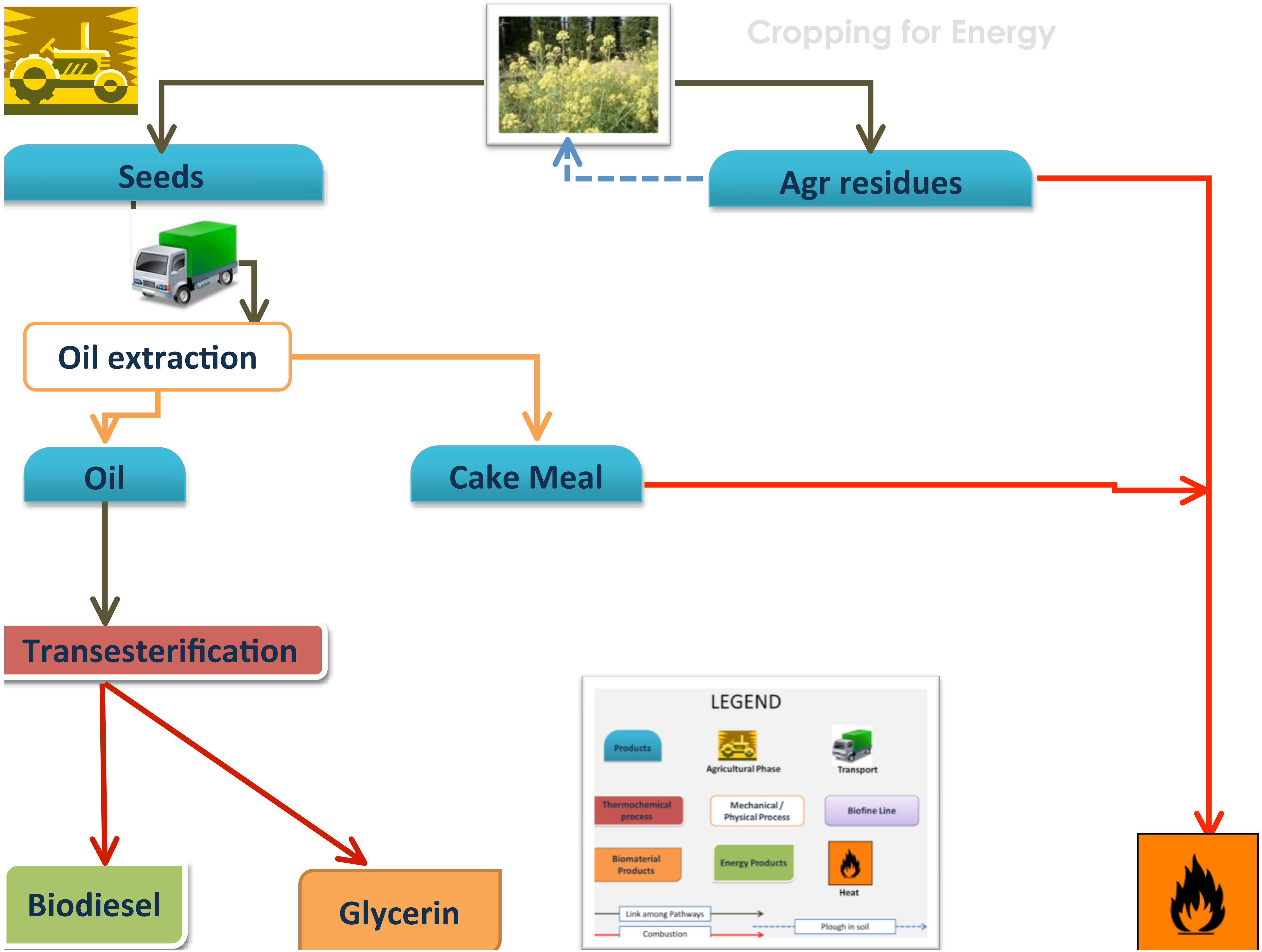
Legend
Provinces
Municipalities
Highly Polluted Areas
Bagnoli-Coroglio
Domizio-Flegreo and Agro-Aversano Shoreline
East Napoli
Hydrographic Sarno River Basin
Pianura District
Vesuvian Shoreline
N
1:500.000


Legend
Highly Polluted Areas
Corine Land Cover 2006
Level 1
Water bodies and Wetlands
Agricultural areas
Forests and semi-natural areas
Artificial surfaces
Rivers
N
1:500.000


N
1:500.000
Legend
Highly Polluted Areas
Not Irrigated Land
Rivers

2. Ethiopian Mustard or *Brassica carinata*

- Differ … a semi-arid ter…
- Low …
- Low …
- Prom … entral-souther…
- Oppo … as for energe…



Cropping for Energy
Seeds
Agr residues
Oil extraction
Oil
Cake Meal
Transesterification
Biodiesel
Glycerin
LEGEND
Products
Agricultural Phase
Transport
Thermochemical process
Mechanical / Physical Process
Biofine Line
Biomaterial Products
Energy Products
Heat
Link among Pathways
Combustion
Plough in soil

Usable and Net Energy Delivered to the user by all the co-products of the different phases of biodiesel production chain (data per hectare).

		Energy content (J/ha/yr)	Usable Energy (for residues 50% less than HHV) (J/ha/yr)	Transportation of residues (5% of energy content) (J/ha/yr)	Usable Energy Delivered (J/ha/yr)	Net Energy Delivered (J/ha/yr)
Low Input	Invested for process	1.82E+10				
	Biodiesel	1.46E+10	1.46E+10	7.30E+08	1.39E+10	
	Cake meal	1.17E+10	5.85E+09	5.85E+08	5.27E+09	
	Straw	4.36E+10	2.18E+10	2.18E+09	1.96E+10	
	Delivered				**3.88E+10**	**2.06E+10**
High Input	Invested for process	2.59E+10				
	Biodiesel	2.06E+10	2.06E+10	1.03E+09	1.96E+10	
	Cake meal	1.66E+10	8.30E+09	8.30E+08	7.47E+09	
	Straw	5.51E+10	2.76E+10	2.76E+09	2.48E+10	
	Delivered				**5.19E+10**	**2.60E+10**

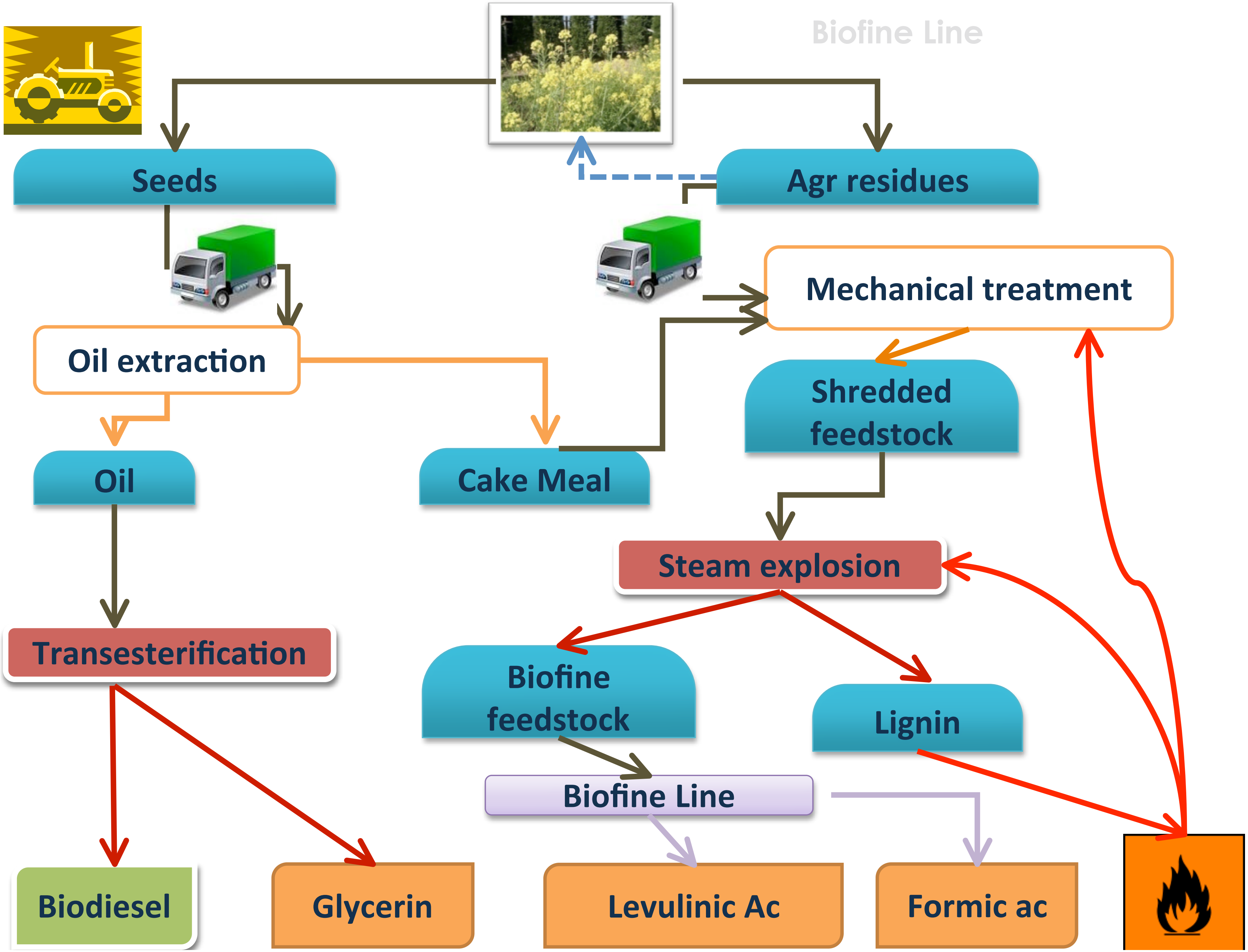
Net Energy Delivered (NED) by the biodiesel production chain and fractions of agricultural and regional energy consumption potentially replaced

.

	Low Input (J/yr)	High Input (J/yr)
Total NED from polluted areas	8.90E+14	1.12E+15
% of energy budget of Campania region	0.33%	0.41%
% of energy budget of regional agricultural sector	10.63%	13.41%

Economic balance between the total economic investment for biodiesel and heat production chain and the saving of economic investment associated to such bio-energy in marginal land.

	Low Input (€/yr)	High Input (€/yr)
Total Economic Investment (a)	3.78E+07	4.62E+07
Value of delivered energy (b)	9.68E+06	1.22E+07
Economic Balance (b-a)	-2.81E+07	-3.40E+07
Ratio a/b	3.90	3.79

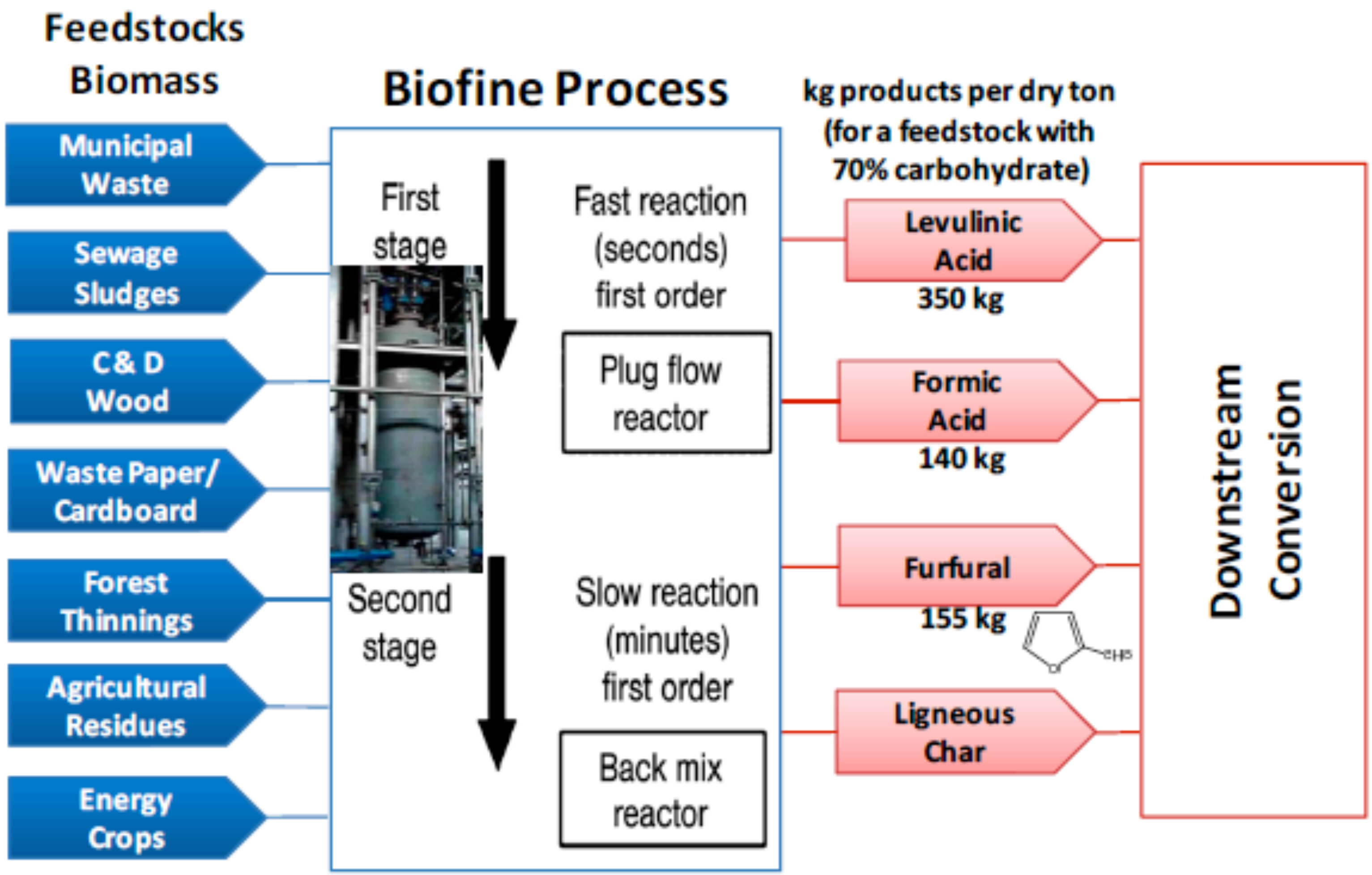


Biofine Line
Seeds
Agr residues
Mechanical treatment
Oil extraction
Shredded feedstock
Oil
Cake Meal
Steam explosion
Transesterification
Biofine feedstock
Lignin
Biofine Line
Biodiesel
Glycerin
Levulinic Ac
Formic ac

An Example: The Biofine Process

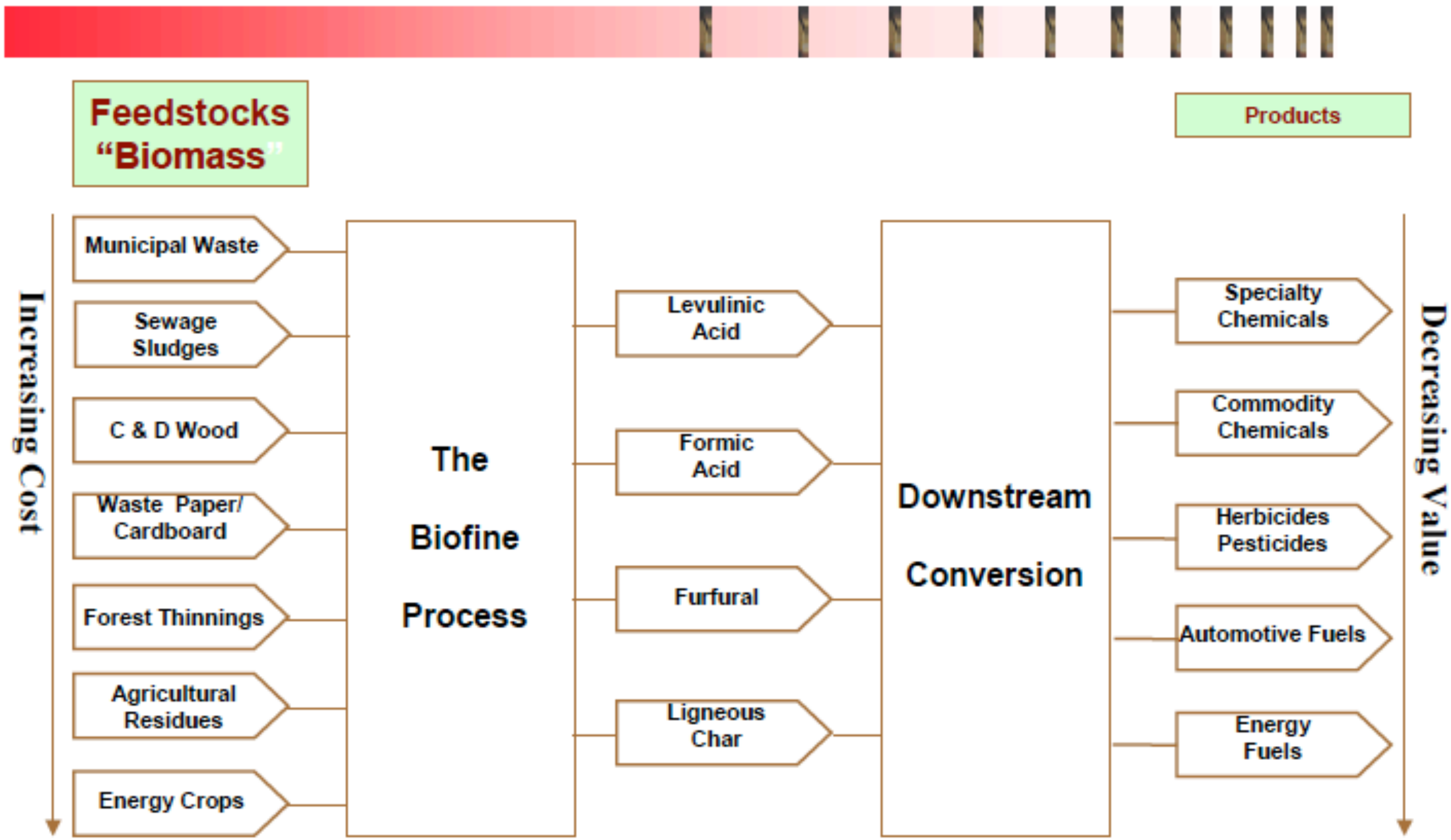
An Existing Process

- A high temperature, fast acid hydrolysis of biomass polysaccharides.
- The feedstock is hydrolysed with 1-5% sulphuric acid in two reactors.
- The first reactor hydrolyses the sugars and produces 5-hydroxymethyl furfural (HMF) from the C6 sugars and furfural from the C5 sugars.
- The HMF goes to the second reactor where levulinic acid is formed (and smaller amounts of formic acid)



Inset: reactor in Caserta Biofine commercial plant

The Biofine Process



Products and by-products	% of extraction	Ref	Mass of product (kg ha^{-1} yr^{-1})	Total mass (*) (kg yr^{-1})	Market Price (€ kg^{-1})	Ref	Total value (€)
Seeds (a)			**1200.00**	**5.18E+07**			
Oil (b)	***33.0%***	[58]	***396.00***	***1.71E+07***			
Lubrificants (c)	6.0%	[58]	23.76	1.03E+06	0.88	[62]	9.03E+05
Biodiesel (c)	98.0%	[58]	388.08	1.68E+07	0.78	[62]	1.31E+07
Glycerin (d)	10.0%	[58]	38.81	1.68E+06	0.11	[62]	1.76E+05
Cake Meal (b)	***58.0%***	[63]	***696.00***	***3.01E+07***			
Proteins (e)	39.0%	[63]	271.44	1.17E+07	1.60	[64]	1.88E+07
Fibers (e)	31.8%	[63]	221.33	9.56E+06	0.11	[65]	1.05E+06
Glucosinates (e)	5.1%	[63]	35.50	1.53E+06			0.00E+00
Soluble sugar (e)	5.7%	[63]	39.67	1.71E+06	2.40	[64]	4.11E+06
Others (e)	18.4%	[63]	128.06	5.53E+06			
Agricultural residues (a)			**3400.00**	**1.47E+08**			
Cellulose (f)							
Glucose	32.5%	[66]	1105.00	4.77E+07	0.30	[64	1.43E+07
Hemicellulose (f)							
Xylose	18.0%	[66]	612.00	2.64E+07	3.50	[67]	9.25E+07
Galactose	1.5%	[66]	51.00	2.20E+06	n.a.		
Arabinose	1.2%	[66]	40.80	1.76E+06	n.a.		
Mannose	1.2%	[66]	40.80	1.76E+06	n.a.		
Lignin (f)	18.7%	[66]	635.80	2.75E+07	0.20	[68]	5.49E+06
Others (f)							
Ash	5.2%	[66]	176.80	7.63E+06			
Extractives	20.9%	[66]	710.60	3.07E+07			
Total economic income from biorefinery chain							**1.50E+08**

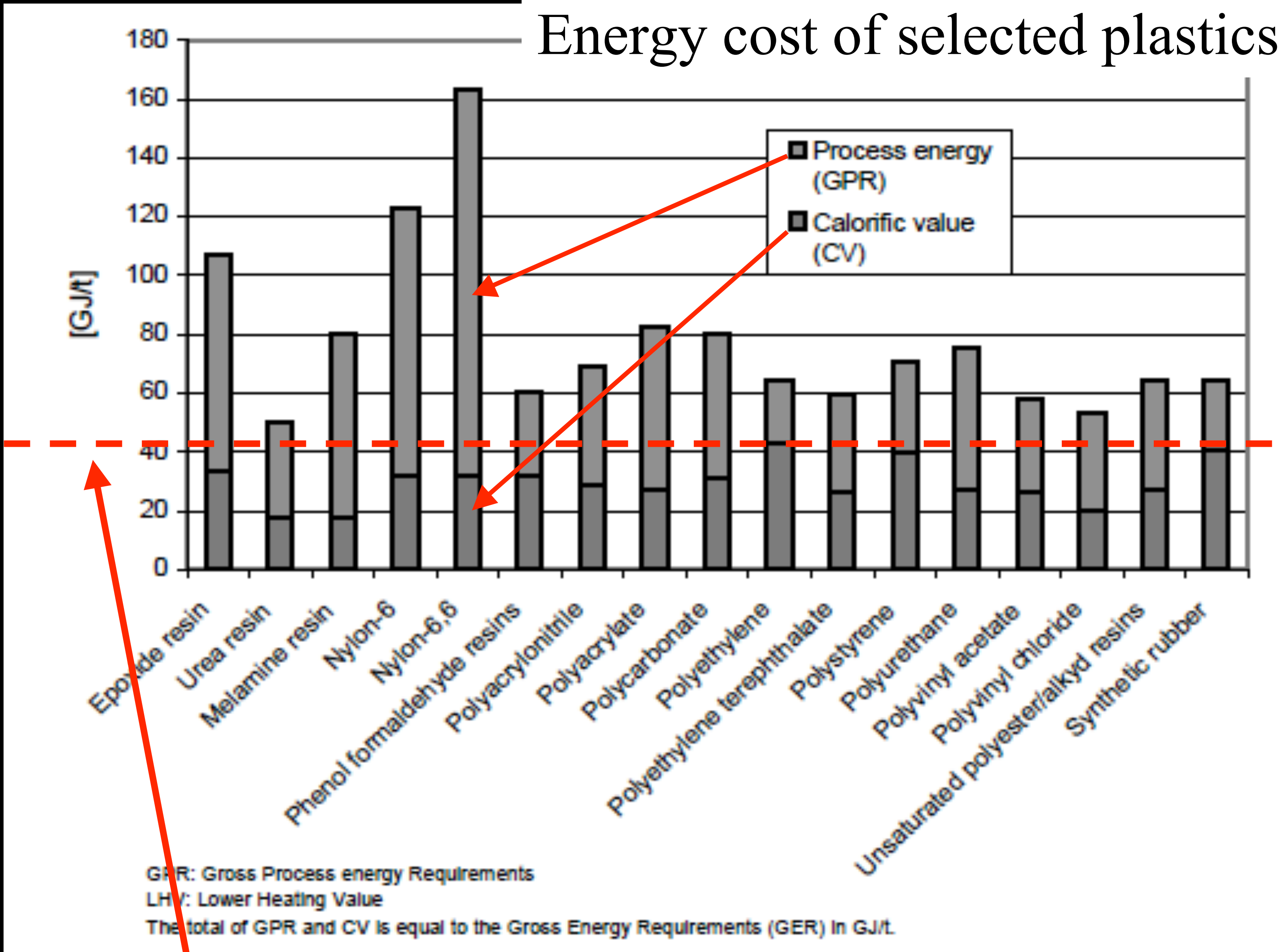
(*) Referred to 43183 ha of Brassica cropping; (a) from Brassica cropping; (b) from seeds; (c) % of oil mass; (d) % from biodiesel; (e) from cake meal mass; (f) from agricultural residues

Economic balance between the total economic investment for biorefinery chain and total production income.

Total economic investment for energy purpose (€/yr)	2.87E+07
Cost for biorefinery plant (€/yr)	4.26E+07
Total cost (a) (€/yr)	7.13E+07
Economic income from biorefinery chain (b) (€/yr)	1.50E+08
Net economic (b-a) (€/yr)	7.90E+07
Ratio b/a	2.11

Indicators	Levulinic Acid	Formic Acid	Biodiesel	Glycerin
Material resource depletion				
MI abiot (g/g)	4.48	0.37	2.68	1.19
MI water (g/g)	26.17	2.17	27.56	12.20
Energy depletion				
GER per unit mass (J/g)	3.29E+04	2.73E+03	2.08E+04	9.19E+03
Oil eq (g oil/g)	0.78	0.07	0.50	0.22
Oil eq (g oil/J)	2.20E-05	8.13E-06	1.32E-05	1.32E-05
Oil eq (g oil/€)	871	871	633	2090
Emergy (demand for environmental support)				
Specific emergy (seJ/g)	3.58E+12	1.24E+13	1.17E+10	1.17E+11
Transformity (seJ/J)	9.83E+07	1.51E+09	3.11E+05	7.02E+06
EYR	1.00	1.00	1.14	1.14
ELR	56.87	56.87	8.28	8.28
% Renewable	2%	2%	11%	11%
Climate change				
Global warming (g CO2 -equiv/ g)	2.46	0.20	1.24	0.55
Acidification (g SO2 / g)	9.66E-03	8.02E-04	3.92E-03	1.73E-03
Eutrophication (g PO4/g)	9.44E-04	7.84E-05	4.10E-04	1.82E-04

Energy cost of selected plastics



42 GJ/ton: approx energy content of raw oil

Energy cost of selected chemicals

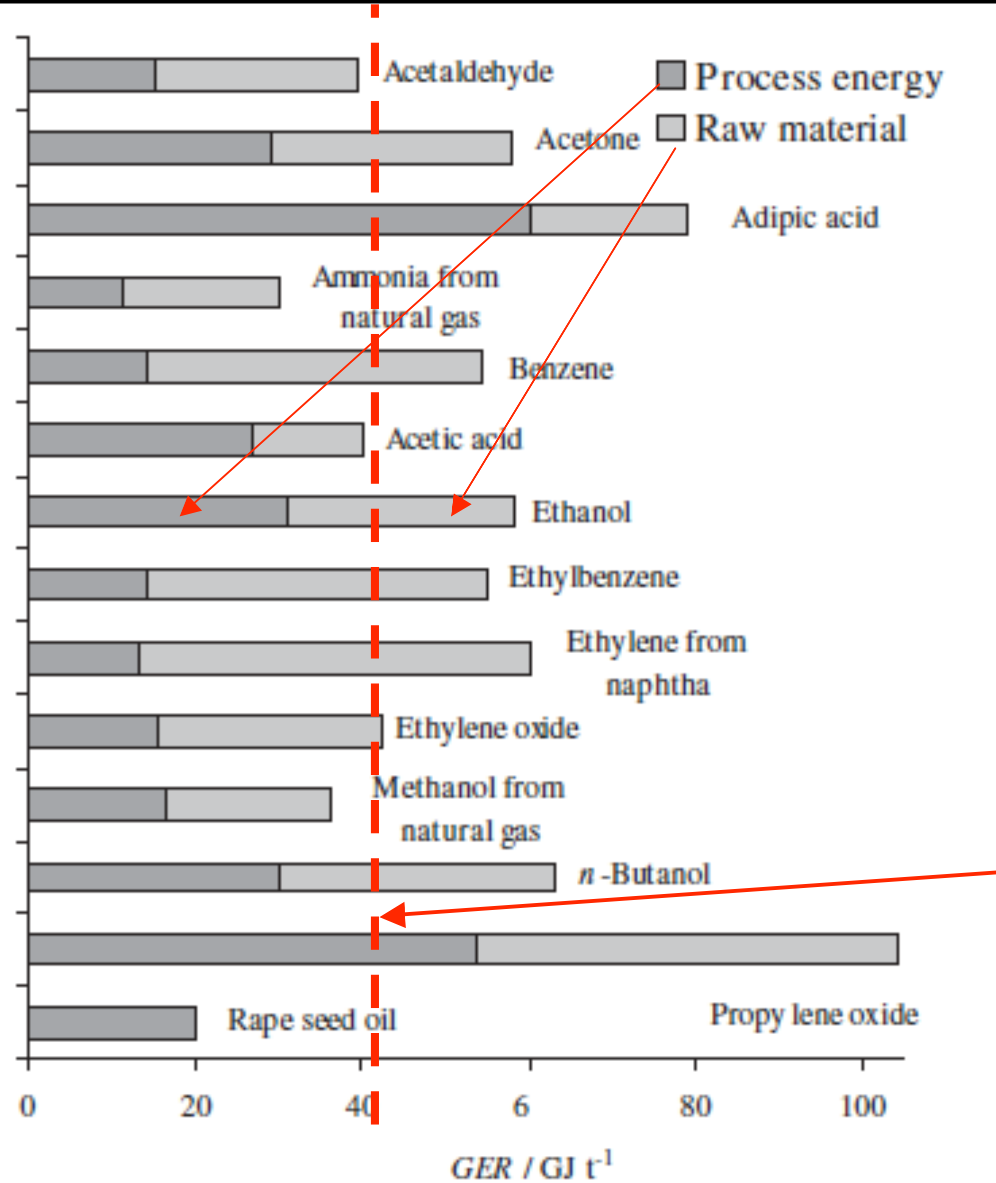


Fig. 4. Gross energy requirements (GER) for important base chemicals [18,19].

Approx energy content of raw oil:

42 GJ/ton:

Concluding remarks

- We will have to rely on biomass for liquid fuels, chemicals and materials, when we run out of cheap fossil fuels. No doubt on this.
- Cropping for energy, even in marginal land, is never an option (a part from Brazilian sugar cane, in some cases) due to low energy return and high costs.
- Instead of expensive cropping, the use of lignocellulose residues and waste provides interesting, substrate abundant, low cost and energy self-sufficient alternatives (biorefinery).
- The biorefinery concept solves the problem of agro-industrial and urban waste, and promises cheap liquid fuels and biomaterials/biochemicals.
- Biochemicals can be already produced at competitive cost with petro-chemicals. Bioenergy is more difficult, because of low hydrolysis yields.
- Some high yield processes (Biofine) are very close to the commercial stage.
- Lignocellulose is everywhere and therefore contributes to the independence from fossil fuels.

Thank you

for your attention !