ALBEMARLE®

GoBio™

The Future of Biofuels

KIVI, Den Haag, 13 December 2011

Dr Frans L Plantenga

Albemarle Alternative Fuel Technologies

FUELING THEIR FUTURE

Albemarle Overview

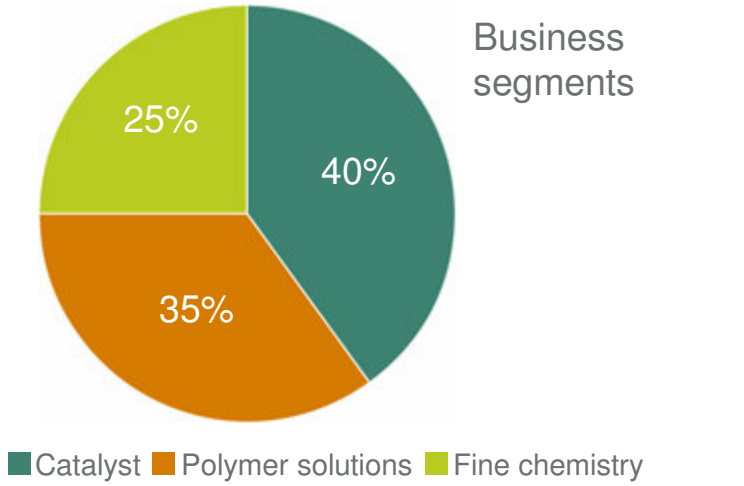
Chemistry solution provider

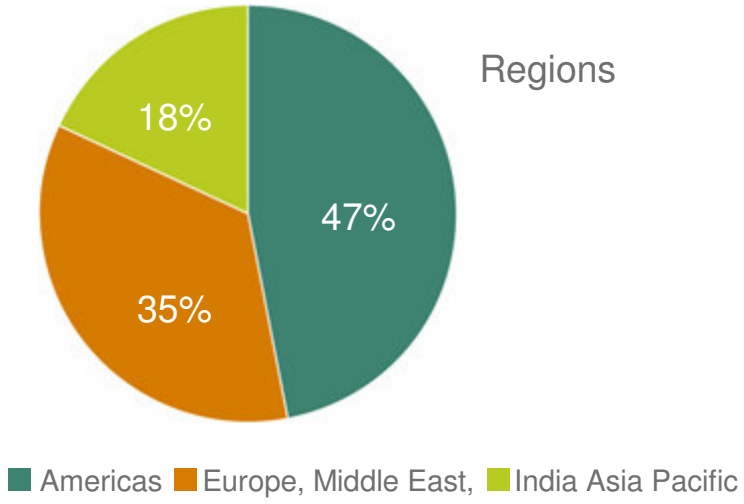
- Highly engineered specialty chemicals
- 4000+ employees and 3400 customers in 100+ countries
- Annual revenue of >$2.5 billion
- Technology and innovation focused

Leading catalysts provider for the refining and chemical industry

Broad portfolio

Strong partners: Petrobras (JV's), UOP (HPC Alliance)





Three strong business segments

Catalysts

- **Alternative Fuel Technologies - AFT**
- Hydroprocessing Catalysts – HPC
- Fluidized Catalytic Cracking – FCC
- Polymer Catalysts

Net Sales (2010)
$890

Polymer Solutions

- Flame Retardants: Brominated, Mineral, Phosphorus
- Antioxidants
- Stabilizers
- Curatives

Net Sales (2010)
$904

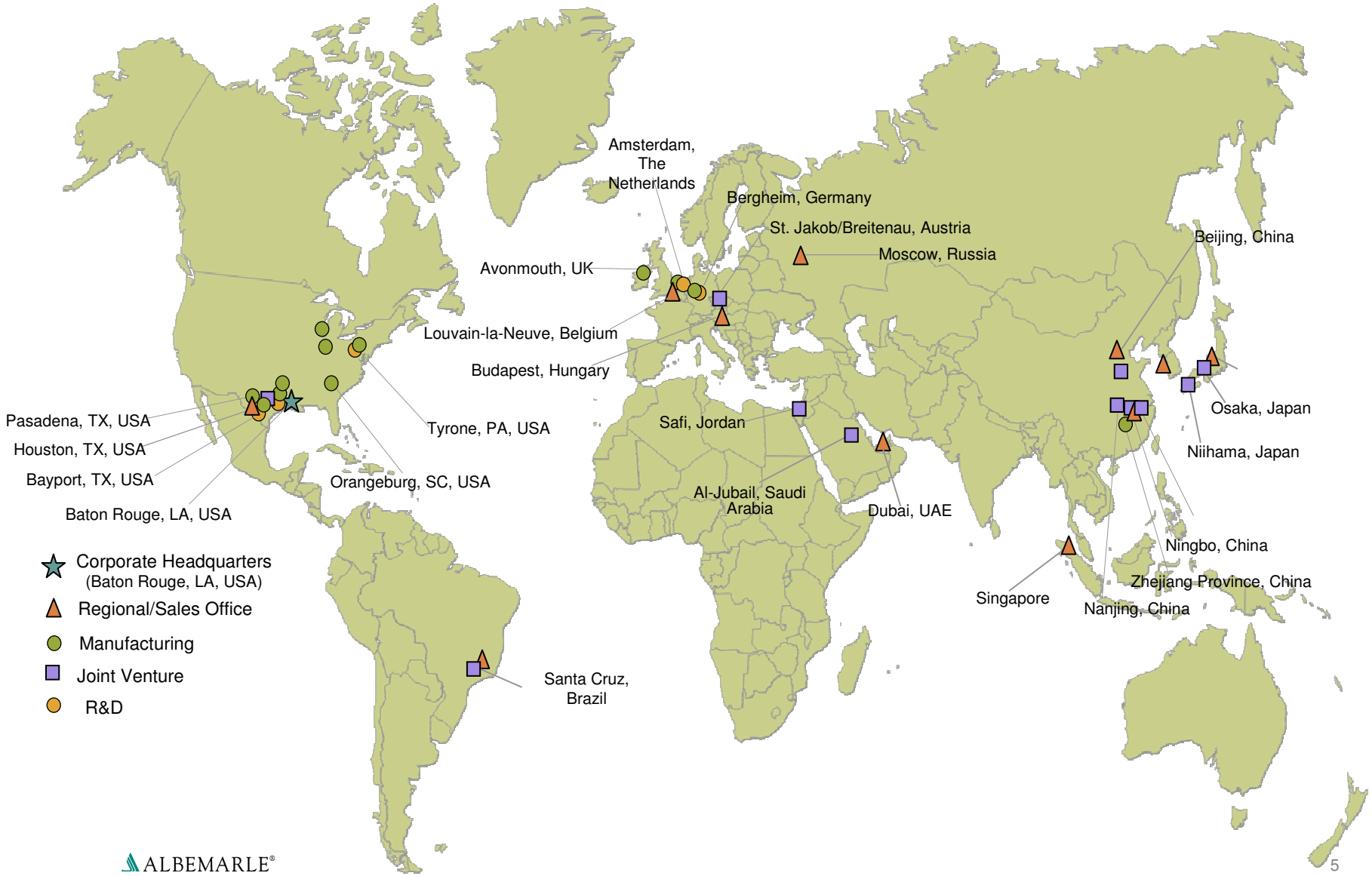
Fine Chemistry

- Pharmaceuticals
- Crop Protection
- Water Treatment
- Food Safety
- Mercury Control
- Oilfield Chemicals
- Bromine & Derivatives

Net Sales (2010)
$596

Scale and scope

2010 Net Sales	Americas	Europe	Asia
	42%	34%	24%



Fueling their future

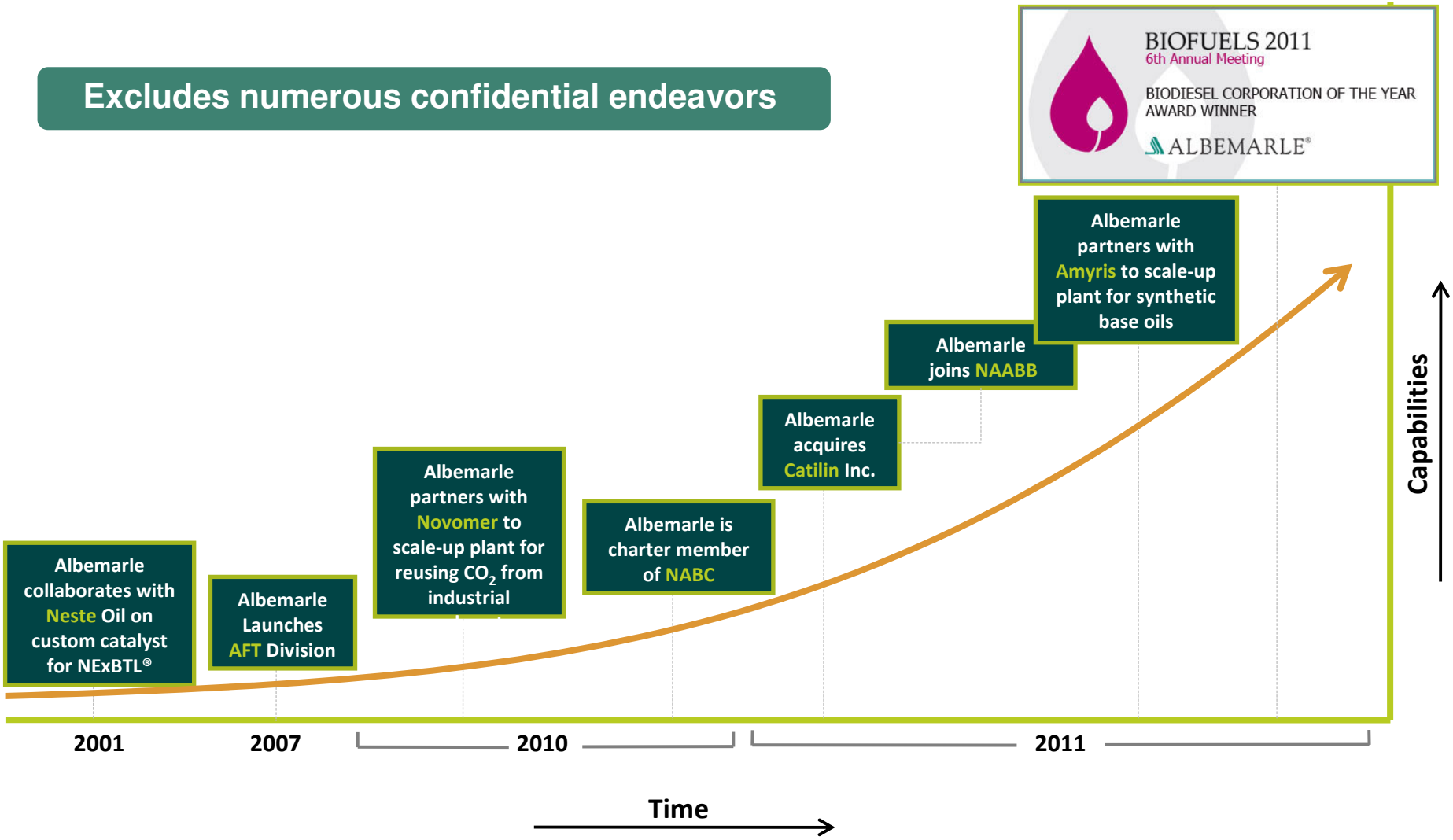
- In 2001, Albemarle started working with a dedicated group on the development of biofuels catalyst technologies
- In 2007, Albemarle officially formed its Alternative Fuel Technologies (AFT) group
- Albemarle is the world's largest supplier of heterogeneous biofuels catalysts
- The AFT group has developed catalytic materials for first-, second- and third-generation biomass conversion into fuels and chemicals

Albemarle offers a portfolio of catalysts for biomass conversion

GoBio™

History of Albemarle's Public Successes In Biofuels

Excludes numerous confidential endeavors



Our Vision

Albemarle believes in taking responsibility for future generations. They will still use liquid hydrocarbon fuels.

- High energy density
- Infrastructure

It is estimated that by 2030 15–20% of transportation fuel will be derived from biomass

- More is highly unlikely
- In perspective: 20% equals about 500 Mt -- Global veg oil production in 2010 150 Mt

Vision 2030

Albemarle will develop enabling catalytic technologies to produce biofuels and chemicals

- Build on existing technologies through high-throughput research and development , and partnerships

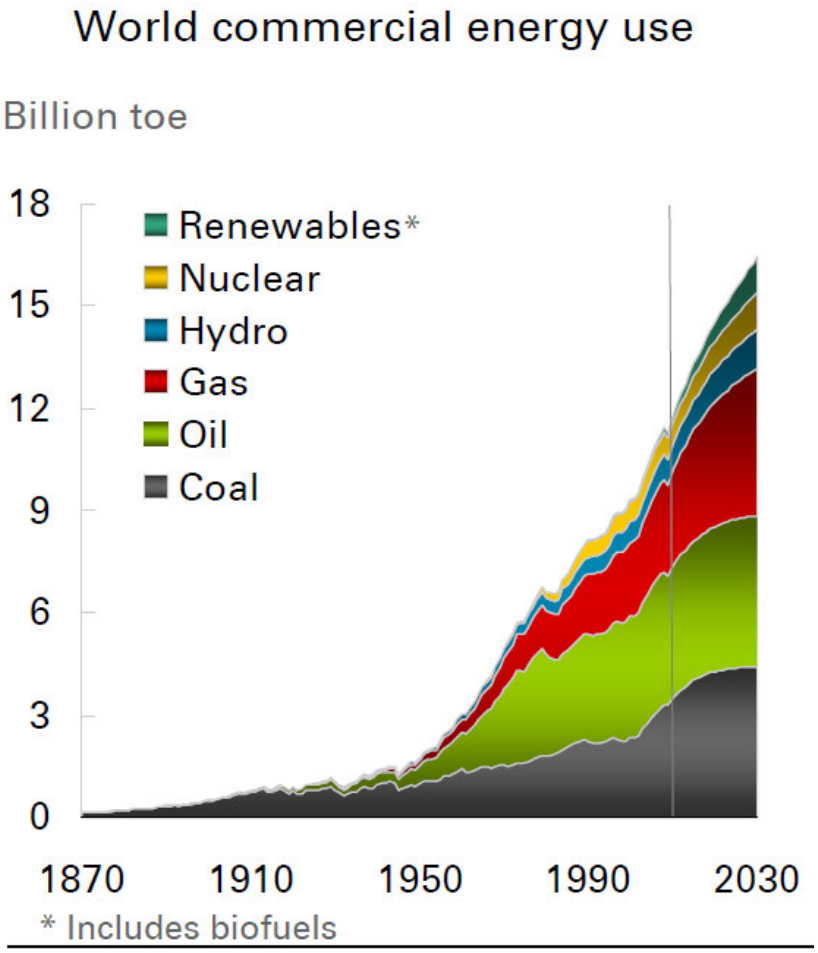
Synthesis and testing in parallel

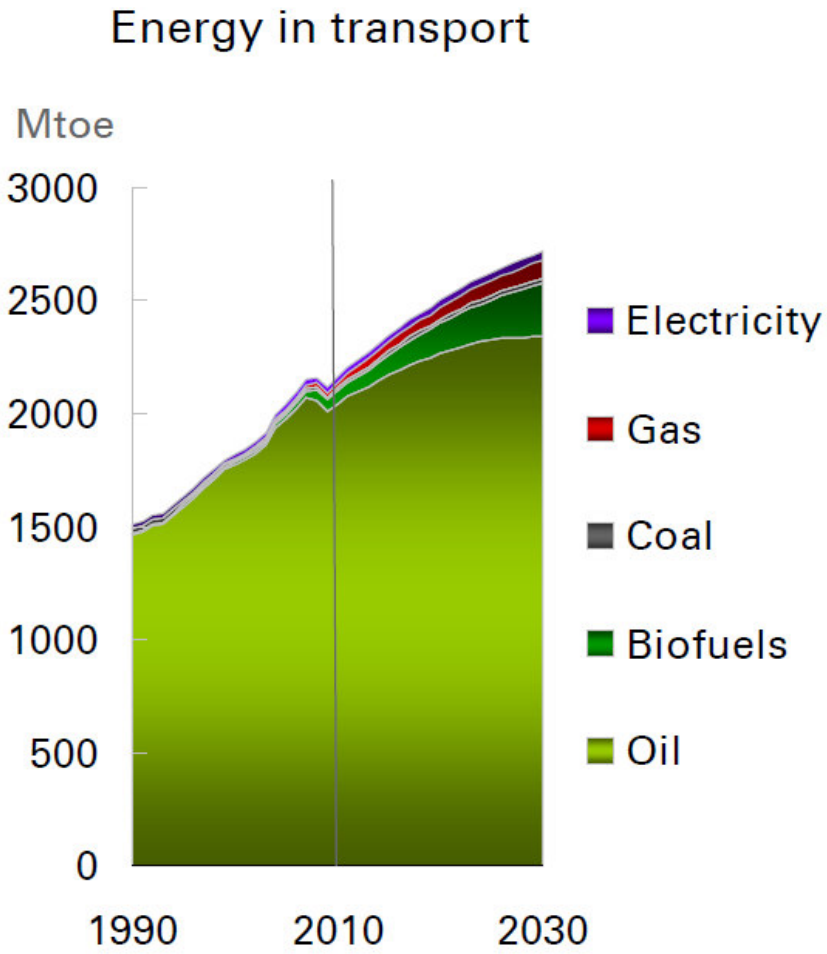
- Much greater development speed
- Higher accuracy leads to better products

New Albemarle GoBio™ Catalysts Family

CATALYST	DESCRIPTION
GoBio TS-15,T-300, TS-400	Transesterification biodiesel
GoBio ME-10	Syngas to methanol
GoBio DME-1	Methanol to dimethyl ether
GoBio MA-15	Syngas to alcohols
GoBio FT-10/20	Fischer-Tropsch
GoBio DX-10/20	Fischer-Tropsch wax upgrading
GoBio PO-10	Pyrolysis oil upgrading
Catalytic flash pyrolysis	In development
NExBTL	Neste custom catalyst

Why do we need biofuels?

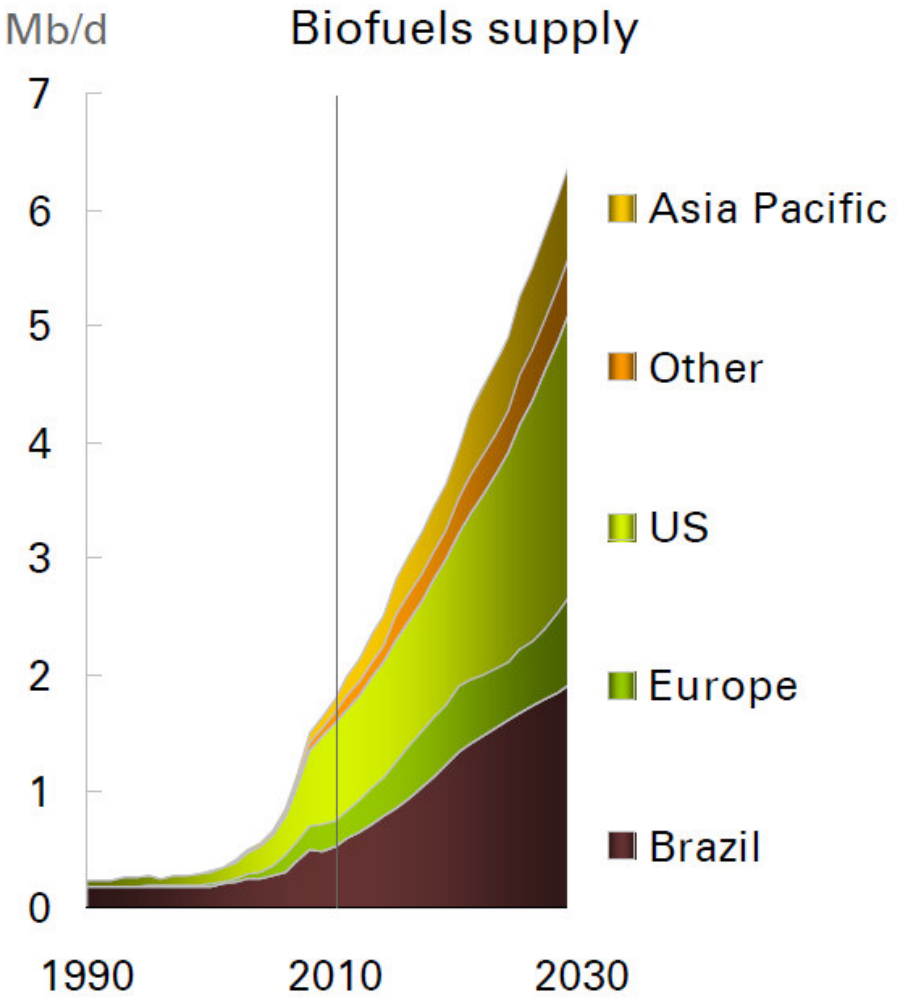




ALBEMARLE®

BP Energy Outlook 2030

Drivers



Drivers for Biofuels

- Oil is finite and new production is more expensive than past
  - Oil price only goes up (stepwise)
- We need liquid hydrocarbon in the future for almost all means of transportation
  - Electrification of transport is limited and takes a very long time
- Climate change
  - Biofuels could provide an efficient way to reduce CO2 emission of the transportation sector

Challenges: Feedstock is the key

- Feedstock
  - The required volumes to replace all of today's fossil fuels are enormousToday we use 87 M bpd or about 3.7 Bton
  - Assume 30% of liquid HC from wood this would be about 12 B ton of wood
  - Today wood growth per year in Sweden is 200 M ton…..
  - So we need 60 times Sweden…
- CO_2
- Cost
  - Cost of the fuel must be competitive with oil
  - Capital required puts a limitation on implementation

Key bottlenecks for large scale biofuels

Feedstocks: Not enough readily available feedstocks to meet the high volume demand

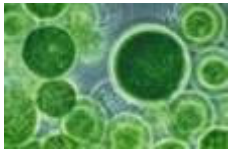
- Alternative feeds need to be developed i.e. energy crops, algae, seaweed,etc
- Waste materials need to be used
- Sustainable production methods need to be developed

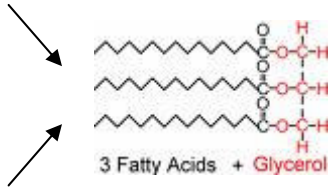
Major difference with oil is that biomass contains a large percentage of oxygen

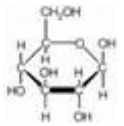
- In order to make fully fungible hydrocarbon fuels complete deoxygenation is required

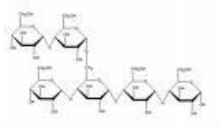
So the development of new technologies focuses on all of the above aspects
"No Silver Bullet"

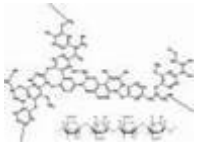
The biofuel challenge: Get out the oxygen.

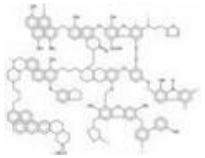












Vegetable oils
(Palm, Sunflower, Algae)

Sugars

Cellulose
(Starch)

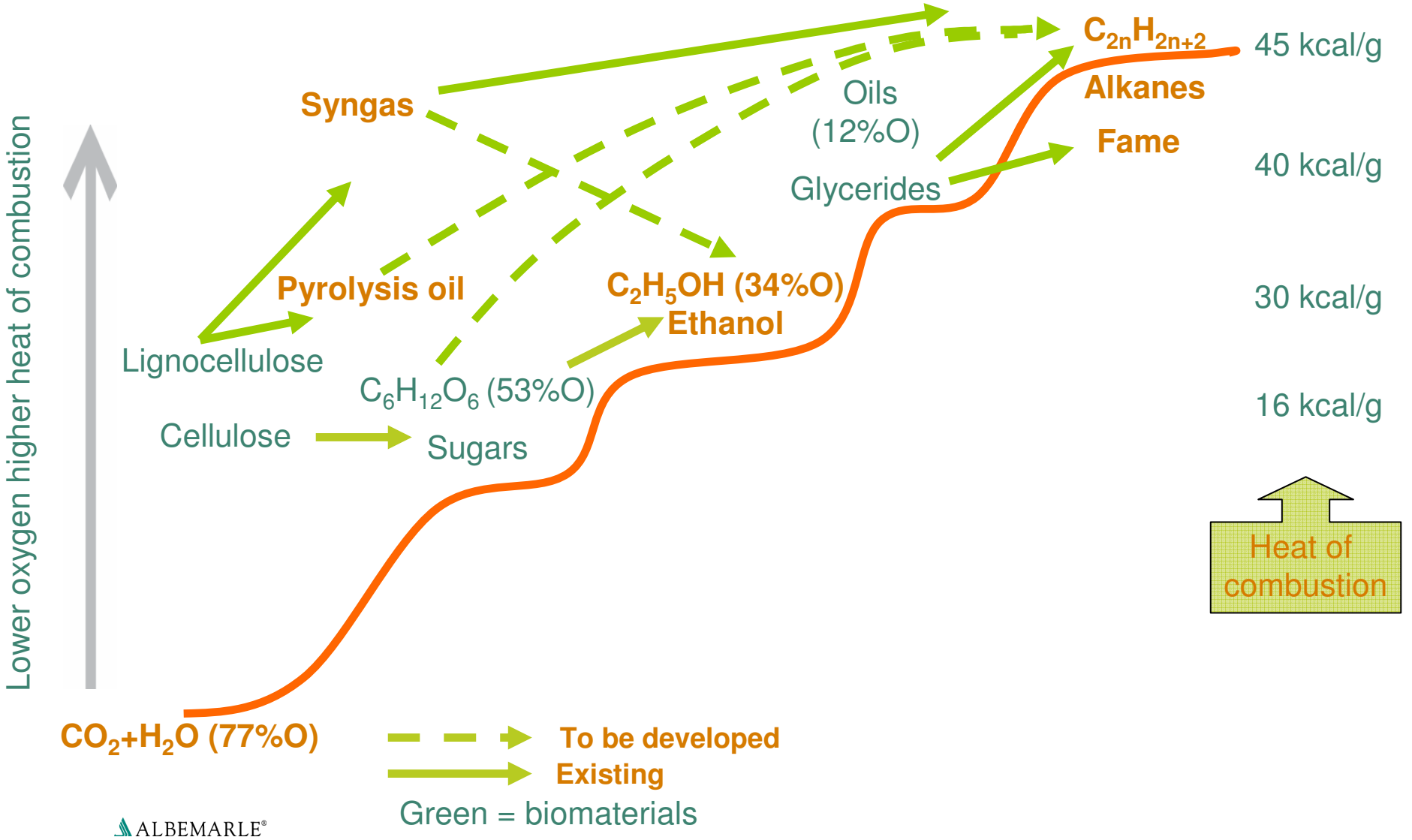
Hemi cellulose
(leaves)

Lignin
(wood)

Coal

More Complex To Process

From biomass to fuels: Higher energy is Lower oxygen

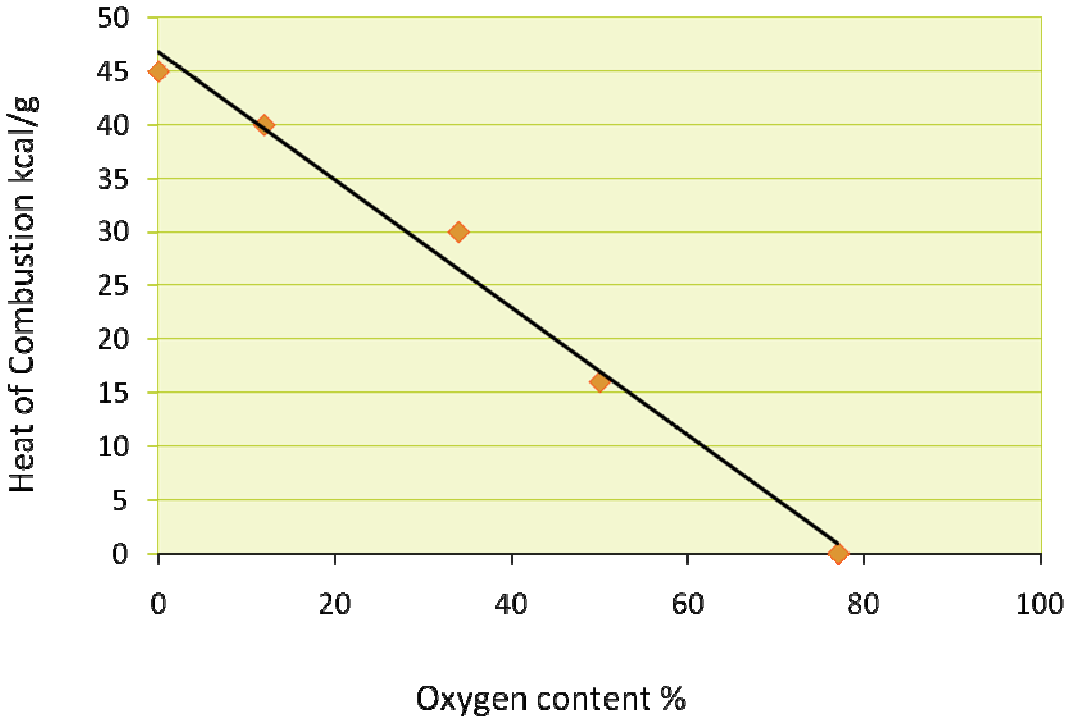


ALBEMARLE®

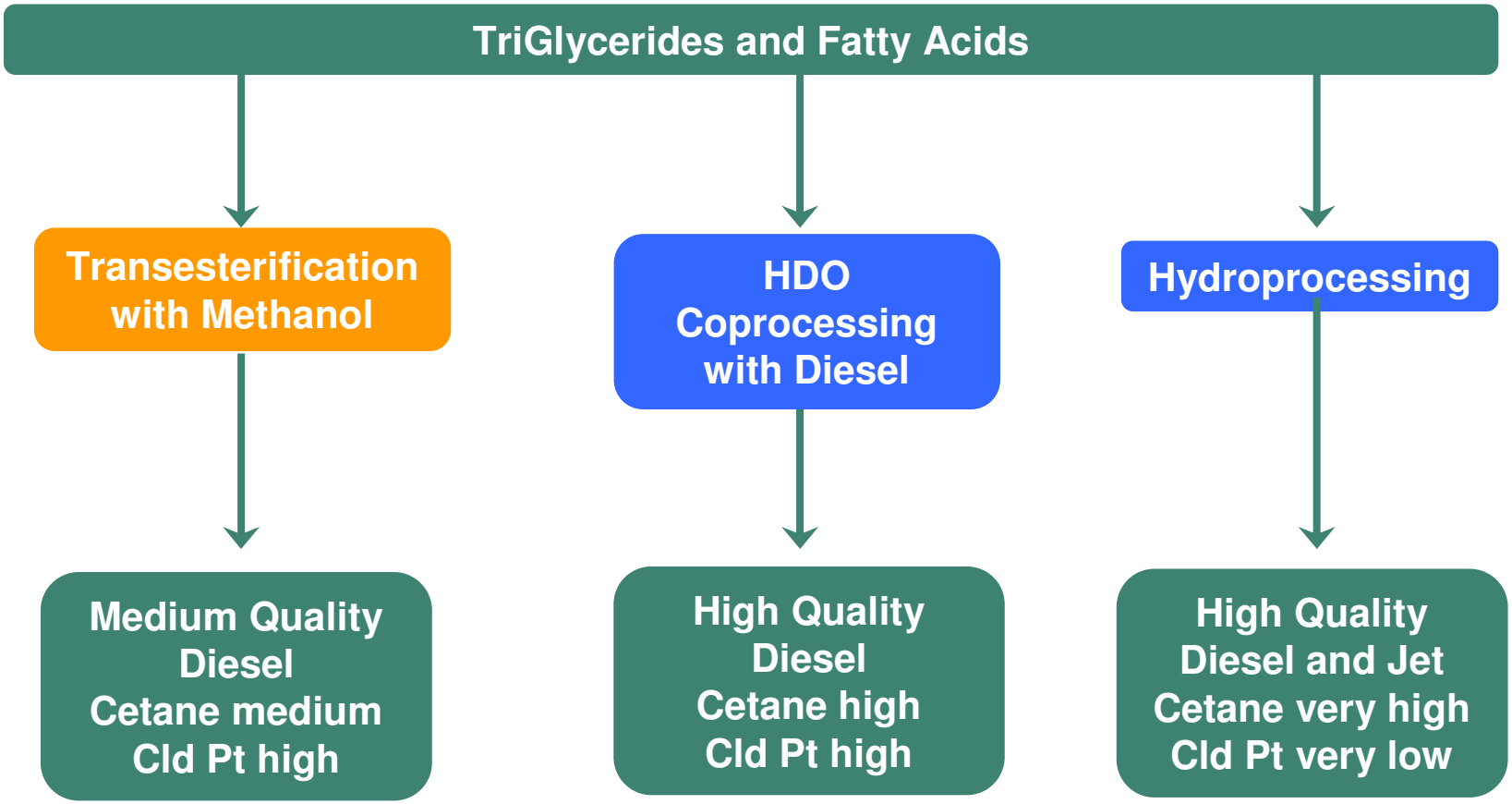
Biomass to fuel is oxygen removal

7 H_2 needs to be added

$$C_6H_{12}O_6 \longrightarrow 6(CH_2)H_2 + 6H_2O$$



Routes to BioFuels 1: Vegetable Oils and Fats



NExBTL Renewable Diesel and Jet Fuel

NExBTL makes fully hydrogenated biodiesel from vegetable oils and fats.

Proprietary catalyst and process technology

- Developed in partnership with Neste
- Four world-scale plants
- Nearly 2 Million tons/year total capacity
- Albemarle supplier of the catalysts

Excellent biodiesel product properties

Low cloud point, high cetane number

Fully fungible

NExBTL Bio-jet

Lufthansa 6 months trial Frankfurt-Hamburg

Co-Processing of Vegetable Oils and Fats

Use of existing Diesel Hydrotreating Units

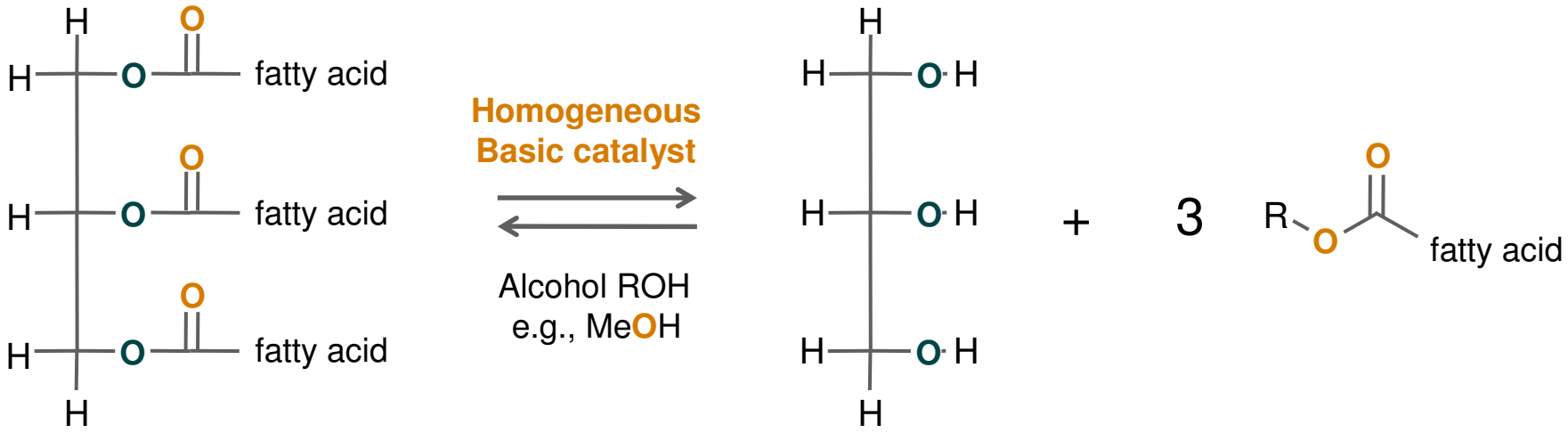
Pro's

- Can be done with minimum investment
- Cetane boost and aromatics reduction

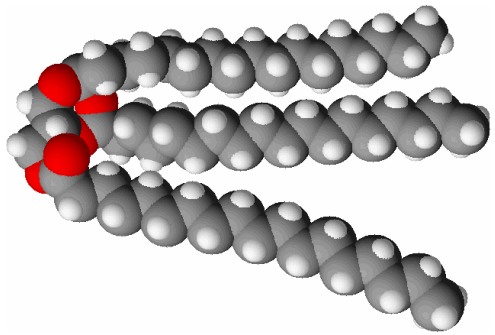
Con's

- CO production with catalyst inhibition and deactivation effects
- Higher hydrogen consumption
- Higher ΔT exotherm
- Possible build-up of CO in the recycle gas
- Less good cold flow properties

Biodiesel FAME



Triglycerides



Glycerol/glycerine

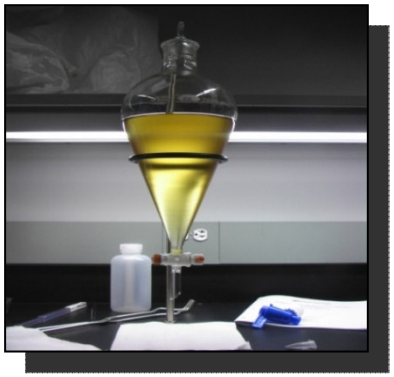
Crude FAME and Glycerol

ALBEMARLE® | CATILIN™

- Catalyst technology developed at Iowa State University.
- Formed as a private company and then acquired by Albemarle in May, 2011.
- Product line focused on catalysts for the renewable energy and chemicals markets.
- Process design work completed through partnerships.
- Commercial experience with revamp of existing plant to slurry phase catalysis
- Expands our catalyst offering with GoBio T-300

2002-2006
ISU Research

2007
Bench scale



2008
Batch Pilot Plant

2011
Albemarle Corporation

Alternative Fuel Technology

Demo Plant

Design capacity is 300,000 gal per year (1,000 mt/yr)

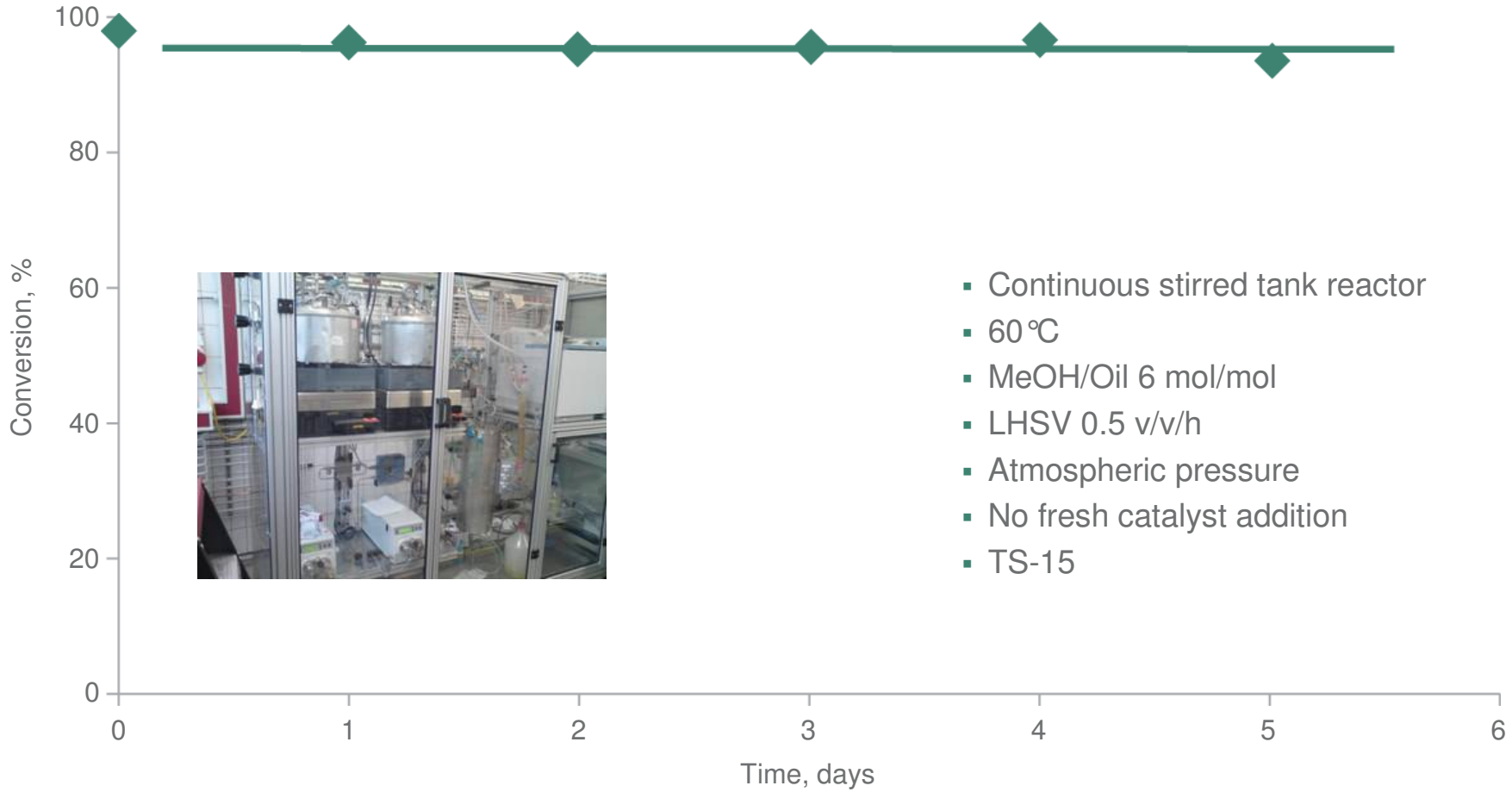
Transesterification Biodiesel

- Slurry phase catalysts
- Excellent particle strength
- High-activity, drop-in solution
- Non-hazardous, low cost disposal

GoBio T-300

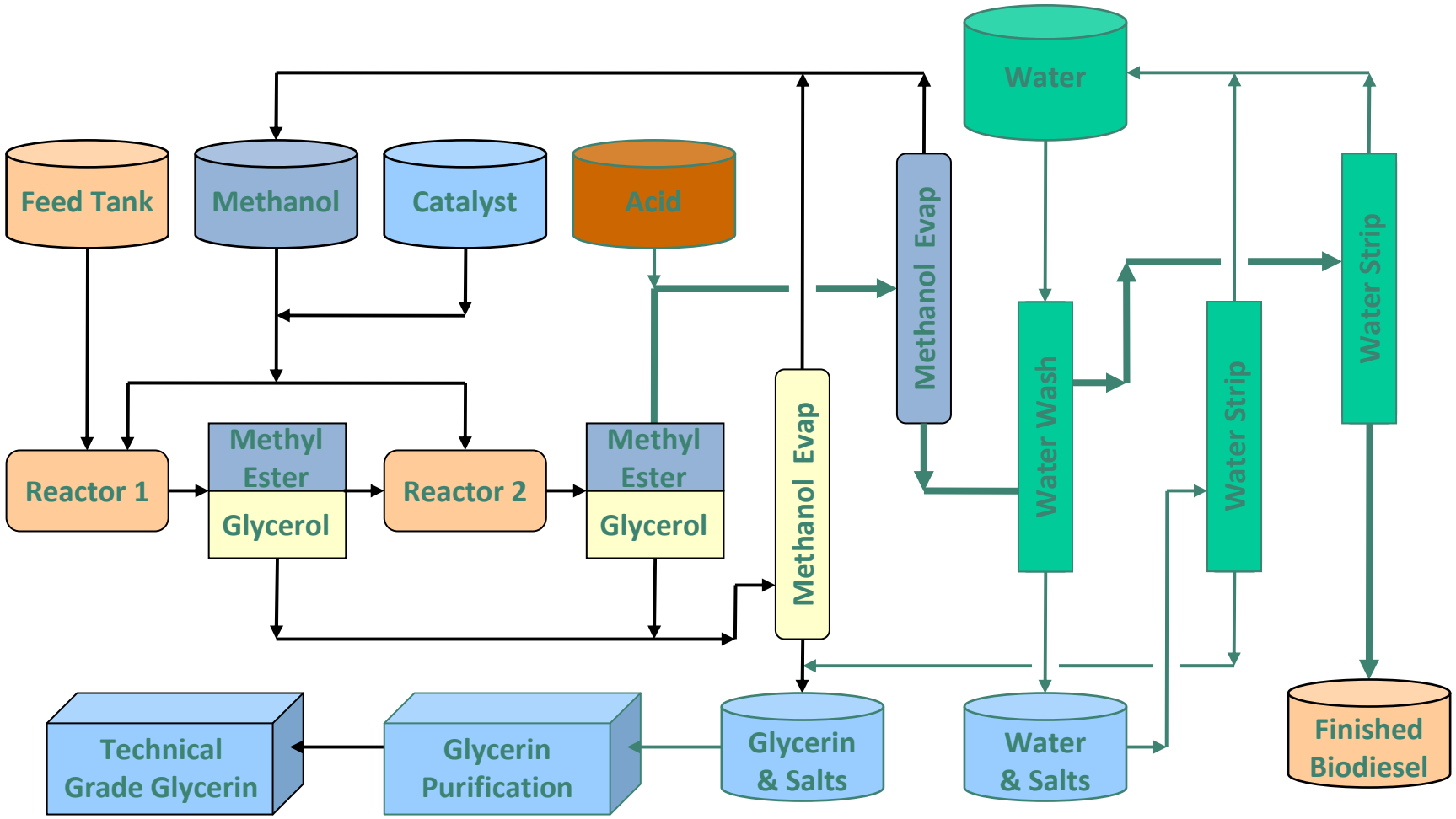
GoBio TS-15

High catalyst activity and stability

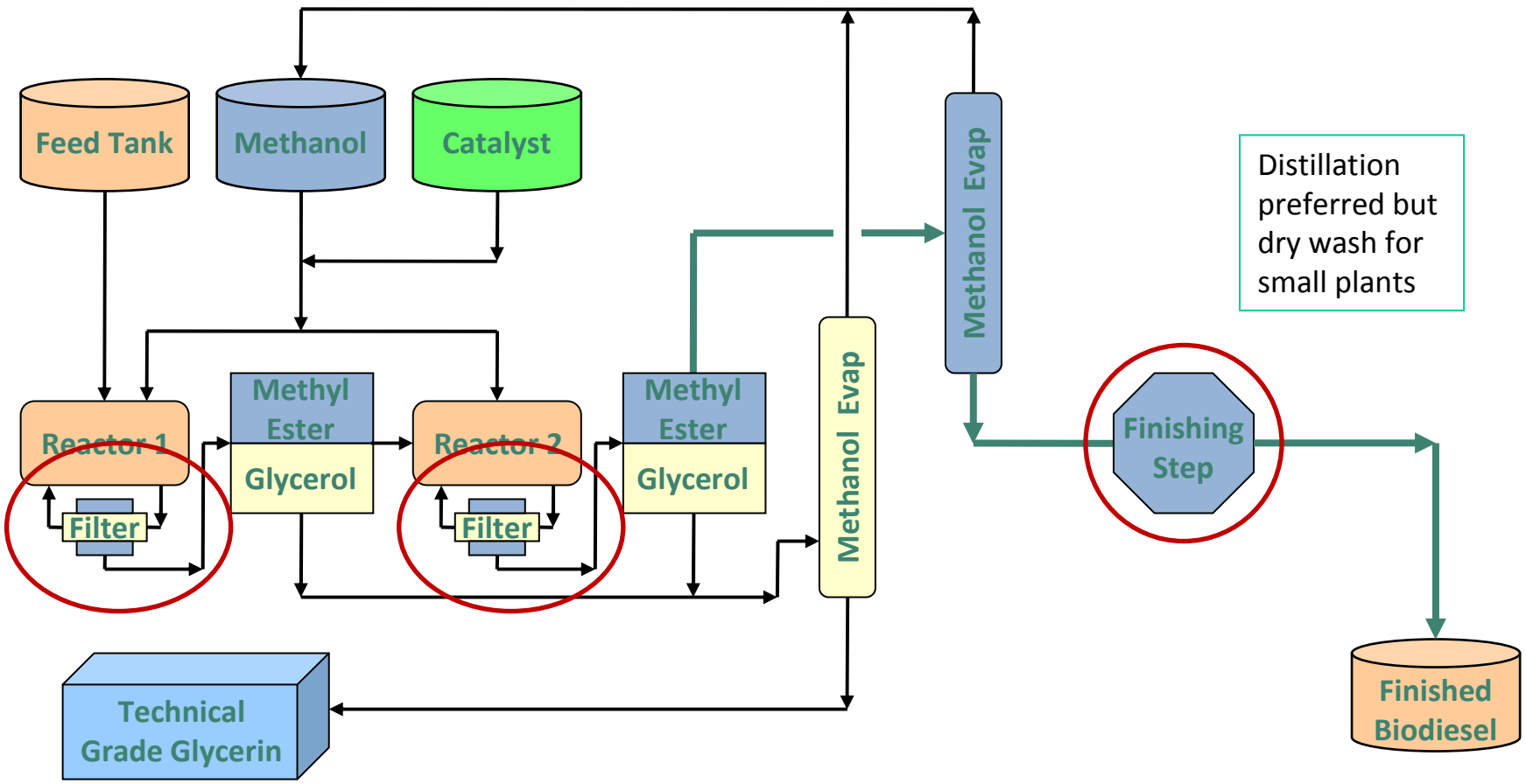


- Continuous stirred tank reactor
- 60 ℃
- MeOH/Oil 6 mol/mol
- LHSV 0.5 v/v/h
- Atmospheric pressure
- No fresh catalyst addition
- TS-15

The conventional FAME technology



The Albemarle Process

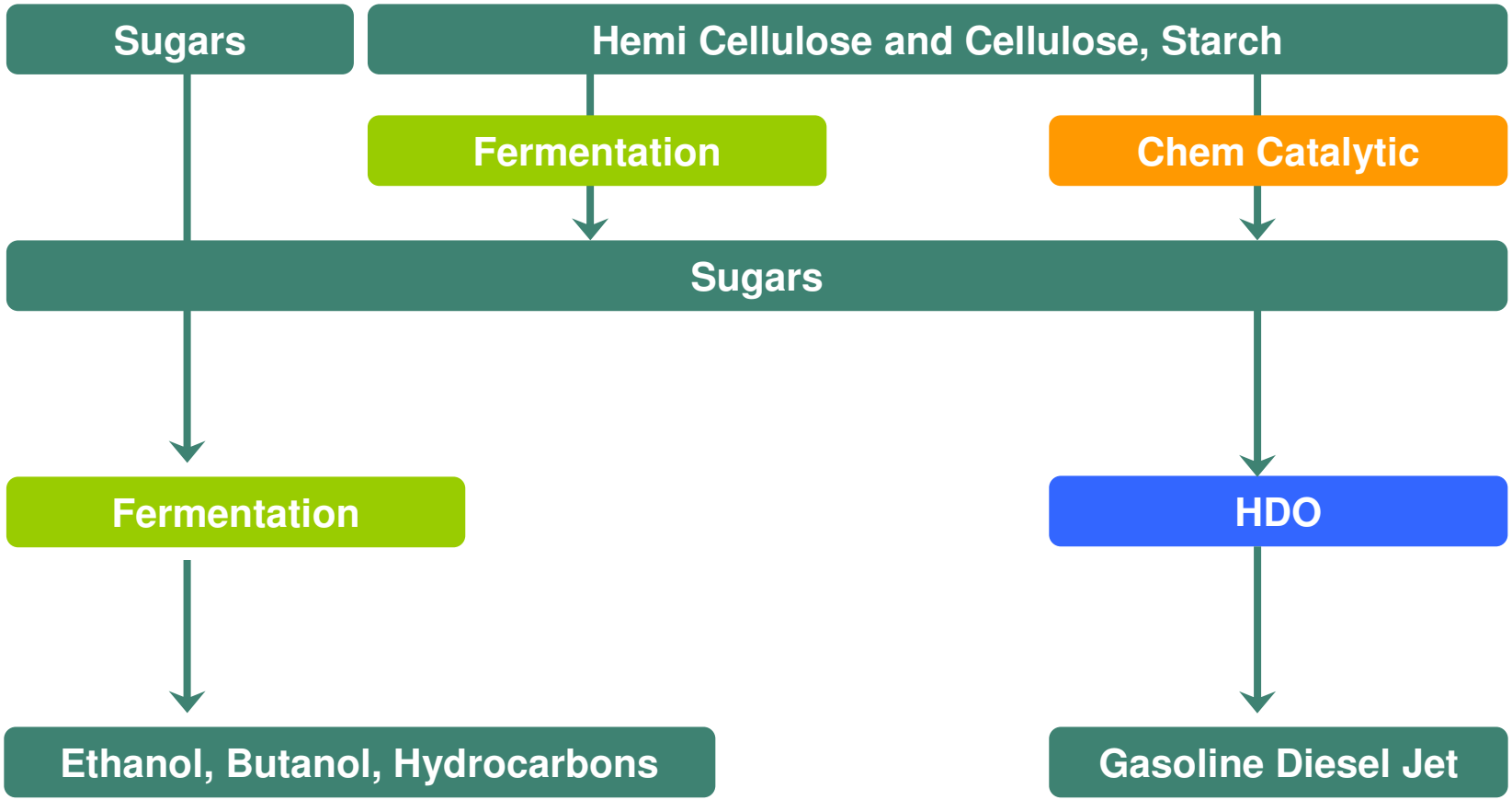


Product Quality

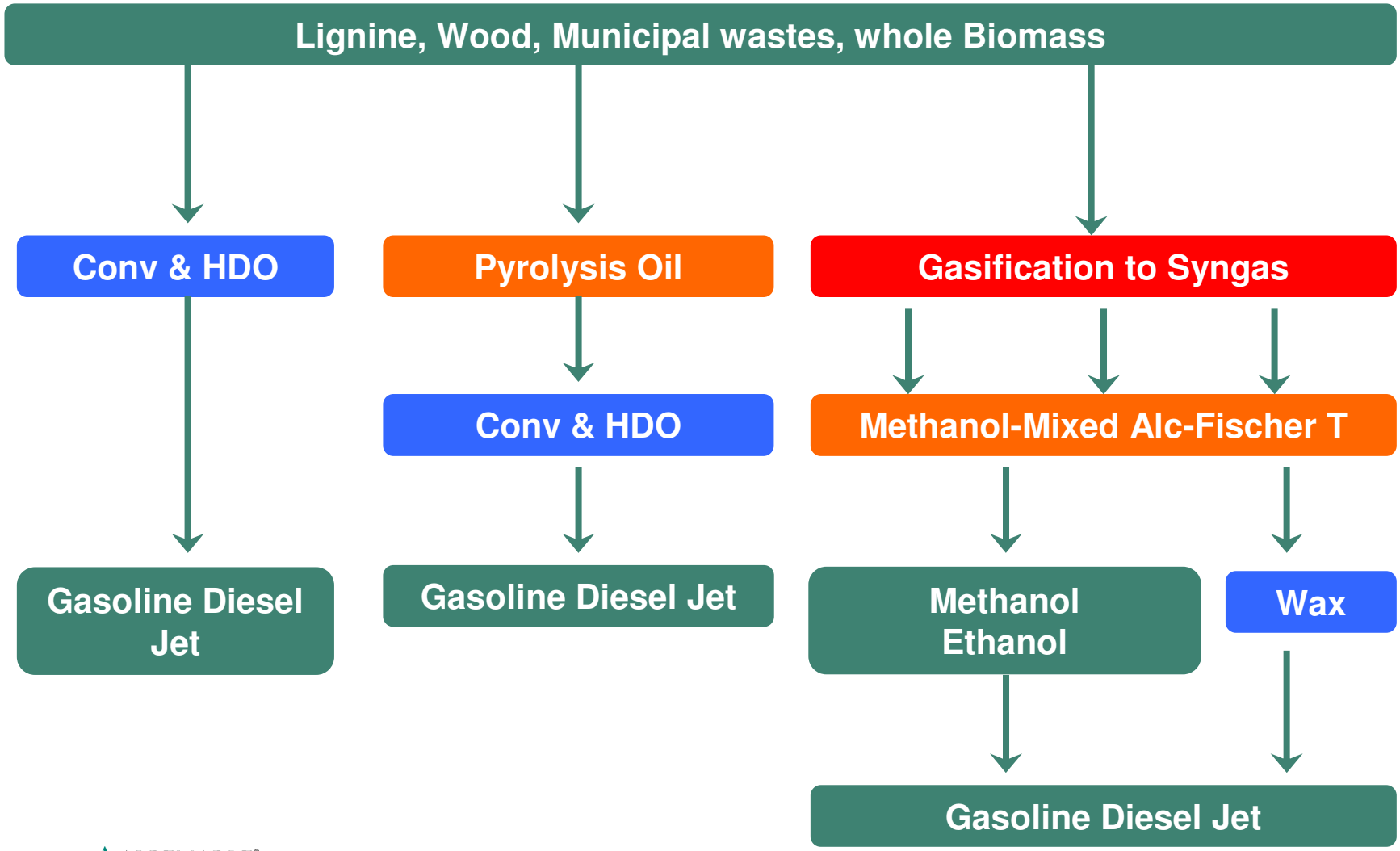
Dry washed pilot plant samples meet all ASTM specs.

Distillation of pilot samples produces USP glycerin and high purity FAME.

Routes to Biofuels 2: Sugars and Cellulose fractions

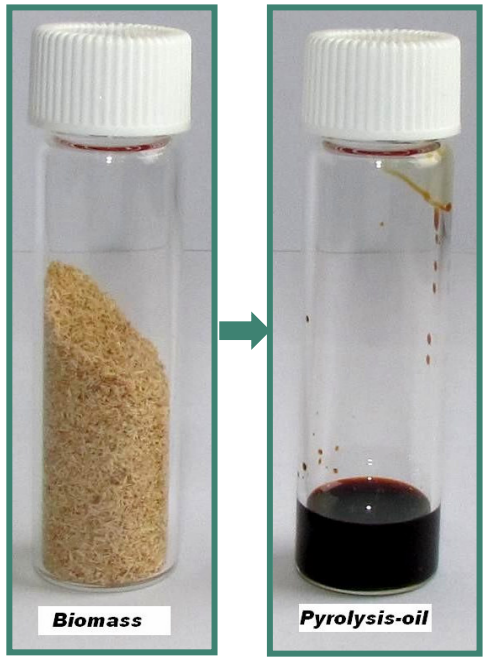


Routes to Biofuels 3: Biomass, Wastes and refractory fractions



Catalytic Flash Pyrolysis & Hydropyrolysis

- Potential benefits
  - **Biomass densification**
  - Better product quality and higher yields
  - Efficient design
- Various technical options are being researched
  - Drop-in or revamp of existing pyrolysis technology
  - It looks like fluidized catalytic cracking but it is different
  - Solid feed rather than liquid
  - Oxygen removal is the key objective
- Catalyst and process development
  - Is ongoing in the private sector, and in public sector programs such as the National Advanced Bio-fuels Consortium (NABC), and the National Alliance for Advanced Bio-fuels and Bio-products (NAABB), to develop new technology for bio-fuels



1.5 GJ/m³ **20 GJ/m³**

Albemarle has comprehensive CFP and HYP in-house programs

Pyrolysis catalysts development at Albemarle

DoE

High Throughput Synthesis

Automated Pyrolyzer

Catalyst: 10 mg

Bench scale

Catalyst: 15 g

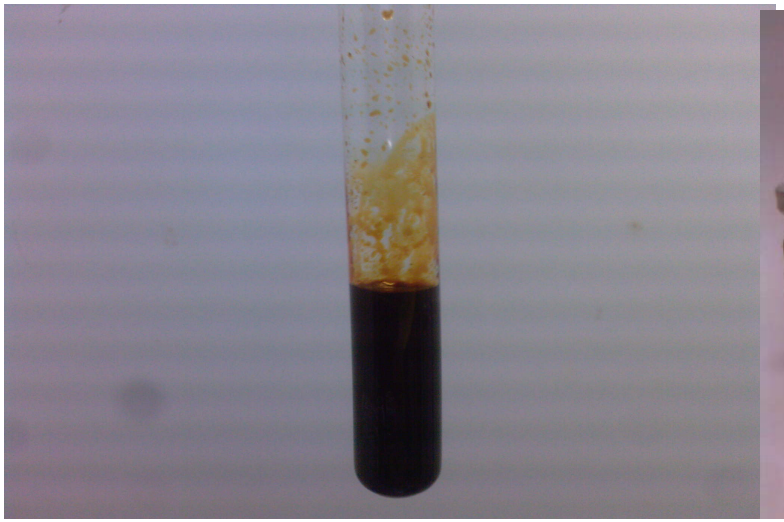
Pilot Scale

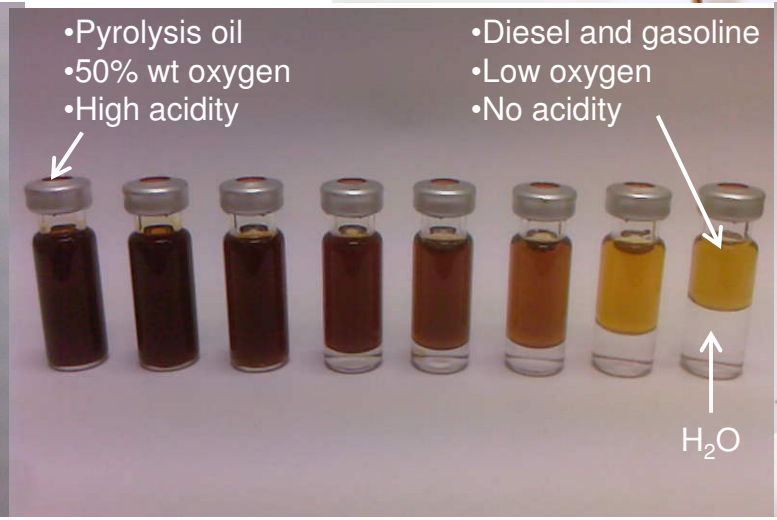
Catalyst: 10 kg

Treating pyrolysis oil

Albemarle has invented a method to treat pyrolysis oil

- Stabilized Py Oil
  - Products are deoxygenated
  - Low in TAN and olefins
- Final product fully fungible diesel and gasoline





Catalytic flash pyrolysis

Potential benefits

- Higher yields
- Better product quality
- Efficient design

Various technical options are being researched

- Drop-in or revamp of existing pyrolysis technology
- It looks like fluidized catalytic cracking but it is different
  - Solid feed rather than liquid
  - Oxygen removal is the key objective

Catalyst and process development

- Is ongoing in the National Advanced Biofuels Consortium, which funded by the US DOE, in which Albemarle is partnering with NREL, PNNL, UOP, BP and Tesoro to develop new technology for biofuels

Catalytic flash pyrolysis – It works

Catalytic pyrolysis works

- Catalyst type and process conditions have a big influence on chemistry

Many variables and catalysts to be investigated

- High throughput is essential
- Albemarle has developed new high throughput testing equipment

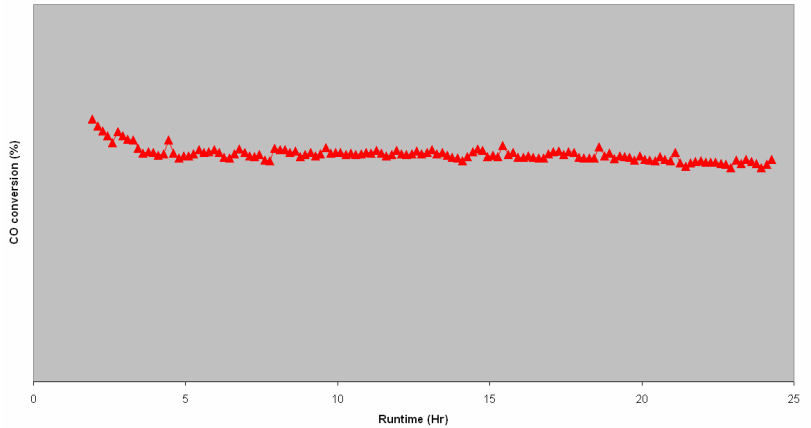
Bio-syngas Conversion

- In addition to classical Fischer-Tropsch and methanol, new technologies are being developed to convert syngas into ethanol and alcohol mixtures
- Albemarle has developed a new technology to manufacture catalysts for syngas conversion
- GoBio MA catalyst has been produced on commercial scale and was applied in a commercial reactor this year

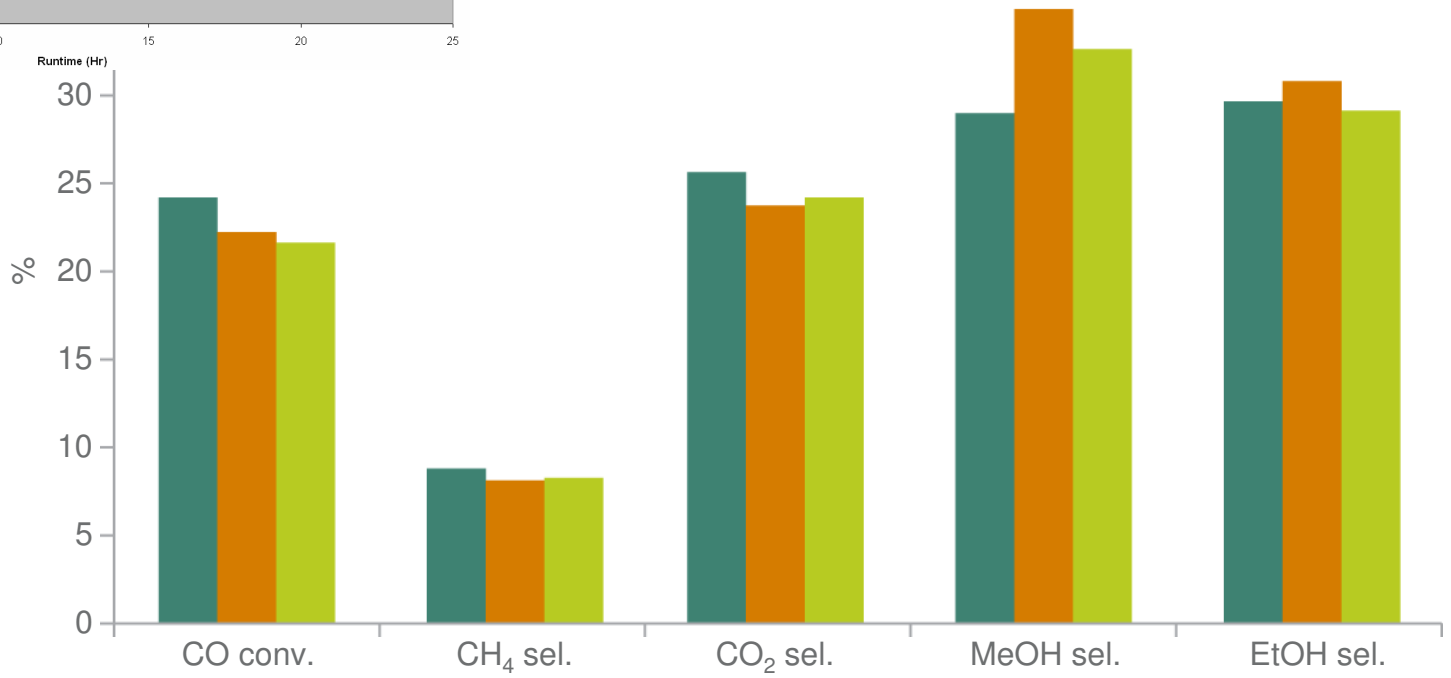
Fischer-Tropsch wax and alcohols from syngas

GoBio ME-10 GoBio DME-1 GoBio MA-15 GoBio FT-10 GoBio FT-20 GoBio DX-10 GoBio DX-20

GoBio mixed alcohol catalyst



- High activity
- Good selectivity
- Robust catalyst



Wood to mixed alcohols via syngas

Pilot at Gussing Bioenergy 2020+ gasifier in the background

Conclusion

Heterogeneous catalysis will be key to develop new technologies for biofuels and chemicals production

Albemarle is introducing new catalysts and technologies

- To improve existing technologies
- To enable new technologies

Albemarle's new family of biofuel catalysts

GoBio

FUELING THEIR FUTURE

The kids in the pictures are "Albemarle children"