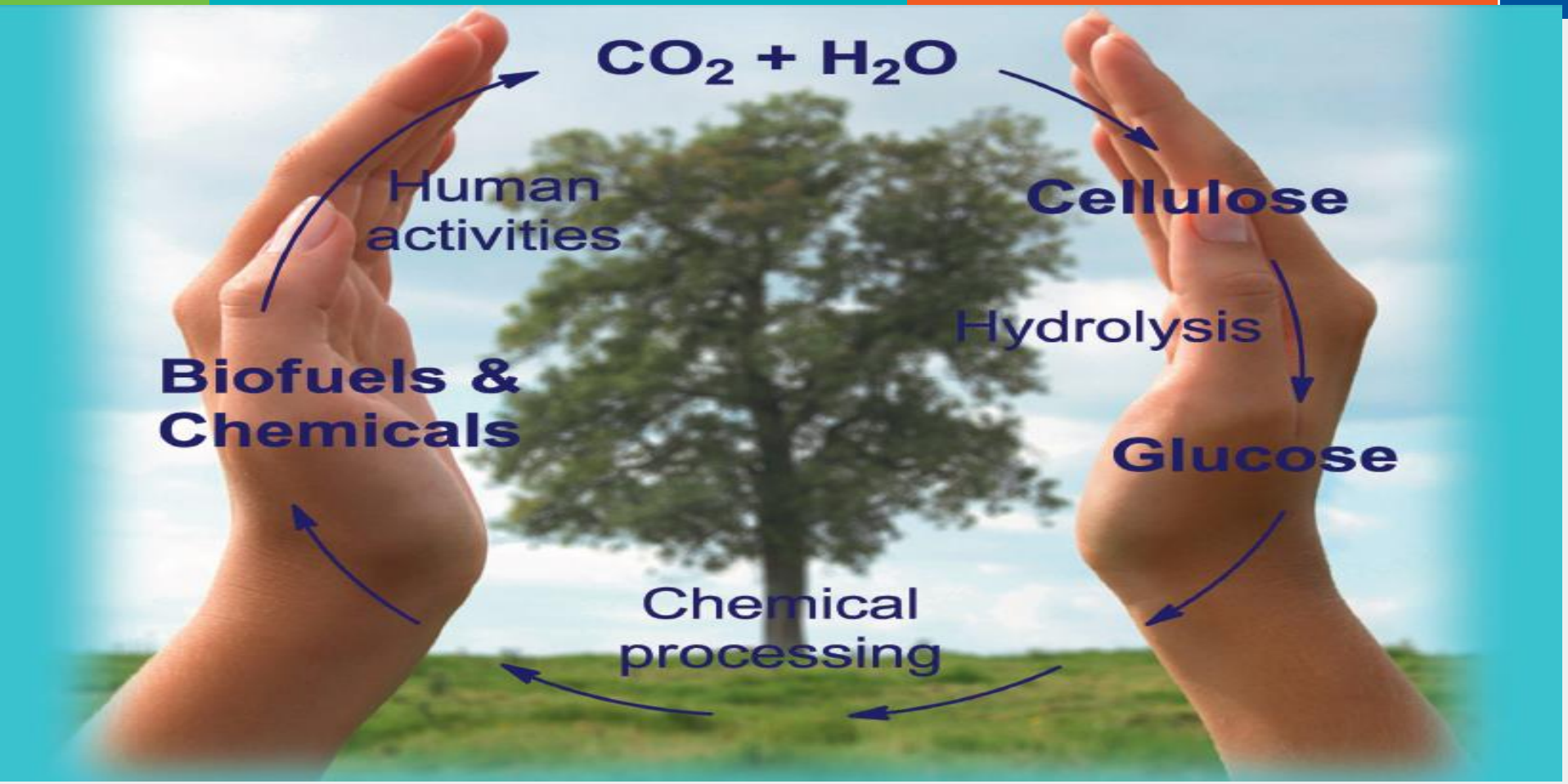


praj

Best Places to Work in the advanced bioeconomy 2020

1

Praj Industries

BiofuelsDigest
The world's most widely read biofuels daily

Renewable Chemicals and Materials
Nature Reimagined

LEED Certified Platinu

PRAJ Voted #8 Amongst Hot 50 hottest companies in the advanced bioeconomy 2019

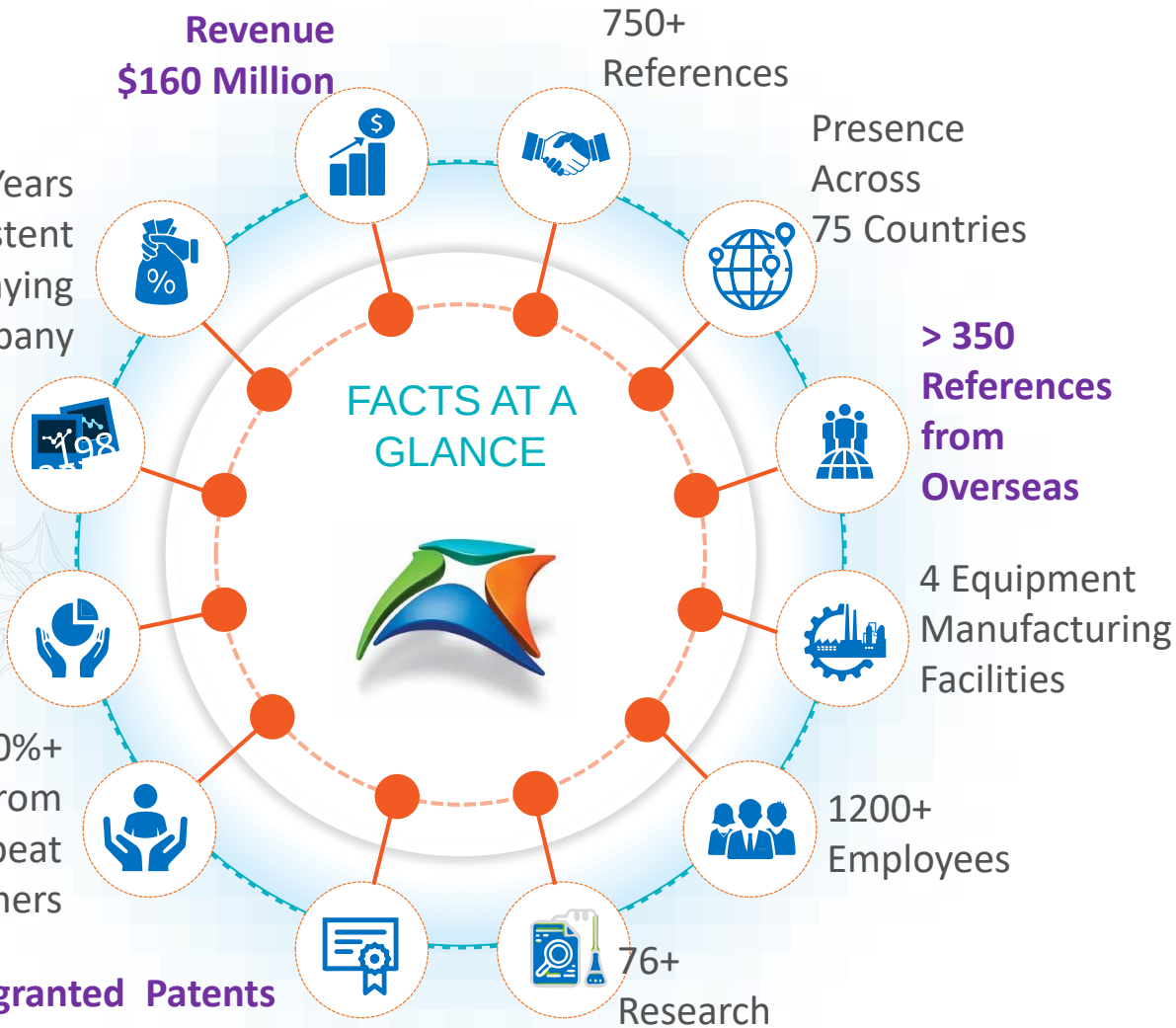
Dr. Pramod Kumbhar
President and CTO
Praj Matrix – R&D Center

17th September 2020

Outline

- Praj Corporate and Praj Matrix-R&D Center
- Bio-Mobilty™ Platform from Praj
- Petrochemical Industry
- Renewable Chemicals and Materials
- Examples : Sorona, PLA, BDO, PHA, PEF
- Bio-Prism™: Choosing Wisely
- Future
- Summary

Praj @ a glance

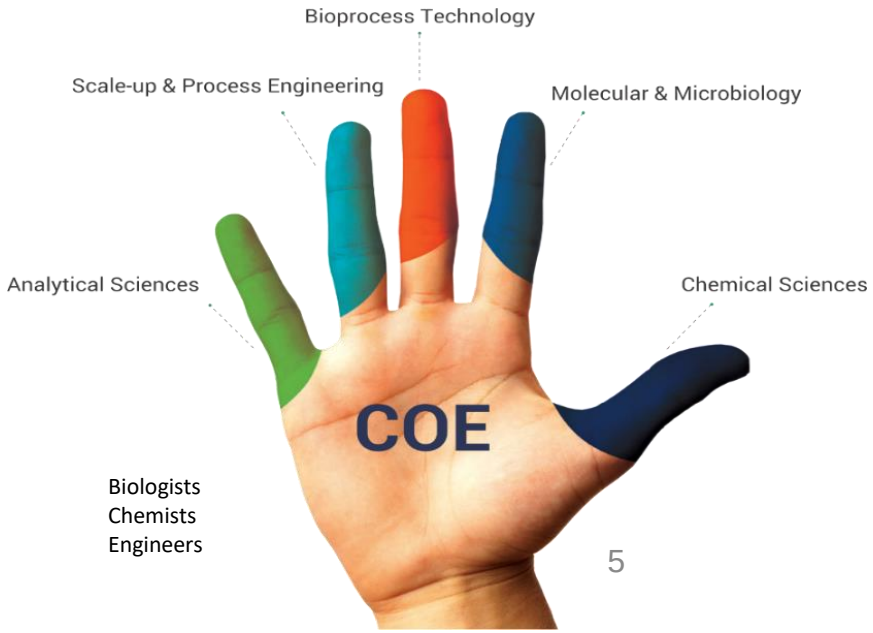


Global Footprint

Global presence : 750 reference in more than 75 countries

Praj Matrix – The R&D Centre

- First of its kind R&D with Bench and Pilot scale facilities which enable validation of scientific assumptions and rapid commercialization
- Focus on "Green technologies' with emphasis on sustainability
- Continuous Design & Development (D&D) endeavor to improve water and energy footprint
- Devoted to developing bio-fuels and renewable chemicals using advanced biotechnology tools.

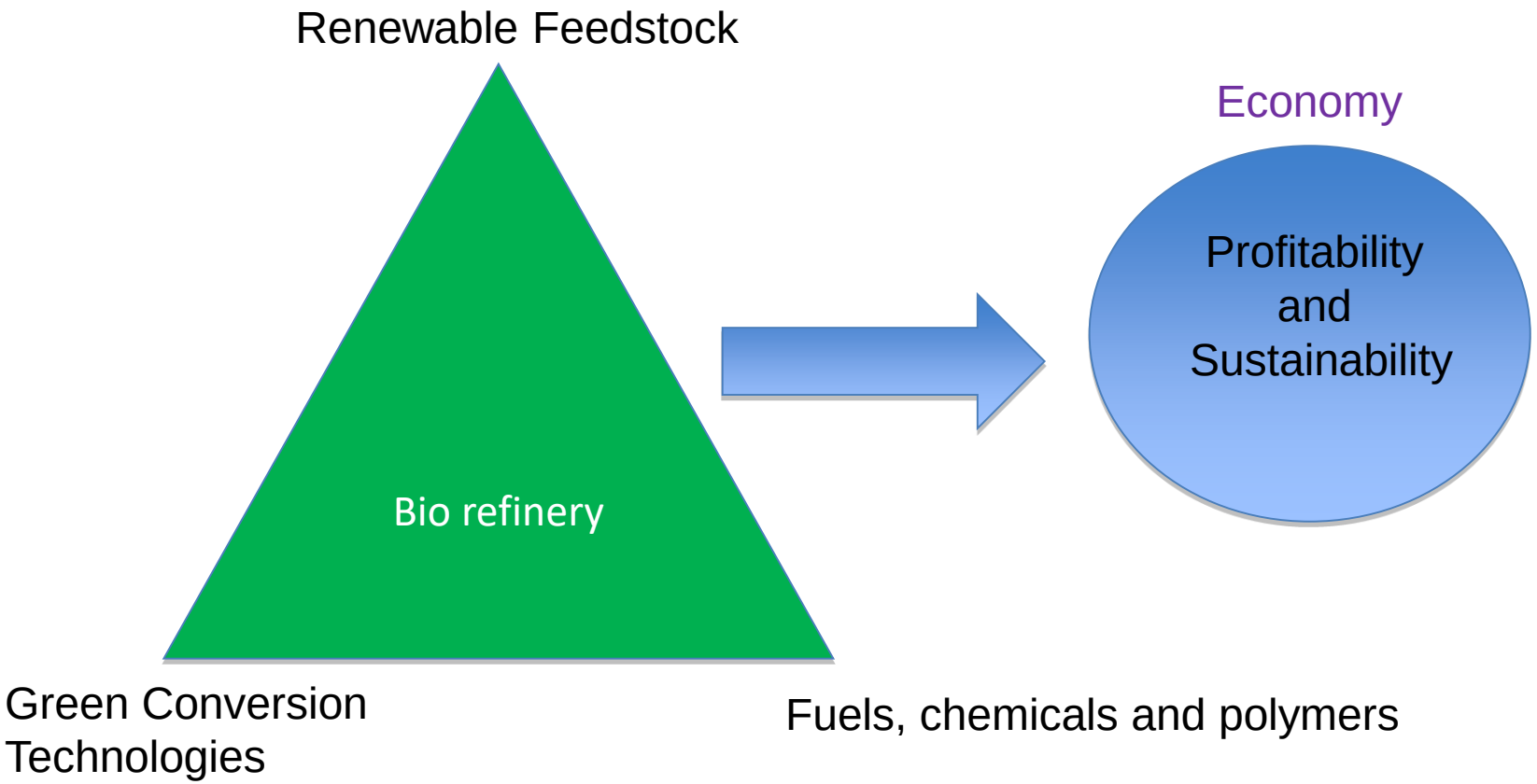


"Praj Matrix ranks up with almost any facility in the world. What is unique about Matrix is that the Labs, Pilot and the Scale-up facilities are all at one location" –

- Vinod Khosla, Bioeconomy Entrepreneur, Former Co-Founder Sun MicroSystems

Ph.D.'s: 19
Masters: 55

Focus



Development of Bio refinery : integral part of new Bio economy

Frontiers in Bio economy

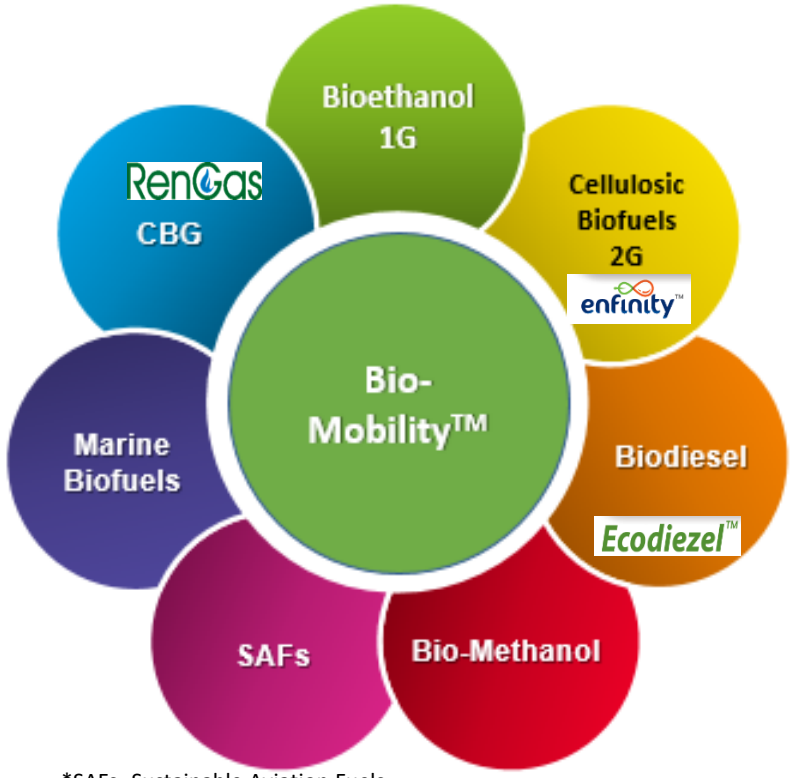
Leveraging Feed stock,
Technology and Product expertise

Bio-Mobility™

Renewable Chemicals Materials (RCM)

Bio-MobilityTM platform from Praj

Bio-Mobility™ denotes carbon neutral renewable transportation fuel produced from Biological resources

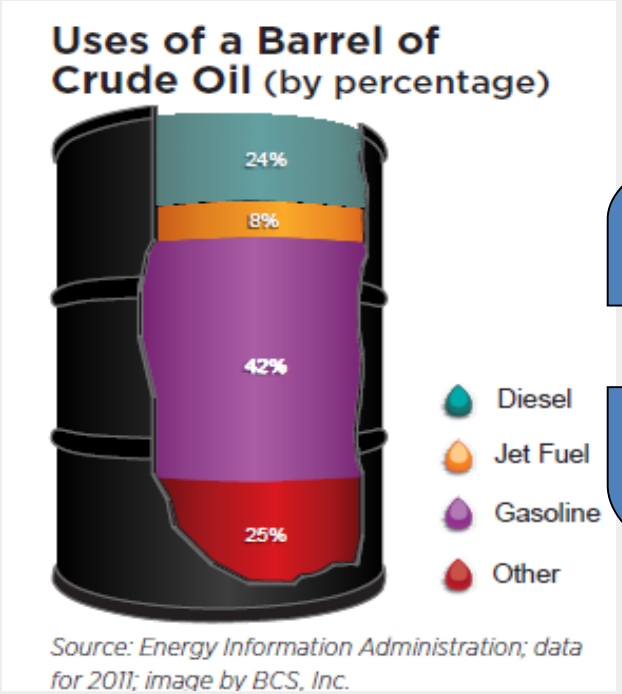


*SAFs- Sustainable Aviation Fuels

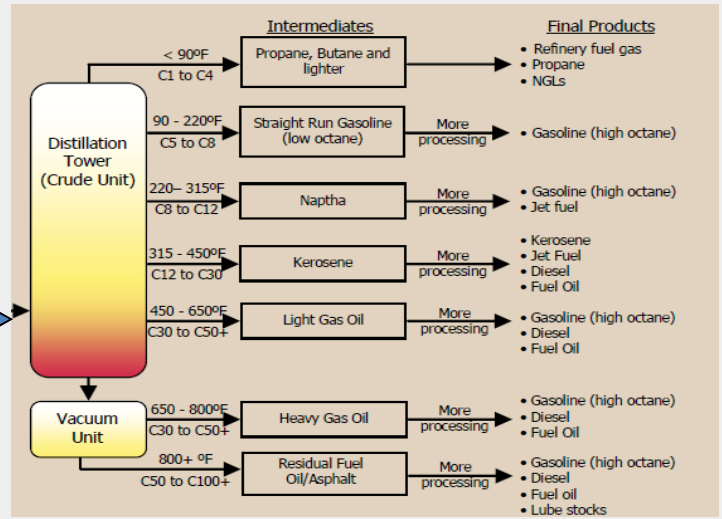
- **Demand** for transportation fuel is **ever rising**
- Transportation sector the **major contributor** to rising **GHG** emission
- Both, major cause for **environmental Pollution** and major **health hazard**
- **Bio-Mobility™** based transportation helps minimize **carbon footprint**

Facilitates sustainable decarbonization through circular bio-economy

Crude Oil : Carbon Utilization

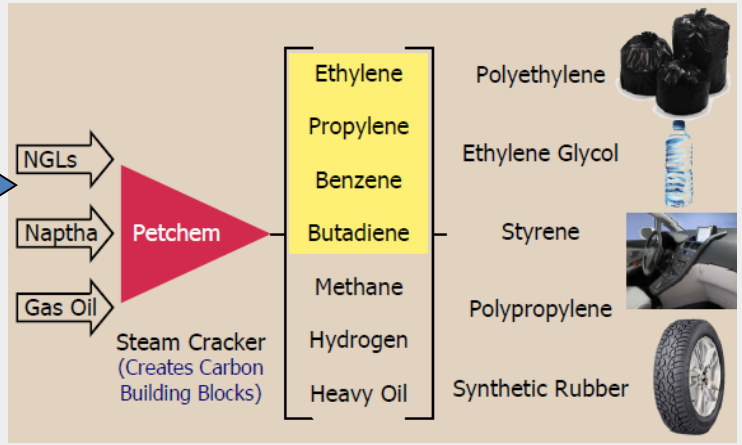


Refinery



Fuels & Energy

Downstream



Chemicals & Polymers

- ~70% of crude oil gets converted for energy
- < 5% for chemicals and polymers
- 100 % carbon utilization for value addition

} Generate same revenue

Processes Used TODAY to Make Petrochemicals

- Processes highly optimized, very cost effective
- $100's of Billions of invested infrastructure
- Chemicals, solvents, plastics, and materials are made from a few "building blocks"
- Fuels also are made from the "building blocks"

Distillation

Steam Cracking

Olefins

Ethylene

Propylene

Butylenes

Butadiene

Pyrolysis Gasoline

Naphtha

Aromatics

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

Adipic Acid

Nylon 66

Cyclohexane

Caprolactam

Nylon 6

Toluene Diamine

Toluene Diisocyanate

Polyurethane

ortho-Xylene

Phthalic Anhydride

Plasticizers

meta-Xylene

Isophthalic Acid

Unsaturated Polyesters

para-Xylene

Terephthalic Acid

Polyesters (PET)

Source: Adapted from Nexant

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Toluene

Xylenes

Hydrocarbon Fuels

>750 Billion Gallons

Diesel

Gasoline

Jet Fuel

Chemicals and Materials

340 million MT

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

Cumene

Ethyl Benzene

Styrene

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Unsaturated Polyesters

para-Xylene

Terephthalic Acid

Polyesters (PET)

Source: Adapted from Nexant

The Most Important Petrochemicals

Primary Petrochemicals:
The building blocks from which nearly ALL fossil based chemicals, plastics, solvents, plasticizers, lubricants, as well as fuels, can be or are made.

Distillation

Steam Cracking

Olefins

Ethylene

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Butylenes

Butadiene

Pyrolysis Gasoline

Naphtha

Aromatics

Benzene

Toluene

Xylenes

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Jet Fuel

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340 million MT

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MTBE

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Vinyl Chloride

Poly(vinyl cloride)

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Ethylene Glycol

Polyester

alpha-Olefin

Ethanol

Isobutene

Polyisobutylene

Polypropylene

Propylene Oxide

Polyols

Acrylonitrile

Polyacrylonitrile

Polybutadiene

Cumene

Styrene-Butadiene

Polystyrene

Ethyl Benzene

Styrene

ABS

Methyl Methacrylate

SB Latex

Adipic Acid

Nylon 66

Cyclohexane

Caprolactam

Nylon 6

Toluene Diamine

Toluene Diisocyanate

Polyurethane

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Distillation

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Olefins

Ethylene

Propylene

Butylenes

Butadiene

Pyrolysis Gasoline

Naphtha

Aromatics

Benzene

Toluene

Xylenes

Hydrocarbon Fuels

- Diesel
- Gasoline
- Jet Fuel

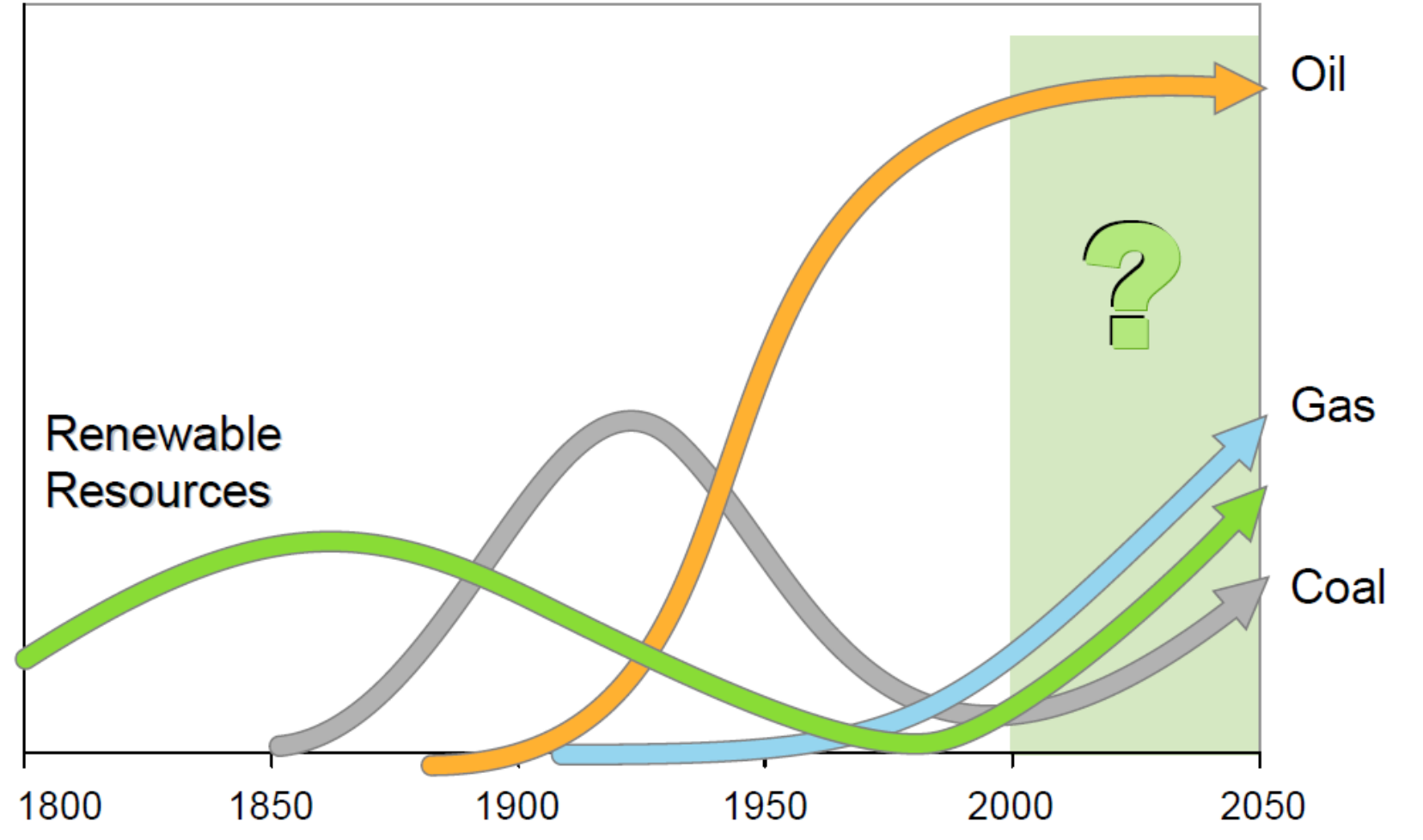
Chemicals and Materials

Ethylene (2 Carbons)	Packaging, durable goods, fibers, consumer goods
Propylene (3 Carbons)	Packaging, Automobile plastics, carpet, clothing, consumer goods
Butylenes (4 Carbons)	Rubber for tires, lubricants, fuels, other chemicals, polymers
Butadiene (4 Carbons)	Rubber, other chemicals
Benzene (6 Carbons)	Nylon
Toluene (7 Carbons)	Polystyrene (packaging plastic), fuels
Xylenes (8 Carbons)	Raw material for PET, other polyesters, fuels

Source: Adapted from Nexant

Renewable Chemicals

Renewable chemicals : Is it new?



As recently as the late 1940s, the world depended on bio-based processes to produce many chemicals

Definition

A ***renewable resource*** is a natural resource with the ability to reproduce through biological or natural processes and replenished with the passage of time.

- Photosynthetic biomass
  - Starchy crops
  - Sugar crops
  - Oil seeds
  - Lignocellulosics
- Water
- Atmospheric gases (e.g. CO_2, methane)

Renewable does not mean it is biodegradable!

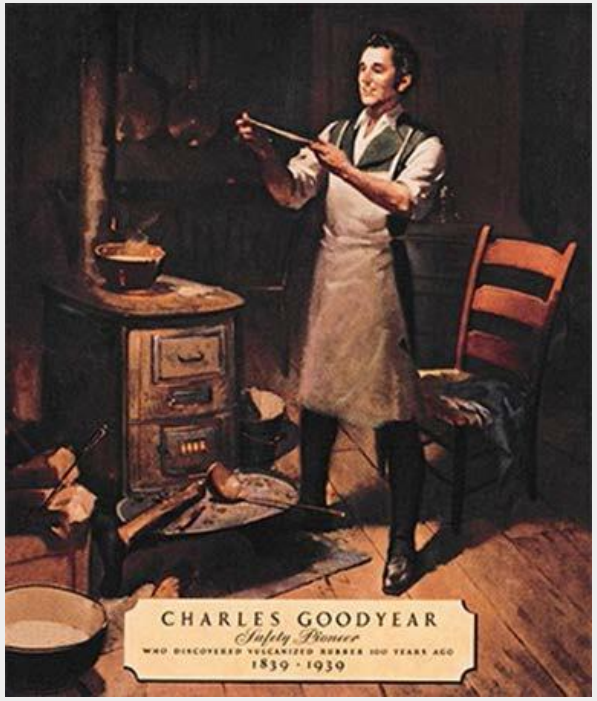
Past : 1800-1945

Before World war 2 motorcars were invented and guess what

Car needed two things: rubber tires to roll, and gasoline for its engine !

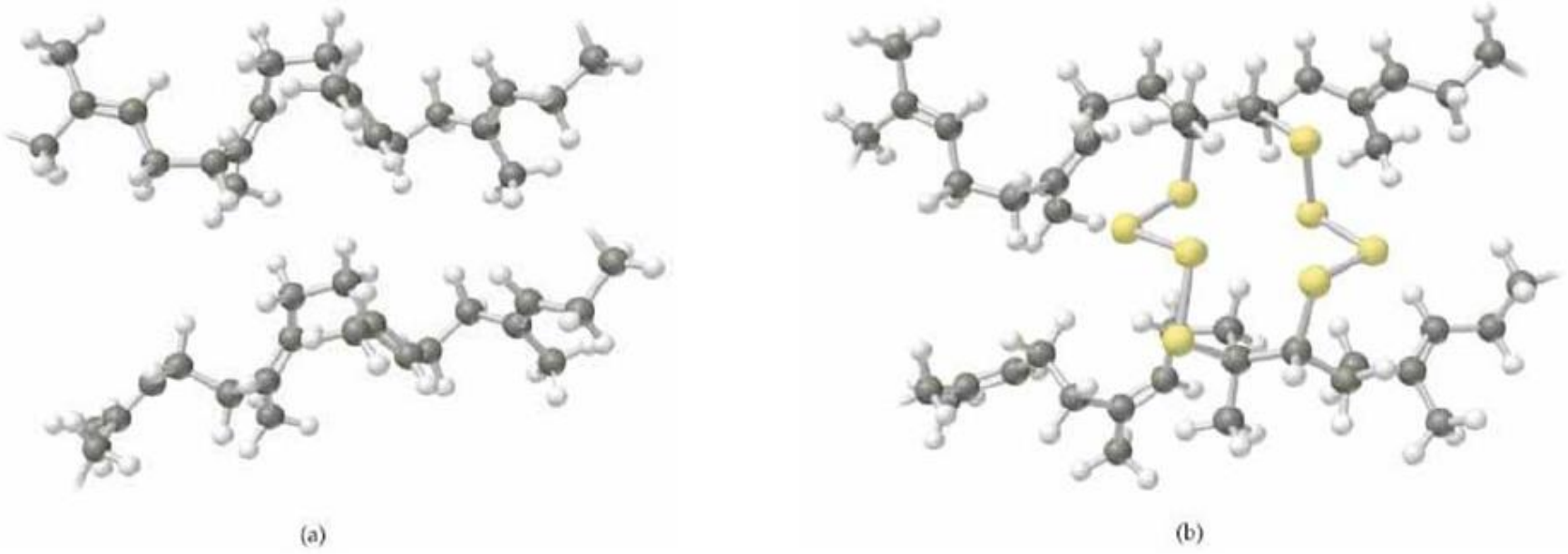
Rubber Tapper

Charles Goodyear

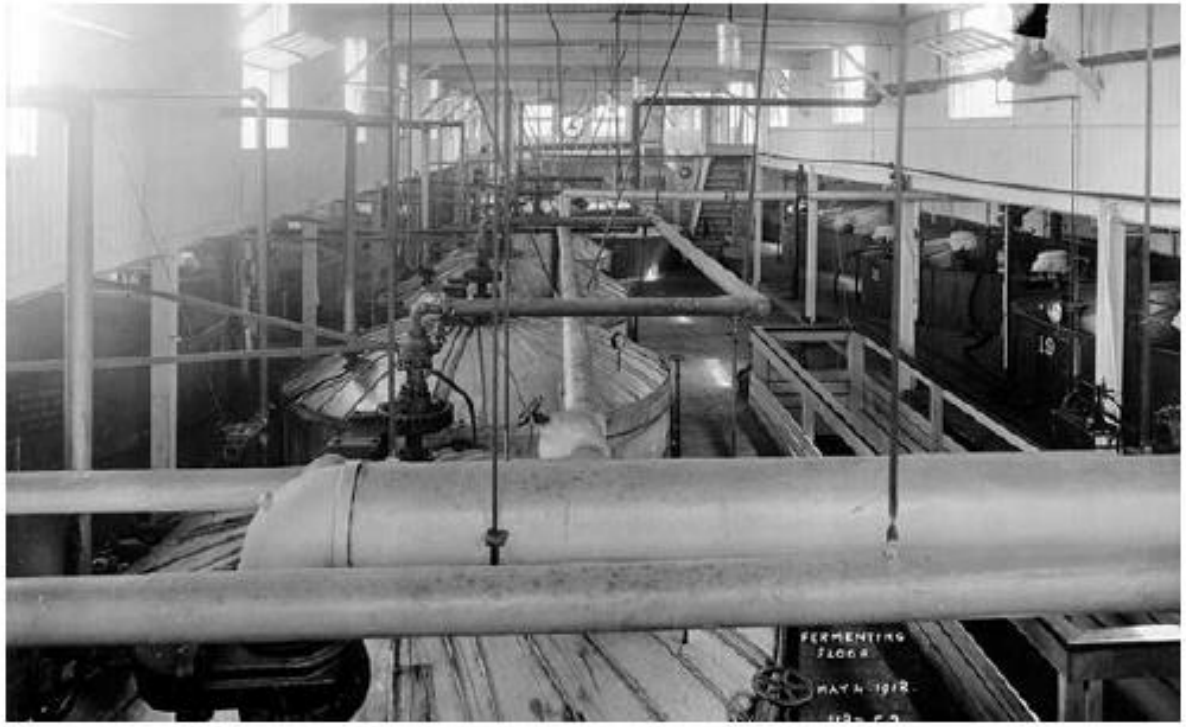


Isoprene

Figure: cis-polyisoprene structure of natural rubber



Aectone-Butanol-Ethanol (ABE)



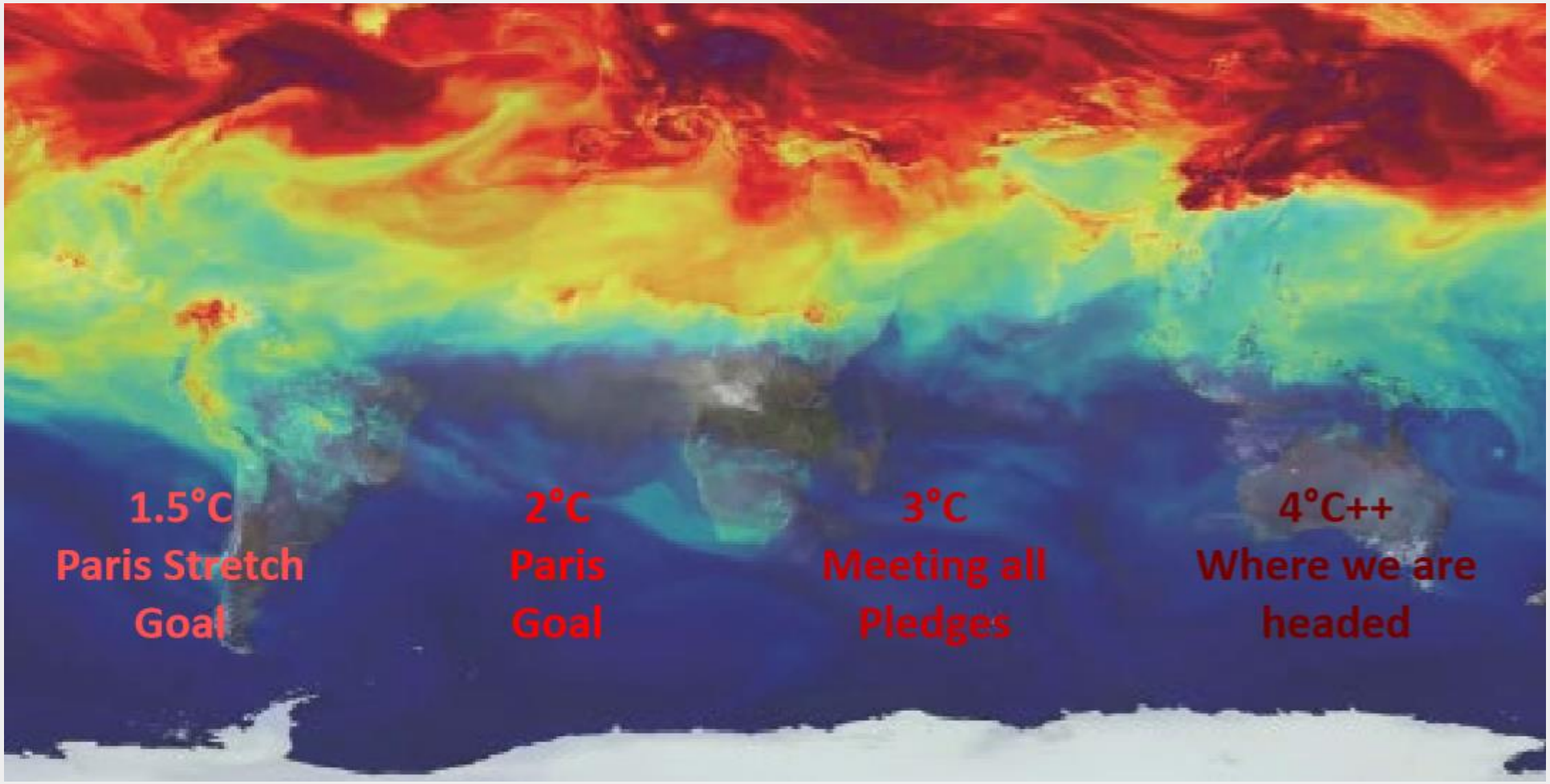
Fermenters in Toronto ABE Fermentation Plant 1918 (photo: Toronto City Archives)

© IWM (Q 27892)

Women workers weighing cordite in the Quick Firing Cartridge Factory, Woolwich, Arsenal, May 1918. (Imperial War Museum)

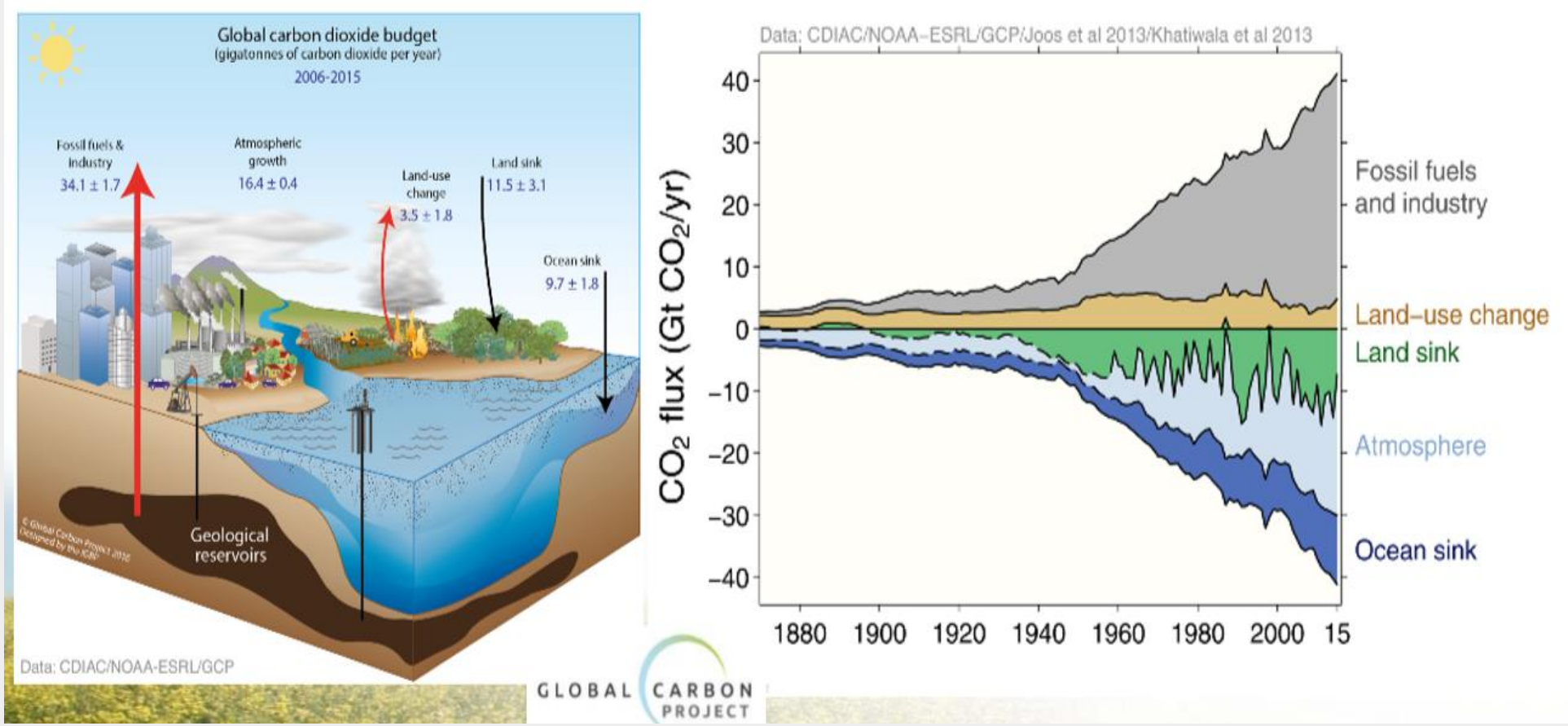
Present

Climate Change Challenge



To achieve 1.5 C Paris stretch goal will require halving emissions by 2030 and net zero by 2050 and negative there after

Global CO2 (2006-2015)



Renewable chemicals : Why it is important now?

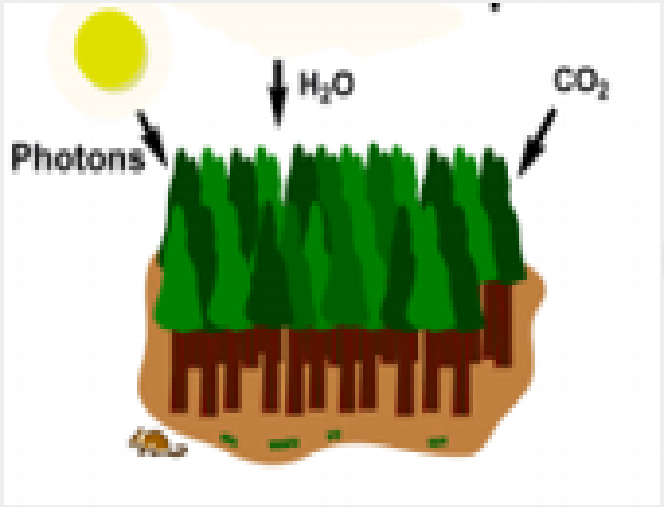
- Driven by societal and technology megatrends, two main factors will reshape the Chemical Industry in the course of the next two decades (2020–2040)

1) the global demand for better, lighter, more durable, healthier, and greener functional products by the industry's largest' customers and

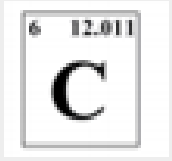
2) the uptake of decentralized production based on clean chemical technology

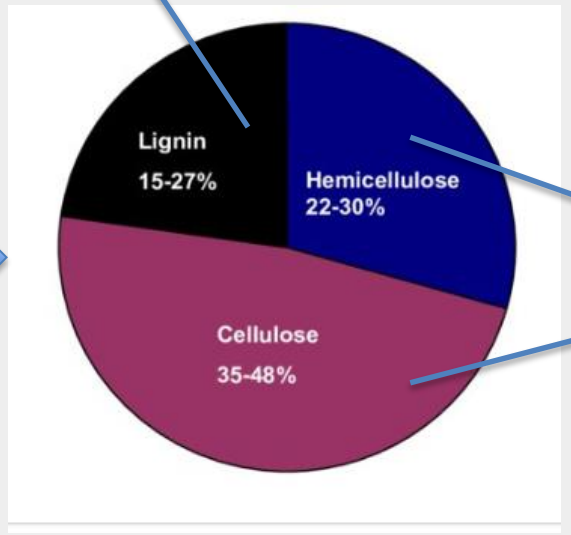
Biomass : Carbon Utilization

??? Bottom of the barrel



Biomass Residue

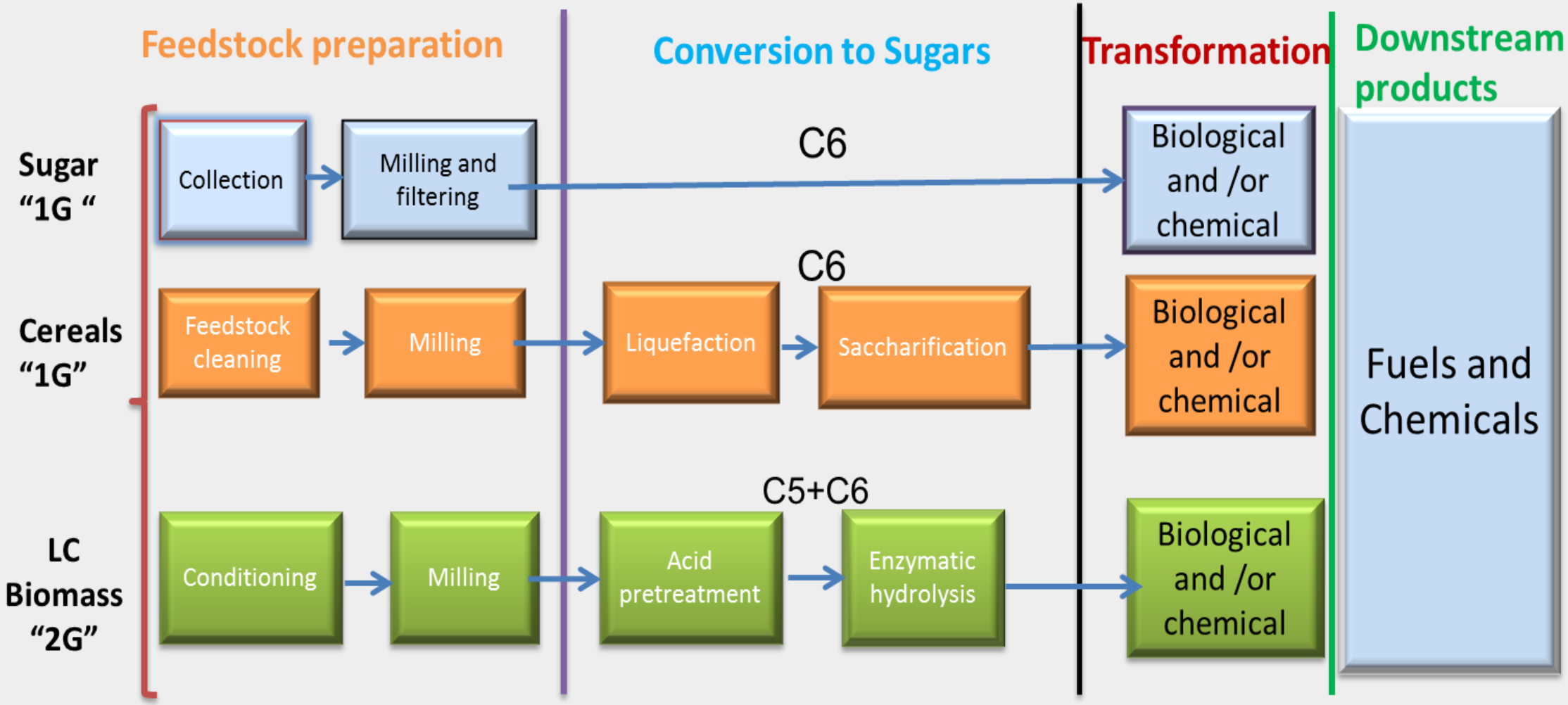




Fuels and Chemicals

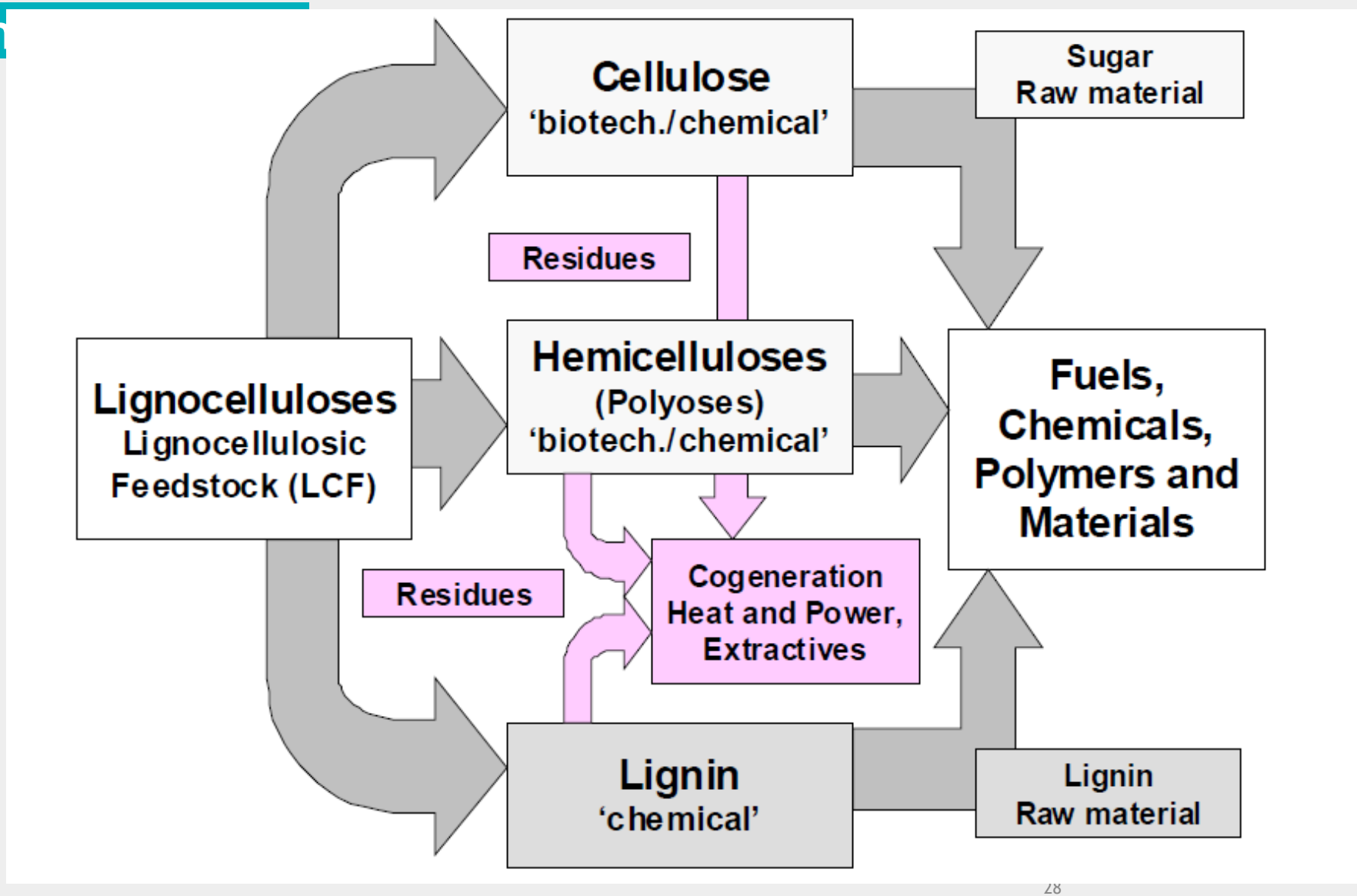
To compete with Fossil based economy, Need to valorize all the carbon

Moving from “1G” to “2G”



LC : Most Sustainable but Challenging to master

The LC Bio-refin



Bio-refinery : Processing plant where biomass feedstocks are converted and extracted into a spectrum of valuable products

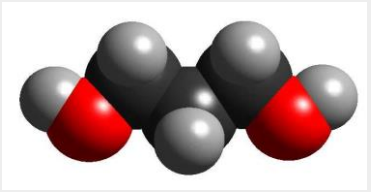
Circular Economy

Bio-economy is essential part of Circular Economy

Sorona® (PolyTrimethyl Terephthalate, PTT)

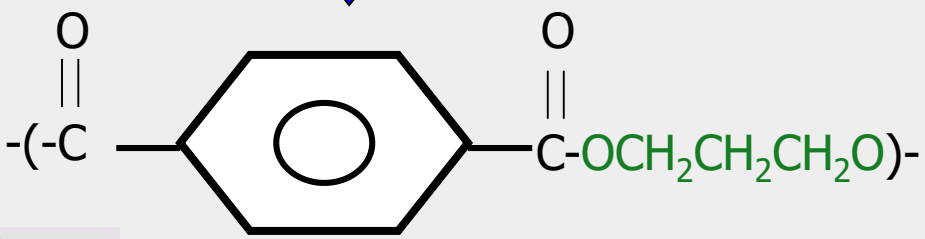
DuPont™ Sorona® Bio-Based PTT Polymer

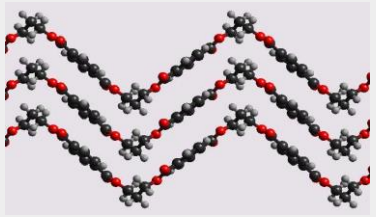
Bio-PDO™



\+ DMT / TPA

Catalyst





Sorona® polymer

- Unique polymer with versatile properties
- 37wt% renewable content

DuPont™ Sorona® - Carpet & Apparel Applications

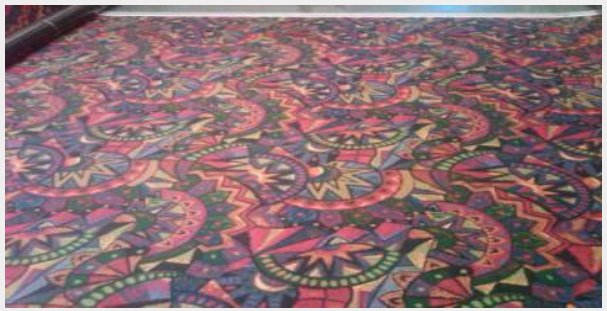
Residential Carpet

- Stain Resistance “Engineered Into” the fibers
- Resiliency
- Bright color & Infinite Color Choices
- Superior Soft Touch
- Bio-PDO™Strong Environmental Benefits

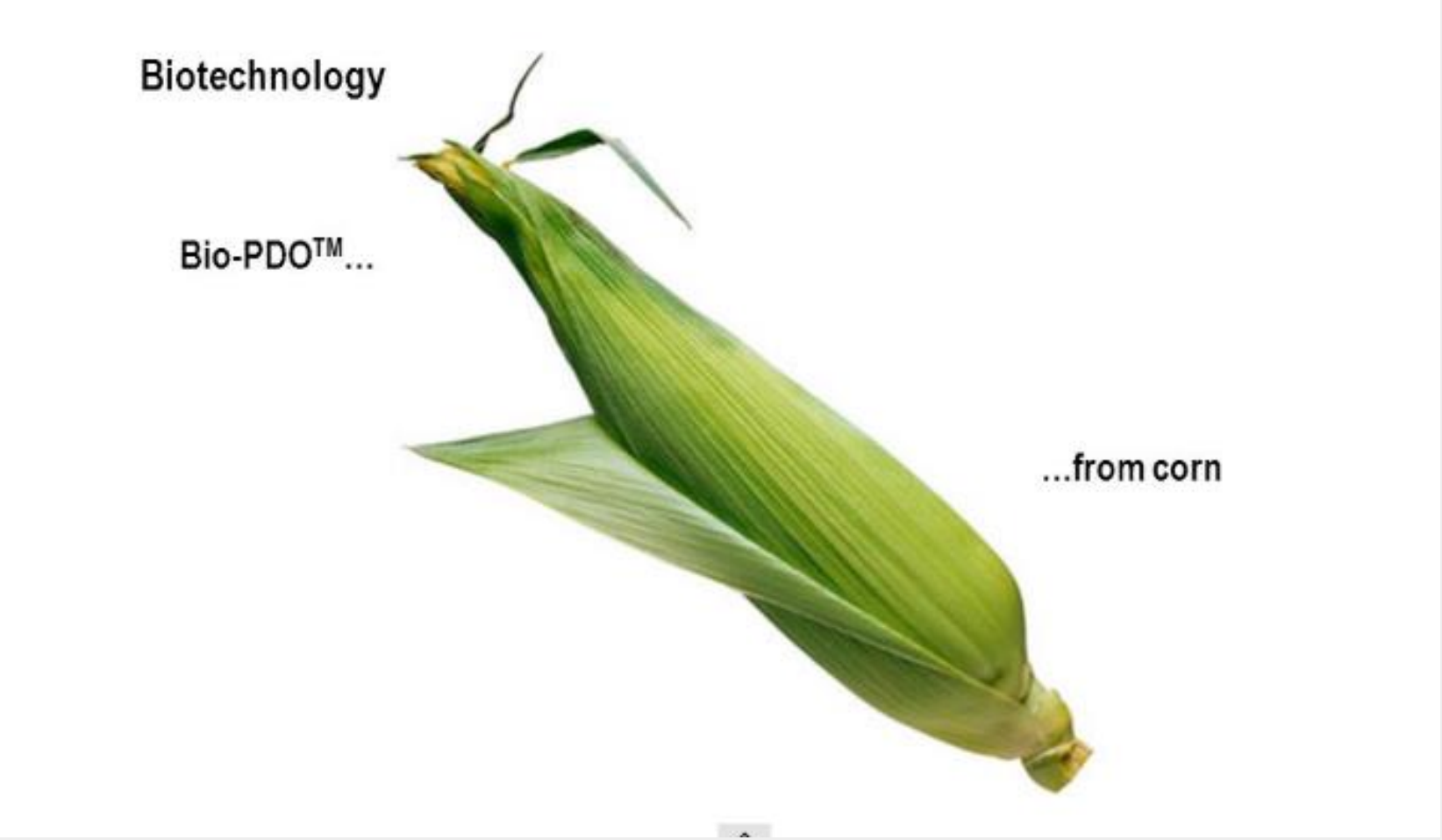
Aotomotive Carpet

Apparel

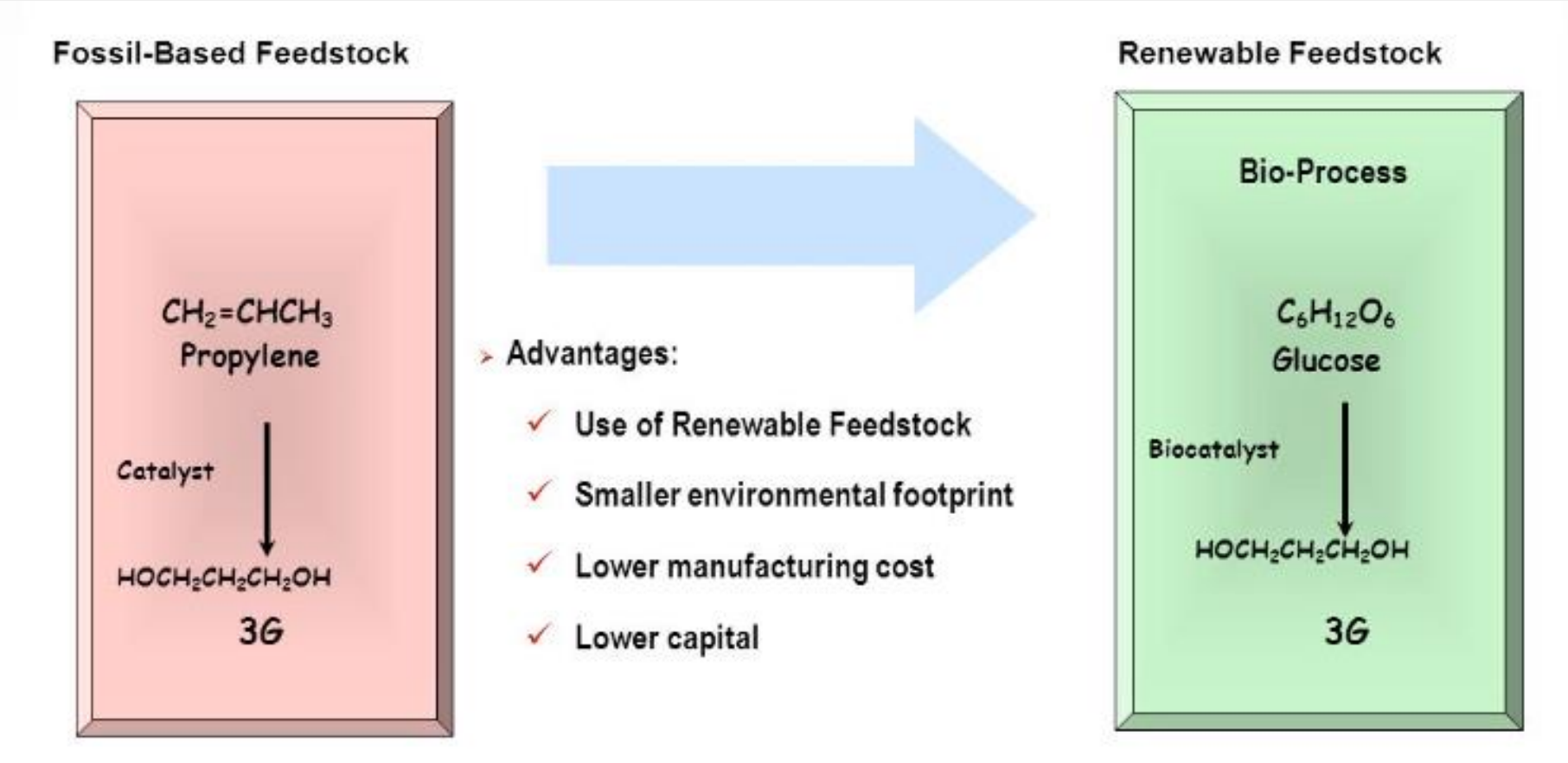
Commercial Carpet



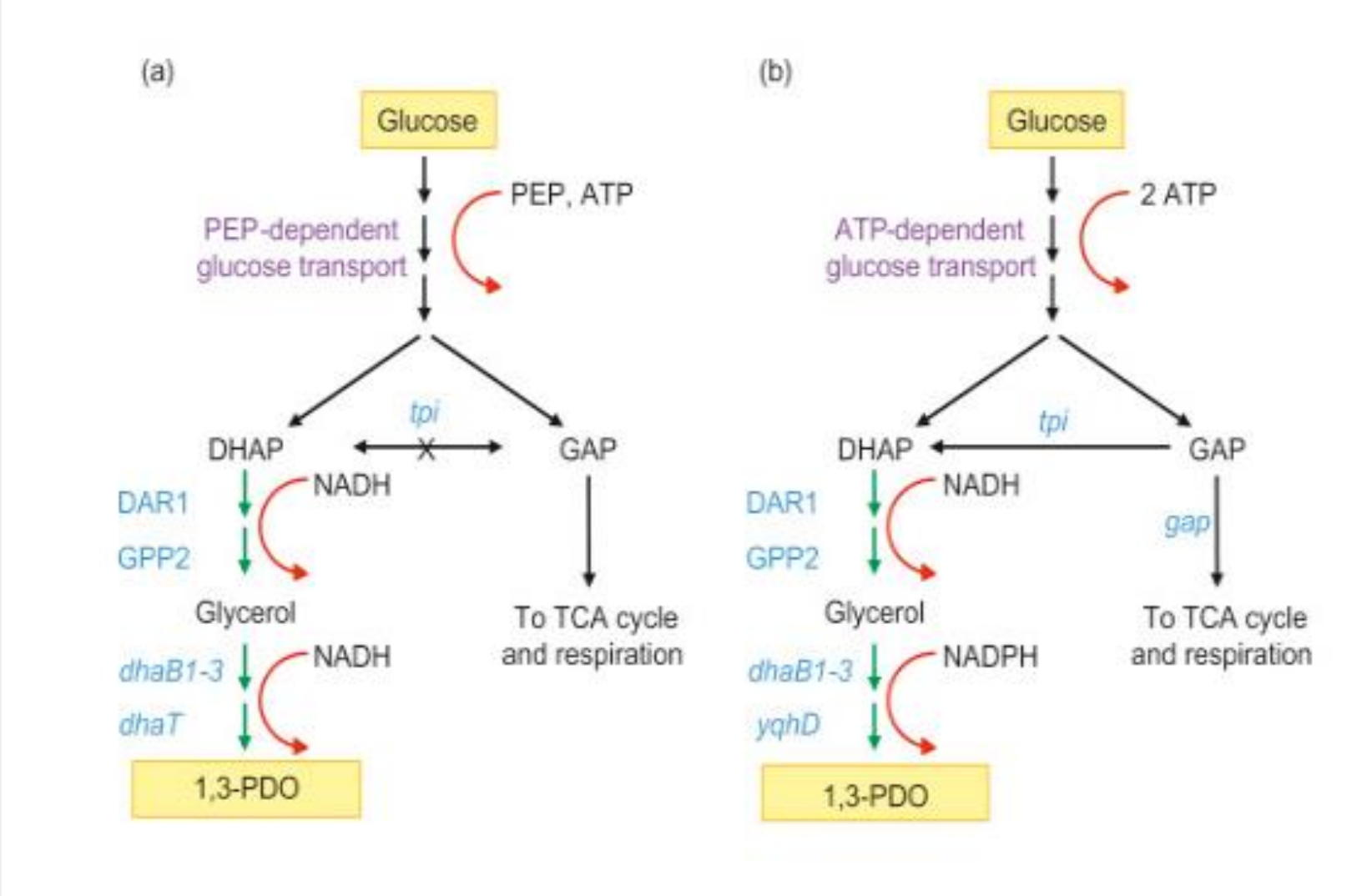
Bio PDO



Bio PDO : Process



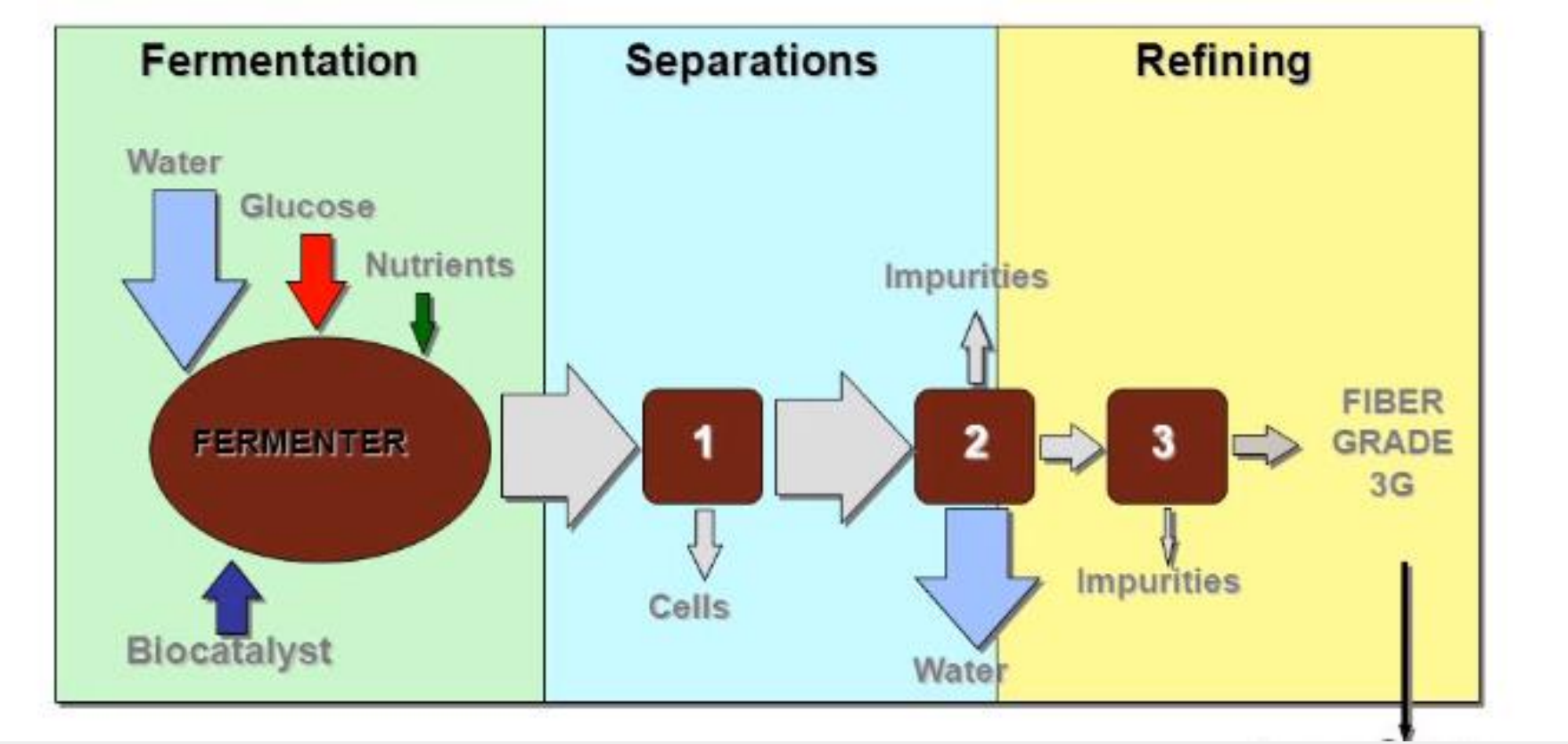
Bio PDO : Pathway



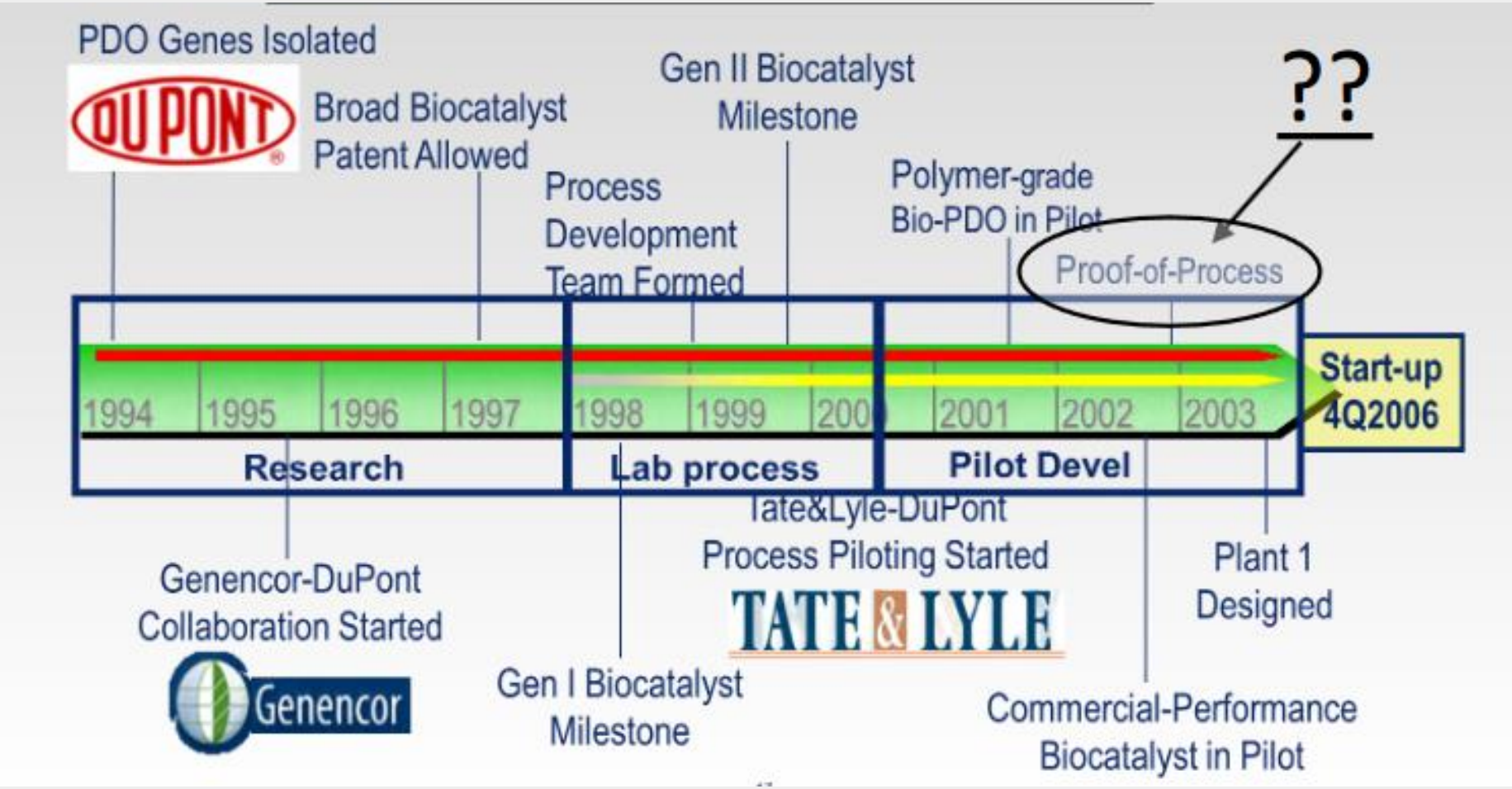
Early construct

Improved construct

Putting it altogether



1.3 -Propanediol : Dupont



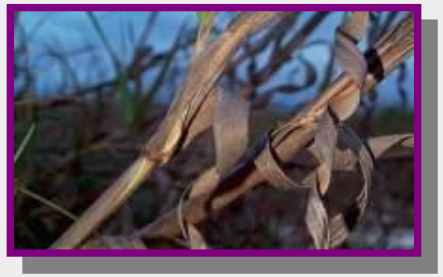
Long Timelines !

Polylactic Acid (PLA)

Poly Lactic Acid (PLA)

Sugar

Future:



Fermentation

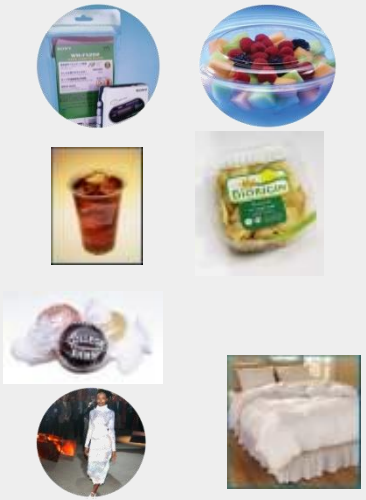
Lactic Acid

Monomer Production

Lactide

Polymer Production

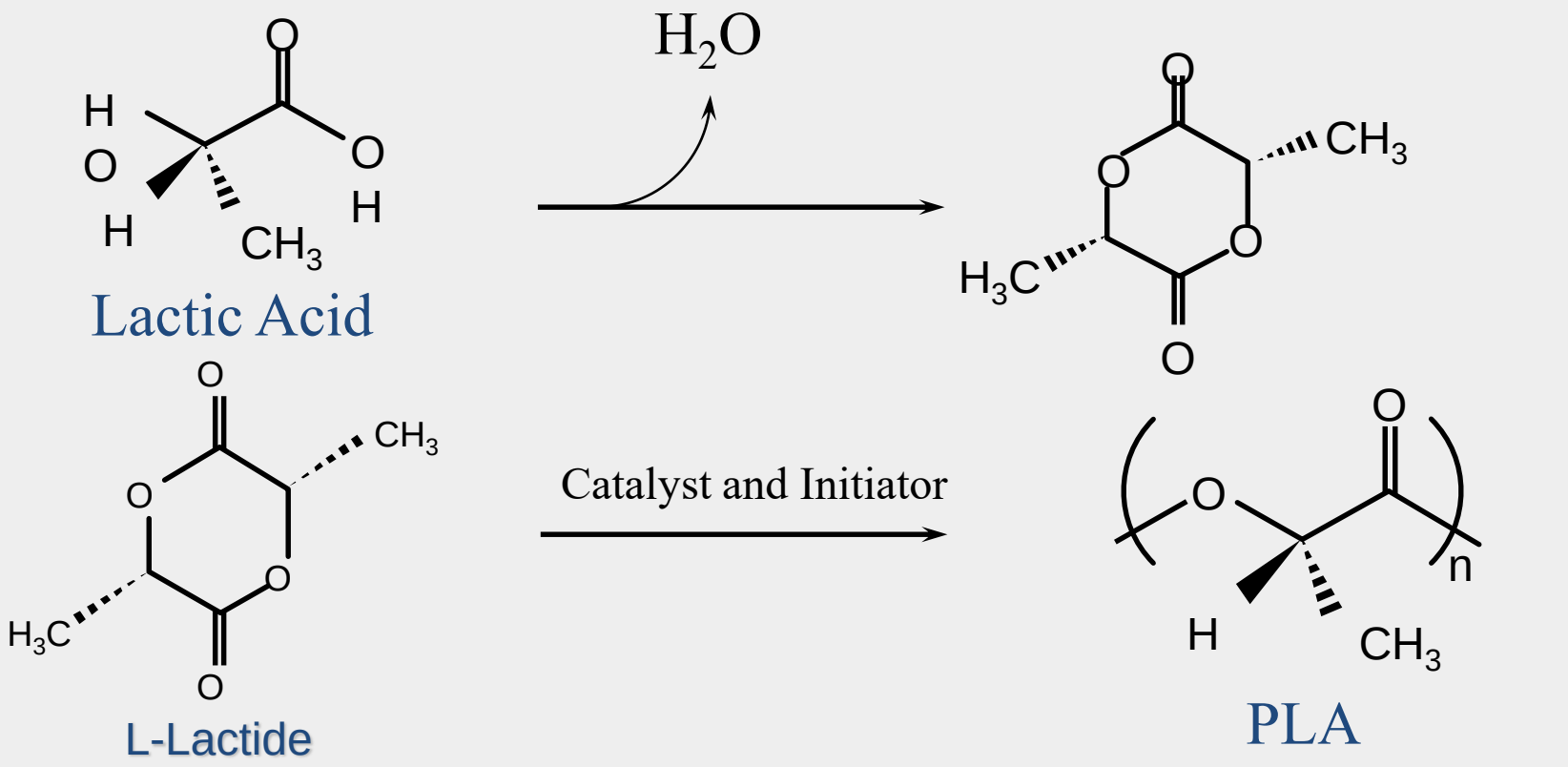
PLA



Polymer Conversion

Industrially Biodegradable plastic

Polymerization through Lactide Ring Opening



- Molecular weight control by lactic acid concentration
- Control optical composition through composition of lactide feed

PLA : Properties

	PLA	GPPS	PET	PP
Tensile Strength, MPa	53.1	45.5	58.6	35.9
Elongation at Break, %	4.1	1.4	5.5	350
Tensile Modulus, GPa	3.45	3.03	3.45	1.31
Izod Impact, J/m	16.0	21.4	26.7	48.1
Tg, ° C	60	102	74	-20
Melting Point, ° C	170-220	none	270	165
Density, g/cc	1.25	1.05	1.35	0.9

PLA has similar properties to other thermoplastic materials

PLA : Products

Thermoformed products

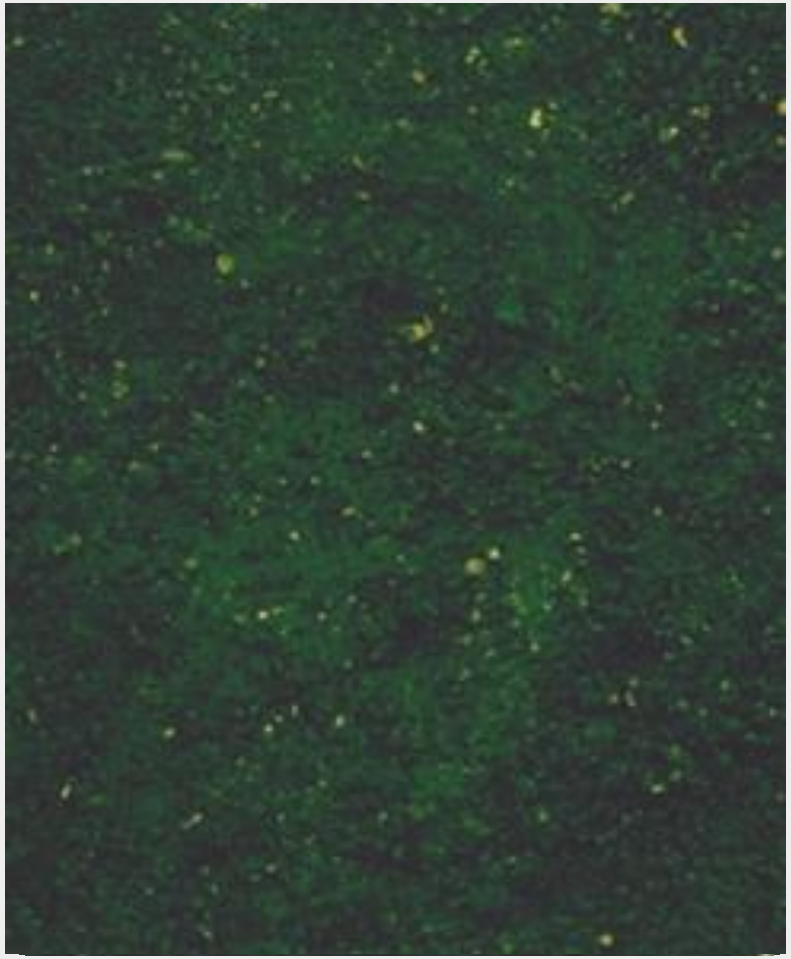
Bottles

Films

Compostable

•Specific Conditions requirement allows for products to be designed for normal use

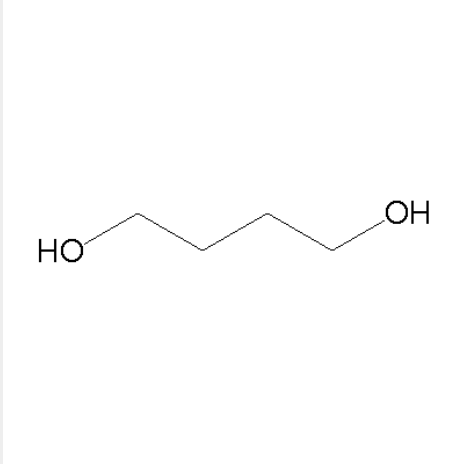
•Requires the specific conditions of high temperature and moisture found in municipal compost systems

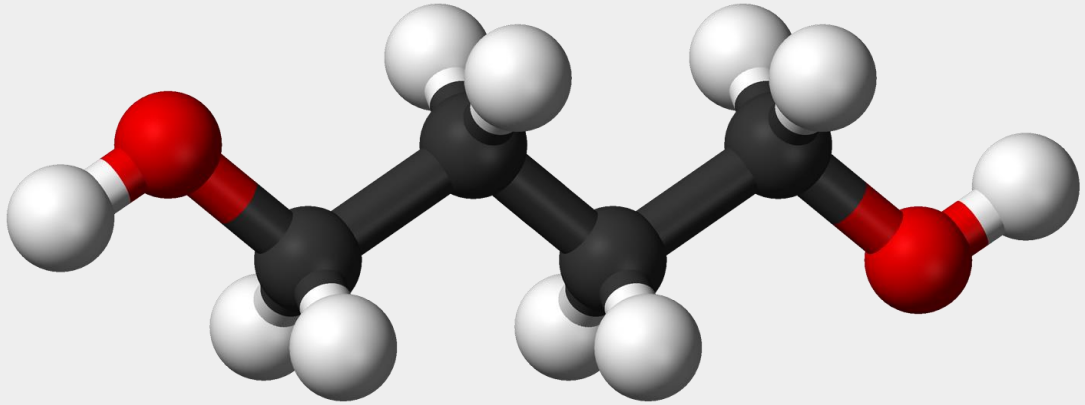


Day 47

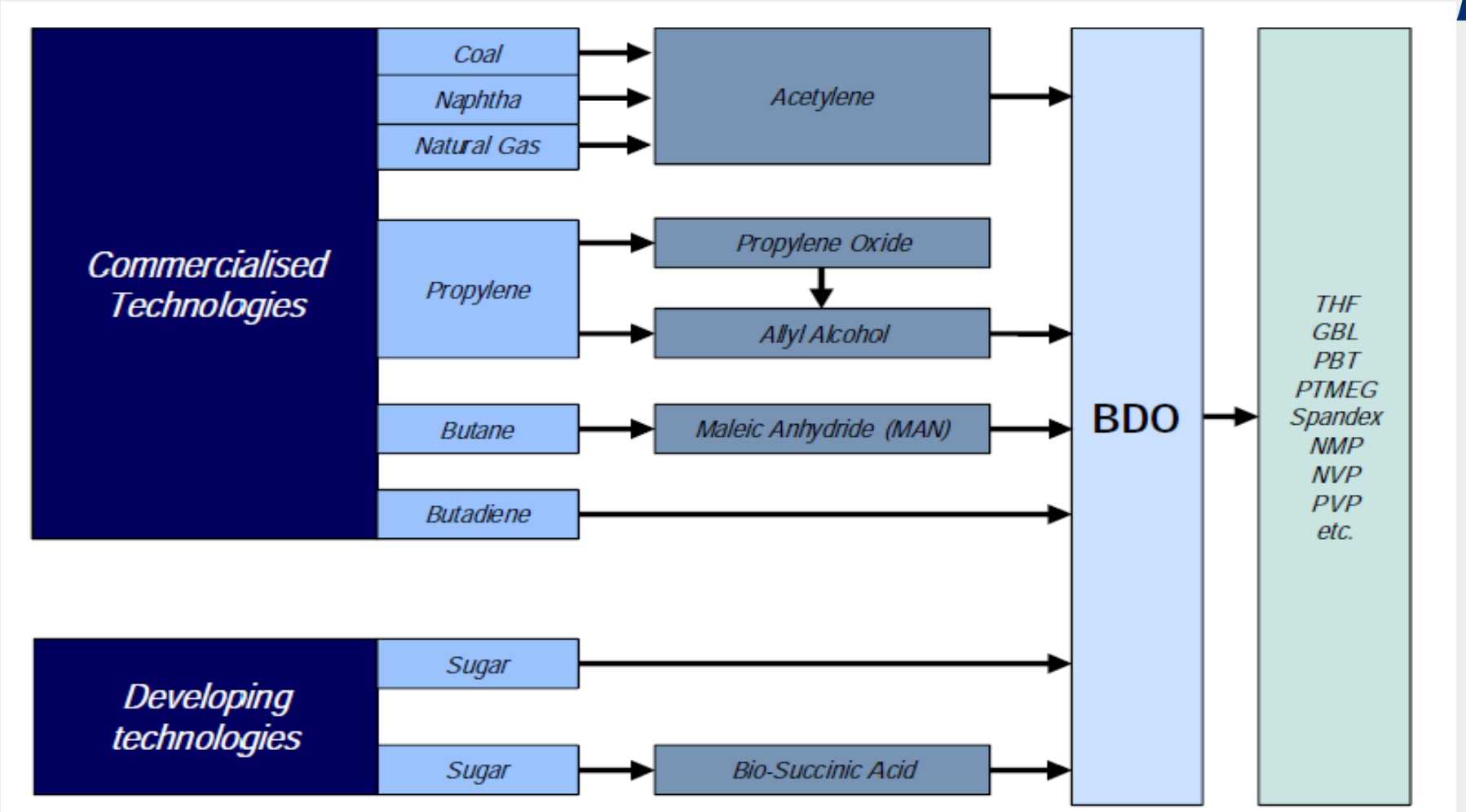
Industrially Biodegradable plastic

Bio 1,4-Butanediol (BDO)



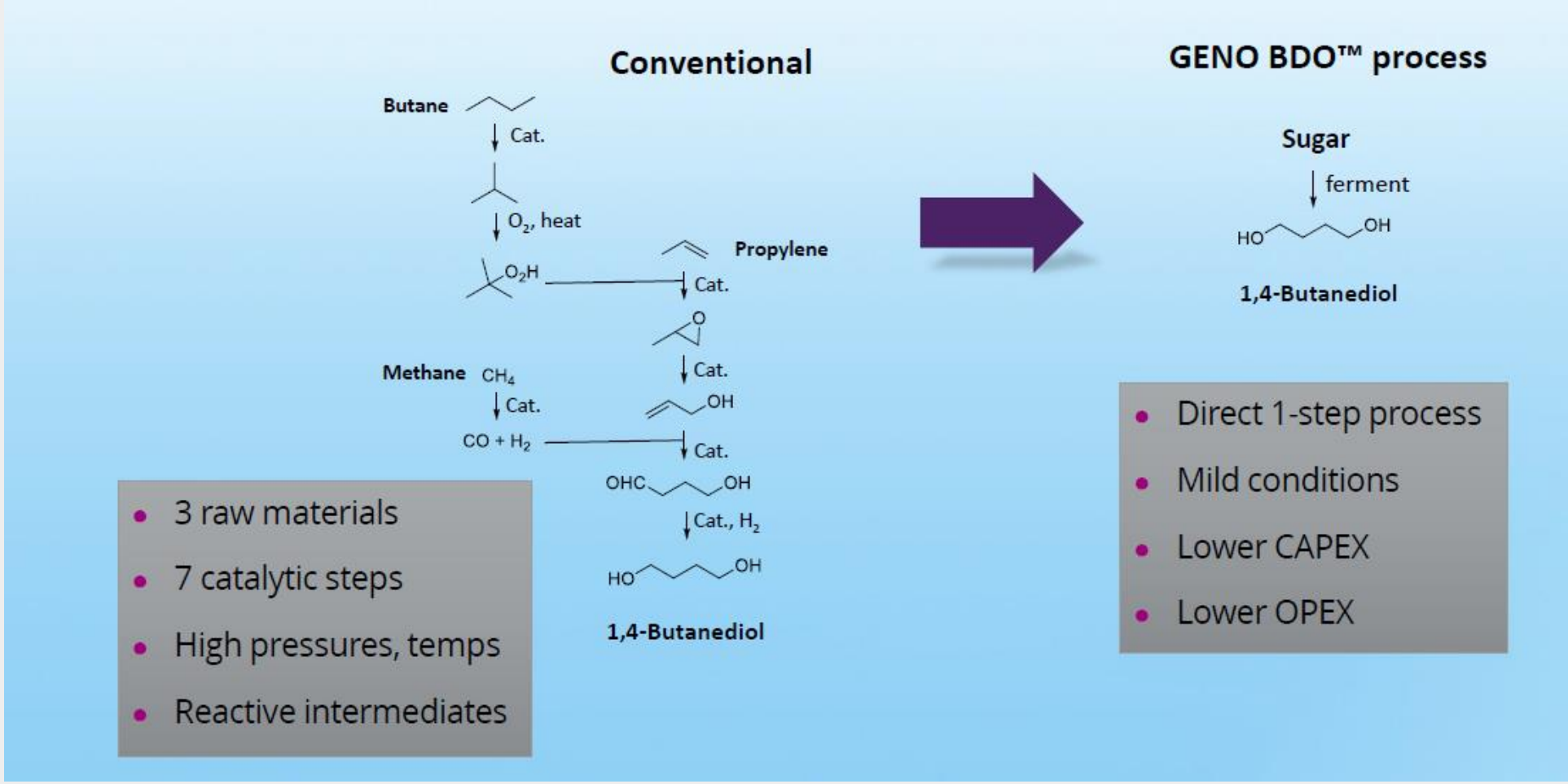


Production Technologies



- Market size : 2 MM MTA
- Price : $ 2-3 /kg

1,4-BDO

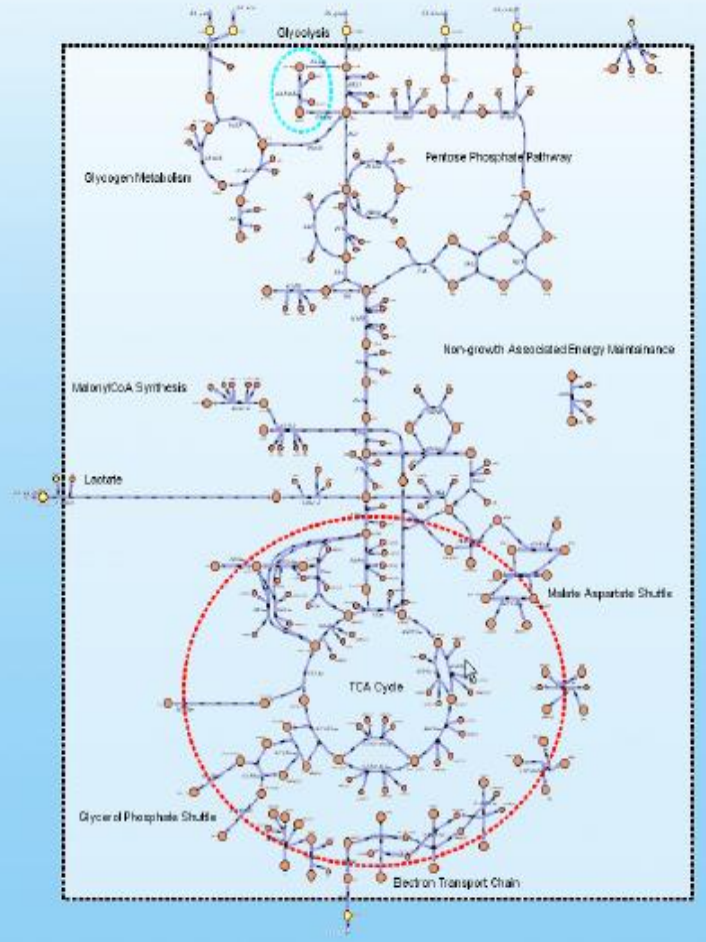

Conventional
Butane
Cat.
O_2, heat
O_2H
Propylene
Cat.
Methane CH_4
Cat.
$CO + H_2$
Cat.
Cat.
OH
Cat.
OHC
OH
Cat., H_2
HO
OH
1,4-Butanediol
3 raw materials
7 catalytic steps
High pressures, temps
Reactive intermediates
GENO BDO™ process
Sugar
ferment
HO
OH
1,4-Butanediol
Direct 1-step process
Mild conditions
Lower CAPEX
Lower OPEX

Bio 1,4-BDO : Challenges

- Not produced in Nature
- Not synthesized by any organism
- No complete biosynthetic pathway to harness BDO production

Need a deNovo approach to make in bio-catalytically!!

Genomatica : Pathway Engineering in E. Coli

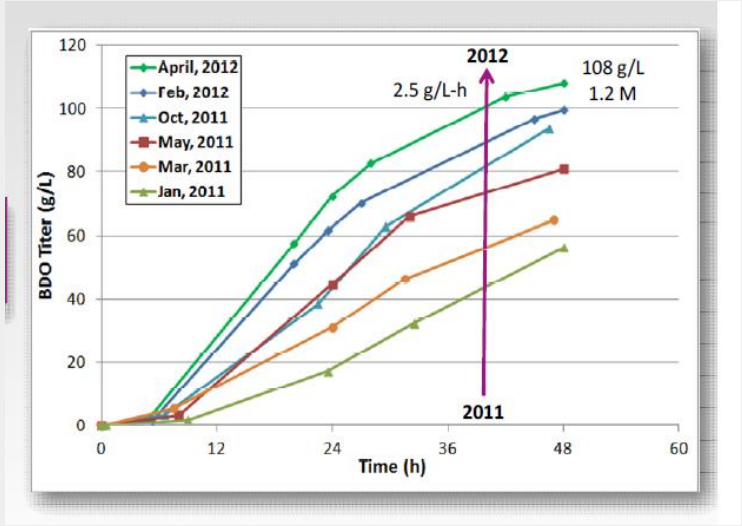


Organism engineering achievements

- Near-theoretical yields
- Multiple feedstocks
- 21 enzyme catalyst changes
- 6 heterologous genes
- >40 chromosomal edits

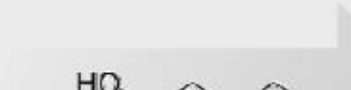
BDO biosynthetic pathways introduced into *E. coli.* *Enzymes for each numbered step are as follows: (1) 2-oxoglutarate decarboxylase; (2) succinyl-CoA synthetase; (3) CoA-dependent succinate semialdehyde dehydrogenase; (4) 4-hydroxybutyrate dehydrogenase; (5) 4-hydroxybutyryl- CoA transferase; (6) 4-hydroxybutyryl-CoA reductase; (7) alcohol dehydrogenase. Steps 2 and 7 occur naturally in E. coli*

Development and commercialization

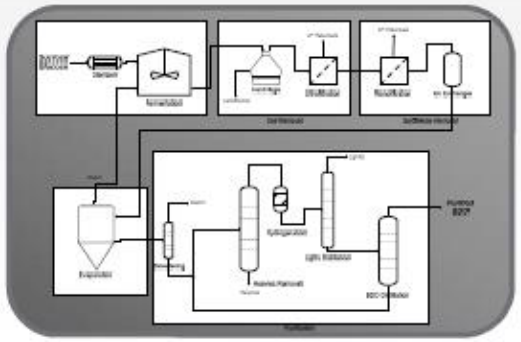


Higher Titre, rate and yield
The power of strain engineering!!

2008
first production of 1,4-BDO from carbohydrates



2013
commercial scale production (40M lbs/yr)



Poly-hydroxyalkanoates (PHAs)

Poly-hydroxyalkanoates (PHAs)

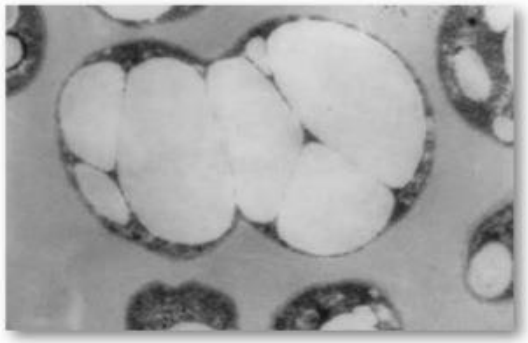
- PHA stands for "Polyhydroxyalkanoate", a class of biopolyesters synthesized by a variety of microorganisms.

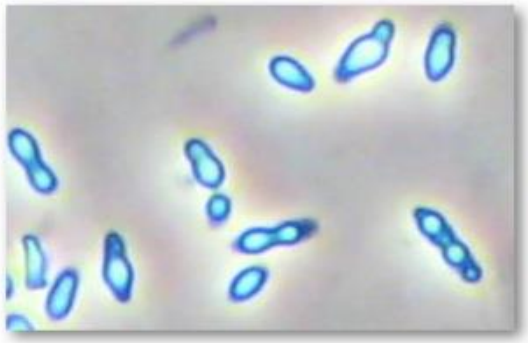
- **Key Characteristics**

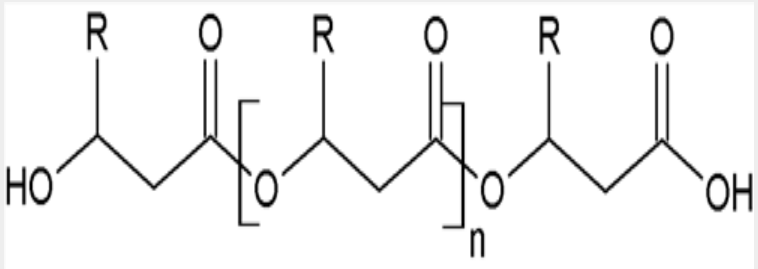
  Sustainable

  Biodegradable

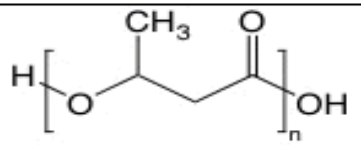
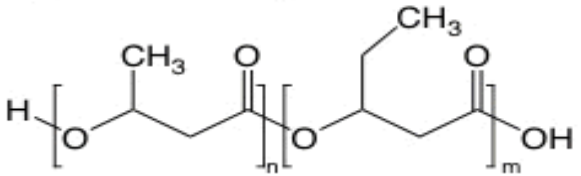
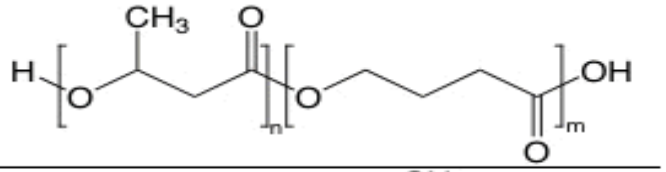
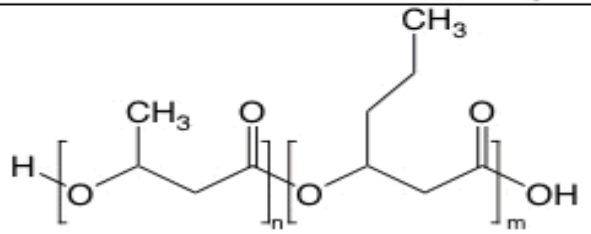
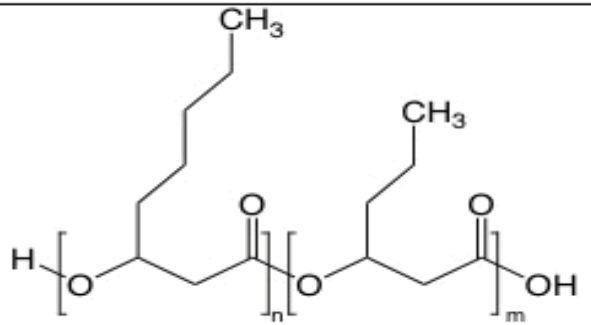
  Biocompatible







PHA Synthesizing Microorganisms*

Microorganisms	PHA synthesized	PHA chemical structure
Ralstonia eutropha **Also known as *Cupriviadus Necator***	PHB [poly(3-hydroxybutyrate)]	
	PHBV [poly(3-hydroxybutyrate-co-3-hydroxyvalerate)]	
	P3HB4HB [poly(3-hydroxybutyrate-co-4-hydroxybutyrate)]	
Aeromonas hydrophila	PHBHHx [poly(3-hydroxybutyrate-co-3-hydroxyhexanoate)]	
Pseudomonas putida	PHOHHx [poly(3-hydroxyoctanoate-co-3-hydroxyhexanoate)]	

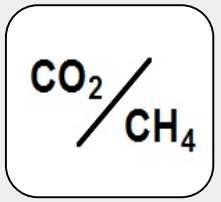
***Representative list only**

Feed stocks and Processes for PHA Production

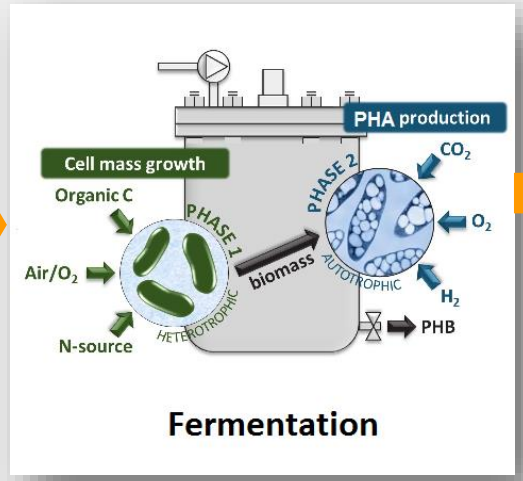
Sugars 1G & 2G

Veg Oil

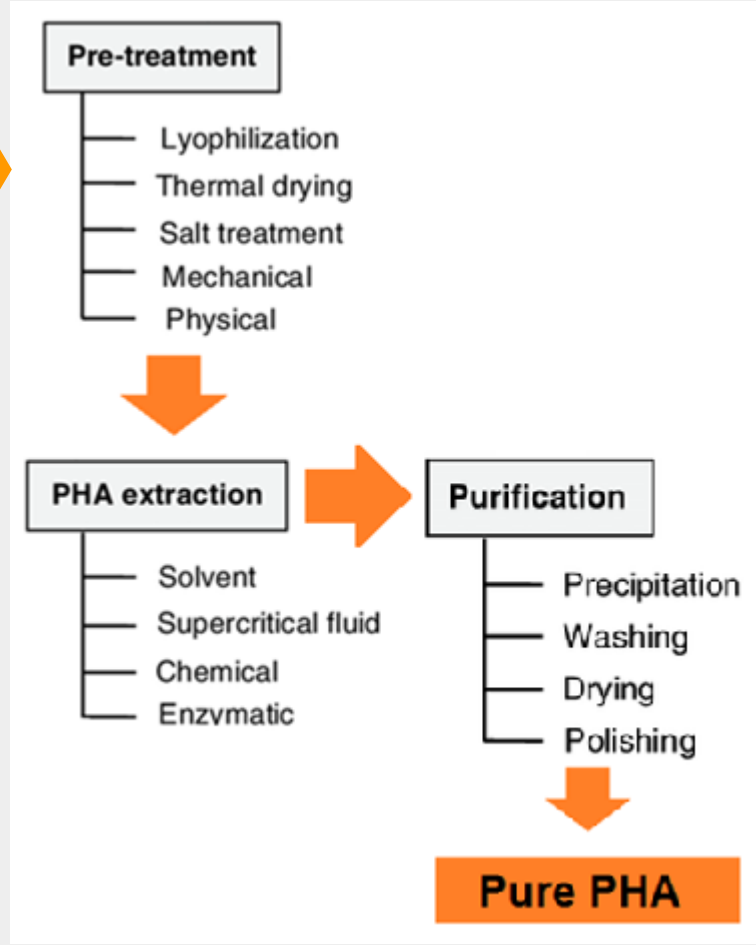
Wastewater Sludge



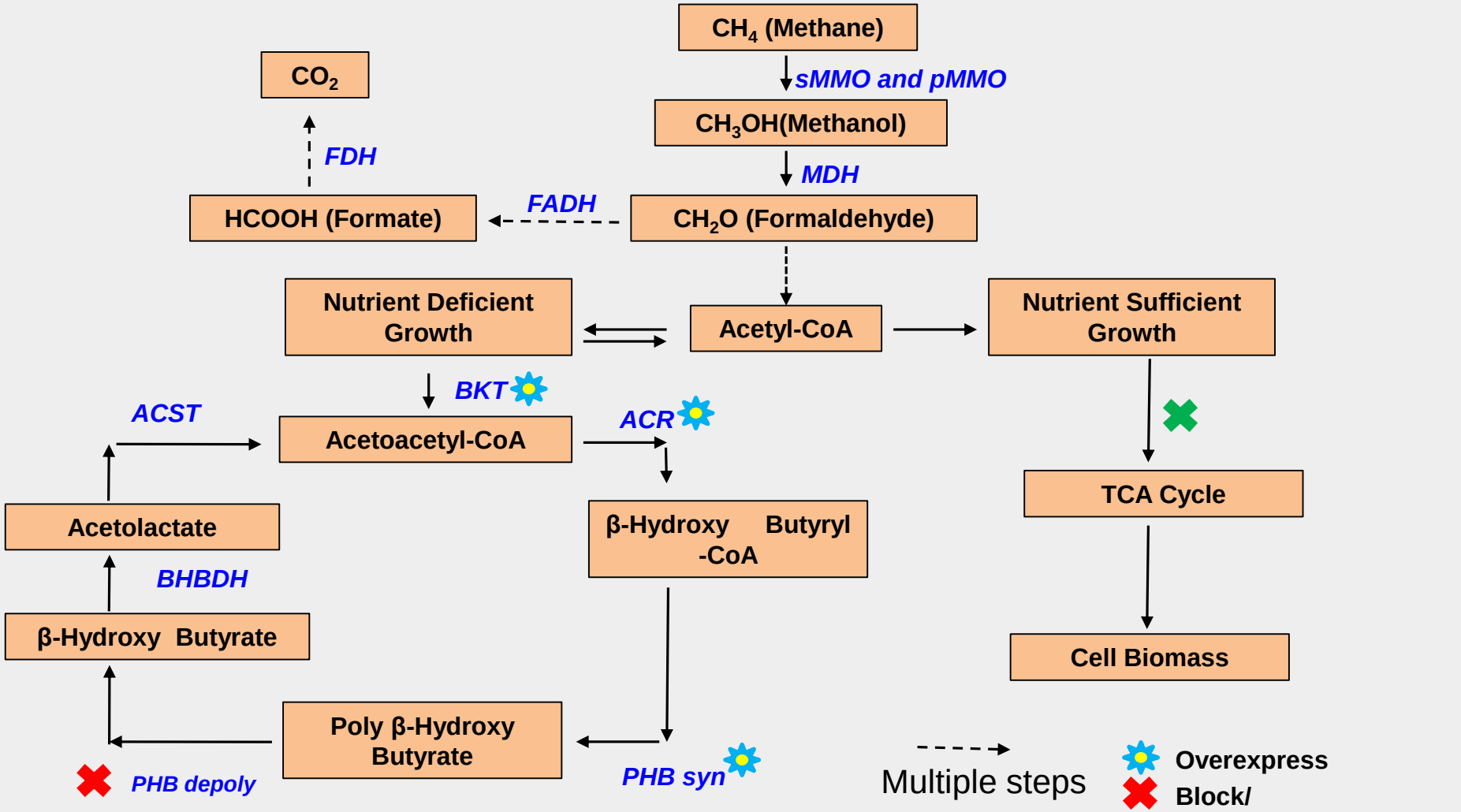
Waste Gases



Harvested Biomass



Methane to PHB Pathway



BKT Beta ketothiolase, *ACR* Acetyl CoA Reductase
PHB Syn PHB Synthase, PHB depoly: PHB Depolymerase
3HBDH 3 Hydroxy butyrate dehydrogenase,

PHA- General Properties

- Optically active linear polyesters with each repeating unit in the stereochemical R-configuration

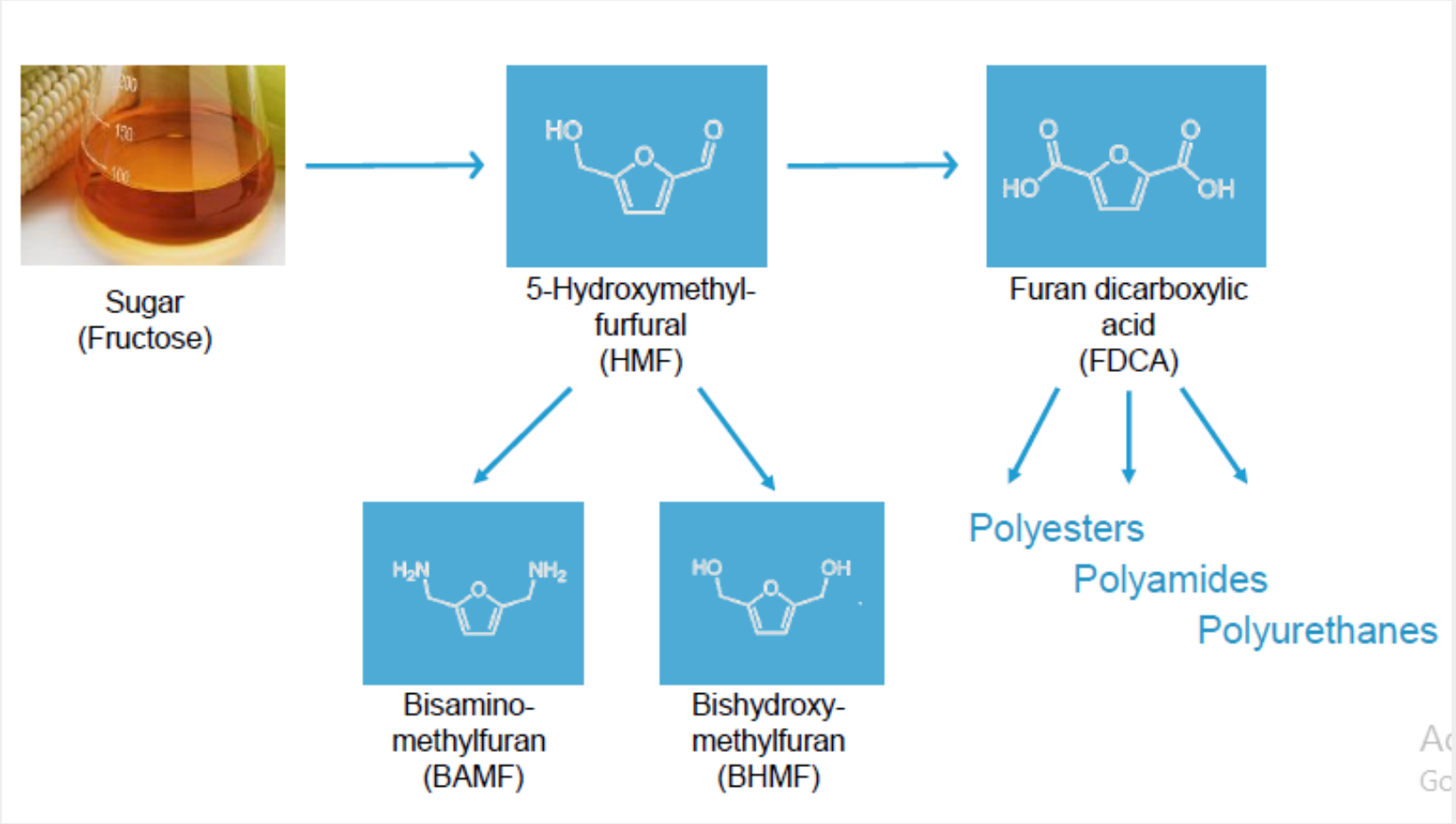
- Physical and mechanical properties are largely determined by the chemical structure and relative amount of the monomers, as well as the molecular weight

	PHB	PHBV	PHBHHx	MCL-PHA
Tm (°C)	170 to 180	130 to 170	95 to 150	40 to 60
Tg (°C)	-5 to 5	-10 to 0	-3 to -1	-60 to -30
Mw x 10^3 (g mol^{-1})	Up to 1500	Up to 1200	/	50 to 300
Density (g cm^{-3})	1.24	1.20	/	1.02
Crystallinity (%)	60 to 80	30 to 80	10 to 50	Up to 30
Tensile strength (MPa)	40	30 to 40	/	Up to 10
Young's modulus (MPa)	3.5 to 4 x 10^3	0.7 to 3 x 10^3	500 (10%HHx)	Up to 15
Elongation to break (%)	3 to 8	Up to 100	Up to 400	Up to 450

Applications of PHAs

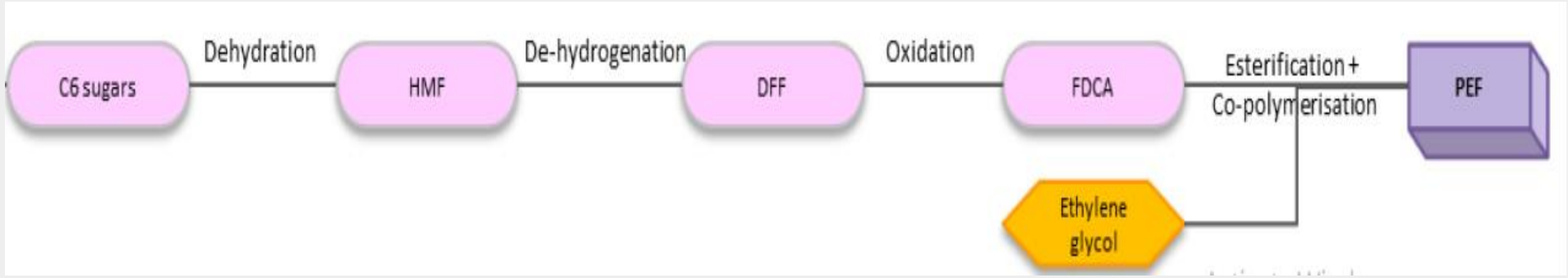
Applications	Examples
Packaging	Food utensils, films, daily consumables, electronic appliances, etc;
Medical	Sutures, surgical meshes, heart valves, vascular grafts, scaffolds for cartilage engineering, controlled drug release, etc;
Others	Coating by PHA latex, paints; Heat sensitive adhesives; Fibers for textile industry; Chiral R-form PHA monomers for fine chemical industry;

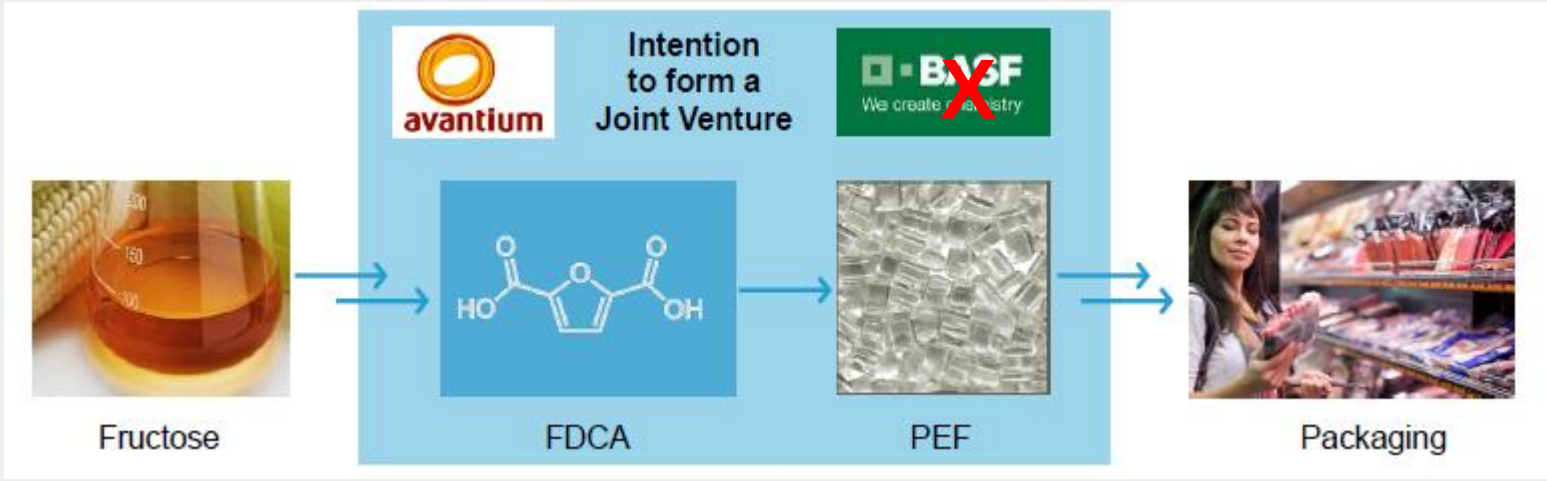
HMF/FDCA



Aventium, Corbian-Purac, Dupont-ADM

PEF : Avenitum





- Better oxygen barrier properties than PET
- Monomer purity is very important

Bio-Prism™ : Choosing wisely

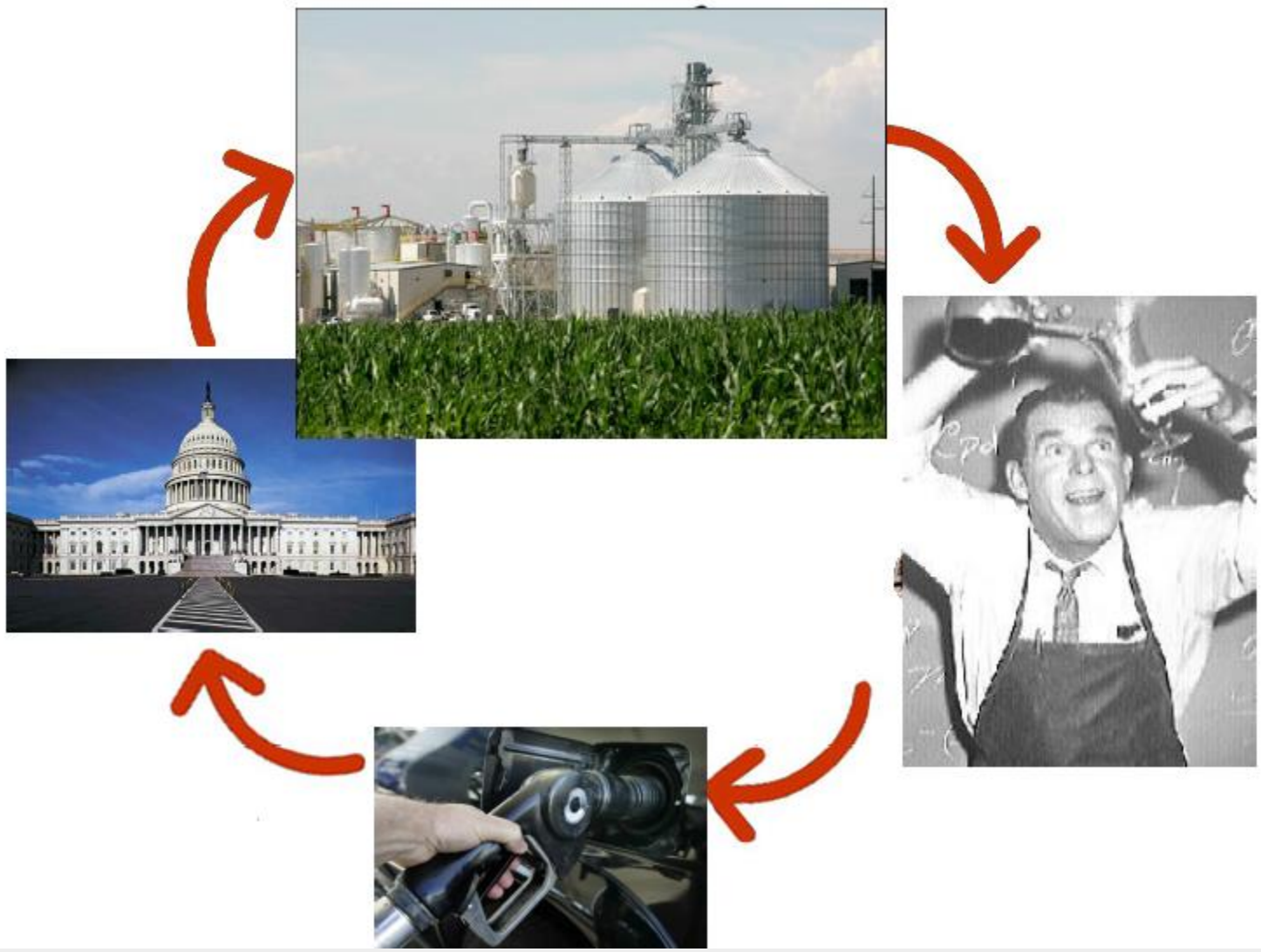
The Next Frontier : RCM Platform

praj
Innovate • Integrate • Deliver

Bio-Prism™ portfolio offers new possibilities in RCM industry

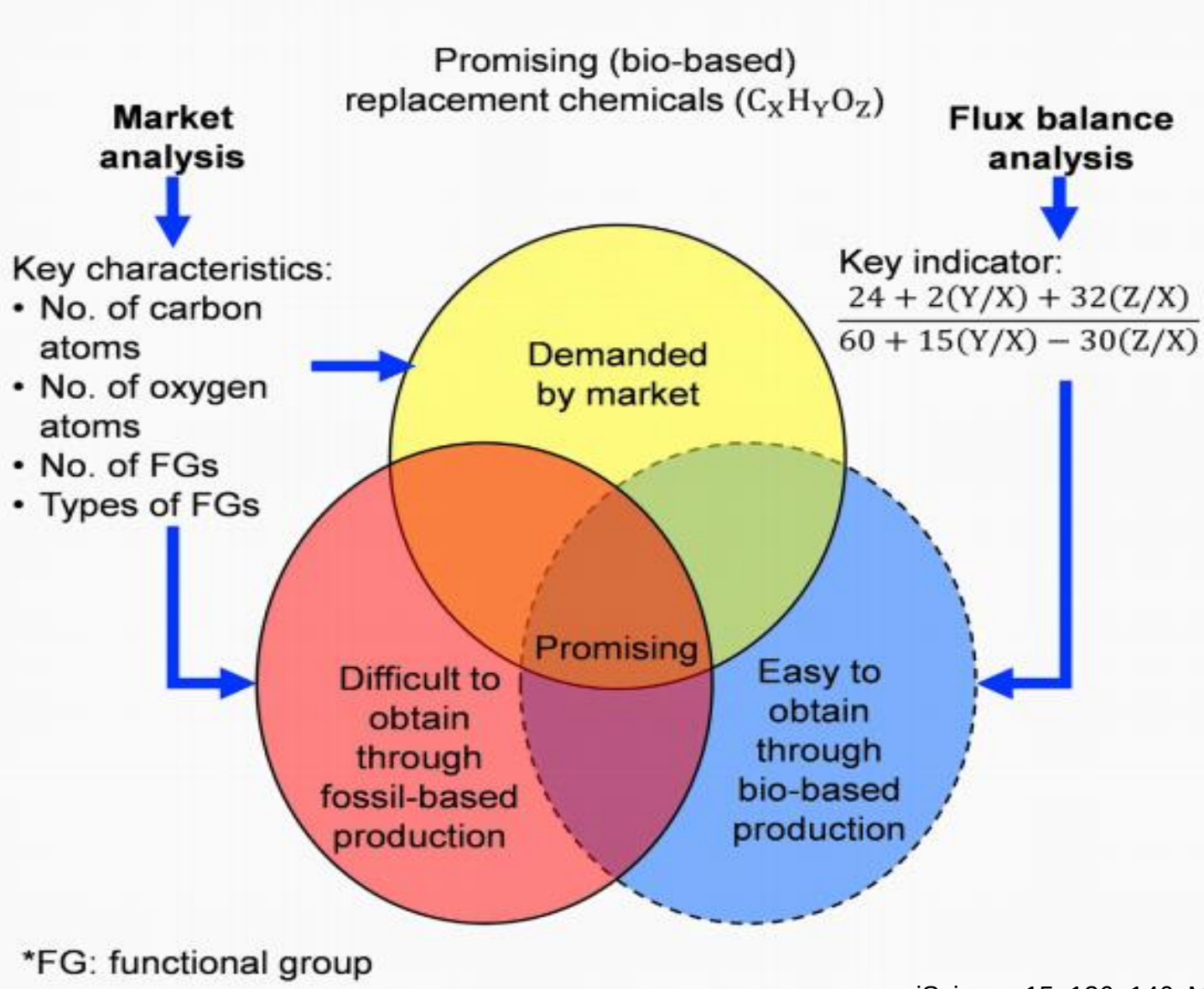
 pramodkumbhar@praj.net

Choosing wisely (1/5)



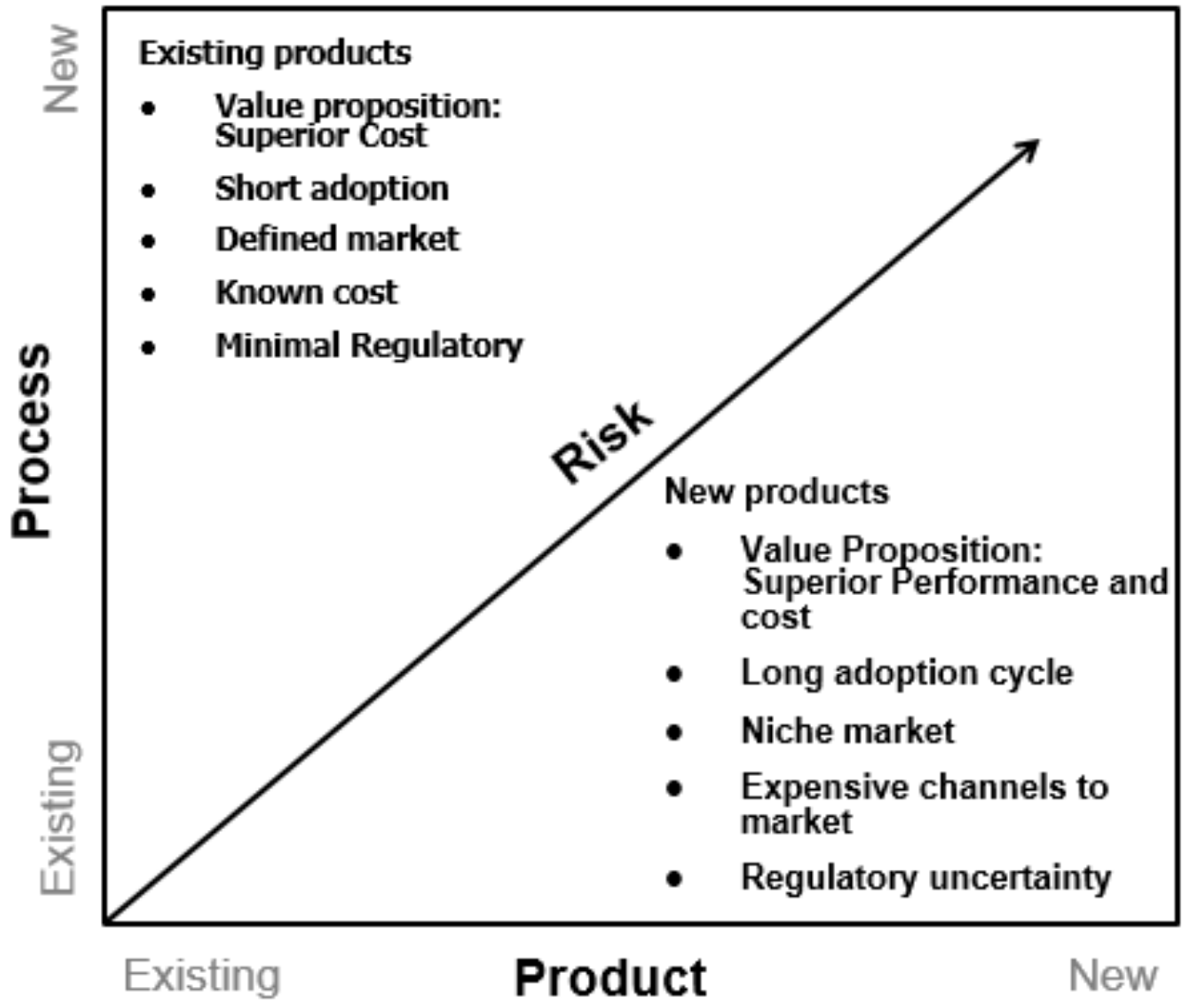
Which first? The molecule or the market?

Choosing wisely (2/5)



iScience 15, 136–146, May 31, 2019

Choosing wisely (3/5)



Choosing wisely (4/5) : Risk Analysis

RISK FACTOR		RISK MITIGATION
New Molecule (Unclear Value Proposition)	→	True drop-in molecule (already used, clear value)
Addressable Market	→	Platform molecule with large multiple accessible markets
Market Adoption Rate	→	Incentivize value chain / target markets, eliminate product uncertainties (regulatory, performance, value)
Economic Performance	→	Technology enables low cost manufacturing position
Capital Intensity	→	Retrofit existing assets
Scale Up and Operability	→	Choose technologies that avoid risks (Fermentation type, organism type, pathway type, equipment type)
Feedstock	→	Design technology to use any fermentable feedstock
Intellectual Property	→	File many patents

Choosing wisely : Approach to Development (5/5/)

Product Market Value

Economics (CapEx/OpEx)

Process Development

Operations
Temperature
Pressure
Process Design/Flow
Shear
Mass Transfer
Robustness
Equipment Designs
Catalysts/Organism

Fermentation Development

Contaminant Management
Mass Transfer
Micronutrients
Microbiology

Organism Development

Pathway Engineering
Microbial Physiology

Genetic Engineering
Protein Engineering

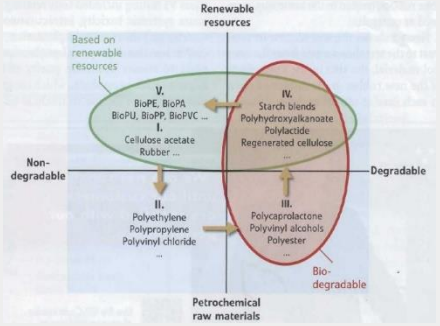
Gene Shuffling
Genomics
Proteomics
Metabolomics

Market Need Based Approach

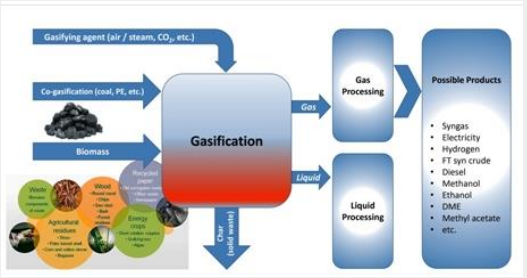
1. Determine market need
2. Determine Required Economic Performance
3. Define process CapEx/OpEx
4. Define Organism performance Requirements
5. Define Pathway requirements
6. Define Enzyme requirements
7. Then apply development skills and tools

RCM : Praj approach (1/2)

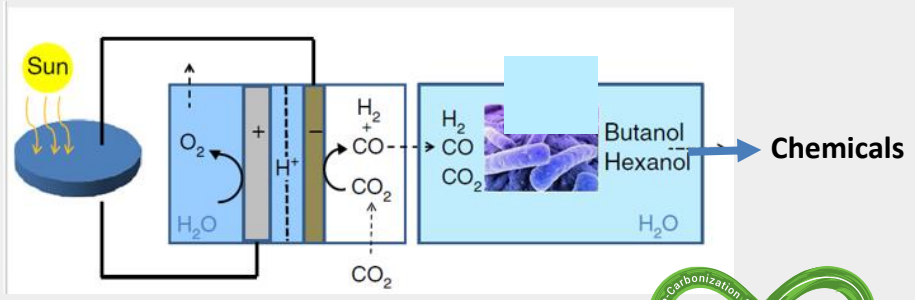
- Chemicals and materials form renewable feedstock
  - Bio-degradable
    - ➢ Fermentation and chemo-catalytic

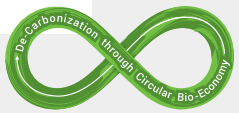


- Biomass Gasification and downstream fuels and chemicals



- Futuristic
  - CO2 Utilization to Fuels and Chemicals





RCM : Three degrees of Complexities

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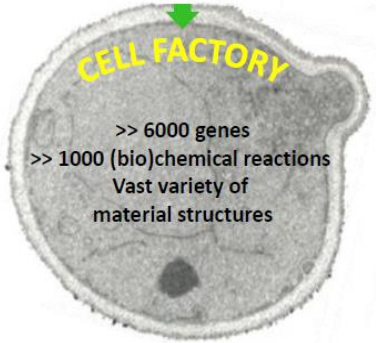
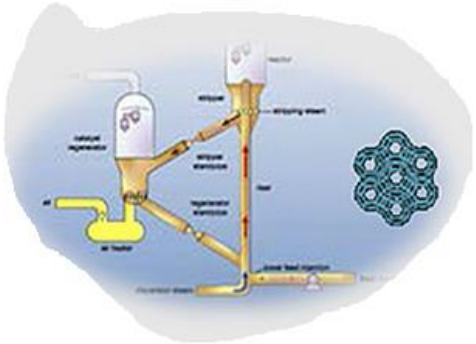
Innovate • Integrate • Deliver

Feed Stock → **Conversion Technology** → **Products**

- 1st Generation
  - Sugar cane
  - Corn
  - Cassava
- 2nd Generation
  - Straws
  - Forestry

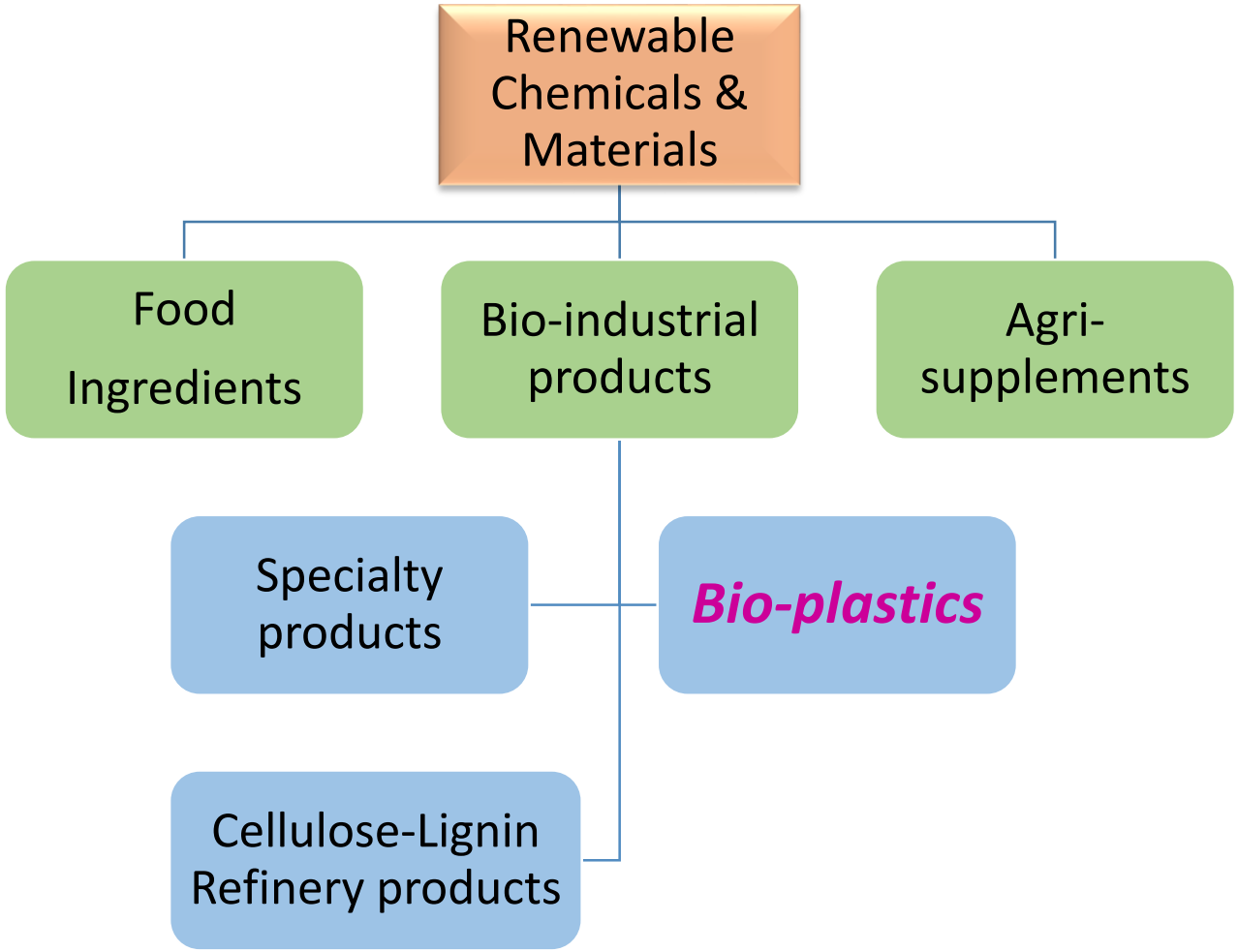




- Bio-catalytic
- Chemo-catalytic
- Thermochemical

- Drop in replacement
- Existing molecules with different economics
- Molecules with new functionality

RCM : Our approach (2/2)



CONCEPT – COLLABORATE- COMMERCIALIZE

Plastics

The Graduate (1967) : Remember one word "Plastics". It has great future

Plastics : The Inconvenient Truth

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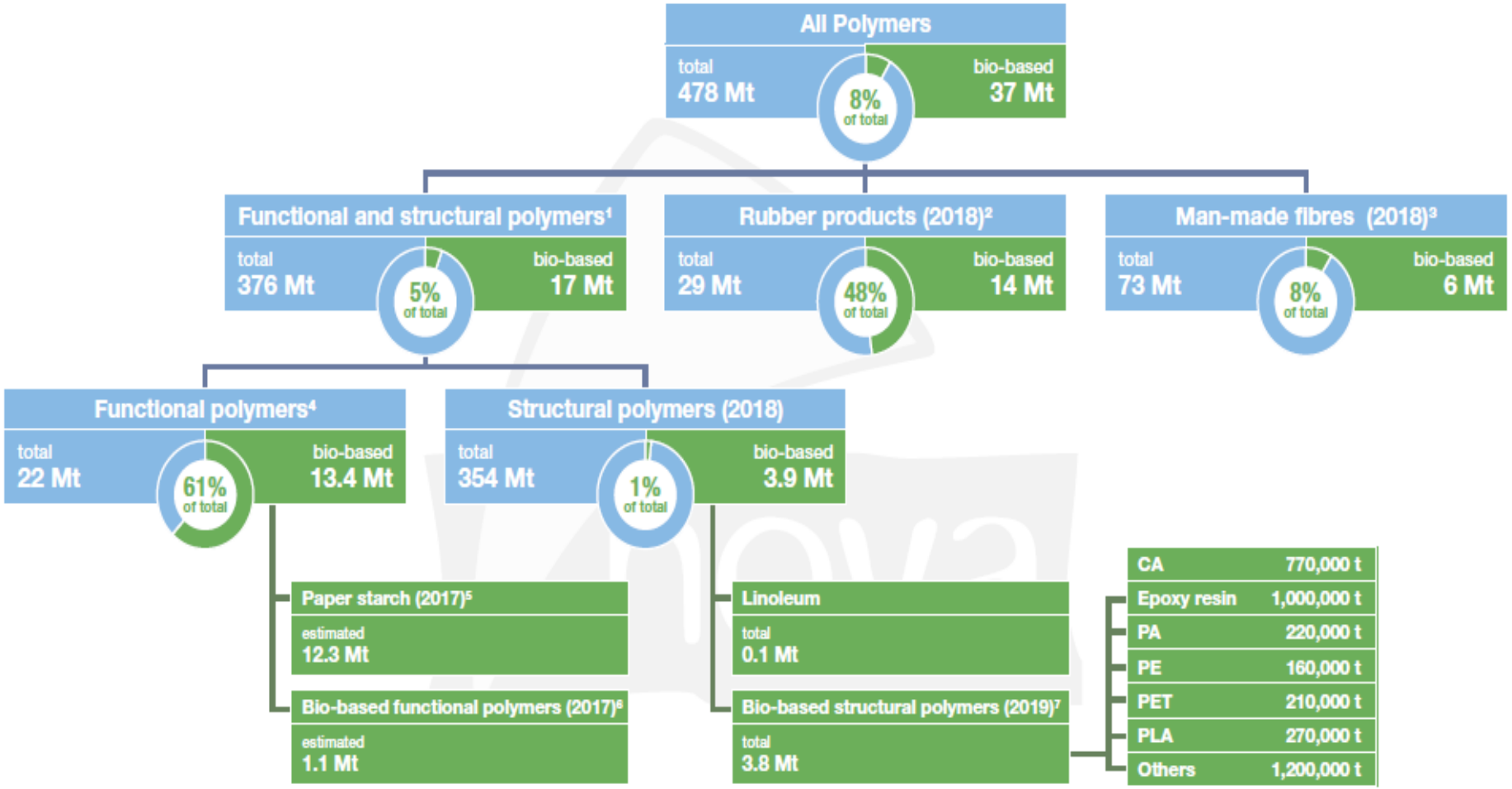
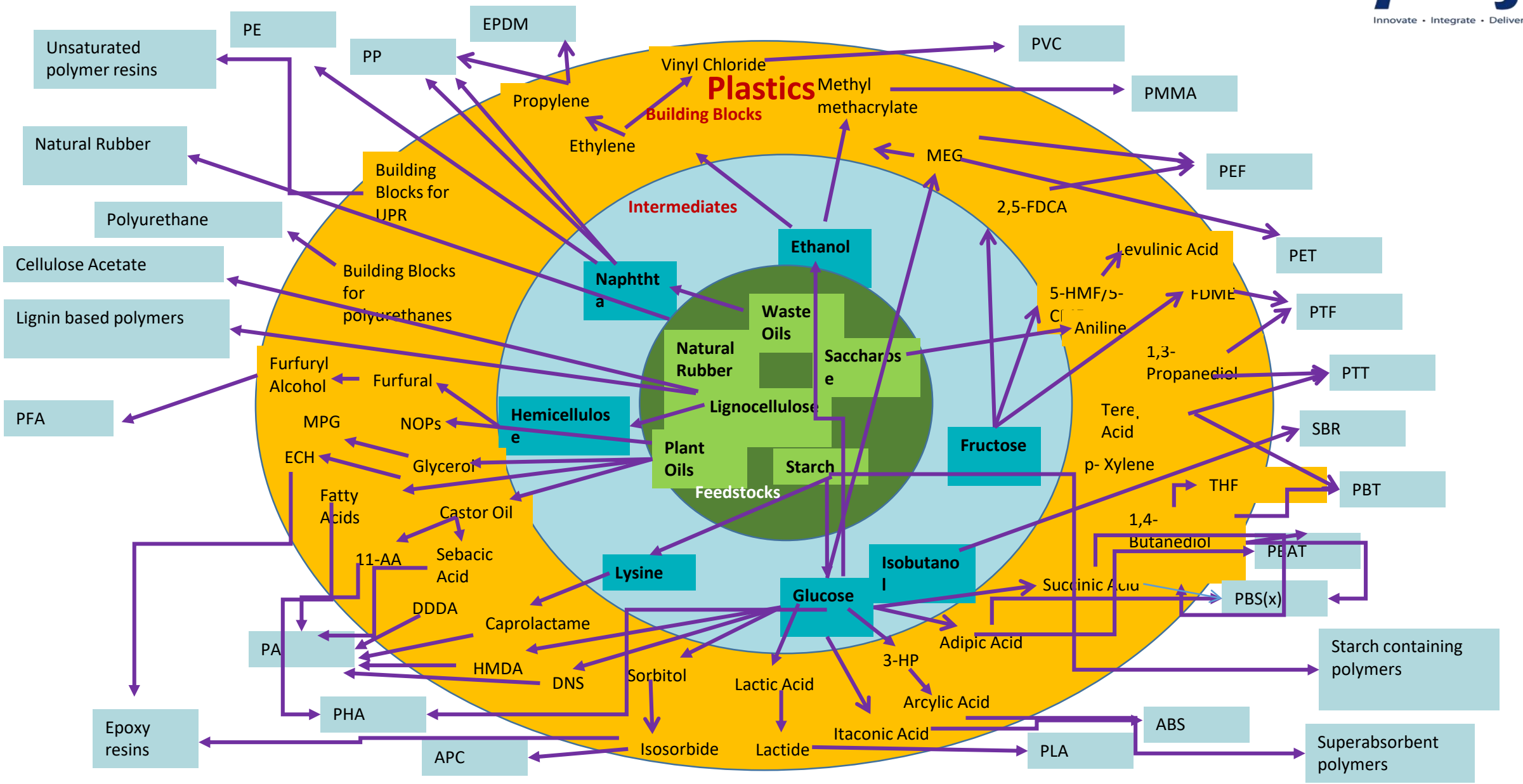
Polymers worldwide : Bio-based share



Sources: ¹ Plastics Europe; ² International Rubber Study Group (IRSG); ³ The Fiber Year 2018; ⁴ Calculations by nova-Institute based on different company and industry reports; ⁵ Calculations by nova-Institute based on CEPI, FAOSTAT, Starch Europe; ⁶ Calculations by nova-Institute based on different industry reports; ⁷ nova-Institute: Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2019–2024, **www.bio-based.eu/reports**

All figures available at
www.bio-based.eu/markets

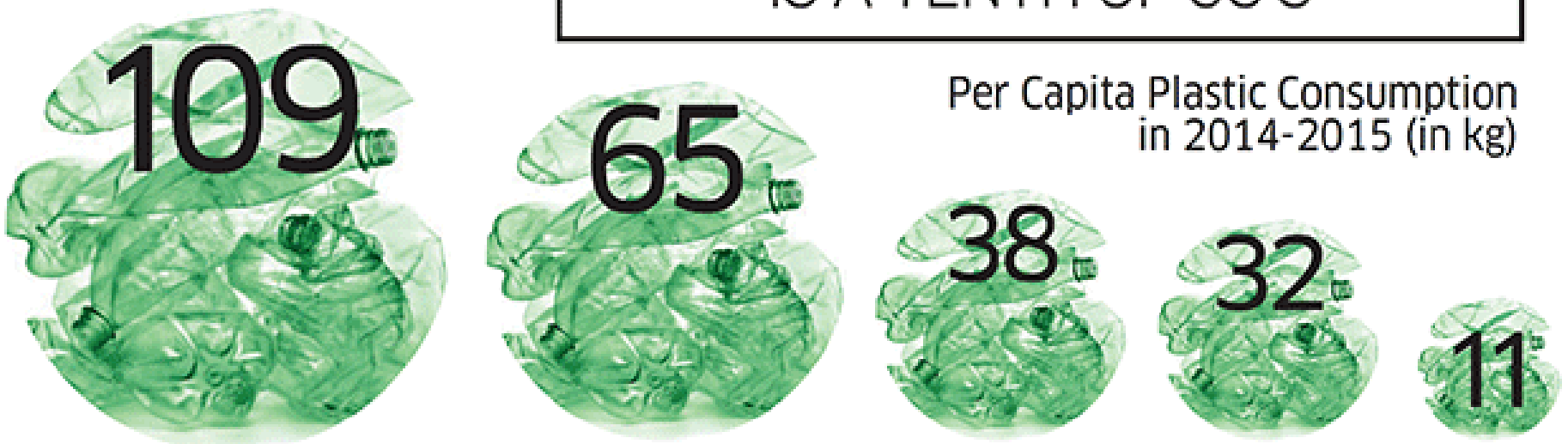
Form Feedstock to Range of Bio-Plastics



Plastics : Per Capita Global consumption

INDIA'S PLASTIC CONSUMPTION IS A TENTH OF US'S

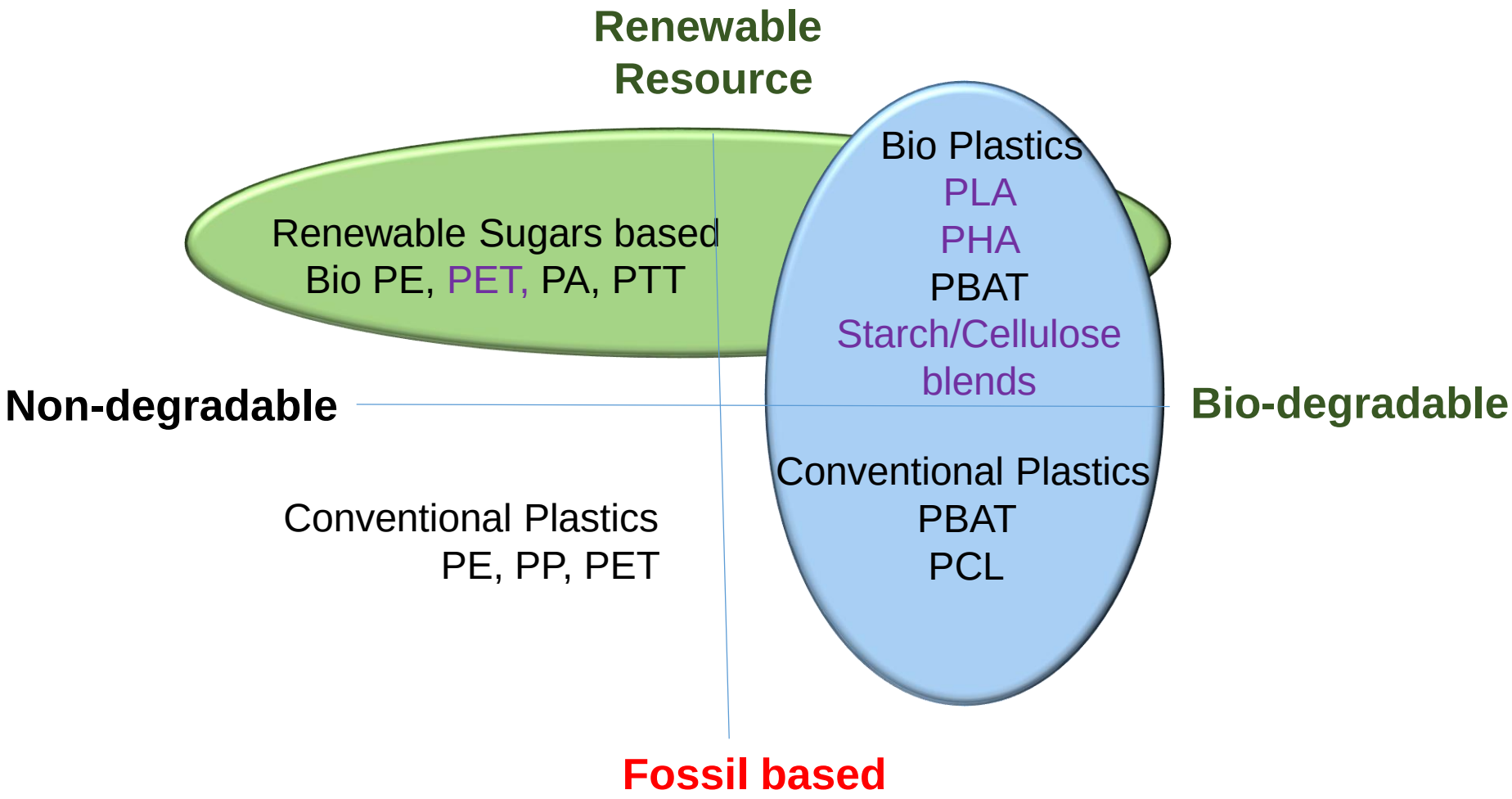
Per Capita Plastic Consumption in 2014-2015 (in kg)



US | Europe | China | Brazil | India

Global Average: **28**

Bio-Plastics : Focus



Displays, Optics, Films

Foams for composites and

Novel Applications (Electronics, Foams, Automotive)

NANOCELLULOSE

CLH/CLiG Composites

Additive to coating and barriers materials

Paper Packaging (Coatings Fillers Films)

Gas barrier aluminium replacement in food packaging

Construction Industry (Cements, Paints, Adhesives)

Reinforcing of acrylic polymers

Cement/Construction/F urnishing

DECONSTRU

NANO-SCAL

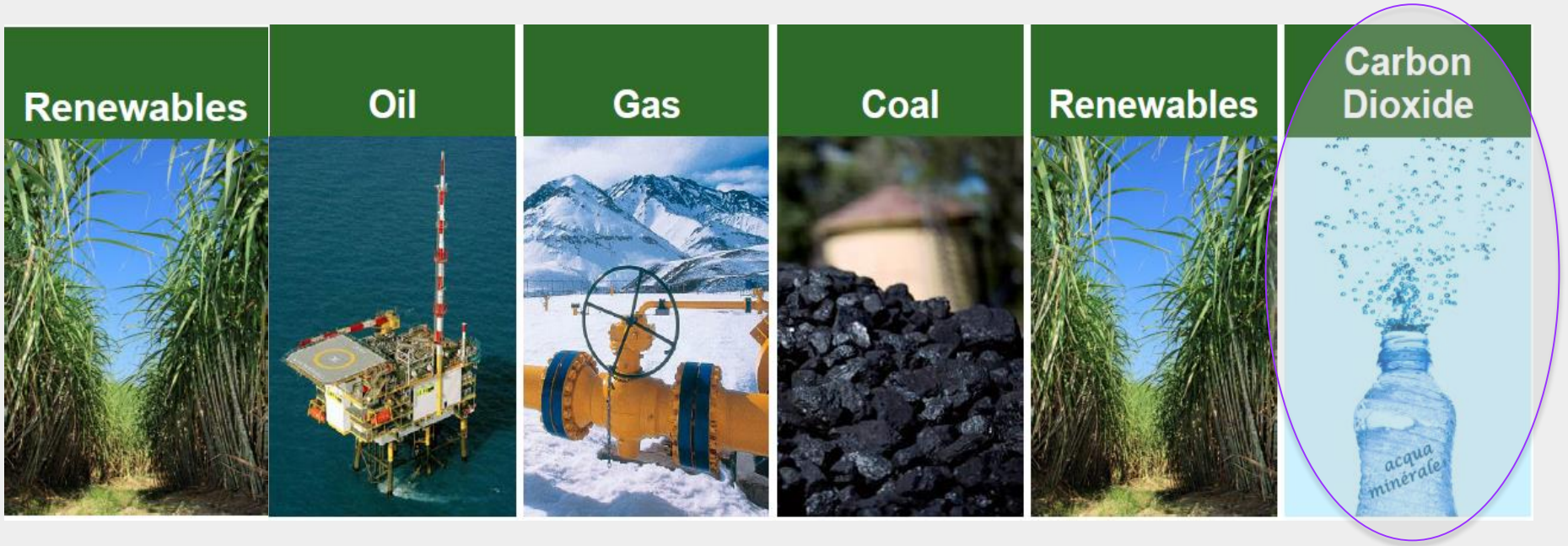
MANY POTENTIAL A

Total Estimate

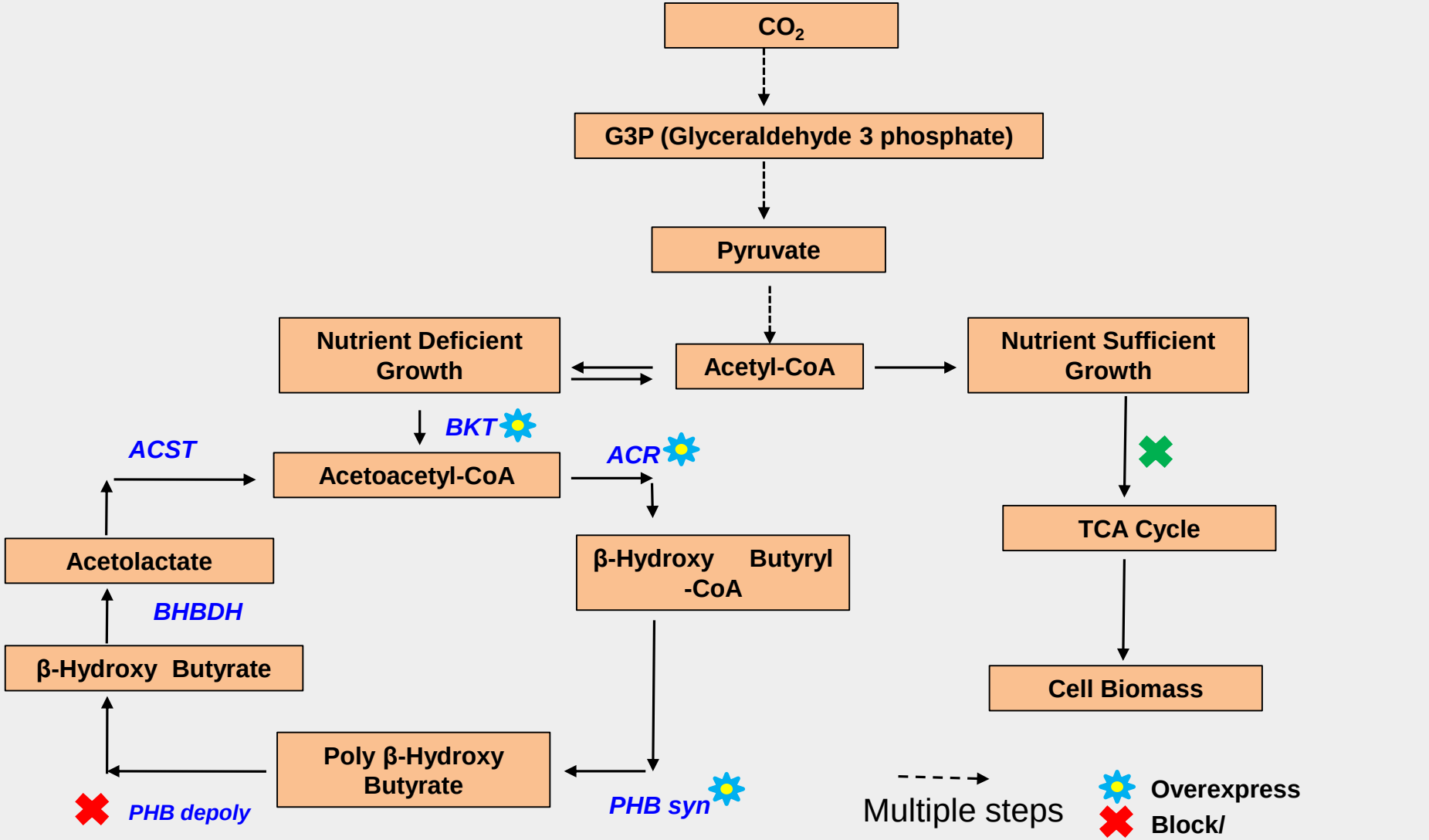
~35 MMT/Year

Additive to plastic (biobased and synthetic)

Future : Carbon Negative Technologies

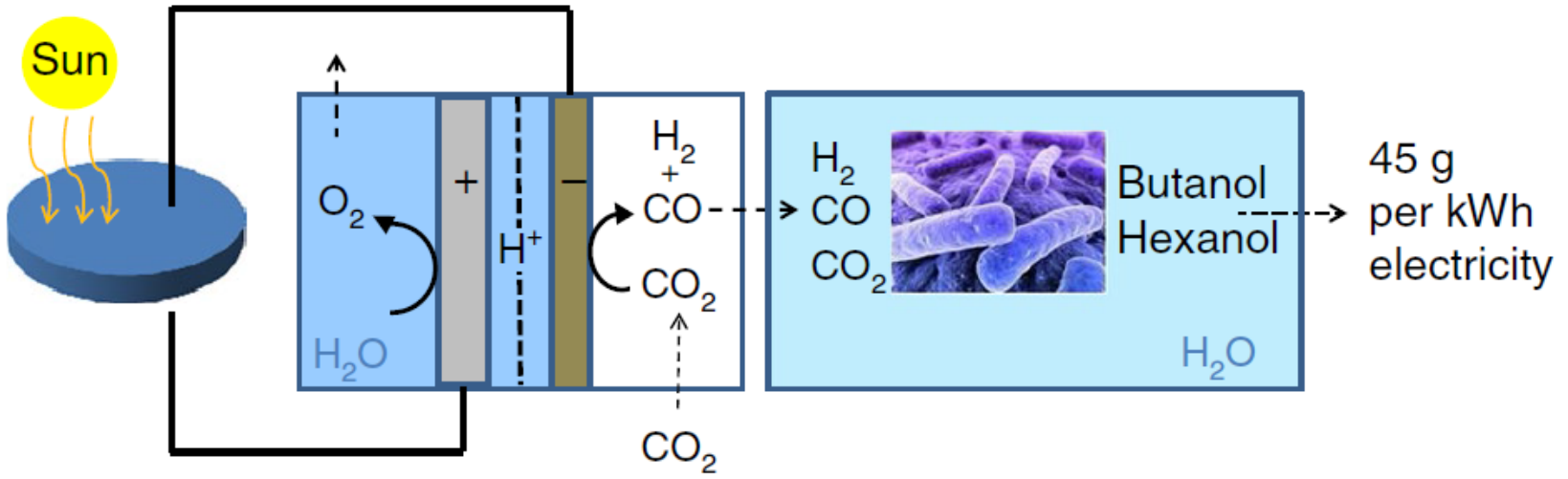


Carbon dioxide to PHB Pathway



BKT Beta ketothiolase, *ACR* Acetyl CoA Reductase
PHB Syn PHB Synthase, PHB depoly: PHB Depolymerase
3HBDH 3 Hydroxy butyrate dehydrogenase,

Future : Carbon Negative Feedstocks



PV cells	**CO_2 and H_2O electrolyser**	**Fermenters**
		Clostridium autoethanogenum + *Clostridium kluyveri*
EE up to 20%	EE-CO up to 47%	
	EE-H_2 up to 70%	EE near 80%
	FE-CO + FE-H_2 near 100%	FE near 100%
Price of 1 kWh PV electricity = 2.5 cents		Price per 45 g alcohol = 5.4 cents

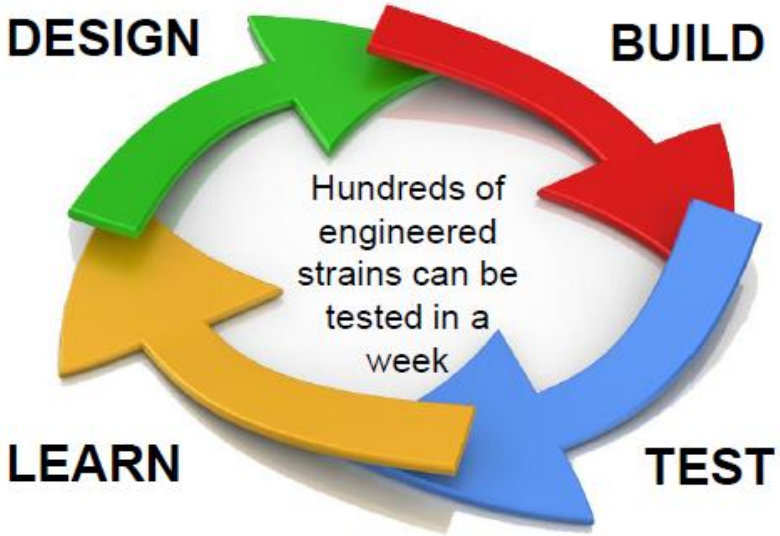
Technical photosynthesis involving CO2 electrolysis and fermentation
Thomas Haas1, Ralf Krause2, Rainer Weber3, Martin Demler1 and Guenter Schmid2*

Nature Catalysis | VOL **32** 1 | JANUARY 2018 | 32–39

Future : Synthetic biology

Computational recepies for the robot to carry out Build and Test phases

Full automation of strain construction and cultivation



Design
Production strains and their parts are designed using computational tools

Construction of production strains
Synthetic DNA is delivered to the cells using genome editing tools such as CRISPR.

Analysis and decisions
Machine learning algorithms can help the researcher to analyse and understand measured data.

Cultivation and measurement
Robots are cultivating the strains and carry out measure-ments. The results are automa-tically stored in databases.

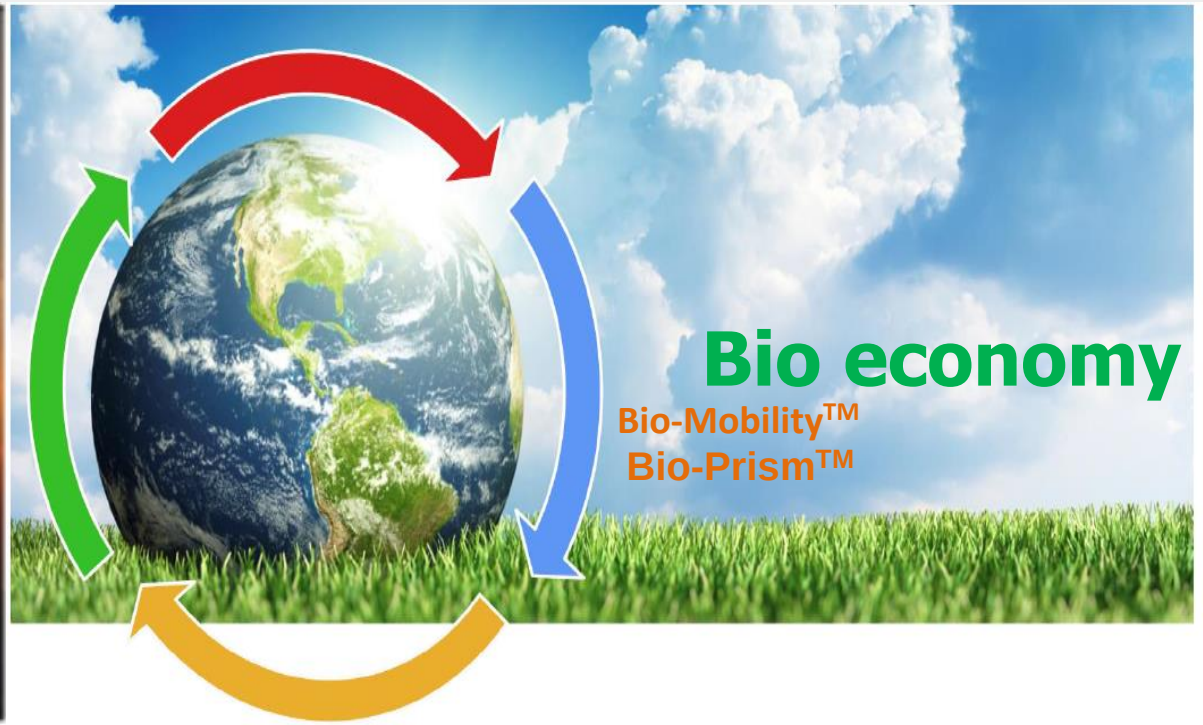
Summary

- Great Potential with Challenges
- Some still may be asking is Bio better Or worse: they assume/believe bio has nothing them to offer
- Some of the “bio-based hype has subsided-But there is still plenty of Buzz and opportunities for growth !!

We, as Praj, are and will make investments thinking about strategic opportunities to be met by bio enabled materials and processes

- Know where are you going
- Begin with the end in mind

There is nothing that biotech can‘t do…..
Today, there is a renewable alternative for almost every conventional material and corresponding application !!



PAST

FUTURE

 pramodkumbhar@praj.net