Potential for Bio-ethanol (from Sugar Beet) to Bio-ethylene
Hummingbird Ethanol-to-Ethylene Technology

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TechnipFMC Process Technology

TechnipFMC

TechnipFMC Process Technology (PT)

- Global technology licensor that offer combined leading proprietary process technologies from TechnipFMC, Badger, Zimmer and others
- Licensing market-leading portfolio of technologies, including own proprietary or through alliances with other technology providers in Refining, Syngas, Petrochemicals, Polymers and Gas Monetization
- In line with TechnipFMC's strategy to focus on technologies that differentiate us from our competitors
- Headquartered in Houston with centers around the world
- Center of excellence for Hummingbird Technology is Milton Keynes, UK
- R&D and piloting facilities in US and Europe

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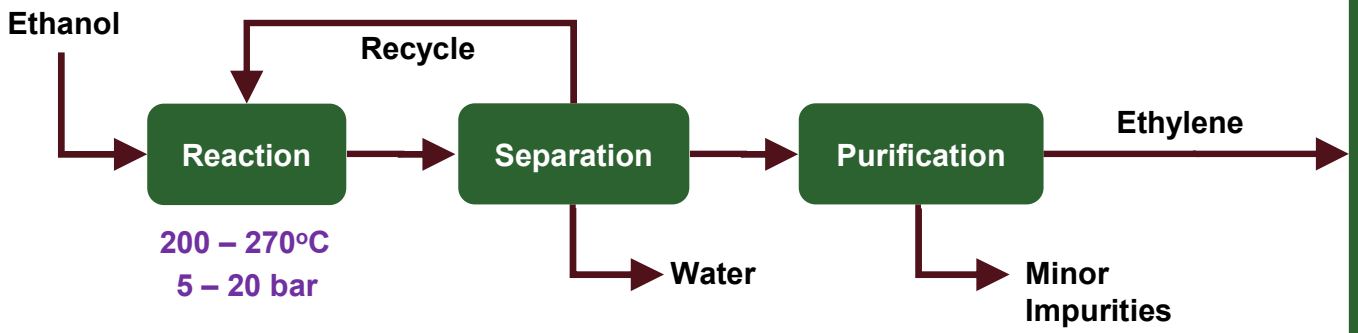
Ethanol to Ethylene Chemistry

Bio-Ethanol → Ethylene

$$C_2H_5OH \xrightarrow{H^+} C_2H_4 + H_2O$$

Gas phase reaction over acid catalyst

Hummingbird® Process: Hetropolyacid [HPA] catalyst system:



- Polyethylene
- Ethylene Oxide
- EDC & Vinyl Chloride
- MEG/PET
- Ethylbenzene & Styrene
- VAM
- LAO

$$2C_2H_5OH \rightarrow C_4H_{10}O + H_2O \quad \text{[Fast Reaction]}$$

$$C_4H_{10}O \rightarrow C_2H_4 + C_2H_5OH \quad \text{[Slow Reaction]}$$

Demonstration Plant Process Development

Features:

- 2-3kg/h ethylene production
- Fully recycling facility with purification columns similar to commercial plant

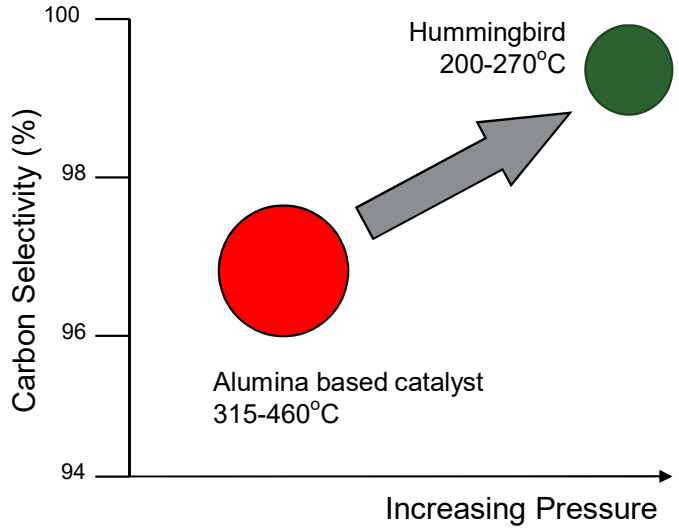
Development Phases:

- Commissioning
  - Experience of cold section
  - Scoping operating zone
- Development
  - Bioethanol feedstock flexibility
- Demonstration
  - Feed clean-up testing
  - Start-up/shutdown operations
  - Operation in operating envelope
- Commercial Catalyst Assurance
  - Commercial catalyst operation
  - Production of multi-kilo quantities of product

Hummingbird® Advantages

A simple low cost process for dehydrating ethanol to ethylene, operating at a lower temperature and higher pressure than first generation alumina based catalyst Ethanol to Ethylene processes, with:

Ultra High Selectivity.



- Over 99% overall carbon conversion to polymer grade ethylene
- Simplified separation and purification, low utility consumption, and no ethane splitter
- Higher pressure reaction section reduces cost for downstream compression

Ethanol Feedstock Specification

Majority of ethanol is made to fuel grade specifications.

- Varying standards around the world
- May also contain denaturant
- Chemical processes can be sensitive different impurities
- Need to look within the fuel grade specification for chemical process application

	USA	EU	China	Brazil
	ASTM D4806-14	EN 15376	GB 18350	Resolution ANP #19
Ethanol (min)	92.1 vol%	98.7 wt%	92.1 vol%	98.0/94.5/96.3 vol%
Methanol	0.5 vol%	0.5 vol%	0.5 vol%	1 wt%
Water	1.0 vol%	0.3 wt%	0.8 vol%	0.7/7.5/4.5 wt%
Acidity as Acetic Acid	56 mg/l	56 mg/l	56 mg/l	30 mg/l
Inorganic Chlorine	10 mg/kg	1.5 mg/kg	8 mg/kg	1 mg/kg

Ethanol Analysis Equipment

hummingbird

Our R&D facility in Weymouth, MA, USA, can analyze potential ethanol feedstocks:

- Many common by-product components in commercial ethanols are diluents (although they will be dehydrated in the Hummingbird® reactor). However, some need to be considered to protect the operation of the catalyst.
- Ethanol analysis is close coupled with process design of Hummingbird® Plant.
- Typical analysis table:

Compositions	Unit
Ethanol	wt %
Water	wt %
Methanol	ppmw
Higher Alcohols	ppmw
Acetic Acid Equivalent	ppmw
Acetaldehyde Equivalent	ppmw
Other Organic Compounds	ppmw
Total Anions	ppmw
Total Cations	ppmw
Total Nitrogen	ppmw
Total Sulfur	ppmw
Involatile materials	ppmw
Appearance	-

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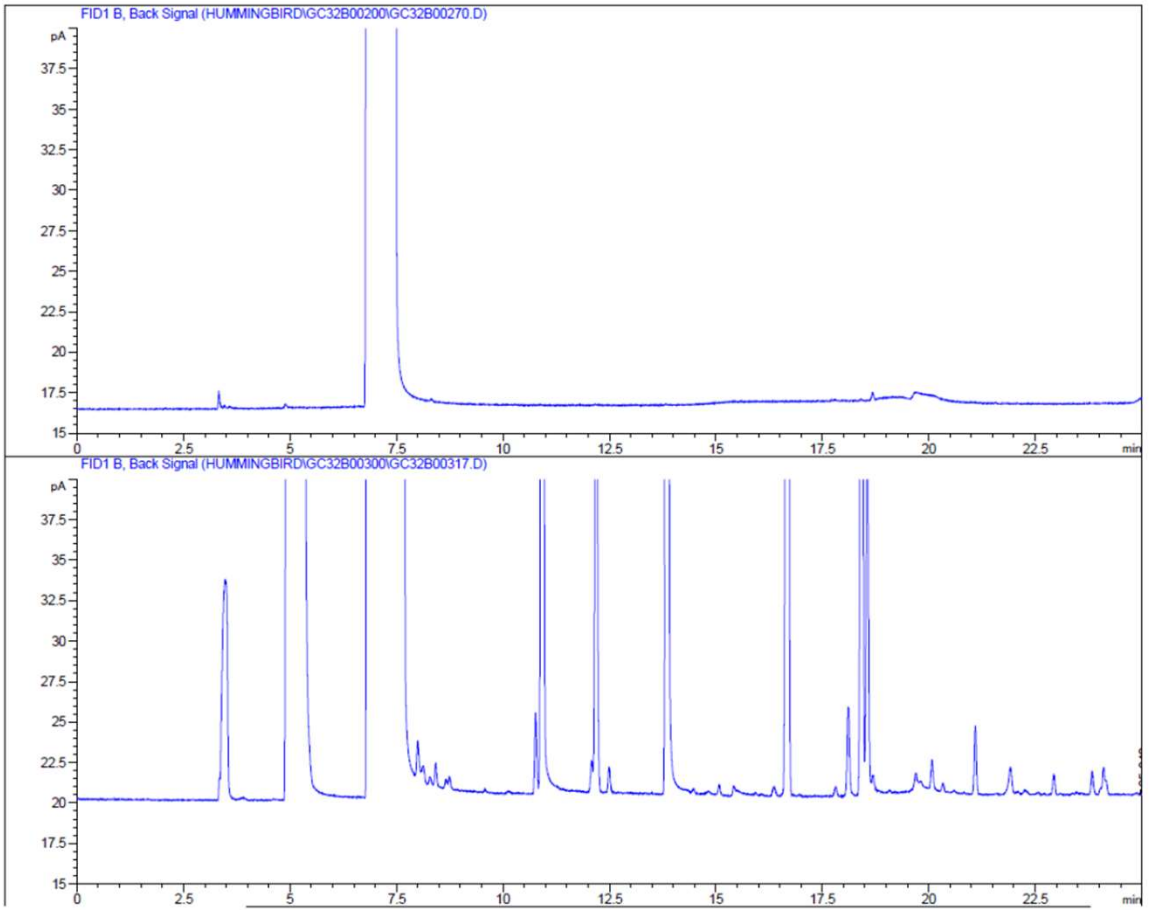
Typical GC Analysis Output

Bioethanol #1

- A typical high purity 1G Ethanol

Bioethanol #2

- A potential fuel grade ethanol



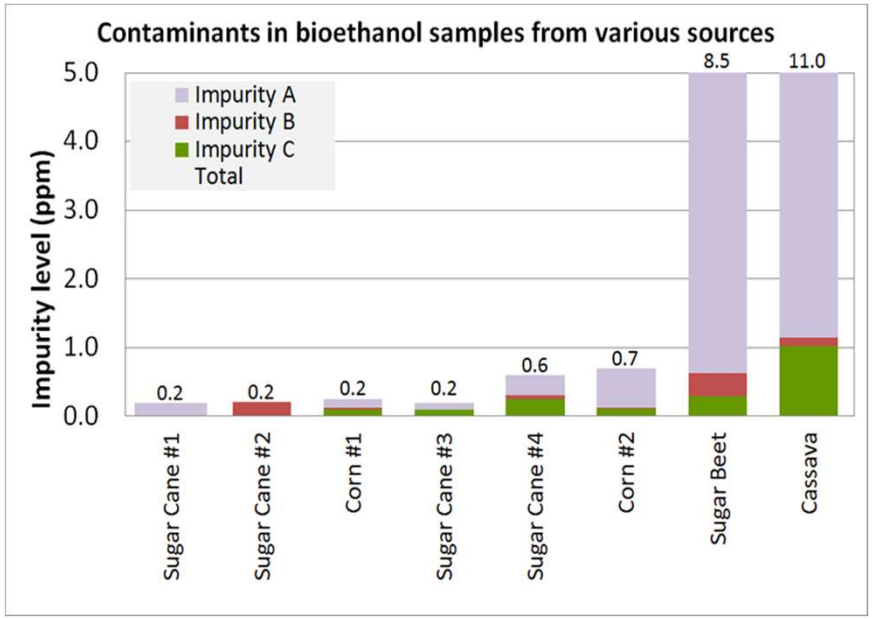
Designing for Ethanol Impurities

Hummingbird® technology includes an ethanol clean-up ‘toolkit’:

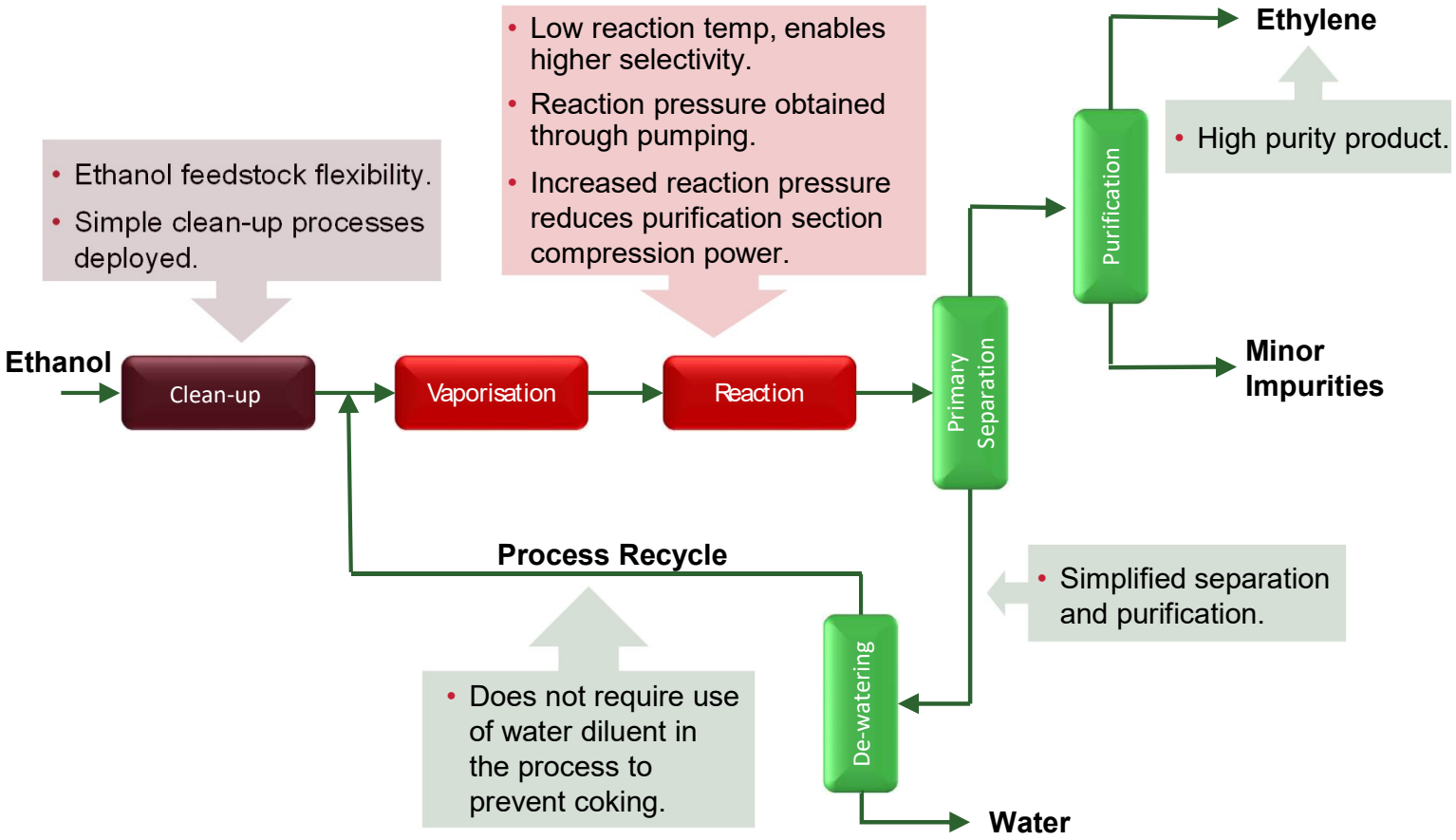
- Ethanol is analysed for certain trace chemicals.
- Design of pre-treatment unit and E2E process is tailored to analysis.
- Growing reference library of commercially available ethanols, with over 60 ethanol samples already tested.

Process designs can accommodate a variety of ethanol feedstocks.

- Process design to characteristics of specific ethanol feedstock.
- Opportunity to process less expensive bioethanols.



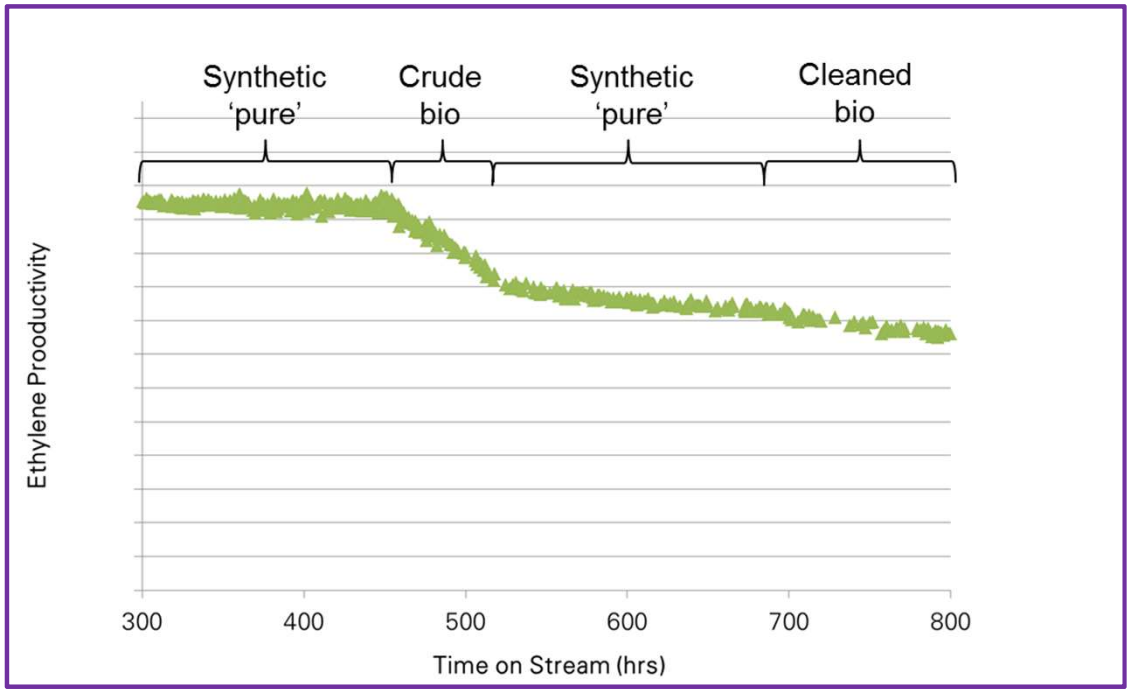
Hummingbird® Flow Scheme



The Effect of Feed Cleanup

Mircroreactor Accelerated Ageing Test

- Crude bioethanol increases deactivation
- Cleanup process on same bioethanol reduces deactivation rate to that for synthetic [pure] ethanol.



Downstream Integration & Product Specifications

- Successful downstream polymerization tests conducted by third party, with pilot plant product (including running co-polymerization tests with 1-hexane) using Ziegler Natta and metallocene catalysts.
- Product specification can vary depending upon the derivative unit being supplied. Typical PE unit shown, although derivative unit may be:
  - EO / MEG
  - EDC
  - VAM
  - Other…

Component	Typical Ethylene Specification
	Polyethylene
Ethylene	99.90%
CH4+C2H6 [ppm]	< 500 -1000
Acetylene [ppm]	< 5
C3 and C3+ [ppm]	< 10
O2 [ppm]	< 10
H2 [ppm]	< 10
CO [ppm]	< 1
CO2 [ppm]	< 2
Sulfur (as S) [ppm]	< 1
H2O [ppm]	< 2
Temperature	ambient
Pressure [barg]	25

TechnipFMC Research Center Pilot Plant

- Operating at commercial plant conditions, it provides an accurate platform to collect data for process design and licensing performance guarantees.
  - Assure Hummingbird® catalyst manufacture
  - Optimize catalyst performance
  - Develop technology improvements

TechnipFMC Research Center provides chemical process development services to a wide range of internal and external clients.

Thank you.

Andrew Simpson

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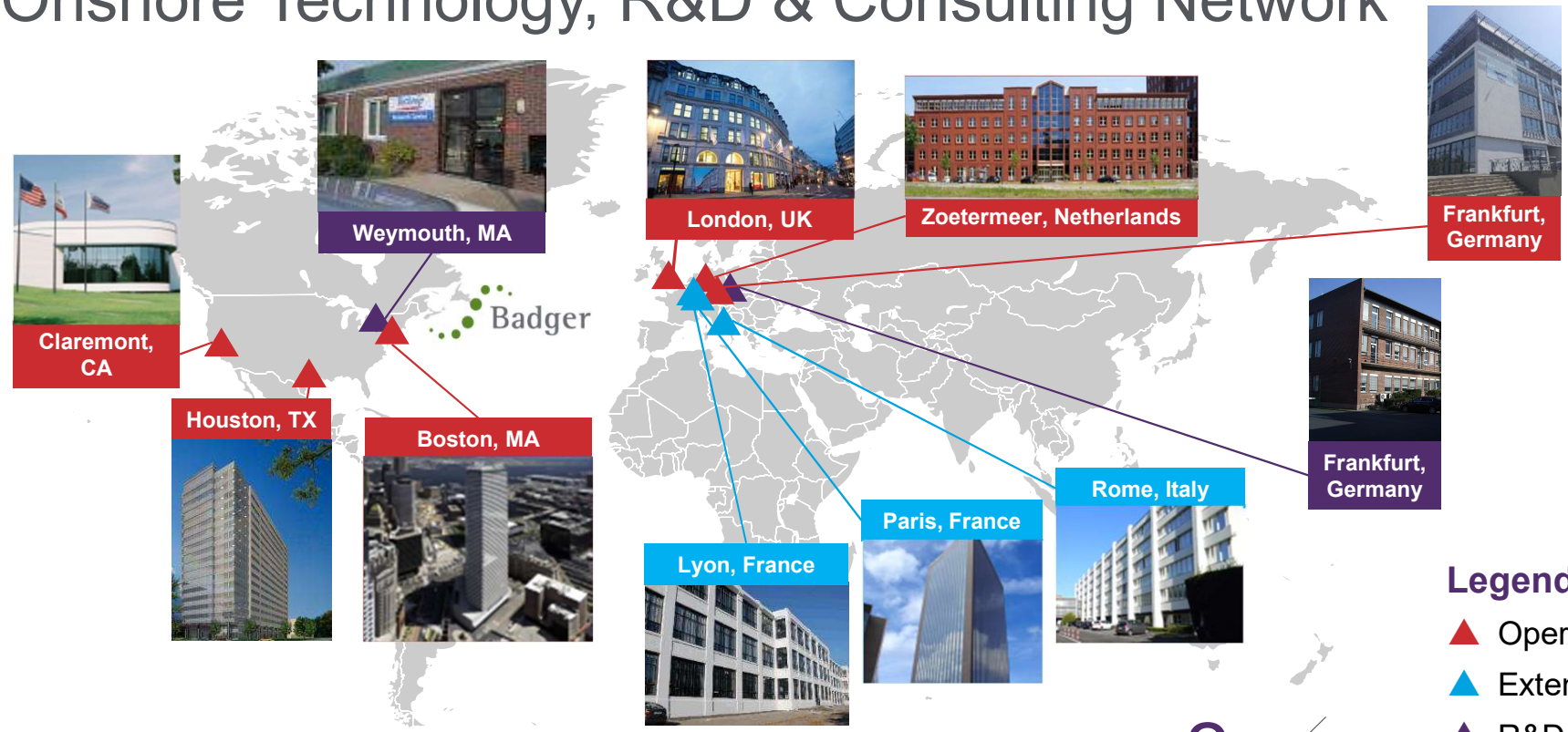
Onshore Technology, R&D & Consulting Network



Legend

- Operating center
- Extended team
- R&D center

≈ 1,000 Employees

9 Locations

2 Research Centers

Technology Design & Operation Support

Our London office manages ongoing Licensee Support, IP Management, and marketing of Hummingbird® technology.

- One of TechnipFMC's Centers of Excellence for ethylene plant design.
- Experienced in the performance of technical evaluations and Feasibility Studies through to full licensed process designs.
- Familiar with integrating ISBL process designs with available site infrastructure.
- Close-coupled with Weymouth for ethanol analysis and catalyst performance support.