Advanced Biofuels from Fast Pyrolysis Bio-Oil

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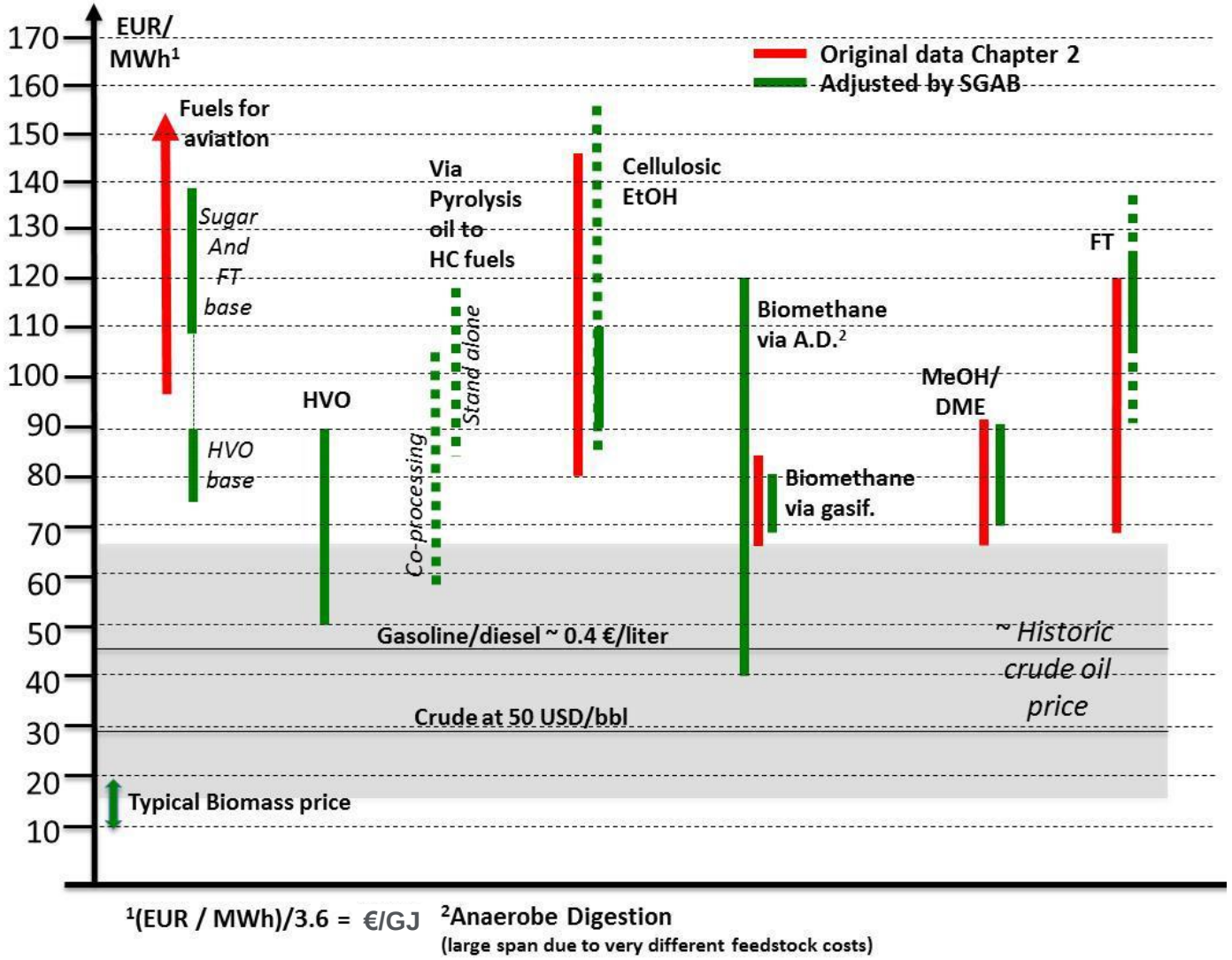
EU Renewable Energy Directive (“RED 2”)

Classification	Alternative Classification	Feedstocks	Technology	Products
First Generation 	Conventional biofuels	Sugar Crops	Transesterification	Bioethanol
		Starch Crops	Fermentation	Biodiesel
		Vegetable Oils	Hydrogenation	Methanol
		Palm Oil	Fischer-Tropsch	Butanol
Second Generation	Ambiguous 	Used Cooking Oil	Gasification	Mixed alcohols
		Animal Fats	Pyrolysis	Jet fuels
		Energy Crops	Hydrolysis	Hydrotreated Vegetable Oil (HVO)
	Advanced Biofuels  steady growth track	Agricultural Residues		Gasoline
		Forest Residues		Fuel Oil
		Sawmill Residues		
		Wood Wastes		
		Municipal Solid Waste		
Third Generation		Algae		

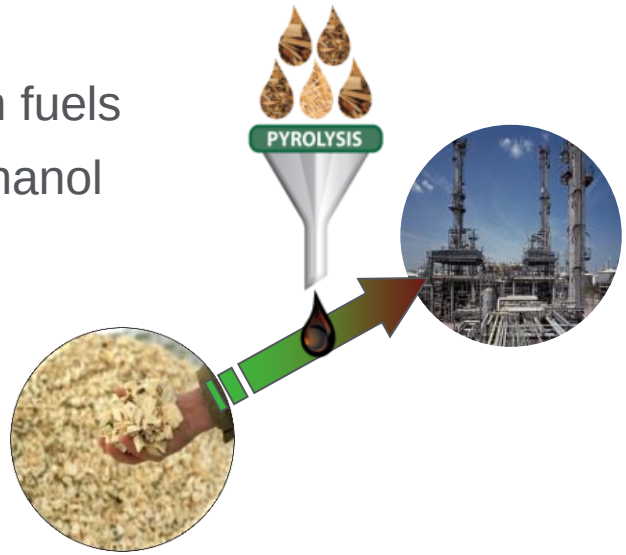
Costs of technologies for advanced biofuels



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

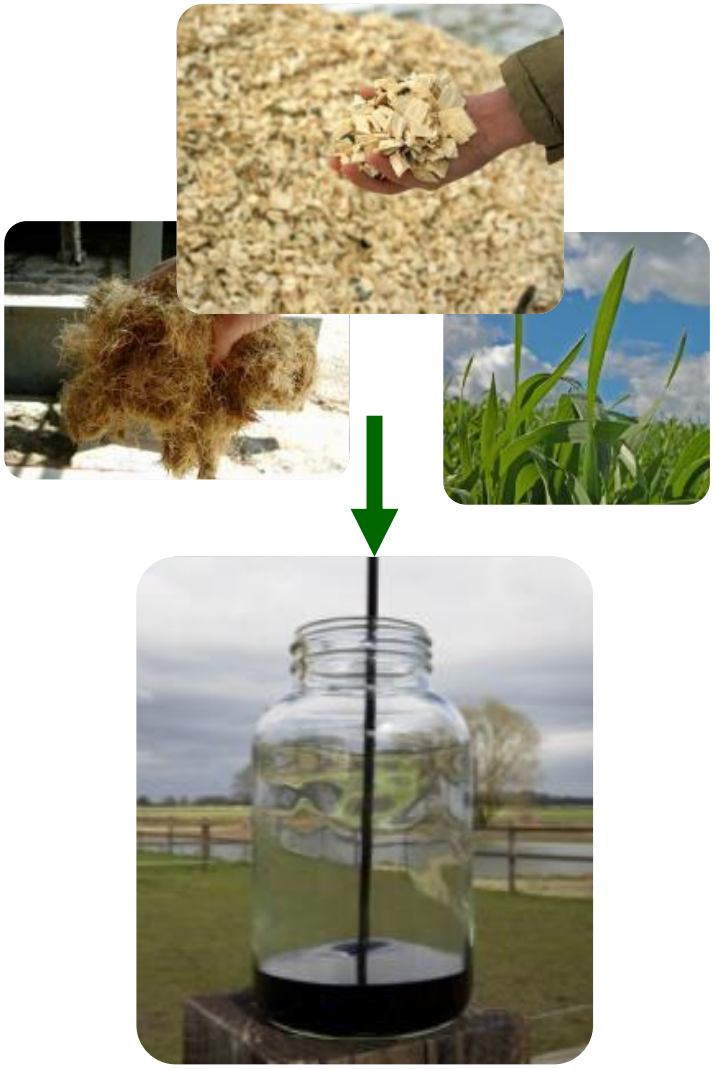
Why advanced biofuels from Fast Pyrolysis Bio-Oil?

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



Fast Pyrolysis Bio-Oil is an attractive renewable feedstock for the production of **advanced biofuels,** thereby sustainably linking agriculture and refining industry

What is Fast Pyrolysis?



Thermal cracking of organic material in the absence of oxygen

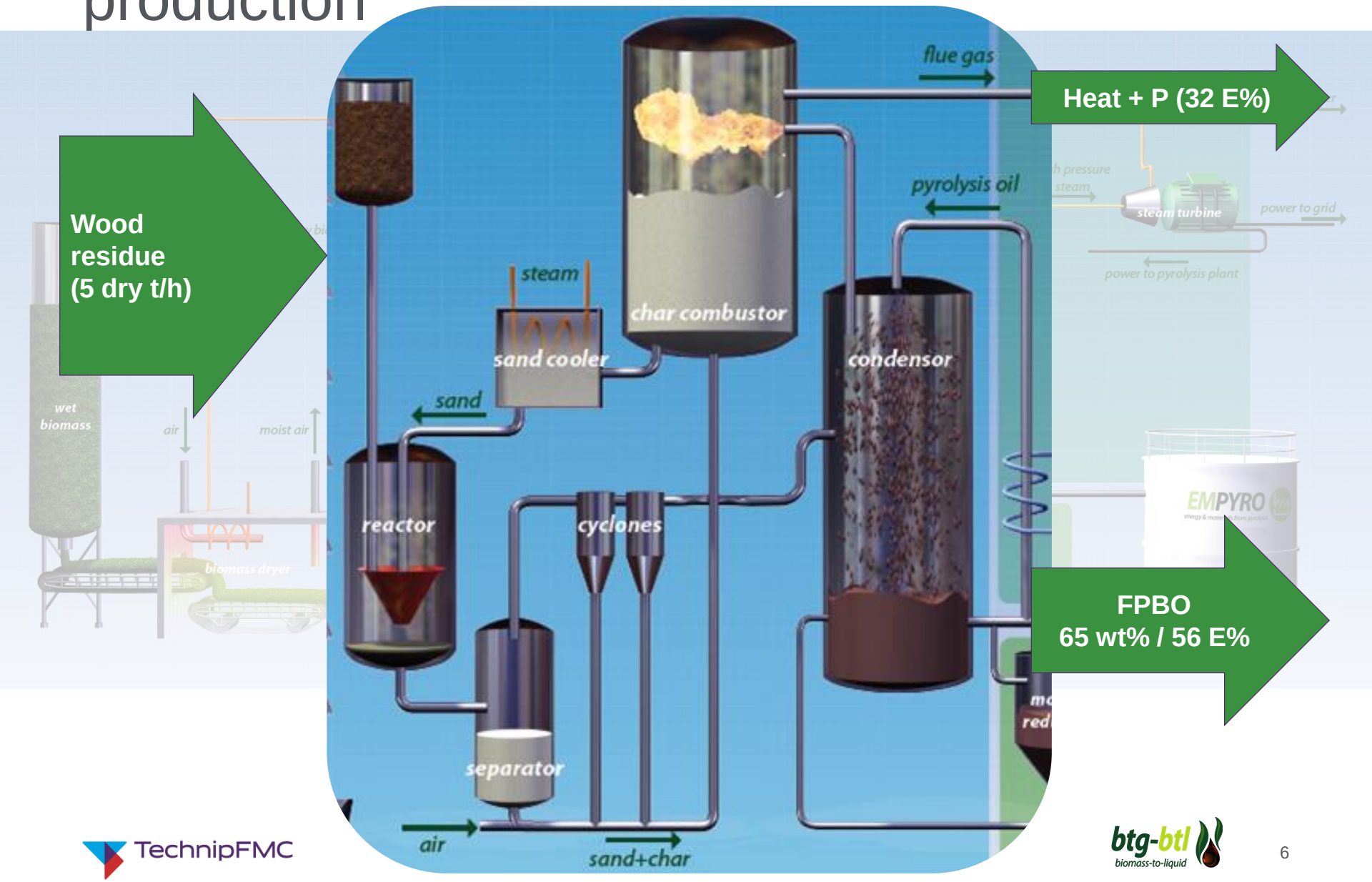
- Main Product = Liquid Bio-oil
- Process conditions:
- T = 400 - 600°C
- P = atmospheric
- By products:
  - Heat (Steam)
  - Power (Electricity)

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

Commercial Fast Pyrolysis Bio-Oil production



TechnipFMC

btg-btl biomass-to-liquid

Commercial Fast Pyrolysis Bio-Oil production

Plant Data	
Capacity	120 tonnes of dry biomass/day
Feedstock	Wood Residue
Output per year	
Oil	24,000 tonnes
Electricity	2,200 MWh
Steam	80,000 tonnes
CO2- eq. reduction	24,000 tonnes
Plant Milestones	
Mar 2015	Start-up
May 2015	First oil delivery to Friesland Campina
Dec 2018	30.000.000 liters produced

Empyro in Hengelo, the Netherlands

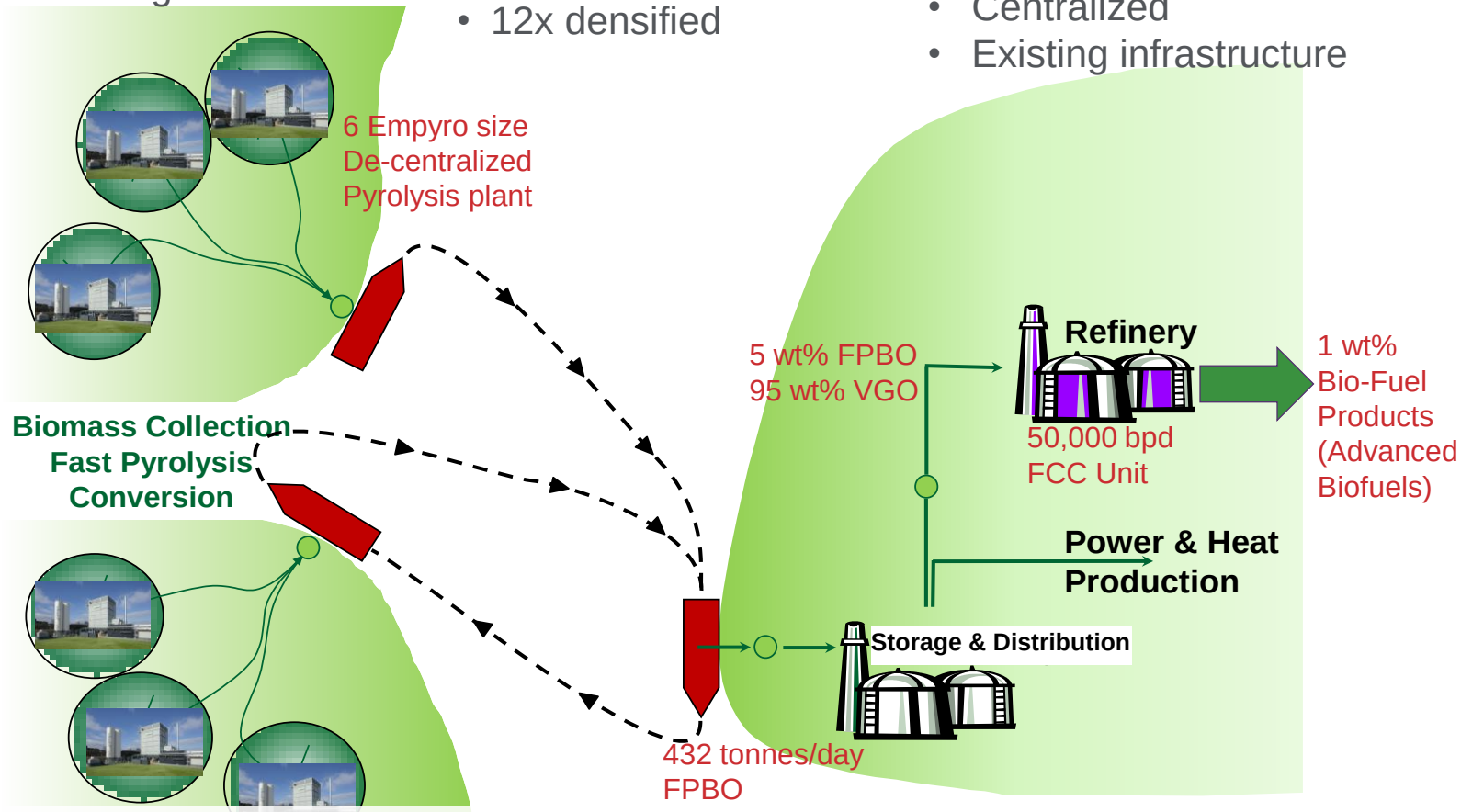
Plant now runs steadily at design capacity

Fast Pyrolysis Bio-Oil as refinery feedstock

1. Biomass conversion
- Local processing
- Returning minerals

2. FPBO transport
- Biomass liquified
- 12x densified

3. Processing & distribution
- Centralized
- Existing infrastructure

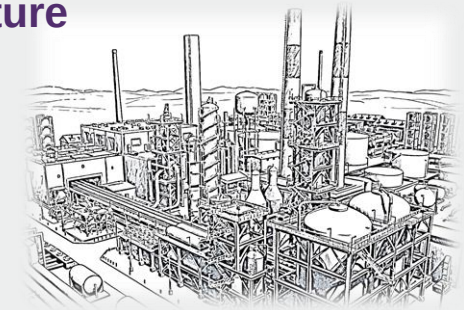


FPBO, the link between agricultural and refining industries!

Advanced biofuels: drop-in & co-processing

Existing infrastructure

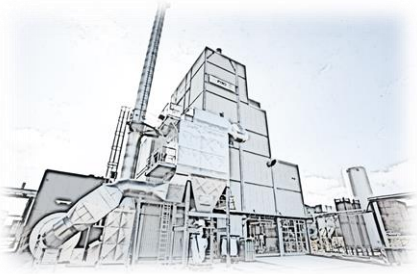
to refinery



co-processing

to customer

<u>Co-processing</u> in existing refinery units (e.g. FCC)



<u>Drop-in</u> route, using new conversion units (e.g. hydrotreaters) & existing blending infrastructure

BTL - TechnipFMC collaboration

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

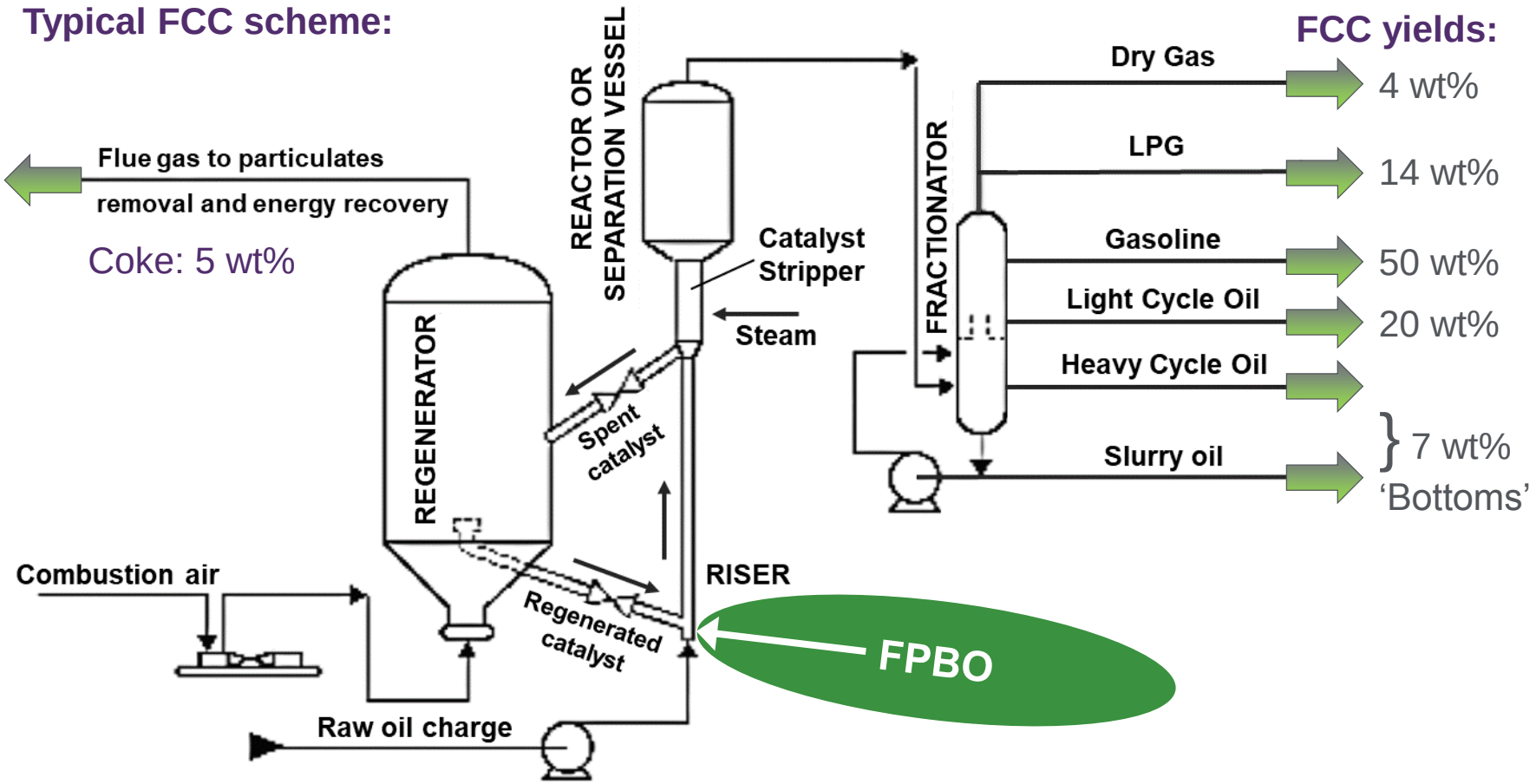
About TechnipFMC:

- 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 (Fluid Catalytic Cracking) technology

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

Co-FCC of FPBO, how does it work?

Typical FCC scheme:



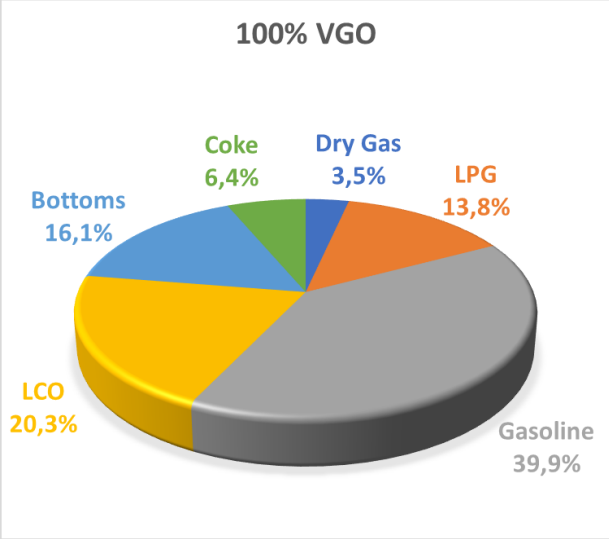
Commercial FCC yields:

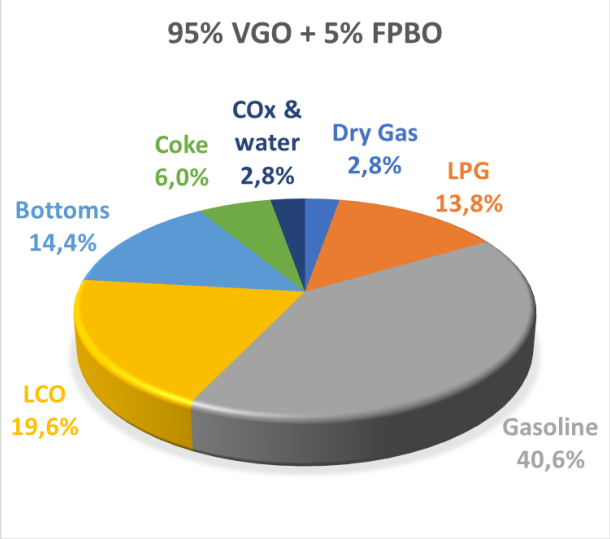
- Dry Gas: 4 wt%
- LPG: 14 wt%
- Gasoline: 50 wt%
- Light Cycle Oil: 20 wt%
- Heavy Cycle Oil + Slurry oil: } 7 wt% 'Bottoms'

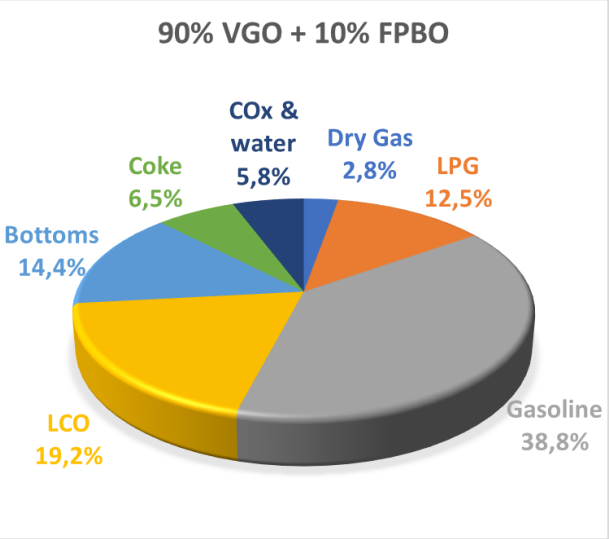
Figure adapted from U.S. Energy Information Administration

Co-FCC of FPBO, what happens to the yields?

Co-processing 5-10 wt-% FPBO has little impact on yields of the wanted products:







LPG + Gasoline + LCO : 74.0 wt%

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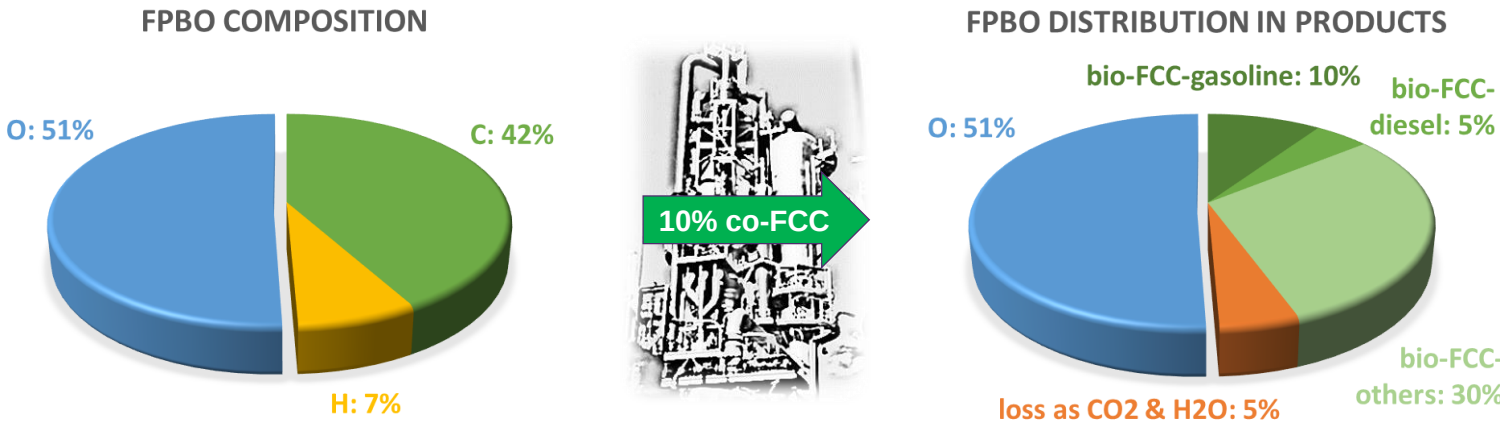
LPG + Gasoline + LCO : 70.5 wt%

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

Co-FCC of FPBO, where does the biomass go?

- Half of the mass of FPBO comes from oxygen atoms, in water or oxygenates:



- About 15% of the FPBO (30% of the bio-C) 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?

Data: Petrobras 2015, using FPBO in an FCC demo unit

FPBO co-processing challenges

- Potential corrosion impact of oxygen in raw bio-fuel – Most of the oxygen is converted to CO2, H2O with some phenol formation.
- Risk of Fouling in Bio-Oil injection system (needs proper design)
- Acid number typically higher than that found in petroleum
- Metals increased and different type than found in refinery streams
  - Petroleum: Ni and V
  - FPBO: Alkali and alkaline earth metals (Analogy with Shale Oil Refining)
- Chlorides typically present in biological feedstocks sometimes high

Fast Pyrolysis Bio-Oil co processing solutions:

- New injection nozzle
- Review metallurgy in fractionation section
- Catalyst management – increased flushing rate

Conclusion

- Government mandates for advanced biofuels require refiners to look at an alternative way to meeting 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. %).
- Process performance showed encouraging results in a demo plant.
- Many refiners show interest in exploring FCC co-feeding.
- 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.