The Next Generation of Biofuels

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Biofuels

Energy source products that are generated from organic raw materials.

Organic materials primarily part of living plants or animals.

Examples:

- **Stems, stalks, and/or roots of grasses or trees**
- **Fruits or seeds of corn or soybeans**
- **Flesh or fats of animals**

1st Generation Biofuels: Two Commercial Products

Ethanol from Corn

Gasoline-Based Engines

Biodiesel from Vegetable Oils

Diesel-Based Engines

1st Generation Biofuel Limitations

Ethanol:

- Compatibility with existing fuels
- Energy density
- Energy transformation efficiency
- Feedstock availability/cost

Biodiesel:

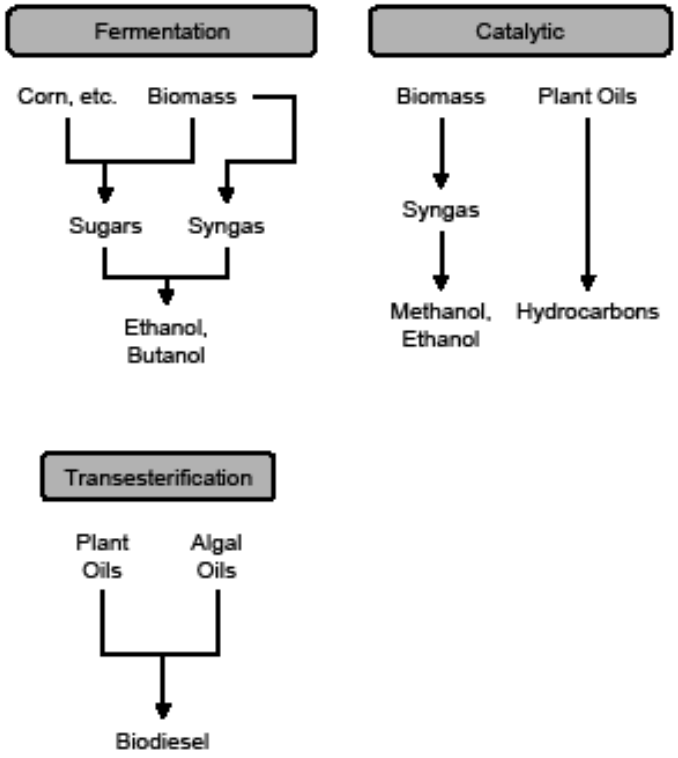
- Cold flow limits
- Energy density
- Stability
- Feedstock availability/cost

Next Generation Biofuel Pathways

- **Biochemical Conversion** - Biomass is broken down to sugars using either enzymatic or chemical processes and then converted to ethanol via fermentation.
- **Thermochemical Conversion** - Biomass is broken down to intermediates using heat and upgraded to fuels using a combination of heat and pressure in the presence of catalysts.
- **Crop Oil Conversion** – Triacyl glycerides/fatty acids/lipids are chemically transformed to fuels

Meeting Key Market and Environmental Criteria

LS9, INC.
the renewable petroleum company™



	Renewable	Scalable	Compatible	Domestic	Economic	Product Diversity
Corn-Based Ethanol	✓			✓		
Cellulosic Ethanol	✓	✓		✓	✓	
Butanol	✓	✓	✓	✓	?	
Oil-Based Biodiesel	✓		✓	✓		
Oil Hydrocracking	✓		✓	✓	?	?
CTL & GTL		✓	✓	✓	?	✓
Renewable Petroleum™ Biofuels	✓	✓	✓	✓	✓	✓

The alternative fuel to ultimately succeed in the market will possess the benefits of petroleum-derived fuels and be renewable, domestically produced, and cost competitive.

** Most commonly discussed alternative fuels; not comprehensive of all possible approaches*

Gregory Pal, LS-9, "BIO World Congress: Panel Discussion", The 5th World Congress on Industrial Biotechnology & Bioprocessing, April 27-30, 2008, Chicago, Illinois

Next Generation Biofuel Pathways

Biochemical Conversion

The Sugar Platform

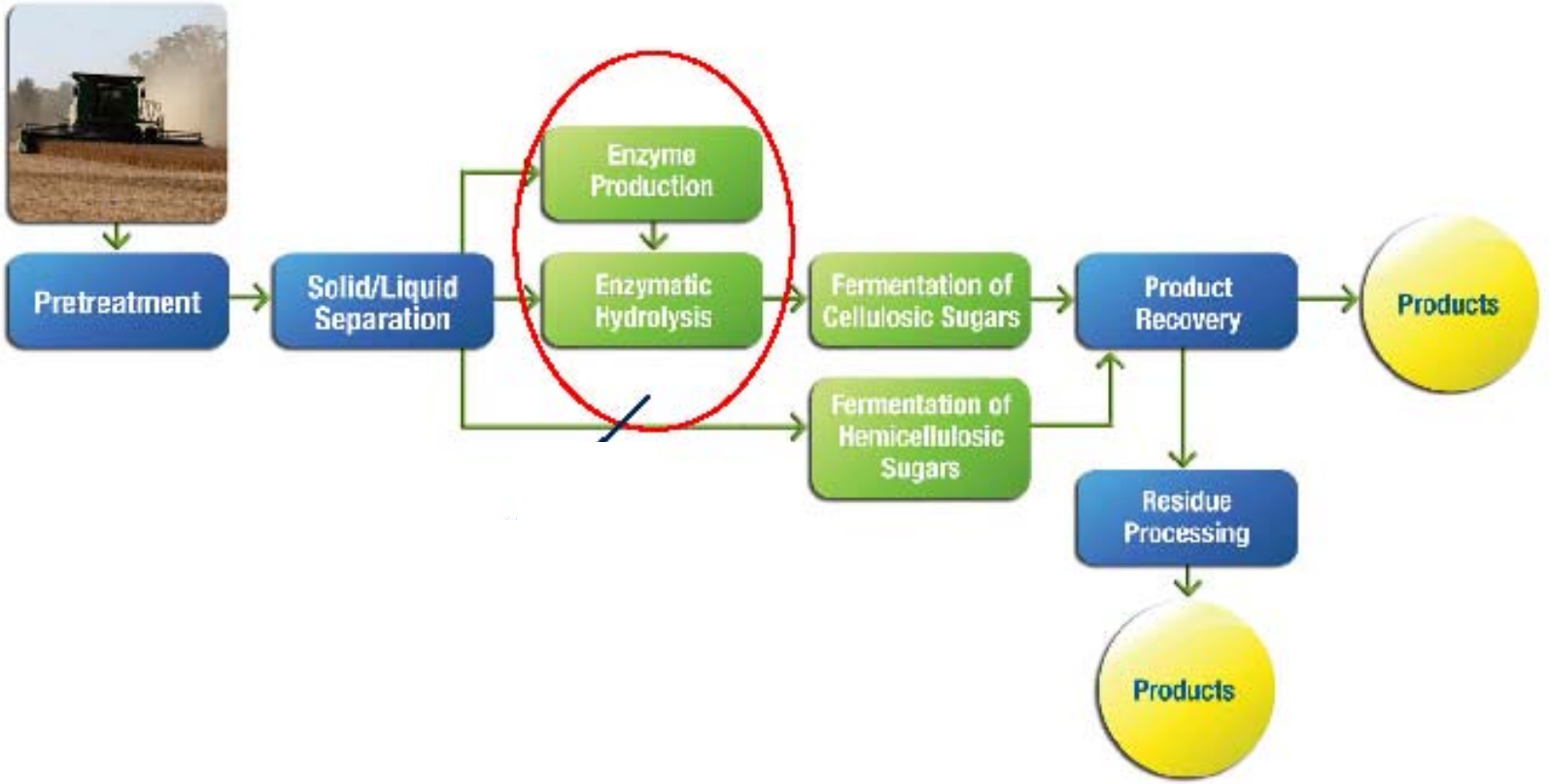
Some examples of current work.

There are MANY others

System (Enterprise) Level Solution

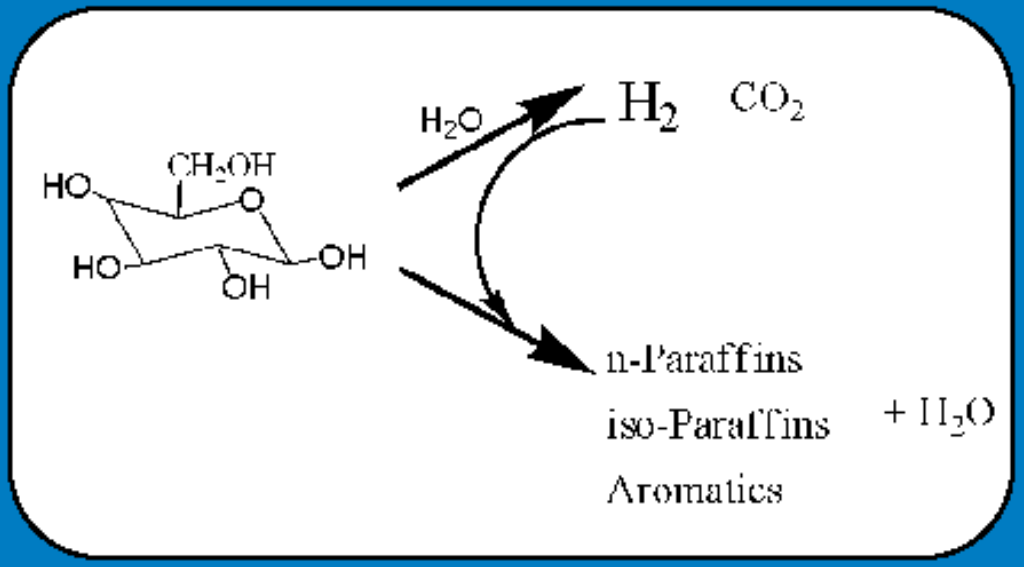
GENENCOR
A Danisco Division

Figure 1: Production of ethanol from cellulosic biomass.



Colin Mitchinson, Genencor, “Development of an Enzyme Product for Cellulosic Biomass Conversion”, The 5th World Congress on Industrial Biotechnology & Bioprocessing, April 27-30, 2008, Chicago, Illinois

Generation of Hydrocarbons from Sugar with In-situ Hydrogen Generation



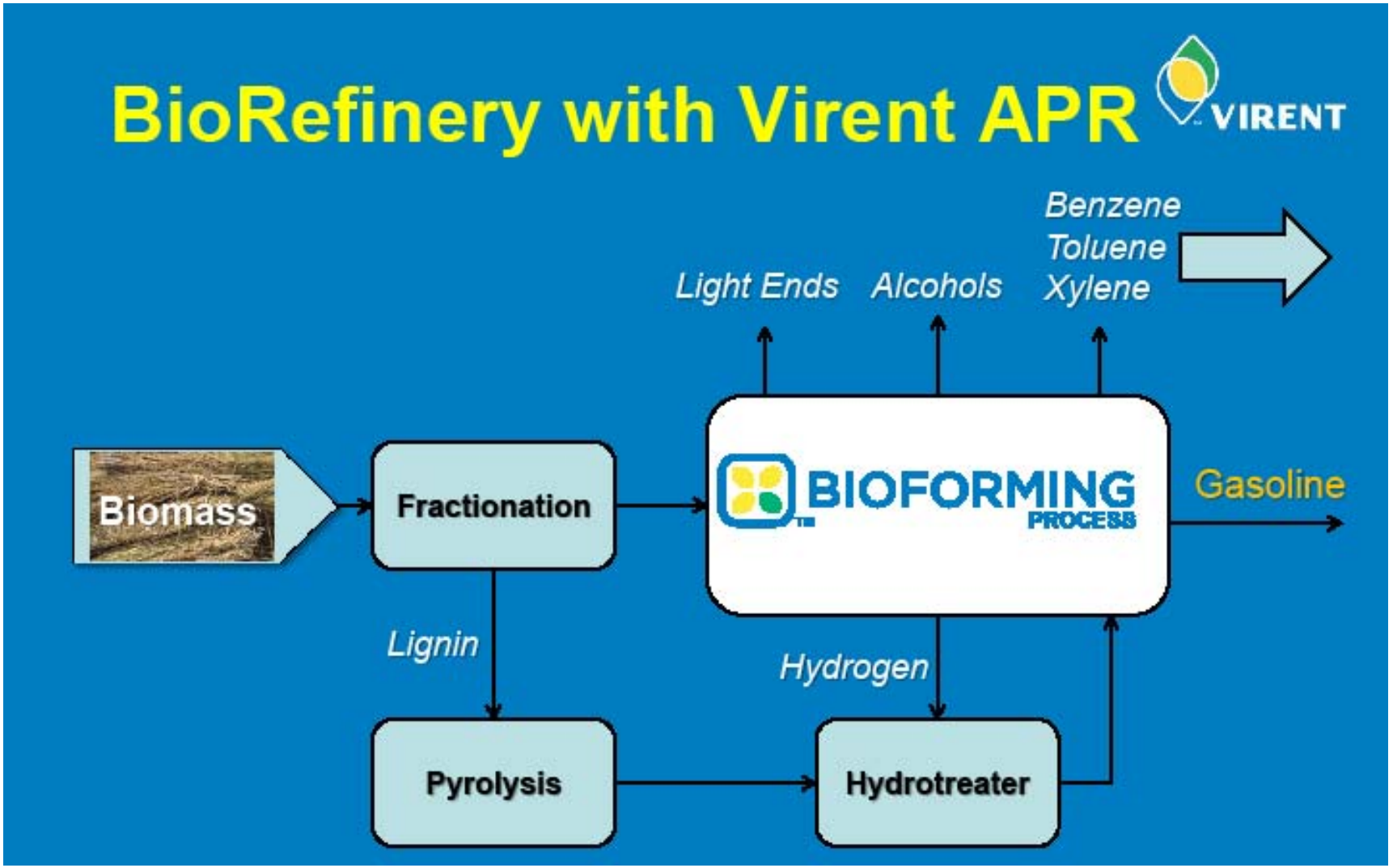
Overall Theoretical Stoichiometry

$3.58\ C_6H_{12}O_6 \rightarrow C_{14}H_{30} + 7.5\ CO_2 + 6.5\ H_2O$

Hydrocarbon contains 65 % of Sugar Carbon

Hydrocarbon contains 94% of LHV of Sugar

Randy Cortright, Virent Energy Systems, “Liquid-Fuel Generation from Sugars Utilizing Aqueous-Phase Reforming”, The 5th World Congress on Industrial Biotechnology & Bioprocessing April 27-30, 2008, Chicago, Illinois

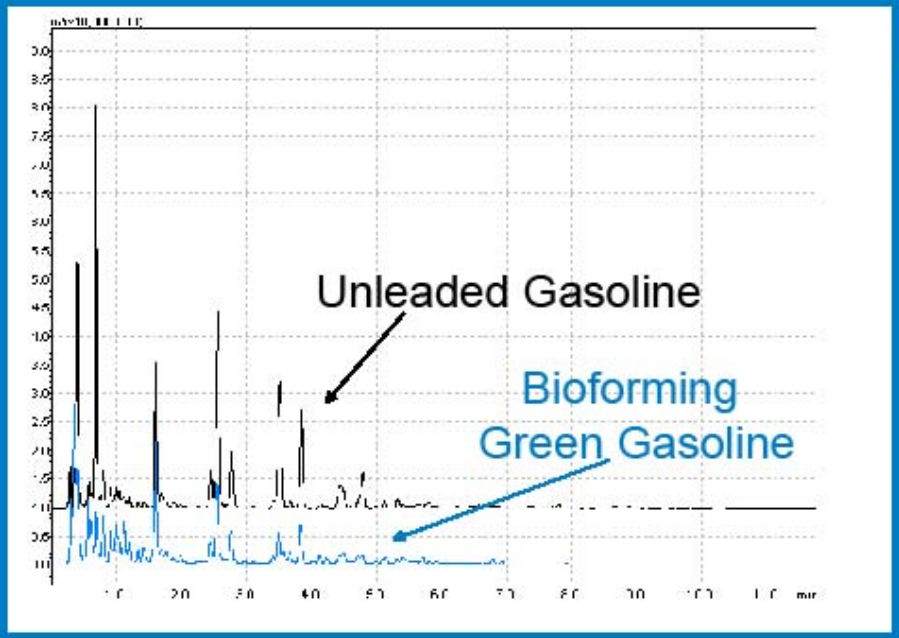


Randy Cortright, Virent Energy Systems, “Liquid-Fuel Generation from Sugars Utilizing Aqueous-Phase Reforming”, The 5th World Congress on Industrial Biotechnology & Bioprocessing April 27-30, 2008, Chicago, Illinois

Bio-Gasoline Composition

VIRENT

Same Components as Standard Unleaded Gasoline



Unleaded Gasoline
115,000 BTUs/Gal

Bioforming
Green Gasoline
115,000 BTUs/Gal

Ethanol
76,000 BTUs/Gal

Randy Cortright, Virent Energy Systems, “Liquid-Fuel Generation from Sugars Utilizing Aqueous-Phase Reforming”, The 5th World Congress on Industrial Biotechnology & Bioprocessing April 27-30, 2008, Chicago, Illinois

Next Generation Biofuel Pathways

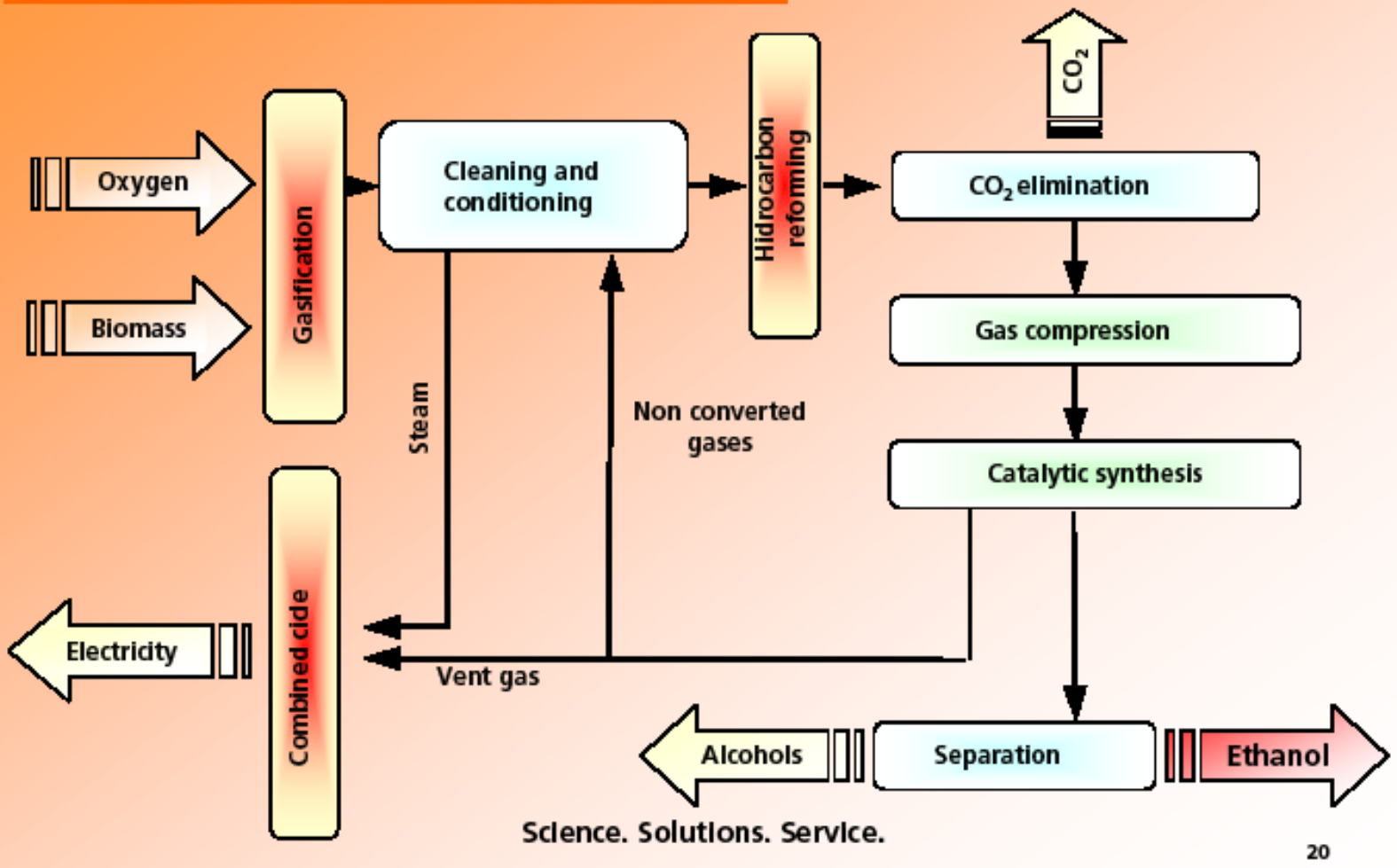
Thermochemical Conversion

Gasification Example

ABENGOA BIOENERGY
NEW TECHNOLOGIES

Thermochemical Pathway

Gasification and Catalysis Process



Science. Solutions. Service.

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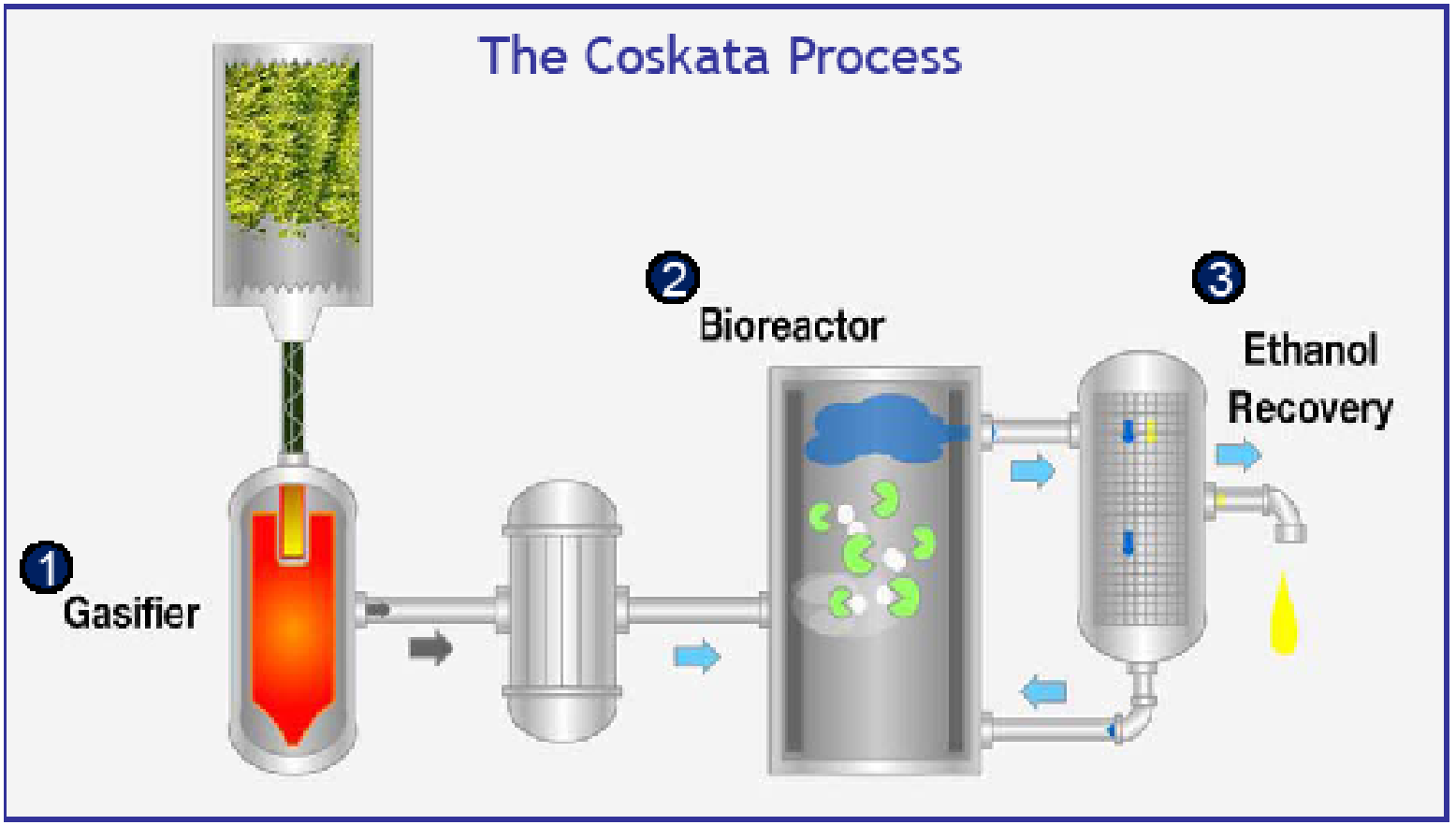
Gerson Santos, Abengoa, “Next Generation Biofuels: An Abengoa Market Perspective”, The 5th World Congress on Industrial Biotechnology & Bioprocessing, April 27-30, 2008, Chicago, Illinois



William Roe, Coskata, “Coskata’s Vision”, The 5th World Congress on Industrial Biotechnology & Bioprocessing, April 27-30, 2008, Chicago, Illinois

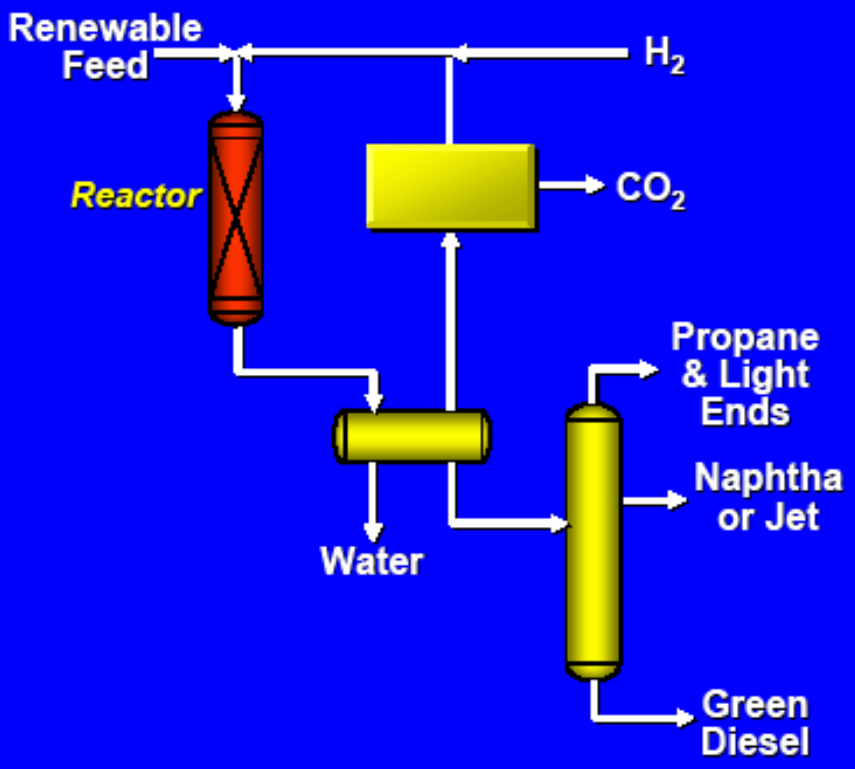
Next Generation Biofuel Pathways

Crop Oil Conversion

1. **UOP Example**

2. **Our Work**

Simplified Process Flow Diagram



UOP/ENI Ecofining™ Process

- Extension of catalytic hydroprocessing used in petroleum refineries
- Complete deoxygenation 100% conversion to paraffinic hydrocarbon
- High selectivity to diesel
- Diesel quality controlled by isomerization of paraffins
- Propane, Naphtha co-products
- Water and CO_2 byproducts

Tom Kalnes, Terry Marker, David Shonnard, and Kenneth Koers, "Life Cycle Assessments for Green Diesel Production", The 5th World Congress on Industrial Biotechnology & Bioprocessing April 27-30, 2008, Chicago, Illinois

Process Chemistry

C=C saturation

Hydrodeoxygenation

$$C_n\,COOH \xrightarrow[\text{Catalyst}]{3H_2} nC_{n+1} + 2H_2O$$

Hydroisomerization

$$nC_{n+1} + nC_n \xrightarrow[\text{Catalyst}]{} iC_{n+1} + iC_n$$

Decarboxylation

$$C_n\,COOH \xrightarrow[\text{Catalyst}]{} nC_n + CO_2$$

$$CO_2 + H_2 \underset{\text{Catalyst}}{\rightleftharpoons} CO + H_2O \quad \text{Water Gas Shift}$$

UOP 4963-07

Tom Kalnes, Terry Marker, David Shonnard, and Kenneth Koers, “Life Cycle Assessments for Green Diesel Production”, The 5th World Congress on Industrial Biotechnology & Bioprocessing April 27-30, 2008, Chicago, Illinois

SUNRISE

SUstainable e**N**ergy
Research **I**nitiative **&** **S**upporting **E**ducation

An interdisciplinary cluster of North Dakota researchers committed to solving complex energy related problems.

25 Faculty in 12 Departments
One Spin-off Company (SUNRISE Renewables)

NDSCS UND NDSU Mayville State University

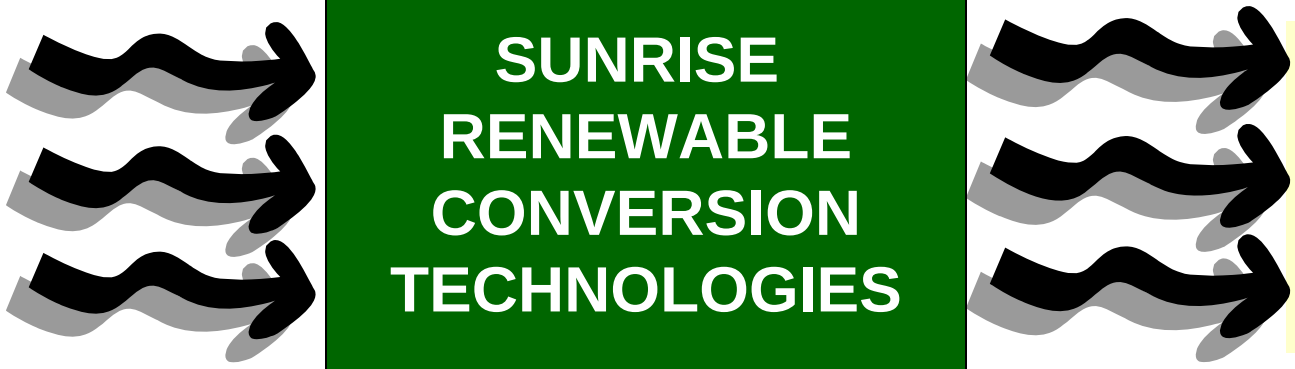
Research Programs

- Sustainable Coal Utilization
  - DOE EPSCoR IIP
- Crop Oil Conversion Technologies
- Energy from Diffuse Sources (wind/solar)

OUR VISION
THE CROP OIL REFINERY

Multiple Feedstocks

Canola
Soybean
Corn
Cottonseed
Jatropha
Jojoba
Linseed
Tallow-Beef
Tung oil



SUNRISE RENEWABLE CONVERSION TECHNOLOGIES

Multiple Products

Syngas
LPG
Gasoline
Jet Fuel
Diesel
FA Chemicals
Aromatics

COMMERCIAL PARTNERSHIP

Sunrise Renewables

GAS
Global Agricultural Solutions

Kadrmas Lee & Jackson
Engineers Surveyors Planners

NWM
NORTHWOOD MILLS

BAYER
Bayer CropScience

CROWN
Crown Iron Works Company

Where We Are

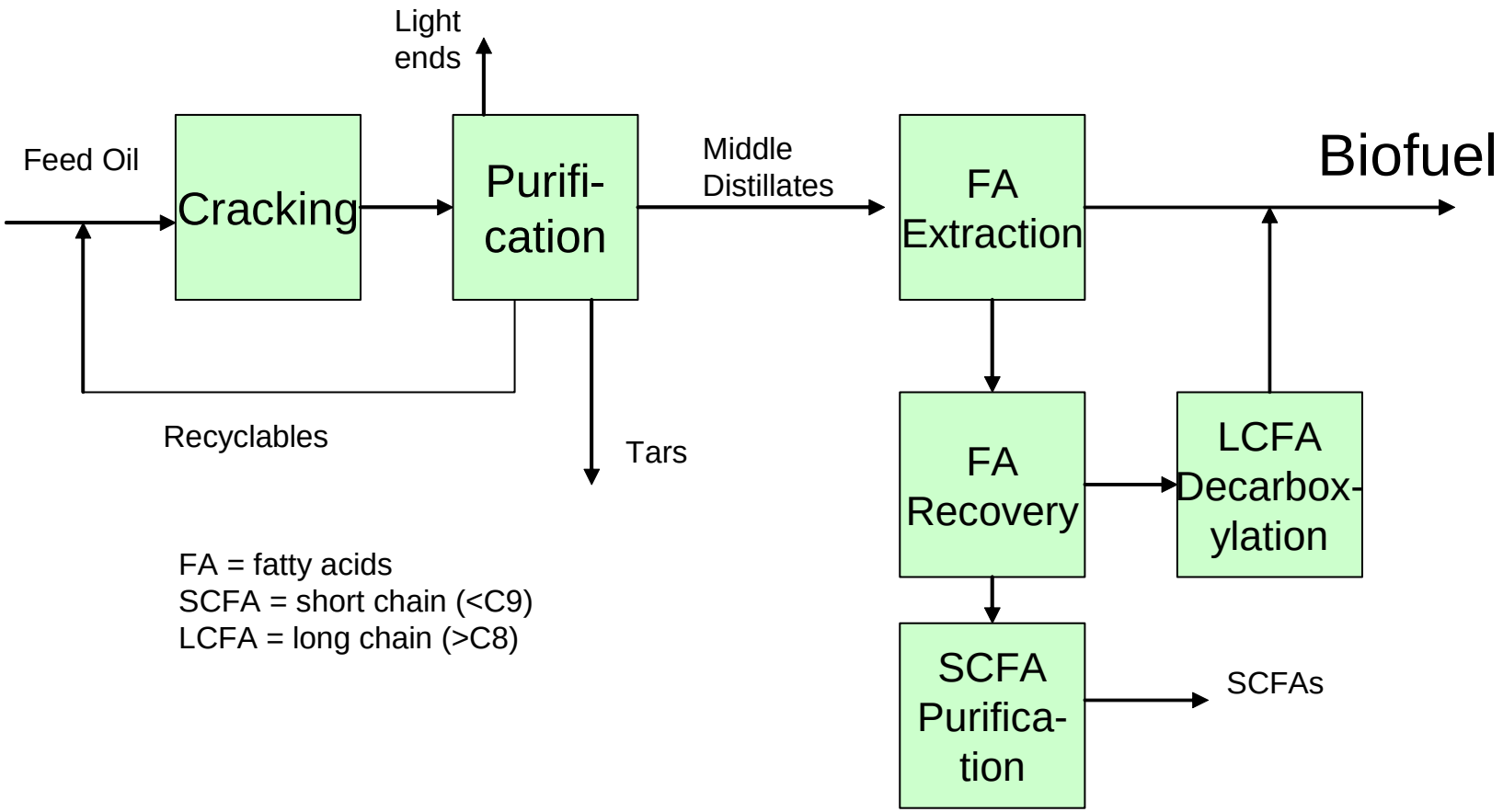
OFFICES: UND Technology Incubator
4300 James Ray Drive, Suite 175
Grand Forks, North Dakota

The Pilot Plant facility is the right hand portion of the building.

The Center of Excellence in Life Sciences and Advanced Technologies (COELSAT), a 50,000 SF2 facility is being constructed on UND's West Campus in UNDRF's Research Enterprise and Commercialization (REAC) Park.

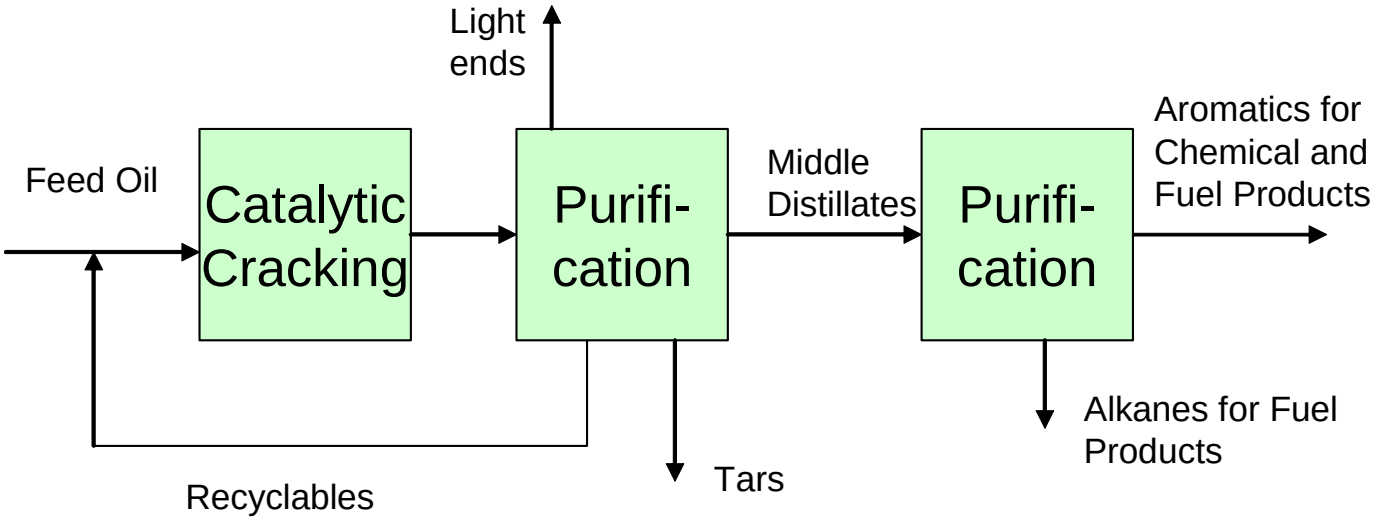
Northwood Mills - first demonstration facility site.

Biofuel from crop oil with fatty acid extraction



FA = fatty acids
SCFA = short chain (<C9)
LCFA = long chain (>C8)

Biojet fuel from Crop Oil Maximizing Aromatic Chemical Production



STATUS

- Base Biofuel Process:
  - 90 gallon per hour feed capacity pilot scale facility under construction
  - Samples of biojet fuel with USAF research lab to certify compliance with JP-8 specifications
- SCFA By-Product Process: bench scale optimization and evaluation
- Aromatics By-Product Process: lab scale research complete – bench scale planned

Conclusions

- Next generation biofuels will become commercial in the next 2-5 years
- Viable processes from all three pathways are predicted
  - Biochemical, Thermochemical, Crop Oil Conversion
- Next generation biofuels will overcome many of the limitations of the two existing biofuel products

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