Chemical)Engineers Lead World Renaissance to Sustainability

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Flow of Presentation

- Role of Chemical Engineers
- New sources of Oil and Gas
- Green based Economy
- Comparison between Oil and Gas with Biomass feedstock
- Comparison between Biotechnology and Chemical Technology
- Drop in Biofuels
- Drop-in chemicals
  - Bio-Polymers
  - Bio-Lubricants
  - Diols
- Laboratory studies at UMS

Chemical Engineers Rise to Challenges

Scale up new chemical reactions from test tube to plants

producing millions of tons at economically viable price for the needs of common man.

Chemical engineers played critical role in developing technology during second world war
DuPont, Exxon, Shell and others

World War II:
Critical Role for Chemical Engineers

Polyethylene for radar shielding





A synthetic rubber industry when Japan occupied Malaysian rubber plantations



Mass production of key war materials: antifreeze, solvents, nylon (parachutes), ammonia (explosives), vinyl tents

Chemical engineers lead in designing and building very large, highly efficient plants for these new products

- Polyethylene
- Polypropylene
- Polystyrene
- PVC
- Plexiglass



- Polyester Fiber
- Nylon Fiber
- Acrylic Fiber

- SBR Rubber
- Butyl Rubber

- New Technologies
- New Types of Equipment
- Continuous Processing
- Giant Plants

Switching to energy-Develop new sources of gas and oil

- Fracking-Horizontal drilling to recover more oils from existing fields by drilling sideways to recover larvae oil
- Fracking with pressure and chemicals -vast quantities of new natural gas and crude oil from shale formation.
- Two enabling technologies
- New way of gathering natural gas from tight rock deposits of organic shale

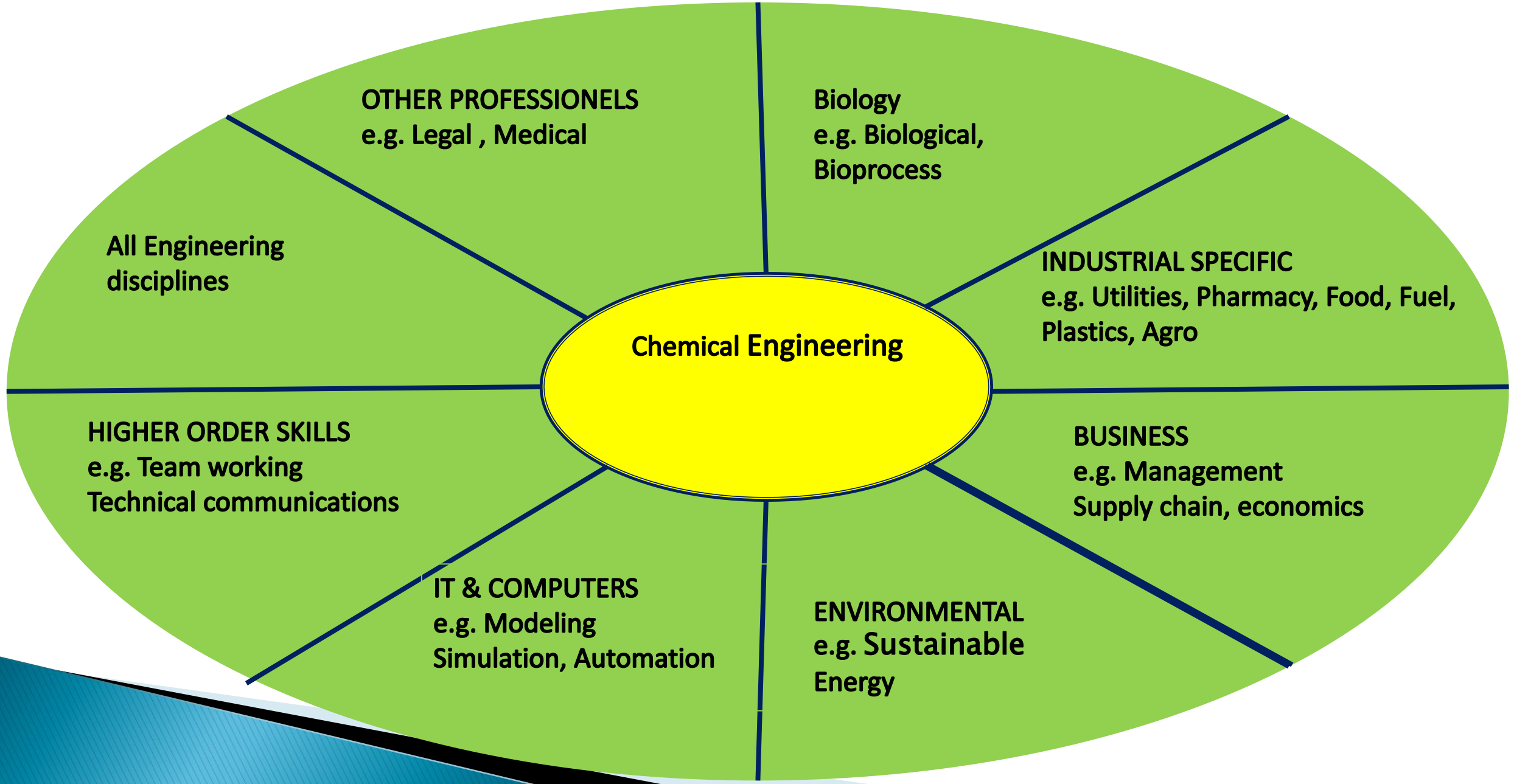
1. **Horizontal drilling**
   - Drilling horizontal wells. 1 and ½ miles beneath the surface Lateral lengths of 10,000 feet
2. **Hydraulic fracturing-**
   - Fracture of the rock by using water pressure aided by polymers, gelling agents, foaming agents.
   - Typical well regimes 2 to 3 million gallons of water and 1.5 million pounds of sand for just one well. About 99.5% mixture is sand and water.

Who are Chemical (Green) Engineers?

Design, Develop and Commercialize processes and products

- That are feasible and economical
- Minimizing risk to human health and the environment
- Generation of pollution at the source
- Transform existing processes and practices to promote sustainable development

Chemical ENGINEERING-BORDERLESS SCIENCE

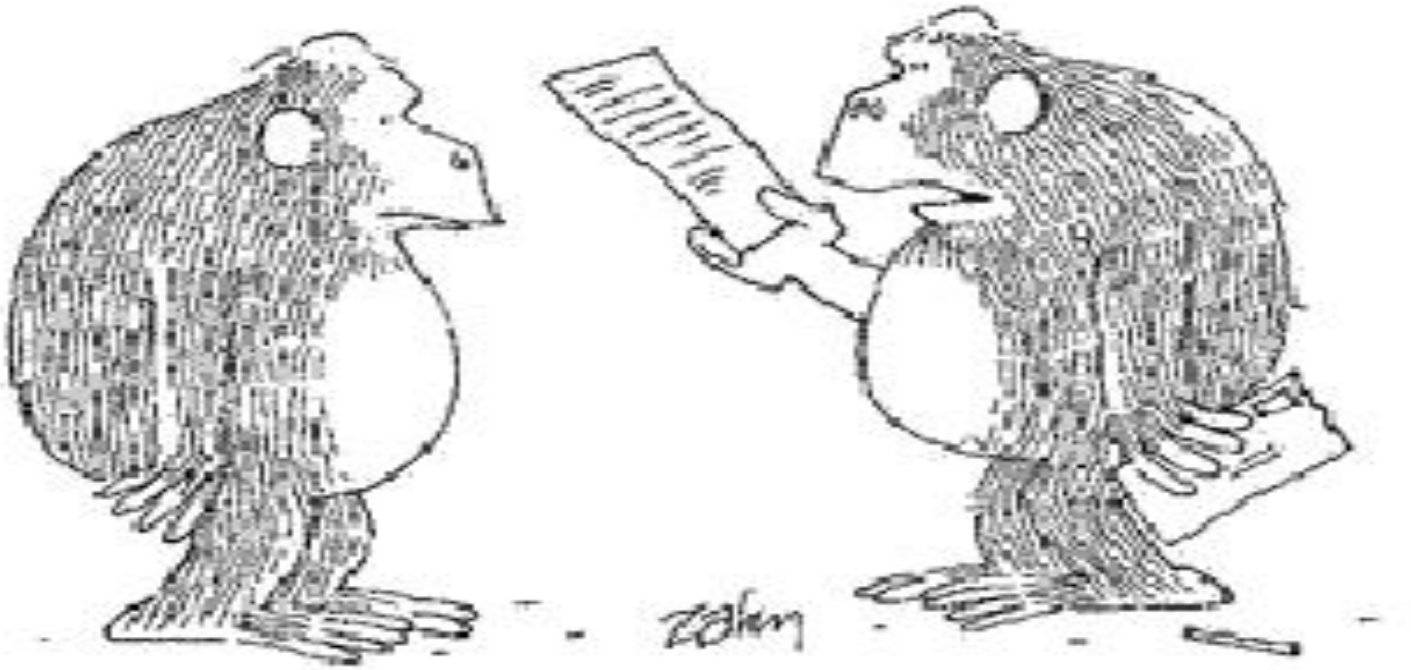


SUSTAINABILITY

- Meeting the needs of society in ways that can continue indefinitely into the future without damaging or depleting natural resources.

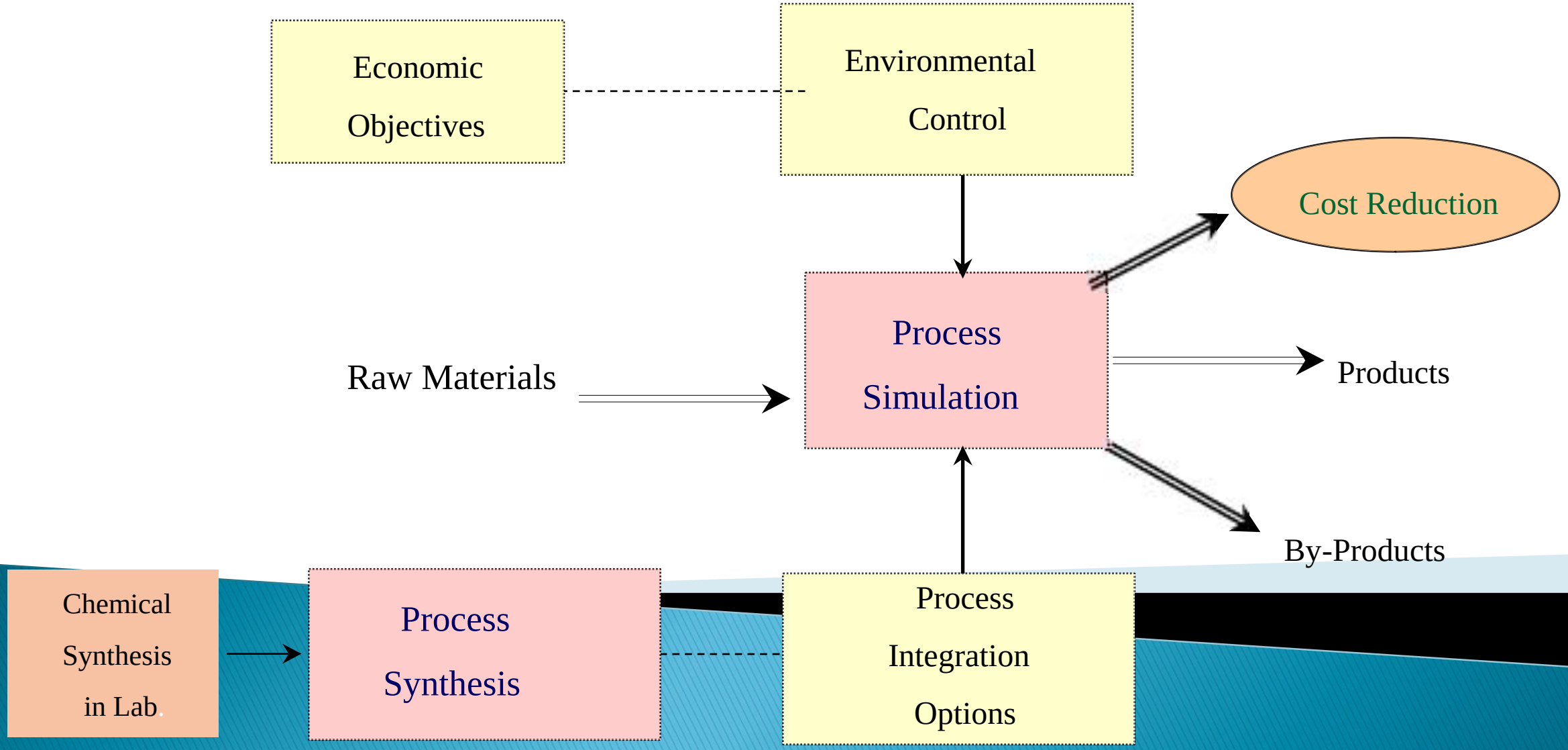
- In short, meeting present needs without compromising the ability of future generations to meet their own needs.

Green Design and Sustainability



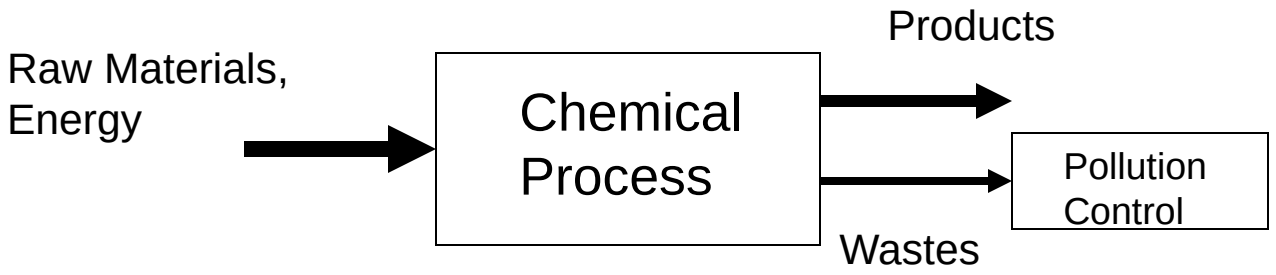
"It's from the government—we'll have to file an environmental-impact statement before we can evolve."

Traditional Process Design Steps

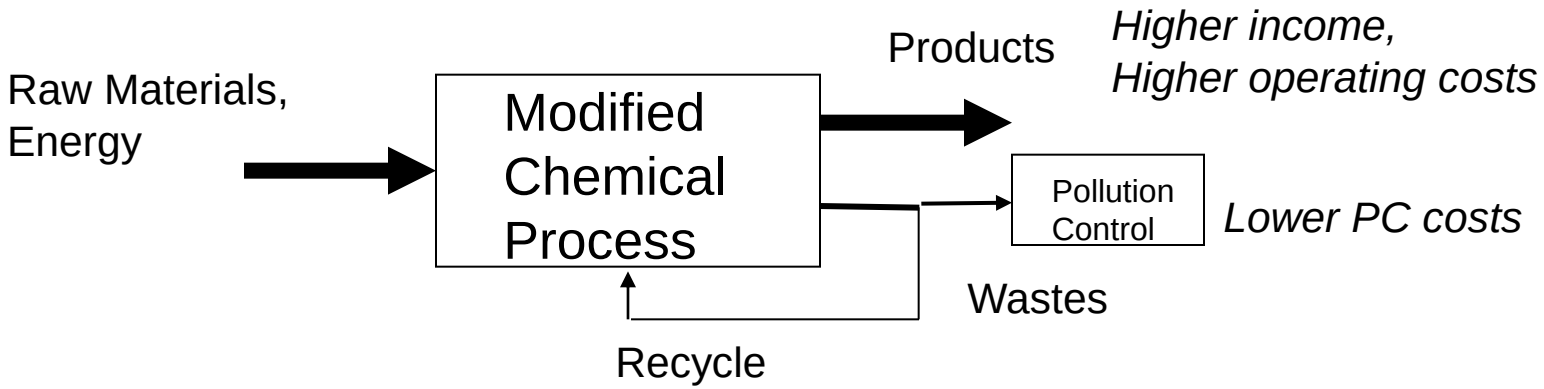


Green Chemical Engineering-Pollution Prévention (PP) vs. Pollution Control (PC)

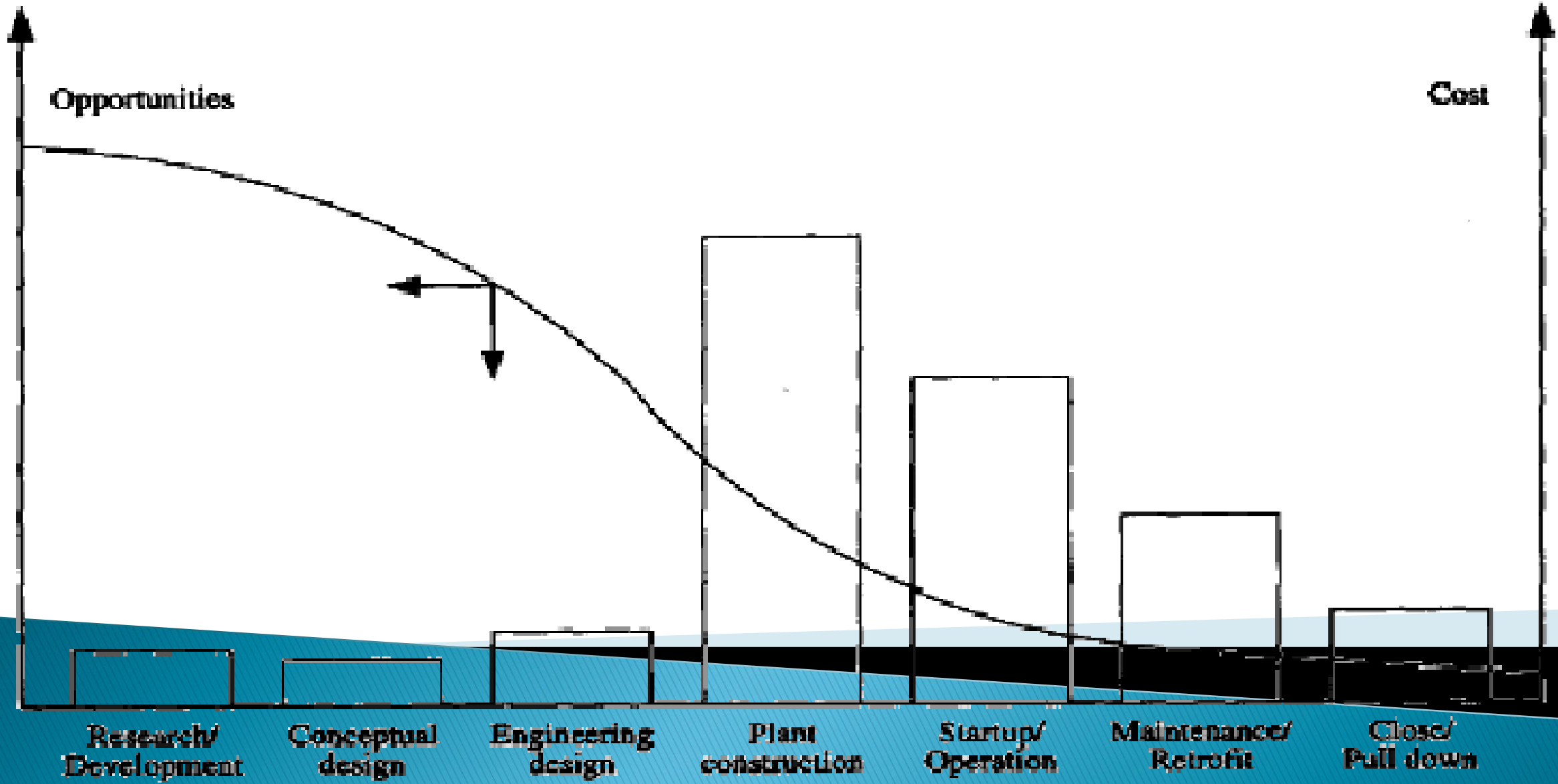
Traditional Process



Greener Process

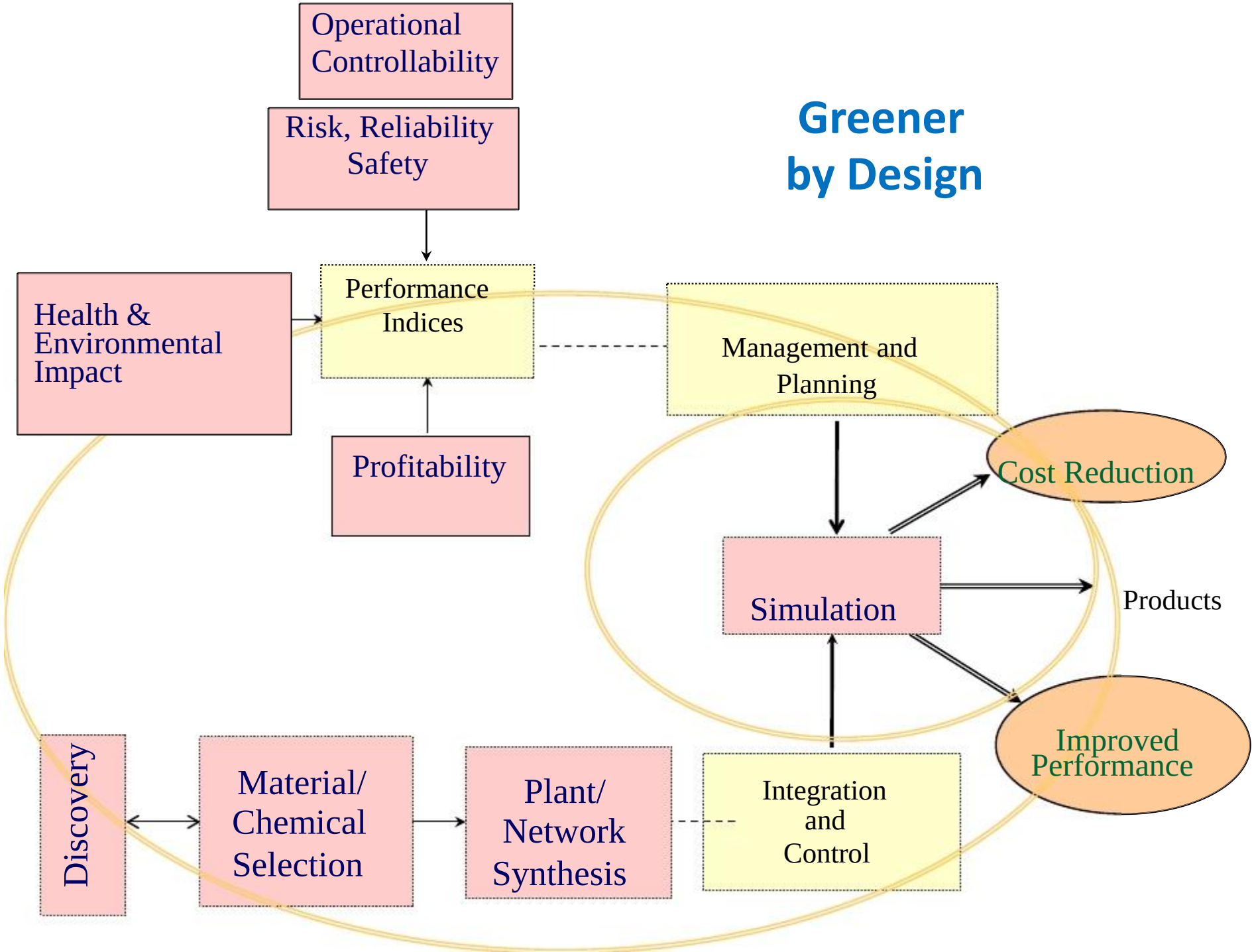


Opportunities in Waste Minimization in Green Engineering



Y.Q. Yang and L. Shi. Integrating environmental impact minimization into conceptual chemical process design a process systems engineering review. Comput. Chem. Eng, 2000, 24, 1409-1419.

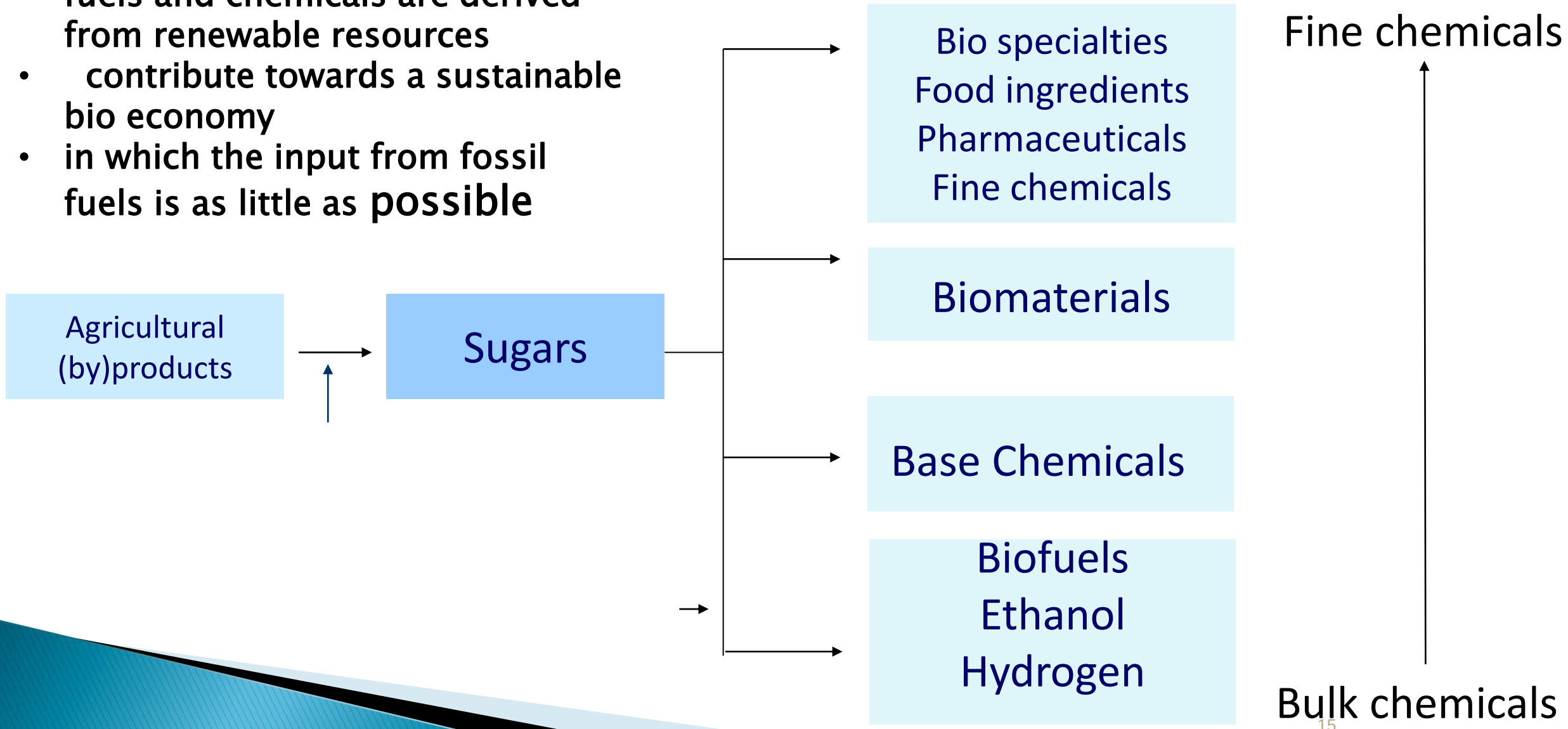
Greener by Design

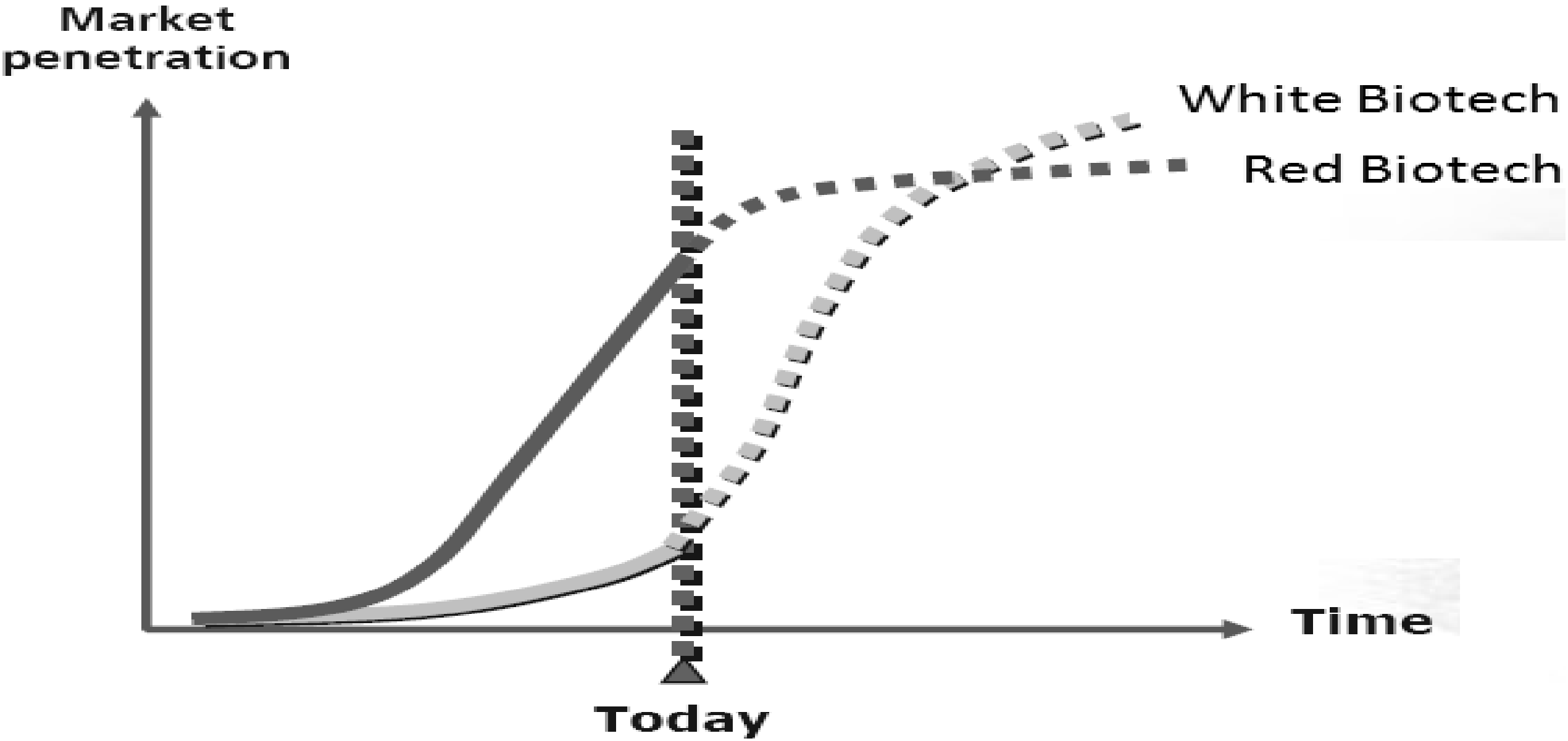


Green Economy Value Chain

An economy in which

- fuels and chemicals are derived from renewable resources
- contribute towards a sustainable bio economy
- in which the input from fossil fuels is as little as possible





Growth of Green(Chemical) Engineering

Drivers for explosive growth of Green Chemical engineering industry in the 21st Century

- Thrust for Process sustainability
- Climate change & Global warming
- Science and Bio Technology advances

>Synthetic Biology and Metabolic engineering

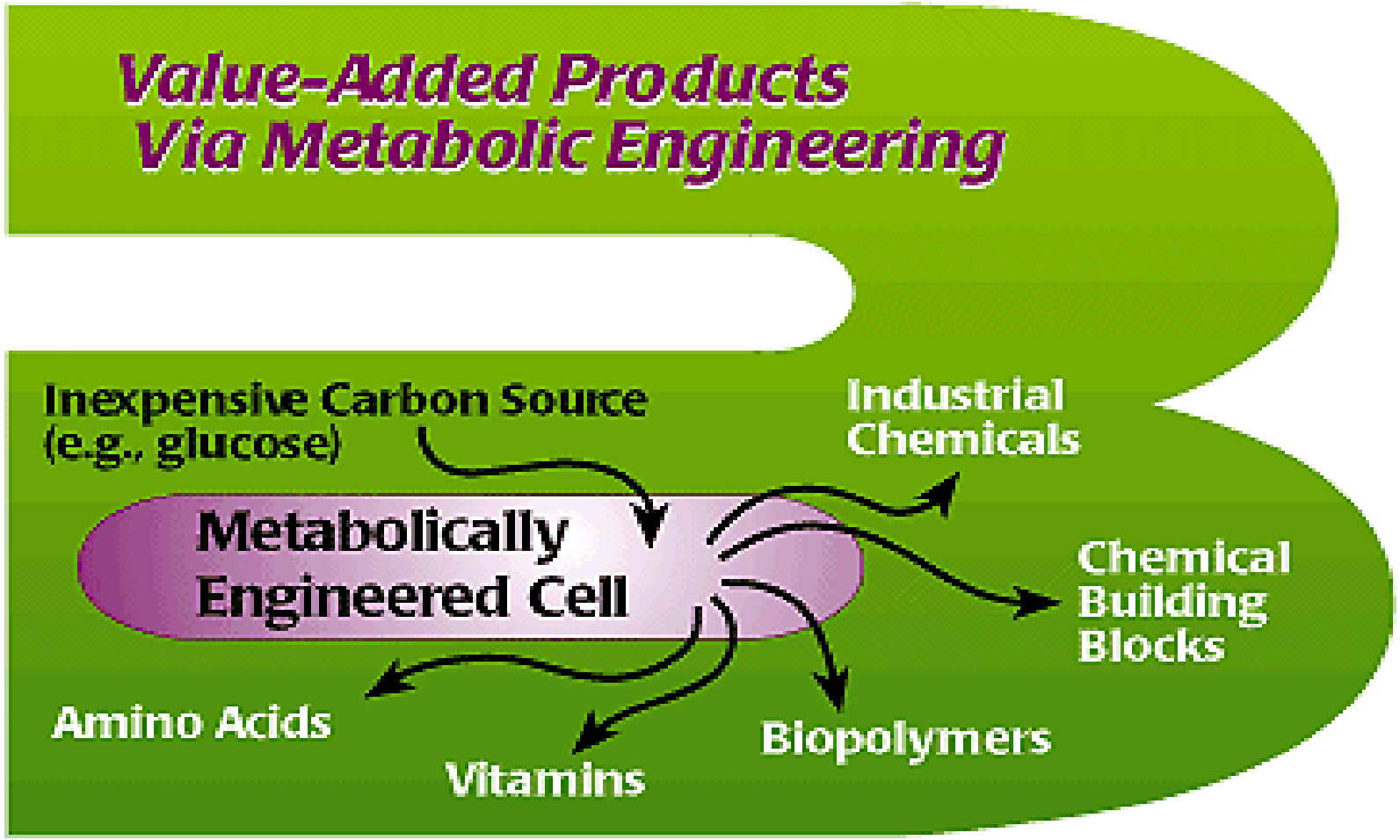
>Engineering microbes for any conversion at very high selectivity

Synthetic biology and Metabolic Engineering

- Teaching microbes new tricks to alter gene mapping
- Engineering new chemistry in microbes to perform any conversion
- basically many value added chemicals in our daily lives at very high selectivity.
- Biology beyond Medicine
- Biotechnology beyond Biofuels such as bio products

Cells to Bio products towards a sustainable and Green economy

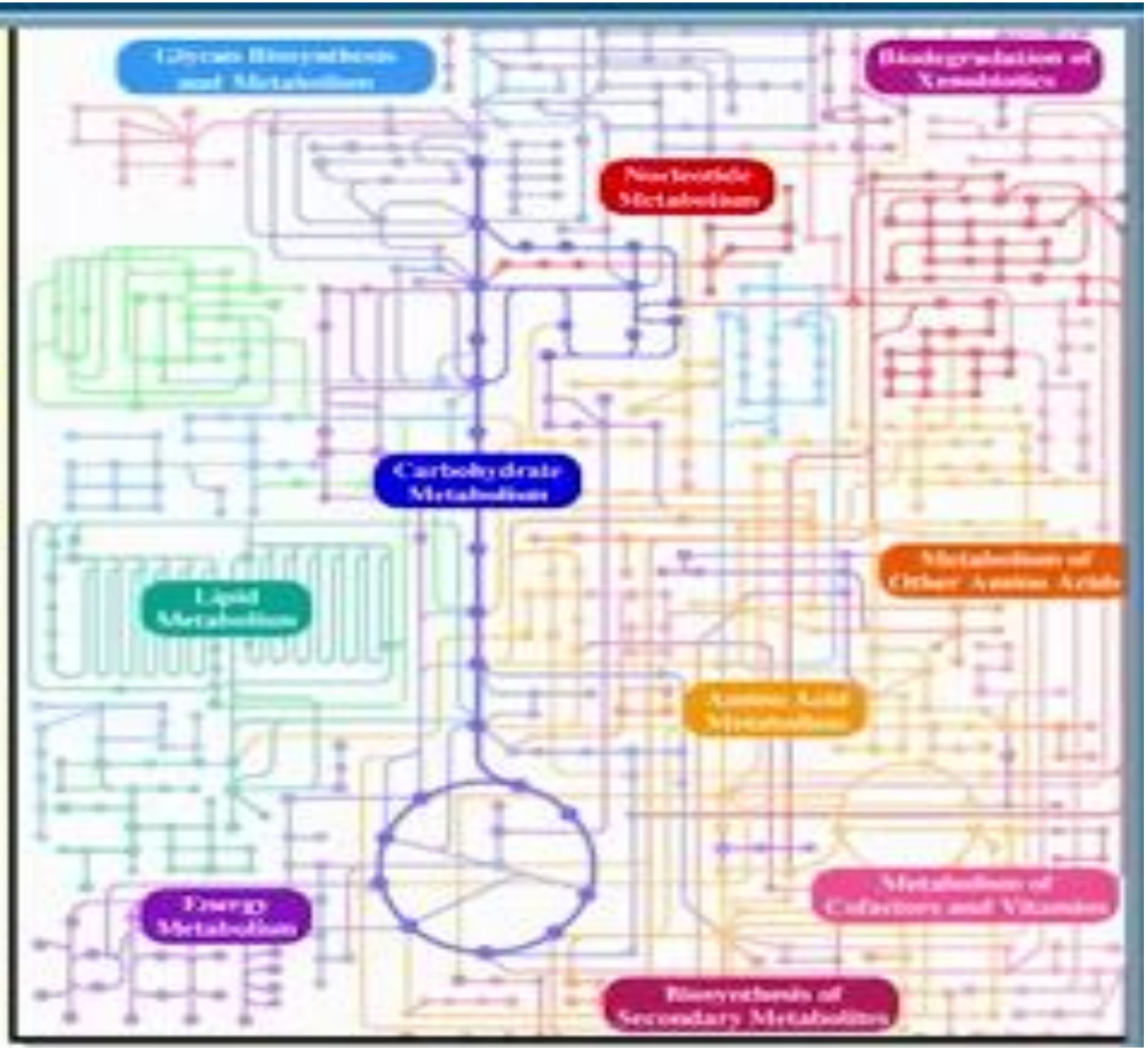
- Cells are little chemical factories with thousands of chemical compounds
- Interconverted through thousands of Chemical reactions
- Main substrates are Si
- Virtually infinite Produ



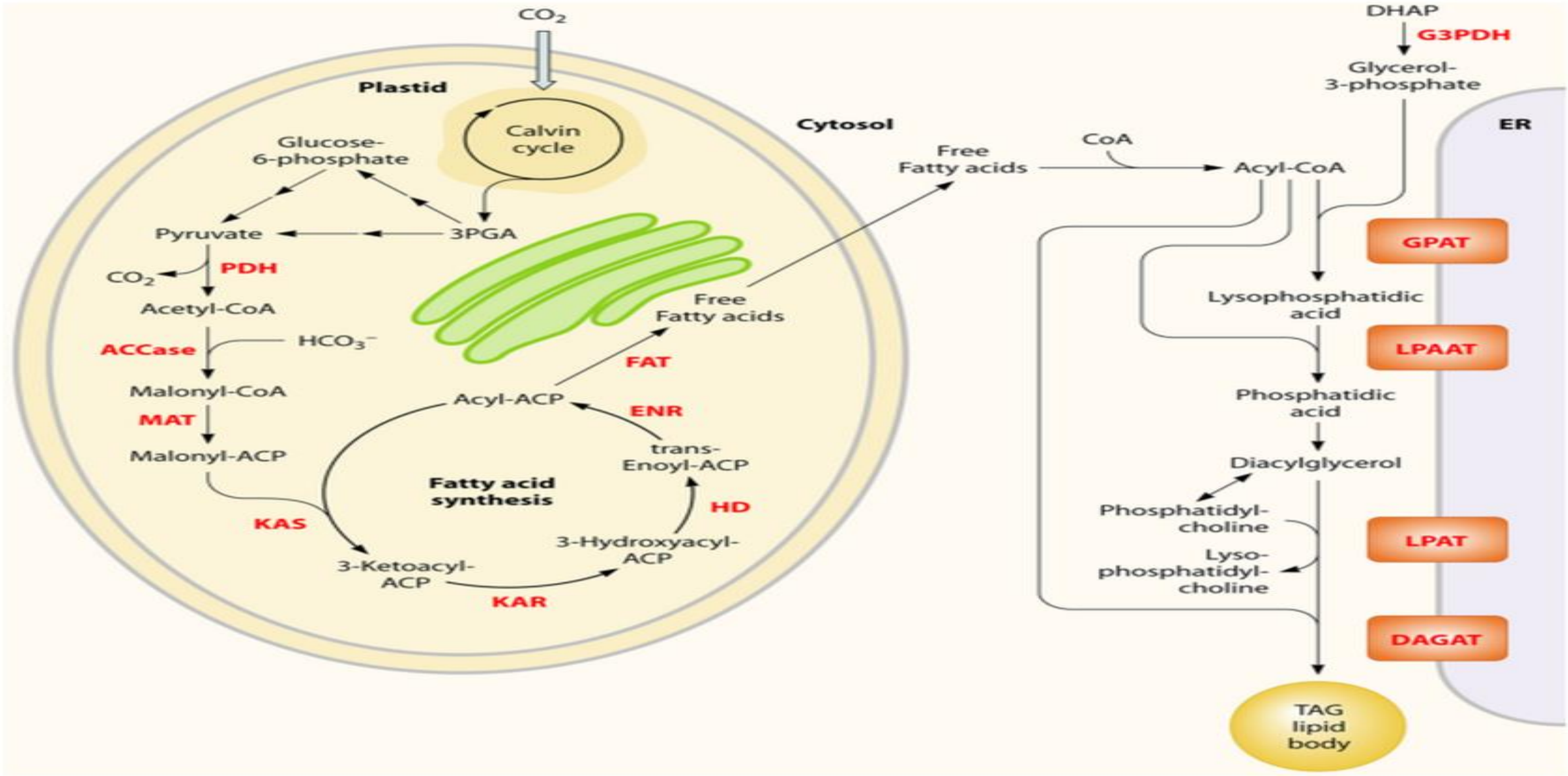
Cells:
Little chemical factories with thousands of chemical compounds interconverted through thousands of chemical reactions

Main substrate: Sugars

Products: Virtually infinite



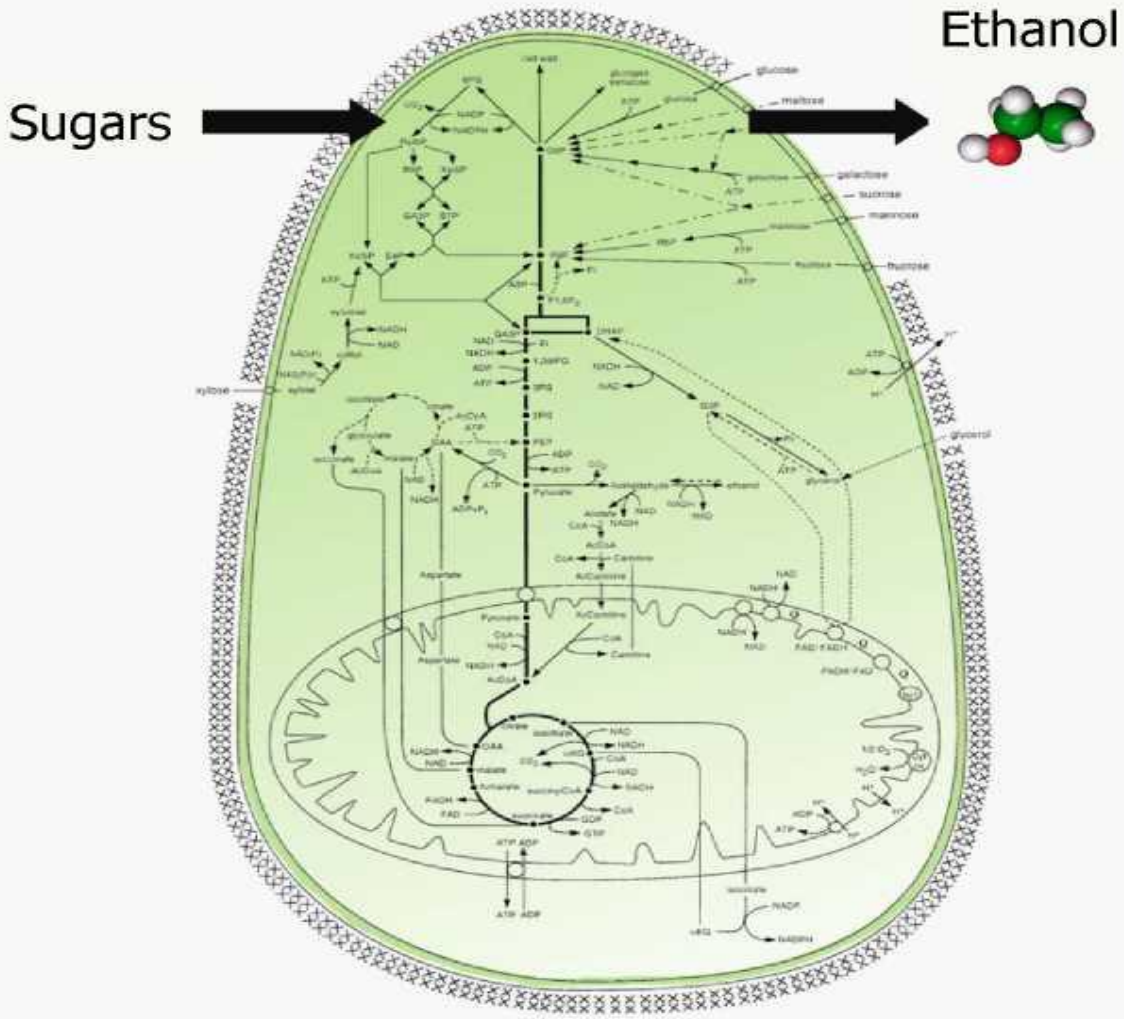
Engineering the lipid biosynthesis pathway

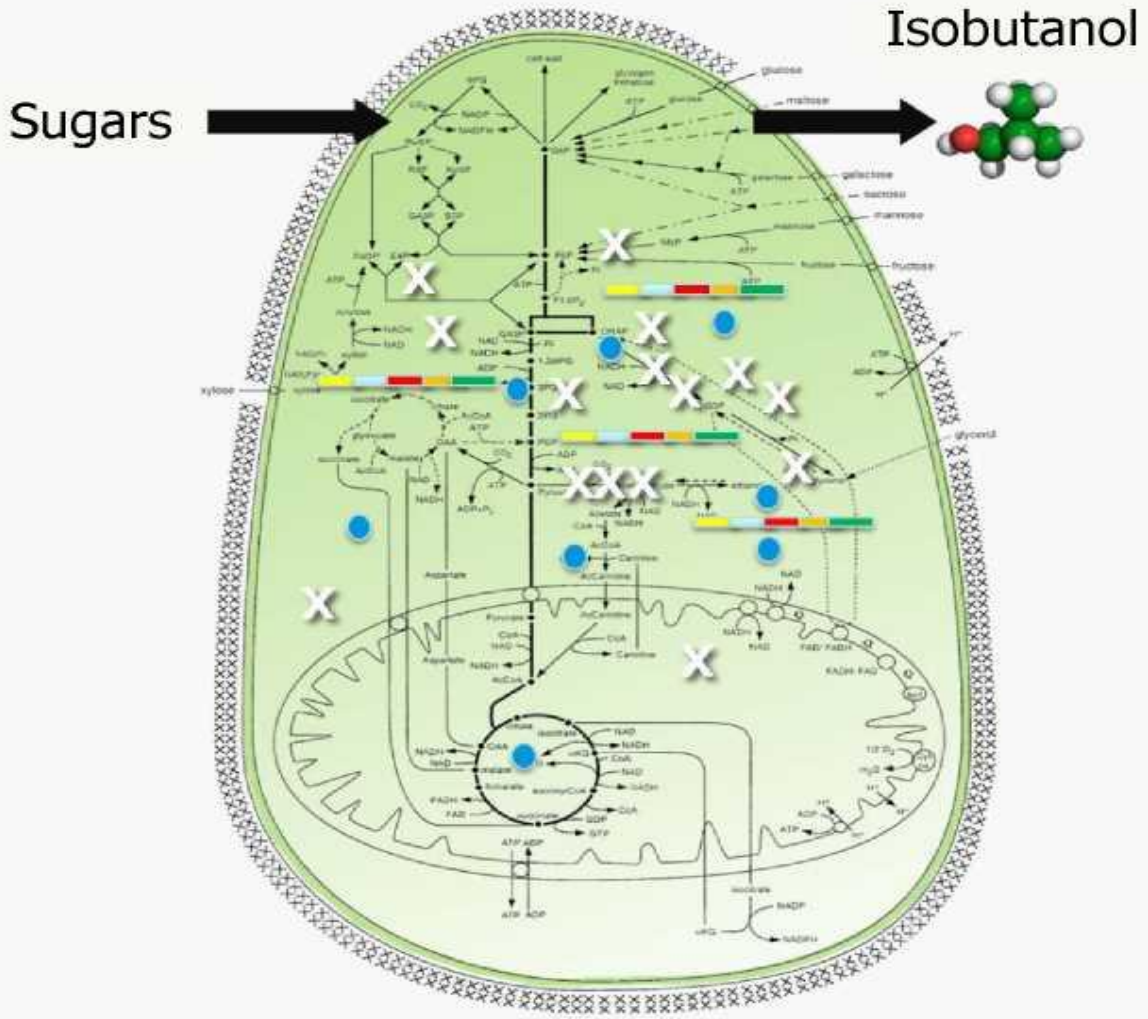




Synthetic gas

Retrofit Commercial Yeast with Metabolic Engineering





Anaerobic

Primary Pathway

High Yield GMO

Biochemicals-Conventional Poly Lactic Acid (PLA)

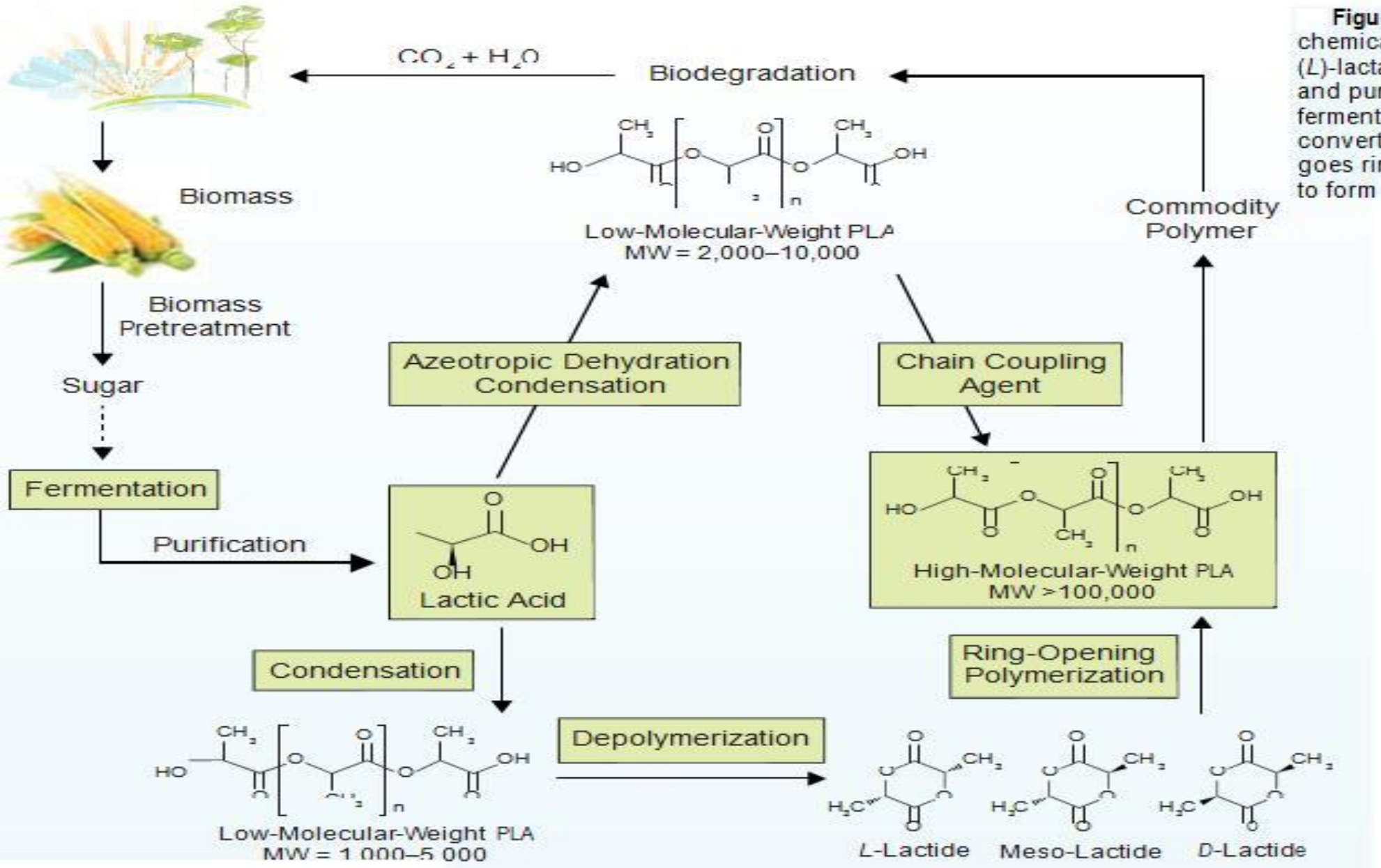
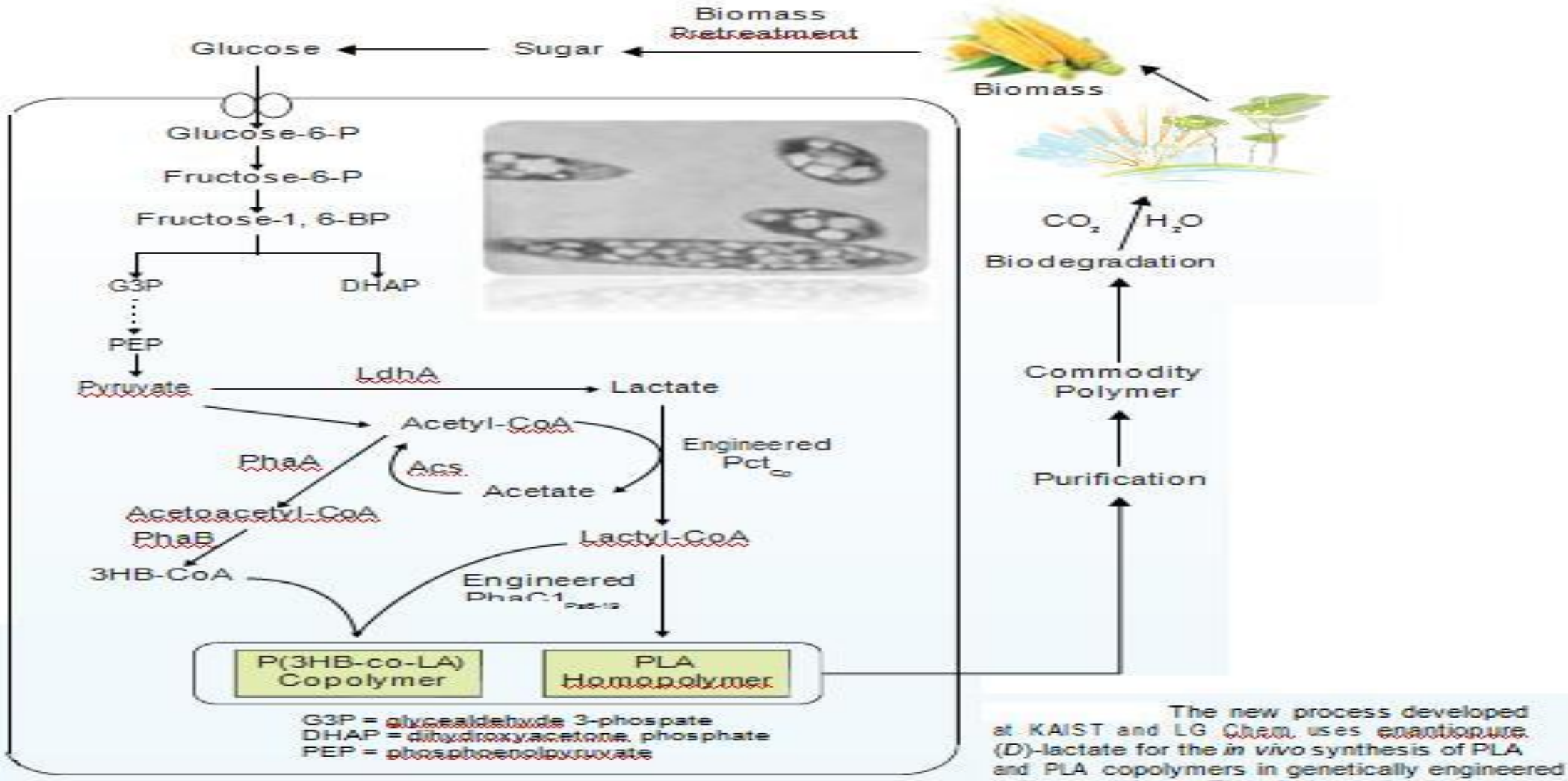


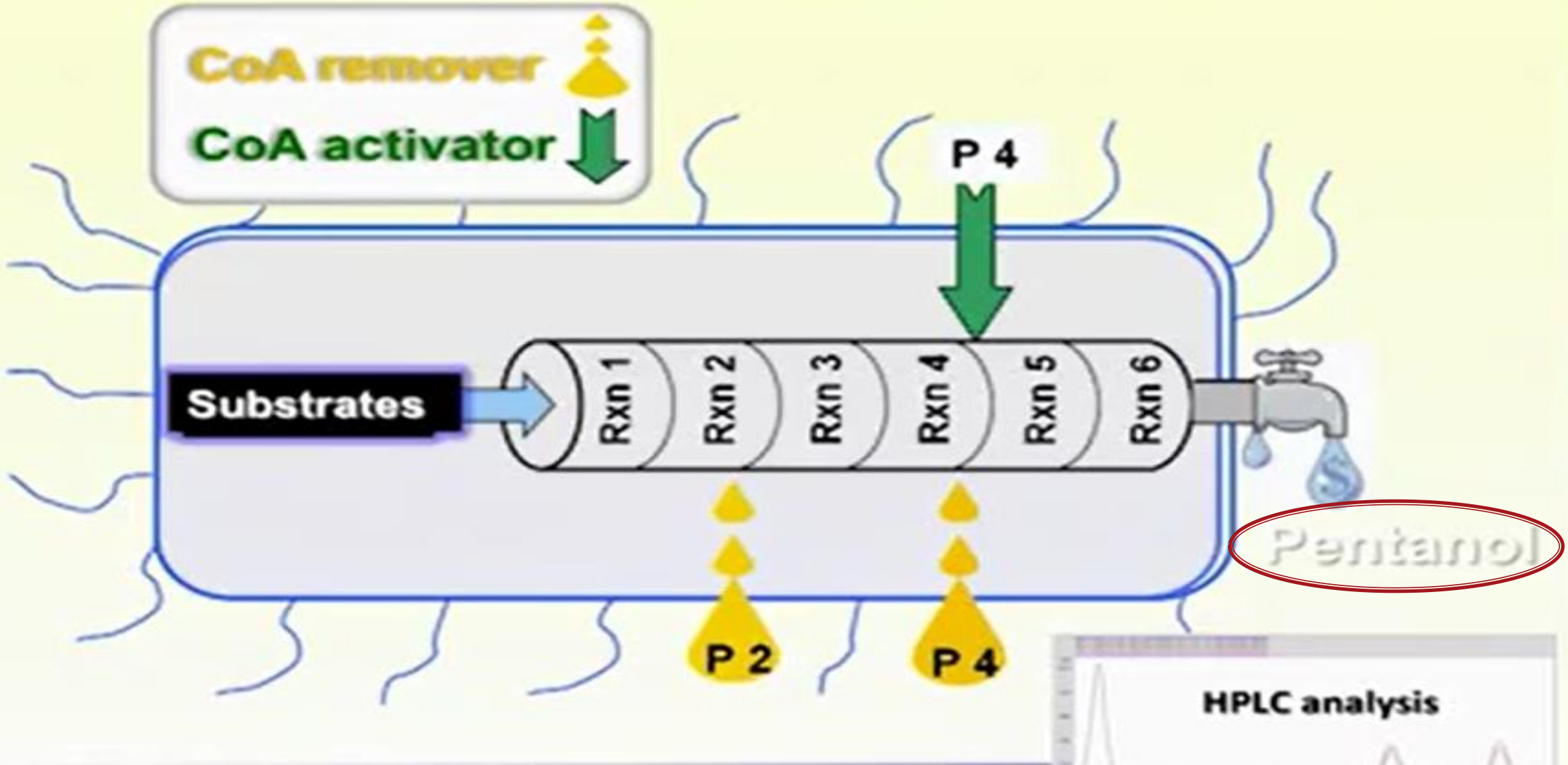
Figure In the conventional chemical process for making PLA, (*L*)-lactate is produced by fermentation and purified to obtain (*L*)-lactic acid. The fermentative (*L*)-lactic acid is converted to (*L*)-lactide, which undergoes ring-opening polymerization (ROP) to form (*L*)-PLA.

New process for PLA



The new process developed at KAIST and LG Chem uses enantiopure (*D*)-lactate for the *in vivo* synthesis of PLA and PLA copolymers in genetically engineered microorganisms. The photograph shows recombinant *E. coli* that accumulates P(3HB-co-LA) from glucose.

Engineering microbes to produce any product



A model of microbe can replace industry process



Microorganisms

They are found everywhere, from the human gut to the hot springs of Yellowstone Park



Feedstock cost Comparison between Oil and Gas with Bioprocess Technology

- Does it make sense, economically, to propose bioprocess technology and renewable feed stocks for the fuels and chemical industry?
- Particularly natural gas, Naphtha are so inexpensive $50/barrel.
- What is the current state of affairs in commercial applications of Industrial biotechnology?

Landscape of Industrial Biotechnology: Littered by one failure after another

- Qteros: Bankrupt
- LS9: Bought by REG
- Gevo: Fighting for its life (stock $8 $0.50)
- Butamax: No product (butanol) yet
- Amyris: Stock down from $28 to $3.50
- Codexis: Downsized to one third of its size
- Mascoma: Bought by Lelamont
- Kior: Bankrupt
- Green fuels: Bankrupt
- BP: Ended operations in cellulosics

➢ **A total disaster in Industrial bioprocess technology world**

Yet, many signs of optimism

- **Biochemtex**: Two BioEtOH plants (Crescentino, NC, USA)
- **DSM–Poet**: Inaugurated BioEtOH plant (Sept. '14)
- **Gevo – POET: 22 MM GPY Isobutanol plant in Luverne, MN, USA**
- **Gevo-ICM: 50 MM GPY Biobutanol in Redfield, SD, USA**
- **Terrabon : 50 MM GPY ketones, Bryan, TX, USA**
- **DuPont, Abengoa**: BioEtOH plants
- **GrandBio (Brazil)**: Two new BioEtOH plants
- **Other BioEtOH**: Stovenia, Equador, FYROM
- **Genomatica**: New BDO process (Michelin, Goodyear)
- **Myriant, Bioamber, DSM**: Bio succinate
- **Novogy**: Lipids for biodiesel
- **Solazyme**: Lipids for biodiesel, specialties (algae)
- **Various**: Muconic acid (for adipic, terephthalic)

Successful Companies in Green Chemical Engineering

- DSM (NETHERLAND)
- DuPont (USA)
- BASF (GERMANY)
- Novozymes (DENMARK)
- Cargill Dow (USA)
- Degussa (GEMANY)
- Amano (JAPAN)

What is happening with the price of oil?

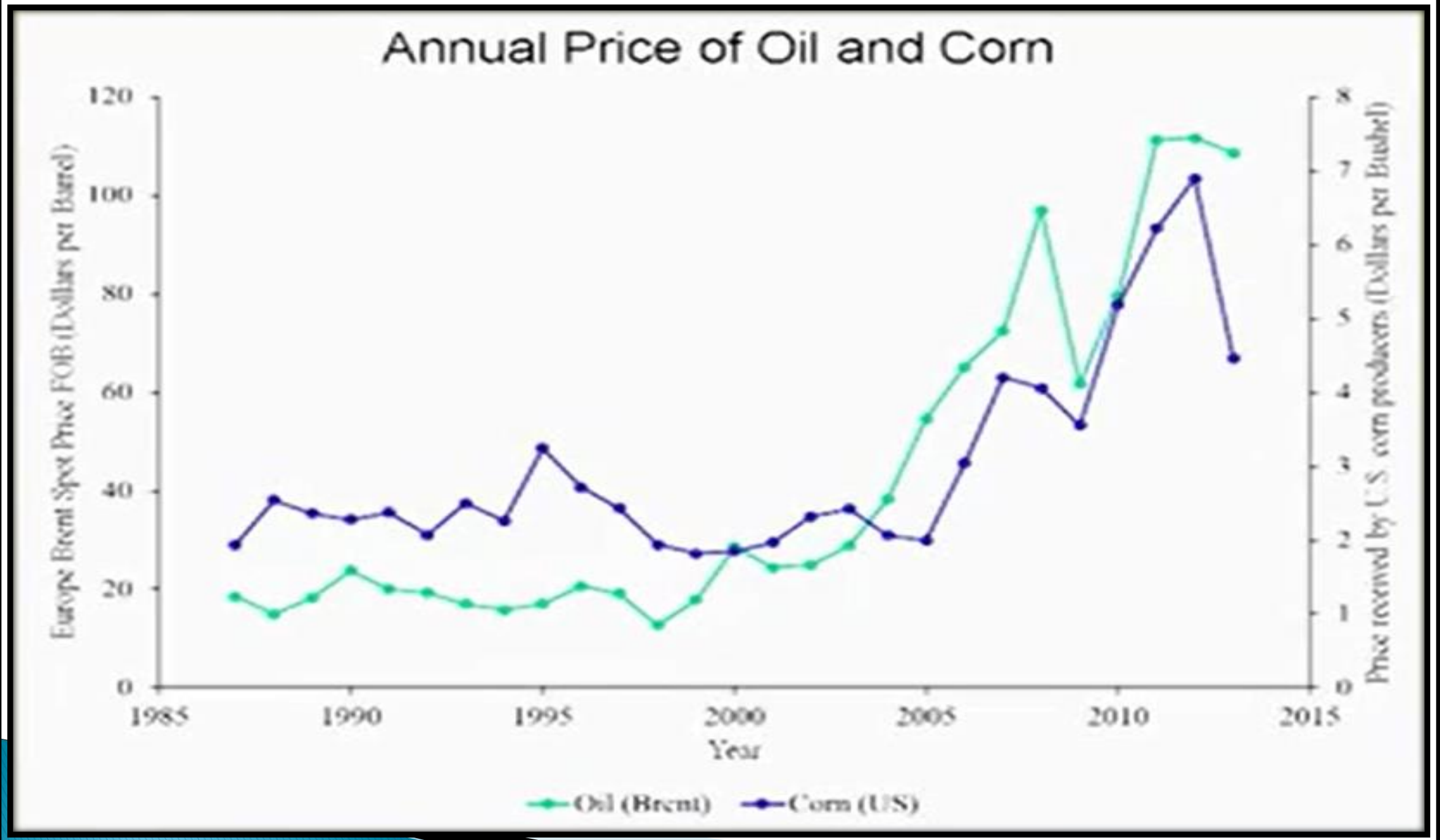
- Ethanol from Corn and now with Cellulose
- Biodiesel commercialized using vegetable oils and fats
- Plasticizers from starch and biomass(Coca Cola, Pepsi bottles)
- Polyethene from sugarcane
- Bio based chemicals and biofuels are a feedstock story

Some simple calculations for ethanol

- With $400/ton of Glucose (or $6.70/bushel (bu) of corn), feedstock cost of Ethanol is $800/ton or $3.58/GGE(gallon of gasoline equivalent).

- With $270/ton of Glucose (or $4.50/bu of corn), feedstock cost of Ethanol is $540/ton, or $2.41/GGE.

- With 10c/pound of Glucose ($220/ton of Glucose), feedstock cost of Ethanol is $1.96/GCE.


Annual Price of Oil and Corn
Europe Brent Spot Price FOB (Dollars per Barrel)
Price received by U.S. corn producers (Dollars per Bushel)
120
100
80
60
40
20
0
8
7
6
5
4
3
2
1
0
1985
1990
1995
2000
2005
2010
2015
Year
Oil (Brent)
Corn (US)

Biomass as feedstock for bio chemicals and biofuels

- Biomass at $50 per dry ton. Assuming 70% of cellulose and hemicellulose and 70% saccharification yield
  - 10c per pound for the cost of simple sugars,
    which are produced from biomass,
    which is a good number, if you pay $50 per ton of dry biomass

Biomass feedstock vs. oil

- **Fuel from Oil at:**

$30/bbl yields refined products: $1.50/gal
$60/bbl yields refined products: $2.37/gal
$100/bbl yields refined products: $3.56/gal

  - Assuming $20/bbl processing cost and 80% of crude oil are refined products.

- **Fuel derived from Biomass at:**

$25/ton yields EtOH (Ethyl alcohol) from sugars: $1.64/GGE
$50/ton yields EtOH from sugars: $2.20/GGE
$100/ton yields EtOH from sugars: $3.29/GGE

  - Assuming 50% sugar yield/ton, 10c/kg sugar enzyme cost, 50% EtOH yield, and 30% of feedstock for processing cost

Comparing with oil price

- If a barrel of oil with a cost of $50-$60, (It means if we pay for gasoline or diesel at pump station)
- If I have one ton of biomass and deconstruct to sugars and convert into ethanol or diesel
- Cost of final product as function of how much money I pay per ton of biomass

Biomass processor's MWTP and biomass producer's MWTA

- Biomass Processor's WTP:

$$P_{Biomass} = (P_{Gas}{}^{*}E_V + T_{Credit} + V_O + V_{RP} - C_K - C_V - C_F - C_E)Y_E$$

$$P_{Biomass} = MWTP$$

- Biomass Supplier's WTA:

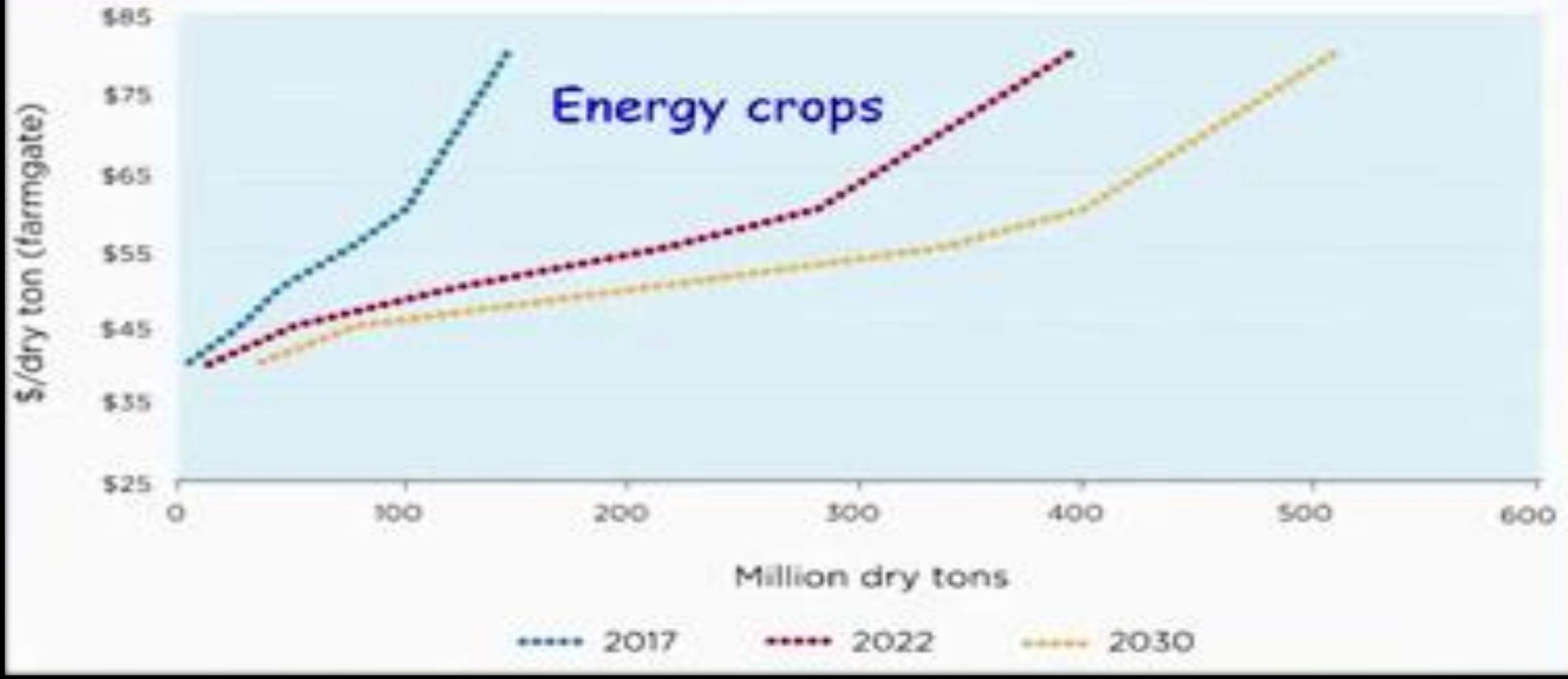
$$P_{SBiomass} = C_{NR} + C_{HM} + C_S + C_T{}^{*}D + (C_{ES} + C_{Opp})/Y_B$$

$$P_{SBiomass} = MWTA$$

- Break-even market equilibrium: MWTP = MWTA

Expected supply curves for biomass

http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf



Chemicals: Feedstocks Costs:

- ***Current glucose price (from corn): $250/ton***
- Projected glucose price from cellulosic biomass: $220/ton from biomass at $60-80/ton
- Projected biomass cost (Brazil): $25-30/ton
- Biomass waste (Opp. cost=0): 20-25 E/ton

Chemicals Comparison.'

- Glucose at : $400/ton, Lipids produced at yield of 0.25g lipids/gram Glucose
- Feedstock cost: $1600/ton (vs. $1000 selling price)

Uneconomical to produce lipids from glucose as selling price is less than cost price of glucose.

- But, Mono ethylene Glycol at Yield: 0.50g/g would give Feedstock cost: $800/ton(vs. $1200 selling price)
- Or Glycolic acid at Yield: 0.70 g/g would give
- Feedstock cost: $560/ton (vs. $2000 selling price)
- Ethylene glycol
- Glycolic acid (Product cost $2000/ton)
- Lipid synthesis for biodiesel production

With Carbohydrates (C6, C5)-Engineering the lipid biosynthesis pathway)

Summary

- There are plenty of opportunities for new innovative biotechnology processes in producing bio chemicals and biofuels.
- Advancing biotech depends more on how well it competes with chemistry than the price of oil.
- Space time or productivity

Chemistry vs. Biotechnology

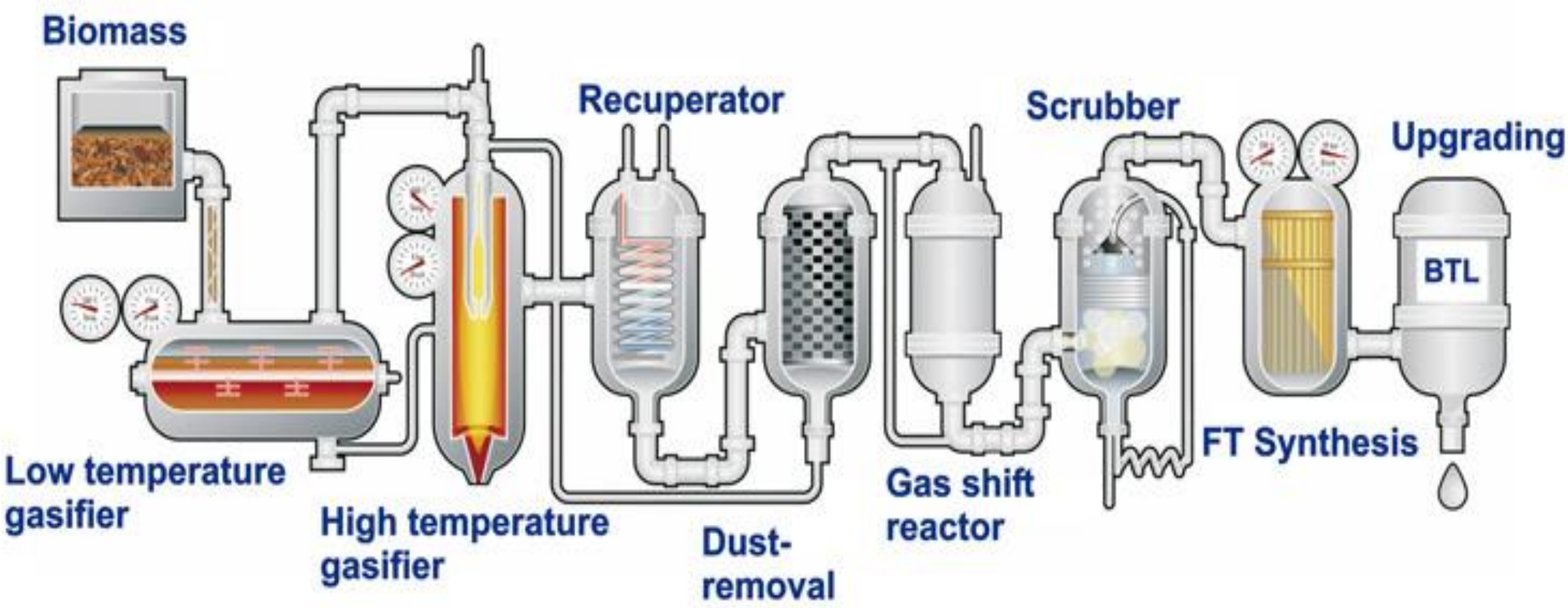
Creative destruction:

- Replace depreciated low cost chemical plants with modern high-biotech processes.
- Why?

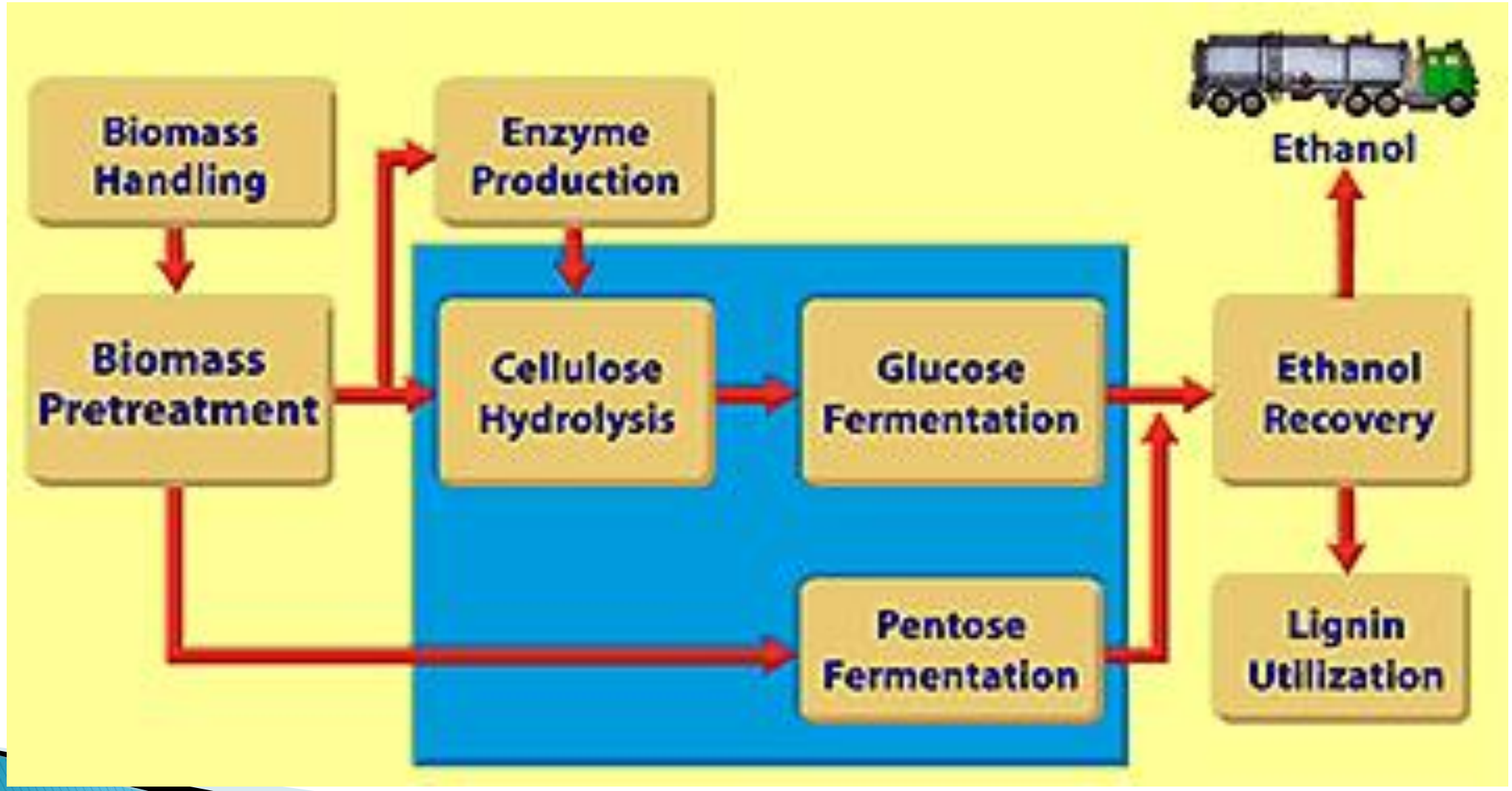
Biochemical vs. Catalytic or Thermochemical

- Thermochemical (via syn gas)
  - Advantage: Feedstock agnostic
  - Disadvantage: Requires large, integrated plant to offset large capital costs
- Biochemical (mainly sugar platform)
  - Advantage: Simple, linear process, high selectivity, smaller plants
  - Disadvantage: Depends on availability of cheap sugars

Process flow diagram for Fischer-Tropsch (FT) Ethanol

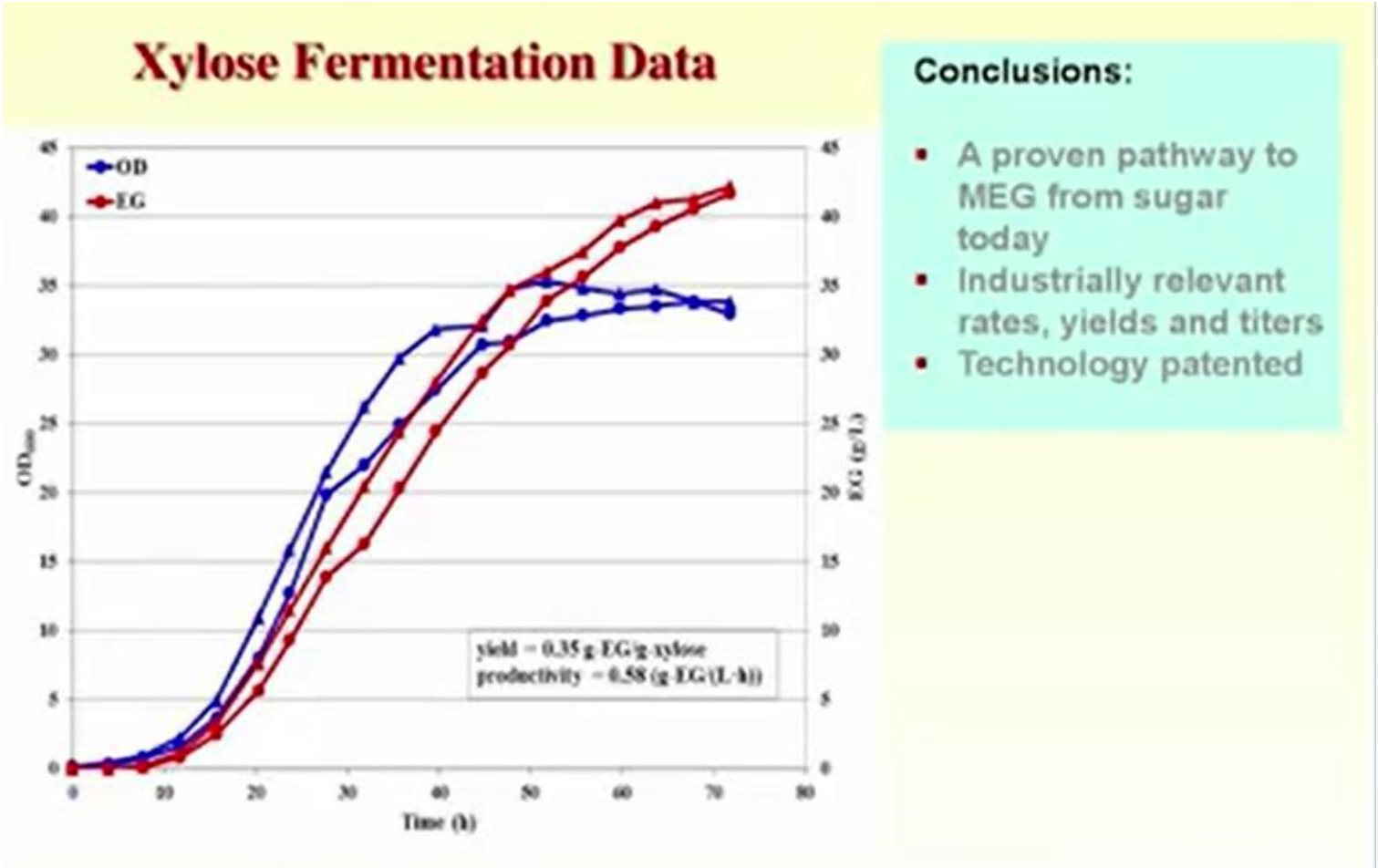


Cellulosic Ethanol process flow diagram



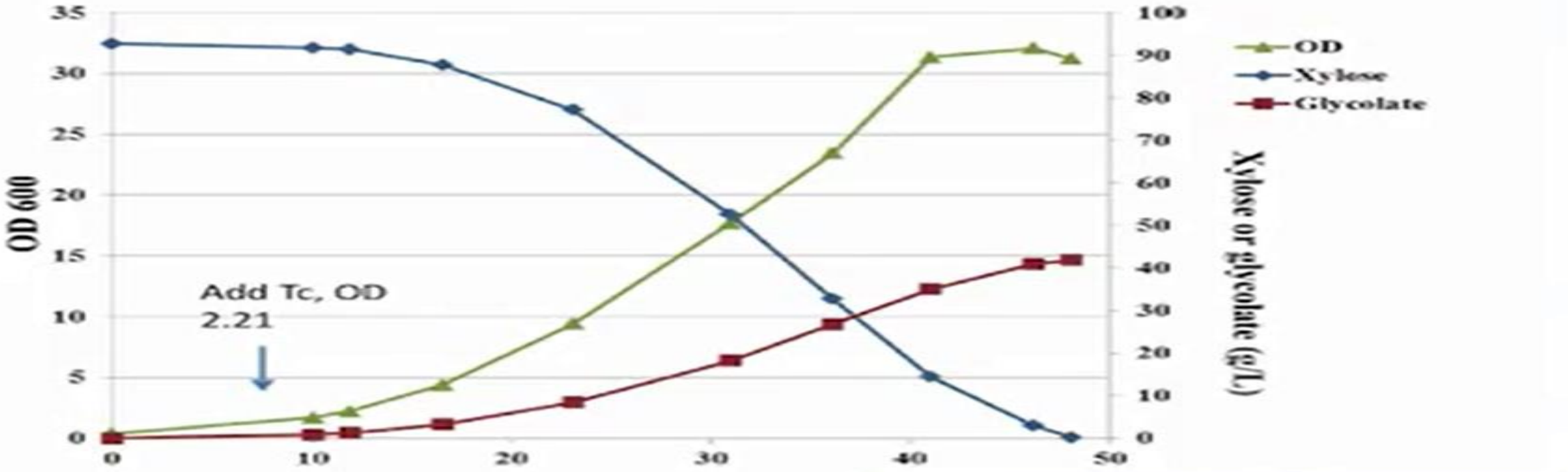
- Selectivity of Bioprocesses:
- Simple, single product, low capex plants
- Product cost is dominated by feedstock cost (greater than 55%)
- Aqueous systems (dilute)
- Sugar substrates
- Sensitivity of catalysts
- High temperatures avoided
- Biochemical vs catalytic or thermochemical processes
- Ex: Process flow diagram of FT ethanol vs. Cellulosic Ethanol Process Flow Diagram
- Succinic acid; Propane diol
- Feed cost is 65-80% of the cost of product.

Commercial applications: Essential commodities



Glycolic Acid

Combination of C2 and C3 Pathway in Bioreactors

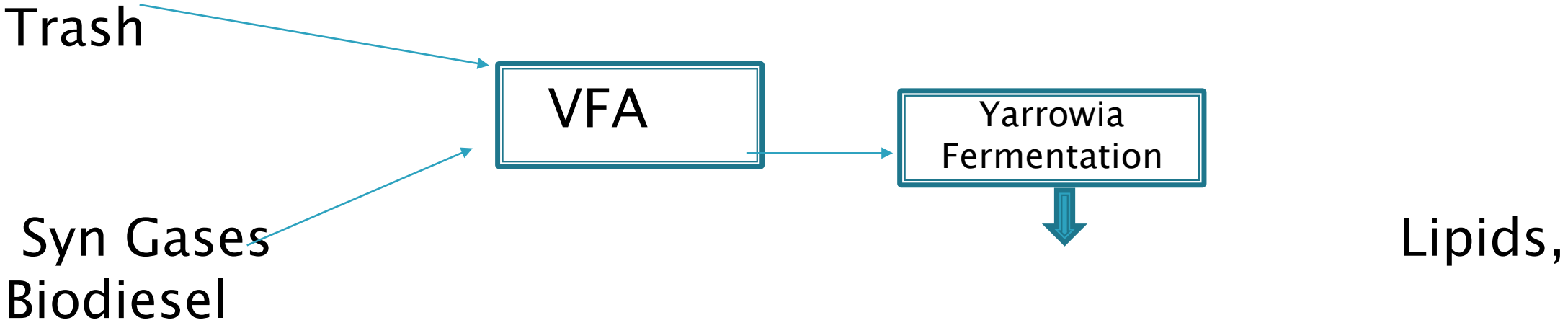


Time 0 h, OD 0.368,
Xylose 92.7g/L

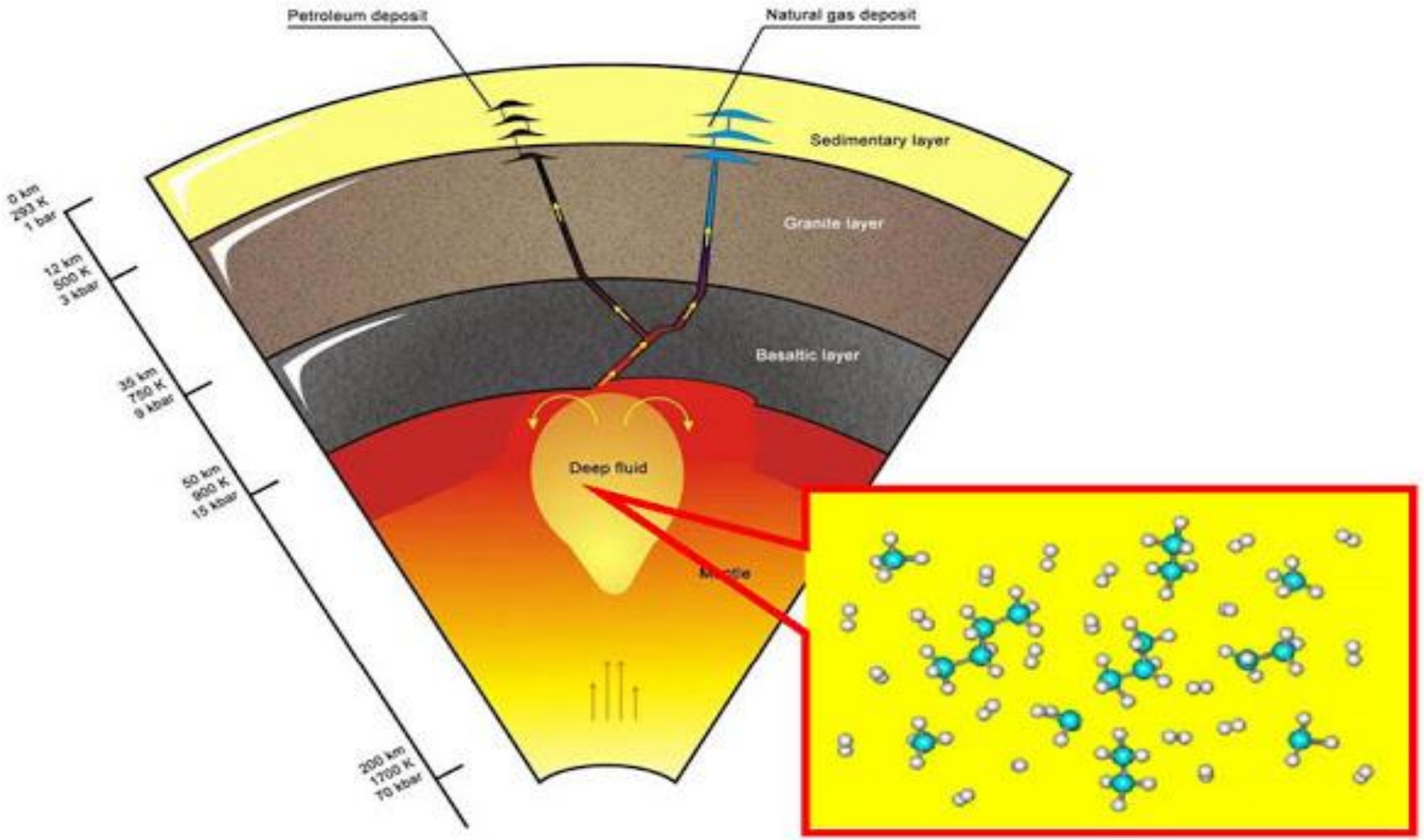
Glycolate 41.89 g/L
Productivity 0.87 g/L/h
Yield 0.453 (C2 0.447, 0.443)

Alternative feed stocks

- Glucose is expensive
- Acetic acid is interesting alternative. Can be supplied at large volumes from
- Anaerobic digestion
- Fixation of CO_2 with CO or Hydrogen using anaerobic bacteria



Renewable Hydrocarbons for the Drop-in Chemicals and Drop-in Fuel Markets



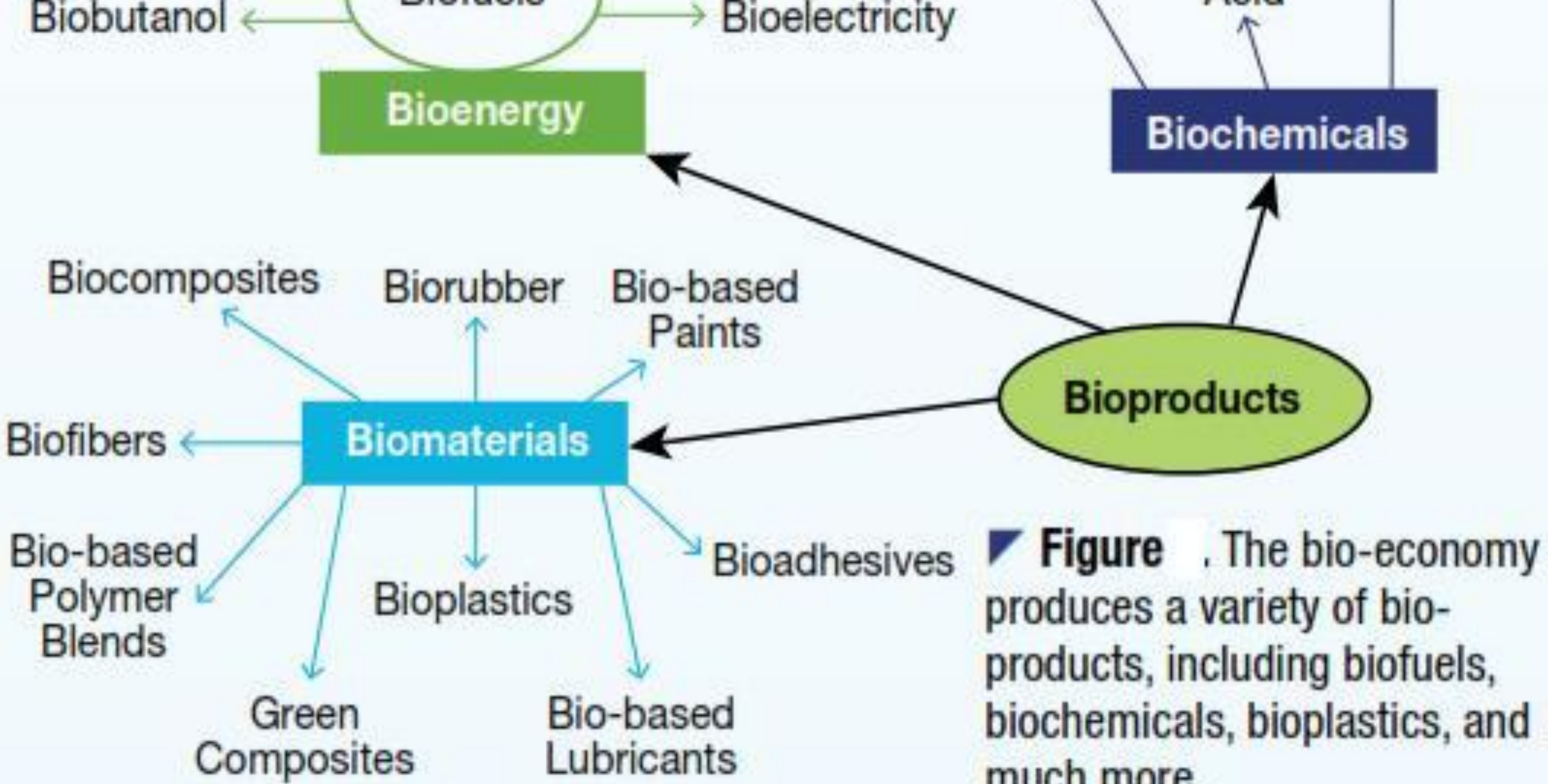


Figure . The bio-economy produces a variety of bio-products, including biofuels, biochemicals, bioplastics, and much more.

Sustainable biomaterials

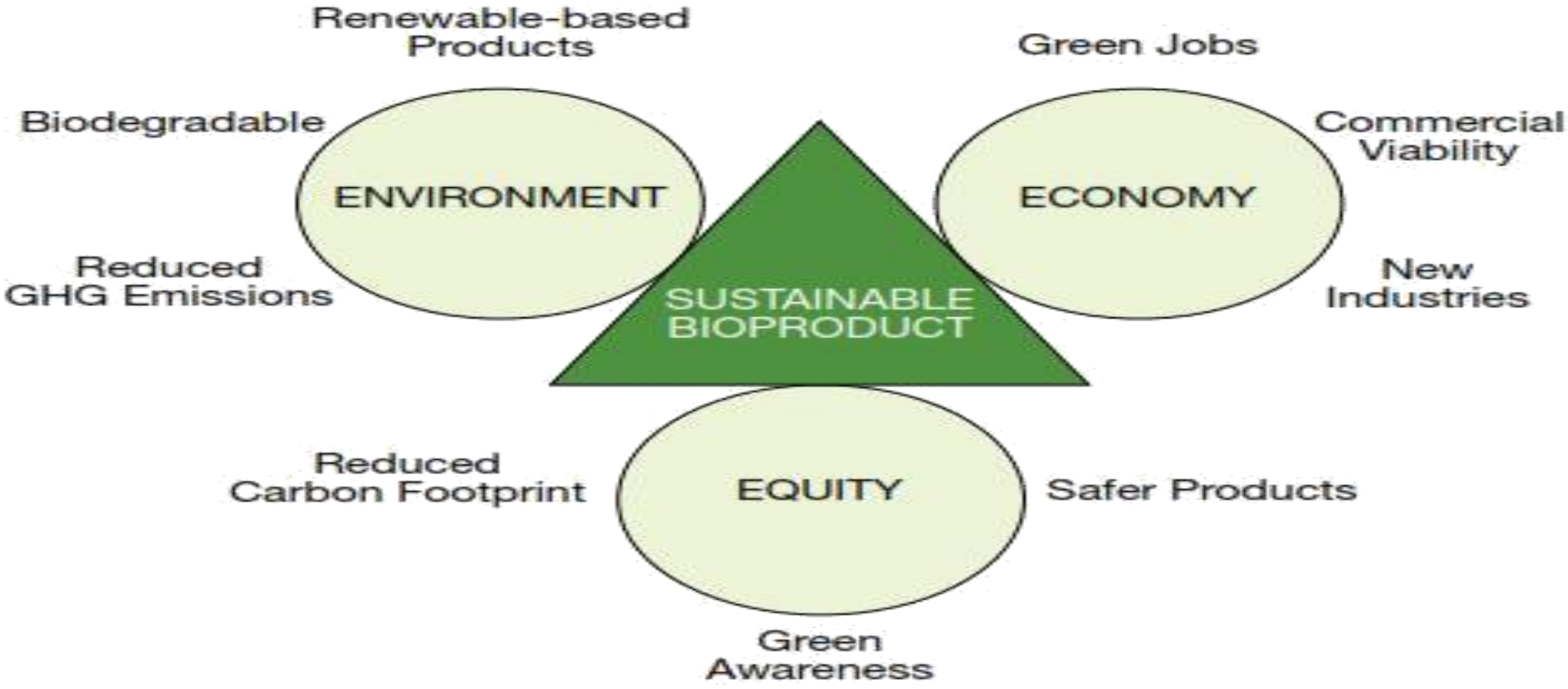


Figure Sustainability incorporates elements of the environment, the economy, and social equity.

Biomaterials for Bio-plastics



Lignin
(Bioethanol Industry)



Lignin
(Paper Industry)



Water-Soluble Lignin
(Paper Industry)



Crude Glycerol
(Biodiesel Industry)



Distillers Dried Grains with Solubles (DDGS)
(Corn Ethanol Industry)



Canola Meal
(Canola Oil Industry)



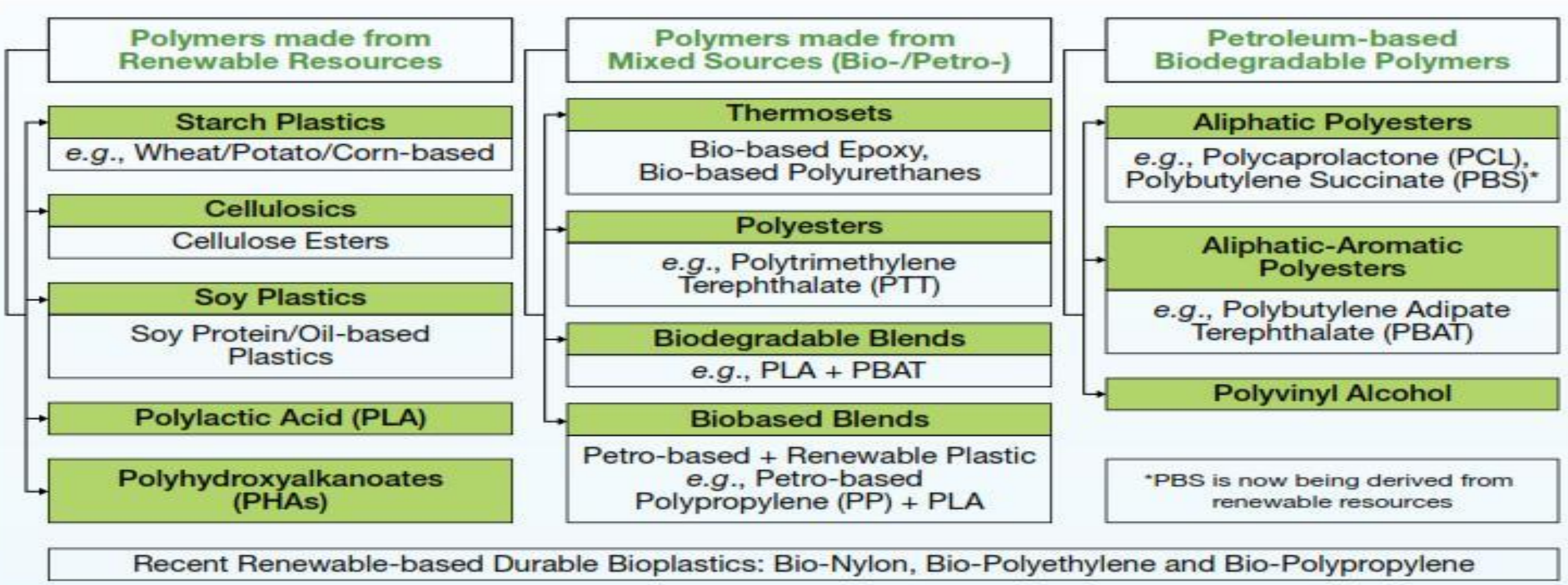
Jatropha Meal
(Jatropha Oil Industry)



Soybean Meal
(Soybean Oil Industry)

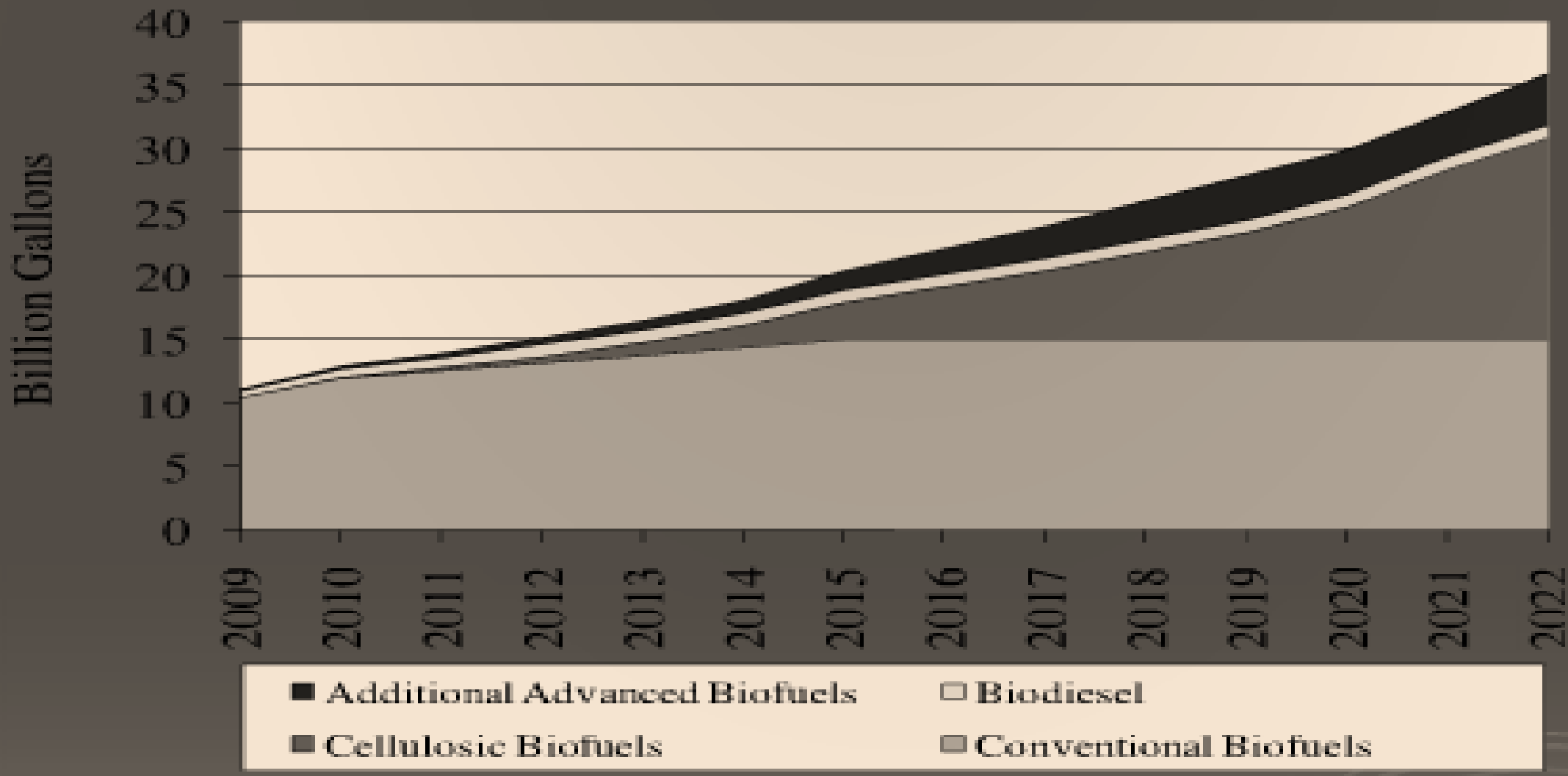
Figure: Potential raw materials for bioplastics; by products and co-products of the biofuels and paper industry

Bio plastics from different feed stocks



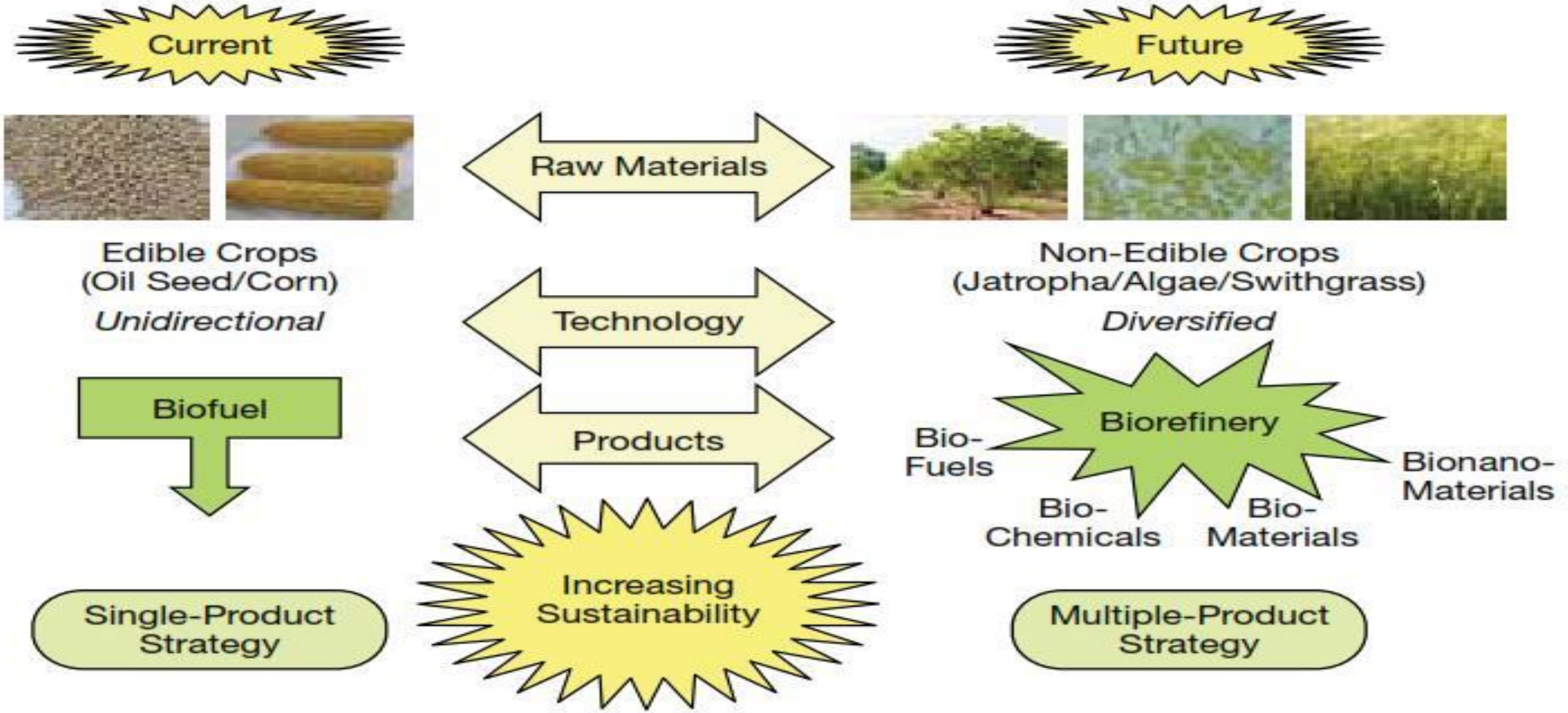
◀ **Figure** Bioplastics may be made of renewable resources, petroleum-based biodegradable polymers, or a combination of bio- and fossil-based feedstocks.

Renewable Fuels Standard



Source: Renewable Fuels Association

Bio Energy Value Chain



▲ **Figure** . Diversification of the biofuel value chain can improve sustainability.

Petrochemical Industry Map





Steam Cracking

Olefins

Naphtha

Aromatics

Pyrolysis Gasoline

Ethylene

Propylene

Butylenes

Butadiene

Benzene

Toluene

Xylenes

Hydrocarbon Fuels

Diesel

Gasoline

Jet Fuel

Chemicals and Materials

Polyethylene

MTBE

EDC

Vinyl Chloride

Poly(vinyl cloride)

Ethylene Oxide

Ethylene Glycol

Polyester

alpha-Olefin

Ethanol

Isobutene

Polyisobutylene

Polypropylene

Propylene Oxide

Polyols

Acrylonitrile

Polyacrylonitrile

Polybutadiene

Butadiene-Styrene

Cumene

Phenol

Acetone

Polystyrene

Ethyl Benzene

Styrene

ABS

Methyl Methacrylate

SB Latex

Nylon 66

Cyclohexane

Nylon 6

Toluene Diamine

Polyurethane

ortho-Xylene

Plasticizers

meta-Xylene

Isophthalic Acid

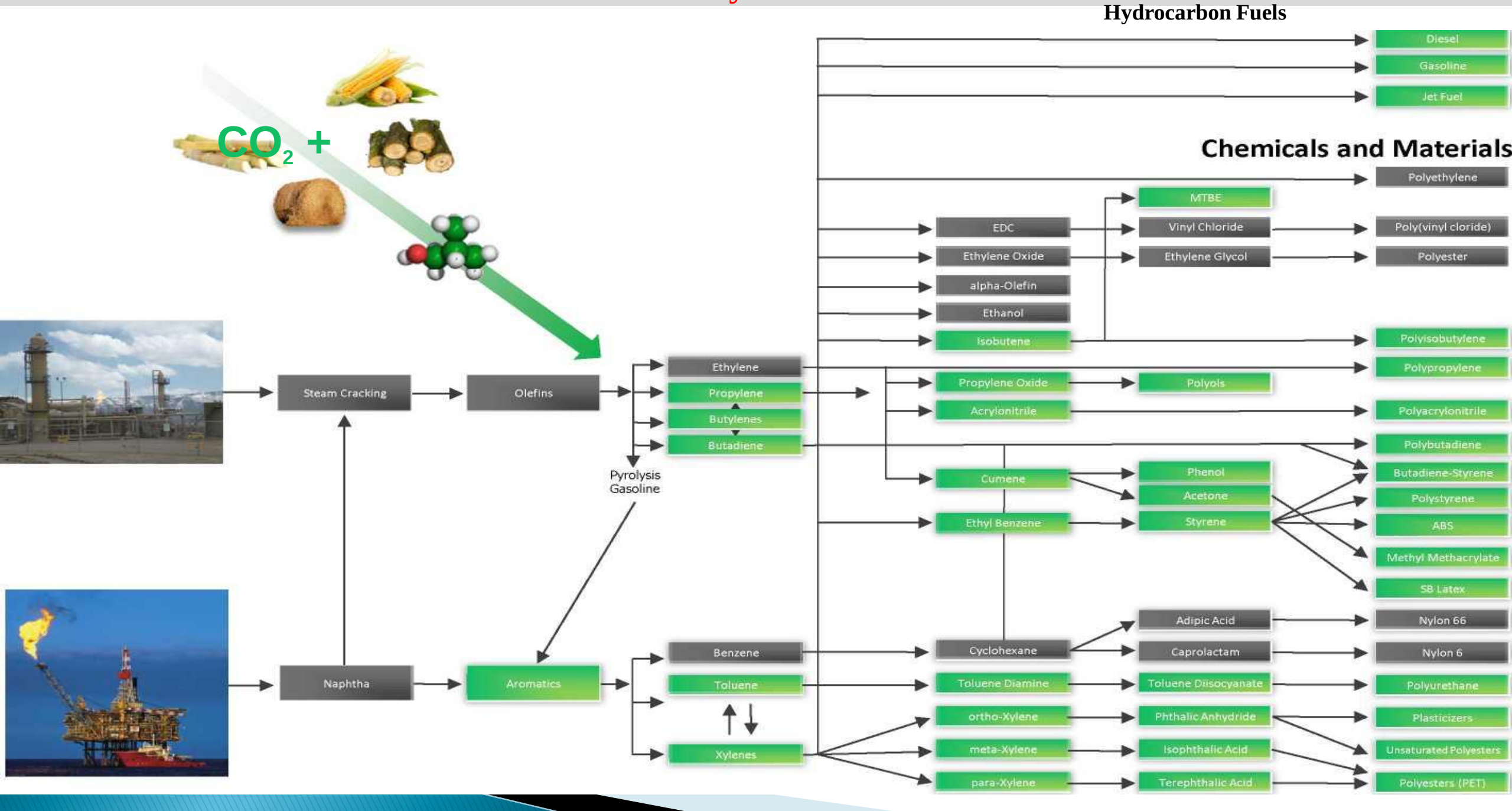
Unsaturated Polyesters

Polyesters (PET)

para-Xylene

Terephthalic Acid

Isobutanol: A Gateway to Chemicals and Fuels



Multiple Feedstock, One Gateway, Multiple Markets

Feedstock Flexibility

Today



Corn



Sugar Cane

Future



Agricultural Residue



Wood

Retrofit

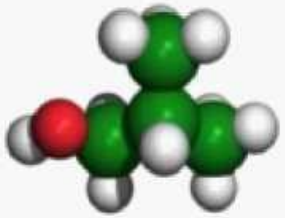


Proprietary Platform: Yeast



Proprietary Separation Unit

Gateway Product



Isobutanol

Drop-in Chemicals



Drop-in Fuels



Shift in Petrochemical Feedstock Drives Opportunity

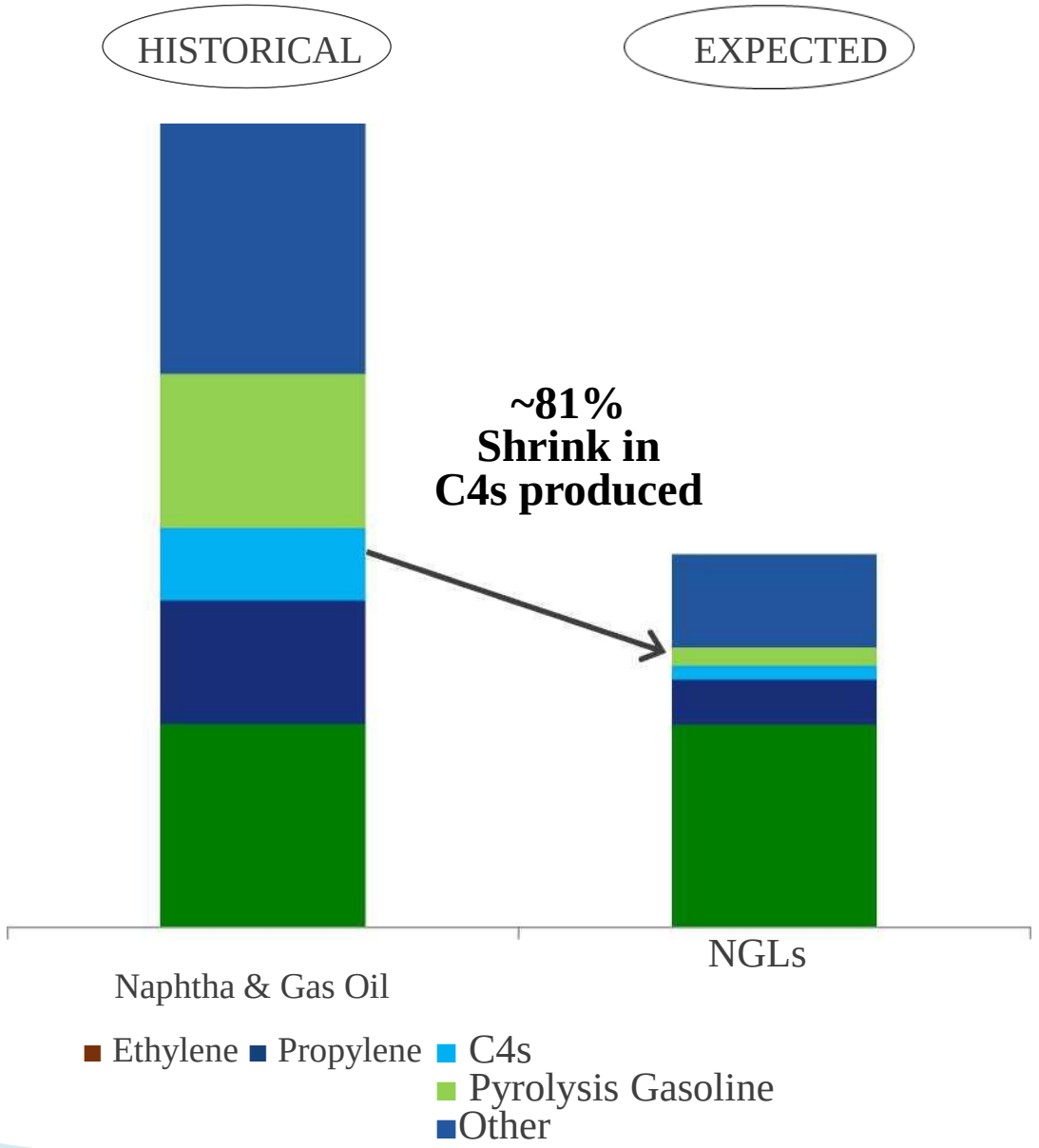
Shell Oil: June 2011

- Announced world scale ethylene cracker for Marcellus Shale region (>$1 billion investment and 3-5 year construction project)

Dow Chemical: April 2011

Ethylene cracker for startup in 2017 and will use feedstock from Marcellus and Eagle Ford shale regions

- Announced world scale



Addressable Markets With Drop-In Solutions

SOLVENTS

>$5 BILLION MARKET



BIOJET

>$160 BILLION MARKET



UNITED



RUBBER AND LUBRICANTS

>$5 BILLION MARKET





SPECIALTY GASOLINE BLENDSTOCKS

>$5 BILLION MARKET

TOTAL





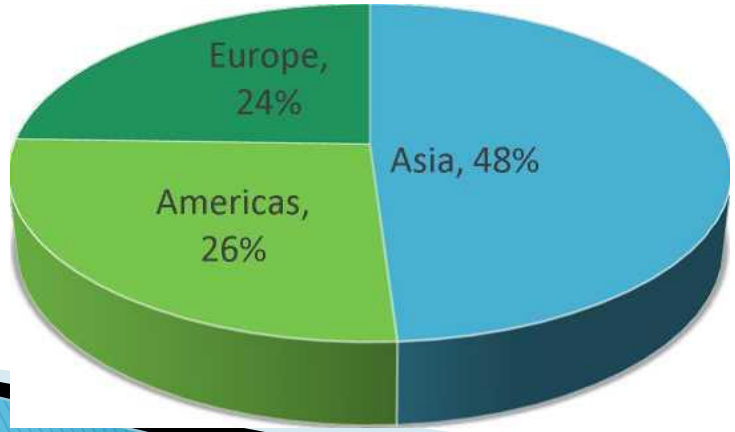
Butanol Solvent/Specialty Chemical Opportunity





The Butanol Market is:

- 1.2 billion gallons sold per year
- 80% substitutable
- Or approximately $7 billion TAM
- Growing 3%/yr or >350mmgpy



Market strategy

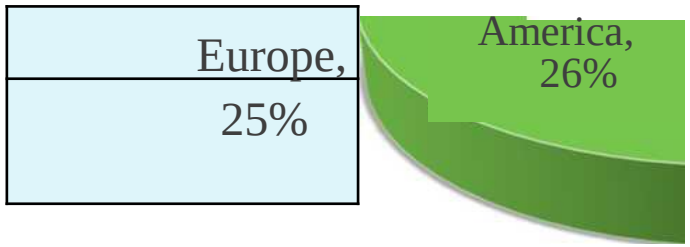
- Sasol definitive off-take in place
  - Represents the majority of plants #1 & #2
  - ASP Indexed to our feedstock
  - Non-Americas exclusive for "high purity" grade
- Sasol generates >$16b in revenue and is the global leader in Fischer-Tropsch chemistry

'C4' Opportunities: Rubber/Lubricants



The C4 Market is:

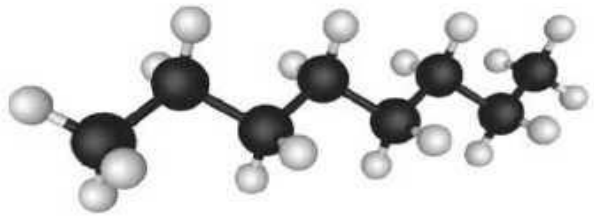
- 6.4 billion gallons sold per year
- Or approximately $39 billion TAM
- Growing 3%/yr or > 1bgpy
- Automotive drives >70% of demand



Market strategy

- Lanxess supply agreement
  - Expected revenue to begin in 2013
  - ASP Indexed to our feedstock
- Lanxess generates over $10b in revenue and is the Global leader in synthetic rubber

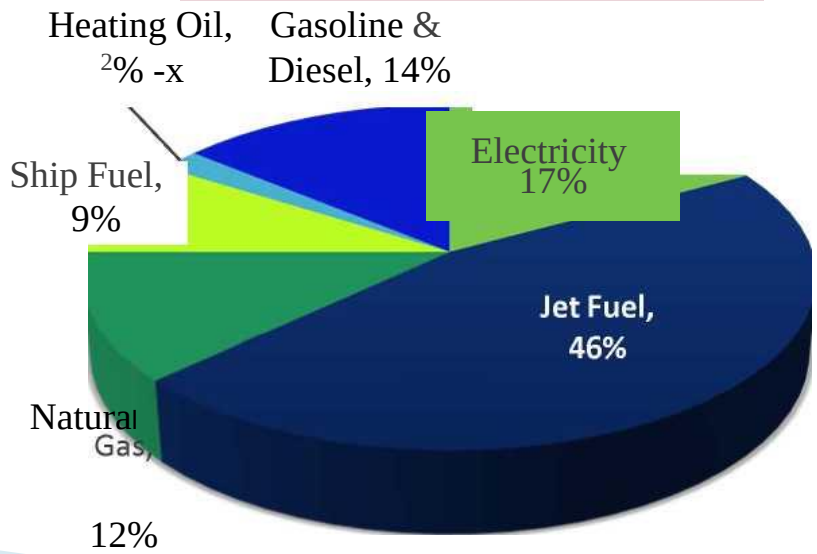
Alcohol-to-Jet (ATJ)





*In terms of fuel types, jet fuel accounts for more than 50% of total DoD energy consumption, and nearly 60%o of its mobility fuel. **

US Government Energy Use**



ATJ bio-jet fuel under development

Alcohol-to-Jet

- ASTM Certification underway
- Initial volumes being tested

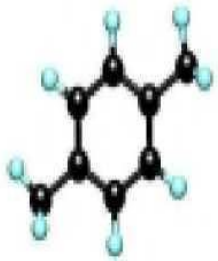
Cellulosic Strategy

- Yeast Development underway
- Partnerships being evaluated
- Advanced bio-fuel credit available

Market strategy

- USAF - first PO in-hand
  - Working in parallel with ASTM process
  - Expect larger order post certification
- South Hampton Resources
  - Demonstration facility under construction
  - Initial bio-jet volumes expected in 2012
- USDA & Northwest Advanced Renewables Alliance (NARA)
  - Grant to help advance the conversion of woody biomass to bio-based hydrocarbons

BIO-PET (Polyethylene Terephthalate)

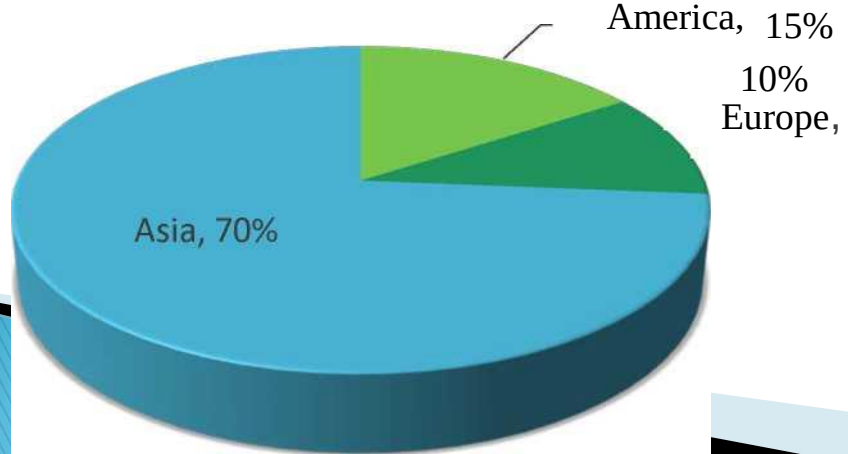




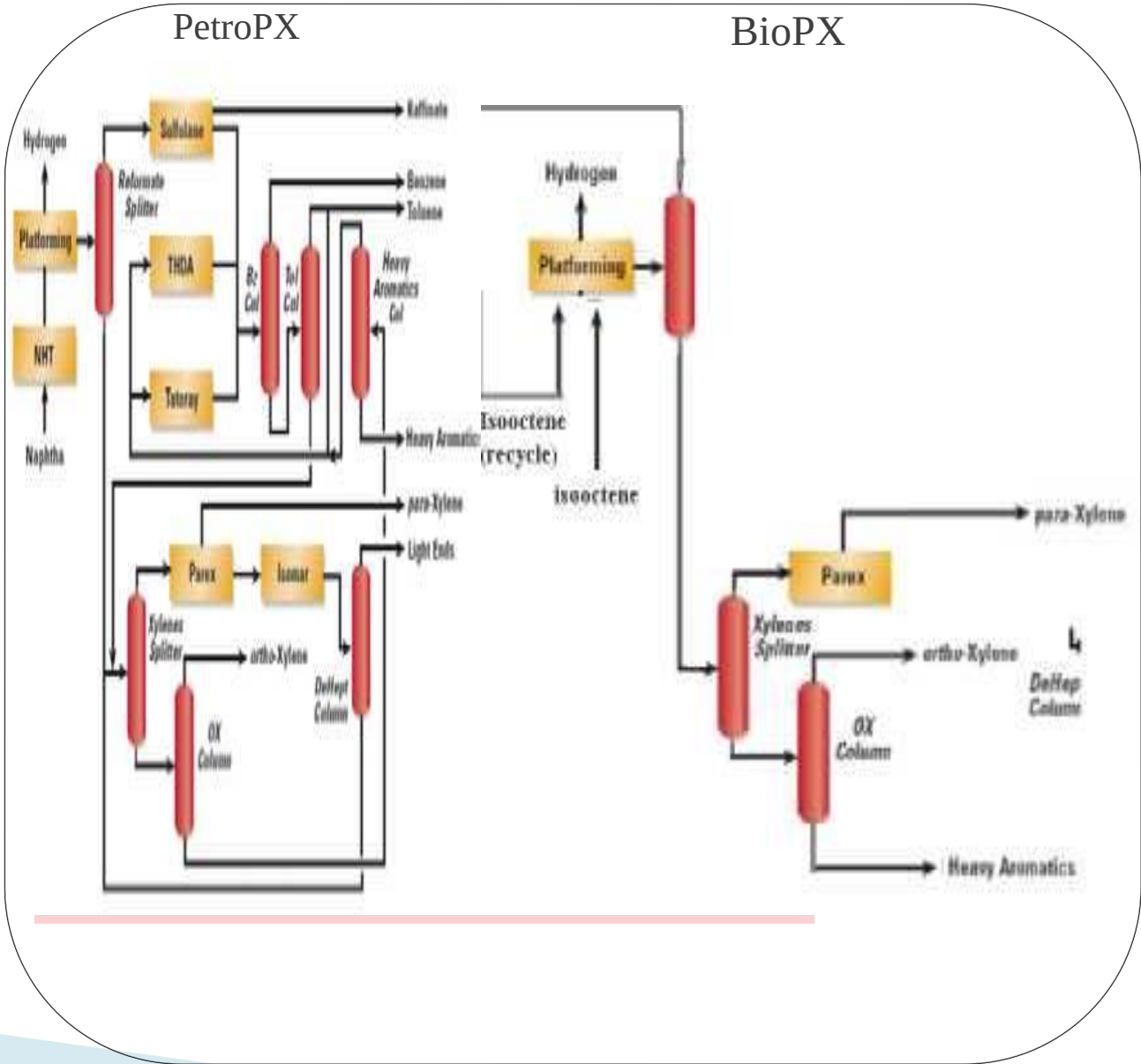
- Up to 30% plant-based 100% recyclable bottle
- Redesigned plastic, recyclable is ever.

The PET Market is:

- 31 million metric tons per year
- Or approximately $60 billion TAM
- Growing 5%/yr, equivalent to 600mmgpy IBA/yr



r-PX is CAPITAL EFFICIENT

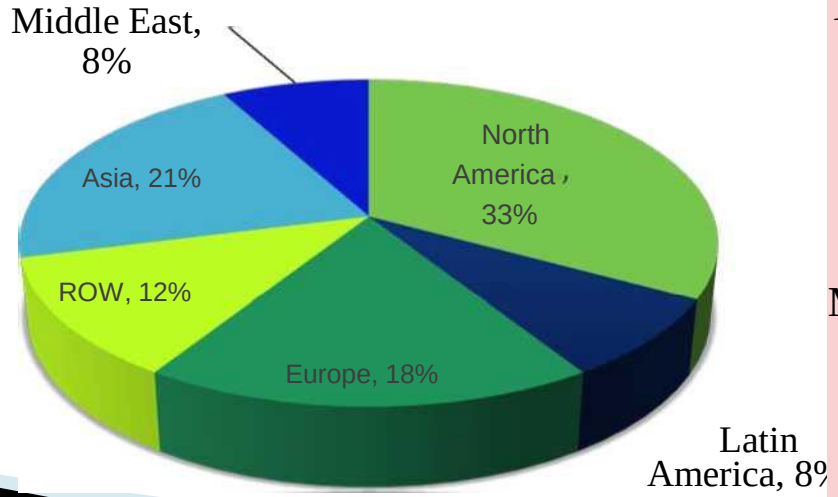


Gasoline Blend stock



The Fuel Market is:

- ~340 billion gallons of gasoline per year
- ~95 billion gallons of jet fuel per year
- ~375 billion gallons of diesel per year



IBA PERFORMANCE ENABLED

Isobutanol - in gasoline

- Infrastructure Compatible
- Satisfies Mandates
- Can Improve Margins

Outdoor Power Equipment Institute (OPEI)

- Tested IBA blend in Briggs & Stratton engines
- Superior Performance v ethanol blends

Total - TX refinery

- Has capacity to take >150m+ gallons
- IBA for gasoline LOI in place
- Negotiating off-take

Mansfield - distribution & off-take

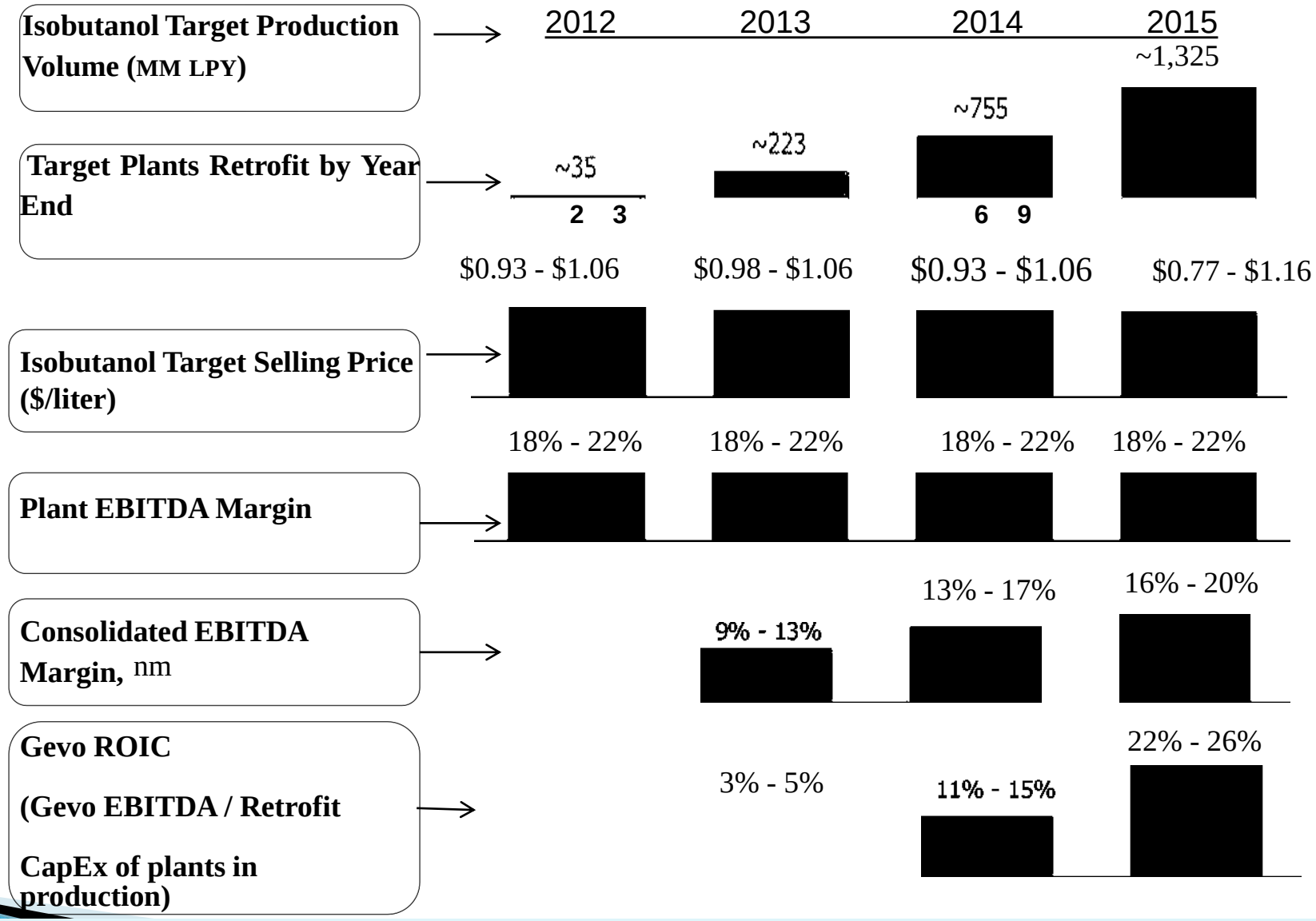
- "Sub-sim" gasoline blend logistics
- Focus on marine and small engine

Outstanding Gasoline Blending Properties

	Ethanol	Iso-butanol	Gasoline
Blend RVP (psi)	18-22	4-5	7-9
Blend Octane	112	102	87
Energy content: % of gas	65%	82%	100%
Infrastructure Compatible	No	Yes	Yes
Oxygen Content	35%	22%	0%

- Low volatility reduces ozone, optimizes blending
- Properties enable alkylate & aromatics replacement
- Higher energy may improve fuel mileage, performance
- Infrastructure compatible (pumps & pipelines)
- Compatible with gasoline engines of all types w/o modification

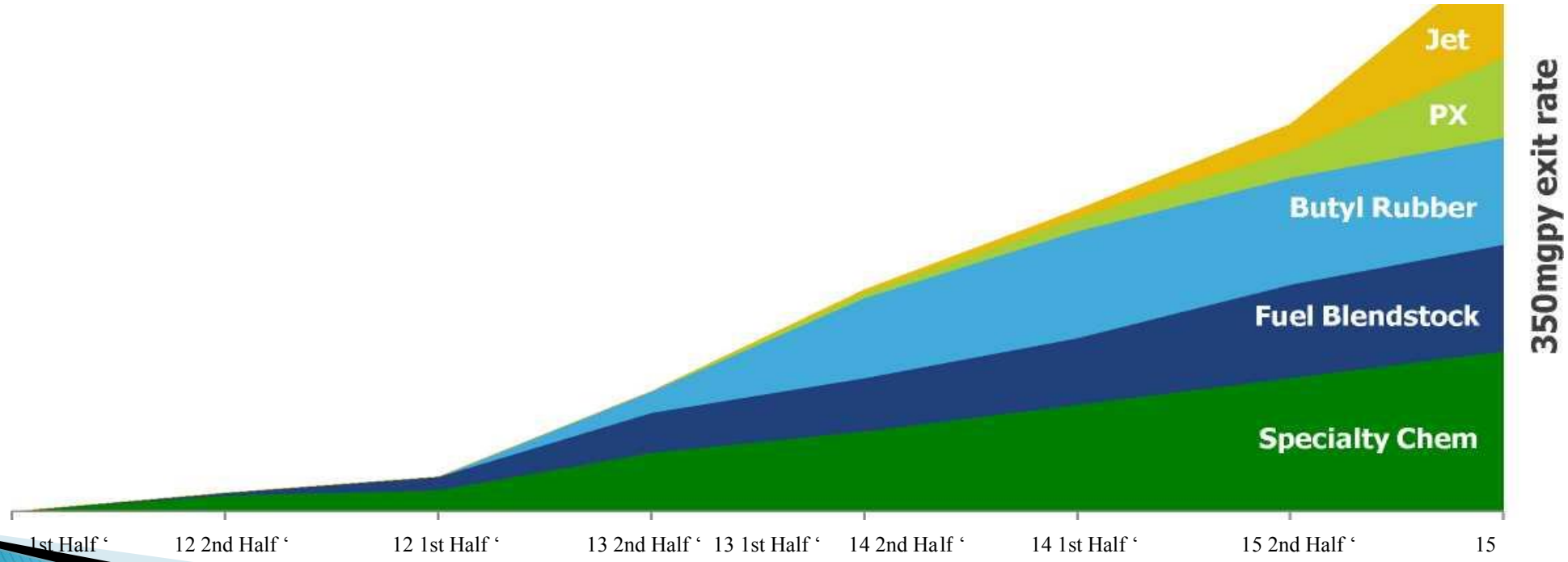
Economics Remain Attractive as Volume Ramps



- Note: Assumes $6.50/bu CBOT corn and $95/bbl oil. The projected growth of our production volumes, selling price and gross margin percentages depicted above reflect our targets based on the estimates of our management and there can be no assurance that we will be able to reach our targeted levels of production, selling price

Commercialization Strategy

- Replace the entire barrel of oil
  - Make and sell isobutanol into high value chemicals and fuels markets
  - Make and sell high value protein into feed markets
  - Convert isobutanol to hydrocarbons & seed larger markets - collapse the value chains
  - Select high growth, high ROCE opportunities for new technologies



Biopolymers from Syngas Fermentation

- To propel the sustainable production of new biopolymers from secondary feedstock.
- To establish a platform that integrates biopolymer production.
- To focus on the integration of innovative physico-chemical, biochemical, downstream and synthetic technologies
- To create a platform will empower the treatment and recycling of complex biological and chemical wastes and raw materials in a single integrated process

Steps for Biopolymers Production from Syngas Fermentation



PRE-TREATMENT



SYNGAS PRODUCTION

CO + H_2

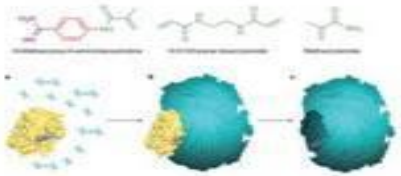


REACTOR DESIGN

RECYCLING

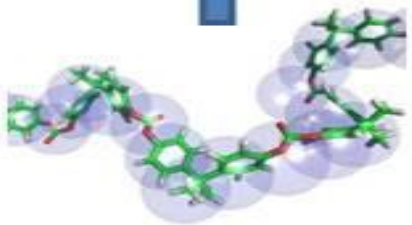


DEGRADATION





LIFE CYCLE



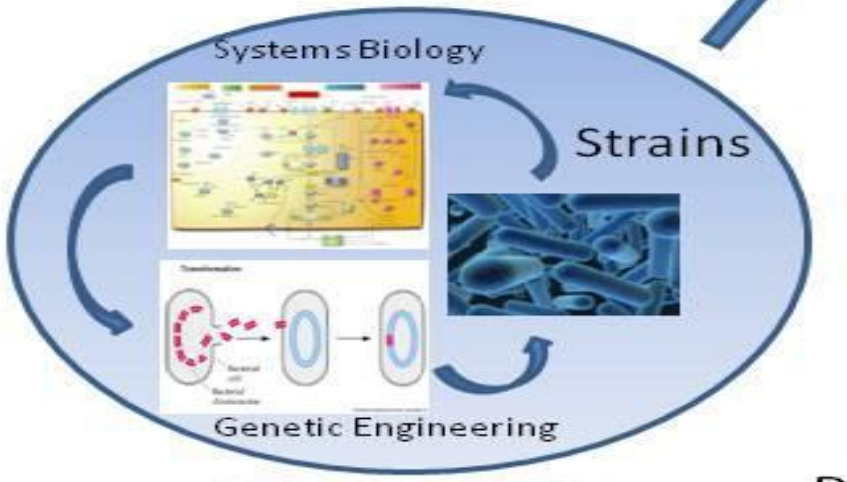
POLYMER SYNTHESIS



DOWNSTREAM PROCESS

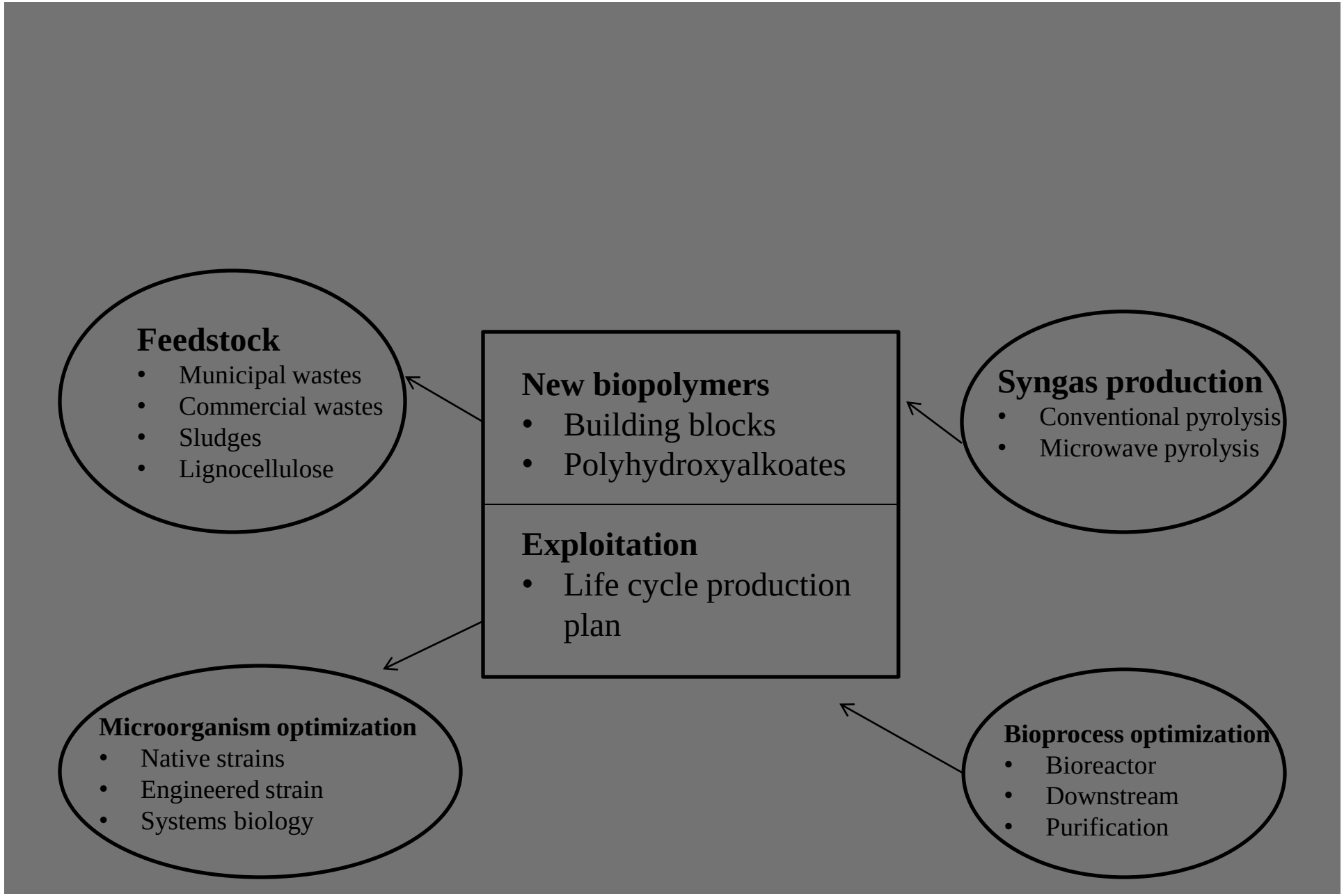


PILOT PLANT



STRAIN DESIGN

Syngas Fermentation Technology



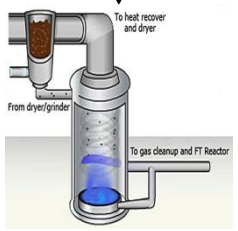
Integrated Processing Technology

Secondary

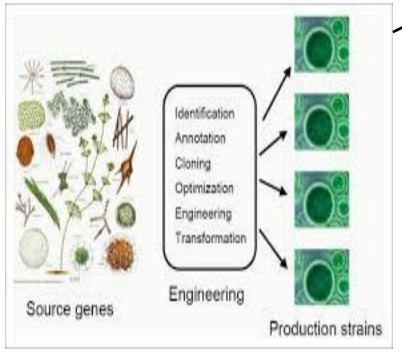
Feedstock



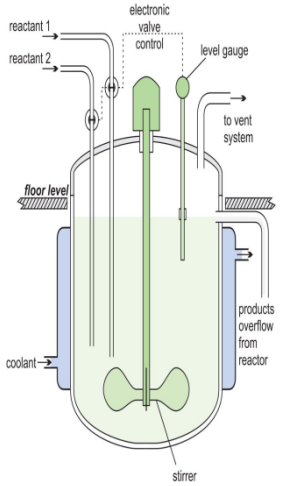
Pre-treatment



Syngas production



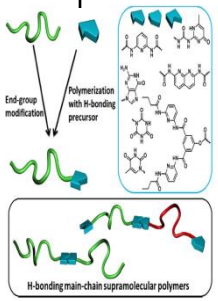
Strain design



Reactor design



Downstream process



Polymer synthesis

recycle

New biopolymers



Degradation



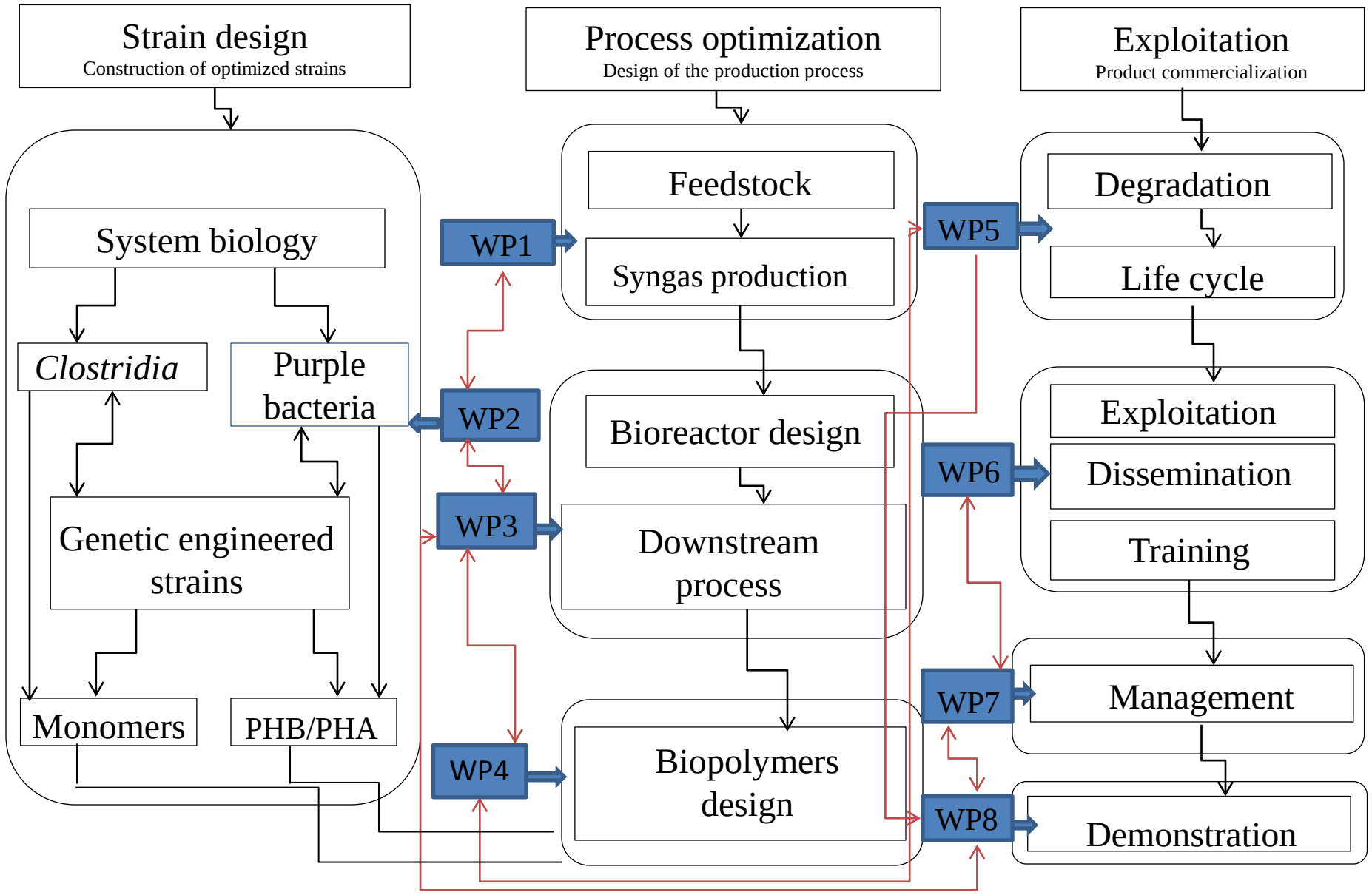


Life cycle



Pilot plant

Work Plan (WP) for value added Biopolymers



The work plan (see Figure) comprises three main goals:

i) Strain design

ii) Process optimization

iii) Exploitation

These goals will be achieved through the implementation of the following WPs which are dealing with:

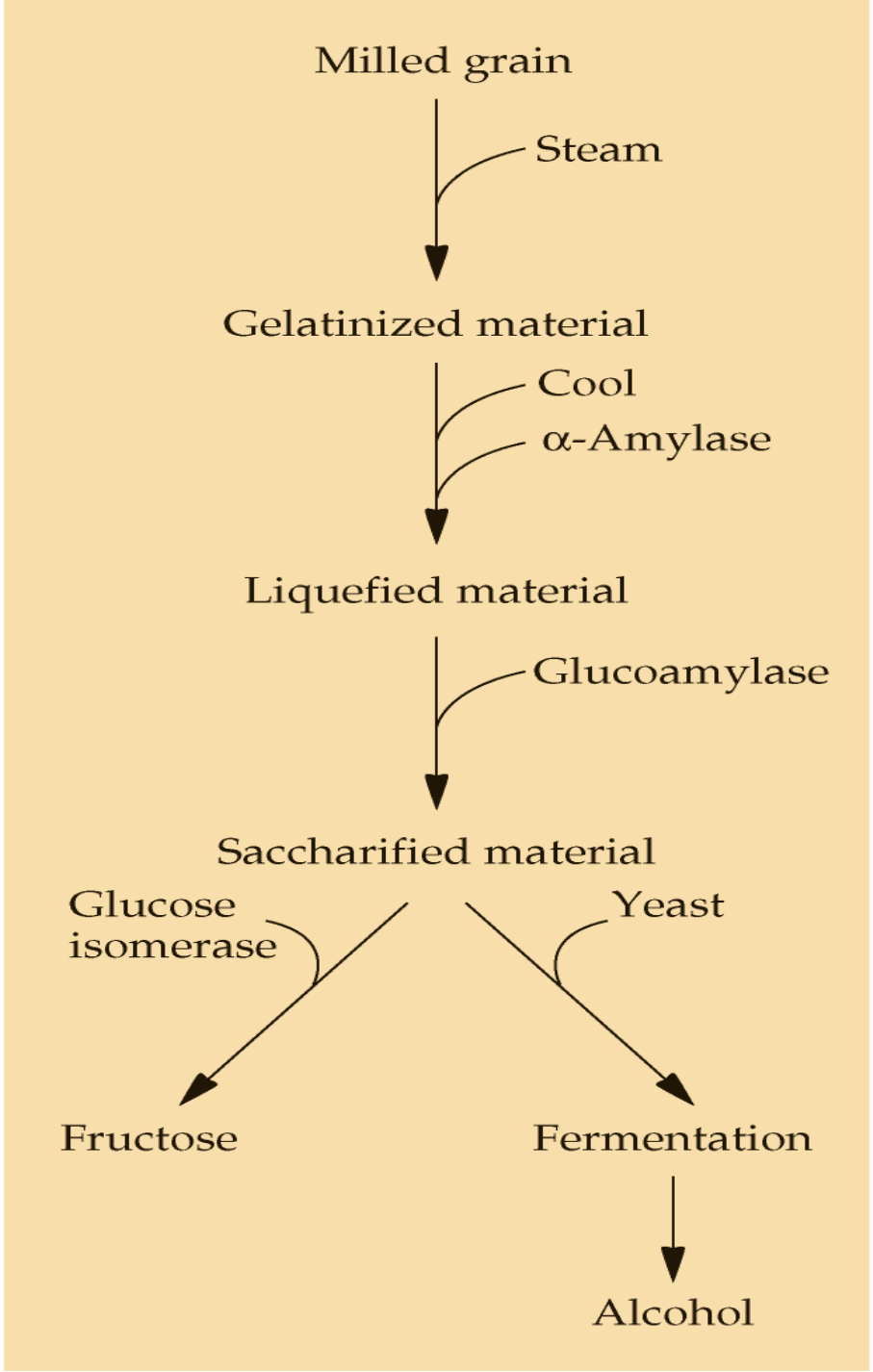
- (WP1) Production of syngas
- (WP2) Improvement of microorganisms
- (WP3) Fermentation design
- (WP4) Biopolymers design
- (WP5) Biopolymer degradation and life cycle
- (WP6) Exploitation, dissemination and training activities.
- (WP7) Management.
- (WP8) Demonstration.

Biomass (e.g., starch)utilization

- To generate alcohol and fructose thanks largely to the action of 3 key enzymes.







Sustainable Processes for Production of Di-ols

Drop-in Chemical Value Chain

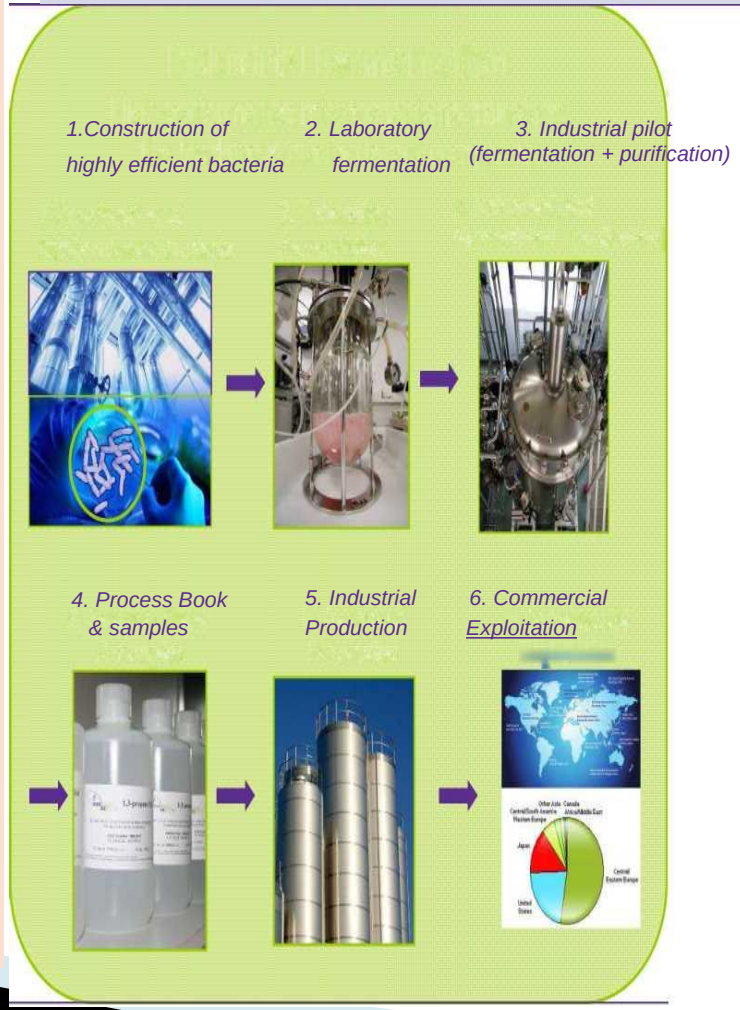
Bio Based raw materials

Many different *2nd Generation feedstock*

Upstream Producers and processors of Agri-resources

Industrial Fermentation

High-performance microorganisms transform the feedstock into the target compound

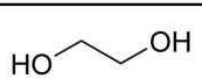
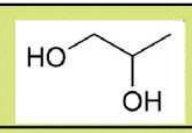
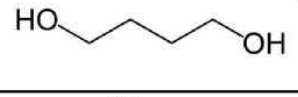
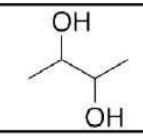


Products derived from existing bulk chemicals

Downstream : Productions of everyday goods / Chemicals manufacturers



Current Market of Di-Alcohols

Di-alcohols	Formula	Approx. current production capacity	Major producers	Bio-based development
Mono ethylene glycol		20 millions tons	SABIC, JUPC, Shell, Nan Ya, Honam...	✓
1,2-propanediol (PDO) Mono propylene glycol (MPG)		1,9 millions tons	Dow, LyondellBasell	✓
1,4-butanediol		50 kilotons	Dupont	✓
1,3-propanediol		1,4 millions tons	BASF, Dairen, LyondellBasell	✓
2,3-butanediol		< 100 kilotons	BASF, Lanxess, Ube	✓
1,5-pentanediol		< 100 kilotons	BASF, Lanxess, Ube	✓
1,6-hexanediol				

Strategic Reasoning beyond PDO & MPG

PDO

- Complex manufacturing via the fossil route
- Several steps (acrolein or EO, catalytic hydrogenation, ...)
- Selectivity is not high enough and purity is a key element for further valuation, i.e. PTT

Bio based PDO

- Fermentation with optimized strains leads to PDO in one step
- High purity products, leading to easiness of further processing
- Sourcing from different feedstock

MPG

- Requires propylene to start with and propylene, PO supply will not grow as quickly as the demand (steam cracker vs ethane based)
- An end market looking for renewable based products

Bio based MPG

- Solution based on biotech process and not chemical process from renewable feedstock
- Product obtained in one step
- Very high purity
- Sourcing from different feedstock

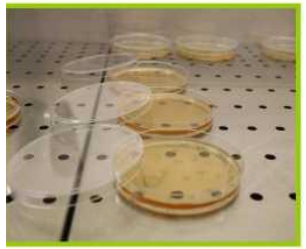
A Unique Integrated Asset for Industrialization

R&D
Design of production process

Laboratory

Validation of economic and technological feasibility using METEX technology platform

Micro-organisms optimized in the laboratory. Fermentation criteria defined





Pre-industrial pilot (fermentation)

Validation of laboratory results
Unit fermentation process books drawn up



Industrialization
validation of process book

Industrialization pilot (fermentation + purification)

Process books finalized by combining fermentation and purification phases in a single facility



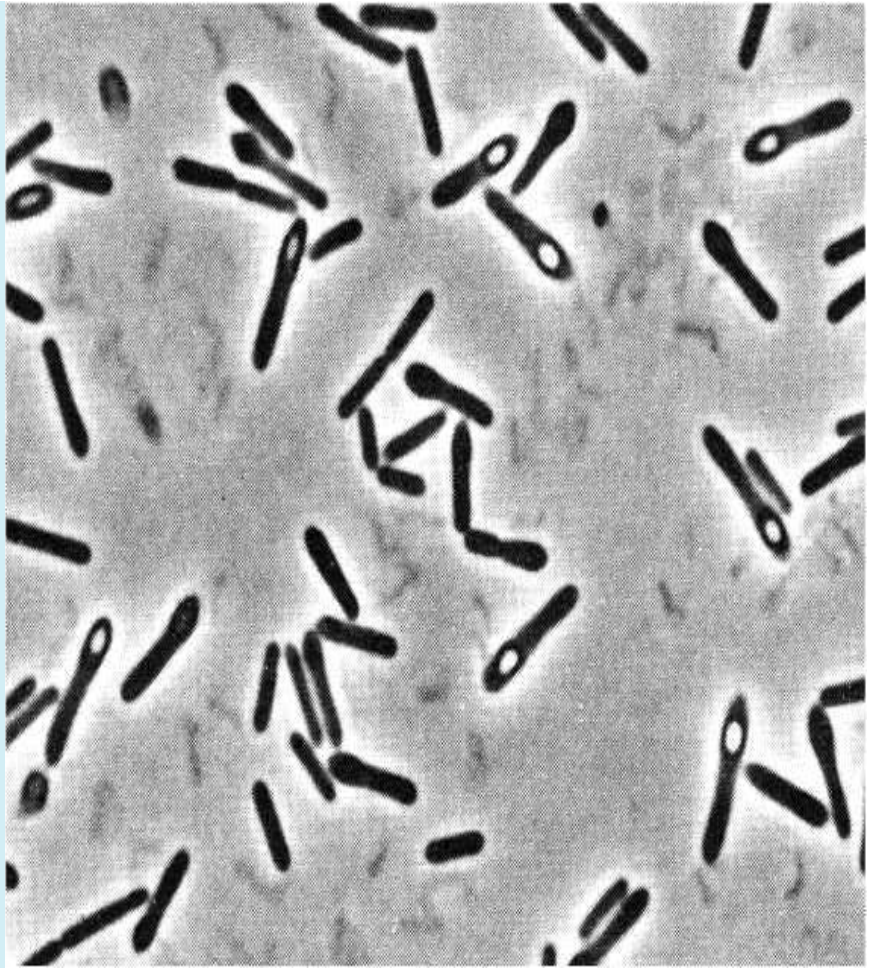
Industrial and commercial exploitation



Clostridium acetobutylicum, Our Engine to Produce 1,3 Propanediol

Clostridium butyricum

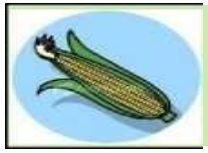
- A gram positive bacterium
- A strictly anaerobic bacterium
- DNA is AT rich (72%)
- Can convert a wide variety of substrates to acetate, butyrate and...1,3 propanediol
- Metabolic engineered to optimize yield, titer and selective production of PDO



Conversion of Municipal and Agricultural Solid Waste into Drop-in Biofuels

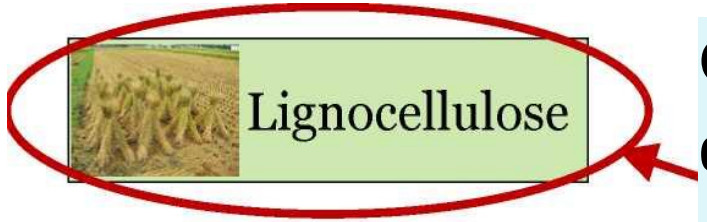
Routes to Biofuels

"Drop-in biofuels are liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure"

Feedstock		Intermediates		Liquid fuels
	Lignocellulose	Pyrolysis Bio-oil	→	Drop-in Biofuels
	Starch Crop	Syngas (i.e., CO + H_2)	→	Ethanol
	Sugarcane	Sugar (e.g., sucrose)	→	Butanol
	Oil Crop	Carboxylate (e.g., fatty acids)	→	Bio-diesel

Routes to Biofuels

Feedstock Intermediates Liquid Fuels





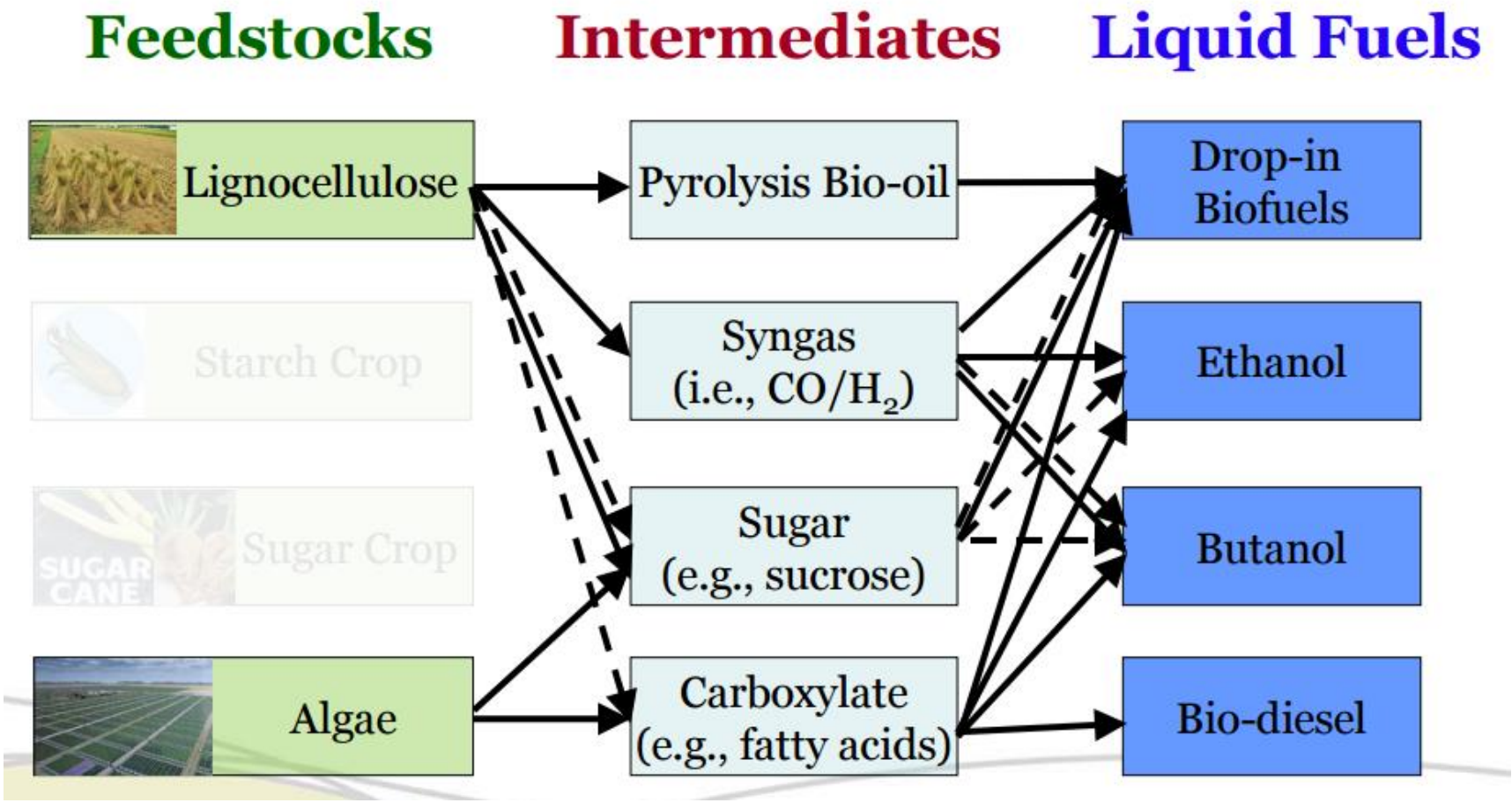


Only feedstock with enough quantity with present and/or future availability that can be produced virtually anywhere in the World



Algae &		Carboxylate (e.g., fatty acids)		Bio-diesel

New Routes to Biofuels



New Routes to Biofuels



Routes to Biofuels

Feedstock	Intermediates	Liquid fuels
 Lignocellulose	Pyrolysis Bio-oil	Drop in biofuels
	Preferred products because they seamlessly fits with present infrastructure	
 Algae	Carboxylate (e.g., fatty acids)	Biodiesel

Routes to biofuels



Lignocellulose → Pyrolysis Bio-oil → Drop-in Biofuels



Starch Crop → Syngas (CO/H_2) → Ethanol



Sugar Crop → Sugar sucrose → Butanol



Oil Crop → Carboxylate (e.g., fatty acids) → Bio-diesel

→ **Chemical route**

— — ▶ **Biolog[illegible] route**

The Conversion



Biomass



Fermentation Broth



Organic Salts
(e.g., sodium acetate)

Biological Conversion



Ketones
(e.g., acetone)



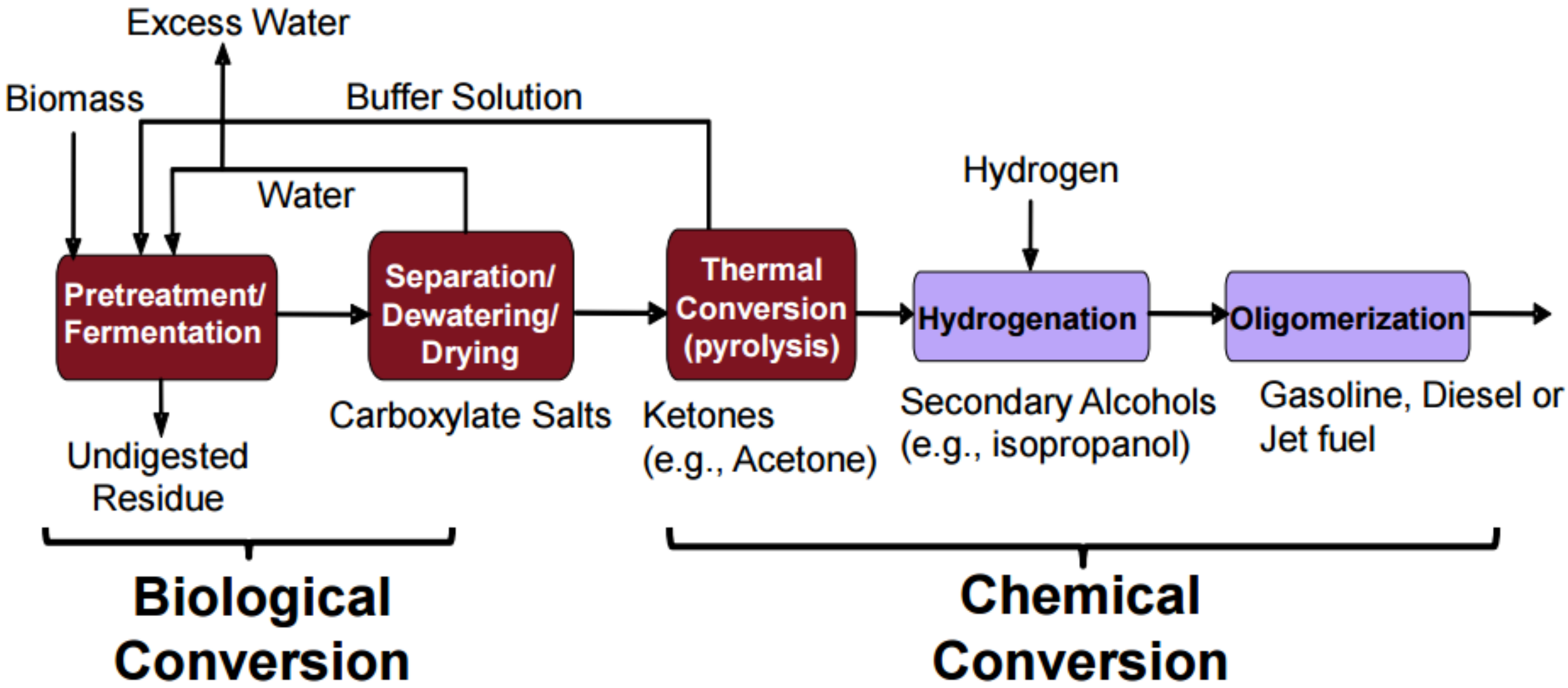
Secondary Alcohols
(e.g., Isopropanol)



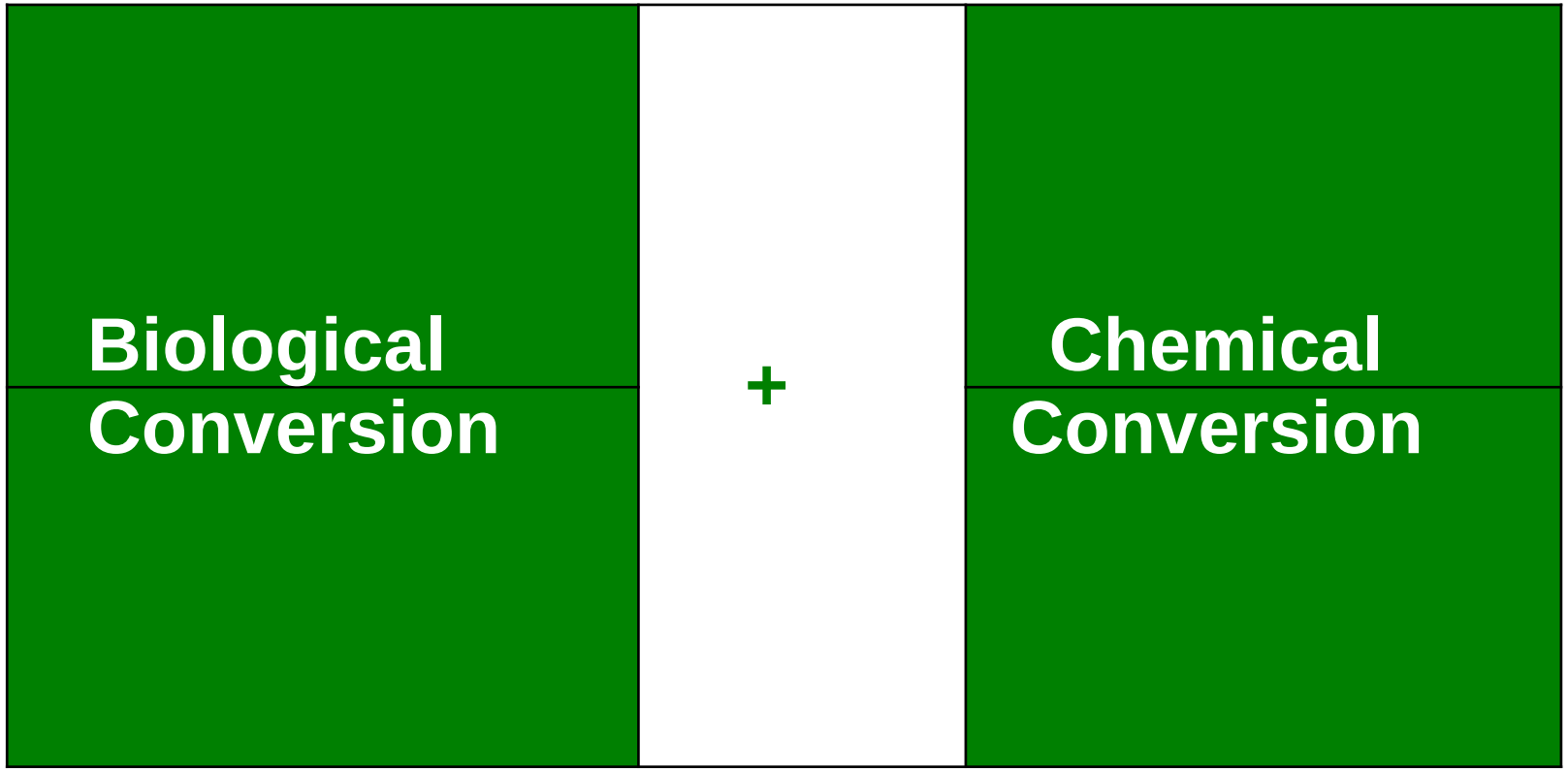
Drop-in Biofuels
(e.g., bio-gasoline)

Chemical Conversion

The Conversion



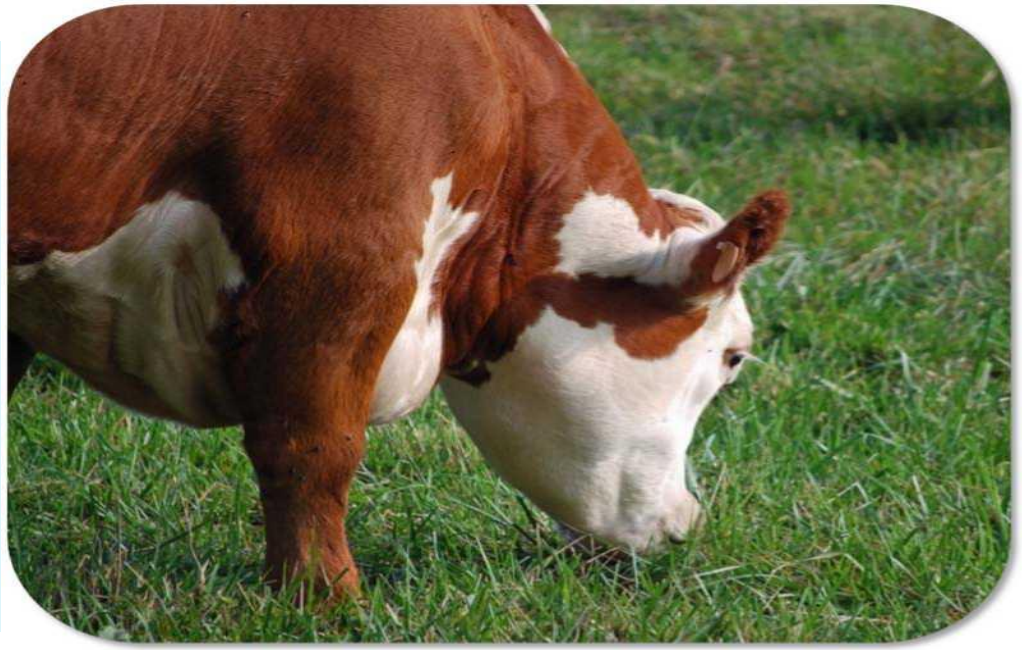
The Best of Both Worlds



Biological Side

Mixed-acid fermentation: The most ancient and widespread commercial fermentation

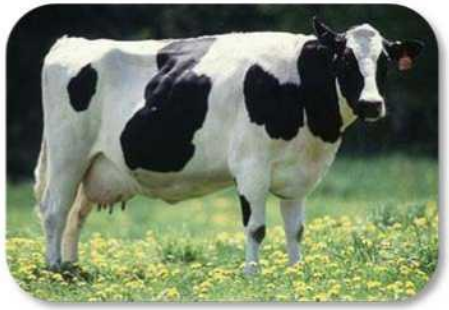
- Cumulative volume: 200 bn L*
- Producing useful products: Milk, meat and wool
- The fermentation is Cellulosic



* Based on UN FAO report 2004 (1.522 x 10^9 cattle and 1.851 x 10^9 sheep)

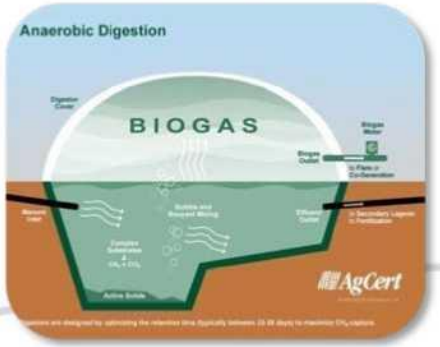
Nature's Fermentation: Environments Where Carboxylic Acids Naturally Form

- Animal rumen
  - Cattle
  - Sheep
  - Deer
  - Elephants
- Anaerobic digesters
- Swamps
- Termite guts







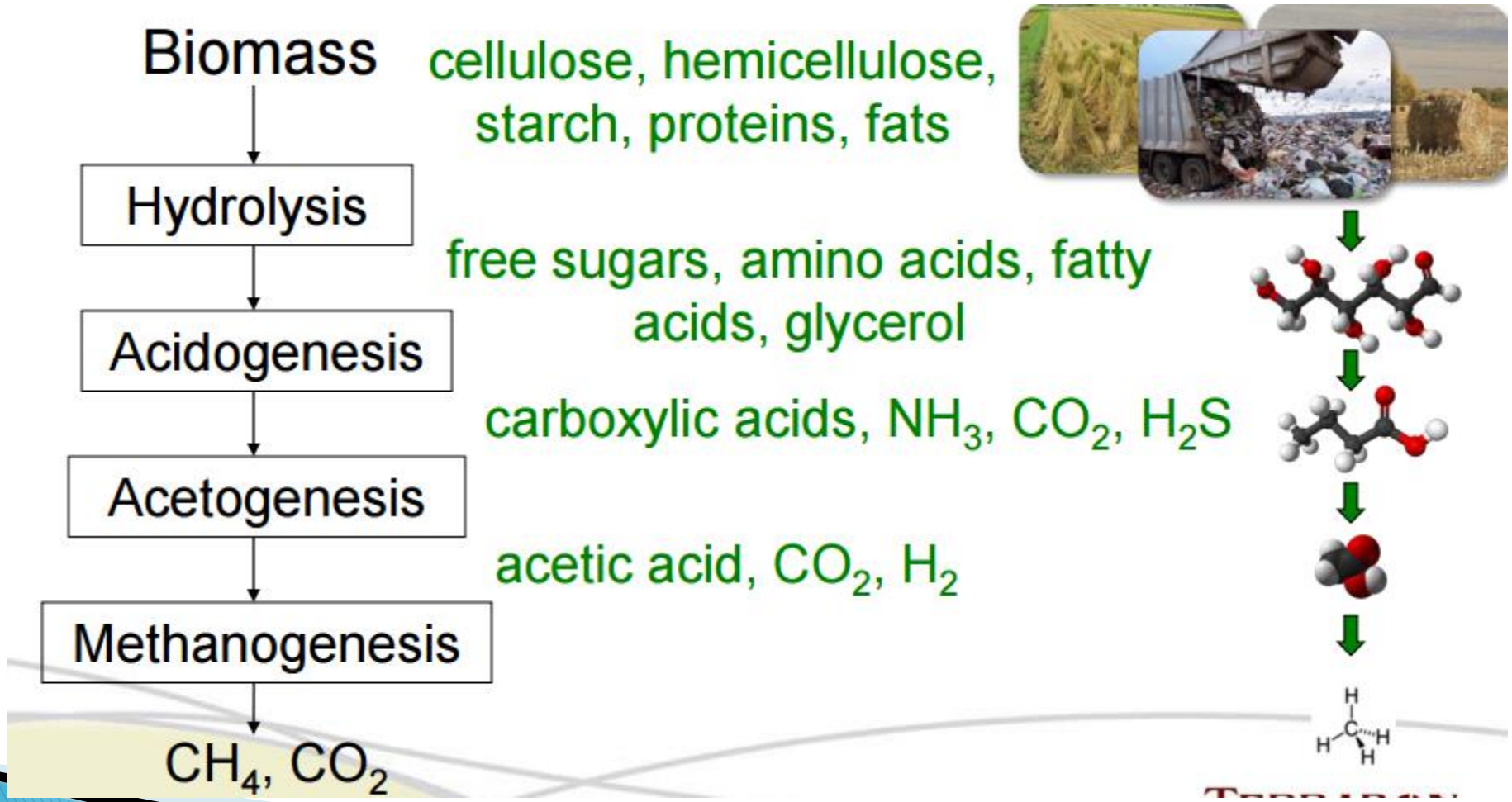




TERRABON

Anaerobic Digestion

Goal: Produce carboxylic acids - Acetic, propionic, butyric, etc. - From C2 to C8 - a.k.a. volatile fatty acids



Anaerobic Digestion

Goal: Produce carboxylic acids – Acetic, propionic, butyric, etc. – From C2 to C3 – a.k.a. volatile fatty acids

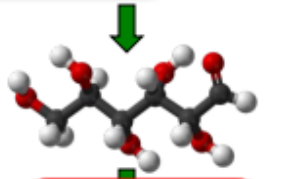
Biomass

cellulose, hemicellulose, starch, proteins, fats



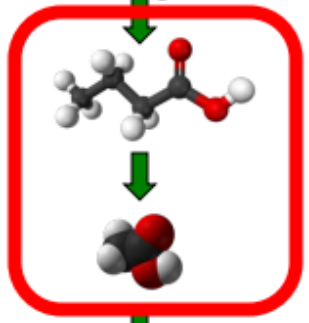
Hydrolysis

free sugars, amino acids, fatty acids, glycerol



Acidogenesis

carboxylic acids, NH_3, CO_2, H_2S

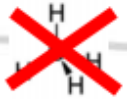


Acetogenesis

acetic acid, CO_2, H_2

Methanogenesis

Inhibitor

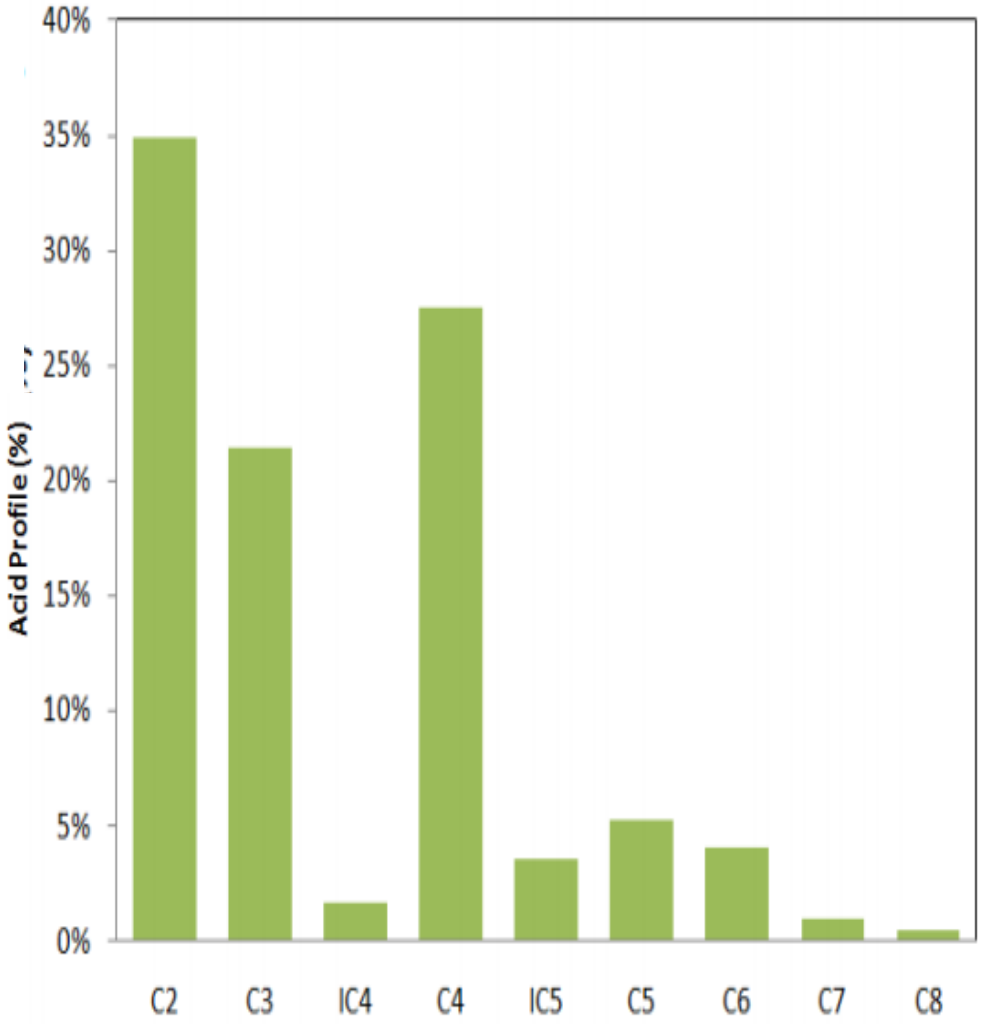


CH_4, CO_2

Product Spectrum

- C2–C8 Carboxylic Acids
- C2 – Acetic (vinegar)
- C3 – Propionic
- iC4 – Isobutyric
- C4 – Butyric
- iC5 – Isovaleric
- C5 – Pentanoic (valeric)
- C6 – Hexanoic (caproic)
- C7 – Heptanoic (Enanthic)
- C8 – Octanoic (Caprylic)

- We add buffer (e.g., Na2CO3) to control pH around neutrality, thus producing the salts of these acids as a dilute solution or fermentation broth (~20 to 40 g/L)



Feedstocks successfully tested

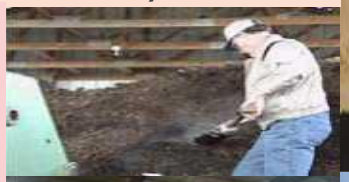
- Food wastes
- White office paper
- Paper-mill fines
- Sugarcane bagasse
- Aloe vera rinds
- Pineapple waste
- Glycerol
- Corn stover
- Rice Straw
- Cotton gin trash
- Switch grass
- Poplar wood
- Sorghum stalks
- Water hyacinth
- Sugarcane molasses
- Cellulosic municipal solid wastes








- Municipal Sewage sludge
- Bio-sludge (from chemical plant WWTP)
- Chicken manure
- Pig manure
- Cattle manure
- Corn steep liquor
- Yeast extract
- Wet DGS
- Soluble from corn ethanol production
- Lipid-extracted micro-algae
- Whole micro-algae
- Pulp-mill molasses (also known as wood molasses)
- Orange peels
- Oil palm empty fruit bunch







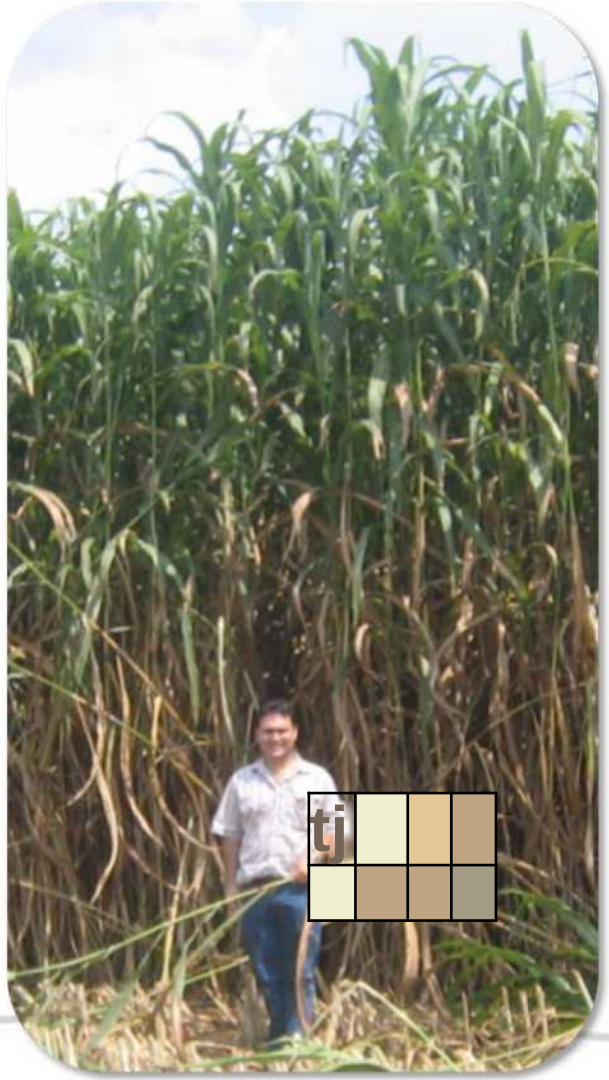




Feedstock Supply Chain

Advanced Biofuels Feedstock Challenges

- Limited economic feedstocks with critical mass
- Present supply infrastructures are limited:
  -Corn (U.S.)
  -Sugarcane (Brazil)
  -Oil Palm biomass (South East Asia)
  - Wood (for pulp)
  -Municipal Solid Waste
- Cellulosic feedstocks face collection and storage challenges
- Energy crops face adoption hurdles



Feedstock Supply Chain

An Existing, Worldwide Feedstock Supply Infrastructure



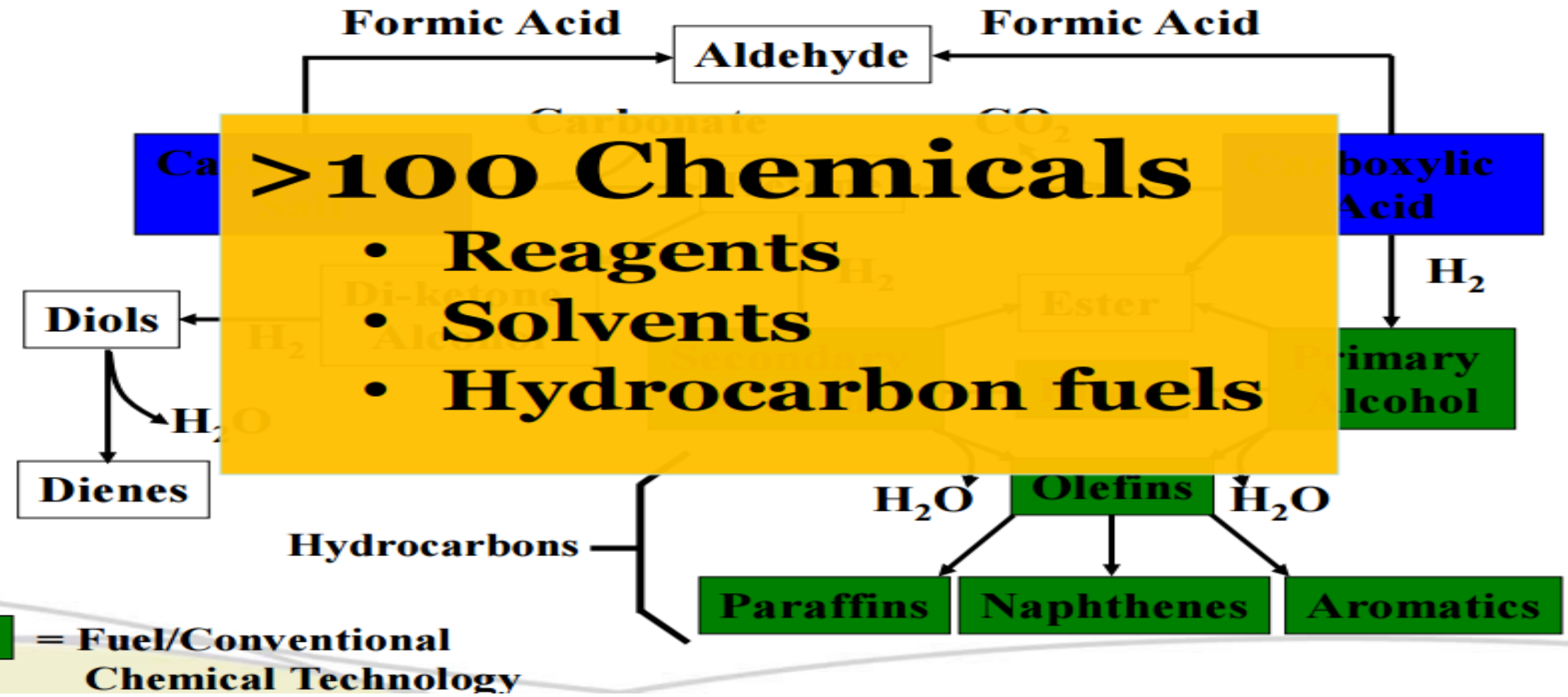


Municipal Solid Waste

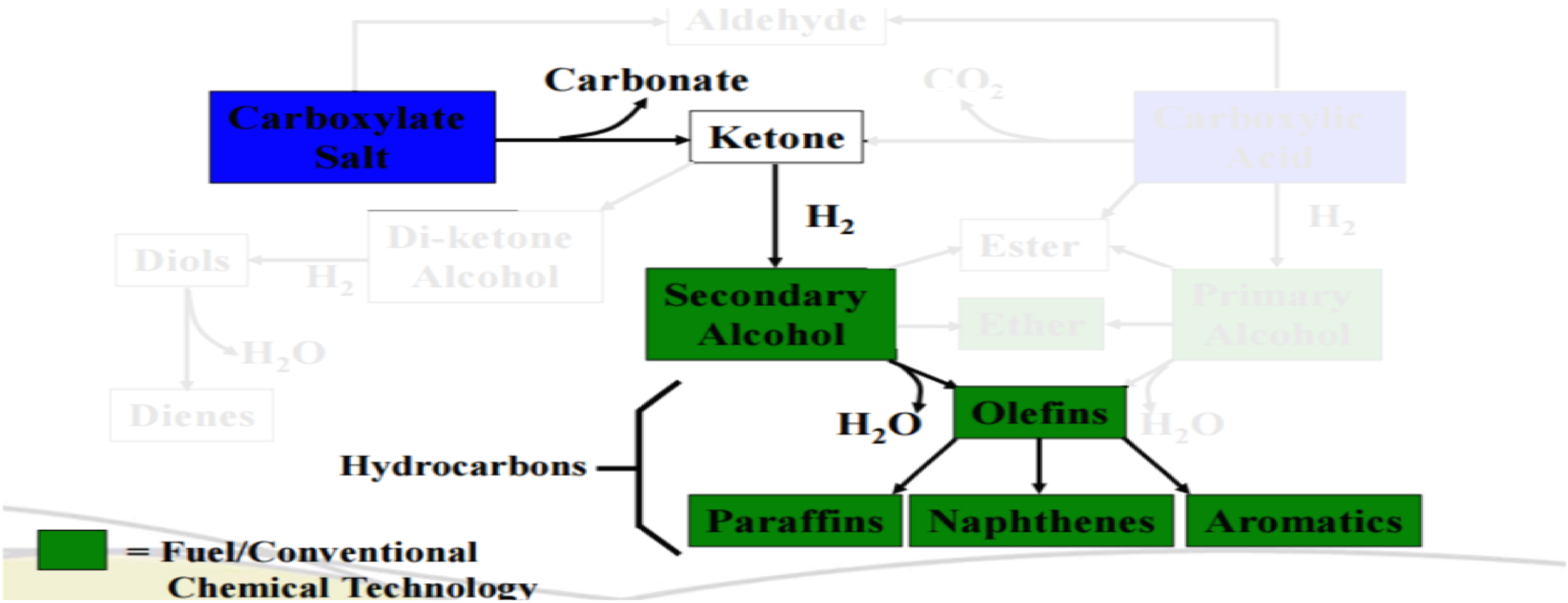
- Worldwide MSW collection infrastructure
- Constant feedstock deliveries
- Tipping fees versus feedstock costs
- US Supply for almost 2 billion gallons per year ($5 to $6 billion/yr market)
- Cost structure eliminates dependence on oil prices and subsidies

- **Utilize Other Feedstock As Markets Develop (i.e. Energy Crops & Algae)**

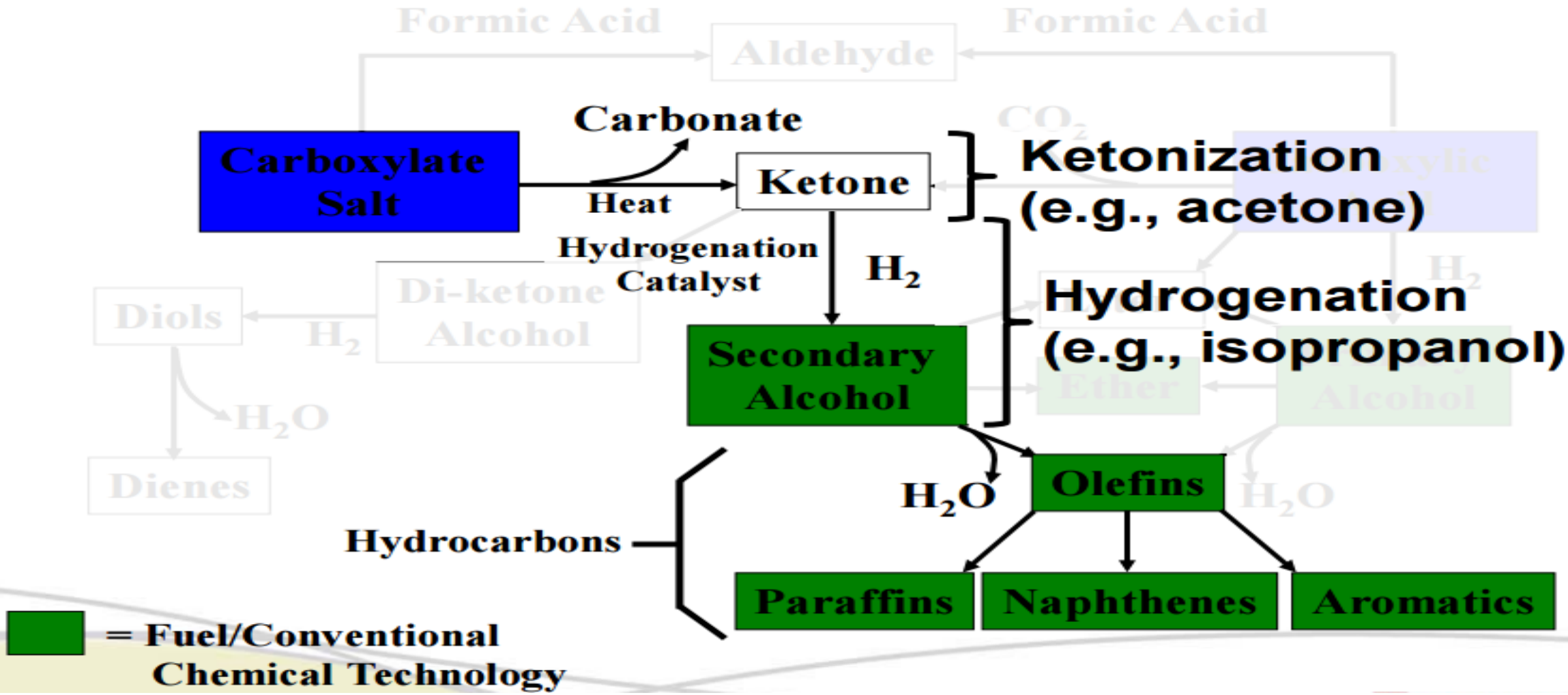
Chemical Side



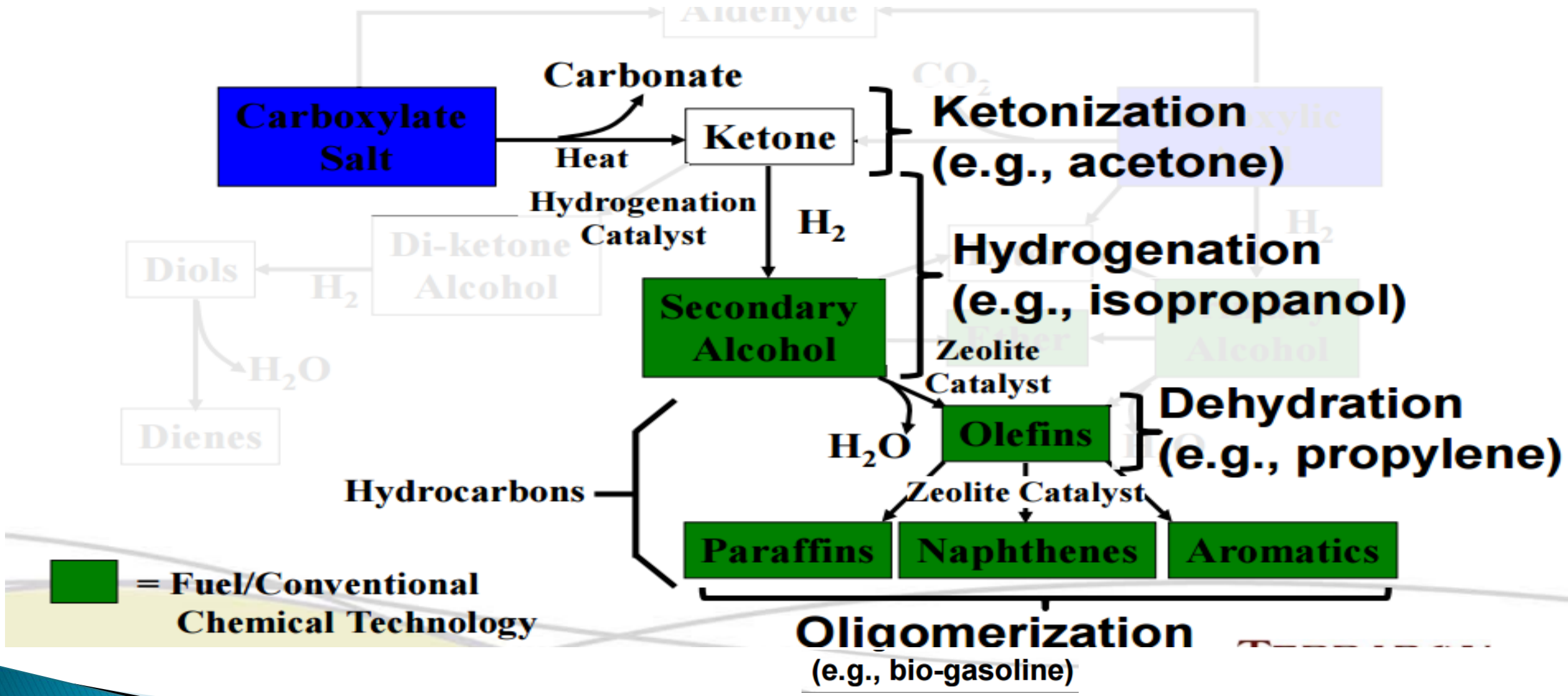
Downstream Conversion Process



Downstream Conversion Process

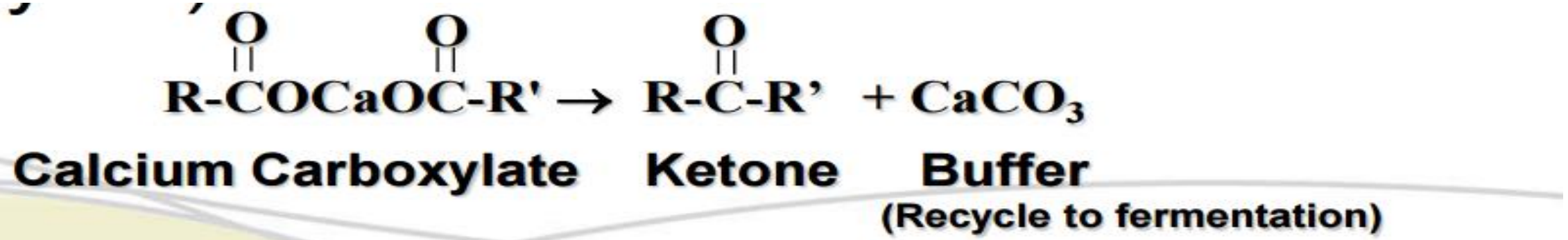


Downstream Conversion Process

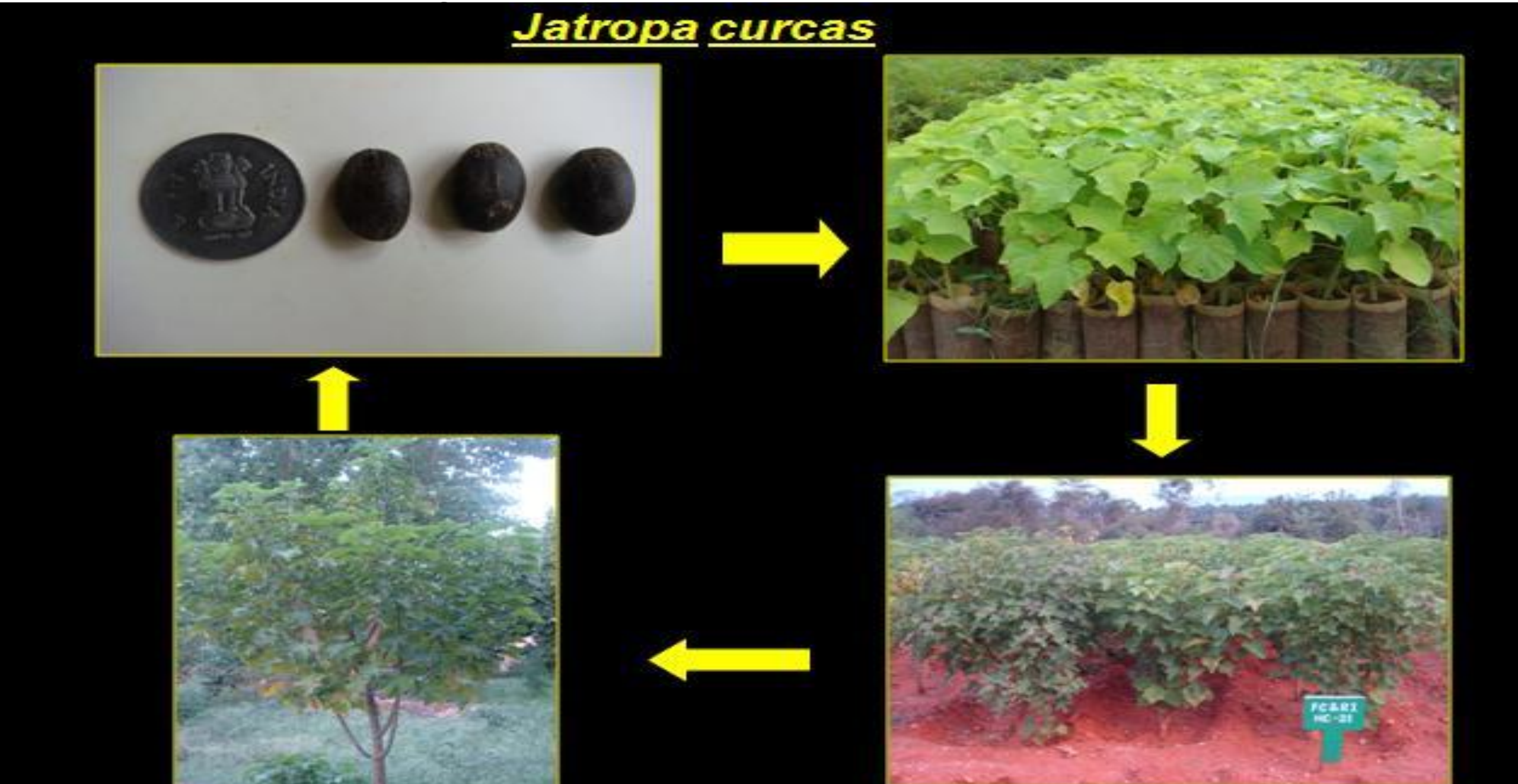


Ketonization

- Pyrolytic conversion of carboxylate salts into ketones
- Because salts are more defined and chemically malleable, the chemistry of the pyrolysis is better controlled
- Mostly ketones are produced (>95% yield)



Bio lubricant from Crude Jatropha Oil at Faculty of

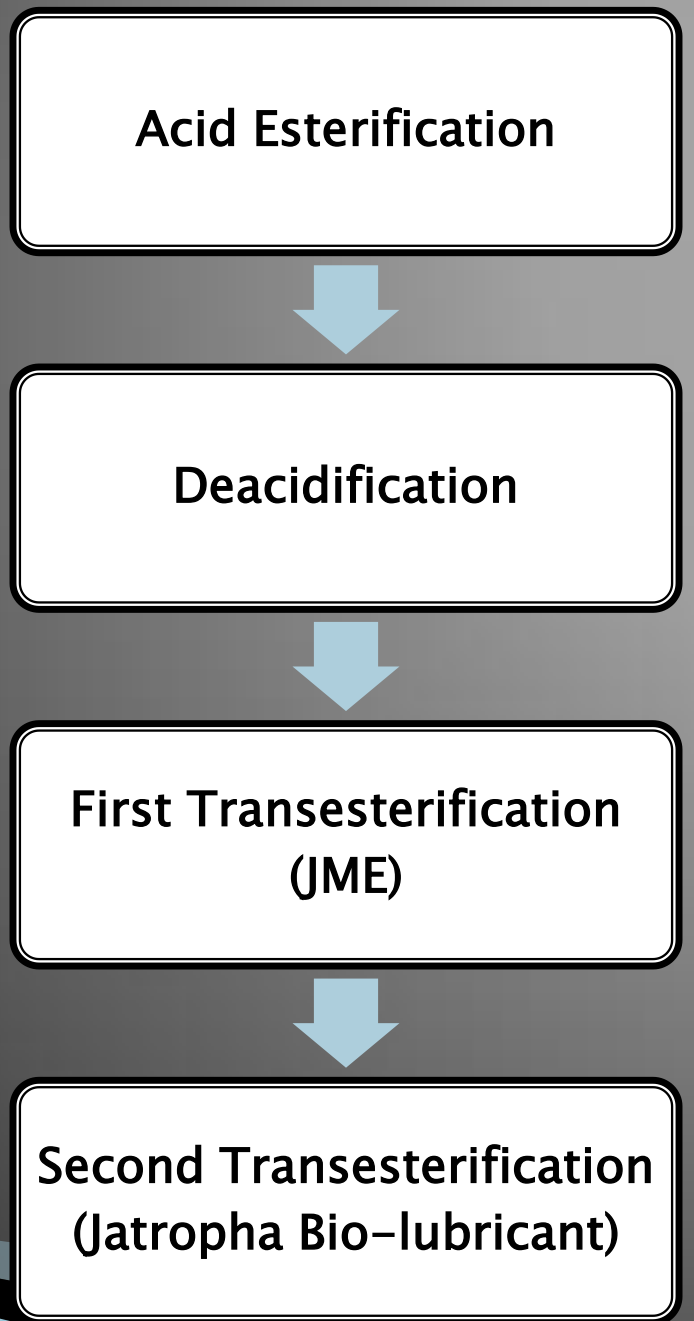


Bio lubricant characteristics

- **Problem**
- Replacing hydrocarbon lubricants in plant with bio lubricants.
- **Challenge**
- Long term test during new construction at Eden project
- **Technical Solution**
- Plant-derived lubricants used in hydraulic systems, engines bearing greases and transmission fluids. Performance compared with a mineral oil used.
- **Benefits**

- Tenth of the metal wear
- Reduced pollution (groundwater/soil/food)
- Smaller carbon footprint
- Biodegradable
- Low-toxicity
- Excellent lubricity (lower friction coefficients than mineral oil)
- Lower evaporation: up to 20% less than mineral oils
- Higher flashpoint and viscosity indices
- Enhanced performance in some applications

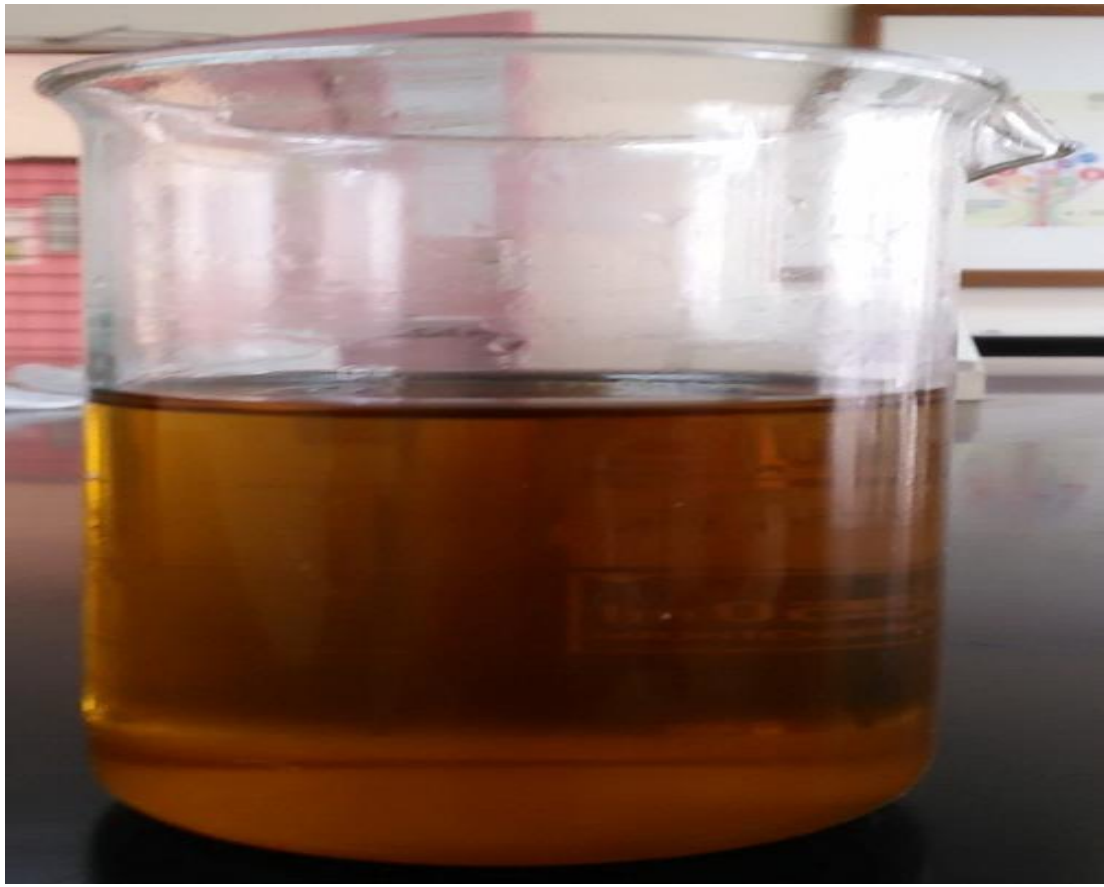
Bio lubricant Production Process Stages



Crude Jatropha Seed Crusher

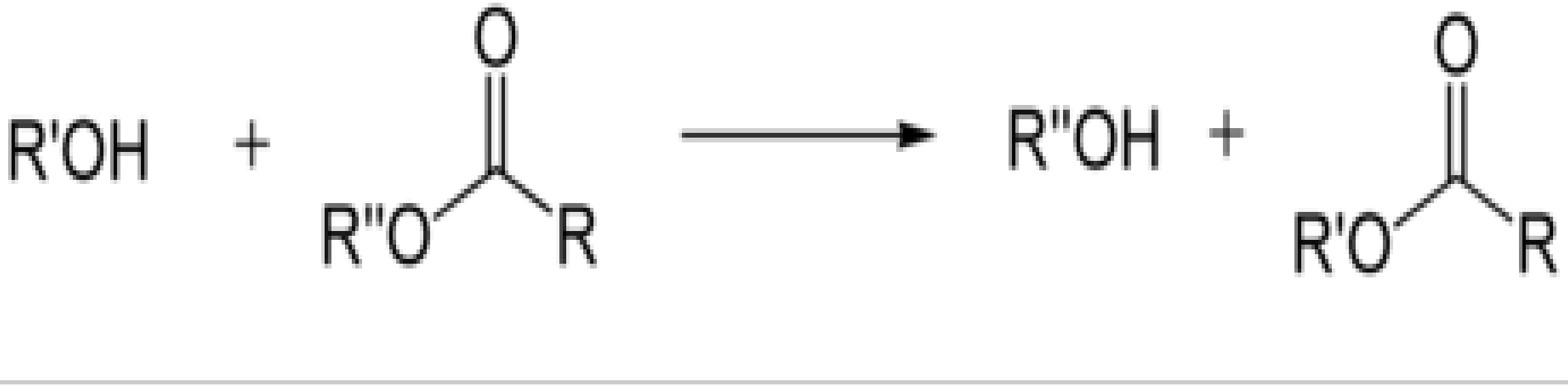


Crude Jatropha Oil (Feed)



Double Trans esterification Mechanism

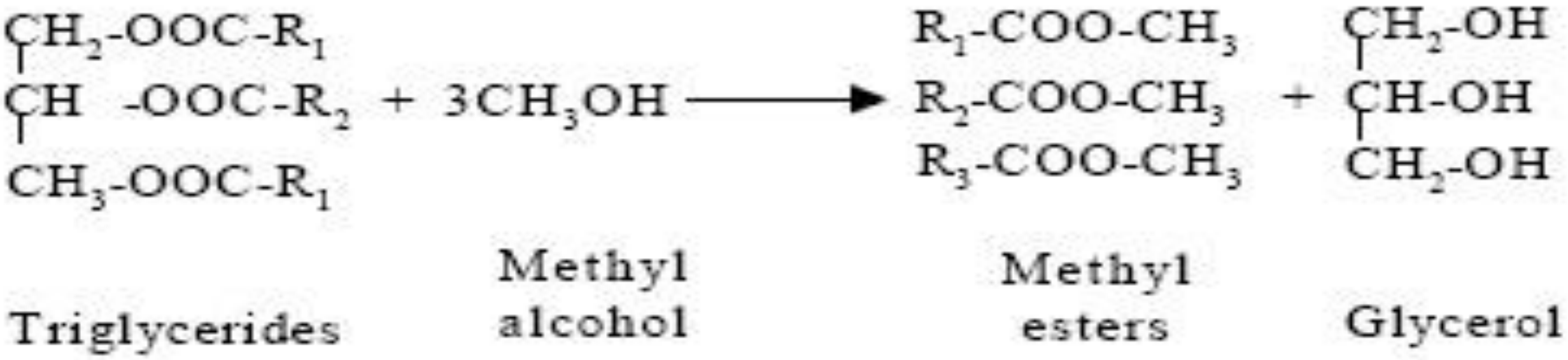
- Trans-esterification
- Exchanging the organic group R" of an ester with the organic group R' of an alcohol



Transesterification: alcohol + ester → different alcohol + different ester

First Trans-esterification

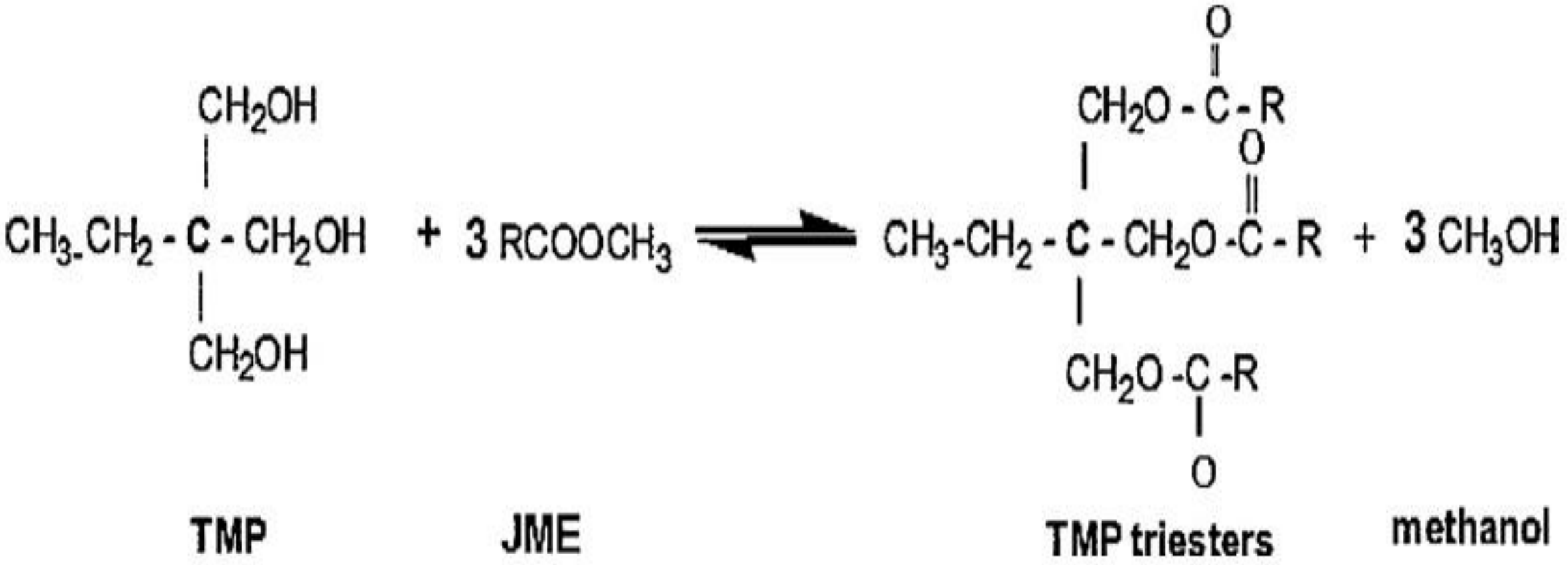
- To produce Jatropha methyl ester(JME) from Jatropha crude oil.
- Catalyst: Sodium Hydroxide, Reaction Temp.: 60^{O}C,



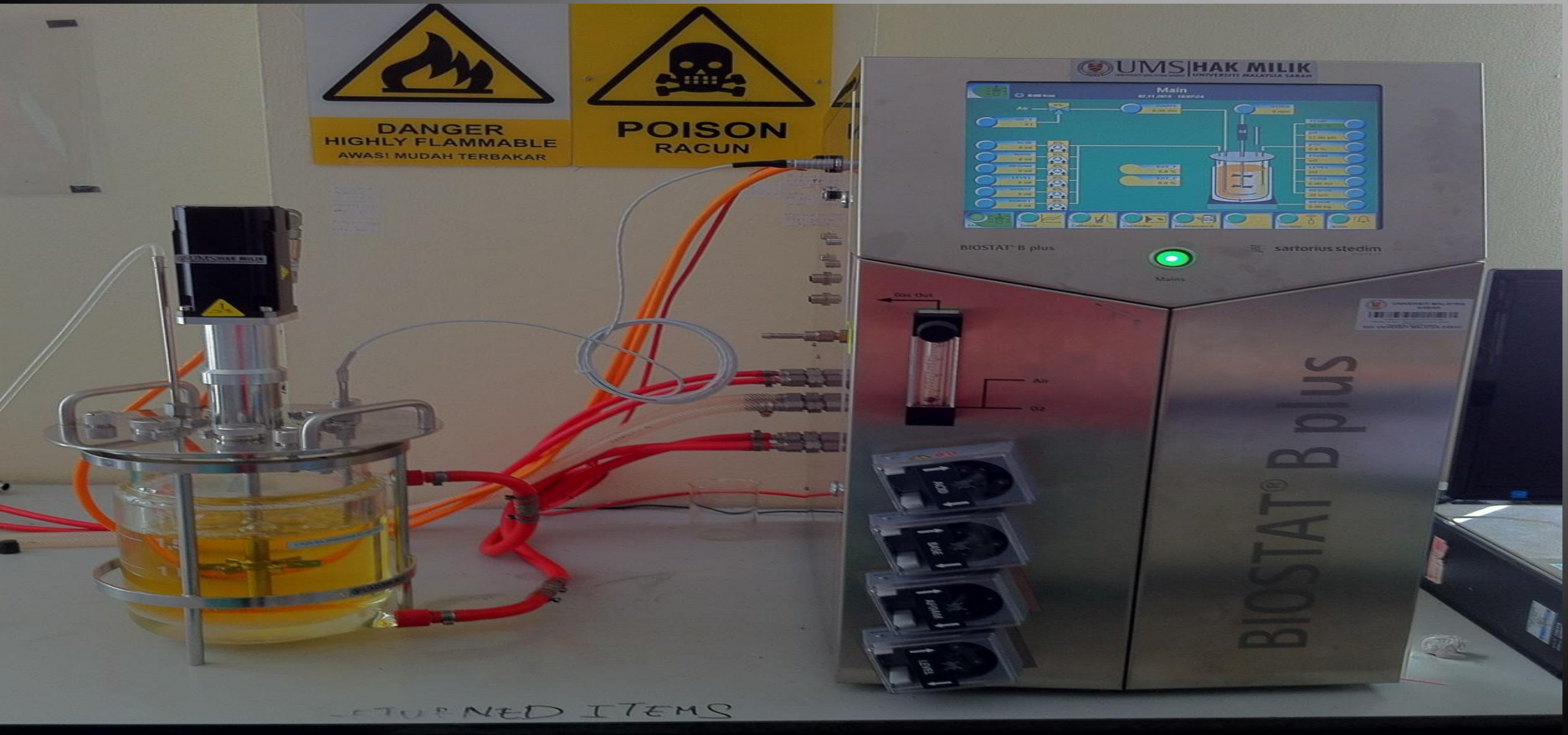
Trasesterification of triglycerides

Second Trans-esterification

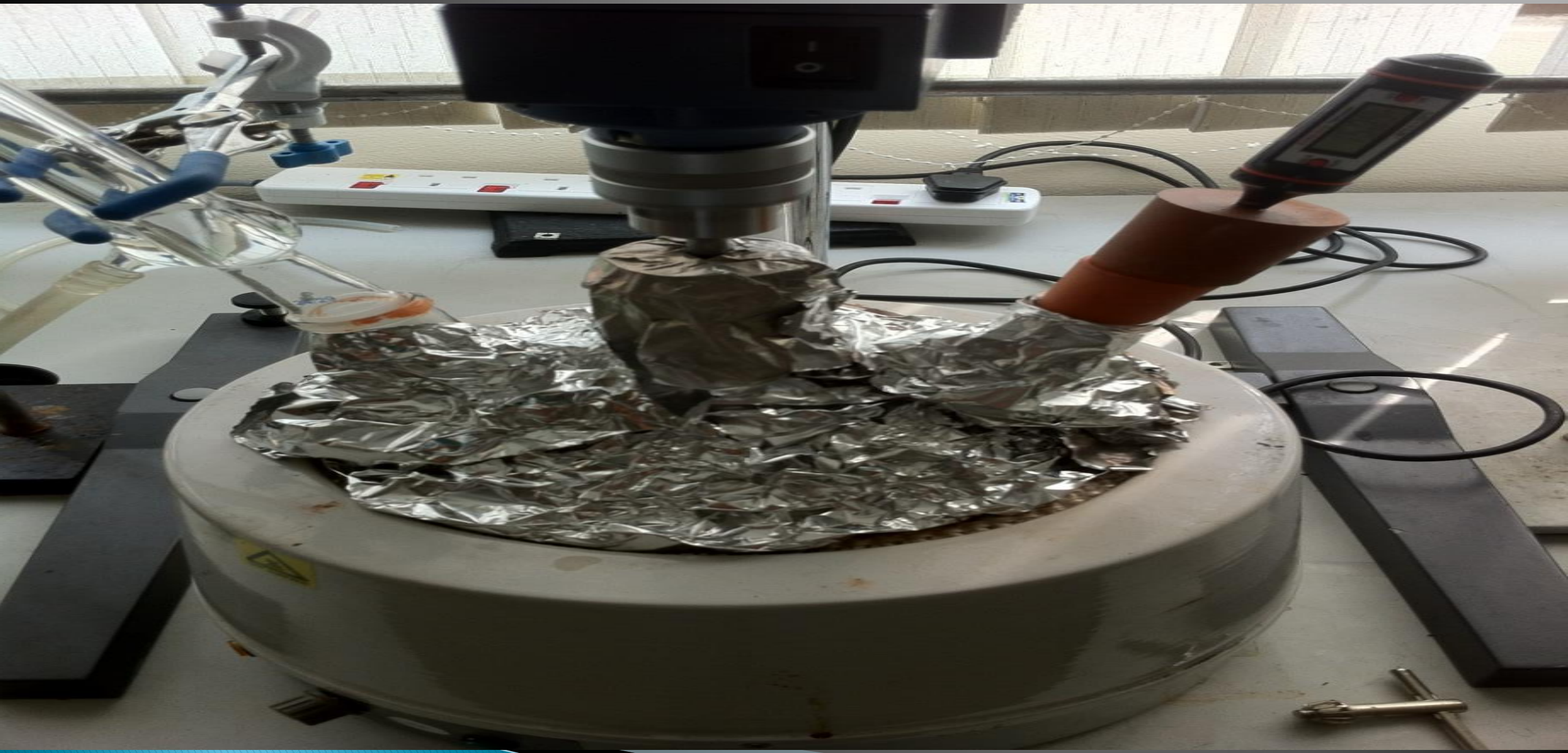
- To Produce Tri-methylol propane tri-esters (Bio lubricant).
- Catalyst: Sodium Methoxide, Additives : Tri-methylol propane, Reaction temp.: 150^{O}C, Reaction time: 3 hour.

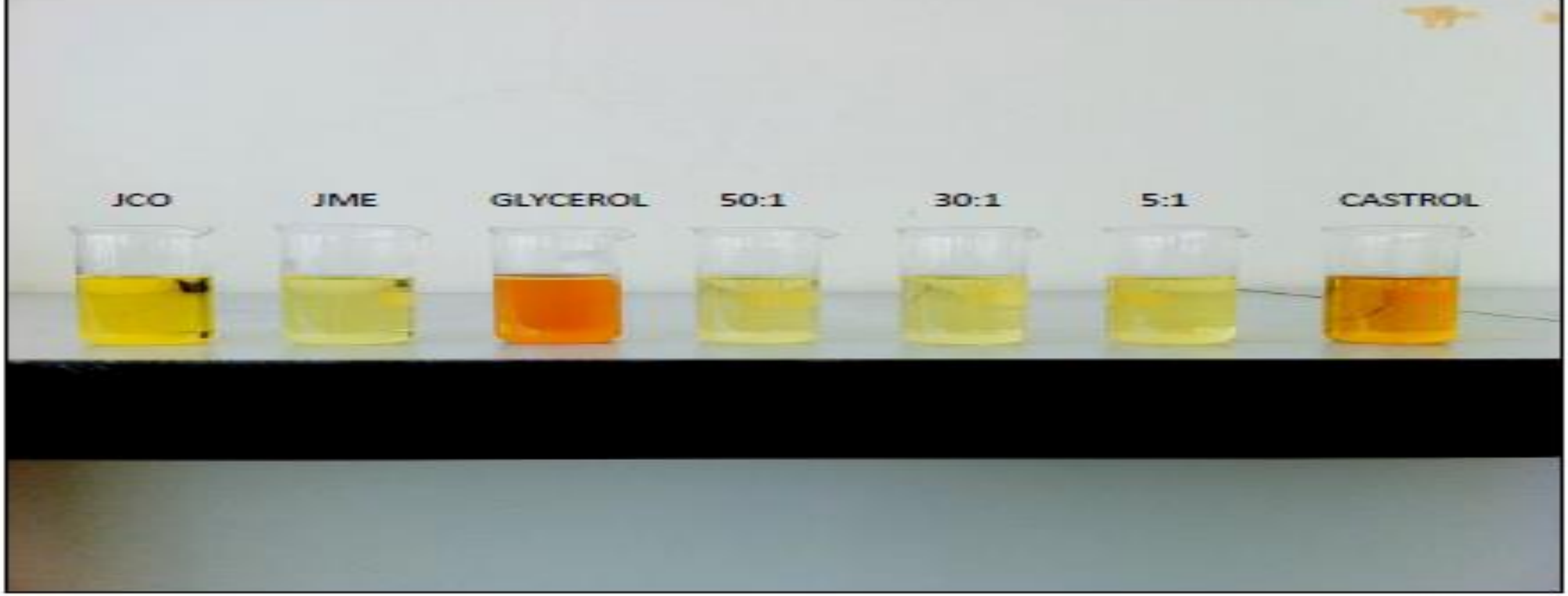


Bio Lubricant production reactor



Bio-lubricant production in three necked flask





JCO	:	Jatropha Crude Oil
JME	:	Jatropha Methyl Ester
50:1	:	Jatopha Bio-lubricant (JME:TMP)
30:1	:	Jatopha Bio-lubricant (JME:TMP)
5:1	:	Jatopha Bio-lubricant (JME:TMP)
CASTROL	:	Petroleum Base Lubricant

Viscosity analysis using Brookfield DV-111 Ultra Programmable Rheometer



LAB SCALE PRODUCTION OF DROP-IN BIOFUELS

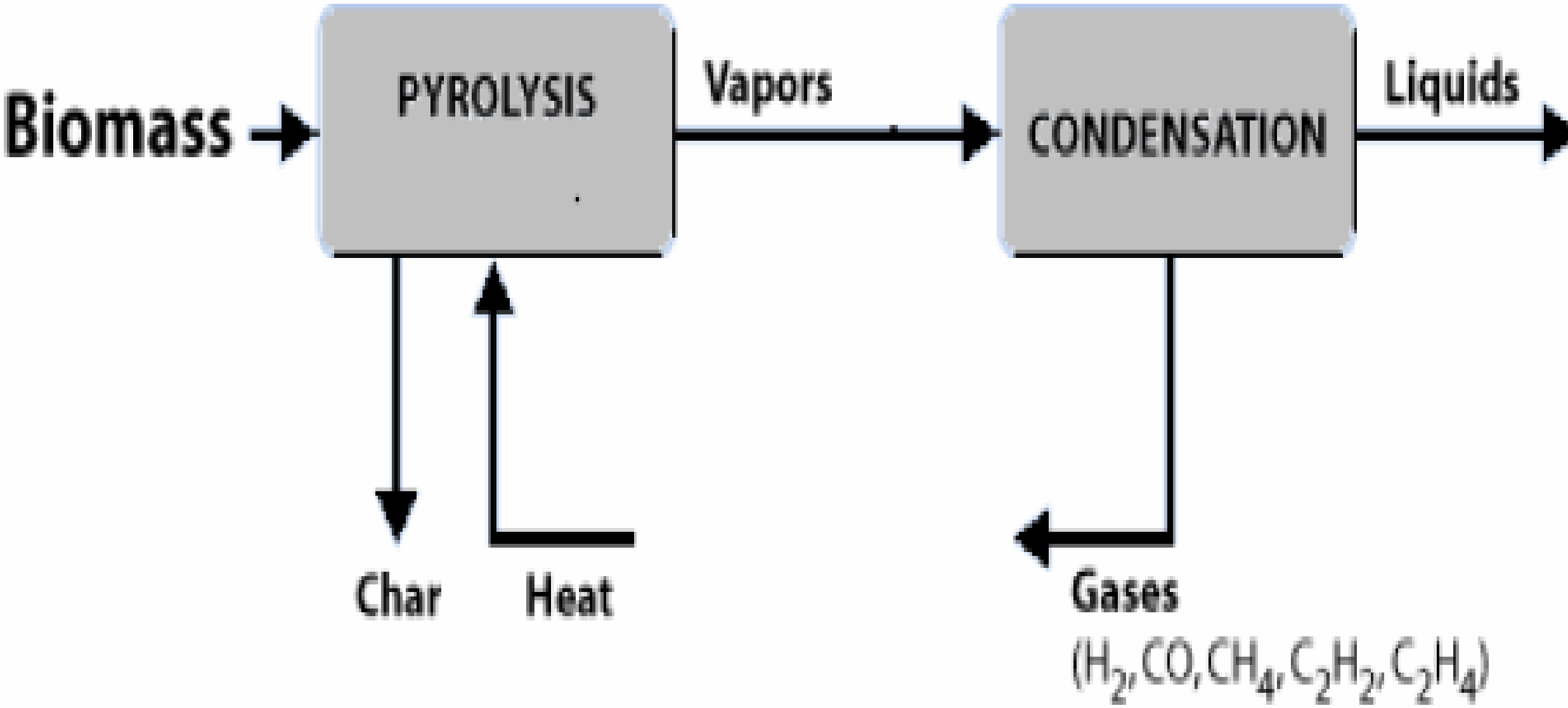




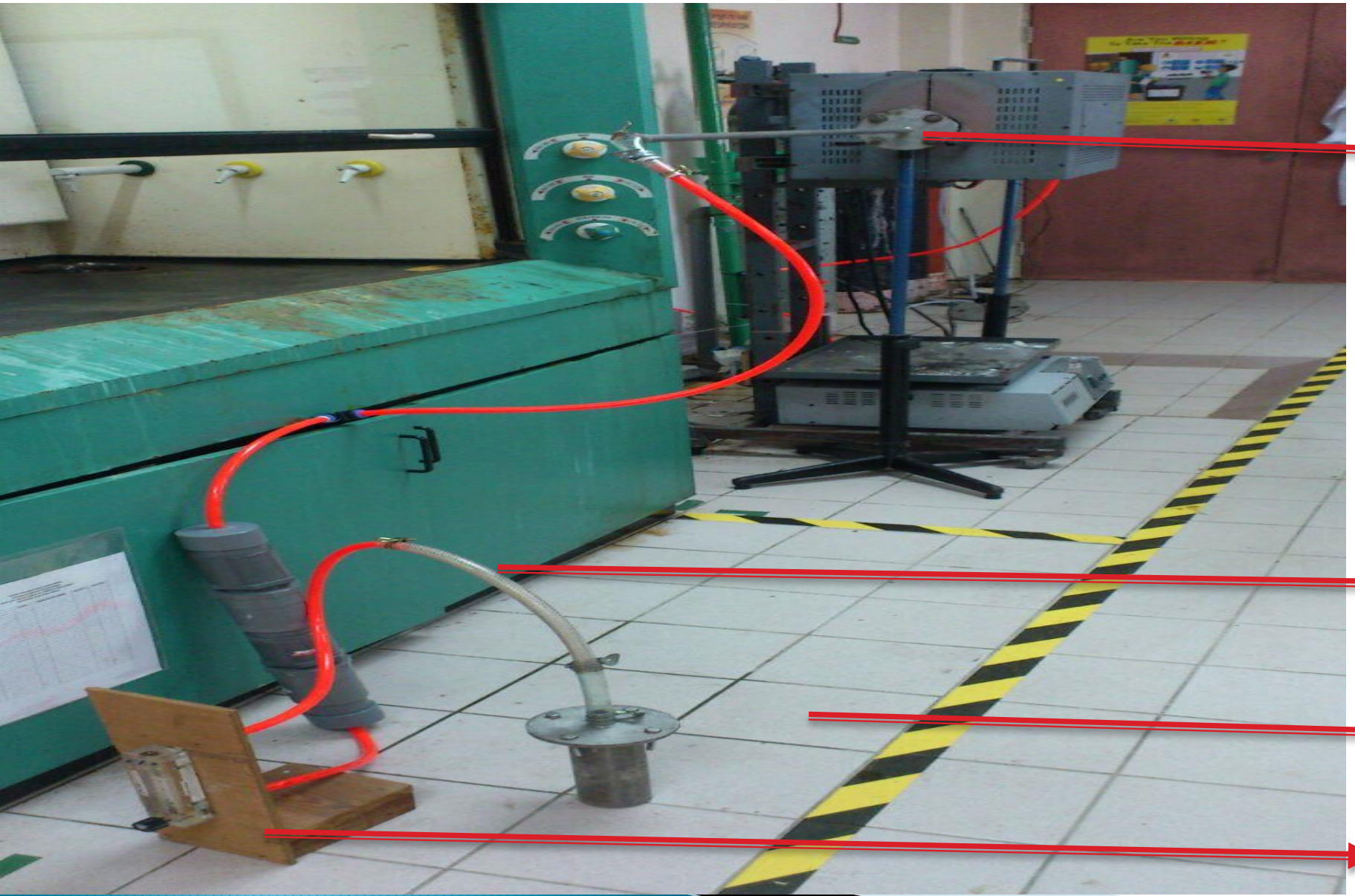
Empty Fruit Bunch from local industry



Reaction pathway of pyrolysis of Empty Fruit Bunch



Production of Drop in Fuel from EFB Biomass
Faculty of Engineering, UMS Laboratory

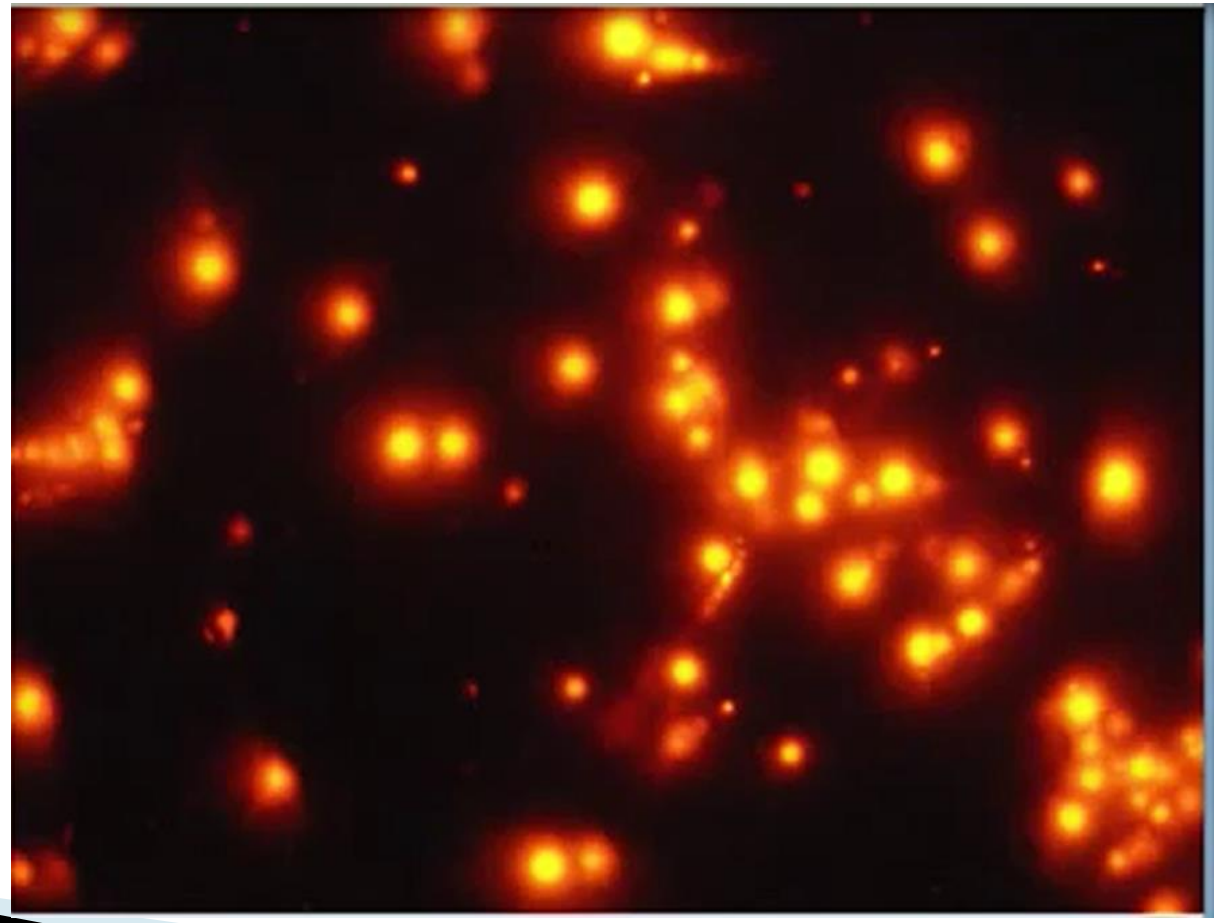


Syngas gasifier

Syngas scrubber

Fixed bed reactor

Flow meter



Opportunity in Asia

- "Demand-pull" in place via Lanxess, Sasol and multiple other customers that are interested in Asia based production assets

- Gevo has a flexible business model for roll out of the development
  - Considering both licensing and joint venture opportunities

- Opportunity to retrofit existing fermentation facilities in region
  - Feedstock supply already established

- Opportunity to build new fermentation capacity
  - Believe there will be cellulosic conversion technologies commercialized over next12 months
  - 80 mm liter per year facility will require ~315,000 MT of biomass
  - Ability to aggregate required feedstock will drive opportunity

- Goal is to build large scale bio refineries to service portion of Asia market

Lessons & Summary

- Technical success depends on balanced use of rational genetic engineering and controlled evolution
- Process design is mandatory to move from lab scale to pilot and industrialization
- Key-points for engineering a strain with economically viable performances are identified
- Depending on products, several different carbon sources can be used

➢ **Sustainable process, sustainable solutions are also the results of technical and financial partnerships**

Optimization problem…



My job responsibility: Min distance {Q – A }
Subject to availability of Question and Answer Constraints

THANK YOU ALL…