# Lignocellulosic Biomass Conversion Technologies to Bio-fuels

## Barriers and Opportunities

**Dr Eid M A Megeed**

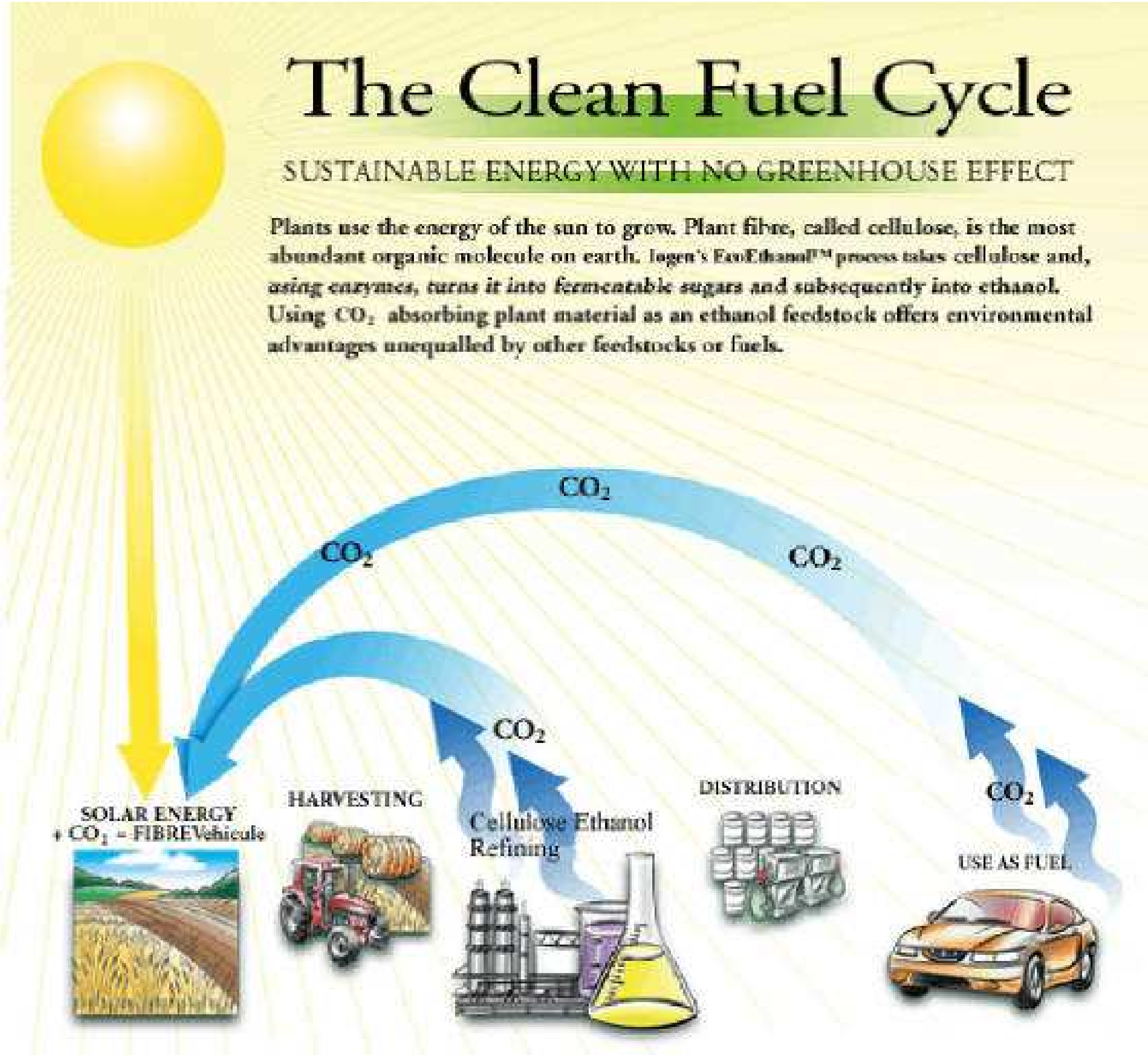
# Energy and commodity industrial-chemicals

- During the last 30 years, the fossil crude oil and natural gas have been the center of interest as industry development tools to provide energy
- The combustion of oil-based products have generates much of air pollution and most of green house gases that threaten to change the Earth' climate

# Energy and commodity industrial-chemicals

- Concern for other alternative resources for energy has been expressed.
- Depletion in fossil oils resources motivate stakeholders to secure development and future strategy.
- Biofuels from Biomass

- **Biofuels** are liquid transportation fuels
- Biofuels (Ethanol and biodiesel) can be blended/ substitute gasoline and diesel.



# Why biofuels

- **Reduction of $CO_2$ emission,**
- **decreasing vehicle contribution to local air pollution. Since most biofuels have a cleaner burning than common fossil fuels, add more sources of fuel, which can stabilize fuel prices,**
- **development of new industry with its economic impact, and**
- **biofuels point out different solution to the way out of fossil oil dependence.**
- **The transportation fuels represents about 27% of the world primary consumption, and this share continuous to grow and today it is mainly dependant on fossil oil .**
- **In Egypt the transportation fuels represent around 30% of total fuel consumption .**

- Henery T. Ford when he designed his Model T automobile in 1908, expected ethanol, made from renewable resources to be the fuel. (the fuel of the future’
- Rudolf Diesel thought that his compression ignition engine would be run on vegetable oils

# Global prospective

**Africa**

- marginal, the potential is enormous.
- Bioethanol plant is being built in South Africa (Bothaville).

**Asia**

- From waste wood, in Japan. China, India and Thailand. Biodeisel production is on the agenda

**Europe**

- A transport fuels blend of 5.75% (energy value) 2010 and 10% by 2020.
- A tax exemption of up to 100% on biofuels was implemented
- Zeiz (Germany) using wheat, barley and triticale starch, 260000m3/year with an extension using sugar beet to 360,000m3 /year.
- 2.5 MT of biodeisel has been produced in the year 2005 in Germany from rapeseed oil
- Germany allowed tax exemption on biofuels,

Brazil

- Gasohol, which contains 21-23% ethanol.
- 15 billion litres of bioethanol have been produced (sugarcane)
- 2 billion litres of biodiesl per annum by 2020.

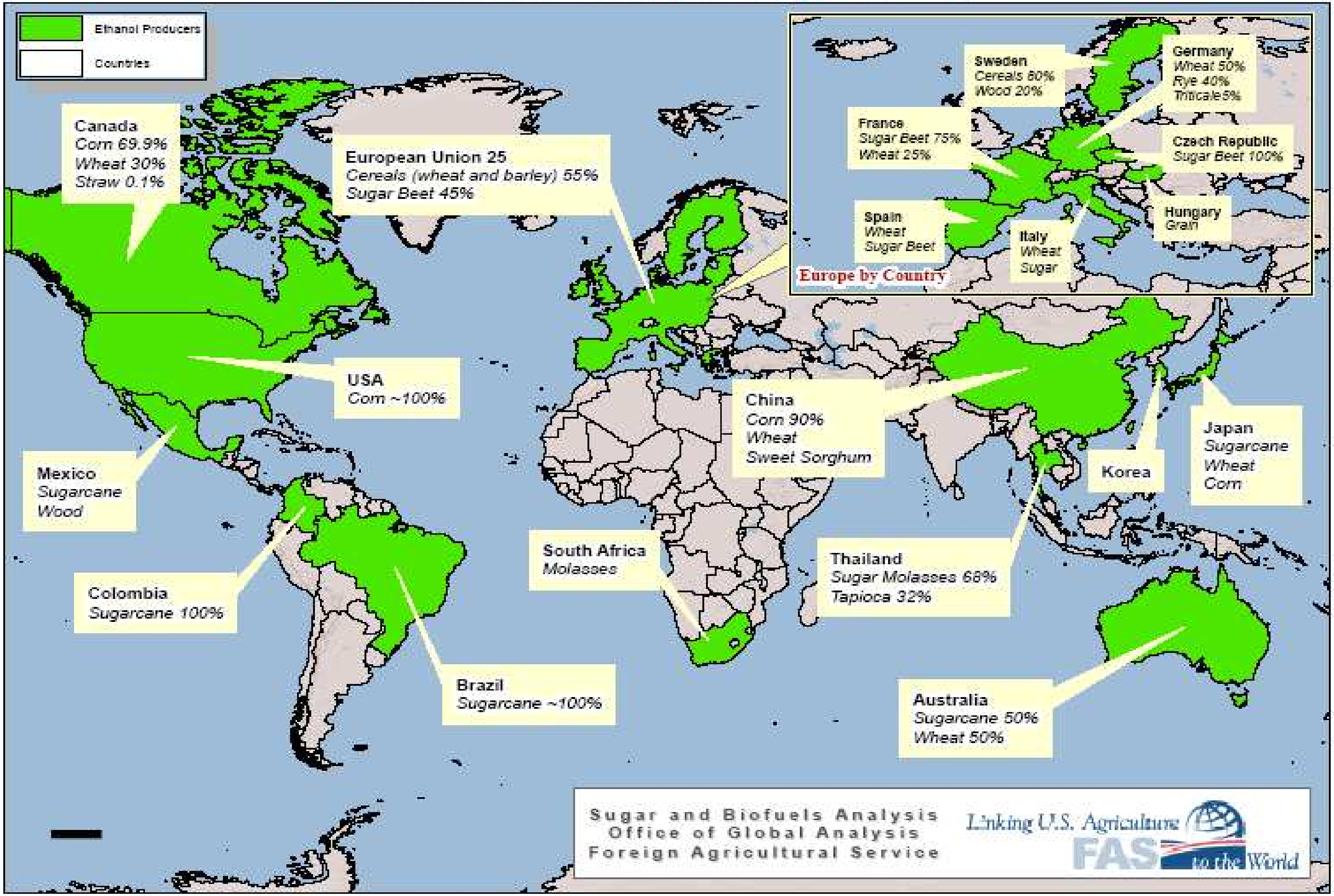
USA

- 2006, installed annual capacity of 18 billion litres
- An additional 8 billion litres planned for the future. The Energy
- Tax Act (1978) was the primary motive for tax exemptions on biofuels

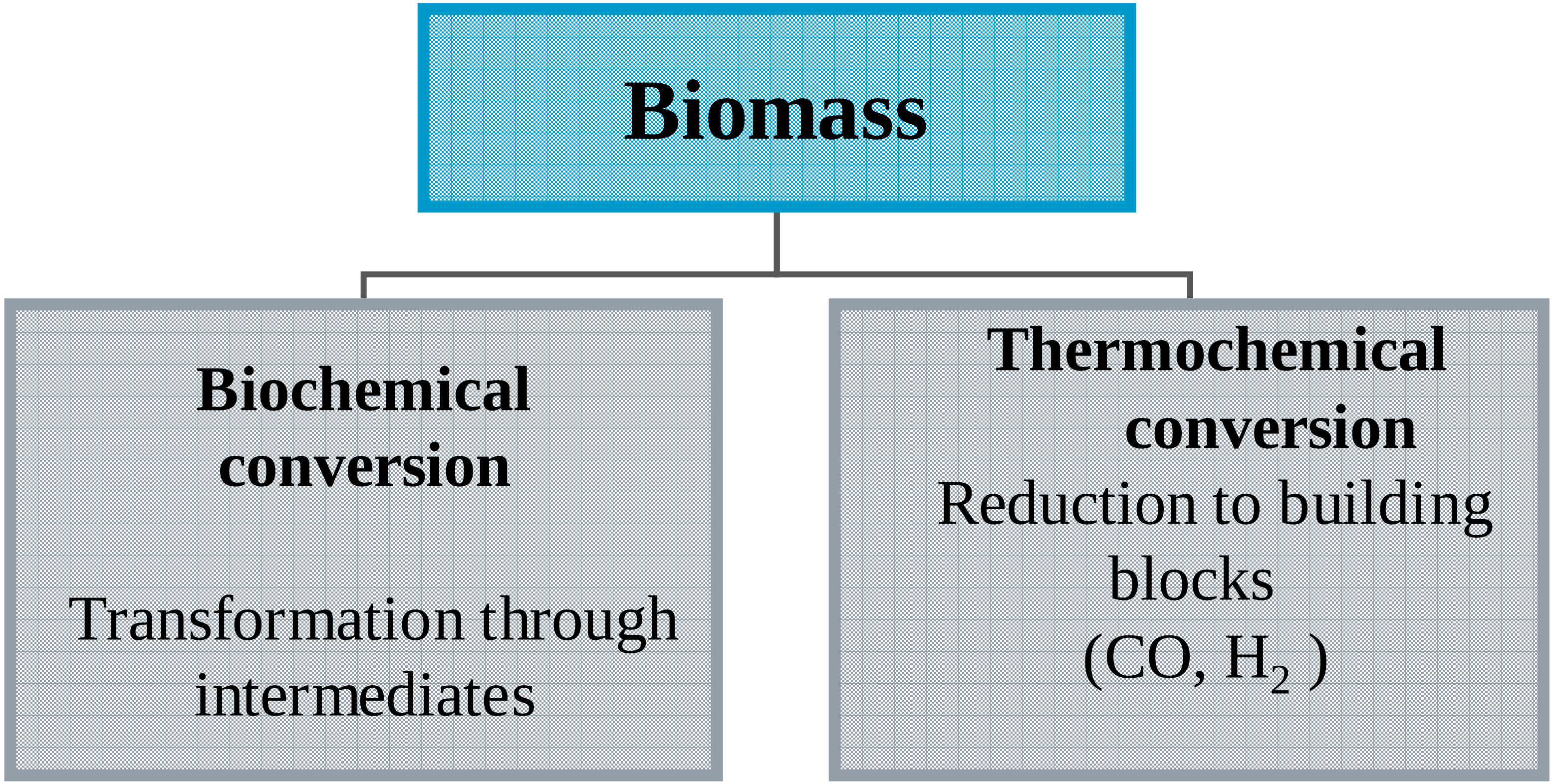
Canada.

- An investment programme to achieve 3.5% biofuel use by the year 2020.

# Countries Producing Ethanol by Feed Stock



# Conversion technologies of biomass to biofuels



# Biomass Benefits

- Abundant
- Renewable
- Carbon-neutral
- Available worldwide
- Only sustainable source of hydrocarbons

Biomass can:

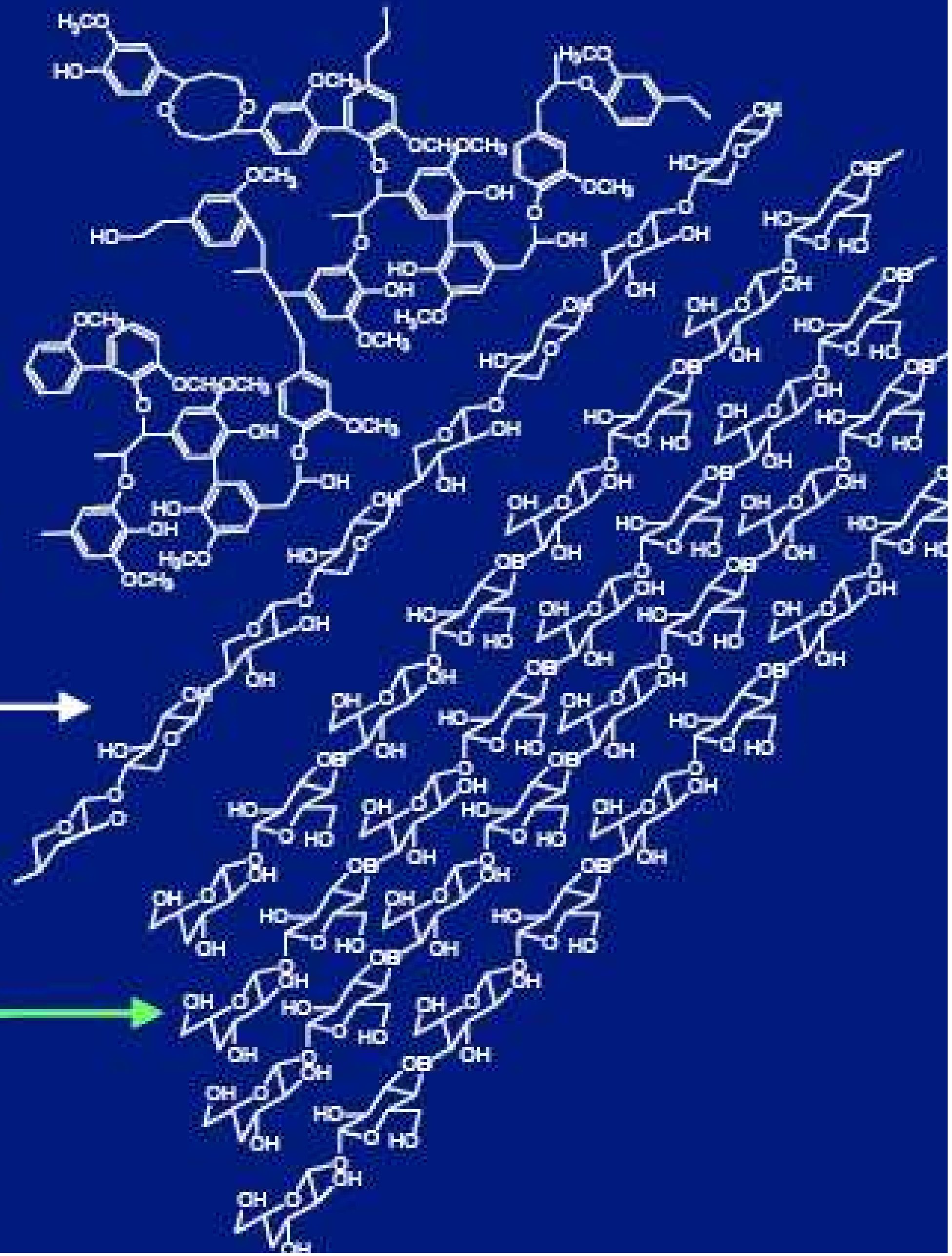
- Be used with the existing petroleum infrastructure
- Fill the gap between energy demand and petroleum availability.

# Biomass Chemistry 101

Lignin: 15-25%
- Complex aromatic structure
- Resists biochemical conversion
- Requires high temperatures to convert

Hemicellulose: 23-32%
- Polymer of 5- and 6-carbon sugars
- Easily depolymerization
- 5-carbon sugars hard to metabolize

Cellulose: 38-50%
- Polymer of glucose
- Susceptible to enzymatic attack
- Glucose easy to metabolize



# The biomass or feedstock of biofuels

**Four groups :**

- Cereals, grains, sugar crops and other starches which can be easily fermented to produce ethanol,
- lignocellulosic materials (grasses, trees, agriculture waste product such as rice and wheat straw, corn stove) These can be converted into ethanol or synthetic gas, but the processes are more complex,
- oil seed crops (soybean, sunflower and rapeseed) which can be converted into methyl esters and can substitute normal fossil diesel , and
- organic waste materials, meat waste, animal oils, mature and organic wastes. The availability of this waste is often limited.

# Biomass Conversion Technology

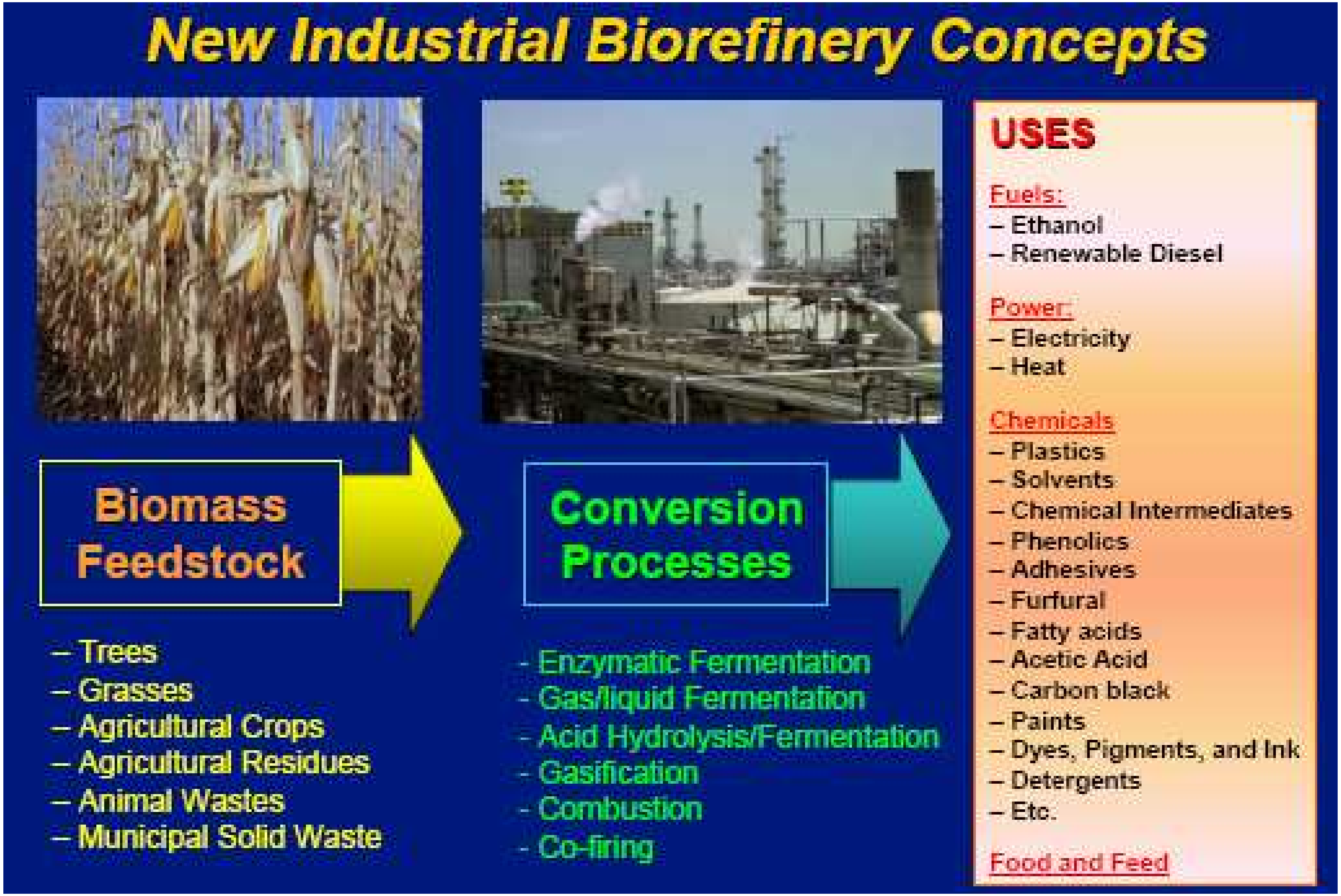
- Biomass has been proposed as alternative large supply, low-cost feedstock materials.
- The hydrolysis platform technology of cellulose materials to fermentable sugars and then fermentation can supply many of the fuels and chemicals
- Thermo-chemical platform technology transform soild biomass to gas and then converted to biofuels (gas and/or liquid)
- Bio-refineries

# Biochemical conversion

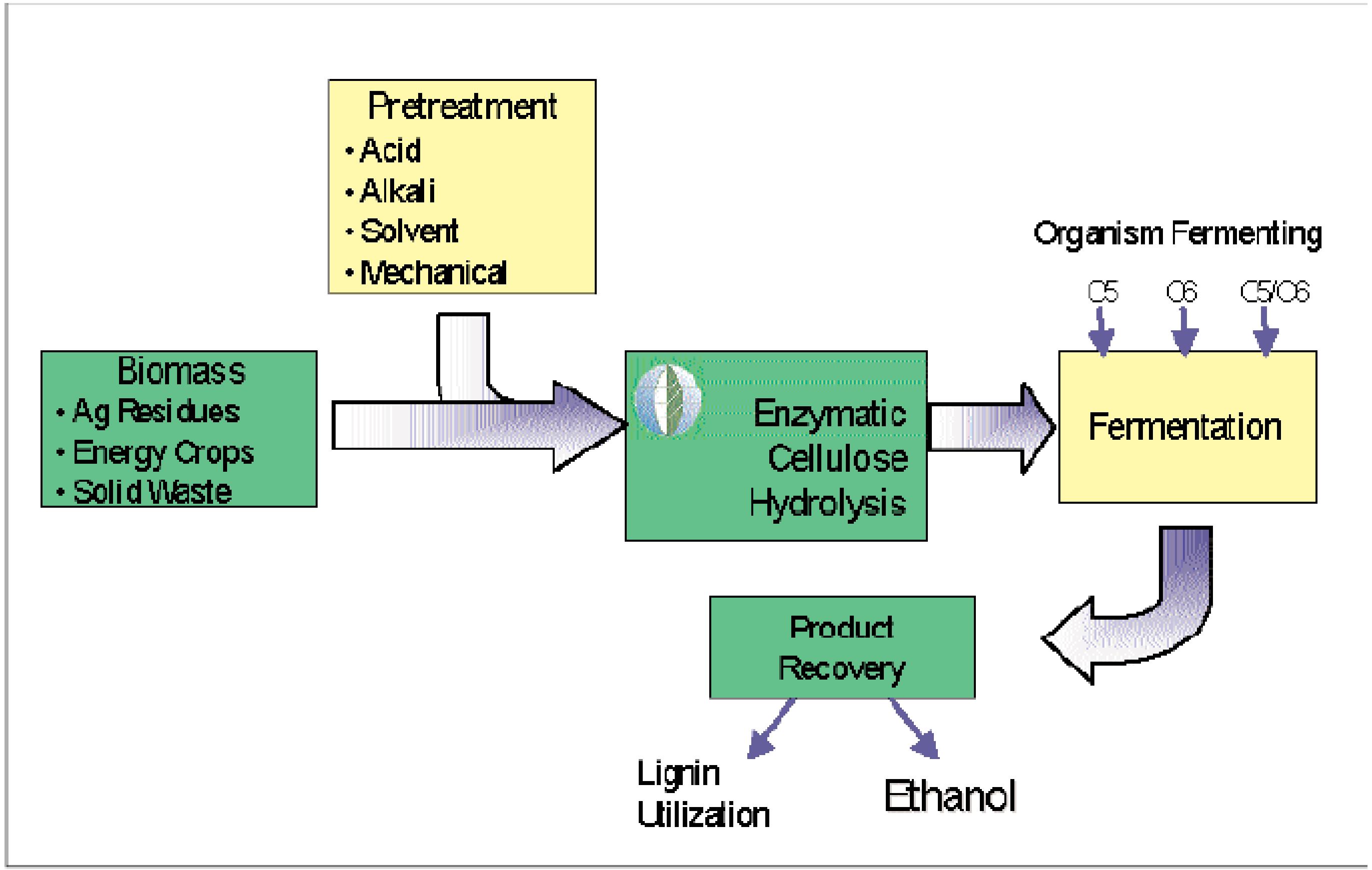
- The potential of lignocellulosic biomass is large than the commodity crops and starch.
- A main challenge is to recover sugar content of biomass .

Consists of the following;

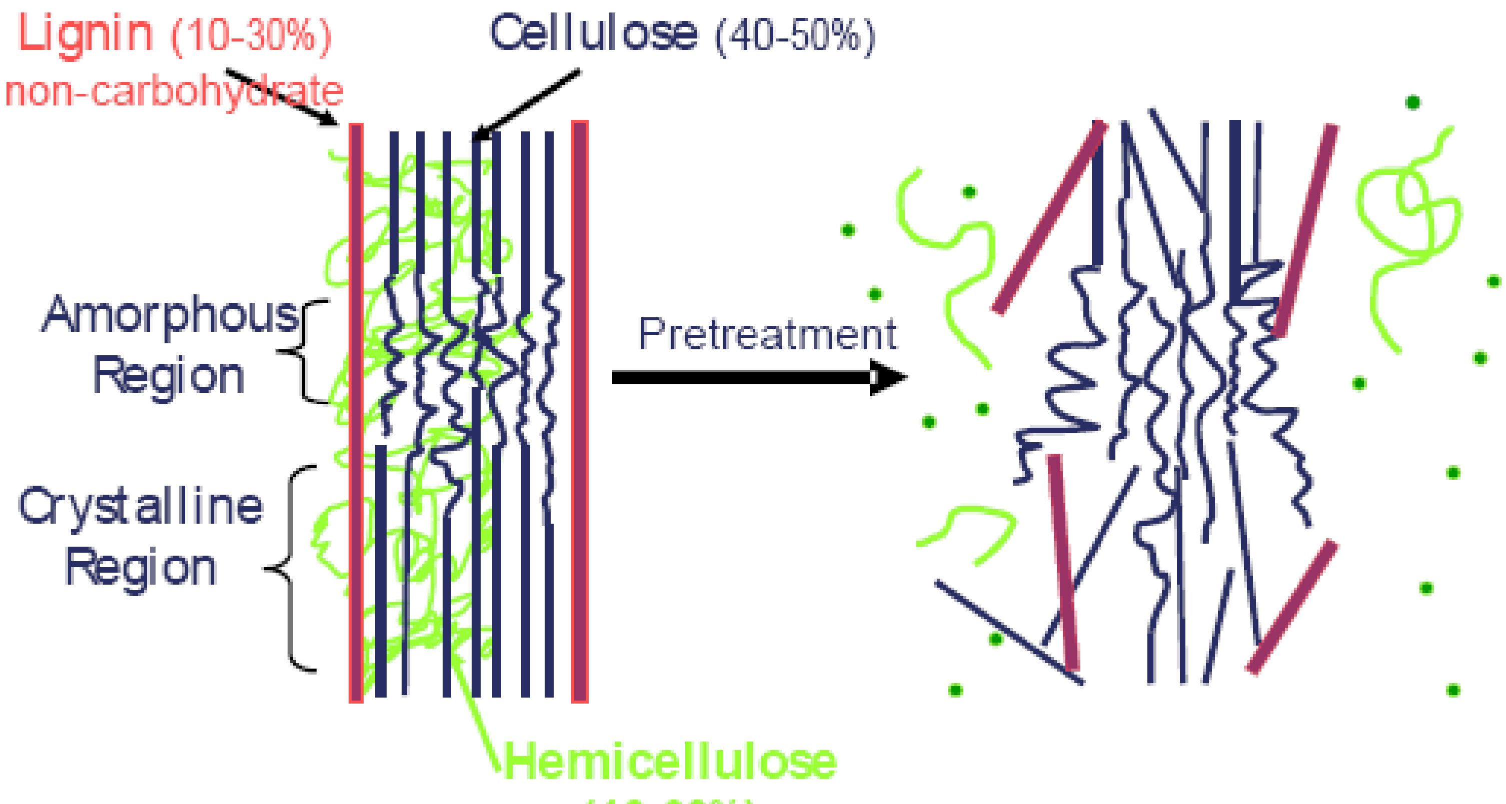
- Biomass raw materials, which include, agriculture residues,  energy crops and solid waste,
- Pretreatment, mechanical, acid, alkali, and solvent,
- Enzymatic cellulose hydrolysis,
- Organic, C5, C6, and C5/C6 fermentation, and
- Products recovery, ethanol or butanol, and lignin utilization.


New Industrial Biorefinery Concepts
Biomass Feedstock
– Trees
– Grasses
– Agricultural Crops
– Agricultural Residues
– Animal Wastes
– Municipal Solid Waste
Conversion Processes
- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Gasification
- Combustion
- Co-firing
USES
Fuels:
– Ethanol
– Renewable Diesel
Power:
– Electricity
– Heat
Chemicals
– Plastics
– Solvents
– Chemical Intermediates
– Phenolics
– Adhesives
– Furfural
– Fatty acids
– Acetic Acid
– Carbon black
– Paints
– Dyes, Pigments, and Ink
– Detergents
– Etc.
Food and Feed

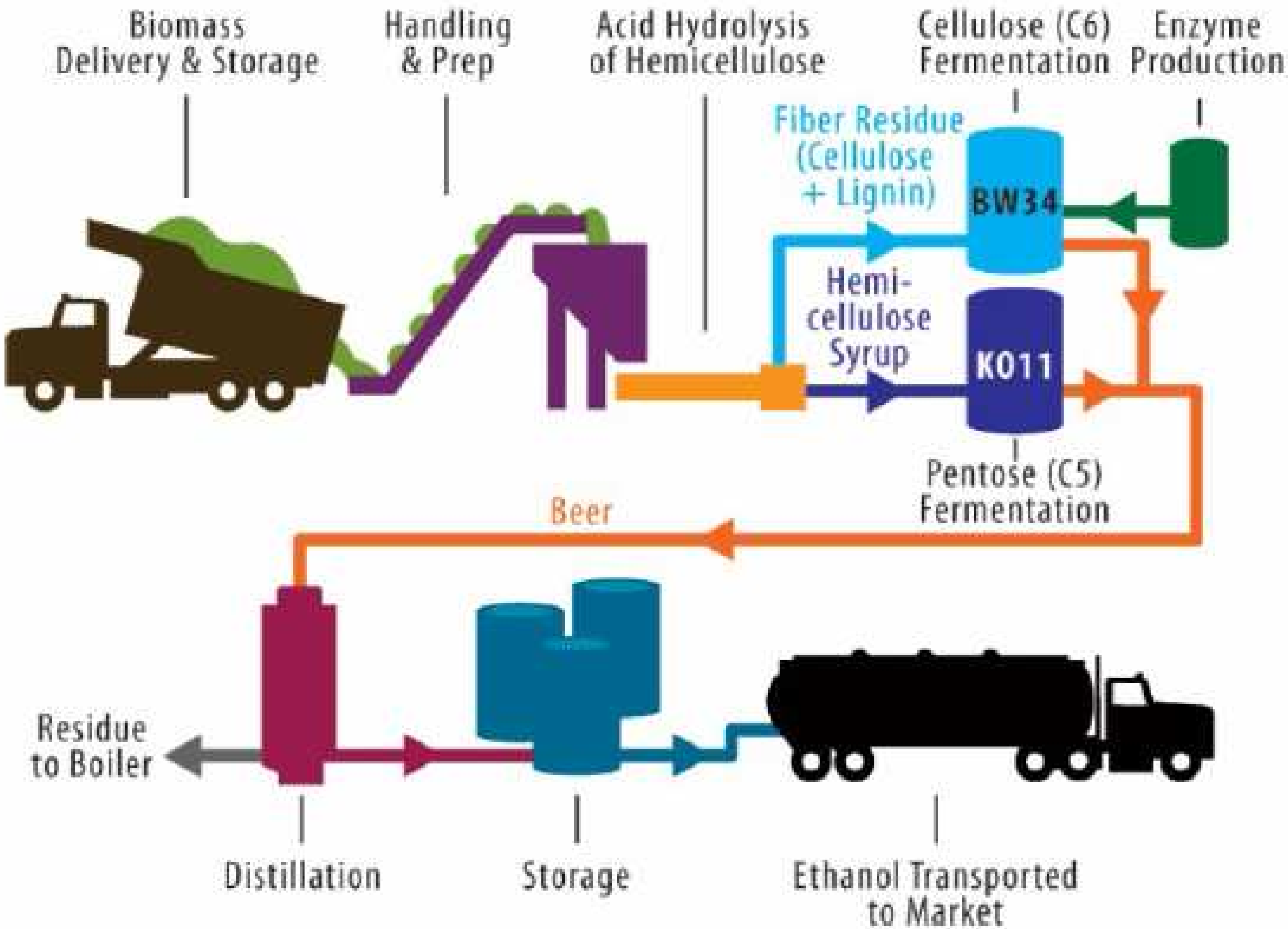
# Block diagram for bioconversion of biomass



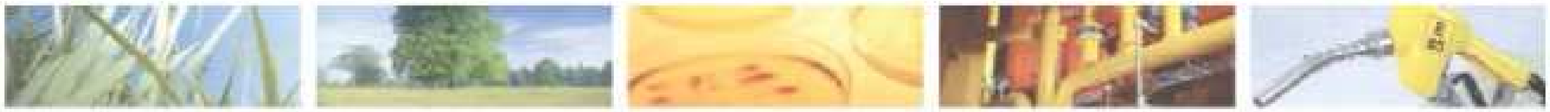
# Pretreatment Challenge



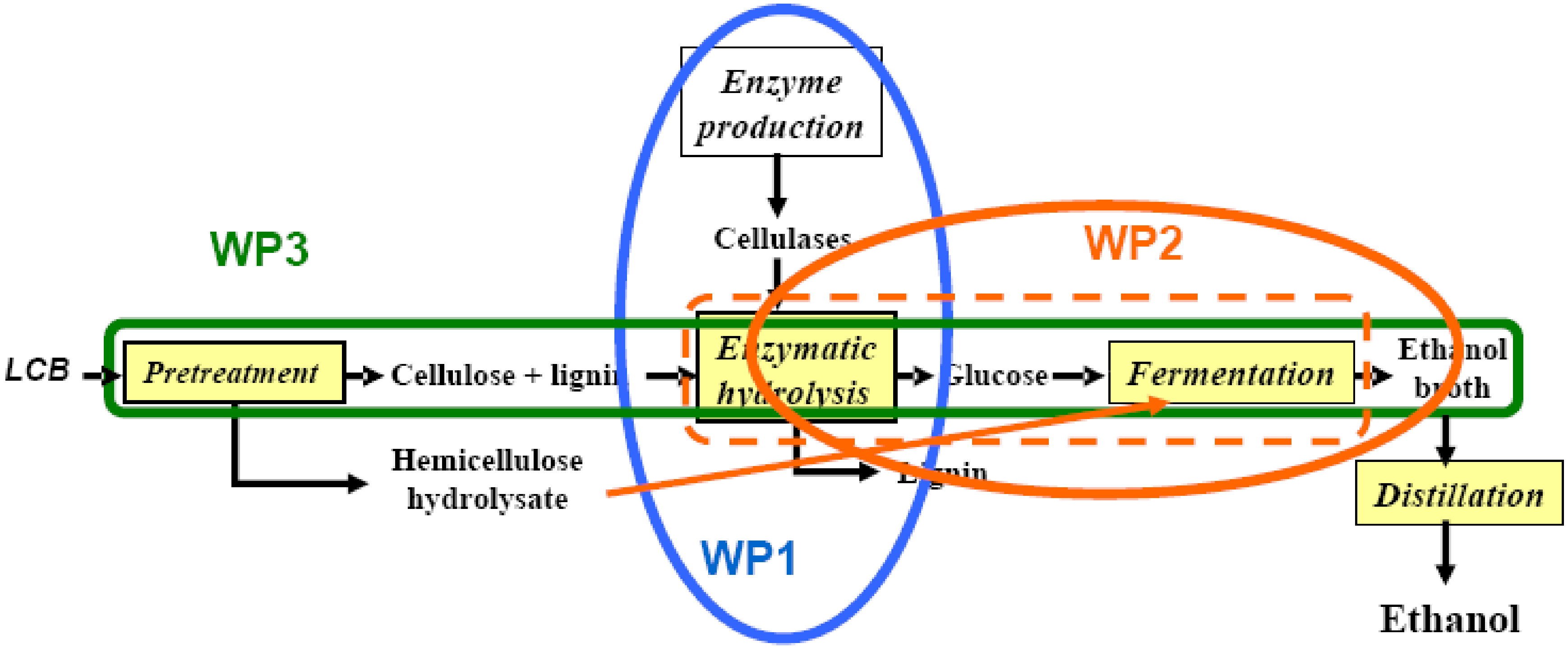
# The Celunol Process




Celunol
www.celunol.com



# Project structure (2)




- ➔ Optimised hydrolytic system
- ➔ Pentose-fermenting yeast strains & SSF
- ➔ optimised process and ethanol production cost

# Pretreatment

actions to

- clean and size the biomass (1-3 mm ), give a larger surface area
- allow ease and fast transport of the catalysts and steam to the fibers,
- allows the enzymes to penetrate the fibers and reach the sugar oligomers
- make the cellulose and hemicellulose feedstocks more digestible by enzymes, the surrounding lignin is removed.

# Pretreatment

**Chemical pretreatment**

- use dilute acid (o.5-1.5%), alkaline, ammonia, organic solvents, sulfur dioxide, carbon dioxide and other chemicals for hydrolysis.
- sugar yields 75-90% yields of xylose [2.5].
- The acid should be recycled

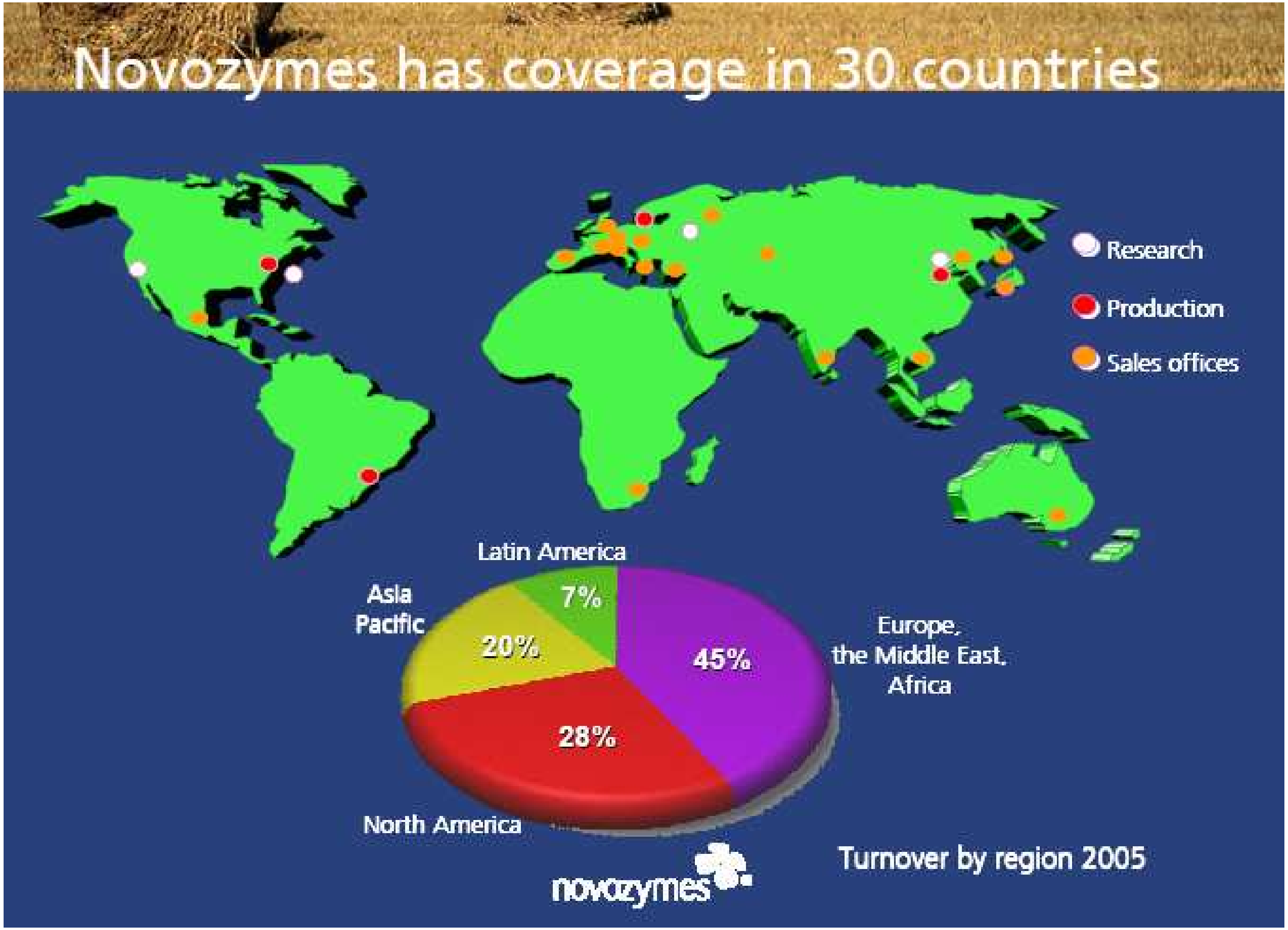
**Steam explosion and liquid hot water (LHW)**

- xylose sugars recoveries between 45-98%)
- **A biological pretreatment**
- low energy use and mild environmental conditions. very low hydrolysis rate

**Ammonia Fiber Explosion (AEFX)** i

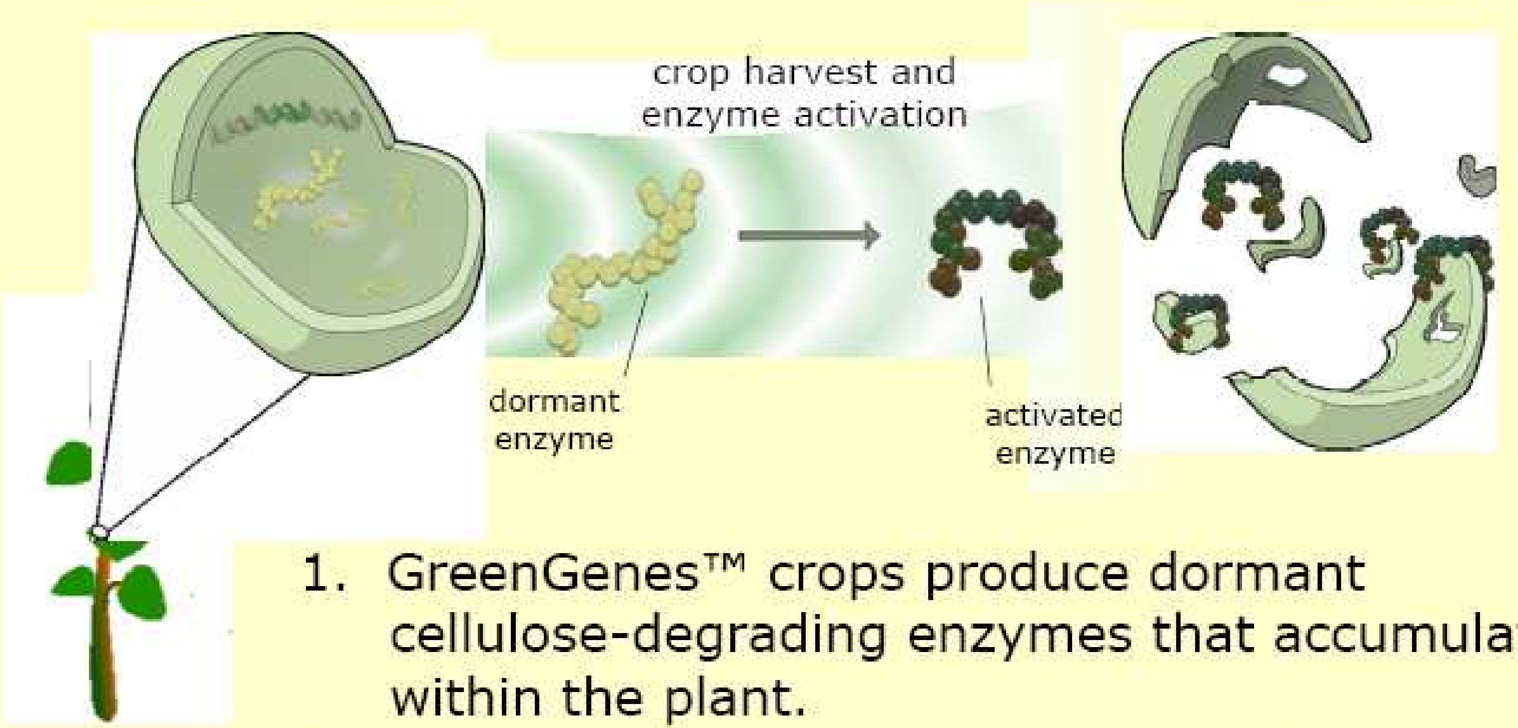
**Cellulose hydrolysis (Enzyme hydrolysis)**

- Converts cellulose ed into glucose sugars
- Without pretreatment, hydrolysis of cellulose yields typically <20%, whereas after pretreatment the yield exceed 90%.


Novozymes has coverage in 30 countries
Research
Production
Sales offices
Latin America
7%
Asia Pacific
20%
45%
Europe, the Middle East, Africa
28%
North America
Turnover by region 2005
novozymes

Agrivida

# GreenGenes™ Technology




1. GreenGenes™ crops produce dormant cellulose-degrading enzymes that accumulate within the plant.
2. The dormant enzymes are activated after harvest.
3. The activated enzymes degrade the cell wall.

# Fermentation.

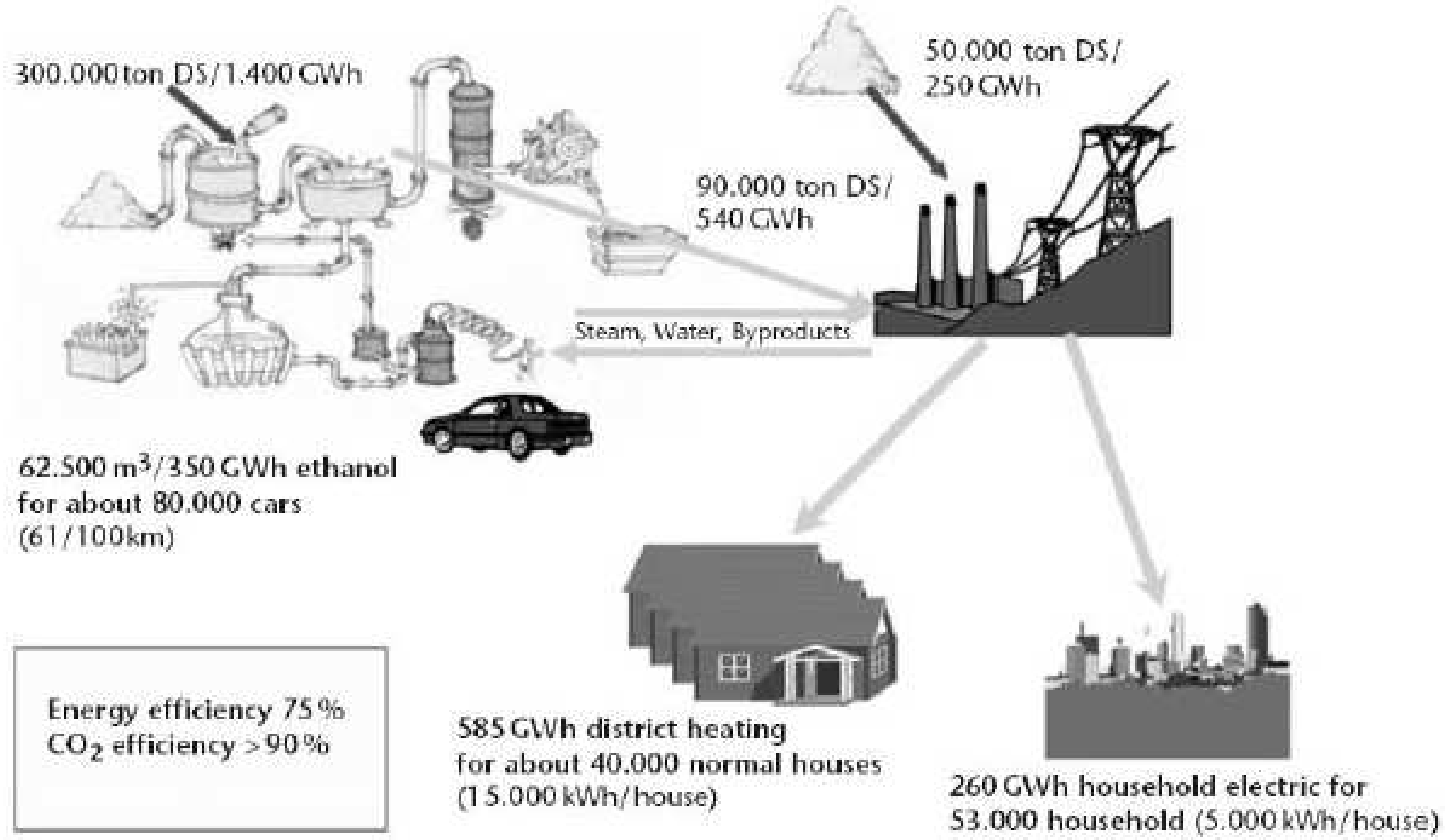
- A variety of microorganisms,
- The theoretical maximum yield is 0.51 kg ethanol and 0.49 kg carbon dioxide per kg sugar:
- Some have the ability to ferment both C5 and C6 sugers are Pichia stipitis, Candida shehatae and Pachysolan tannophilus.
- S.cereviseae strain (VS3) Recombinat yeast, which can metabolizing all form of sugars,

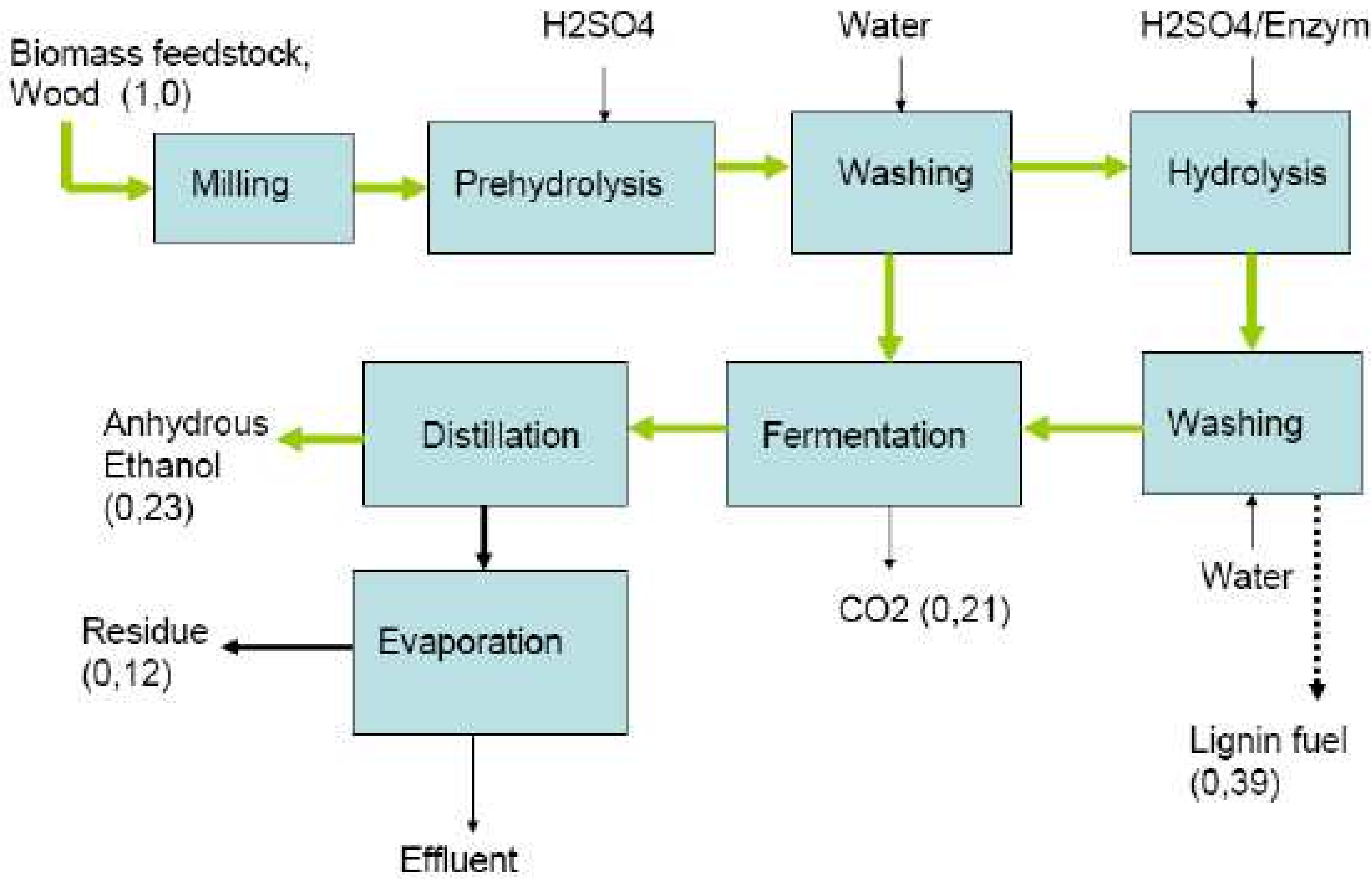
**Ethanol recovery**

- Distillation, where most of the water remain with the solid part.
- The product (37 % ethanol) concentrated in a rectifying column to a 95 %)
- Anhydrous ethanol (99.0 % ), can be mixed with gasoline, (pervaporation membrane)

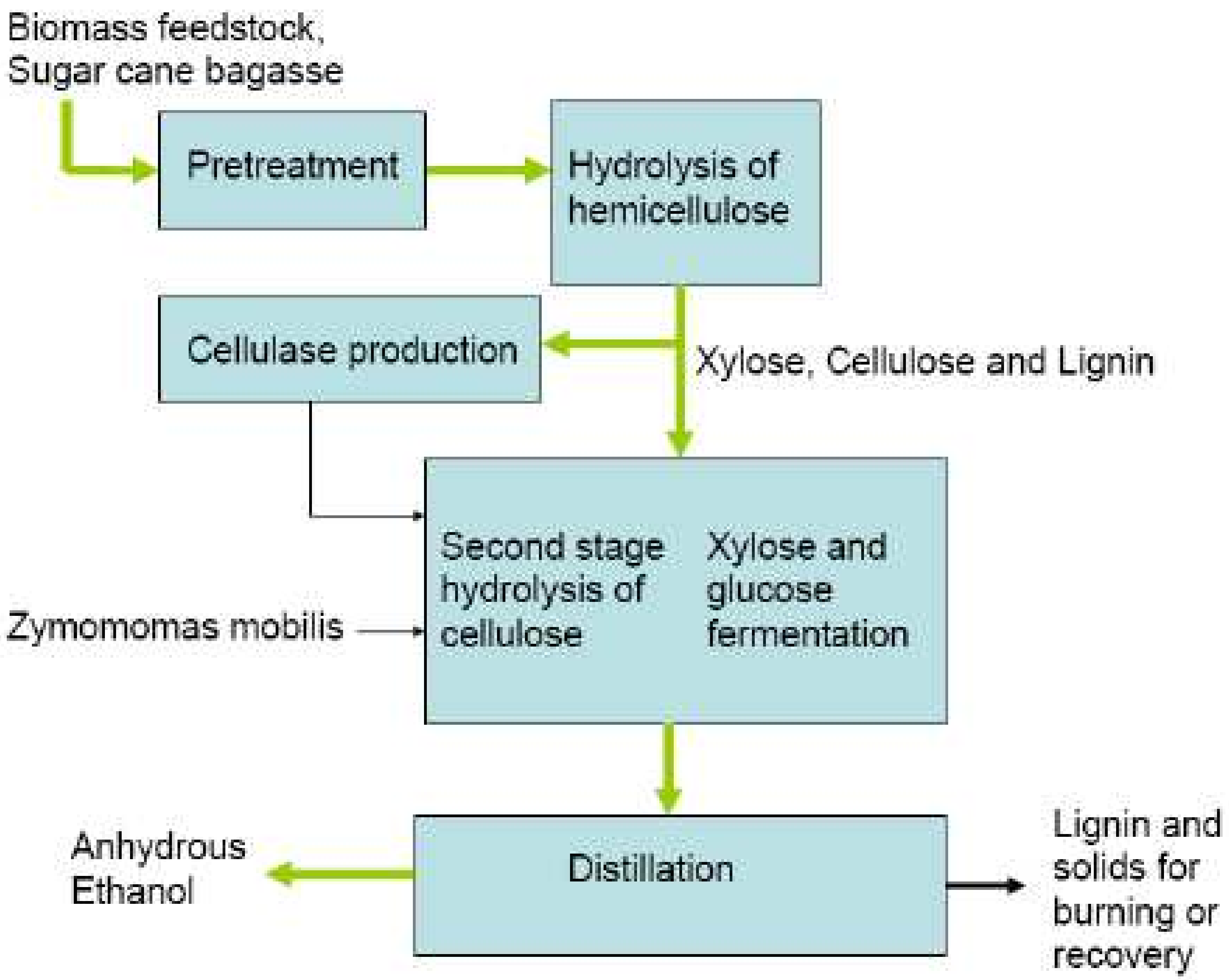
**Residual solids processing**

- Lignin abd sikics
- All residual solids were deployed for production of heat and electricity, and found to be feasible and add some economic aspects for the process.

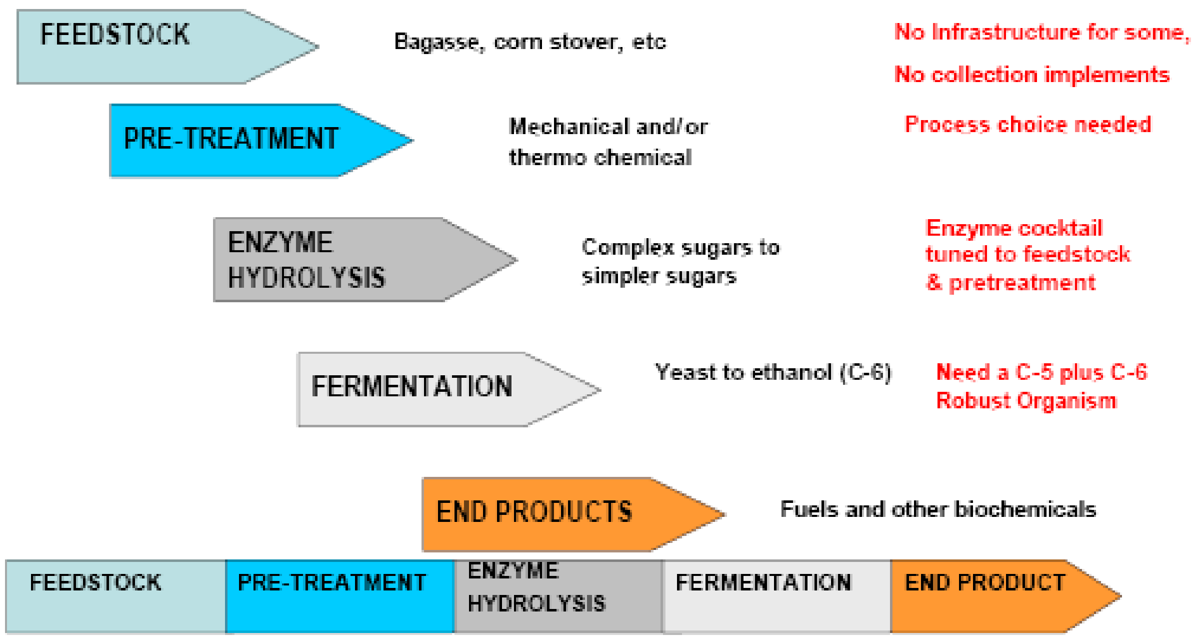

300.000 ton DS/1.400 GWh
50.000 ton DS/
250 GWh
90.000 ton DS/
540 GWh
Steam, Water, Byproducts
62.500 m3/350 GWh ethanol
for about 80.000 cars
(61/100km)
Energy efficiency 75 %
CO2 efficiency >90 %
585 GWh district heating
for about 40.000 normal houses
(15.000 kWh/house)
260 GWh household electric for
53.000 household (5.000 kWh/house)



Biomass feedstock,
Wood (1,0)
H2SO4
Water
H2SO4/Enzym
Milling
Prehydrolysis
Washing
Hydrolysis
Distillation
Fermentation
Washing
Anhydrous
Ethanol
(0,23)
Water
CO2 (0,21)
Evaporation
Residue
(0,12)
Lignin fuel
(0,39)
Effluent


Biomass feedstock,
Sugar cane bagasse
Pretreatment
Hydrolysis of hemicellulose
Cellulase production
Xylose, Cellulose and Lignin
Zymomomas mobilis
Second stage hydrolysis of cellulose
Xylose and glucose fermentation
Anhydrous Ethanol
Distillation
Lignin and solids for burning or recovery

# Biomass Value Chain Integration Status



# Commercialization of Biomass Conversion

*Requires:*

- **Inexpensive lignocellulosic biomass supply, coupled with cost-effective delivery to plant sites**
- **Efficient and cost-effective processing/pretreatment technologies**
- **Advanced enzymes and processes for efficient hydrolysis of biomass**
- **Optimized organism(s) and process(es) to ferment mixed sugars**
- **Efficient and cost-effective technology for product recovery**
- **Integration of process steps for process design and scale up**

# Thermochemical. Gasification, Conversion

- Reduction of the organic building blocks of biomass (Partial oxidation )to carbon mono oxide and hydrogen gases.
- Wide range of biomass resources available, ranging from agriculture crops to residues and organic wastes.
- Biomass drying to a certain percent of moisture and subsequent addition of moisture as super-heated steam to gasifier,
- Pyrolysis to give gases, vaporized tars or oils and a solid char residue,
- Produces Syngase CO, CO2, H2O and H2 and impurities
- **Gas cleaning**

# Syngas fermentation

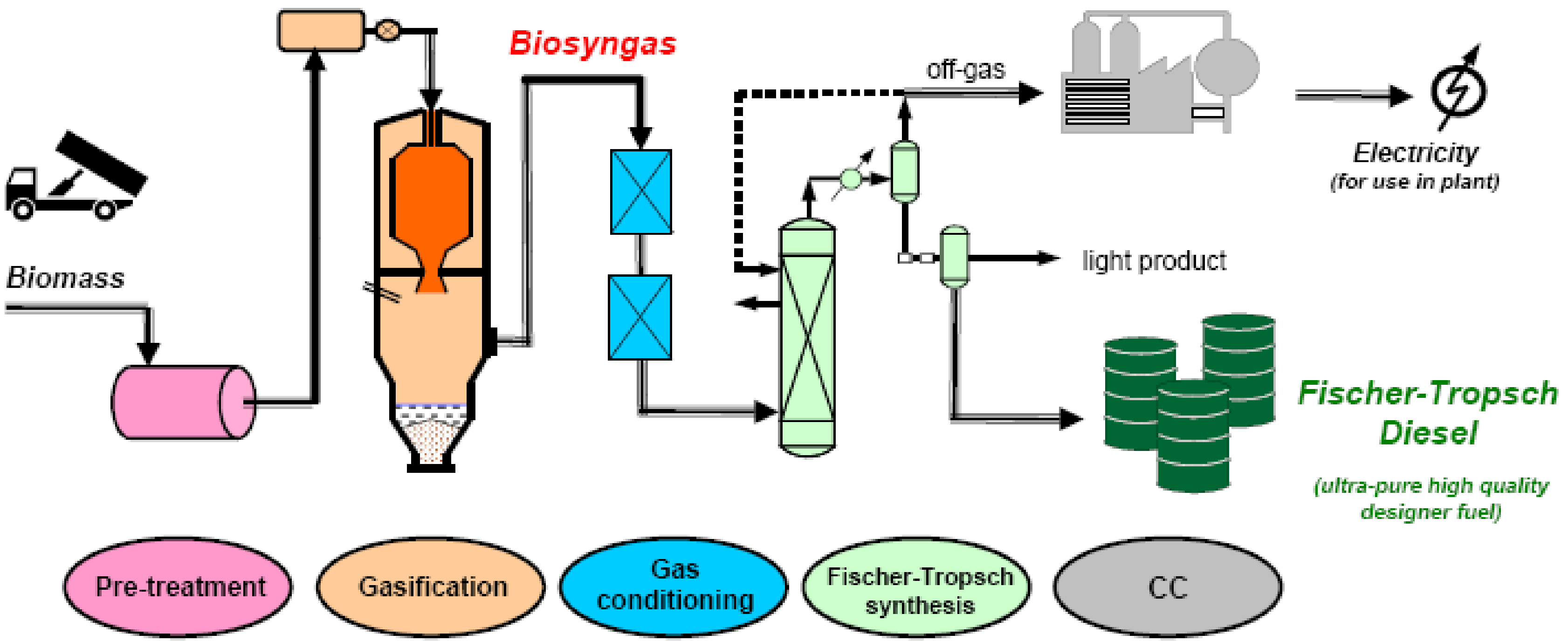
- Anarobic bacteria (*Clostridium Ijungdahlii')*are able to grow on Syngas components ($CO_2$, CO and $H_2$) to produce acetate and ethanol (in aqueous phase, where the pressure is ranging from 0.8- 2.0 bar, and the temperature is 35-37 oC).
- Typical CO conversion is 90% and 70% for $H_2$ conversion .
- The reaction time from biomass to distill ethanol have been proven to be very short ( 7-8 min)

# Fischer-Tropsch

- **Fed by Syngas**
- The FT synthesis is in principle a carbon chain building process, where CH2 groups are attached to the carbon chain.
- The  synthesis reactions are dependent on the catalyst used. Iron, cobalt nickel or ruthenium catalyst
- he FT process produces different olefins and paraffin of different length.

# Biomass to liquids

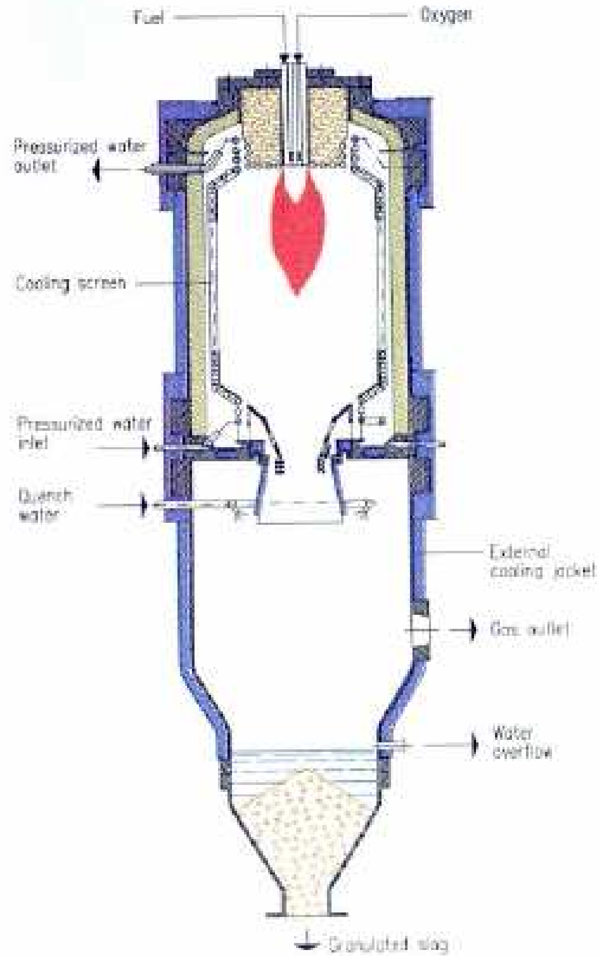
***System line-up of Fischer-Tropsch diesel production***



[Shell]

Freiberg, Germany

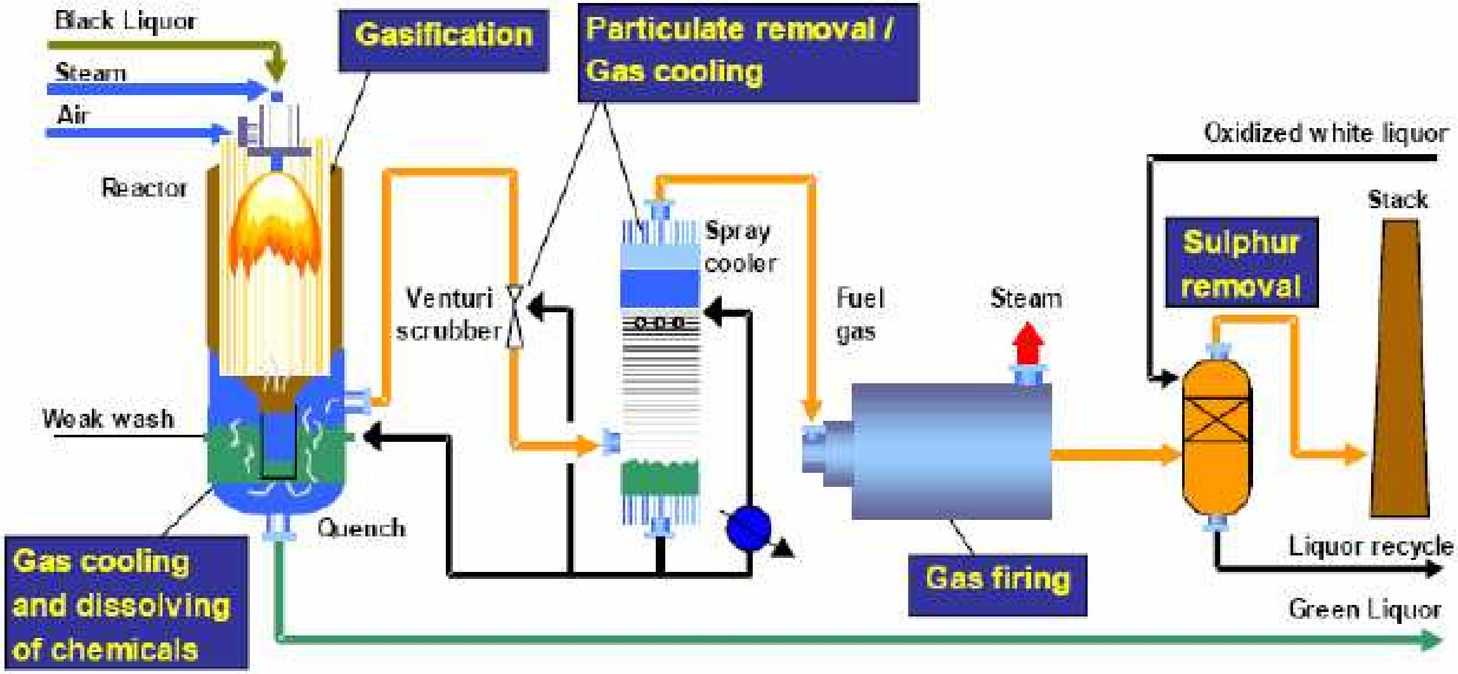
Buggenum, Netherlands

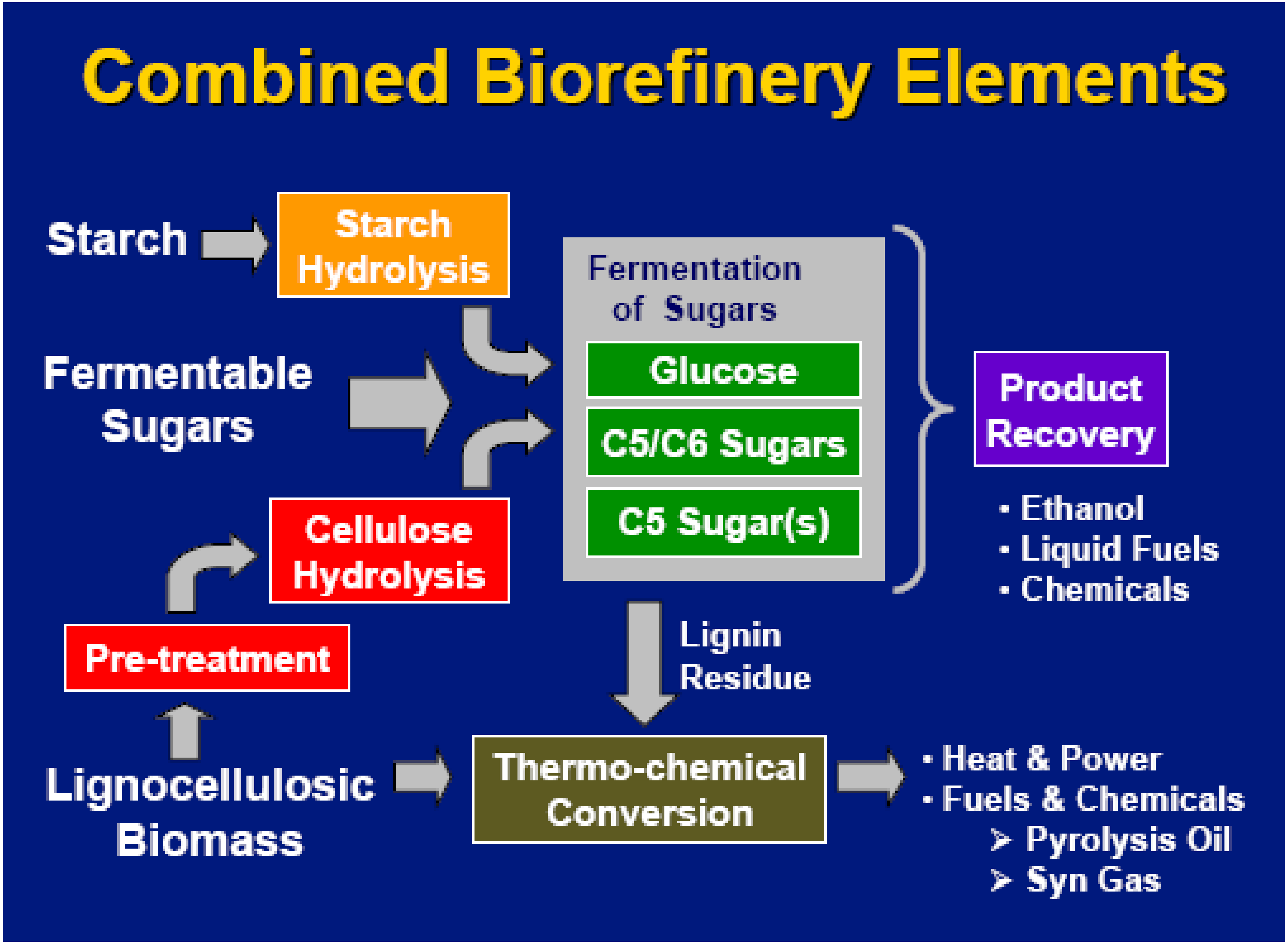



[Siemens]

# ▶Black Liquor Gasification Piteå, Sweden

## CHEMREC® BOOSTER PROCESS




Combined Biorefinery Elements
Starch
Starch Hydrolysis
Fermentable Sugars
Fermentation of Sugars
Glucose
C5/C6 Sugars
C5 Sugar(s)
Product Recovery
• Ethanol
• Liquid Fuels
• Chemicals
Cellulose Hydrolysis
Pre-treatment
Lignin Residue
Lignocellulosic Biomass
Thermo-chemical Conversion
• Heat & Power
• Fuels & Chemicals
➢ Pyrolysis Oil
➢ Syn Gas

# Biomass resources in Egypt

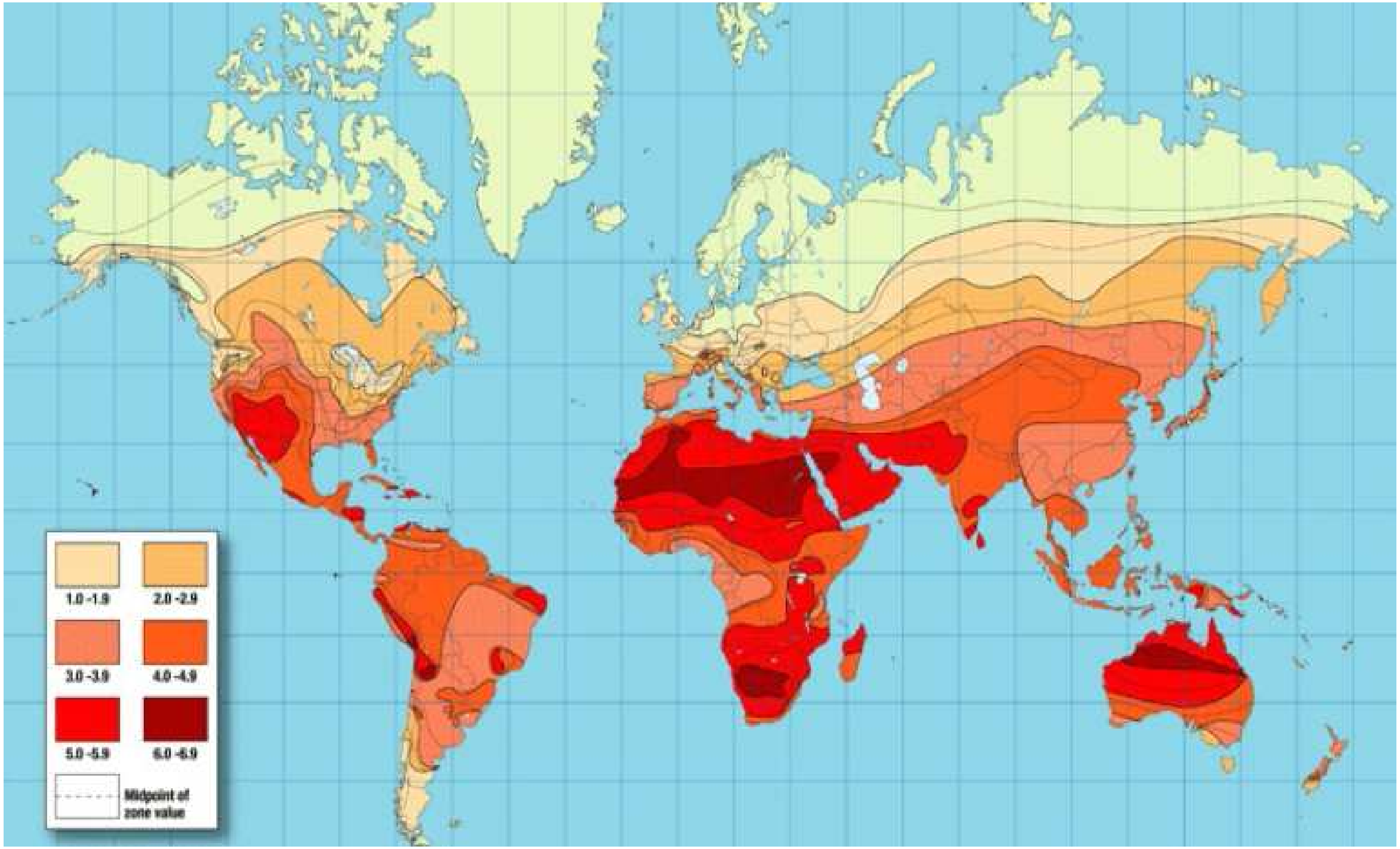
- Egypt is endowed with high intensity of direct solar radiation ranging between 2000-3200 kwh/m2 /year from North to south. The sun shine duration ranges from 9-11 hours per day
- Study funded by IMC (Energy Research Center, 2006).

Agriculture sector (Crop residues) has been estimated to be 27.3 million metric tons/year

- There are additional crop-related residues from post harvest processing, e.g. rice husk 1.6 million tons per year and bagasse 4.7 million tons

Solid Municipal Waste

- The estimated quantities of municipal solid wastes generated in urban areas are around 25 million tons/year
- According to the conclusion of the above mentioned study, it appears that there is a good potential for the utilization of biomass resources in Egypt for bio-refinery.
- Out of the estimated amount of 60 million tons per year a conservative estimate of 20% of that biomass resources can be easily collected and used for bio-refinery production in the short term.



1.0 -1.9
2.0 -2.9
3.0 -3.9
4.0 -4.9
5.0 -5.9
6.0 -6.9
Midpoint of zone value

Example

- current cropping systems generally are designed to optimize grain production and are not designed to harvest all the above ground portion of the plants
- Significant, immediate national programs are needed, along with changes in policy, to address challenges limiting the sustainable production and efficient use of non-commodity biomass as a feedstock for bio-refinery industry

| Governorate | Wheat Straw | Rice Straw | Maize stalks & cops | Sorghum stalks | Barely straw | Cotton stalks | Sugar cane residues |
|---|---|---|---|---|---|---|---|
| Alexandria | 166 | 11 | 69 | - | 6 | 11 | - |
| Behira | 737 | 696 | 623 | - | 9 | 271 | 4 |
| Gharbia | 426 | 561 | 342 | - | - | 95 | 17 |
| Kafr El-Sheikh | 606 | 911 | 248 | - | 9 | 254 | 2 |
| Dakahlia | 853 | 1480 | 204 | - | - | 115 | 8 |
| Damietta | 61 | 195 | 16 | - | - | 18 | - |
| Sharkia | 1062 | 885 | 835 | - | 31 | 123 | 2 |
| Ismailia | 88 | 11 | 126 | - | 9 | 1 | - |
| Port Said | 10 | 53 | 9 | - | 9 | 1 | - |
| Suez | 4 | - | 9 | - | 3 | - | 1 |
| Menoufia | 312 | - | 866 | - | - | 51 | 1 |
| Qalyoubia | 135 | 62 | 285 | - | - | 14 | 9 |
| Cairo | 0.8 | - | 3 | - | - | - | 1 |
| Giza | 123 | 1 | 309 | 1 | 1 | - | 30 |
| Beni Suef | 396 | - | 395 | 12 | 1 | 66 | 15 |
| Fayoum | 552 | 76 | 127 | 237 | 33 | 45 | 6 |
| Menia | 642 | - | 991 | 27 | 1 | 67 | 575 |
| Assuit | 519 | - | 357 | 481 | 1 | 35 | 32 |
| Sohag | 549 | - | 445 | 411 | 1 | 14 | 298 |
| Qena | 281 | - | 125 | 86 | 4 | - | 2335 |
| Aswan | 52 | - | 25 | 15 | 5 | - | 1189 |
| Luxor | 42 | - | 34 | - | - | - | 350 |
| New Valley | 102 | 26 | 1 | 2 | 40 | - | - |
| Matruh | 16 | - | 11 | - | - | - | - |
| North Sinai | 19 | - | - | - | 44 | - | - |
| South Sinai | 0.08 | - | - | - | - | - | - |
| Noubaria | 458 | - | 203 | - | 6 | 7 | - |
| TOTAL | 8214 | 4968 | 6658 | 1272 | 213 | 1188 | 4875 |

# Lignicellulosic Biomass Distribution in Egypt

- Due to small scale agri business the distribution pattern of the different crops residues (mostly lignocellulosic materials) is very critical
- Rice straw (4.3 million tones) are mostly dominating North and East of Delta areas (Kafr El-Shiekh, Sharkia, Dakahlia, and Gharbia)
- corn stover (3.3 million tones) is dominating Middle of Delta (Monofyia) and South of Nile valley (Menia).
- Sorghum stalks (0.892 Million tones) is dominating far south of Nile valley (Assuit and Sohag)
- Sugar cane residues (3.5 Million tones) in Qena and Aswan.
- There are costs attached to harvest, collect, handle and transport the biomass and deliver to bio-ethanol refinery located within a reasonable distance (60-70 km).

| Table (5) Dominate Agricultural Wastes in Delta Area | | | |
|---|---|---|---|
| Governorate | Rice Straw | Corn Stover | Cotton residues |
| Behira | 696 | 623 | 271 |
| Gharbia | 561 | 342 | - |
| Kafer El Shiekh | 911 | 248 | 254 |
| Dakahlia | 1480 | 204 | - |
| Sharkia | 385 | 835 | - |
| Monofia | - | 865 | - |
| Total | 3943 | 2597 | 525 |

| Table ( 7 ) Municipal Solid Wastes in most populated Urban areas | | |
|---|---|---|
| Governorate | Tones/day | Tones/year |
| Cairo | 8775 | 3203000 |
| Alexandria | 3005 | 1097000 |
| Giza | 3685 | 1345000 |
| Total | | 5645000 |

| Table (6) Dominate Agricultural Wastes in Upper Egypt | | | |
|---|---|---|---|
| Governorate | Corn Stover | Sorghum residues | Sugar Cane Residues |
| Bani Sewif | 395 | - | - |
| Menia | 991 | - | 575 |
| Assuit | 357 | 481 | - |
| Sohag | 445 | 411 | 298 |
| Qena | - | - | 2335 |
| Aswan | - | - | 1189 |
| Luxor | - | - | 350 |
| Total | 2188 | 892 | 4747 |

# Barriers and Opportuhities

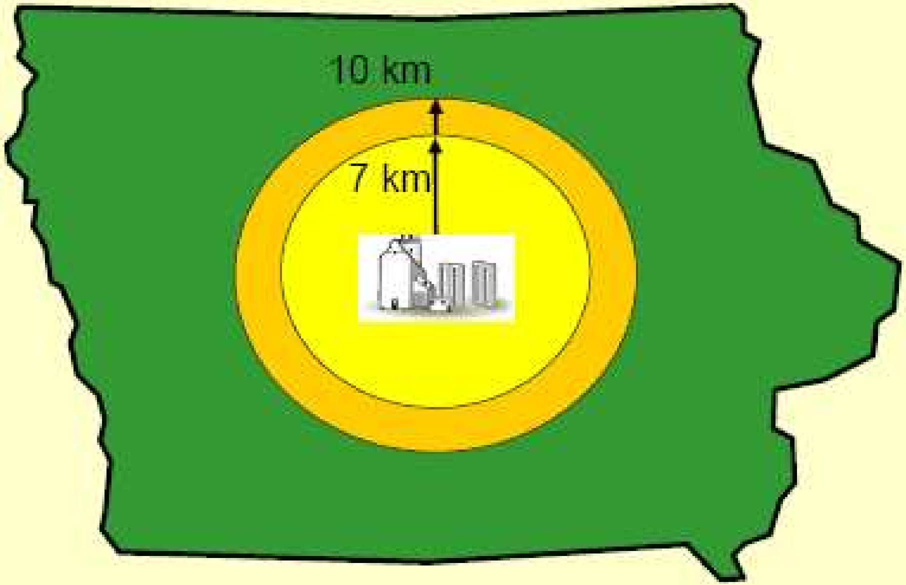
- Technologies to convert lignocellulosic materials to biofuels are in the phase of R&D (biochemical hydrolysis)
- Thermochemical conversion experiences are not feasible in Egypt.

- No enzymes production facilities available even in the region
- Government promotion program
- Tax exemption plan
- Legislation
- Distribution and blending system

# Yield Trait Value

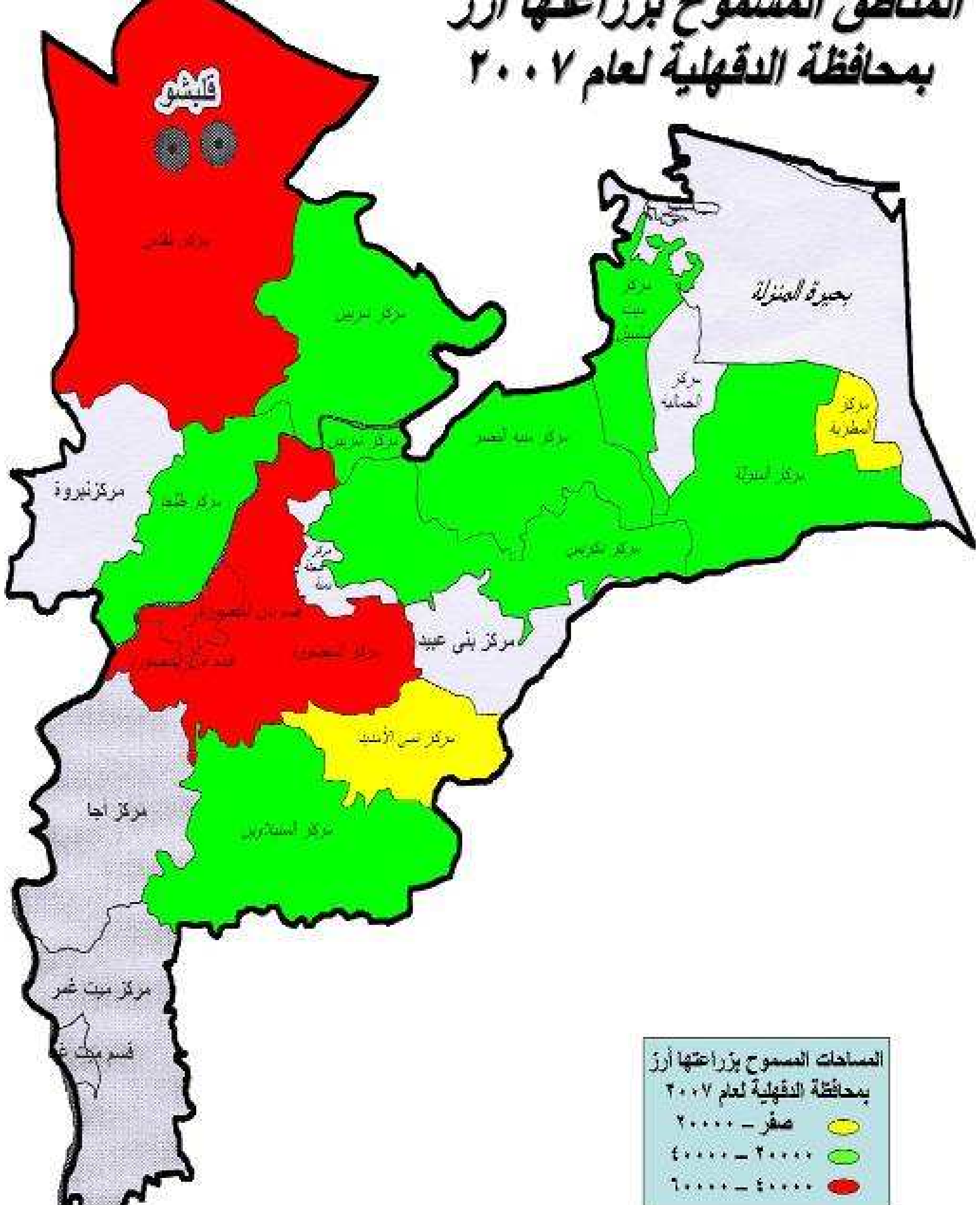
- Yield traits increase capacity and may decrease costs.
  - Transporation costs and supply effects.

Doubling yield only decreases transportation costs by ~30%.

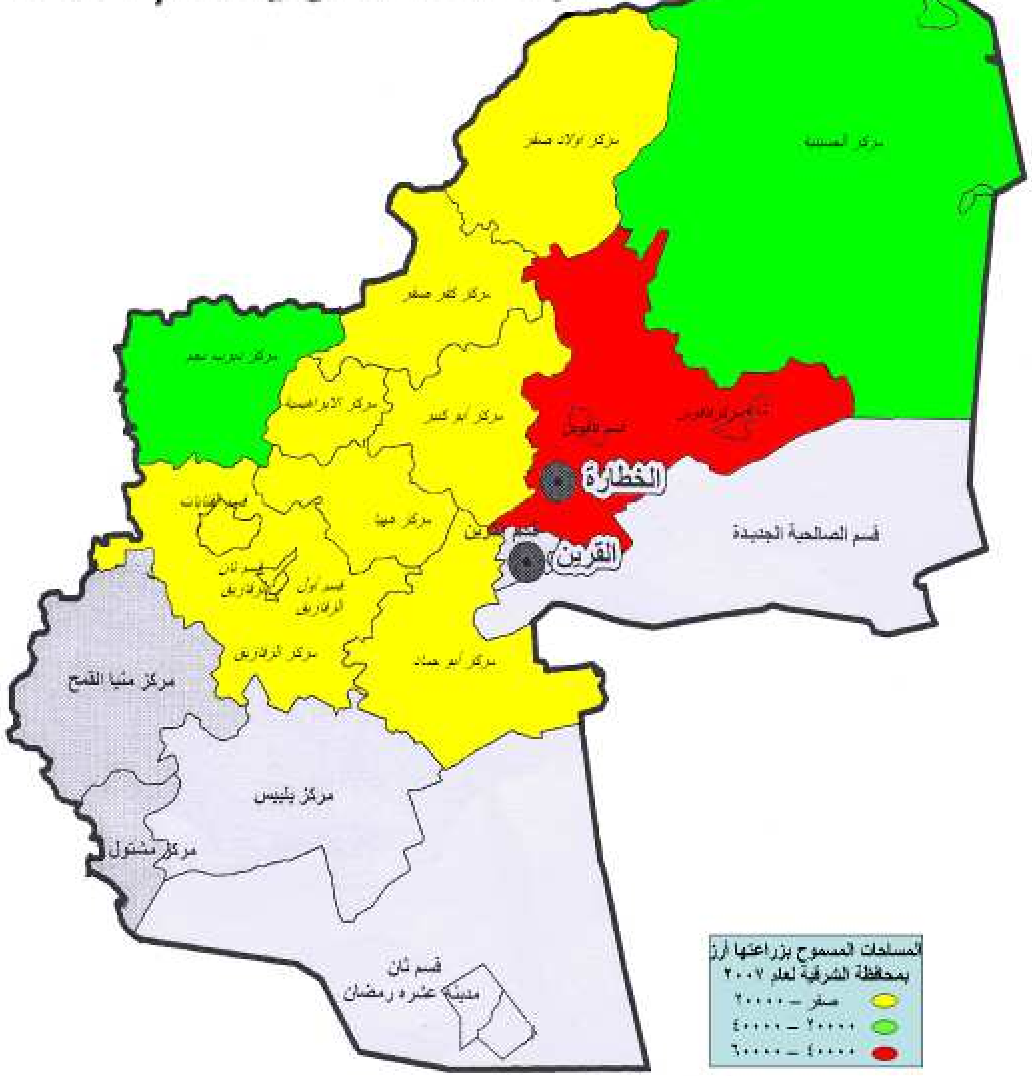



Existing facility in Sas van Gent

# المناطق المسموح بزراعتها أرز
# بمحافظة الدقهلية لعام ٢٠٠٧



# المناطق المسموح بزراعتها أرز بمحافظة الشرقية لعام ٢٠٠٧

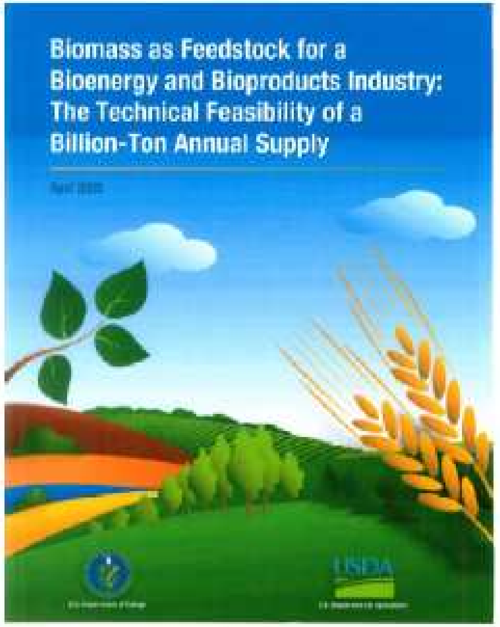


# Industry Opportunity

## Theoretical Ethanol Yields

| Feedstock | Ethanol Yield/Dry Ton* | |
|---|---|---|
| | *Gallons* | *Liters* |
| Cane Bagasse | 112 | 424 |
| Corn Stover | 113 | 428 |
| Rice Straw | 110 | 416 |
| Forest Thinnings | 82 | 310 |
| Hardwood Sawdust | 101 | 382 |
| Mixed Paper | 116 | 439 |

Note: Cellulose & Hemicellulose utilized (C-6 & C-5 sugars)
Source NREL



# Rice Straw- based Biofuels

| Type of Straw | Lignin, % | Cellulose (C6-fraction, %) | Hemi-Cellulose (C5-fraction, %) | Ashes and others, % |
|---|---|---|---|---|
| Rice | 12 | 36 | 25 | 27 |
| Barley | 14 | 34 | 25 | 27 |
| Wheat | 17 | 40 | 28 | 15 |
| Rye | 19 | 38 | 30 | 13 |
| Corn stover | 17 | 38 | 32 | 13 |
| Sugarcane residues | 20 | 43 | 30 | 7 |

With 90% C6 recovery and C6/ethanol conversion rate at 48%, and 80% of C5 recovery and C5/ethanol conversion rate at 42%.

•One tone of dry rice straw yields 234 L of ethanol,

•One tone of dry sugar cane residues yields 277 L of ethanol,

•One tone of corn stover yields 271 L of ethanol..

| Governorate | Recommended crop residue | Available biomass (dry ton) | Projected refinery capacity (tons) | Proposed number of refinery units) | No of direct labour to be offered |
|---|---|---|---|---|---|
| Dakahlia | Rice straw (40%) | 500,000 | 120,000 | 6 | 960 |
| Kafr El-Shiekh | Rice straw (40%) | 360,000 | 85,000 | 4 | 680 |
| Monofia | Corn stover(40%) | 340,000 | 93,000 | 4 | 744 |
| Menia | Corn stover(40%) | 396,000 | 107,000 | 5 | 856 |
| Qena | Sugar cane residues (70%) | 1.634 000 | 442.000 | 4 | 3536 |
| Aswan | Sugar cane residues (70%) | 2.372000 | 642.000 | 6 | 5136 |

# Mass Balance of Bio-Ethanol based on Rice Straw

| **Parameter** | **Value** |
|---|---|
| Dry matter of rice straw | 90% |
| Fermentable sugars | 61% |
| Usable fermentable sugars | 51% (80-83%) |
| Conversion rate of sugars into ethanol | 45% for C6 and 42% for C5 |
| Ethanol production per ton of rice straw | 234 kg |
| Usable by-products (bacterial biomass) | 2% (2,5 kg) |

# Labour Requirement for an Bio-Ethanol Plant based on Straw

| **Process Step** | **Category** | **Number/1.000 tons** |
|---|---|---|
| Straw handling | Blue collar | 1 |
| Production | Blue collar | 2 |
| | White collar | 2 |
| Packaging & Logistics | Blue collar | 1 |
| Administration | White collar | 0,5 |
| Sales | White collar | 0,5 |
| Auxiliary | Blue collar | 1 |
| **Total** | | **8** |

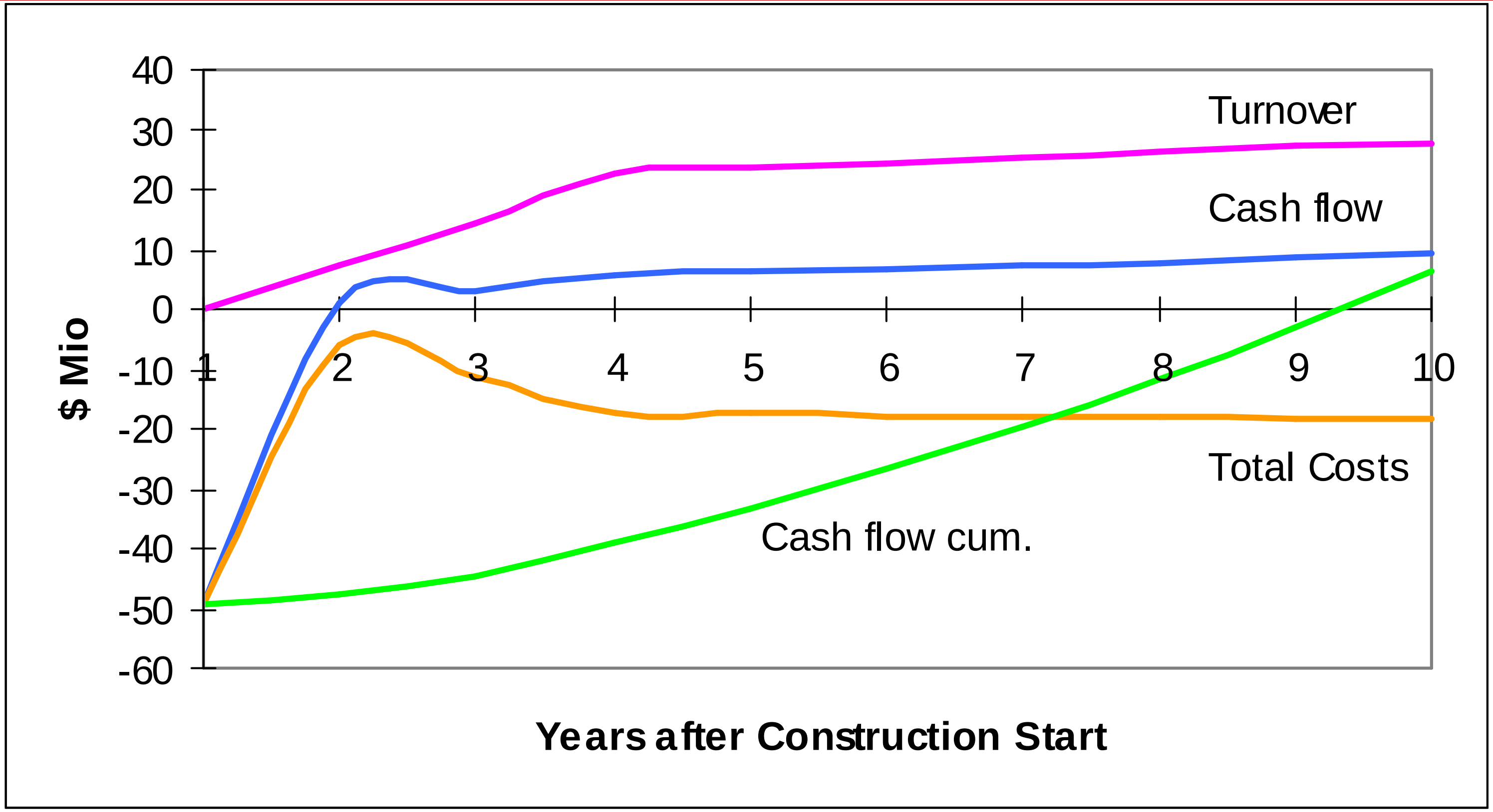
# Raw Material Costs for one Ton Bio-Ethanol based on Rice Straw

| Raw Material | Quantity/ton bio-ethanol | Unit price ($/unit) | Total ($/ton bio-ethanol |
|---|---|---|---|
| Rice straw | 4.27 | 32 | 136 |
| other nutrients | 2% of rice straw costs | | 5 |
| Drinking water | 30 $m^3$ | 0,25 | 7,5 |
| Cooling water | 200 $m^3$ | 0,025 | 5 |
| $H_2SO_4$ | 0,261 tons | 80 | 20 |
| Enzymes | $ 0,25/l ethanol | | 347 |
| Electricity | 4.280 kwh | 0,035 | 149,8 |
| Denaturant[1] | 10 kg | 1,3 | 13 |
| Total | | | 684.3 |

# Labour Costs per Ton of Bio-Ethanol based on Rice Straw

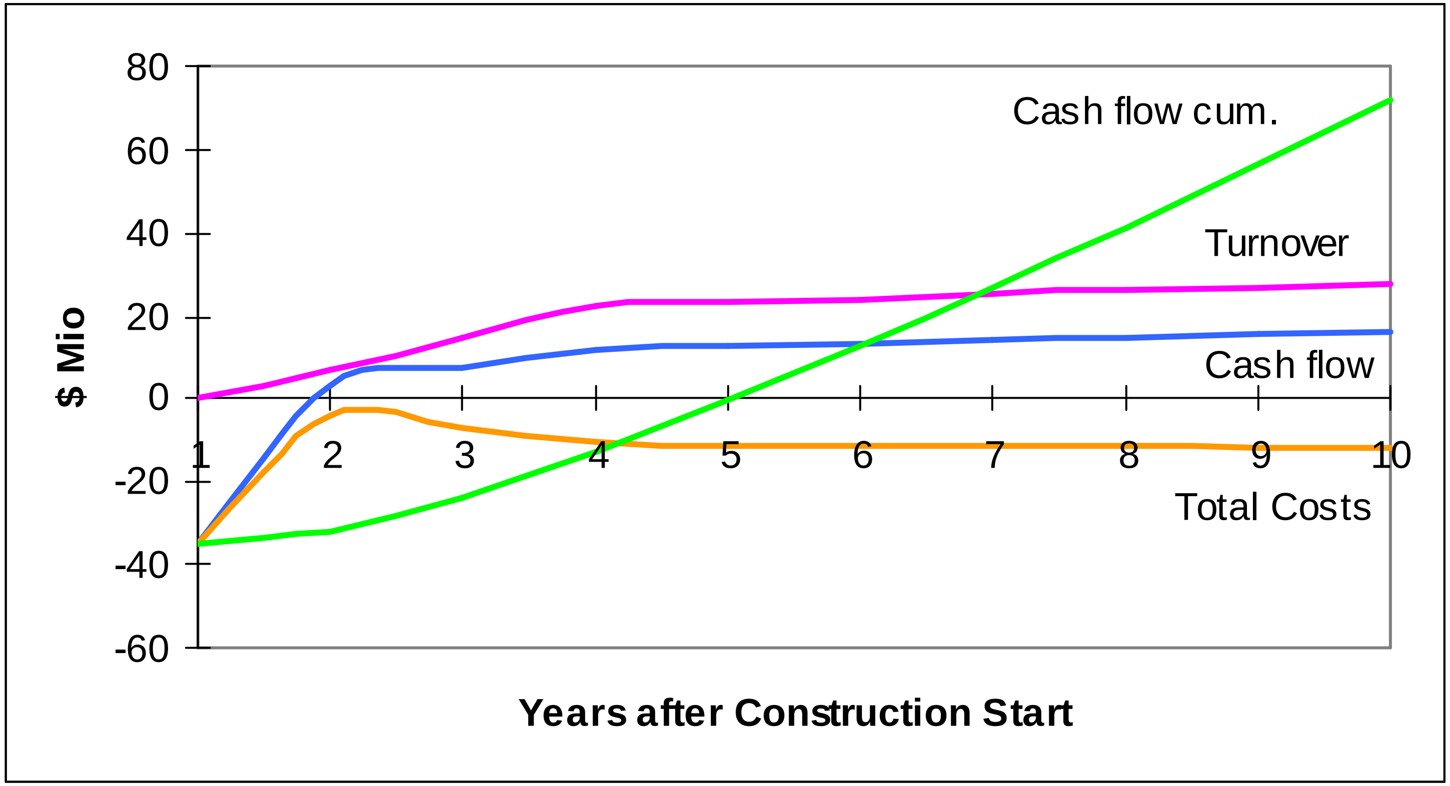
| Process Step | Category | Number/ 1.000 tons | Unit cost ($/year) | Costs/ year ($) |
|---|---|---|---|---|
| Straw handling | Blue collar | 1 | 6.000 | 6.000 |
| Production | Blue collar | 2 | 6.000 | 12.000 |
| | White collar | 2 | 12.000 | 24.000 |
| Packaging & Logistics | Blue collar | 1 | 6.000 | 6.000 |
| Administration | White collar | 0,5 | 12.000 | 6.000 |
| Sales | White collar | 0,5 | 12.000 | 6.000 |
| Auxiliary | Blue collar | 1 | 6.000 | 6.000 |
| Total | | 8 | | 66.000 |

# Cash flow Development
# (basic model)
# IRR 2%




**Investment $2450/ton ETOH, enzyme $0.26/ton ETOH**

# Cash flow Development (optimised system) IRR 24%




**Investment $1750/ton ETOH, enzyme $0.25/ton ETOH**

# Choice of Products

| Fuel | Energy density | Air-fuel ratio | Specific energy | Heat of vaporization |
|---|---|---|---|---|
| Gasoline | 32 MJ/L | 14.6 | 2.9 MJ/kg air | 0.36 MJ/kg |
| Butanol | 29.2 MJ/L | 11.2 | 3.2 MJ/kg air | 0.43 MJ/kg |
| Ethanol | 19.6 MJ/L | 9.0 | 3.0 MJ/kg air | 0.92 MJ/kg |
| Methanol | 16 MJ/L | 6.5 | 3.1 MJ/kg air | 1.2 MJ/kg |

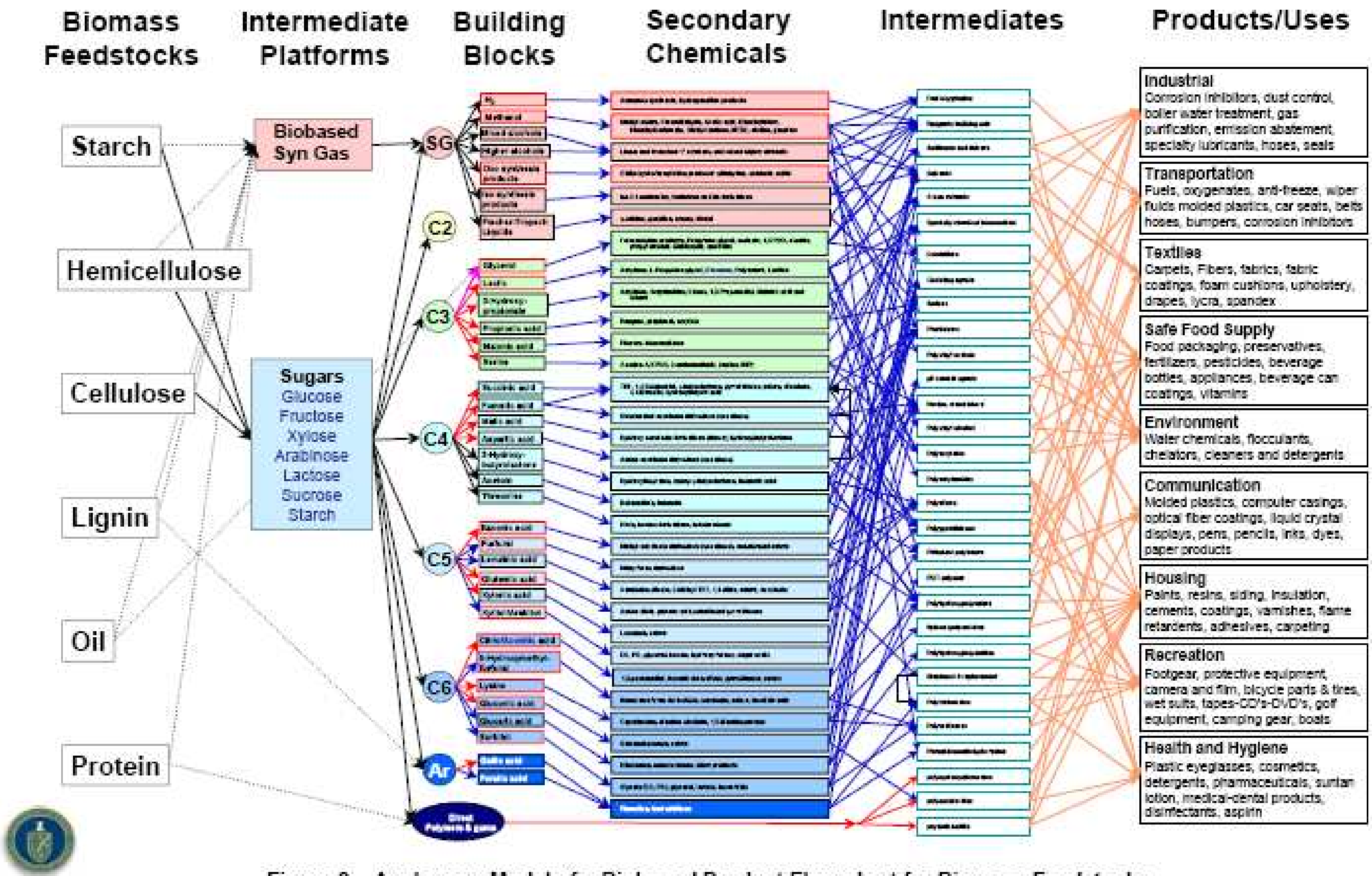
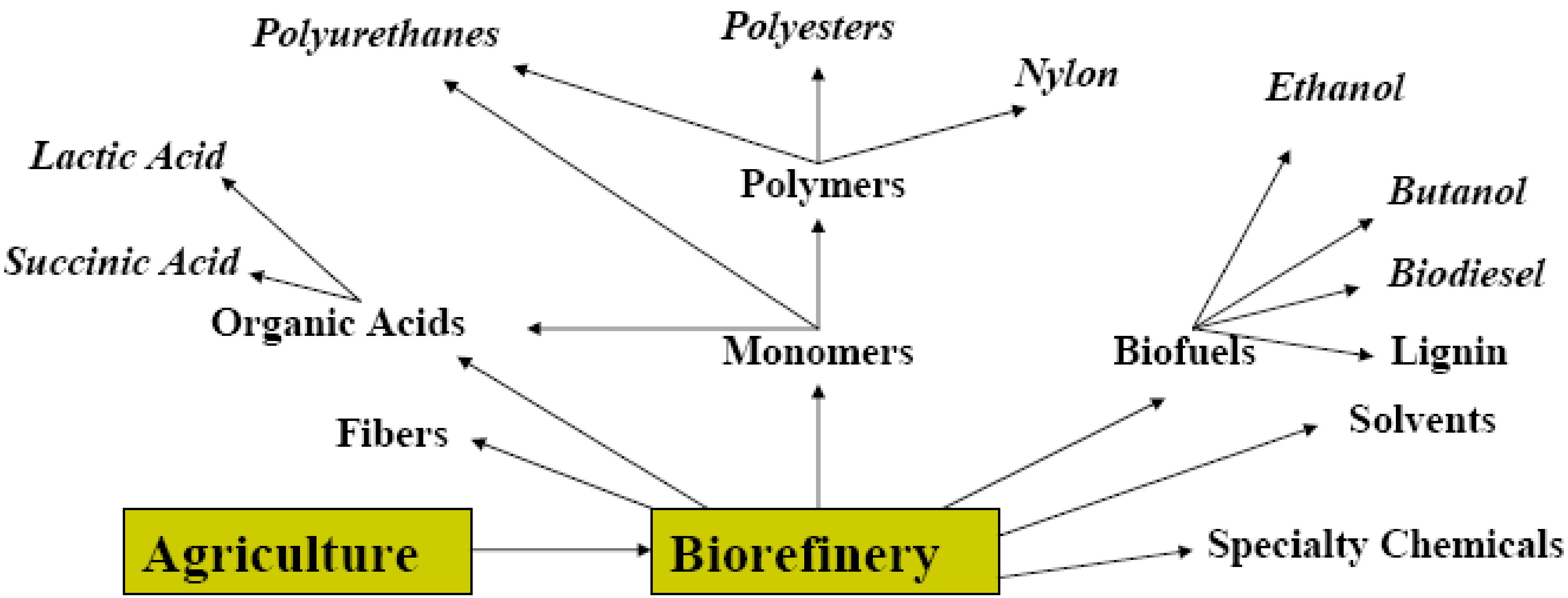


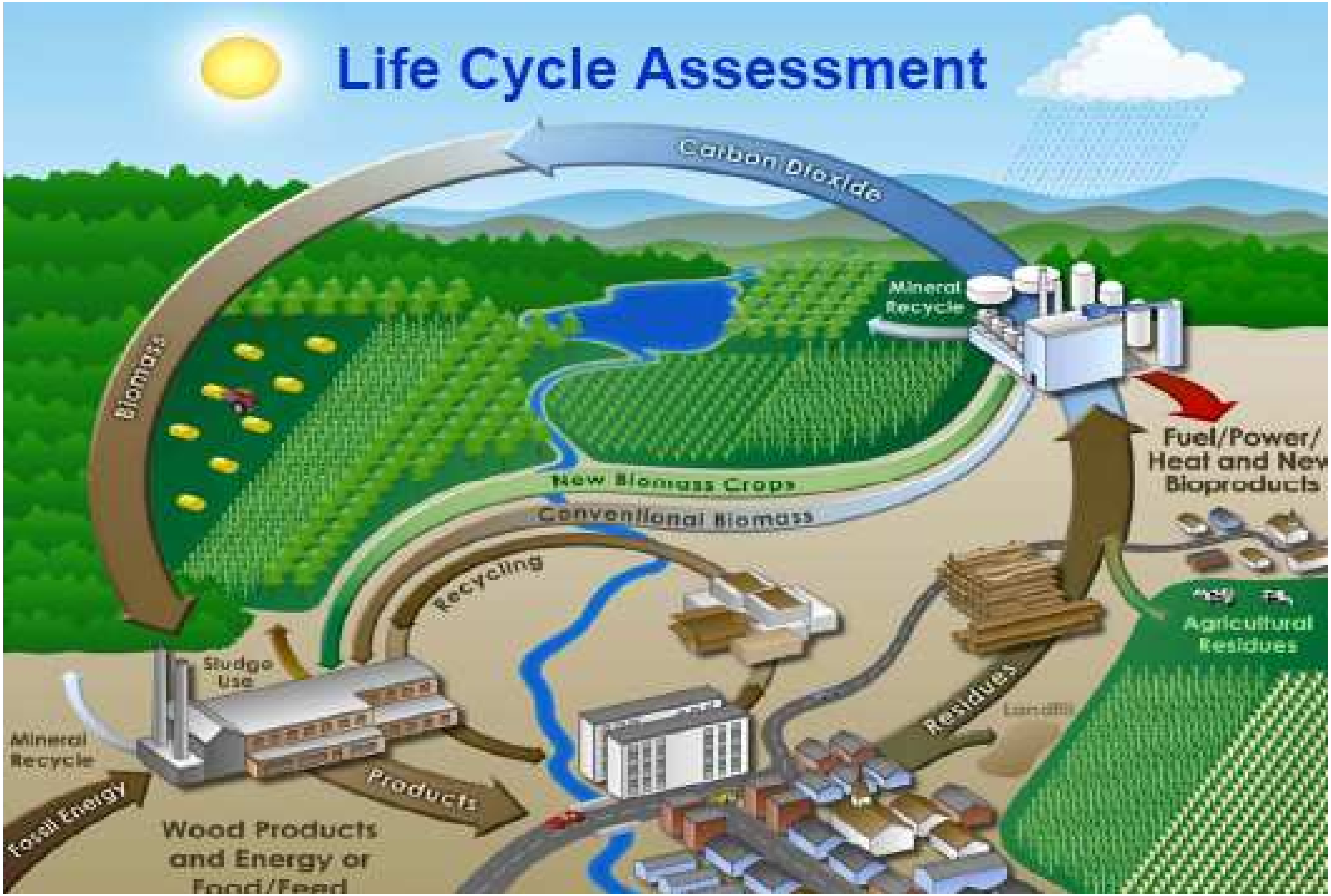

Figure 3 – Analogous Model of a Biobased Product Flow-chart for Biomass Feedstocks

# Opportunity for Tomorrow-

## It's not just about biofuels



# Full scale of semi-pilot facilities – (Quna)


Life Cycle Assessment
Carbon Dioxide
Biomass
Mineral Recycle
New Biomass Crops
Conventional Biomass
Fuel/Power/ Heat and New Bioproducts
Recycling
Agricultural Residues
Sludge Use
Residues
Landfill
Mineral Recycle
Fossil Energy
Products
Wood Products and Energy or Food/Feed