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Advanced Biofuels from Fast Pyrolysis Bio-Oil

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AIChE - Dinner Lecture Meeting
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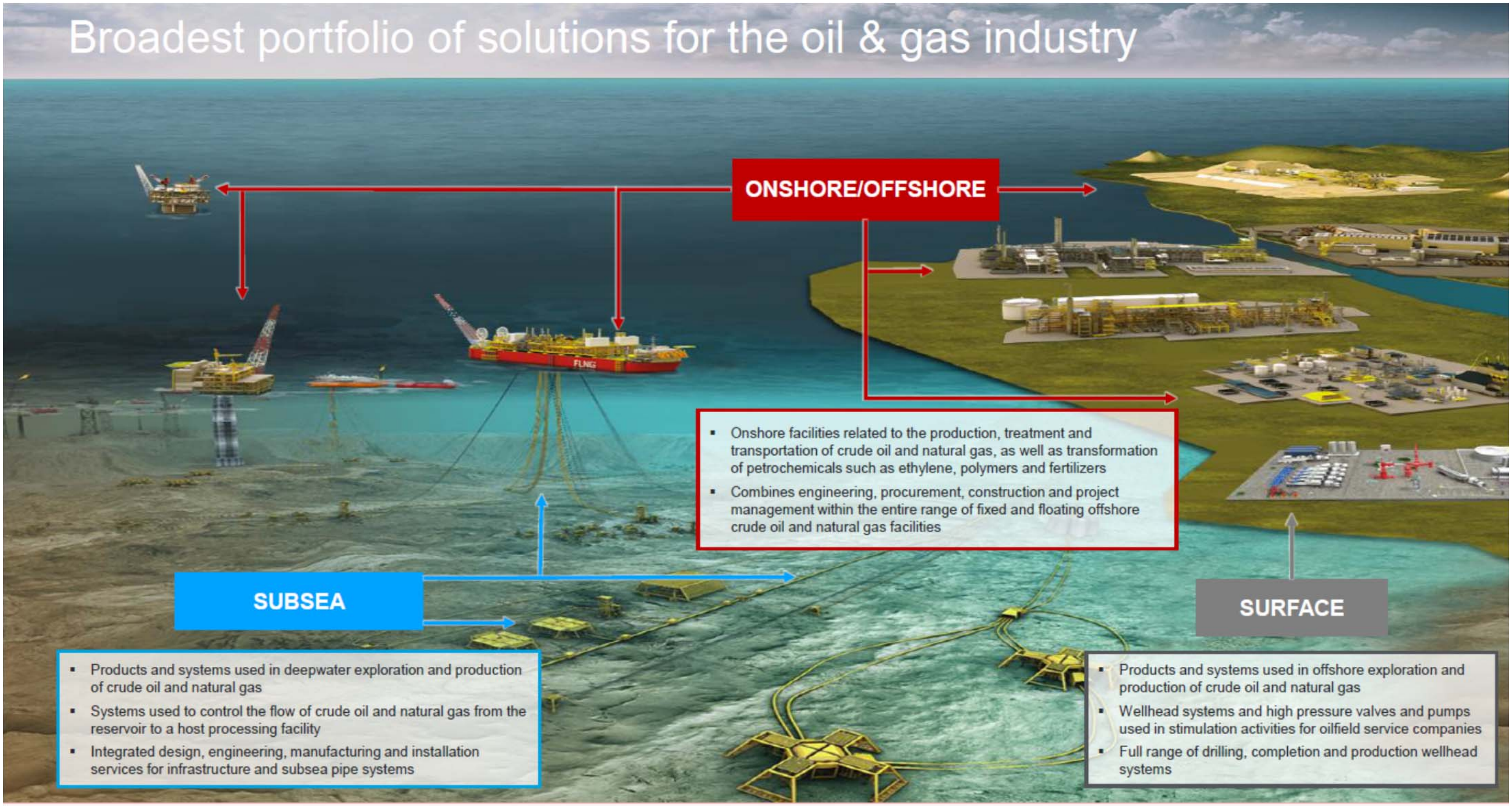
TechnipFMC - Global



TechnipFMC Process Technology (PT) Centers

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Technip Benelux - Capability Highlights

Technip Benelux is your partner for:

- Ethylene Technology
- Hydrogen & Syngas Technology
- Fast Pyrolysis (Bio-Oil) Technology
- EPC execution and EPC services projects
- Services support for operation and maintenance

BTG-BTL - TechnipFMC collaboration

About BTG-BTL:

- Founded in 2007, BTL (BTG BioLiquids B.V.) is a biomass technology provider based in The Netherlands.
- Owns proprietary pyrolysis technology, originally developed at the University of Twente.
- BTL owns international patents regarding biomass pyrolysis.
- Developed the first commercial scale plant in The Netherlands.

About TechnipFMC:

- Global footprint with ~37,000 people in 48 Countries
- Technology leader in Hydrogen, Ethylene, Refining & Petrochemical projects
- >35 years experience in development, design and construction of proprietary FCC Technology

Rolling out Fast Pyrolysis Bio-Oil Technology & commercial production:

- Complete turnkey (EPC) delivery of Fast Pyrolysis Bio-Oil (FPBO) units
- Operational support for commercial production of pyrolysis oil

2010-2020-2030 EU Policy Framework on Climate and Energy

Biofuels Directive 2003-2010	5.75% Renewable fuels and Biofuels		
RED (Renewable Energy Directive) 2010-2020	20% Renewable Energy	-20% GHG Emissions	20% Energy Efficiency
RED II 2020-2030	**32% Renewable Energy**	-40% GHG Emissions	30% Energy Efficiency

ILUC (Indirect Land Use Change) 2015

Reducing GHG emissions, creating jobs & growth, securing energy supply

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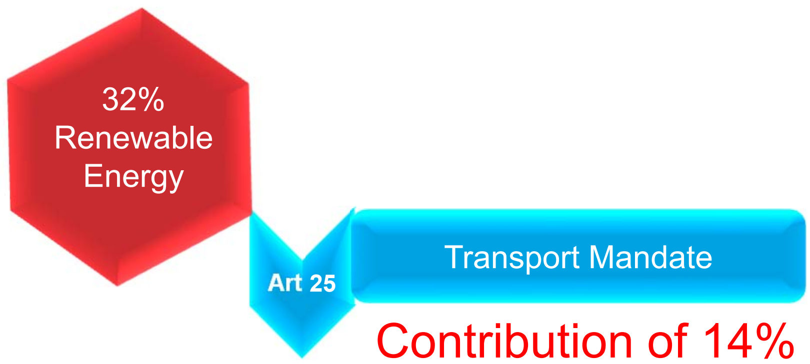
It is all about feedstock

Classification	Alternative Classification	Feedstocks
First Generation Capped 7%	Conventional biofuels	Sugar Crops
		Starch Crops
		Vegetable Oils
		Palm Oil ✖
Second Generation	Ambiguous Capped 1.7%	Used Cooking Oil
		Animal Fats
		Energy Crops
	Advanced Biofuels	Agricultural Residues
		Forest Residues
		Sawmill Residues
		Wood Wastes
	steady growth track	Municipal Solid Waste
Third Generation		Algae

Technologies	Products
Transesterification	Bioethanol
Fermentation	Biodiesel
Hydrogenation	Methanol
Fischer-Tropsch	Butanol
Gasification	Mixed alcohols
Pyrolysis	Jet fuels
Hydrolysis	Hydrotreated Vegetable Oil (HVO)
	Gasoline
	Fuel Oil

Capped % as in maximum allowable contribution in RED II Directive

Current Status of Transport Mandate in RED II



- Fuel volumes from feedstocks part A: 0.2% in 2022, 1% in 2025, 3.5% in 2030. (show a steady growth track)
- Fuel volumes from feedstocks part B: are capped at 1.7% in 2030.
- Marine and aviation fuels excluded from Art. 25

Summary Annex IX (RED II)

Feedstock A*	Feedstock B
Agricultural Residues	Used Cooking Oil
Forest Residues	Animal Fats
Sawmill Residues	Energy Crops
Wood Wastes	
Municipal Solid Waste (organic part)	
Algae	

* Bio-Fuel from Part A and B feedstocks are subject to a multiplier of x2

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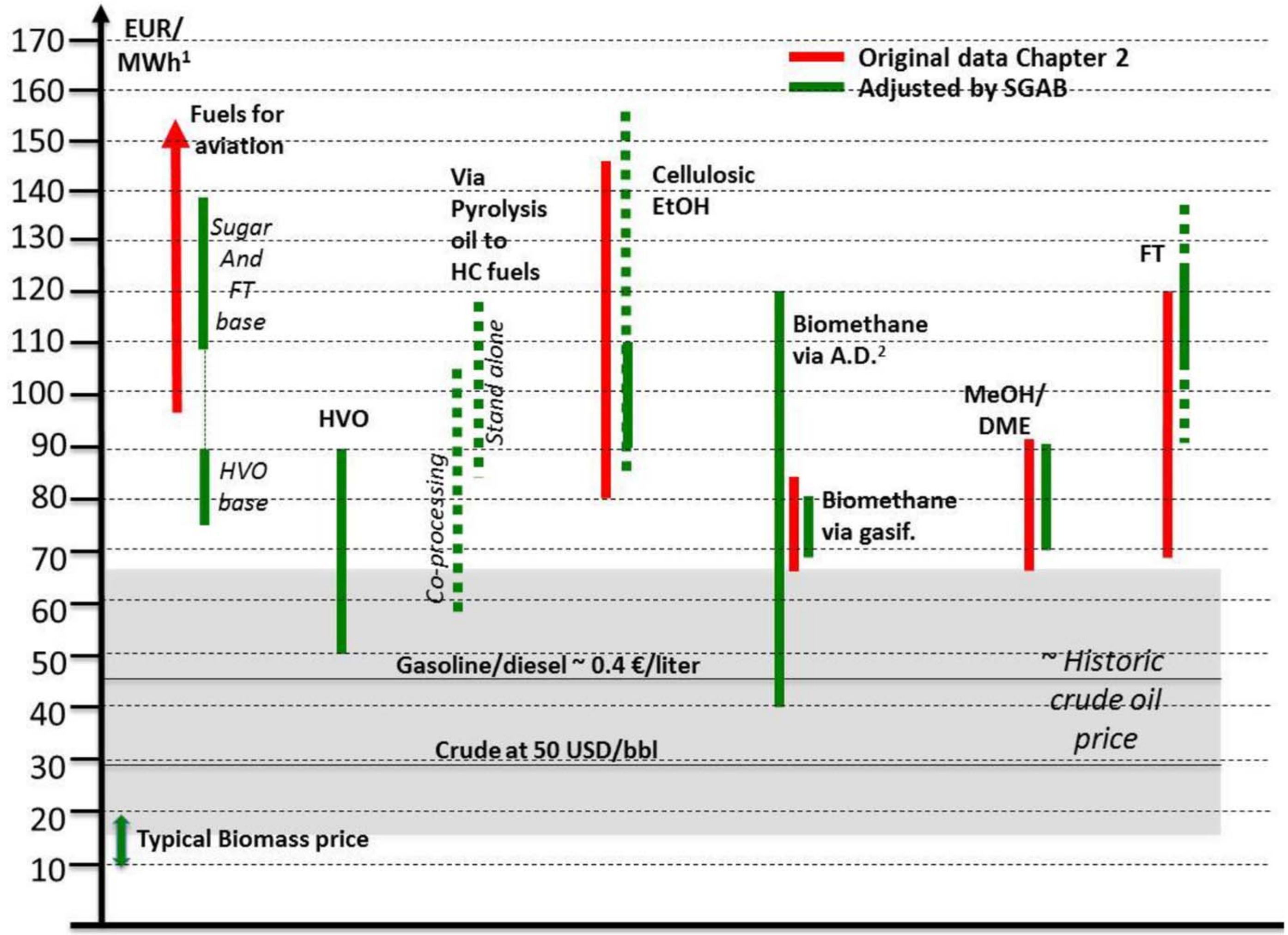
Costs of Technologies



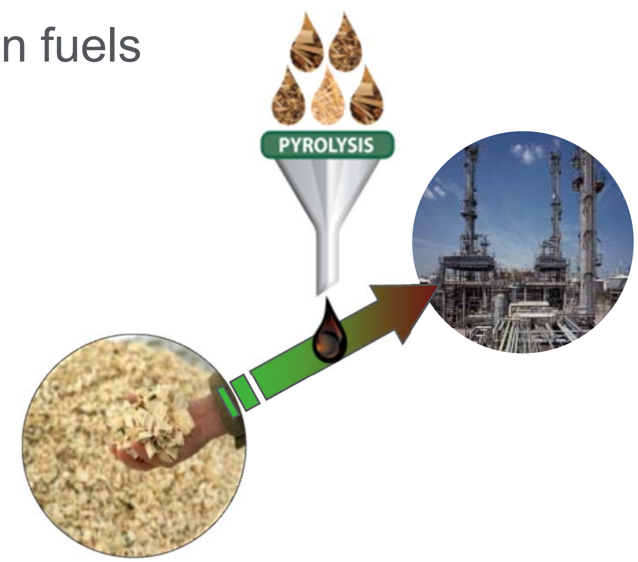
[1](EUR / MWh)/3.6 = €/GJ [2]Anaerobe Digestion (large span due to very different feedstock costs)

Source: Sustainable Transport Forum, Sub Group on Advanced Biofuels, 2017, final report

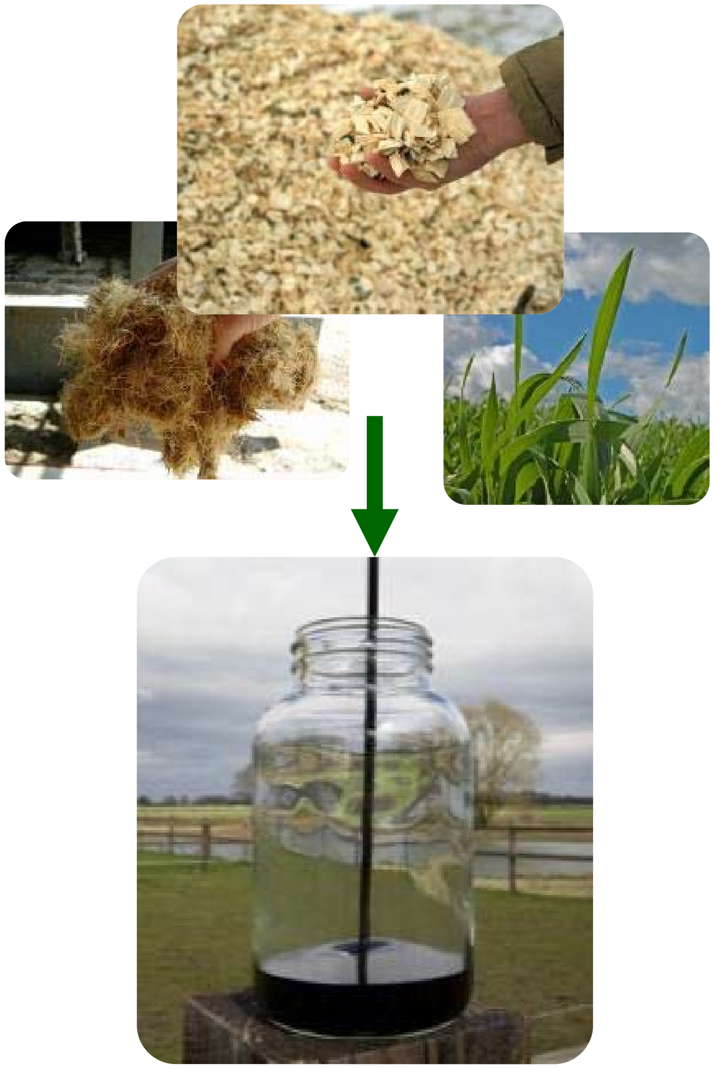
Why advanced biofuels from Fast Pyrolysis Bio-Oil?

- Fast Pyrolysis Bio-Oil is easier to store and transport than solid biomass due to significant volume reduction (on average 12 X)
- Decouple biomass resource from location and scale of application
- Works with a variety of lignocellulosic biomass feedstocks
- Produces a homogeneous 2nd generation bio-liquid, a sustainable alternative to fossil fuels
- High overall energy efficiency of > 85%
- Versatile application: Heat, power and transportation fuels
- Commercially available technology
- Utilize existing fossil fuel infrastructure:

- Pyrolysis oil provides a viable link between the agriculture and refining industry.
- Can be used as a renewable feedstock for the production of **advanced biofuels**.



What is Fast Pyrolysis?



Thermal cracking of organic material in the absence of oxygen

- Main Product = Liquid Bio-oil
- Process conditions:
- T = 400 - 600°C
- P = atmospheric
- By products:
  - Heat (Steam)
  - Power (Electricity)

Works with most lignocellulosic (non-edible) feedstocks

- Wood chips, sugar cane bagasse, straw, sunflower husk, etc.

Typical Pyrolysis Oil Characteristics	
Composition	$C_2H_5O_2$
Density	1100 - 1200 kg/m^3
Heating value	17 - 20 GJ/m^3
• **Water content**	20 - 30 wt.%
• **Ash**	< 0.1 wt.%
• **Acidity (pH)**	2.5 - 3

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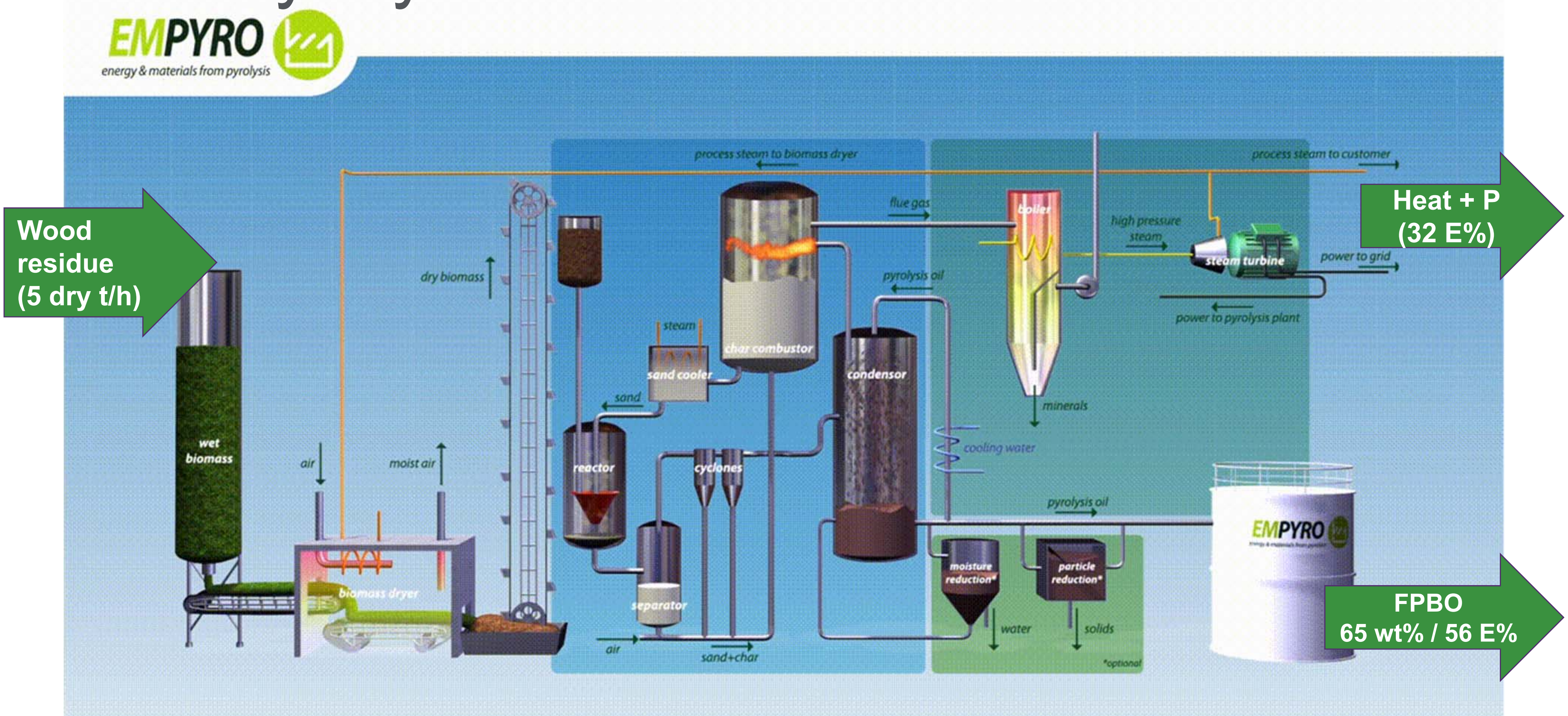
Fast Pyrolysis Process



- Intensive mixing of biomass particles and hot sand in absence of air in the **REACTOR**.
- Char and sand are recycled to a **COMBUSTOR** where the char is burned to reheat the sand.
- Vapors leaving the reactor are rapidly cooled in the **CONDENSER** yielding the pyrolysis oil and some gases.
- The gases and the surplus heat from the **COMBUSTOR** can be used to generate steam for power generation, biomass drying or external use.
- The minerals contained in biomass stay behind in the ashes. They can be reused locally, thus avoiding mineral depletion.

First commercial Fast Pyrolysis Bio-Oil production plant

Plant Data	
Capacity	5 t/h (dry)
Feedstock	Wood residue
Outputs	
Pyrolysis Oil	3.2 t/h
Electricity	300 kW
Steam	10.5 t/h
CO2- eq. reduction	24,000 t/y
Plant Milestones	
Mar 2015	Start-up
May 2015	First oil delivery to Friesland Campina
Jan 2019	Plant sold to Twence

Empyro in Hengelo, the Netherlands

2nd Project awarded by client in Finland

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Fast Pyrolysis Bio-Oil Applications

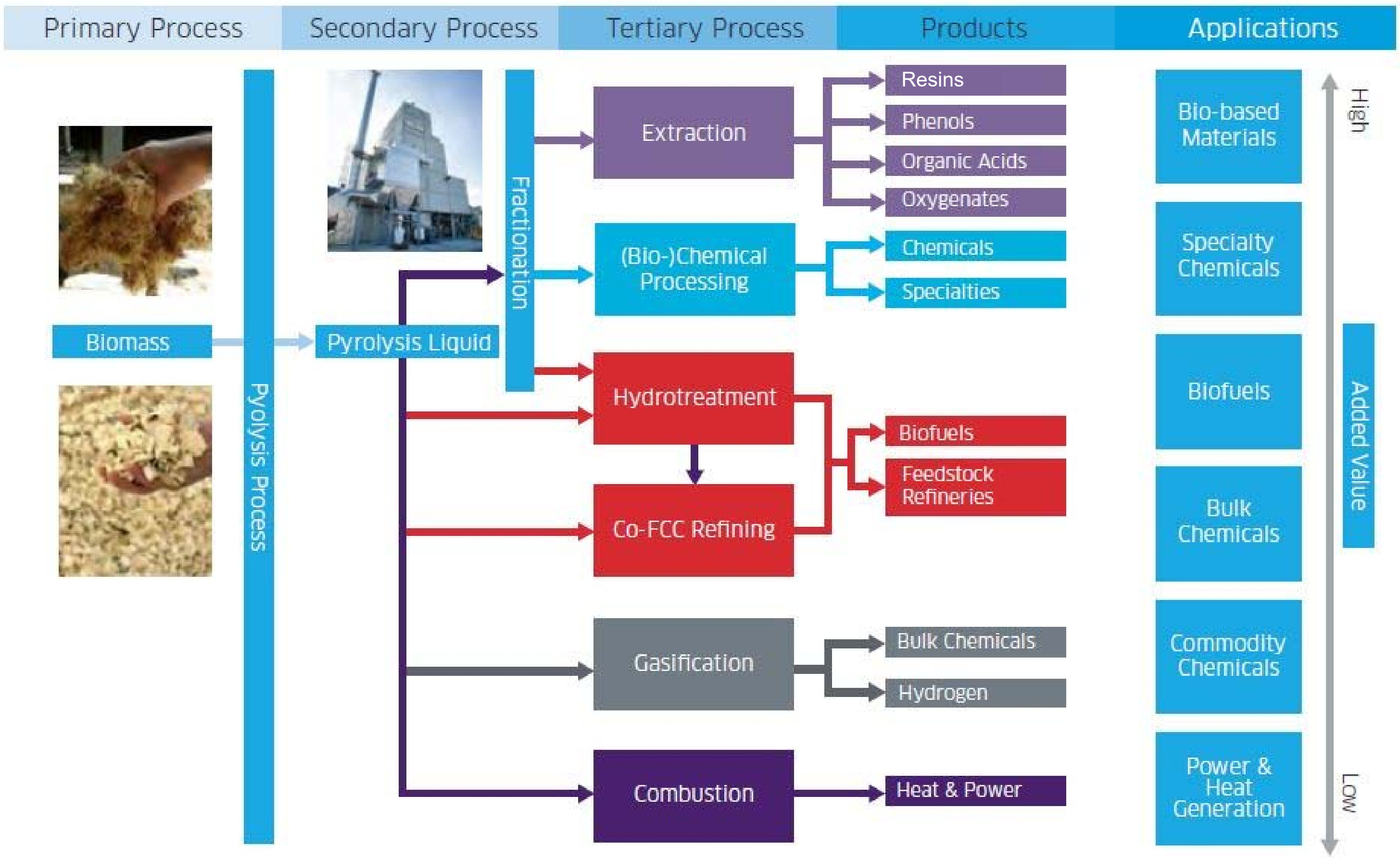
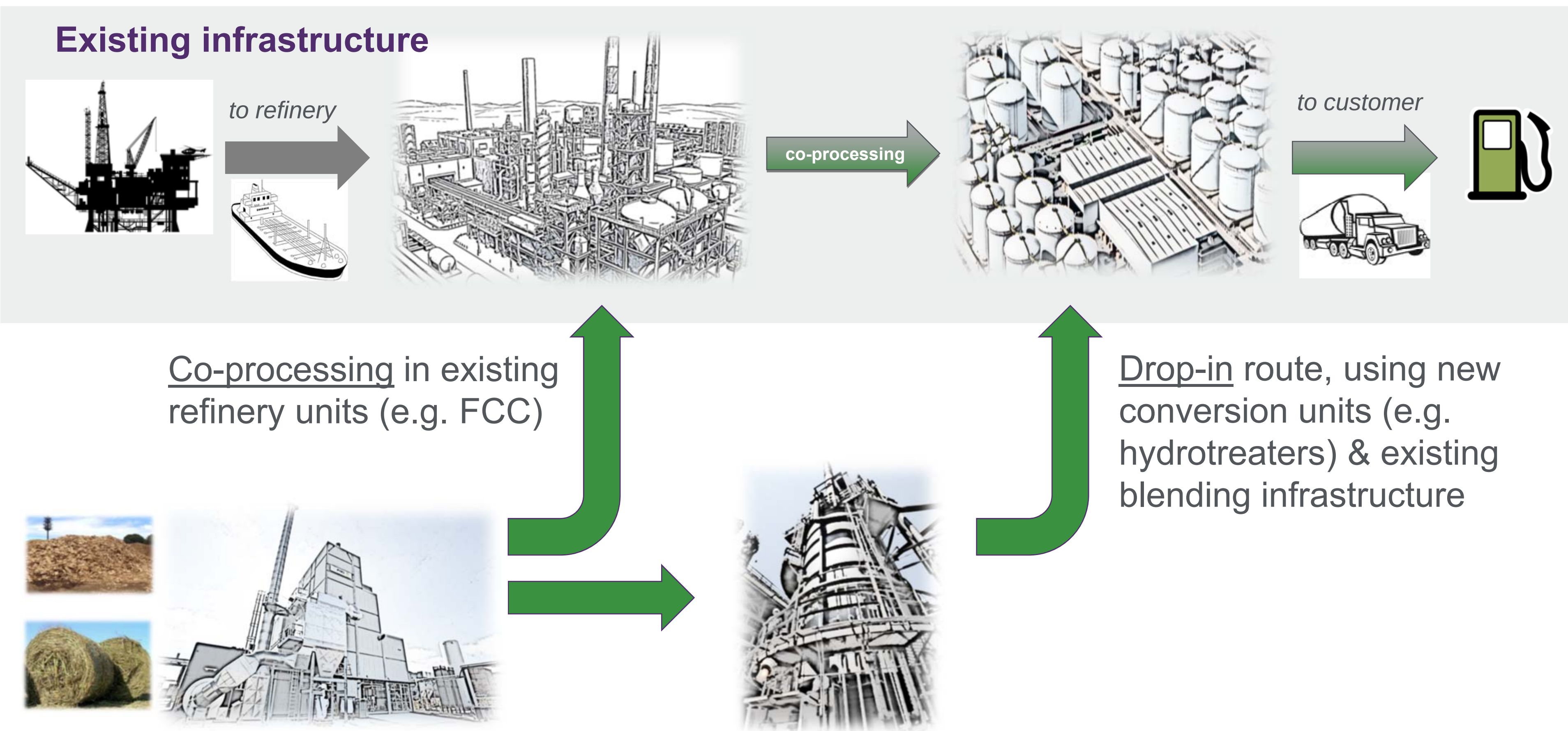


Figure based on BTG Biomass Technology Group B.V. intellectual property

Advanced biofuels: drop-in & co-processing

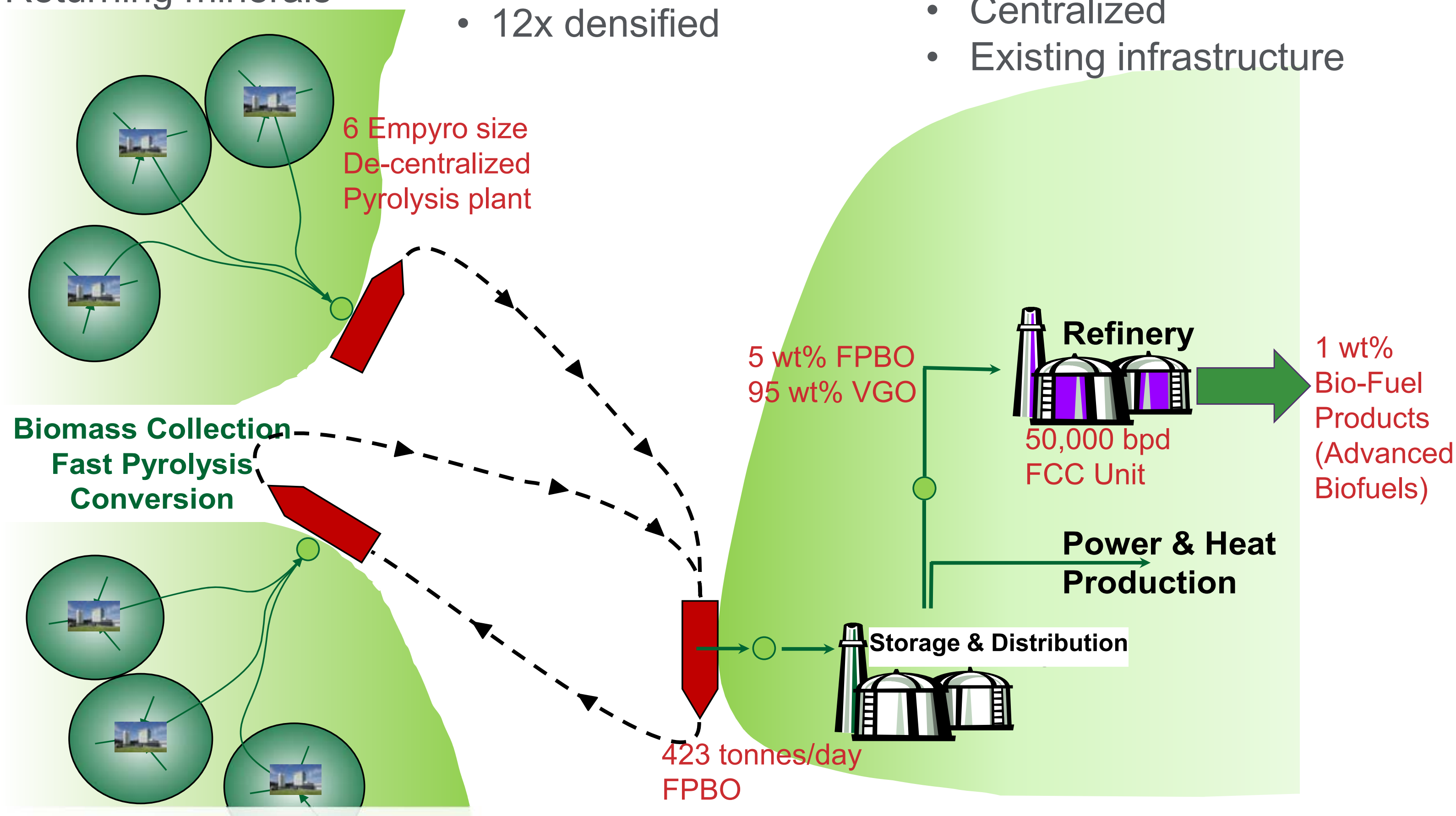


Fast Pyrolysis in the bio-based economy

1. Biomass conversion
- Local processing
- Returning minerals

2. FPBO transport
- Biomass liquified
- 12x densified

3. Processing & distribution
- Centralized
- Existing infrastructure



FPBO, the link between agricultural & refinery industries!

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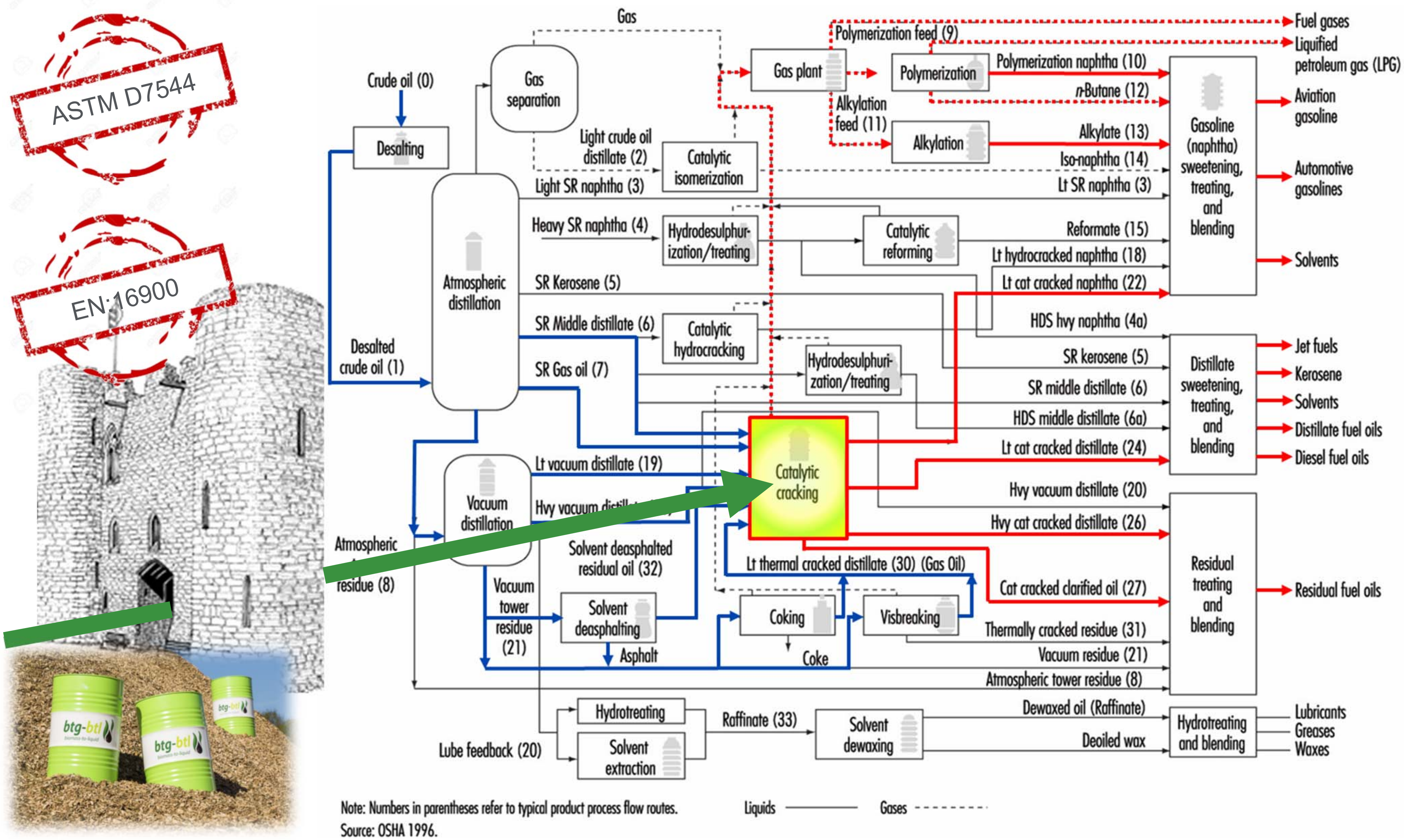
Fluidized Catalytic Cracking unit in a refinery



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Co-FCC of FPBO, how does it work?

Typical FCC scheme:

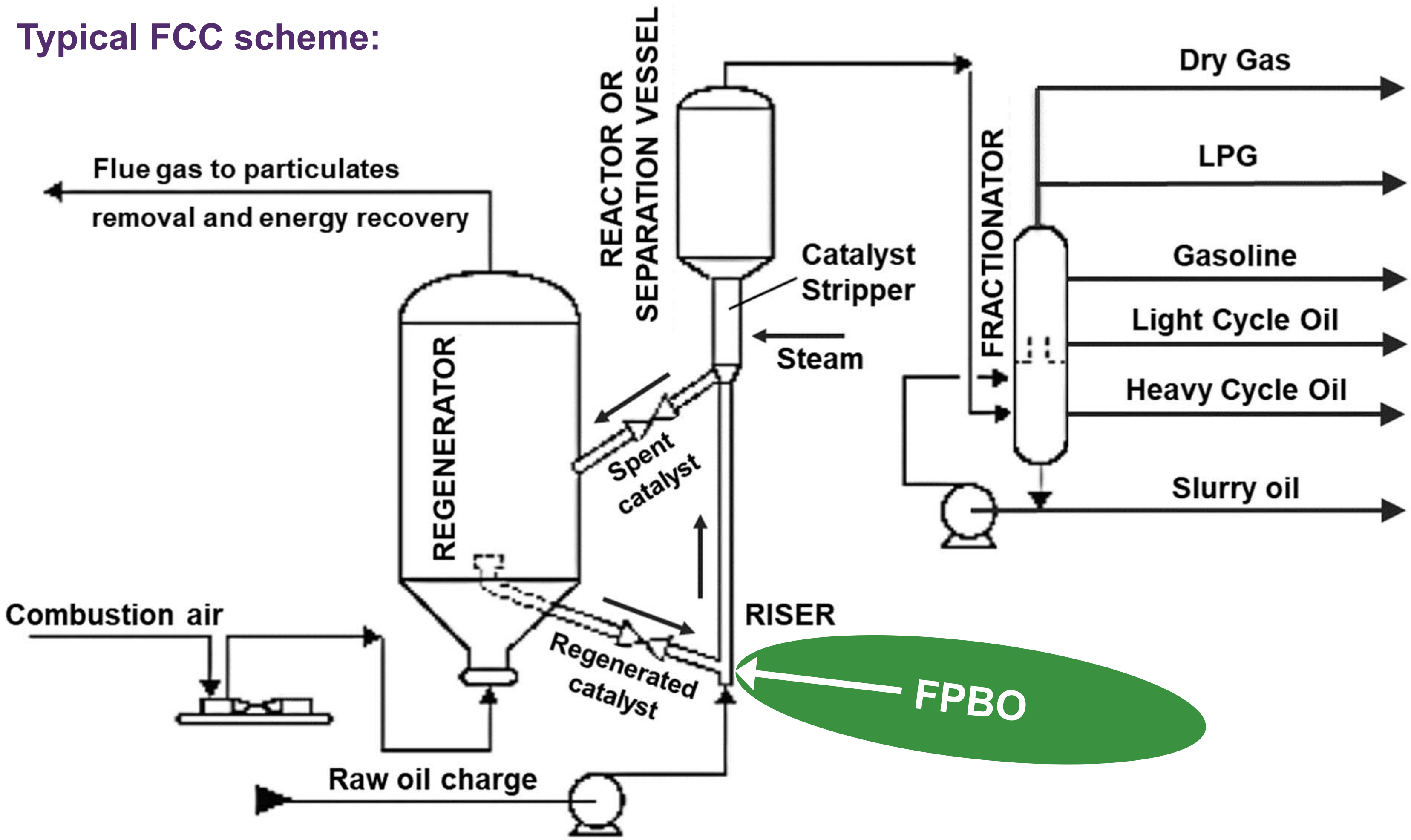
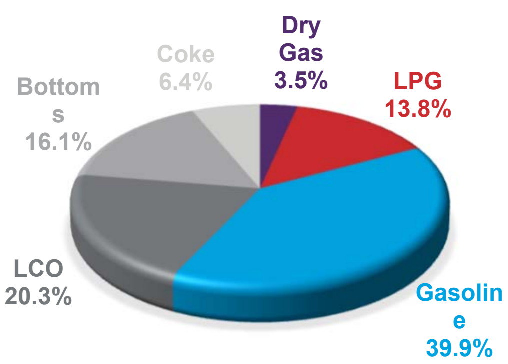


Figure adapted from U.S. Energy Information Administration

Co-FCC of FPBO: Yields

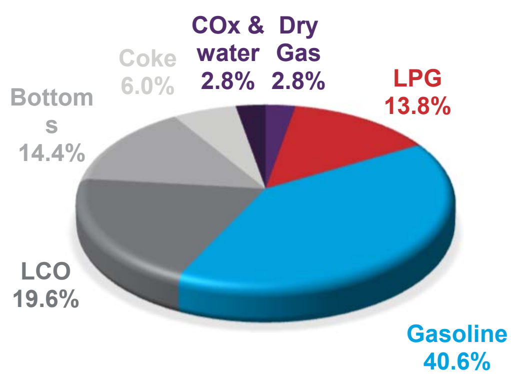
The effect of 5-10 wt% FPBO co-processing on FCC unit yield:

100% VGO



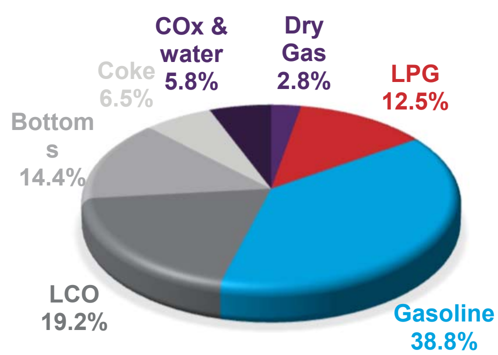
LPG + Gasoline + LCO : 74.0 wt%

95% VGO + 5% FPBO



LPG + Gasoline + LCO : 74.0 wt%

90% VGO + 10% FPBO

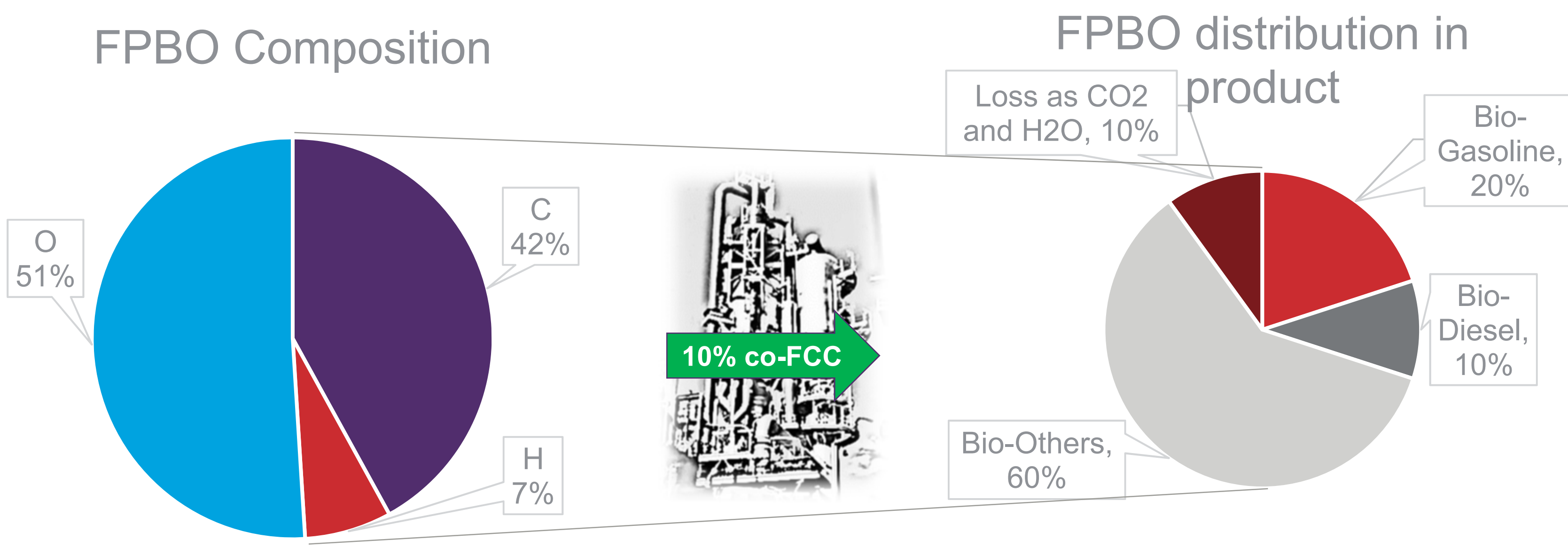


LPG + Gasoline + LCO : 70.5 wt%

Source:
DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review
2.4.2.303 Brazil Bilateral: Petrobras-NREL CRADA

Co-FCC of FPBO: Carbon and Hydrogen balance

- Oxygen makes up half of the mass of FPBO eithers as in water or oxygenates:



- About 30% of the bio-based Carbon and Hydrogen becomes FCC-gasoline + diesel.
- The rest of the bio-C is not lost, and still reduces the use of crude oil for other products (e.g. LPG, olefins, marine fuels, ...) and energy!
- Other products eligible for carbon credits? Mass-balance system?

FPBO co-processing challenges

- Potential corrosion impact of oxygen in raw bio-fuel – Most of the oxygen is converted to CO_2 and H_2O in FCC, with smaller reminder of oxygenated compounds.
- Risk of Fouling in Bio-Oil injection system (needs proper design)
- Acid number of FPBO typically higher than that found in petroleum
- Higher metal content and different type than found in refinery streams
  - Fossil petroleum: Ni and V
  - FPBO: Alkali and alkaline earth metals (Analogy with Shale Oil Refining)
- Some biomass feedstocks contain typically more Chlorides (e.g. verge grass)

Analogy

Catalyst management in co-processing unit

- Monitoring FPBO, cat cracker feed and Ecat
- Choose / develop optimized catalyst for new feedstock (Metal trapping technology needs to take this in consideration when formulating catalyst for co-processing)
- Proper catalyst flushing program (Catalyst withdrawal and makeup rates may increase because of metals especially alkaline metals from FPBO)

Summary and perspectives

- FPBO can be used directly for heat and power generation.
- Government mandate for advanced biofuels forces refiners to look at an alternative way to meet the obligations.
- Co-processing crude Fast Pyrolysis Bio-Oil in FCC units can be a viable way to meet renewable fuel requirements, with little to no impact on refinery operations when co-processing small shares (5-10 wt-%).
- FPBO co-processing showed promising results in a demo plant.
- Many refiners are showing keen interest in exploring co-feeding.
- Co-processing with higher FPBO contribution may call for mild hydrotreatment of FPBO.
- For co-feeding FPBO existing FCC units can be retrofitted at low capital cost.
- Higher metal loading in FPBO can be overcome by proper catalyst management.