Biorefinery
The Theme of Next Generation Biofuels

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Current ‘Organized’ Energy Requirements

Primary (domestic)	40%
Transport	40%
Industry	20%

<u>Did you know</u>

Developing countries use renewable energy up to 40% as source of primary energy !! – Counted as <u>‘unorganized sector’</u>

Share of crude oil and gas end use:

Transport/Primary Energy	90%
Chemical/products	10%

Needed

- Alternative & renewable primary energy source

- Alternative & renewable transport fuel source

- Alternative & renewable platform chemicals source

Needed

- Alternative & renewable primary energy source
- Alternative & renewable transport fuel source
- Alternative & renewable platform chemicals source

Aimed at generating power

Needed

- Alternative & <u>renewable primary energy</u> source

- Alternative & <u>renewable transport fuel</u> source

- Alternative & <u>renewable platform chemicals</u> source

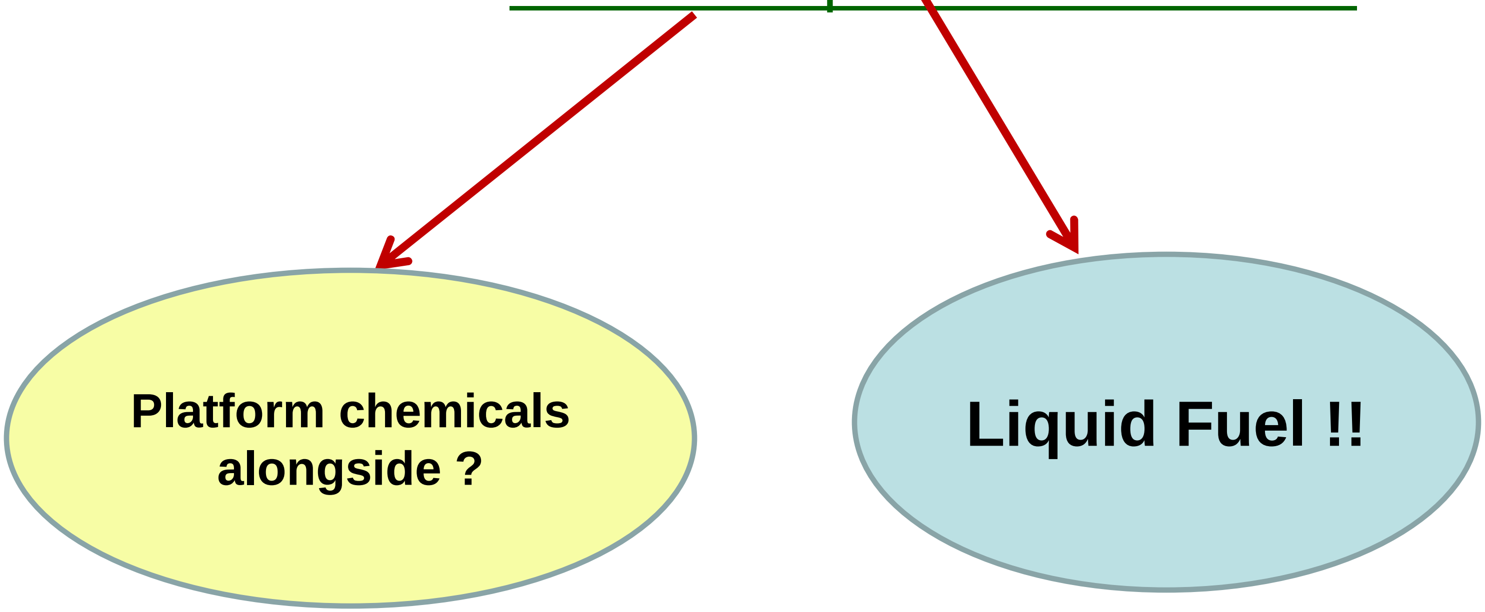
Liquid Fuel !!

Needed

- Alternative & renewable primary energy source

- Alternative & renewable transport fuel source

- Alternative & renewable platform chemicals source



Why biofuels ?

Three Objectives :

1. To reduce dependence on petroleum

   India imports 75% fuel, will rise to 90% by 2020

2. To reduce green house has (GHG) emissions

   Alarming rise in Carbon dioxide levels

3. To reduce the cost of fuel against escalating crude oil prices

Evolution of Biofuels

First generation Biofuels : Corn and sugar to ethanol
Biomass to methane

Second Generation Biofuels : Lignocellulose to ethanol
Vegetable oil to Biodiesel

<u>Challenge</u>

To use renewable source to produce Biofuels
in a sustainable manner

Algal Oil/Biodiesel

Fourth generation Biofuel : Biofuel from high solar efficiency cultivations

Evolution of Biofuels

First generation Biofuels : — **Starch and Sugar to ethanol**
Biomass to methane (??)

Second Generat... — ...se to ethanol
...o Biodiesel
...n syngas to HC oil

FAIL IN FOOD vs FUEL DEBATE

Third generation Biofuels — ...mass to Hydrogen
Algal Hydrogen
Algal Oil/Biodiesel

Fourth generation Biofuel : — Biofuel from high solar efficiency cultivations

Evolution of Biofuels

First generation Biofuels : Corn and sugar to ethanol
Biomass to methane

Second Generation Biofuels : Lignocellulose to ethanol
Vegetable oil to Biodiesel or HCs
Biomass Syngas to HCs

Third generation ... ydrogen

Viable Technologies
not in place

Fourth generation B ... n high solar efficiency
cultivations

Evolution of Biofuels

First generation Biofuels : Corn and sugar to ethanol
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Vegetable oil to Biodiesel
Fisher-Tropsch syngas to HC oil

Third generation Biofuels: Biomass to Hydrogen
Algal Hydrogen
Algal Oil/Biodiesel

Fourth generation … h solar efficiency

The Future : Science and Technologies in Laboratories

Evolution of Biofuels

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cultivations

Essential Requirements for Viable Technologies:

- Economically sustainable
- Ecologically sustainable

Important Points To Remember

- Renewable sources are
  - Technologically complex
  - Socio-politically complex
  - Ecologically complex

- Scale of handling entails
  - "waste' side-streams generation
  - High capital cost
  - Logistic complexities

The concept : BIOREFINERY

"A Biorefinery is collection of processes that utilizes
a renewable biological or bio-based source to produce an end product,
or products, in a manner that is a zero-waste producing, and whereby each component of the renewable biological or bio-based source, or a product there from, is converted or utilized in a manner to add value, and hence sustainability to the plant."

KEY TO SUSTAINABILITY

Complete and Judicious Use of our Agricultural Produce

We can make a biorefinery out of :

Molasses alcohol fermentation plant
Vegetable oil processing or Biodiesel plant
Grain processing plant
Dairy products plant
Lignocellulosic ethanol plant

Biological or Bio-Based Renewable Resources

- Microbial/Contained Cell cultures
- **Plants**
- Animals

PLANTS - The All Important Renewable Source

Major Issues with Plants/Agriculture as Renewable Source

- Which plants ?
- Where do we grow them ?

India (and Asia) situation:

- Land per capita far less than USA, Canada,
  Australia, Brazil
- **Cannot use land that can grow food**

Options :

- Develop **perennial crops** (Future of agriculture !)
- Use marginal lands and develop suitable crop varieties (why not food ?)
- **Use present day agricultural crops completely and judiciously**
- **Use sea/ocean for growing 'plants' – A VERY USEFUL OPTION**

Utilization of Existing Agricultural Produce

Non-food and non-fodder agricultural 'waste'

India Facts :

- Currently at 250 million ton/year
- Mostly put to low value utilization
- Can be used as feed-stock for
  - *BioFuels*
  - *Chemical Building Blocks*

Examples :

- Cotton stalks
- Wheat Straw
- Corn Cobs
- Banana stem

Biomass Availability- INDIA

Non-food Non-fodder Lignocellulosic Biomass sources:

- *Cotton Stalk*
- *Wheat Straw*
- *Rice Straw*
- *Sugar Cane tops*

Crop residues	Production Million tons	
	1994	**2010 (projected)**
Field based residues		
Cotton stalk	19.39	30.79
Rice straw	214.35	284.99
Wheat straw	103.48	159
Maize Stalk	18.98	29.07
Soybeans	12.87	34.87
Jute stalk	4.58	1.21
Sugarcane tops	68.12	117.97
Ground nut straw	19	23.16
Processing Based residue		
Rice Husk	32.57	43.31
Rice Bran	10.13	13.46
Maize cob	2.59	3.97
Maize Husk	1.90	2.91
Coconut shell	0.94	1.50
Coconut husks	3.27	5.22
Ground Nut Husk	3.94	4.80
Sugarcane bagasse	**65**	**114.04**
Coffee husk	0.36	0.28

Shows Annual availability > 500 MT !!
Bioethanol potential > 100 MT/year
Transport Energy Consumption in India = 50 million tons/year

A 50km x 50km area

→ *2.5 MMT biomass/year*
→***1 million L EtOH/day (~300MW plant)***
→ *Large Plant !!*

Crop/ha	Component	Ethanol/ha	Remarks
Cane :100t	Sugar (10%) Lignocellulosic dry residue (20%)	5000L 5000L*	*bad energy economy against burning of bagasse
Non-fodder agricultural residue : 7.5t	Lignocellulosic dry mass (100%)	2000L	@300Mt/y this meets liquid fuel requirement ***
Miscanthus or Switchgrass : 15t dry	Lignocellulose (100%)	7000L	For meeting all fuel demand requires 16 MHa cultivation**
Corn : 4t kernel 8t stover	Starch Lignocellulose	4000L 2000L	Case for combined crop utilization or only non-fodder use
Palm oil or Jatropha (5000L/ha)	Biodiesel from all oil incl. edible portion	5000L	Land required For meeting all India demand ~15Mha ie 10% India's cultivable land**

**Cultivable land in India=150Mha; 70Mha is wasteland
***Annual fuel consumption in India = 75Mt/year

Comparison between
Cane-bioethanol and Biomass-bioethanol yields

Cane-Bioethanol

Cane yield/hectare	100 ton (max)
Sugar yield/hectare (@ 10%)	10 ton
Bagasse + biomass yield	20 ton/Ha
Ethanol yield/hectare	5 ton
Additional ethanol from bagasse	6 ton
Total	**11 ton**

Biomass-Bioethanol (Energy Crop e.g. sorghum or switchgrass)

Dry biomass/hectare (max)	20 ton
Bioethanol yield/hectare	**6 ton**

Comparison of Bagasse (biomass) use for BioEthanol vs. Direct Combustion

Maximum power generation	: 1 KWH/kg bagasse (biomass)
BioEthanol generation	: 0.3 liter/kg bagasse (2 KWH/kg bagasse)

Cost of 0.3L ethanol	= 0.3 USD
Cost of 1KWH	= 0.05 USD

Issue → Primary Power vs. Liquid Fuel

Grain-Biomass Scenario in Philippines

Average Rice yield/Ha	3 to 4 ton/Ha
Average rice straw yield	5 ton/Ha
Philippines area under rice cultivation (Total area = 30 million Ha)	4.0 million Ha
Rice Straw/year	20 million ton/year
Bioethanol yield possible	**6 million ton/year**
Philippines area under corn cultivation	6 million Ha
Corn biomass/year	40 million ton/year
Bioethanol/year possible	**12 million ton/year**
TOTAL BIOMASS BIOETHANOL	**18 million ton/year**
Philippines Transport Fuel Consumption	10 million tons/year

POTENTIAL LOCAL FUEL SELF-SUFFICIENCY

India Case

Liquid transportation fuel consumption in India = 45 MT/year

Per capita liquid transport fuel consumption = 45 kg/year

Consumption in 50x50 km area = 150,000 kg/day
(at 400 people/sq km)

Compare with
Production capacity = 1,000,000 kg/day

Local Raw Material and Local Consumption
Will reduce distribution costs that add almost 30-50% to our fuel bill !!

Despite enormous potential Lignocellulosic Ethanol has not been commercially successful due to a number of reasons

Reasons : High Cost and High Risk

- Cost of Production > 1.50 USD/liter
- High capital cost (almost at atomic energy level)
- Waste generating and Non-ecofriendly Technologies

Other Reasons

- No complete demonstration of biomass ethanol technology
  Despite pilot plants the overall economics unreliable
- Biomass source is varied and uncertain
  Technology varies with biomass source
- Pretreatment technologies un-optimized and non-ecofriendly
  Acid treatment technologies generate waste
- Low confidence in enzymatic saccharification technology
  Enzymes far from optimal contributors to cost
- Low confidence in pentose fermentation technology
  Low confidence on xylose to ethanol conversion
- Biorefinery Concept Un-proven
  No reliable information on impact of value added products

Production Comparison of Different Energy Sources
Current Status

No.	Source	Capital cost per MW* (in million USD)	Production cost per KWH (in million USD)	Cost** USD/L
1	Bioethanol (Biomass)	1.00	0.05	1.50
2	Bioethanol (Corn)	0.60	0.06	0.80
2	Coal	1.00	0.01	-
3	Gas	0.60	0.02	-
4	Atomic energy	1.50	0.005	-

*1MW~1ML EtOH/year
** Incl. cost of capital

Other Biomass derived Liquid Fuel Options

Biomass-to-Liquid (BTL) Technologies

Biomass → Syngas → Hydrocarbons → Gasoline/Diesel
OR
Biomass → Pyrolysis → Hydrocarbons → Gasoline/Diesel

Maximum Liquid Yield : 50 gallons/ton biomass
(BioEthanol yield : 100 gallon/ton)

Biomass-to-Gas Technologies

Biomass → SCW Hydrolysis → Hydrogen
(Technologies not yet ready for commercialization)

How to make the technologies eco-friendly
and yet cost-competitive ?

ANSWER : Development of the Biorefinery Concept

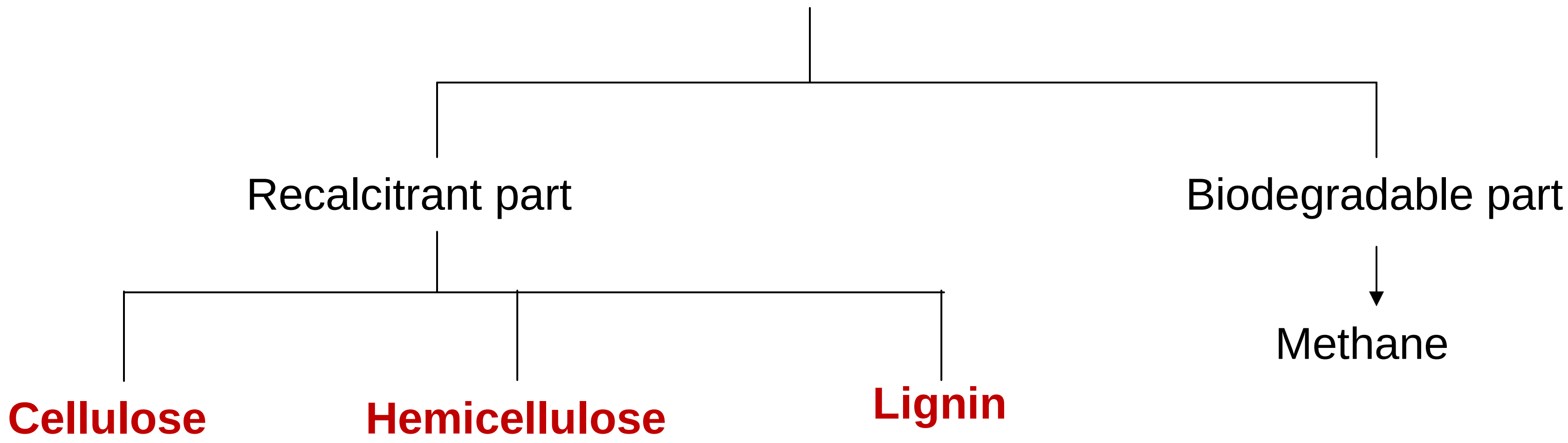
Three Case Studies

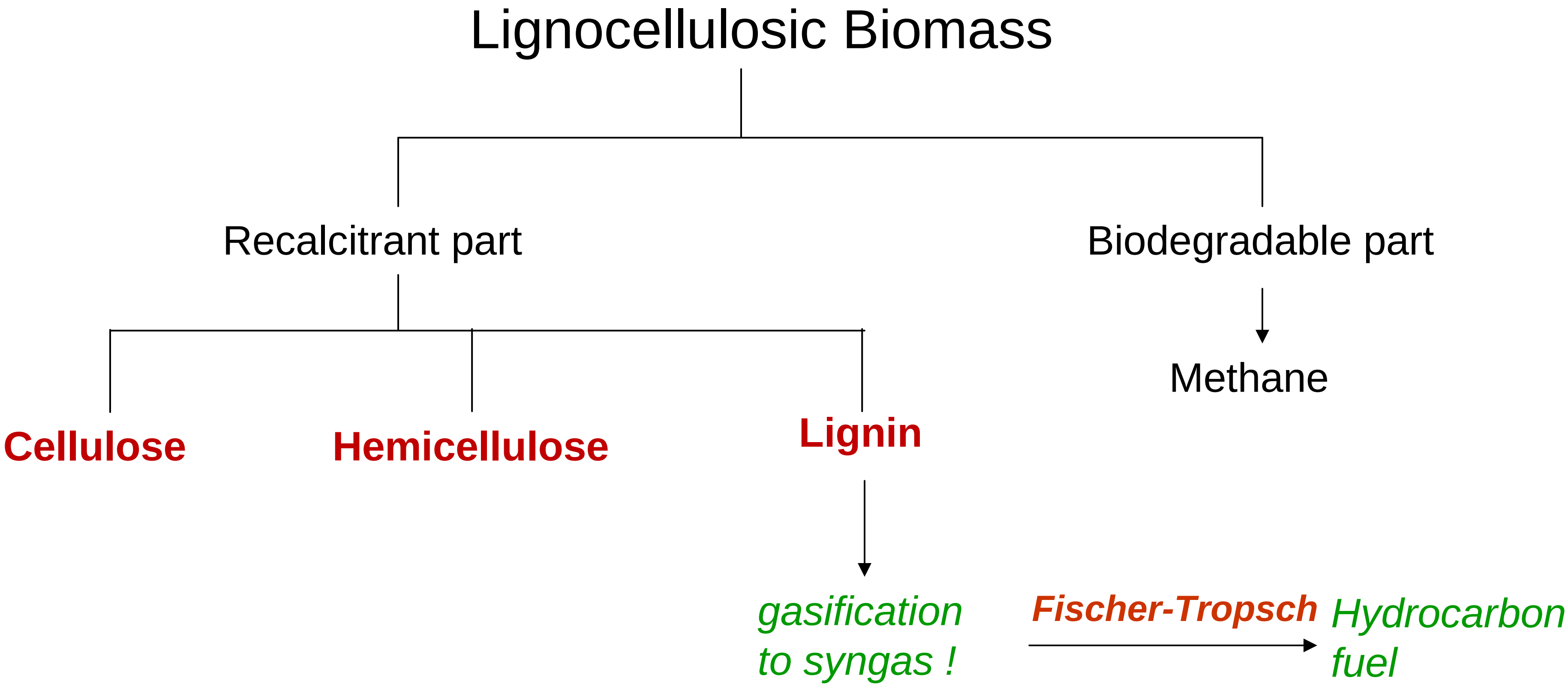
(A)Biomass BioEthanol

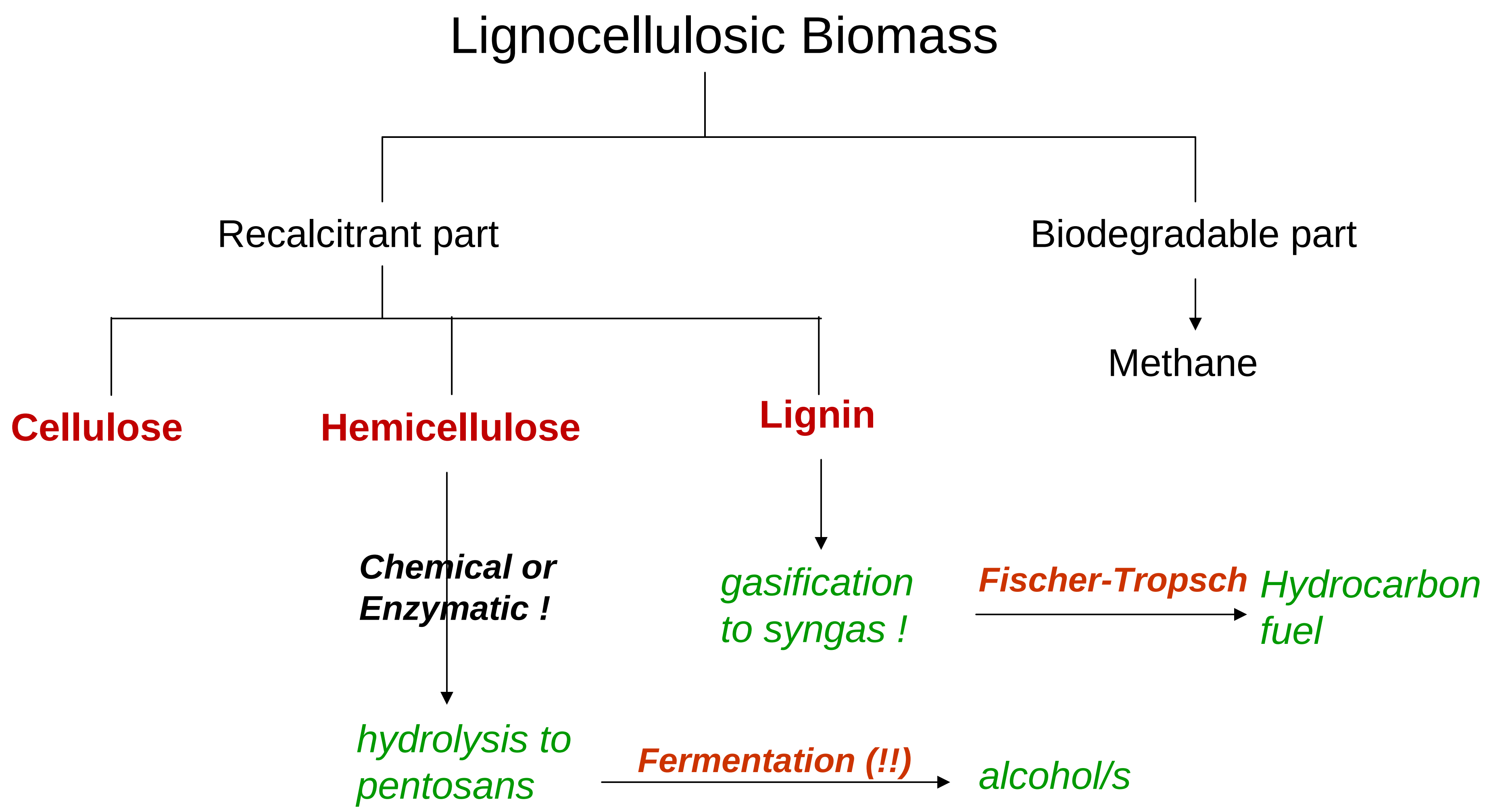
(B) Vegetable Oil to BioDiesel

(C) Algal Biofuels

Case 1 : Lignocellulosic Biomass




Lignocellulosic Biomass
Recalcitrant part
Biodegradable part
Methane
Cellulose
Hemicellulose
Lignin
gasification
to syngas !
Fischer-Tropsch
Hydrocarbon
fuel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Chemical or
Enzymatic !
gasification
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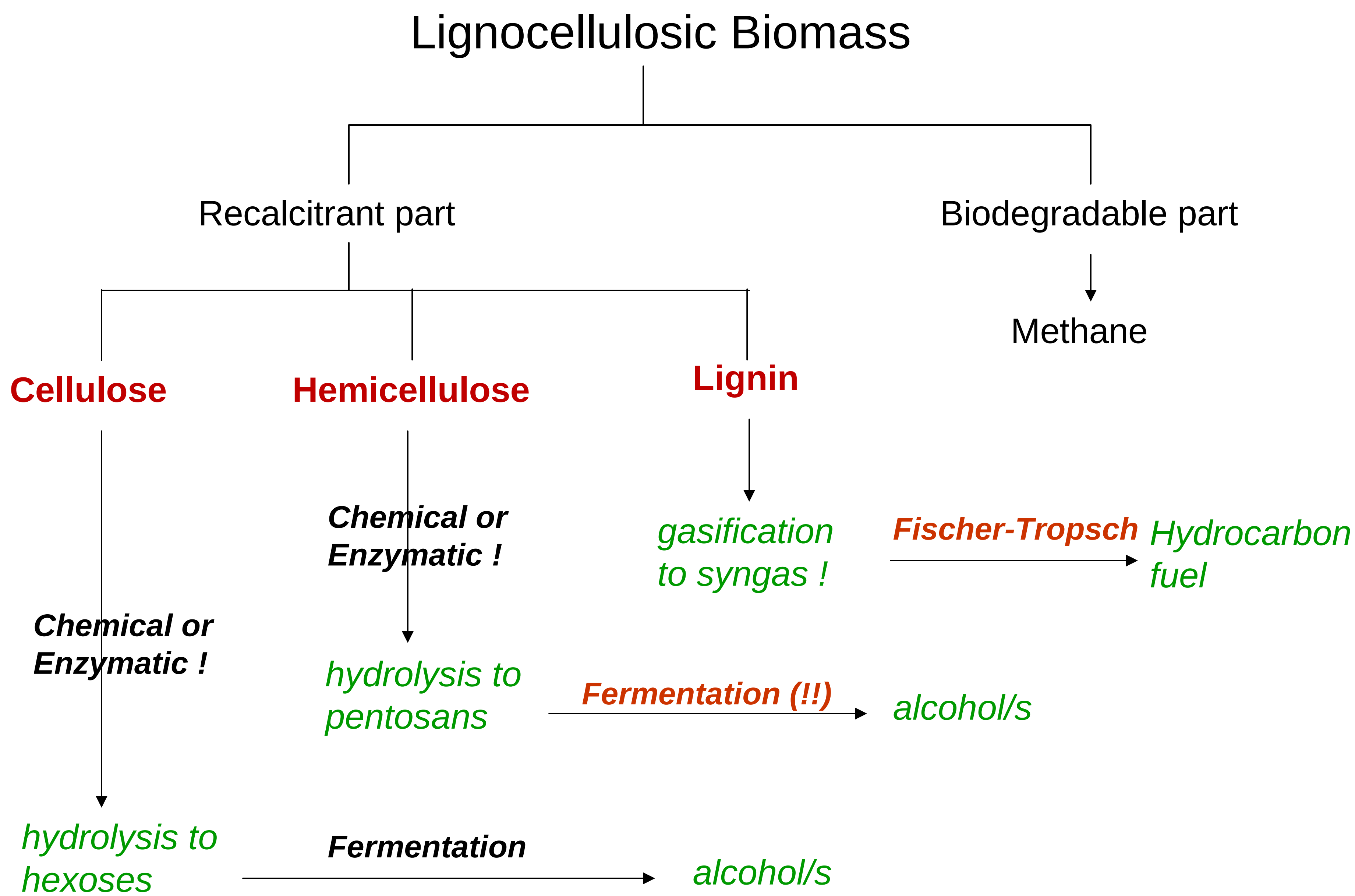
Fischer-Tropsch
Hydrocarbon
fuel
hydrolysis to
pentosans
Fermentation (!!)
alcohol/s


Lignocellulosic Biomass
Recalcitrant part
Biodegradable part
Methane
Cellulose
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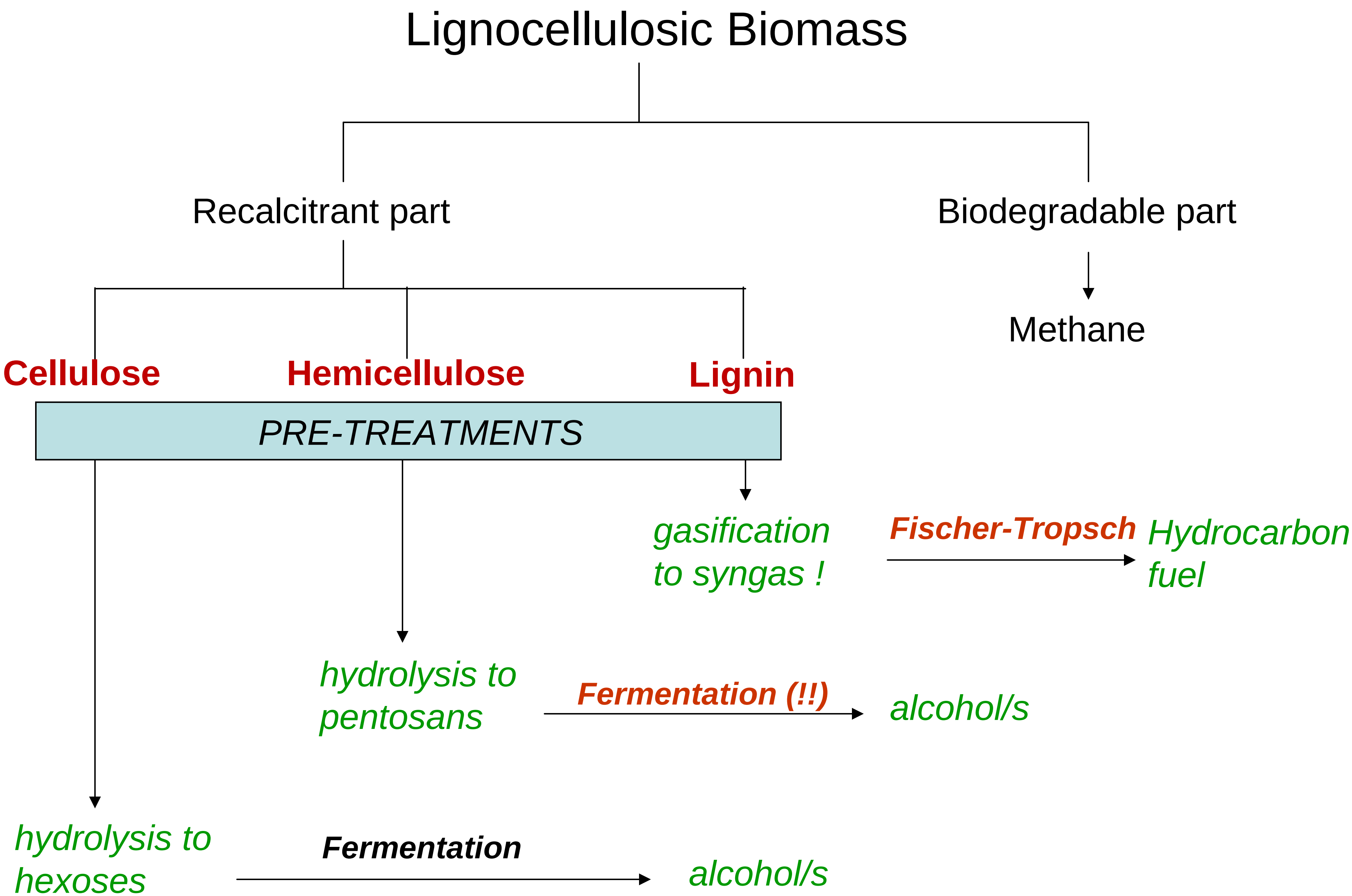
Lignin
Chemical or Enzymatic !
gasification to syngas !
Fischer-Tropsch
Hydrocarbon fuel
Chemical or Enzymatic !
hydrolysis to pentosans
Fermentation (!!)
alcohol/s
hydrolysis to hexoses
Fermentation
alcohol/s


Lignocellulosic Biomass
Recalcitrant part
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Methane
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PRE-TREATMENTS
gasification to syngas !
Fischer-Tropsch
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alcohol/s
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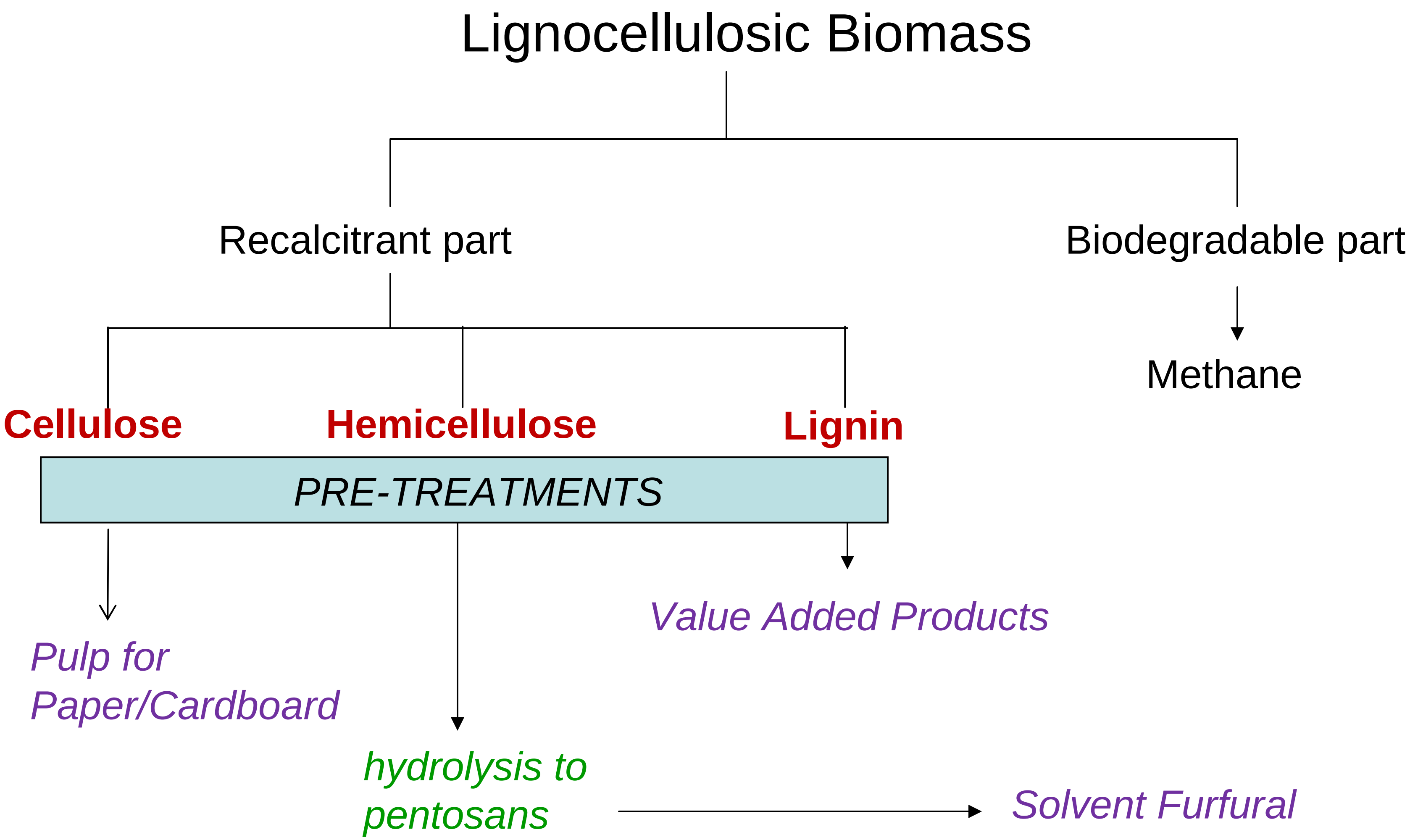
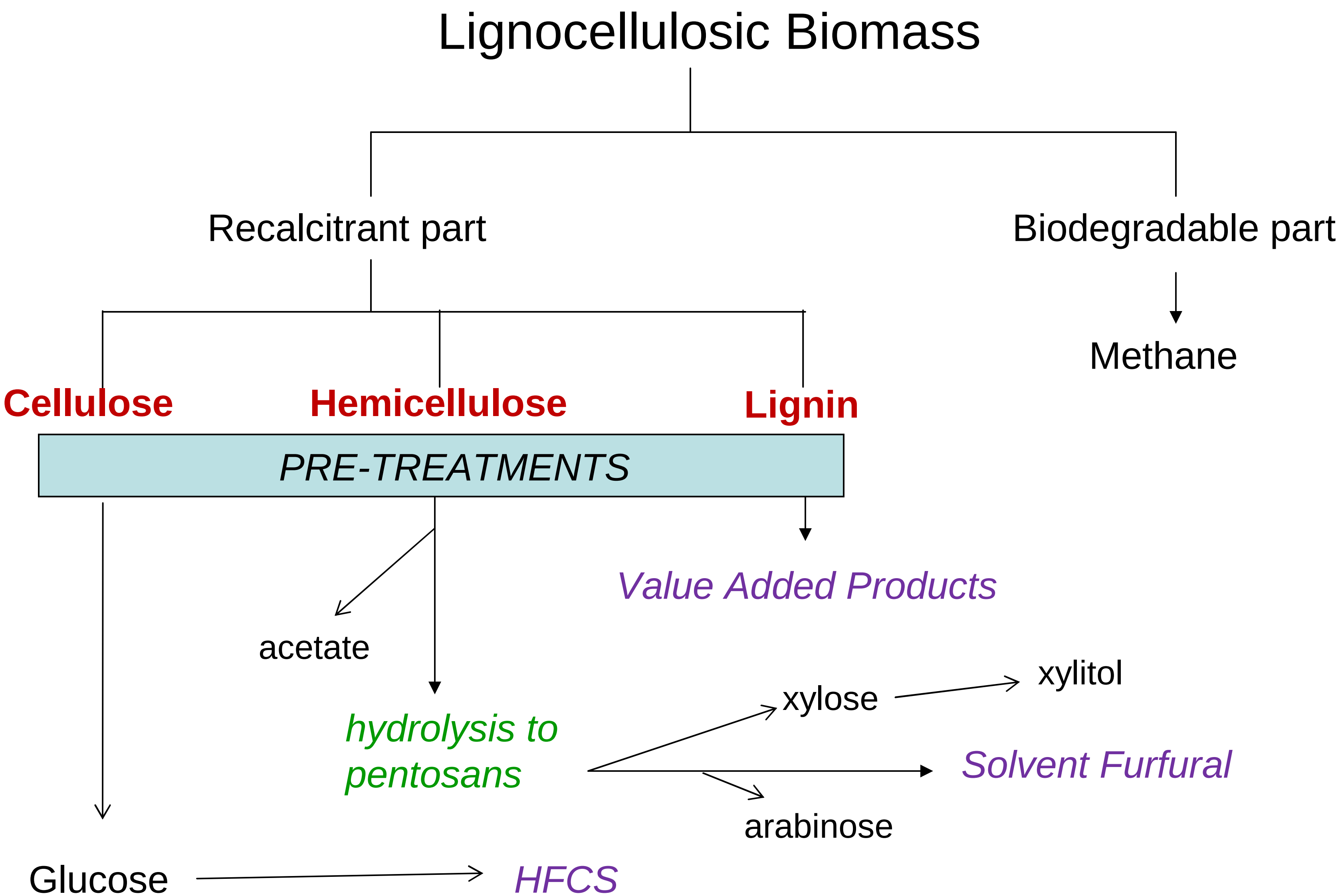
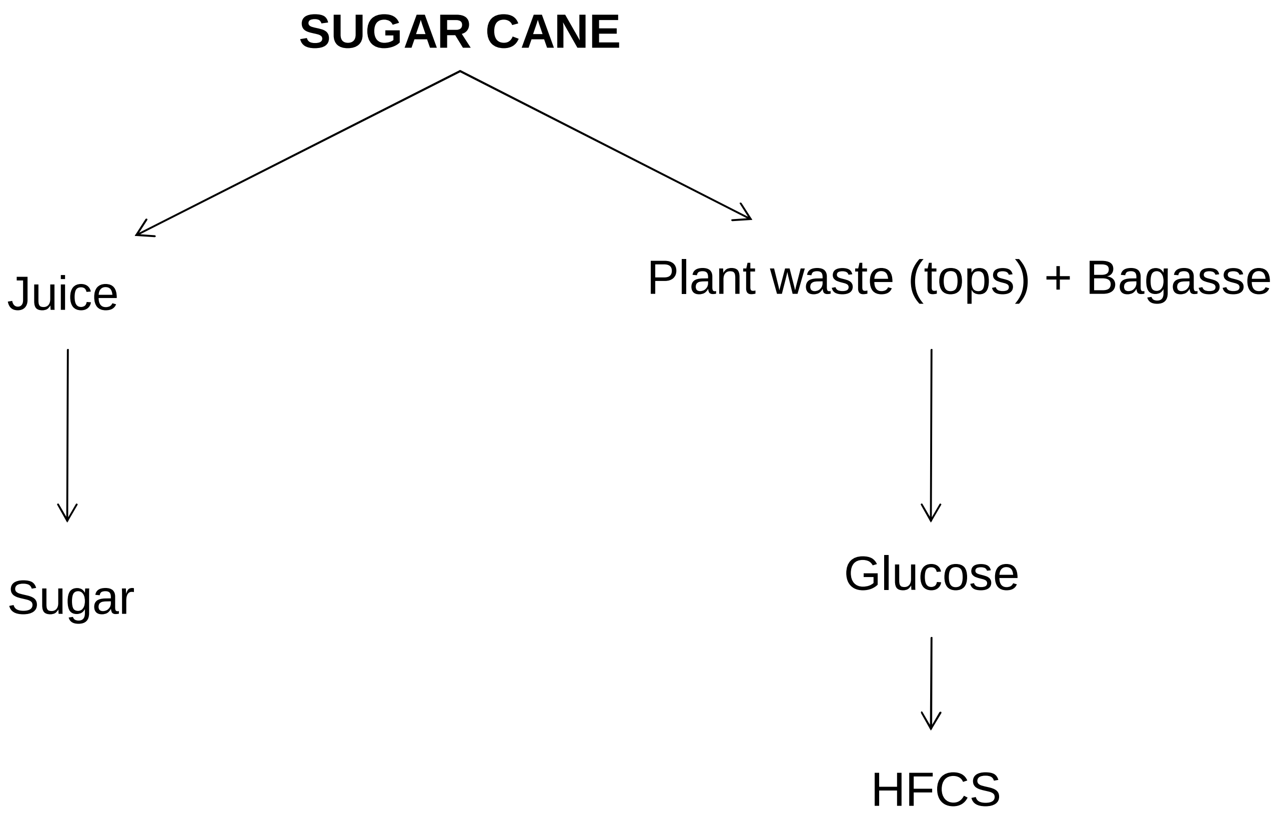
Fermentation
alcohol/s


Lignocellulosic Biomass
Recalcitrant part
Biodegradable part
Methane
Cellulose
Hemicellulose
Lignin
PRE-TREATMENTS
Value Added Products
Pulp for
Paper/Cardboard
hydrolysis to
pentosans
Solvent Furfural


Lignocellulosic Biomass
Recalcitrant part
Biodegradable part
Methane
Cellulose
Hemicellulose
Lignin
PRE-TREATMENTS
Value Added Products
acetate
xylitol
xylose
hydrolysis to pentosans
Solvent Furfural
arabinose
Glucose
HFCS

POSSIBILITY



Case I – Sales from Conversion of total hexose and pentoses to ethanol

Basis : 1 ton of LBM subjected to Chemical/Thermal fractionation of LBM

90% hexose recovery from cellulose, and 54% pentose recovery from hemicellulose

40% hemicellulose converts into furfural

95% yield of EtOH on hexose, and 68% yield on pentose

Products	Applications	Source					
		Softwood	**Hardwood**	**Sugarcane Bagasse**	**Straw**	**Corn cob**	**Cotton stalk**
Ethanol	Fuel (@ Rs. 13/ L)	4240	4705	3670	3160	3910	2330
Lignin	Fuel (@ Rs.3.00/kg)	1050	750	690	510	450	900
Acetic acid	Chemical @ Rs.30/kg	1710	1050	1110	1110	1140	1190
Furfural	Solvent @ Rs 50/kg	765	2050	1500	2650	3900	1020

Case II – Sales from Conversion of hexose only to ethanol

Basis : 1 ton of LBM subjected to Improved fractionation processing of LBM
90% hexose recovery from cellulose, and 90% pentose recovery from hemicellulose
All 100% hemicellulose converted into furfural or other products
95% yield of EtOH on hexose, and no ETOH from pentose
(coumaric acids and uronic acids not considered)

Products	Applications	Source					
		Softwood	Hardwood	Sugarcane Bagasse	Straw	Corn cob	Cotton stalks
Ethanol	Fuel (only from cellulose) @ Rs. 13/L	3250	3588	2821	1956	2938	2015
Lignin	Solid Fuel (@ Rs. 3.00/kg)	1050	750	690	510	450	900
	Asphalt Extender (@ 9.00/ kg)	3300	2358	2169	1603	1415	2829
	Dispersing agent (@ Rs12/kg)	4400	3100	2900	2100	1900	3800
	Intermediate for synthesis of polymers/ resins (@ Rs. 30/kg)	11200	8000	7360	5440	4800	9600
Acetic acid	Chemical @ Rs.30/kg	1710	1050	1110	1110	1140	1190
Furfural	Solvent (@ Rs.50/kg)	2590	5340	5880	7910	10980	3100
Xylose	Xylose (@ Rs.50/kg)	1950	5100	3770	6110	9910	2650
Arabinose	Pharma/Food (@ Rs.5000kg)	105800	27200	322500	176400	151200	65500

Case 2 : Bio-Diesel

Major oil sources

- Palm Oil
- Jatropha Oil

Vegetable Oil Composition

- Major components (triglycerides, FA, PUFA, MUFA)
- Minor components (phytosterols, tocopherol, carotenoids)

Tocopherols and PUFA Content of Common Edible Oils Used in India

Edible oil	**PUFA content per cent**	**Tocopherols, ppm**		
		Tocopherol T1	**Tocotrienol T3**	**Total T1+ T3**
Palm oil	11	642	492	1,134
Safflower oil	73	801	-	801
Cotton seed oil	51	782	-	782
Sunflower oil	49	546	-	546
Groundnut oil	28	367	-	367
Mustard oil	22	576	-	756
Corn oil	57	732	-	732
Coconut oil	2.2	11	25	36
Ghee	1.8	25-30	-	30

Tocopherol > USD 30/kg

Carotenoids content in Red Palm Oil

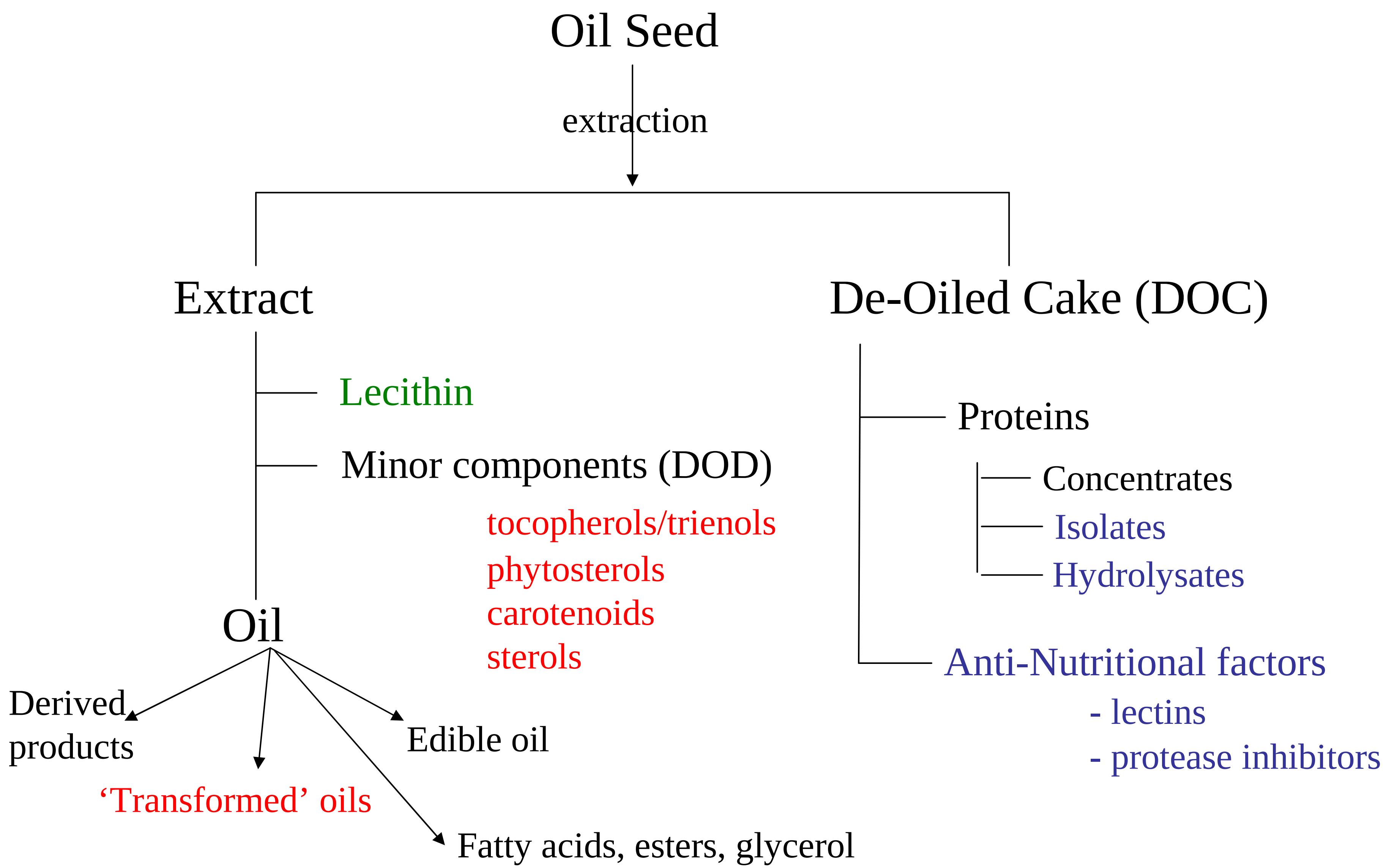
Carotene fraction	Per cent distribution	Actual content ppm
Total	-	545.0
Beta-carotene	47.4	258.0
a-carotene	37.0	202.0
cis o-carotene	6.9	37.6
Photoene	2.0	10.9
Lycopene	1.5	8.2
d-carotene	0.5	2.7
g-carotene	0.6	3.3
Beta-zea carotene	0.5	2.7
Cis beta-carotene	0.8	4.4
Neurosporene	traces	-
o-Zeacarotene	0.3	1.6
Phytofluene	1.2	6.5

Pure Natural Carotene : > 2000 USD/Kg

Red Palm Oil – Value Addition

Component	Content per Ton crude oil	Selling Price USD	Total Value per ton oil USD
Crude Oil	~100%	500/ton	500
Refined oil	~100%	1000/ton	1000
Tocopherols	~500gm	40/kg	40
Carotenes	~500gm	1000/kg	500

Vegetable Oil Bio-Refinery



Some statistical facts : India Scenario

Current liquid fuel required (petrol + diesel) = 65 Mt/year
Rising at >10%/year

300 Mt biomass waste → 75 Mt ethanol/year
30 MHa marginal land → 300 Mt biomass → 75 Mt ethanol/year

Is this enough, say in year 2050?

Both sources will **stagnate** with time.

Remember : Fuel consumption per capita in developing world almost 20 times lower than West !

WHAT NEXT ?

Possible Answer : Third Generation Biofuels

Algal : Algal Oil and Algal Starch

Strains of microalgae and other algae can produce (vegetable) Oil OR Starch *up to 50% of biomass*

Growth in water medium permits better use of sunlight and nutrient Carbon dioxide

1 hectare	→ 100 ton max biomass → 5 ton ethanol
	→ 5 ton vegetable oil → 5 ton biodiesel
	→ 25 ton algal oil → 25 ton biodiesel

ALGAL BIOREFINERY

Algae Cell Mass → Oil (lipids) → Fuel/s

Starch

Mono-sugars
e.g. galactose, mannose, glucose

Minor Constitituents
e.g. tocols, carotenoids

Other expressed metabolites
e.g. amino acids, proteins

Technology Challenges:

Photo-Bioreactor Design

Contained systems to prevent contamination

Carbon dioxide source and transport

Micro-nutrient supply

Land requirement →

- Marine algal systems
- Sea-ponds
- Lagoons
- Shallow back-waters

Concept : Off-shore Marine Algal Biorefinery

Need for research and development in

- Transformed/Improved robust algal species
- Efficient nutrient transport system
- Efficient temperature control systems
- Harvesting and Processing technologies

Strong Case for countries in Asia-Pacific region having long coast lines and marine water bodies

Institute of Chemical Technology (ICT)
Mumbai, INDIA

DBT-ICT Centre of Energy Biosciences

- India’s first National Bioenergy Research Centre

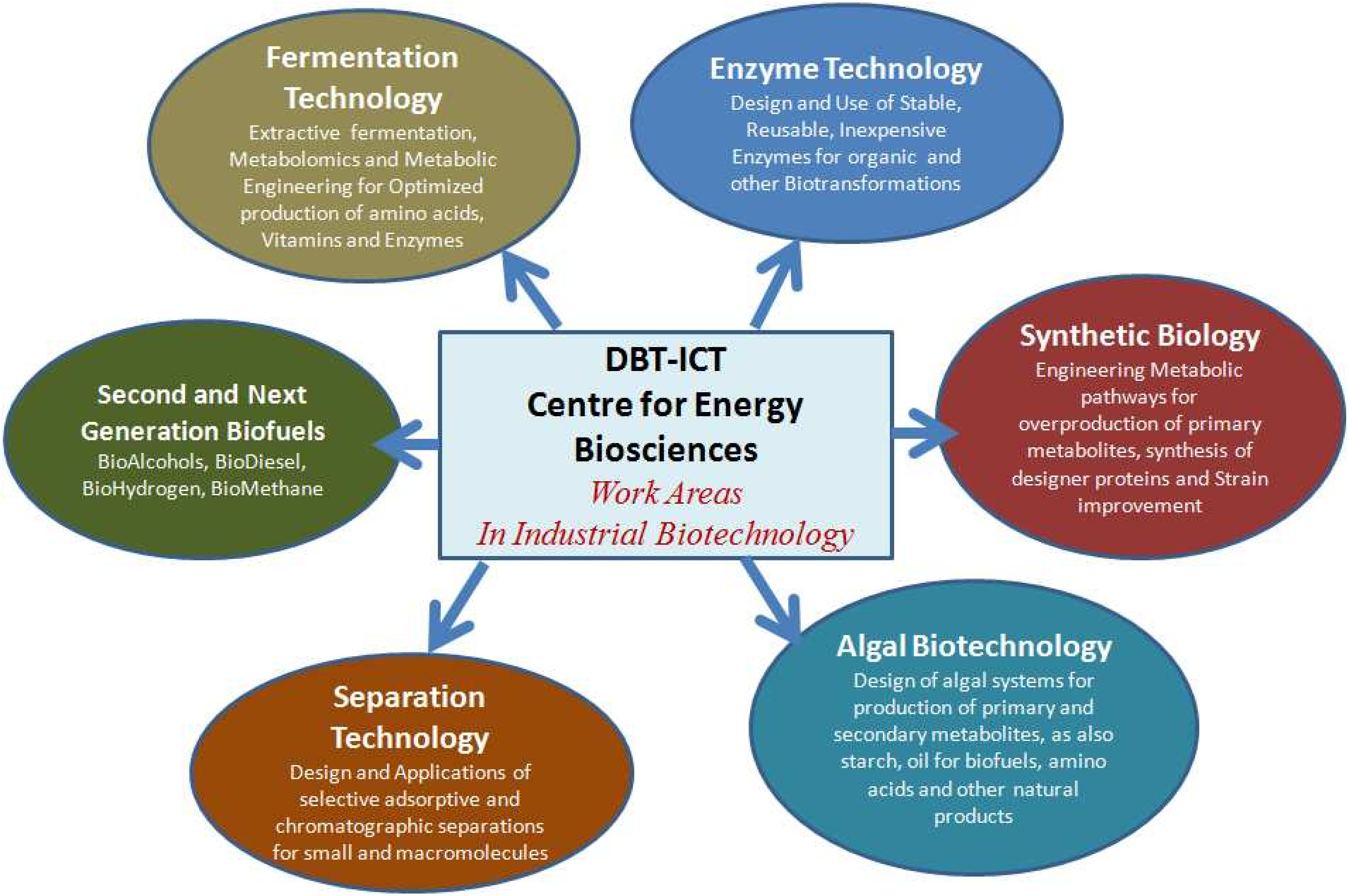
- Being set up at an initial cost of Rs. 24.8 crore

- Multidisciplinary Centre with emphasis on cutting-edge technology development and transfer to Indian industry

- Networked with Institutions & Industry in India and abroad

>40 PhD scholars; several Senior Research Scientists and >10 faculty in different disciplines of modern biological sciences and bioengineering


for Energy


DBT-ICT
Centre for Energy
Biosciences
Work Areas
In Industrial Biotechnology
Fermentation Technology
Extractive fermentation, Metabolomics and Metabolic Engineering for Optimized production of amino acids, Vitamins and Enzymes
Enzyme Technology
Design and Use of Stable, Reusable, Inexpensive Enzymes for organic and other Biotransformations
Synthetic Biology
Engineering Metabolic pathways for overproduction of primary metabolites, synthesis of designer proteins and Strain improvement
Algal Biotechnology
Design of algal systems for production of primary and secondary metabolites, as also starch, oil for biofuels, amino acids and other natural products
Separation Technology
Design and Applications of selective adsorptive and chromatographic separations for small and macromolecules
Second and Next Generation Biofuels
BioAlcohols, BioDiesel, BioHydrogen, BioMethane

The Facility at the Centre equipped for work
In the following areas

- Molecular Engineering at the interface of
  Biology, Chemistry and Engineering
- Synthetic Biology
- Recombinant DNA technology
- Microbial Proteomics
- Metabolomics and Metabolic Engineering
- Fermentation Technology
- Enzyme Technology
- Downstream processing and Separation Technologies
- Bioinformatics and Molecular modeling

Academic and Research Collaborations

- School of Chemical Engineering, **Purdue University, USA**
  Metabolomics and Metabolic Engineering

- Centre for Tropical Crops and Biocommodities,
  Queensland University of Technology, Brisbane, Australia
  Biomass handling, storage, transportation, and algal biofuels

- College of Engineering, **University of Saskatchewan, Canada**
  Biomass-to-Liquid Technologies

- **MAHYCO** Research Laboratories, India
  Development of high yield Biomass varieties – ENERGY CROPS

Industrial Research Collaborations/Partnerships

- Resindion SRL, Italy (100% subsidiary of Mitsubishi Chemical Corporation)
  Chromatographic Separations and Immobilized Enzyme Supports
- Biorad Laboratories, India/USA
  ICT-BioRad Initiative in Chromatographic Purifications
  Bio-Chromatography and Proteomics for Biotech/Biopharma Industry
- Agilent Technologies, India/USA
  ICT-Agilent Initiative in Advanced Analytical Sciences
  Advanced Analytical Sciences in Biology and Chemistry
- HydroAir Research Italia, Italy
  Membrane Separations and Chromatographic Equipment
- Snowtech Equipments Pvt. Ltd., India
  Specialized Equipment Design, Fabrication and Erection
- Novozymes, South Asia and Denmark
  Enzymes Design and Supply
- Advanced Enzyme Technologies Ltd., India
- *Enzyme Design and Supply*

CENTRAL THEME

To Develop Alternative Energy Technologies

- *Through intervention of Biological Sciences*

- *Specific Emphasis on Renewable Liquid Fuel*

- *Innovation and Translation of Technologies*

ICT Technology for Lignocellulosic Ethanol

Salient Features of the ICT Technology (Patents filed)

1. Novel combination of known fractionation technologies to obtain ‘homogeneous’ fractions of CELLULOSE; HEMICELLULOSE AND LIGNIN

2. Two Step Enzymatic Hydrolysis of cellulose and hemicellulose

3. Two Step combination of Membrane Reactor and Column Enzyme Reactor to permit reuse of enzymes over many cycles

4. All steps - pretreatment, fractionation and hydrolysis to fermentable sugars and finally ethanol – operated in continuous reactor systems

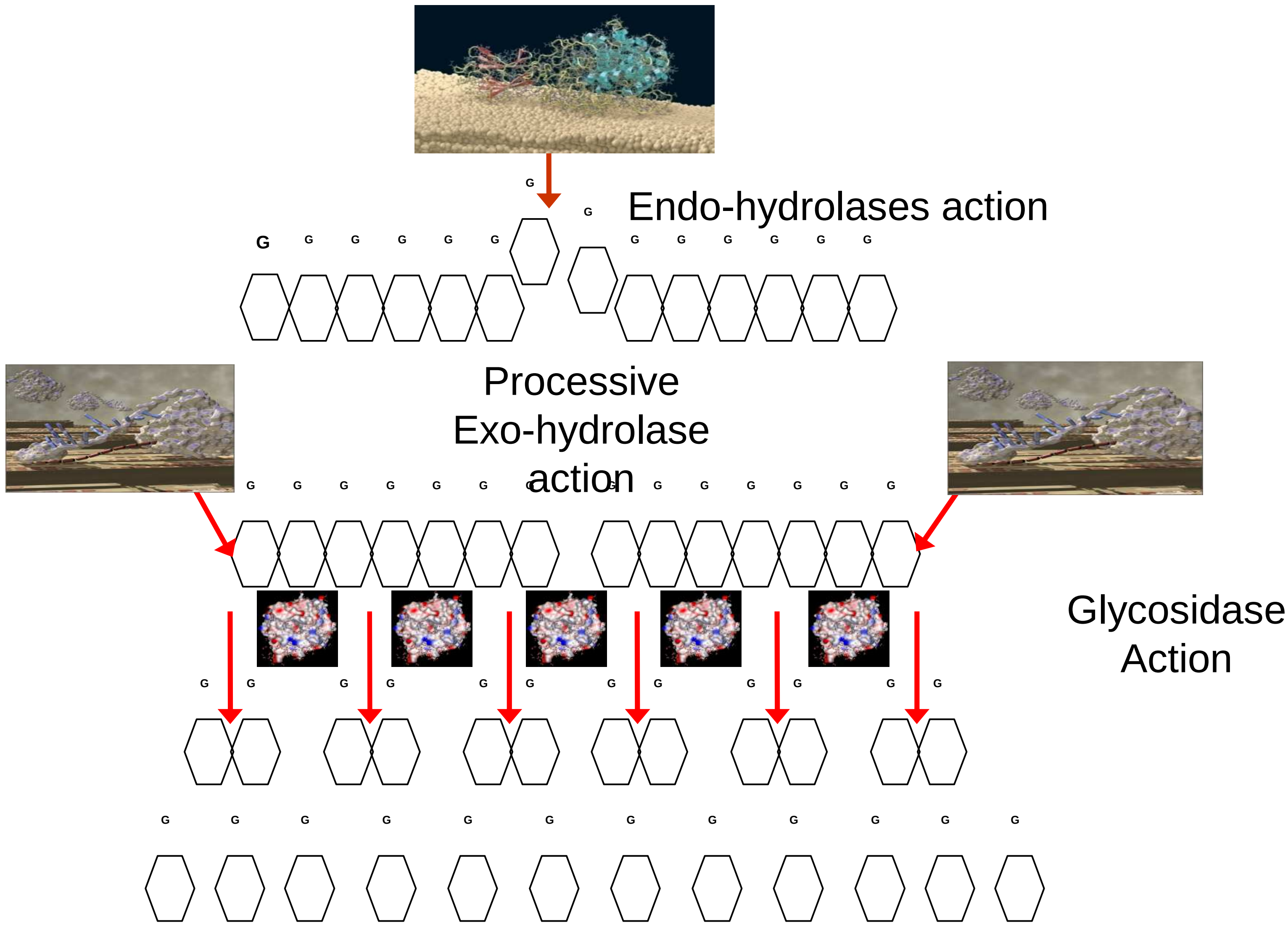
5. Both glucose and xylose converted to ethanol in near theoretical yields using indigenous mutated strains

Biomass Fractionation

The Novel combination Technology

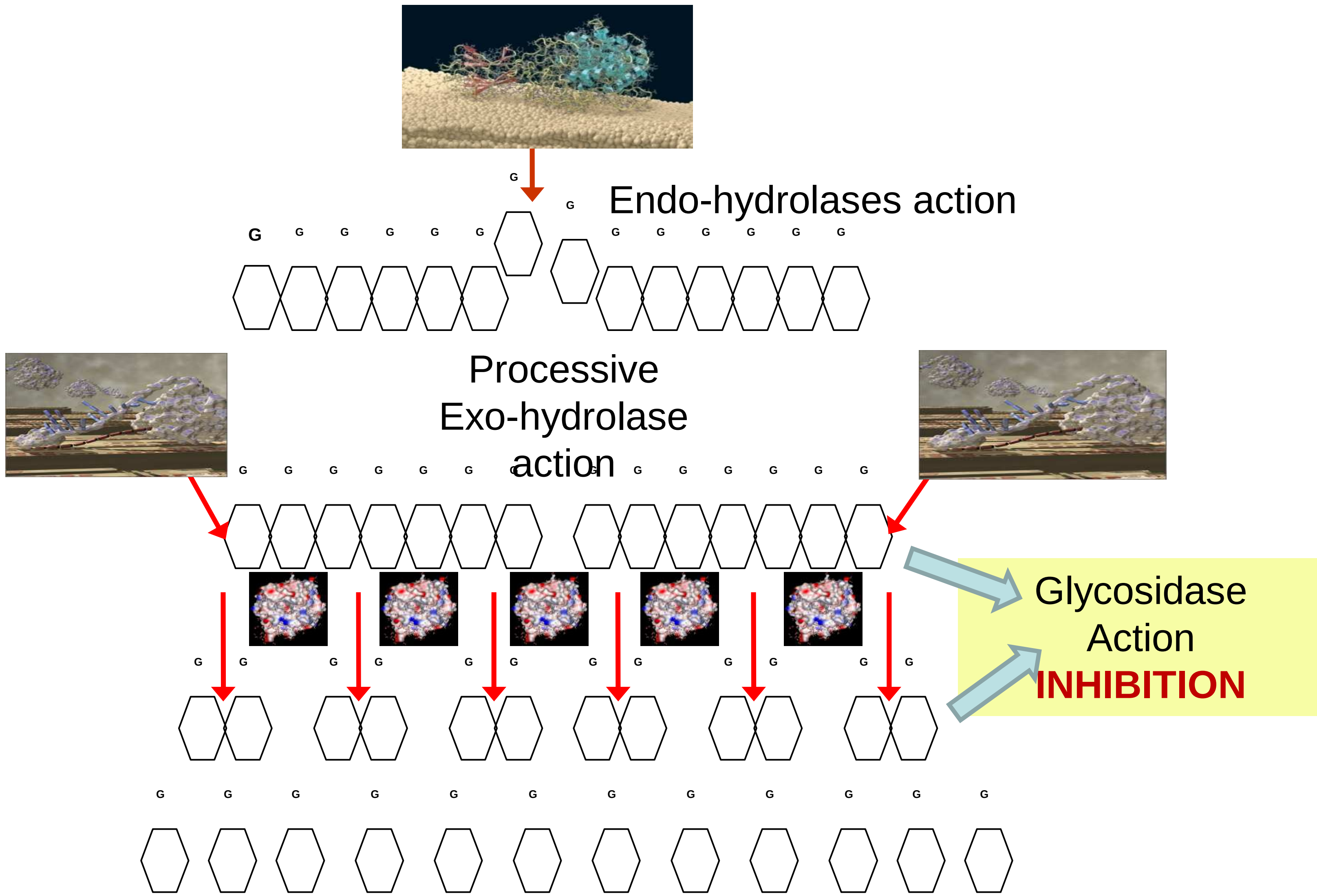
- Converts ‘toughest’ biomass to ‘soft’ biomass to CELLULOSE; HEMICELLULOSE AND LIGNIN
- 125ºC Alkaline Hydrolysis : Mild Conditions
- No un-desirable derivatives
- Products ideal for next step enzyme hydrolysis
- Continuous Process - Easy to control
- Lignin recovered intact for value-added uses
- Complete alkali recovery
- Recovery of acetic acid, silicates, uronates, xylose and arabinose

Enzymatic hydrolysis of cellulose/hemicellulose



Mono-sugars – Glucose and Pentose

Enzymatic hydrolysis of cellulose/hemicellulose



Mono-sugars – Glucose and Pentose

Two Step Enzyme Hydrolysis

- Use Endo- and Exo- Enzymes separate from Glycosidase

- Reaction speeded up 6 times by Division of enzyme action in two steps

- Complete Hydrolysis of cellulose to glucose and hemicellulose to pentose (xylose)

Features/Advantages of the Technology

- Brings down enzyme cost by factor of more than 5

- Brings down energy costs esp. in heat form

- Fractionation produces clean substrates

- Results in longer life of both enzyme reactors and membranes

- Continuous Technology reduces capital cost component

- Both glucose and xylose converted to ethanol

- **Ethanol yield per ton of dry biomass >300L**

- **Estimated cost of production of Ethanol < USD 0.50/L**

Important Events

- **Patents filed for**
  - Two Step Enzyme Process
  - Combination of membrane + immobilized reactors process
  - Composite reactor technology
  - Lignin separation by dual electrolyte process

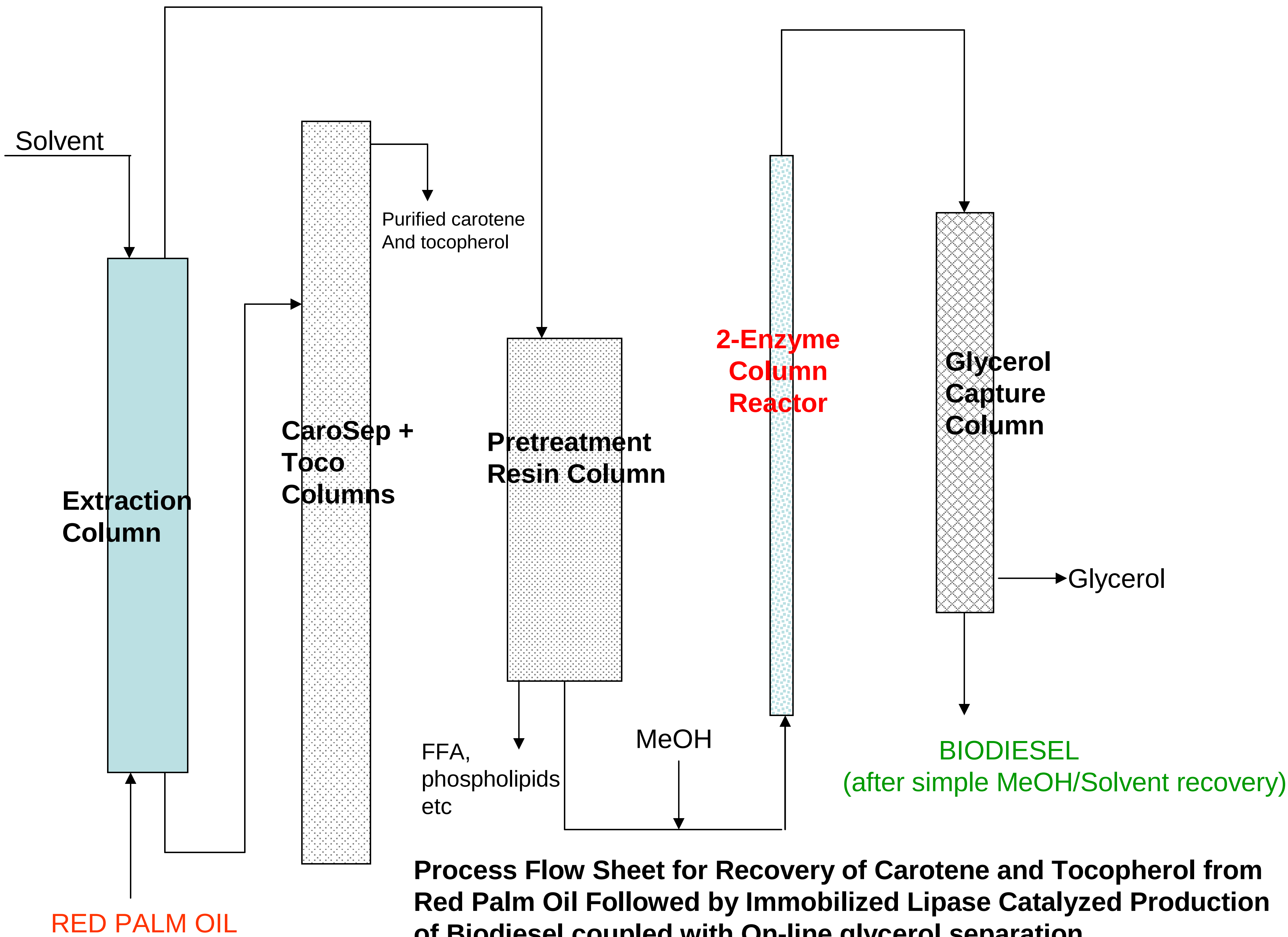
- **MOU signed with India Glycols Limited**, Uttrakhand for Pilot plant Design and Commissioning by Dec. 2009 at capacity of 10 ton biomass/day

Other Biorefinery Concepts : ICT Technologies

- Vegetable Oil Biorefinery

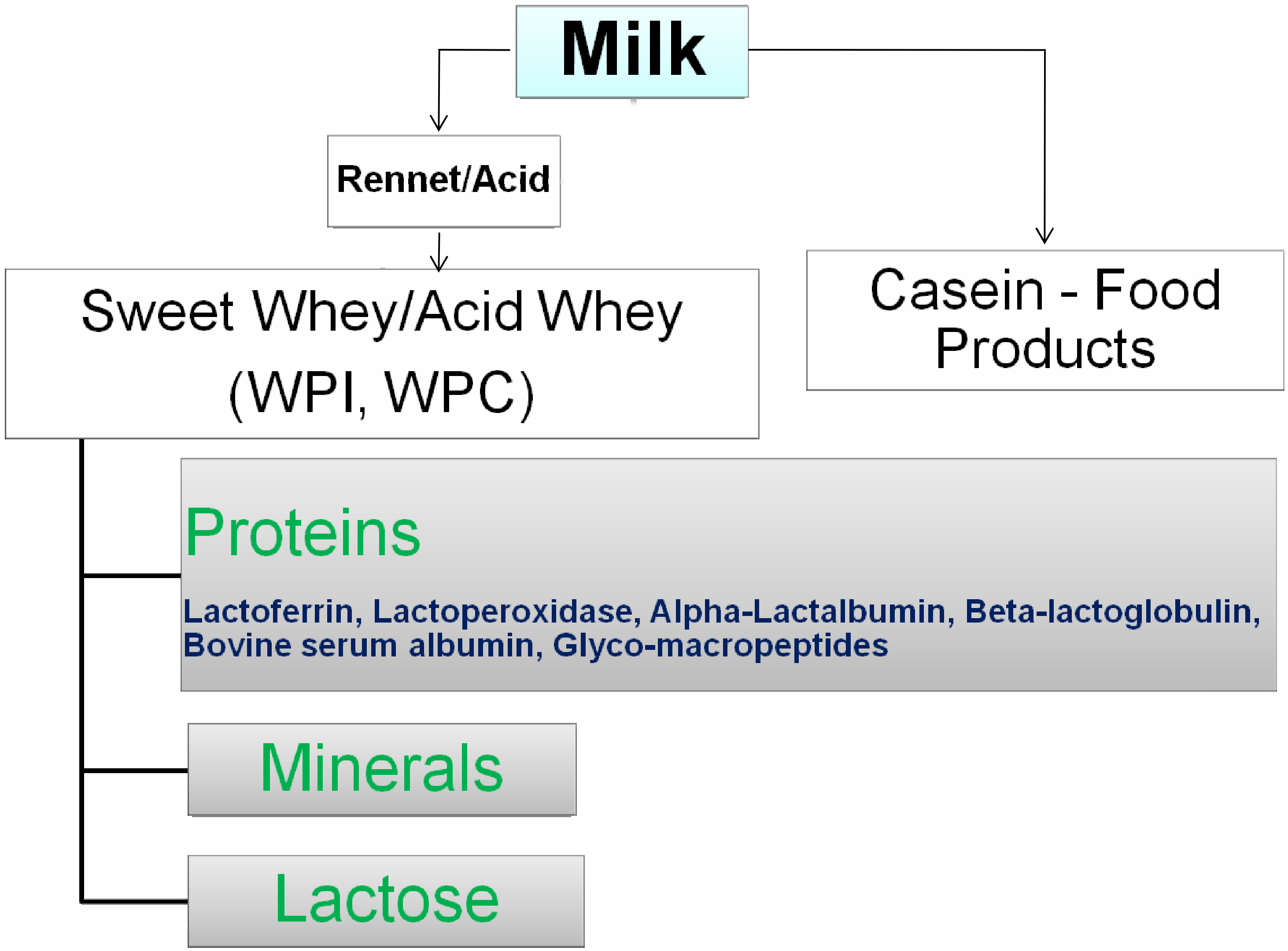
- Milk Biorefinery

- Starch/Grain Biorefinery



Process Flow Sheet for Recovery of Carotene and Tocopherol from Red Palm Oil Followed by Immobilized Lipase Catalyzed Production of Biodiesel coupled with On-line glycerol separation

Milk Biorefinery



Starch/Grain Biorefinery

Grain (corn, wheat, rice)

- → Starch/flour
- → Oil
- → Gluten
- → Minor constituents (ferulic acid, antioxidants)
- → Starch derivatives
  (Soluble fiber, maltose, glucose, HFCS)

Summary Points

1. Farmer can produce both FOOD and FUEL together

2. Agriculture needs to turned into Biorefinery based Industry

3. Bio-based products not only for energy but also for future platform chemical building blocks

4. Need to seriously explore ‘farming’ in the sea

Thank You

for your kind attention and patience

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