BIO ECONOMY
U.S. DEPARTMENT OF ENERGY
2017

Production of Naturally Occurring Carboxylic Acids from Anaerobic Digestion of Organic Materials

EARTH ENERGY RENEWABLES

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Typical Bioconversion Processes for Biofuels and Chemicals

Fermentation

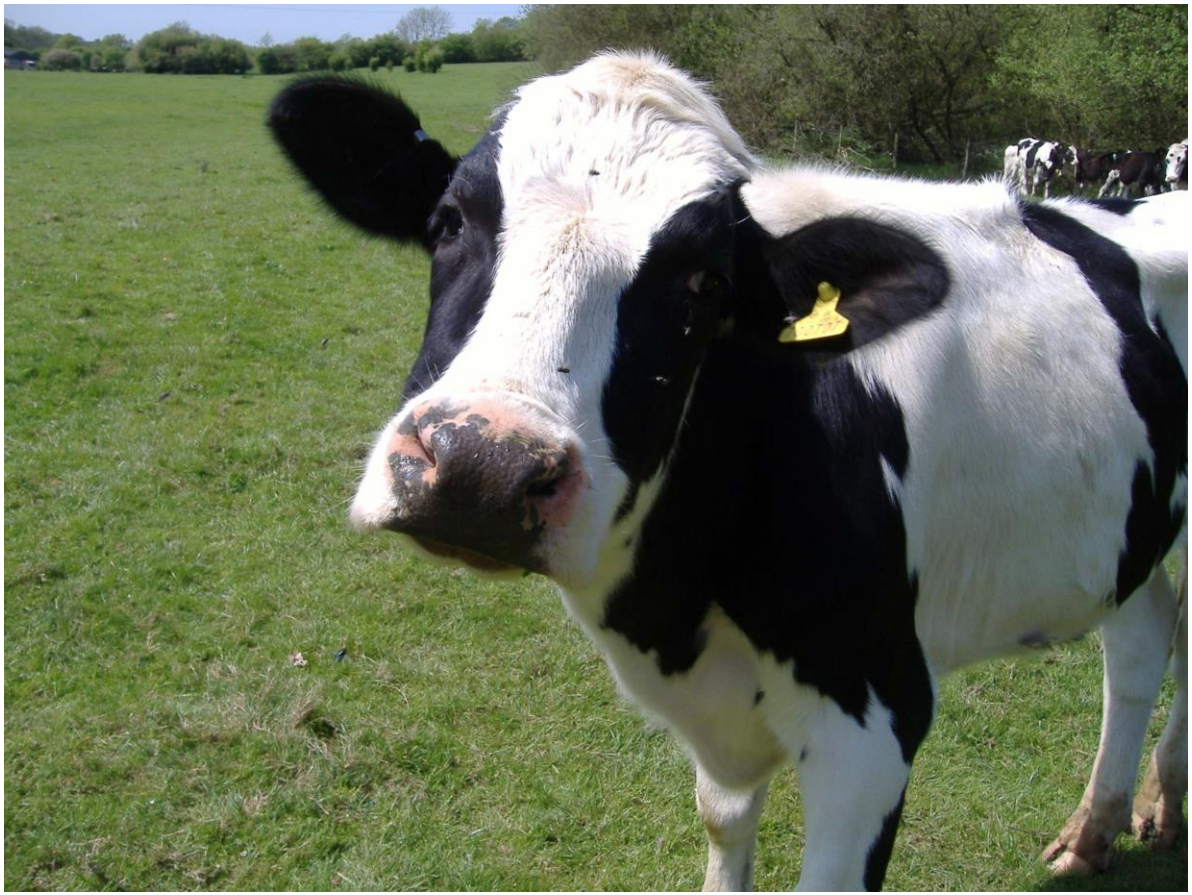
Typical Bioconversion Processes for Biofuels and Chemicals

Pyrolysis/Gasification

Most Common Installed Bioconversion

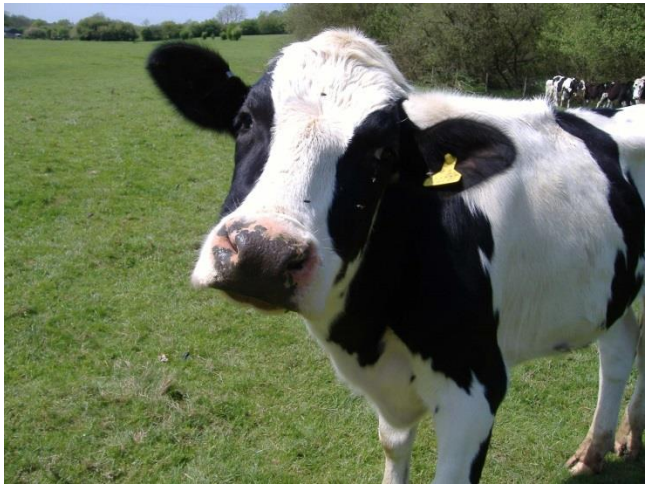
Waste Water Treatment and Anaerobic Digestion

Most common Bioconversion Process

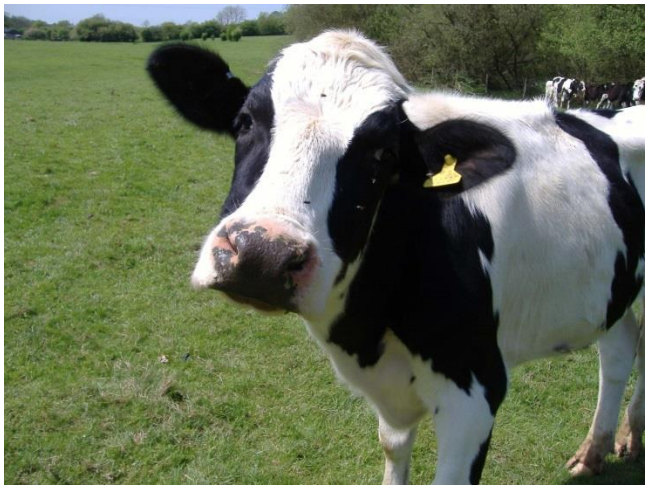


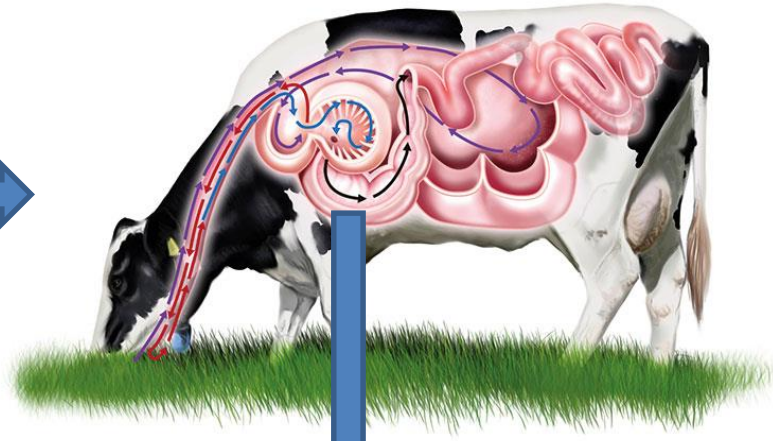
Advantages of Anaerobic Digestion

- Robust non-sterile mixed cultures
- Inexpensive
- Very feedstock flexible
- Natural



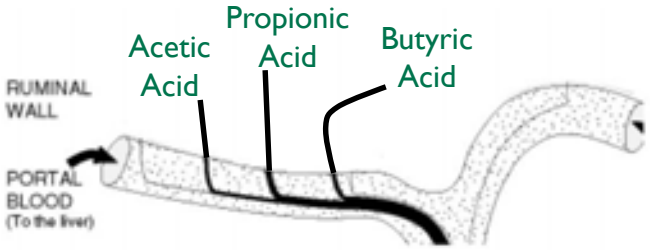
Product from AD in herbivores



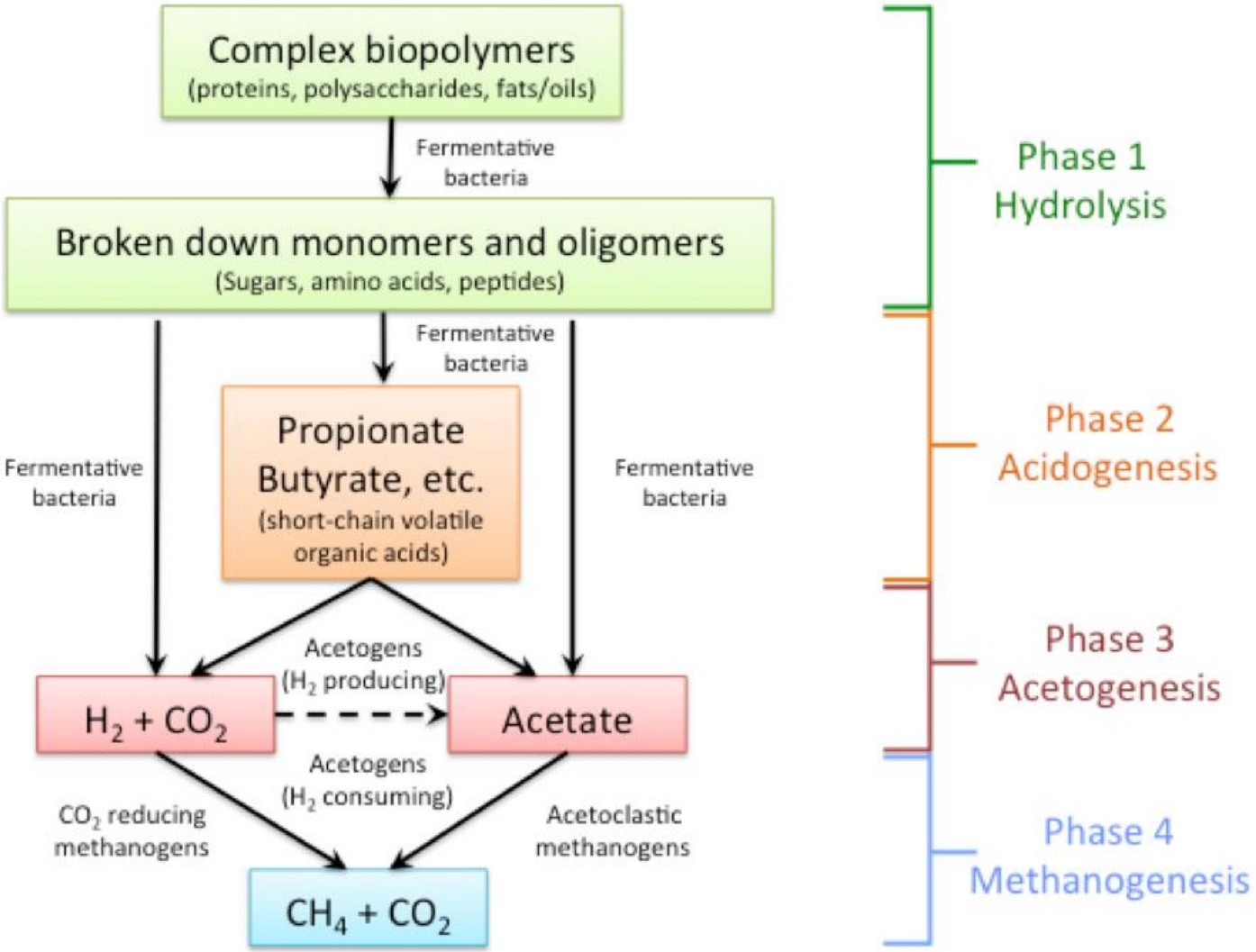


Rumen Bacteria

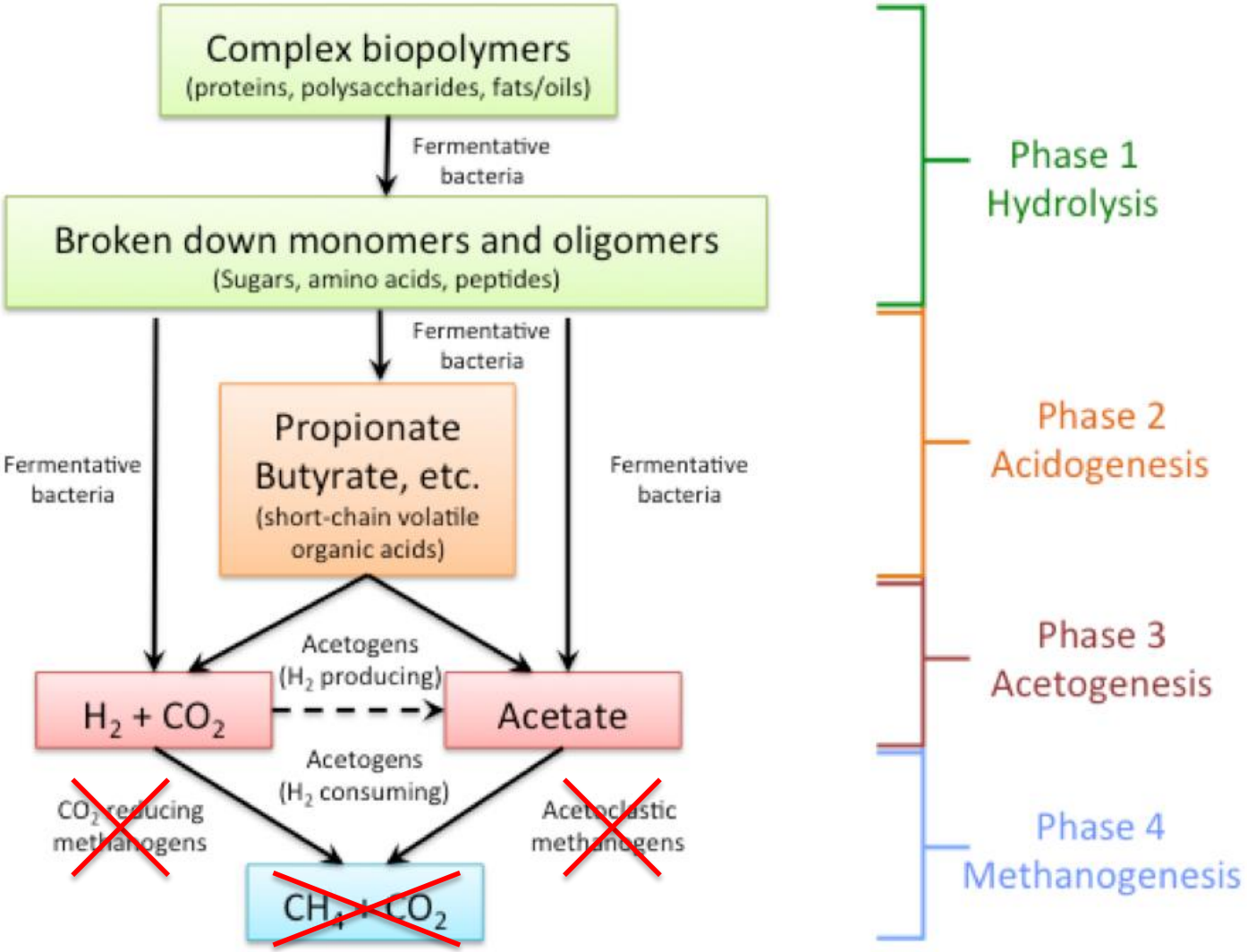
Carboxylic Acids



Anaerobic Digestion Phases



Nature knows best: CH_4 production is avoided or minimized



We have developed a novel but simple and low-cost process to convert bio-degradable materials into high value carboxylic acids

FEEDSTOCK

Food Waste

Orange Peels

Palm Oil Mill Effluent

Crop Waste

Corn Ethanol Stillage

EER CONVERSION

Modified Anaerobic Digestion

Proprietary Extraction

PRODUCTS

$C_2 – C_8$ Fatty Acids

Short- & Medium-Chain Fatty Acids

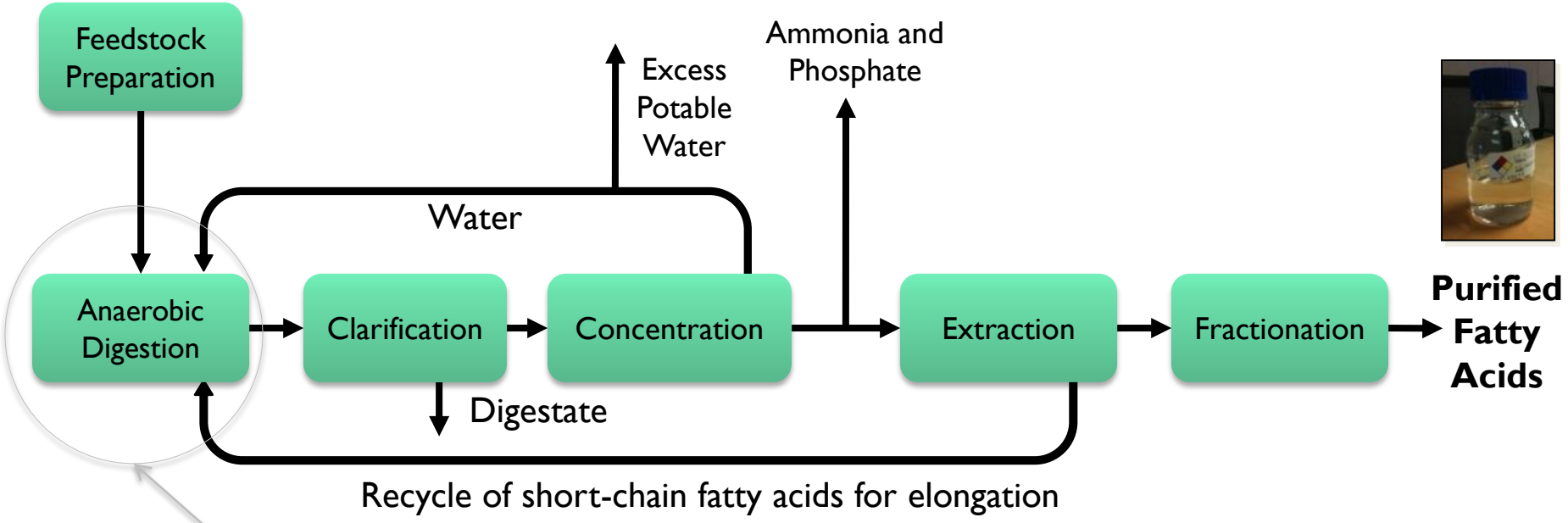
- Acetic acid (C2)
- Propionic acid (C3)
- Butyric acid (C4)
- Isobutyric acid
- Valeric acid (C5)
- Iso-valeric acid
- Caproic acid (C6)
- Heptanoic acid (C7)
- Caprylic acid (C8)

Derivatives

FEEDSTOCK → REFINING PROCESS → INTERMEDIATES → DERIVATIVES

Anaerobic digestion is the heart of the EER process

Innovative integration of mature, well-understood technologies



Anaerobic Digestion

- CH_4 production inhibited
- Non-sterile process, Natural cultures
- Acids thermodynamically favored
- Robust; High yields
- Broth of salts of acids, undigested feed, micro-organisms

Feedstock Flexible = Globally Replicable

Over 30 Feedstocks Tested

- Alfalfa
- Food wastes
- White office paper
- Paper-mill fines
- Sugarcane bagasse
- Pineapple waste
- Glycerol
- Raw Glycerin
- Corn Stover
- Rice Straw
- Cotton gin trash
- Water hyacinth
- Switchgrass
- MSW-Wet organics
- Poplar Wood
- Sugarcane molasses

- Sorghum stalks
- Municipal sewage sludge
- Raw sewage
- Cellulosic municipal solid waste
- Bio-sludge (from chemical plant WWTP)
- Chicken manure
- Cattle manure
- Sugar beet pulp
- Lipid-extracted micro-algae
- Whole micro-algae
- Pulp-mill molasses (wood molasses)
- Orange peels
- Oil Palm empty fruit bunch
- Palm oil mill effluent

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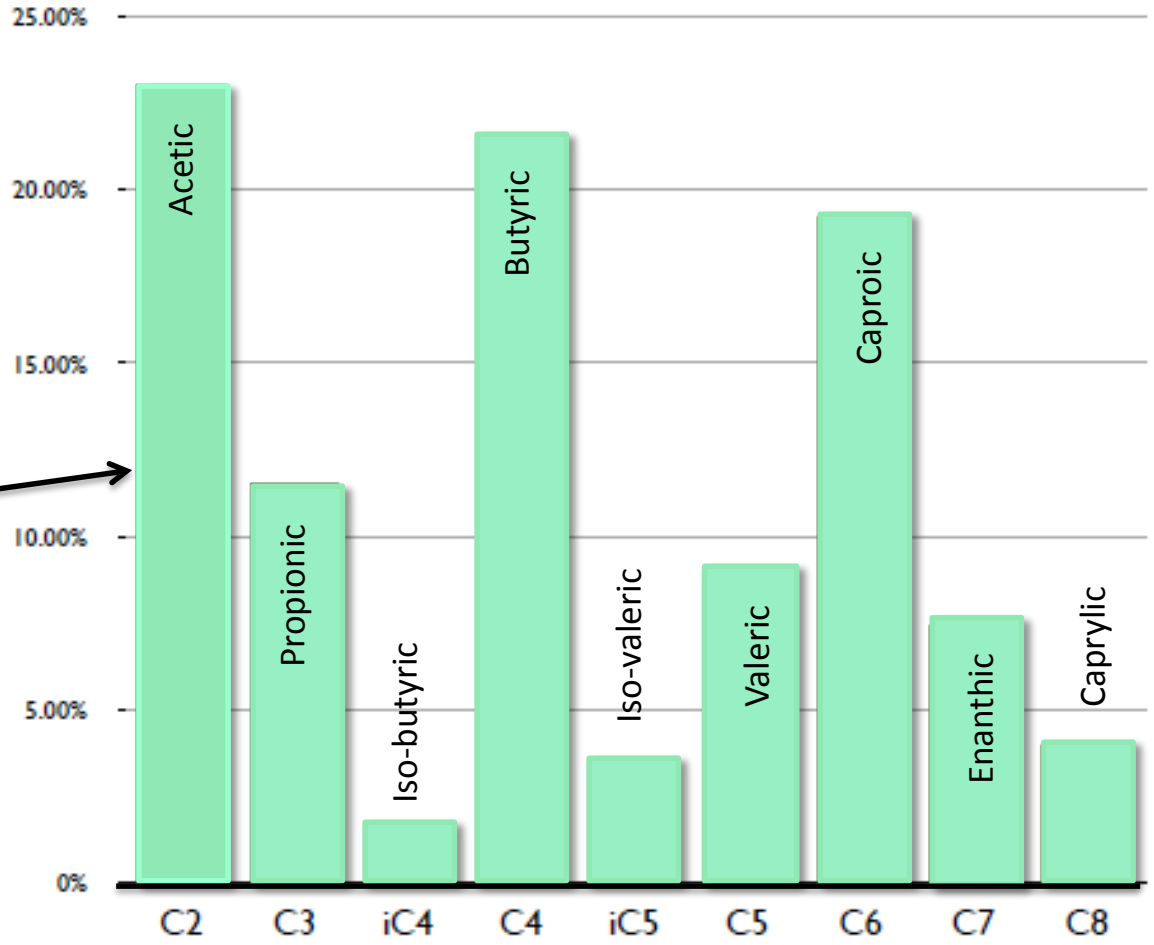
Distribution of C_2 - C_8 acids from food waste (demo)

Typical Fatty Acid Profile in Anaerobic Digestion Broth

Acetic acid can be recycled to elongate it and, thus, eliminate it, thereby increasing C_3-C_8 acids.



The product distribution can be shifted to shorter or higher average chain lengths by employing different feedstocks or modifying operating conditions.

Recovery of acids by extraction and fractionation

Feedstock Preparation

Excess Potable Water

Ammonia and Phosphate

Water

Anaerobic Digestion

Clarification

Concentration

Extraction

Fractionation

Purified Fatty Acids

Digestate

Recycle of short-chain fatty acids for elongation

Extraction

- Proprietary Intellectual Property
- Solvents: Clean; Allow natural prod's.
- Simple, efficient, and effective
- Pure mixed acid stream

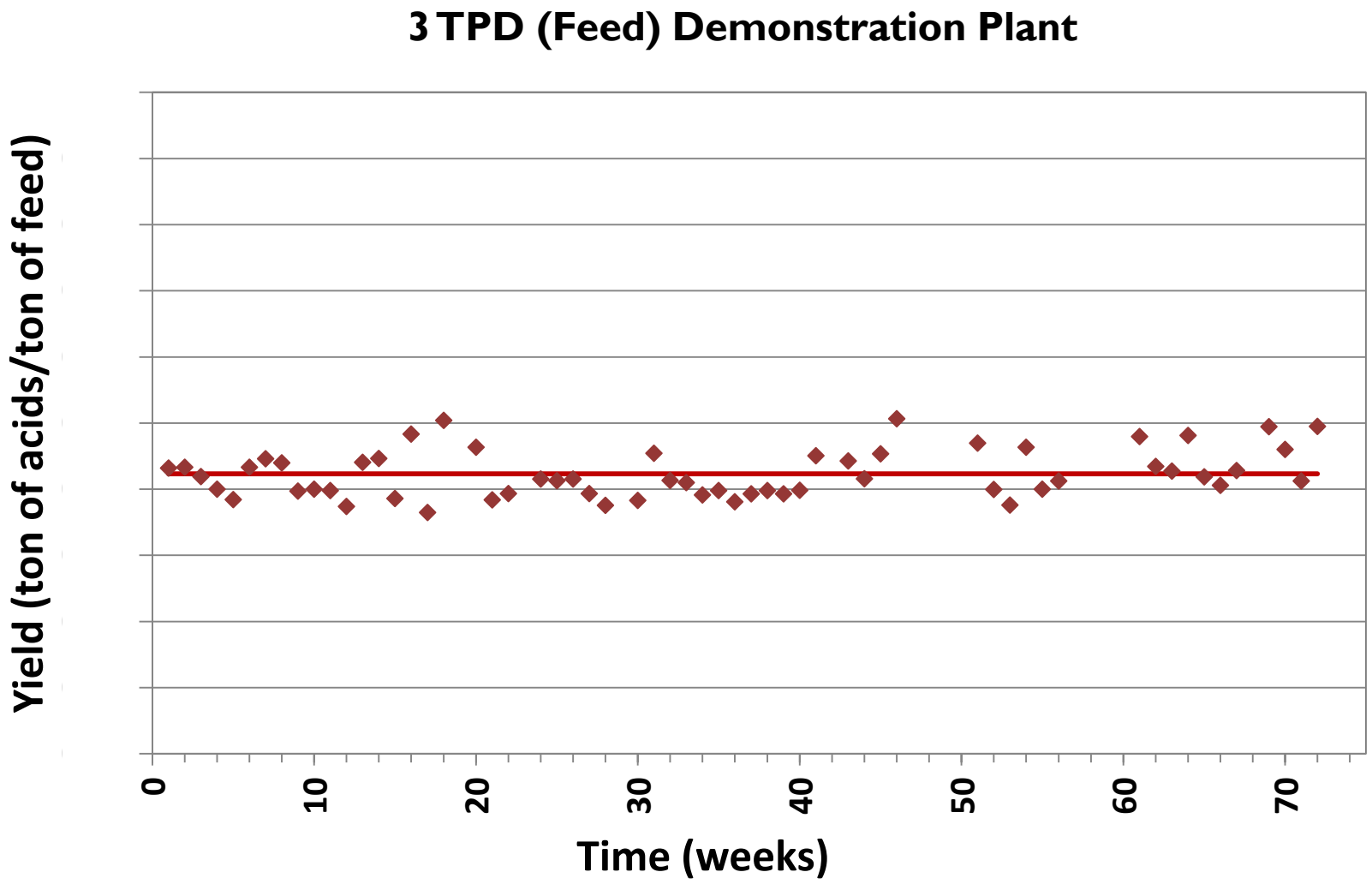
Fractionation

- Distillation
- Separation based on boiling points
- Distinct, purified acid streams

Demonstration Plant

- Field Scale
- Demonstration and Pilot scale operations of process
- Indoor & outdoor operations
- Extensive laboratory capabilities
- 17,000+ hours of operation (fermentation/clarification)

Demostration scale anaerobic digester produced steady and high levels of S/M-chain fatty acids over 72 weeks (12,000 h) of operation



Small- and medium-chain carboxylic acids are used in many applications and sold into both commodity and specialty markets

Propionic Acid

Butyric Acid

Valeric Acid

Caproic Acid

Heptanoic Acid

Caprylic Acid

Animal Feed Supplements
Grain Preservative
Food Preservative
Herbicides
Pharmaceuticals

Cellulose Acetate Butyrate Propionate (CAB/CAP)

Flavor and Fragrance

Neopolyolesters (NPE)

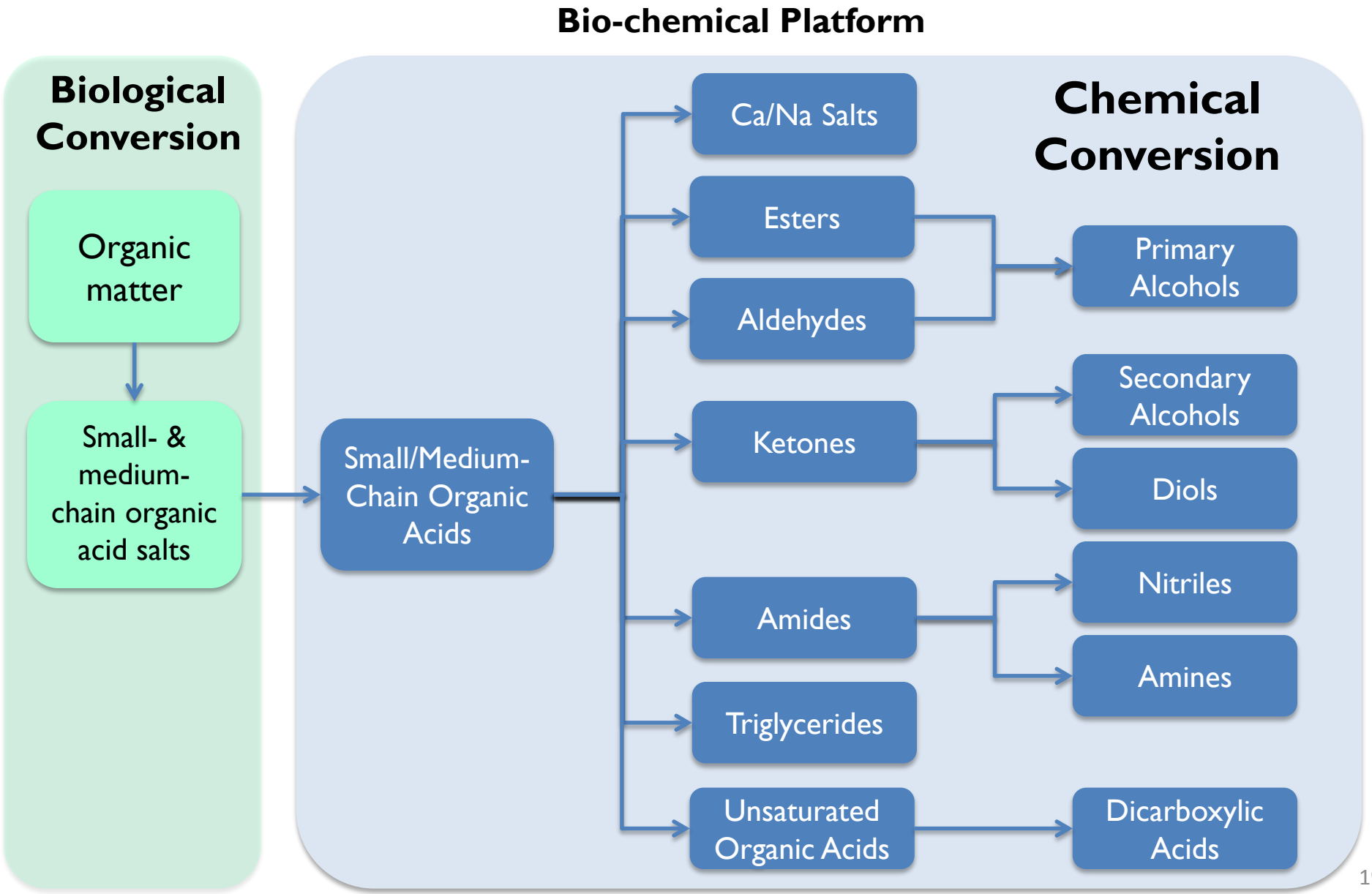
Polyethylene/Propylene Glycol (PEG/PG) Esters

Resins
Rheology Modifiers
Coatings
(Automotive)

Lubricants

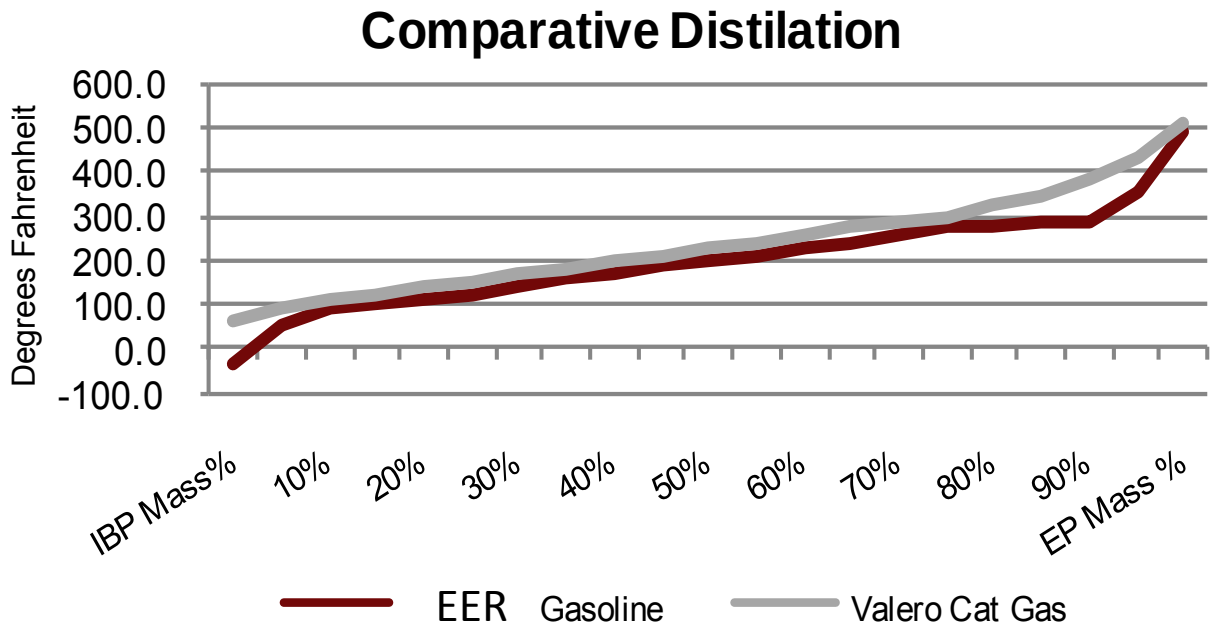
Emulsifiers
Thickeners
Resin Plasticizers
Viscosity Control
Wetting Agent
Emolients

Carboxylic acids are very versatile chemicals



Biofuels

92 octane gasoline based on tests done by Valero



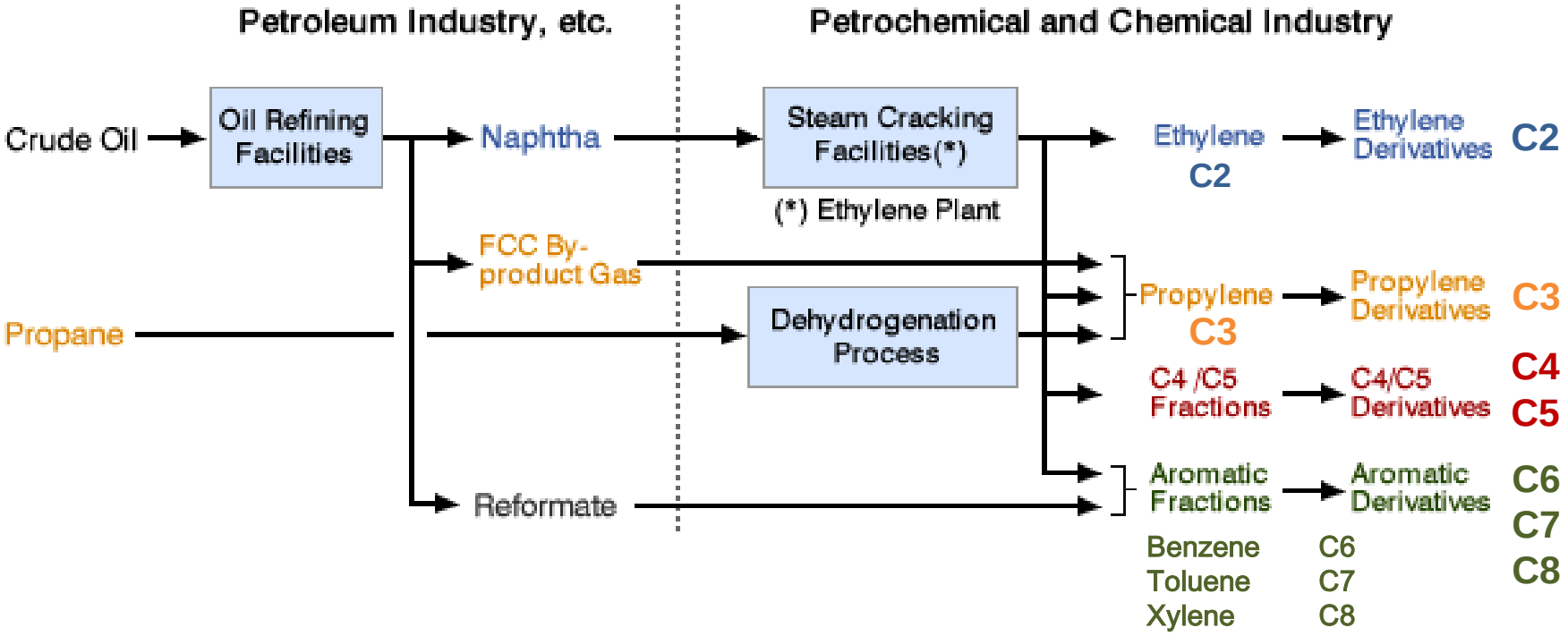
- Initial gasoline produced in Terrabon labs has a distillation range very similar to cat cracker gasoline with 120,000 Btu/gal (35,000 kJ/L)
- Testing was performed in conjunction with CRI Catalysts

Biofuels

JP-8 jet fuel meets or exceeds current industry standards

Sample & Feedstock	MIL-DTL-83133G Specification Requirement	EER's JP-8 from MSW	JP-8 Petroleum 4751
Fuel Property			
Aromatics, vol%	**≤ 25**	**16.7**	**18.8**
Olefins, vol%	≤ 5	0.6	0.8
Heat of Combustion, MJ/Kg	≥42.8	43.1	43.3
Distillation			
IBP (°C)		156	159
10% Recovered (°C)	≤ 205	172	183
20% Recovered (°C)		176	189
50% Recovered (°C)		189	208
90% Recovered (°C)		236	244
EP (°C)	≤ 300	260	265
Residue, % vol	≤ 1.5	1.4	1.3
Loss, % vol	≤ 1.5	0.6	0.8
Properties			
Flash Point (°C)	≥38	52	51
Freeze Point (°C)	**≤ -47**	**-63**	**-50**
API Gravity @ 60 °F	37.0-51.0	46.6	44.4
Density @ 15 °C	**0.775 - 0.840**	**0.794**	**0.804**

A true chemical platform (Petroleum)



FEEDSTOCK → REFINING PROCESS → INTERMEDIATES → DERIVATIVES

A true chemical platform (EER Technology)

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Derivatives

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Markets for derivatives

	Flavor & Fragrance	Animal Feeds	Feed & Food Preservatives	Personal Care, Cosmetics	Herbicides, Pesticides, Fungicides	Pharma	Cleaners, Detergents	Surfactants	Coatings, Adhesives	Plasticers	Solvents, Siccatives	Plastics , Resins	Lubricants	Fuels
Acids/salts	✓	✓	✓		✓			✓	✓	✓	✓		✓	
Esters	✓	✓		✓			✓	✓	✓	✓	✓		✓	
1º alcohols	✓			✓			✓		✓			✓		✓
2º alcohols					✓	✓					✓			✓
Ketones						✓					✓			
Dicarboxylic acids				✓						✓		✓	✓	
Diols				✓	✓							✓	✓	
Amides						✓					✓	✓		
Amines, Nitriles						✓					✓			
Olefins							✓					✓		
Alkanes														✓

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Diols												✓	✓	
Amides						✓					✓	✓		
Amines, Nitriles						✓					✓			
Olefins							✓					✓		
Alkanes														✓

>$500 Billion Global Market

Modest capital requirements together with low operating costs create the potential for substantial investment returns

EER Short- and Medium-Chain Carboxylic Acid Plants Greenfield Builds			
Feed Input, dry tons/day	**30**	**80**	**600**
Feedstock cost, $/dry ton (assume co-location)	$0	$0	$0
Average Product Price, $/kg	$3.00	$3.00	$2.00
Total OPEX (no depreciation), $/yr	$3,332,740	$6,300,452	$23,920,000
EBITDA, $/yr	**$9,369,533**	**$27,572,275**	**$145,444,000**
ROI based on EBITDA	**43.0%**	**61.7%**	**72.4%**
Payback time based on EBITDA	**2.3**	**1.6**	**1.4**
Production cost (no dep) $/ton	**$716**	**$507**	**$257**

- Estimates are based on a greenfield build. Availability of land, infrastructure at feedstock partner facilities offer potential opportunities to reduce capex.
- Co-location with a feedstock provider will significantly reduce capital requirements.

EARTH ENERGY RENEWABLES

Sustainable Platform for the Chemical Industry in the 21st Century

- C2-C8 Carboxylic Acids → Hundreds of valuable products
- Renewable Wet or Dry Organic Feedstocks
- Low-cost Feedstocks and Process (highly profitable)
- Pure and Green EU/US Natural Bio-Based Chemicals
- Funding already organized to attain commercial scale

EARTH ENERGY RENEWABLES

“Simplicity is the ultimate sophistication”

Leonardo Da Vinci