Sustainable Energy Solutions: Case Example of Pyrolysis Technology Development

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Valmet Technologies
Energy R&D Competences

Energy Forum
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Valmet

Contents

Introduction to Valmet

Valmet
FORWARD

- **Leading supplier** of **process technologies, automation, and services** for the pulp, paper, and energy industries

Valmet

A strong **financial profile** and balanced **business portfolio**

2022 key figures of Valmet

Orders received
EUR 5,194 million

Net sales
EUR 5,074 million

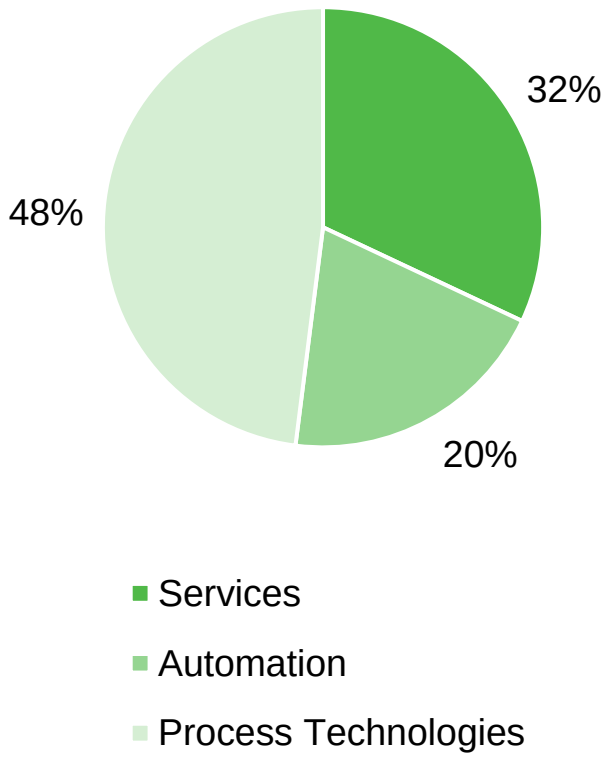
Comparable EBITA
EUR 533 million

Comparable EBITA margin
10.5%

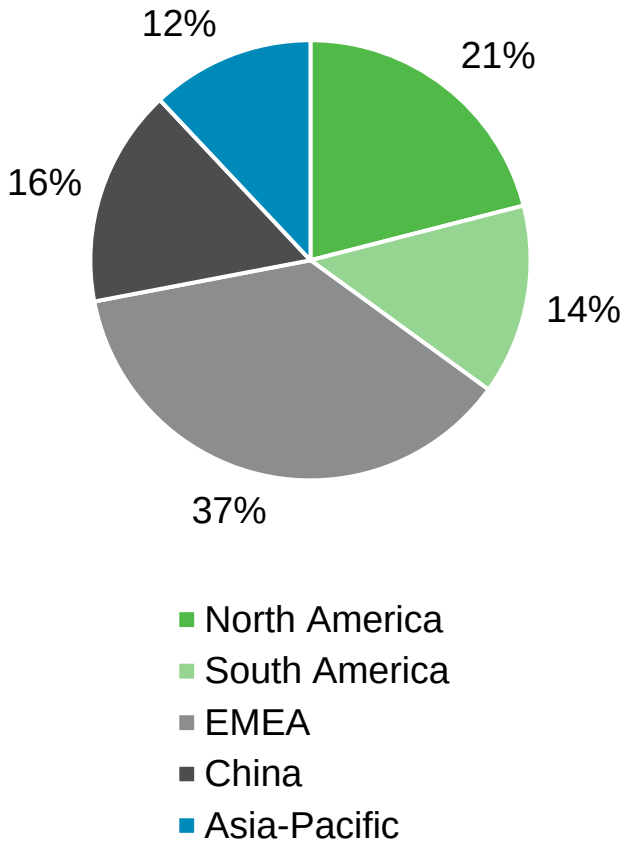
Order backlog
EUR 4,403 million

Employees
17,548

Net sales by segment



Net sales by area



Unique offering combining process technology, services and automation

Board and paper technologies

- Board, paper and tissue production lines
- Rebuilds
- Machine sections

Pulp technologies

- Complete pulp mills
- Pulp mill processes
  - Wood handling, Cooking and fiber line, Pulp drying and baling, Chemical recovery

Energy technologies

- Heat and power generation
- Air emission control
- Biofuels production

Services

- Spare and process parts
- Workshop and roll services
- Fabrics
- Maintenance development and outsourcing
- Field services
- Process upgrades
- Industrial Internet solutions

Flow Control and Automation Systems

- Valves
- Valve automation
- Valve controls
- Distributed Control Systems (DCS)
- Quality Management Systems (QMS)
- Analyzers and measurements
- Industrial applications
- Services and Industrial Internet solutions

Leading technology supplier of biomass and multifuel boiler plants globally

Renewables to energy

Biomass to energy

Sorted waste to energy (RDF-refuse derived fuel)

Multifuel to energy

Co-firing biomass, waste (RDF, SRF) and fossil fuels (coal, gas)

Industrial boilers

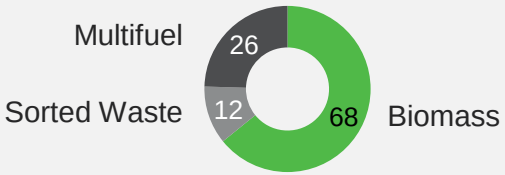
O&G / Process Gas Boiler plants

Heat recovery boiler plants

Air emission control

- Over 200 Bubbling Fluidized Bed boilers (BFB) since 1979
  Capacity 10-400 MW_{th}
- Over 100 Circulating Fluidized Bed boilers (CFB) since 1980 Capacity 50 -1000 MW_{th}
- Over 30 Modularized biomass power plants since 1999 Capacity 2-10 MW_e
- 8 Gasification plants for waste and biomass

Since 2007 ~100 new boiler plants
Total capacity ~ 12 000 MW_{th}



Why Pyrolysis at Valmet?

Strategic direction towards more valuable products

Resources

Biomass
- Forest residues
- Agro residues

Industrial residual wastes
- Pulp & Paper
- Mechanical forest industries
- Process industries

Municipal solid waste (MSW)
- Refuse-derived fuels

Commercial & Industrial wastes (C&I)
- Refuse-derived fuels

Plastics

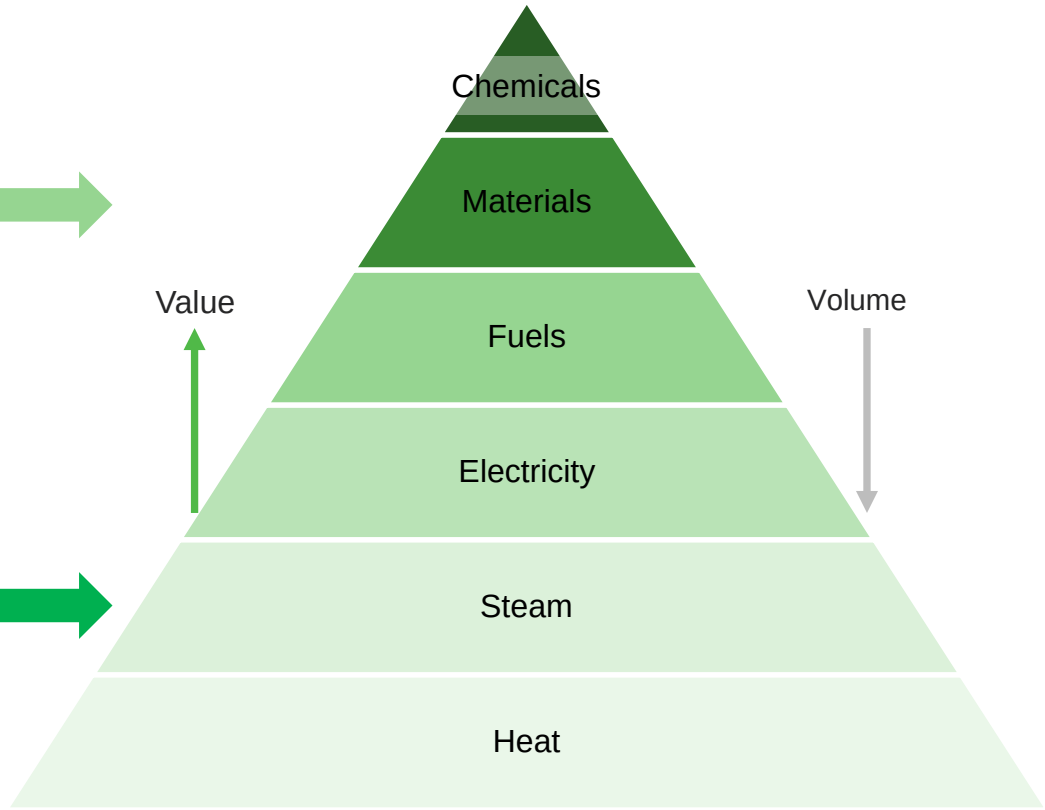
Thermochemical Conversion

Pyrolysis

Gasification

Combustion

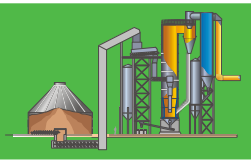
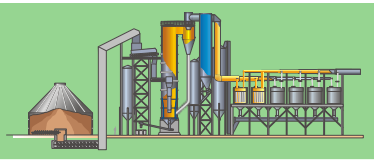
Value

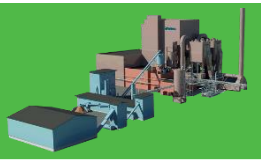


SRF: Solid Recovered Fuel
RDF: Refuse derived Waste

New revenue from bio and waste streams with different technologies

Biomass gasification	Vaskiluodon Voima, Finland, 2013	140 MW gas to replace coal in PC boiler
Waste gasification	Lahti Energia, Finland, 2012	2*80 MW_{th} waste
Biomass indirect gasification	Göteborg Energi, Sweden, 2013	20 MW_{th} SNG
Integrated pyrolysis	Fortum, Finland, 2013	30 MW_{th} bio-oil
Lignin extraction	Domtar Plymouth, USA, 2013 Stora Enso, Finland, 2015	25 000 ton/a lignin 50 000 ton/a lignin
Steam exploded black pellets	FICAP, France, 2020	120 000 ton/a
Biomass pre-treatment	Clariant, Romania, 2021 Orlen, Poland	50 000 ton/a 2G ethanol 25 000 ton/a




Advanced biofuel demand in Europe is targeted to multiply by 8-fold by 2030 and the pace will only accelerate towards 2040

Road transport

- EU Renewable Energy Directive
- National emission reduction targets
- Incentives for advanced biofuels

Demand in 2030: **7** Mtoe

Demand in 2040: *Pending legislation*

Aviation

- ReFuelEU regulation
- Binding SAF blending targets
- Increasing ambition 2030

Demand in 2030: **0.9** Mtoe

Demand in 2040: **5.5** Mtoe

Maritime

- FuelEU Maritime regulation
- Binding fuel GHG reduction targets
- Non-food or feed rawmaterials

Demand in 2030: **0.8** Mtoe

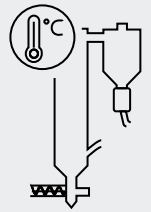
Demand in 2040: **1.5** Mtoe

Global supply of advanced biofuels in 2023 around **1** Mtoe

Demand growth by **2030** **8** Mtoe

Ambition:

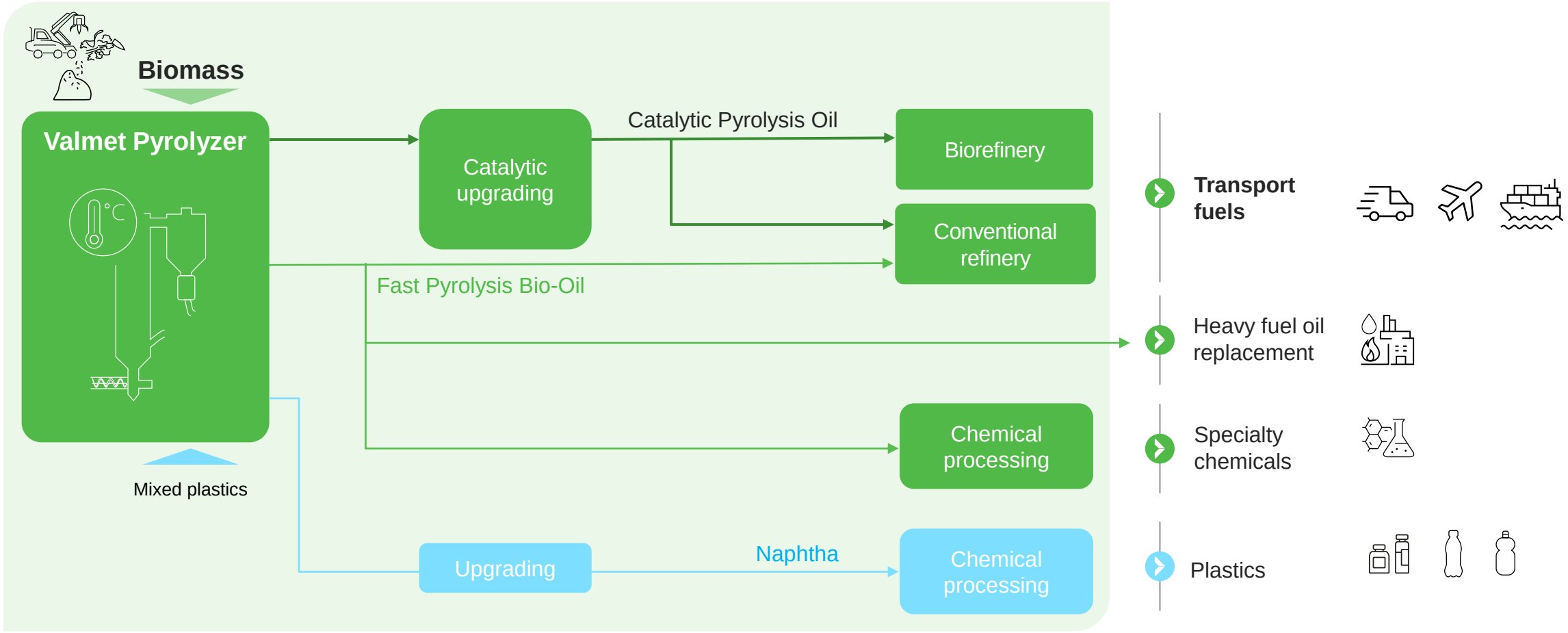
1 Mt/a pyrolysis oil with Valmet's technology by 2035*

10 x  **100 kt/a**

*Pyrolysis-based fuels **10-15**% share of advanced biofuels markets

Source: AFRY
Millions of tones of oil equivalnet

Valmet offers fast pyrolysis and catalytic pyrolysis technology for high-value products



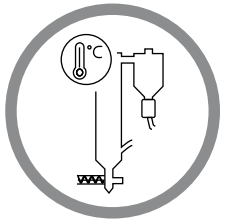
Valmet offers the entire plant solution including automation and services during the operation

Feedstock

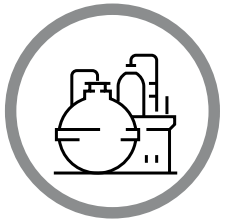
Non-food and lignocellulosic biomass, like woodchips, sawdust and forest residues

Pretreatment

Pyrolysis



Refining



Catalytic pyrolysis oil processing validated by leading refinery technology licensors

Products

Drop-in hydrocarbons, like Diesel, Jet and Gasoline

Valmet core technologies

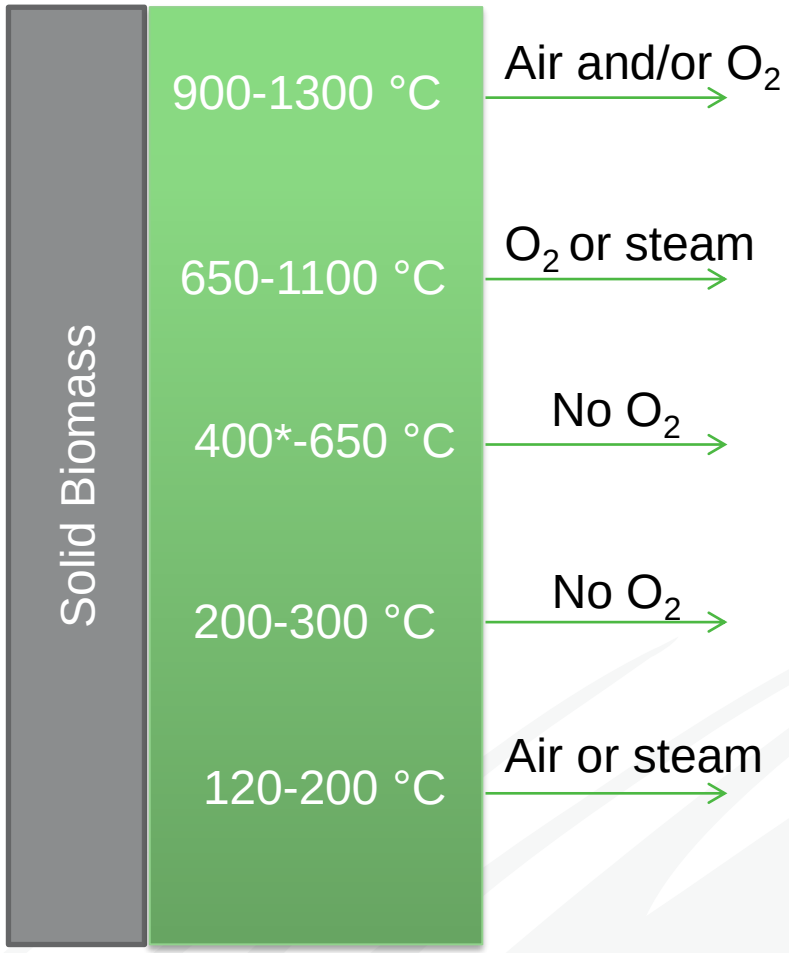
Valmet can provide the entire plant including needed **boiler** systems and **automation**

Valmet offers **service and maintenance** for operating facilities

Pyrolysis Concept

Mechanism

Thermochemical Conversion



Air and/or O_2 → Combustion

O_2 or steam → Gasification

No O_2 → Pyrolysis

Hydrothermal liquefaction (HTL; P:280-370bar)

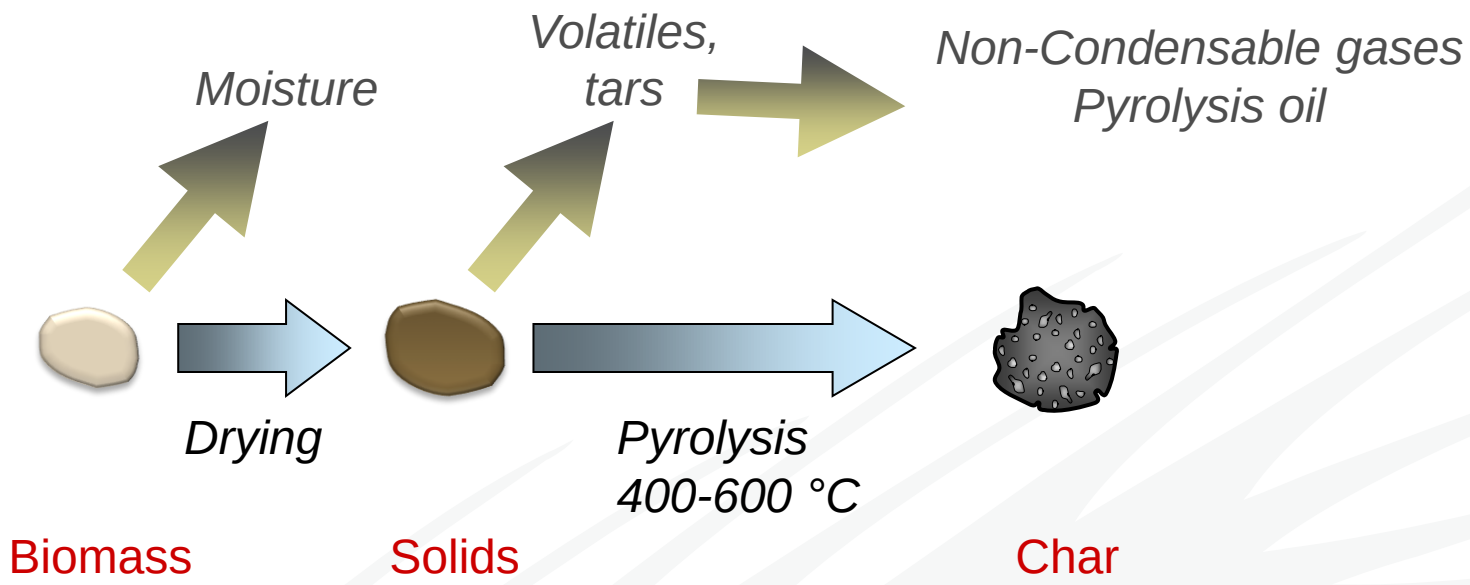
No O_2 → Torrefaction

Steam explosion (P:7-48bar)

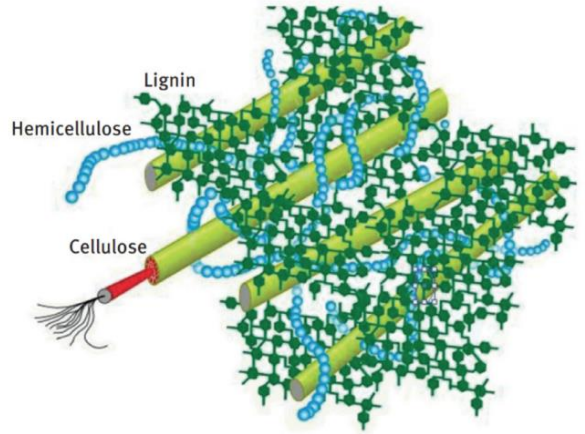
Air or steam → Wood heat treatment

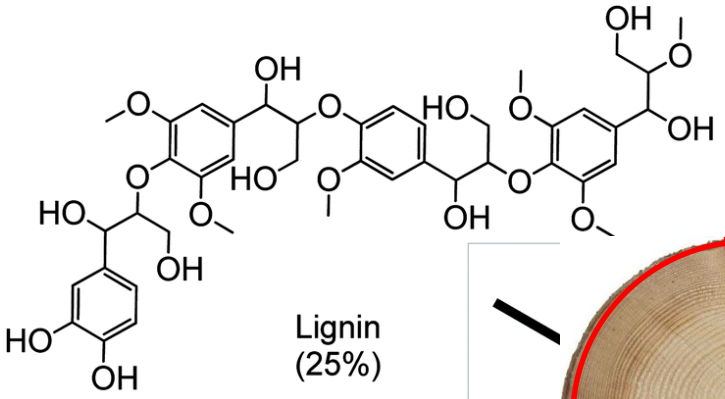
*~300C in presence of catalyst

Pyrolysis (fast vs. slow)



Biomass



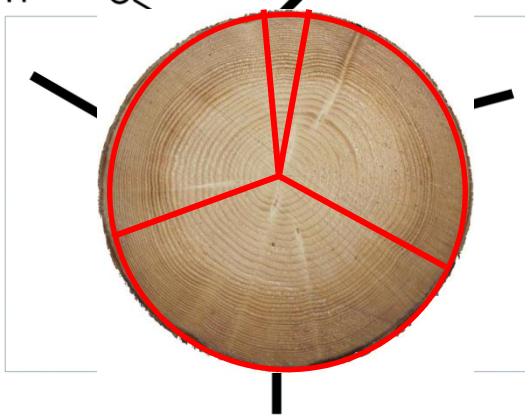


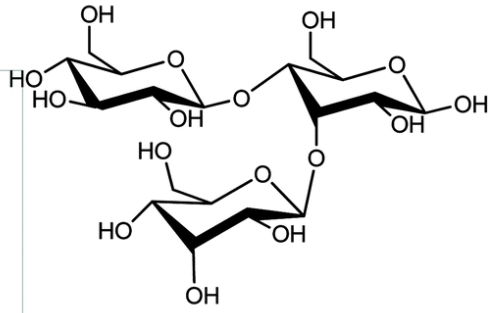
Lignin
(25%)

More char

Ash and Extractives

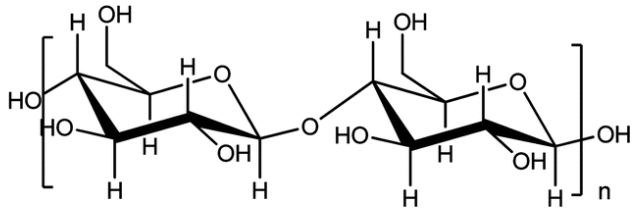
(~5%)





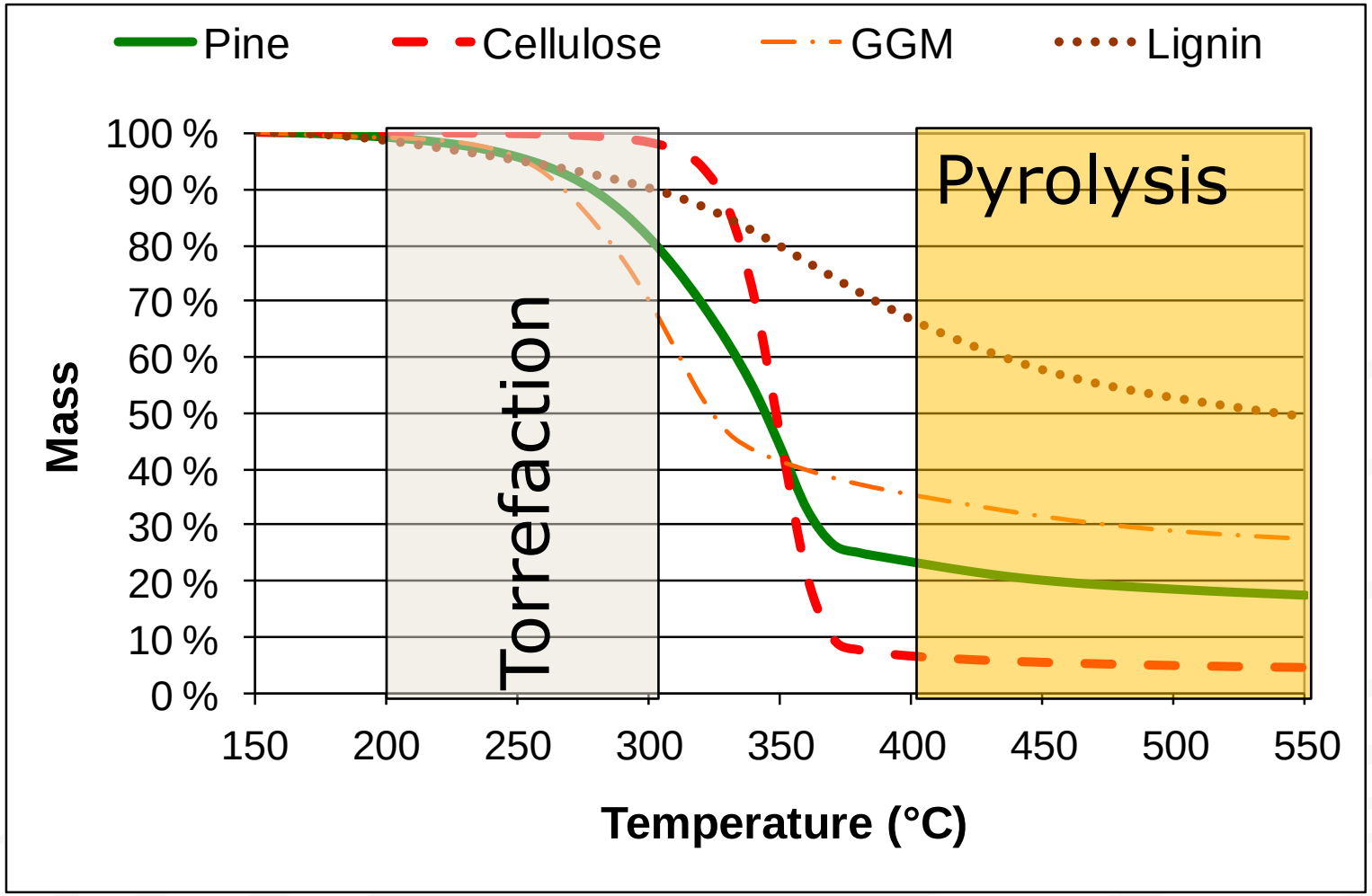
Hemicellulose
(30%)

More volatiles



Cellulose
(40%)

Biomass Components vs. Heat-treatment



Pine, cellulose, GGM: A. Aho *Int. J. Mol. Sci, 2008, 9*
Lignin: I. Linden, Flame days, 2011

High-value products via pyrolysis, routes and potential

Fast pyrolysis

Catalytic pyrolysis

Pyrolysis oil

Heavy fuel oil

Heat plants

Light fuel oil

Raw chemicals for refineries

Biocrude
Chemical recycling

Processing in conventional refinery or biorefinery

Passenger cars
Heavy duty vehicles
Aviation
Marine

Chemical components
Plastics
Specialty chemicals

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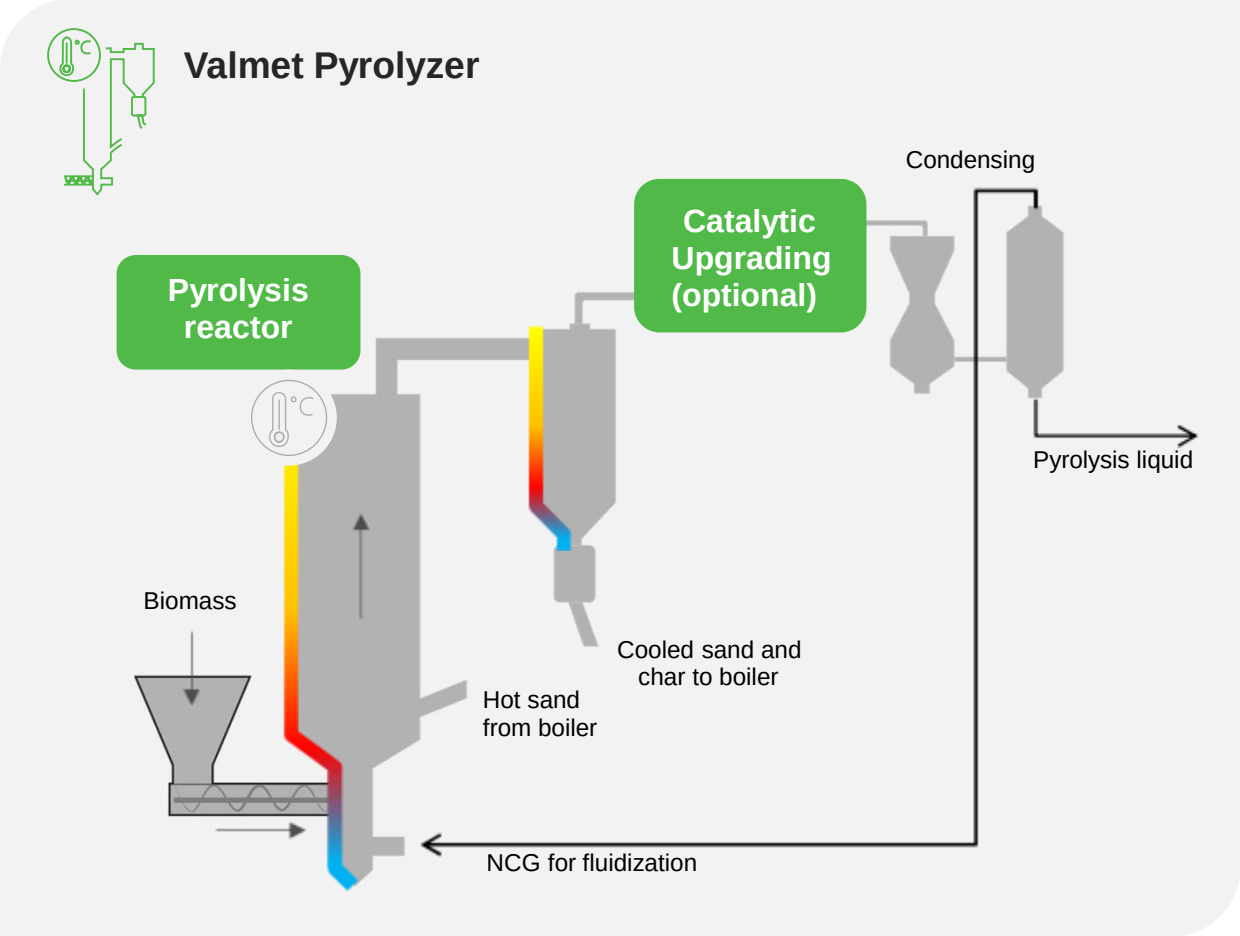
Pyrolysis

Operation Units

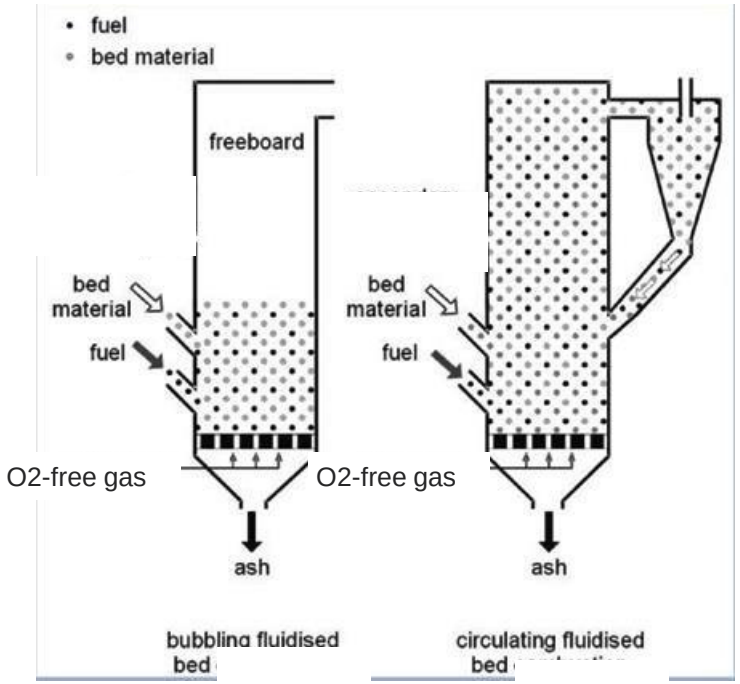
Pyrolysis can be used to convert the biomass into high-value end products such as drop-in fuels and biochemicals

- Pyrolysis is the thermal decomposition of feedstock in absence of oxygen
- The process yields three main components
  - Pyrolysis liquid
  - Char
  - Non-condensable gas (NCG)
- Suitable for most lignocellulosic and plastic feeds
  - Woody biomass such as chips, sawdust or forest residue
  - Styrene or mixed waste plastics
- Products
  - Fast Pyrolysis Bio-Oil (FPBO)
    - Feedstock for refinery, co-processing to biofuels
    - Feedstock for biochemicals
    - Replacing Heavy Fuel Oil in heating
  - Catalytic Pyrolysis Oil (CPO), also known as biocrude, for hydroprocessing in a refinery to produce drop-in fuels



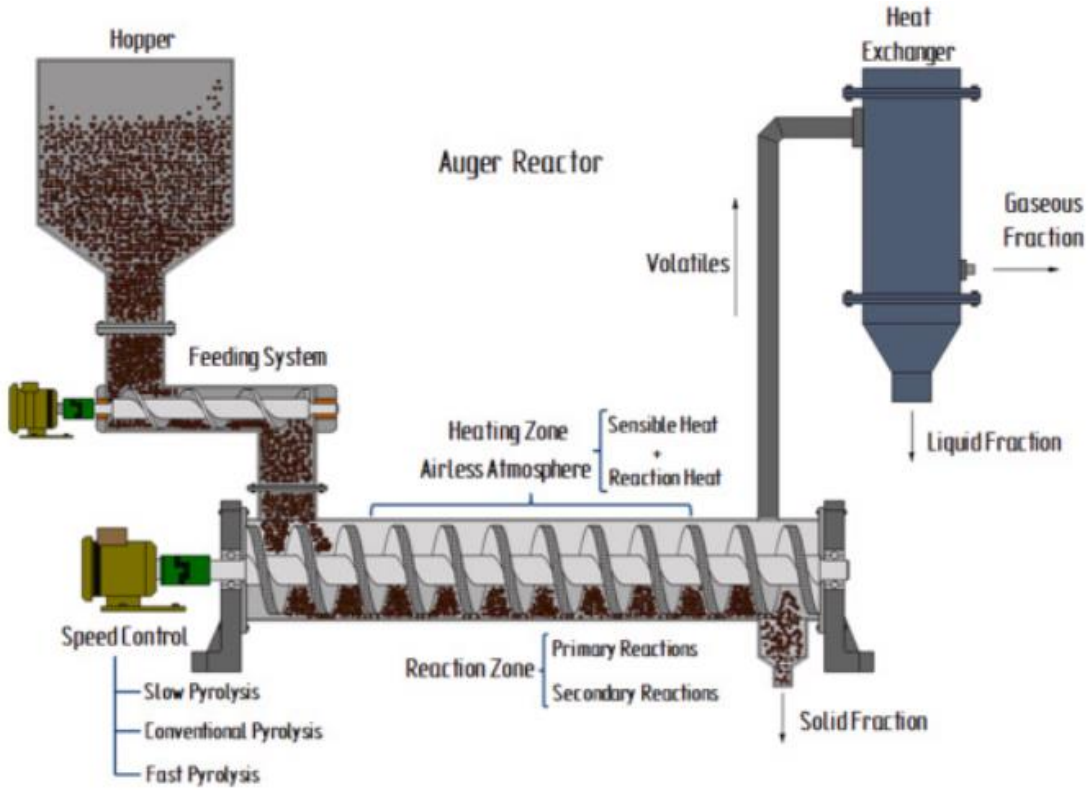
Reactor types for pyrolysis

- Fluidized Bed Reactor



https://www.youtube.com/watch?v=dcBAqLR65Hg
https://www.youtube.com/watch?v=OEuKW7RAmJM

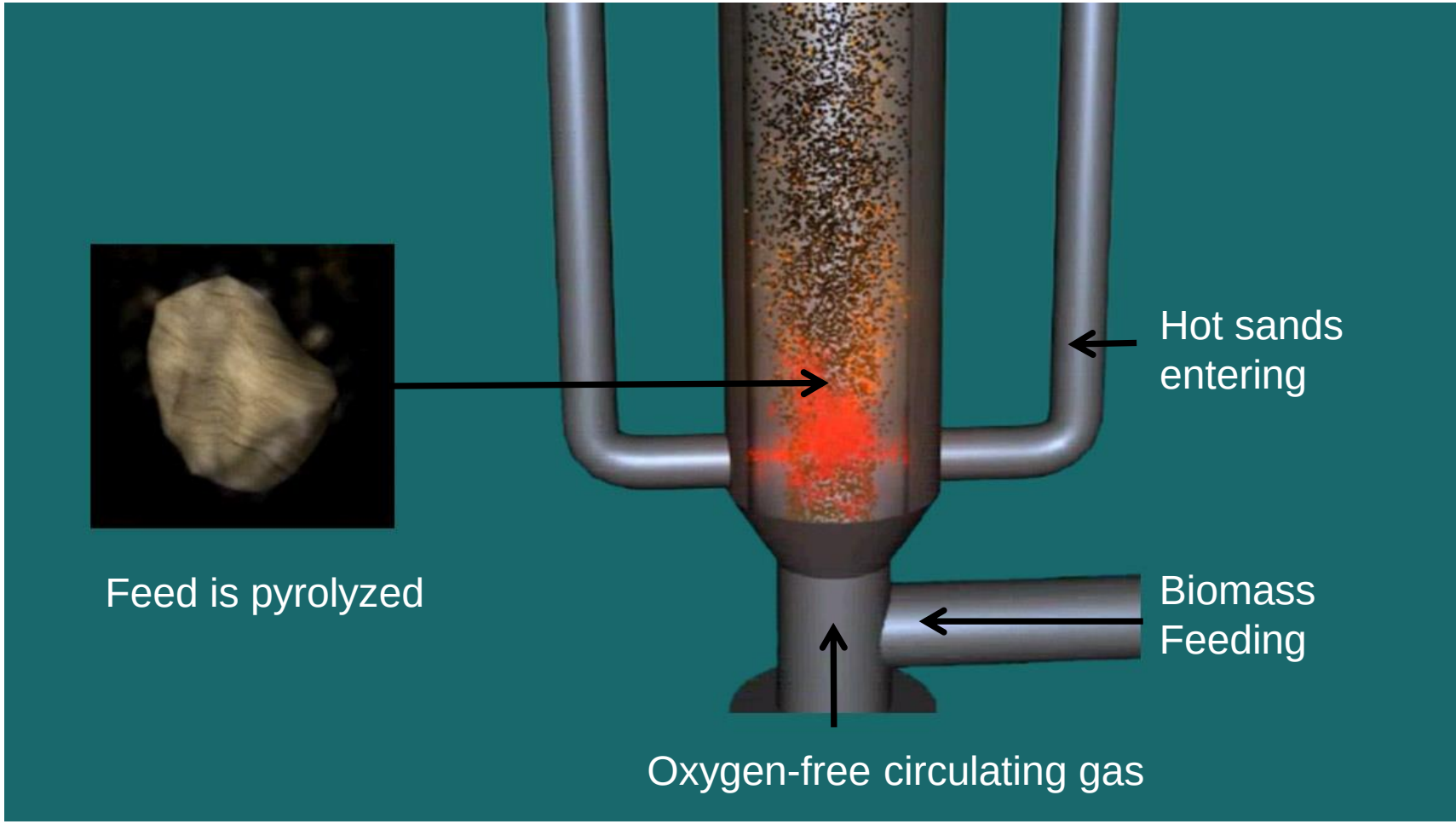
- Auger/Screw Reactor



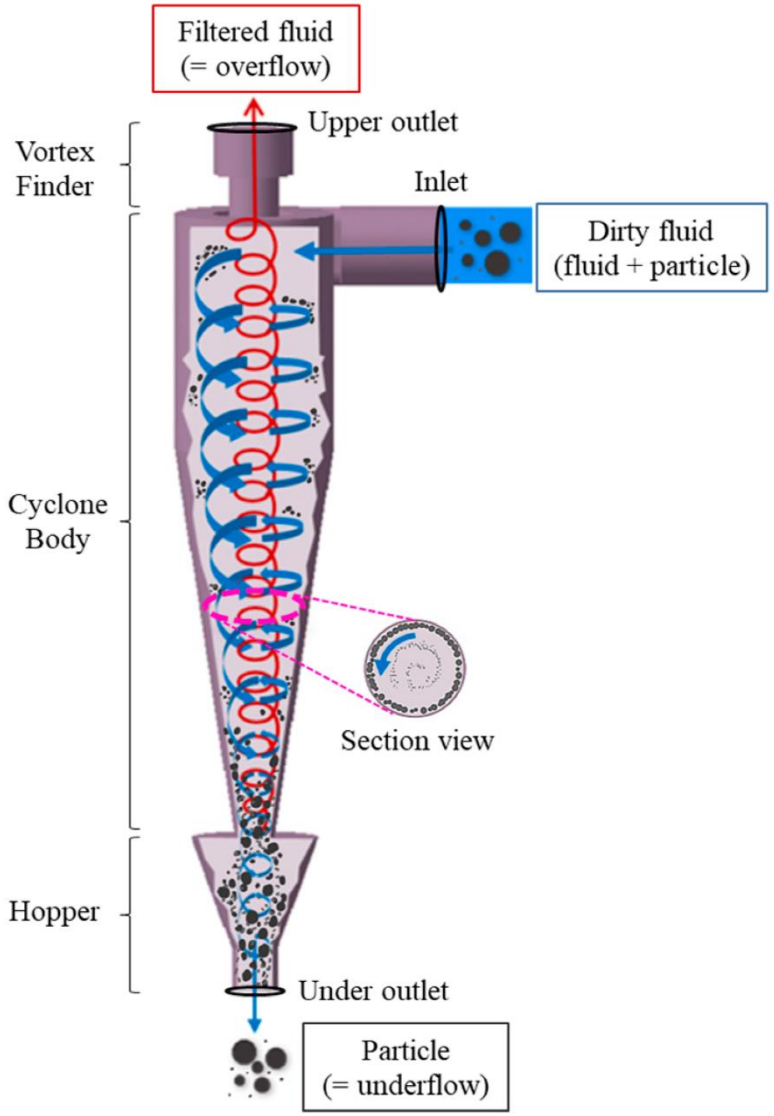
https://www.sciencedirect.com/science/article/pii/S1364032118308098#f0025

Pyrolysis Reactor at Valmet

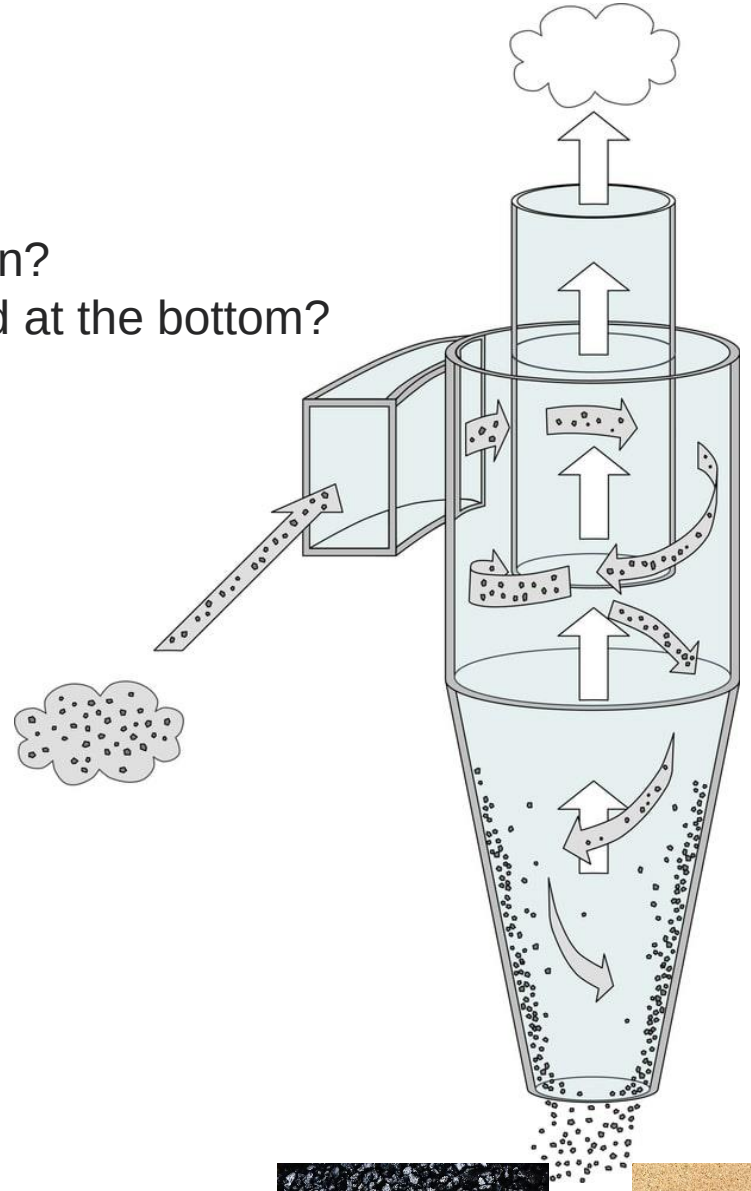
- Fluidized bed reactors could be scaled up
- Residence time is short



Cyclone

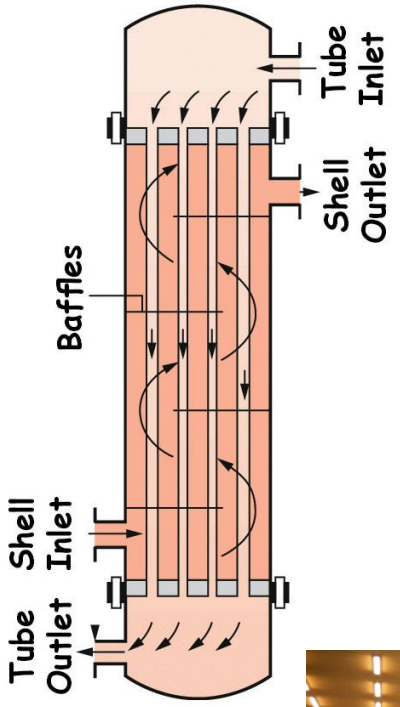


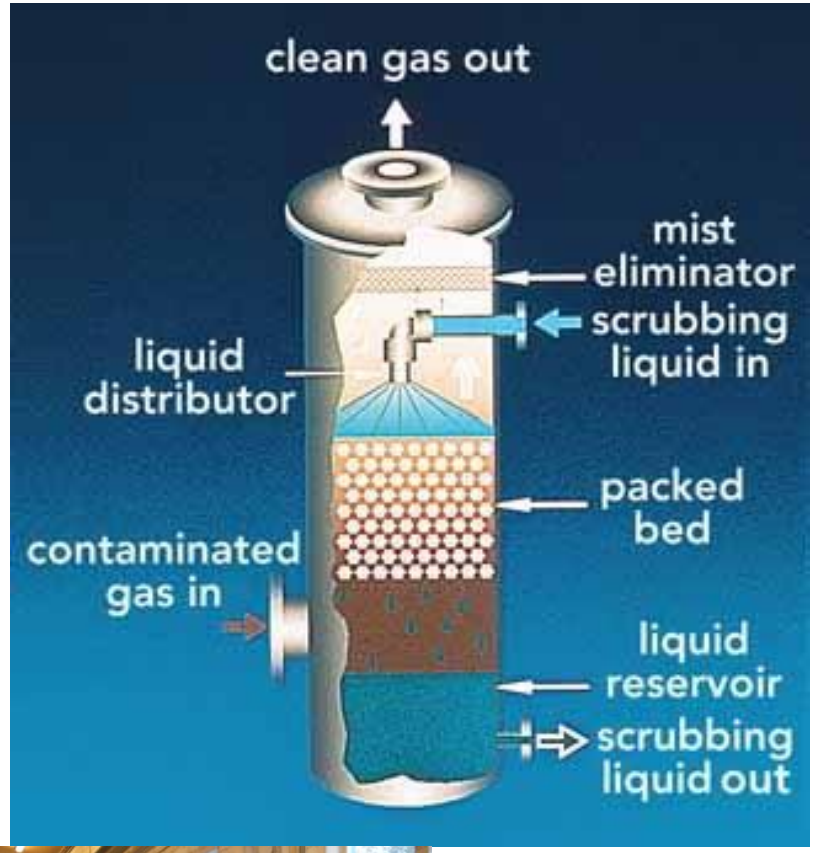
What does inlet contain?
What will be separated at the bottom?
What leaves on top?

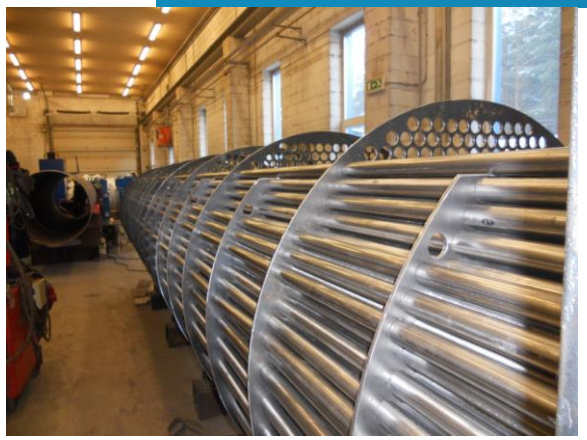


Sand, char
and vapors

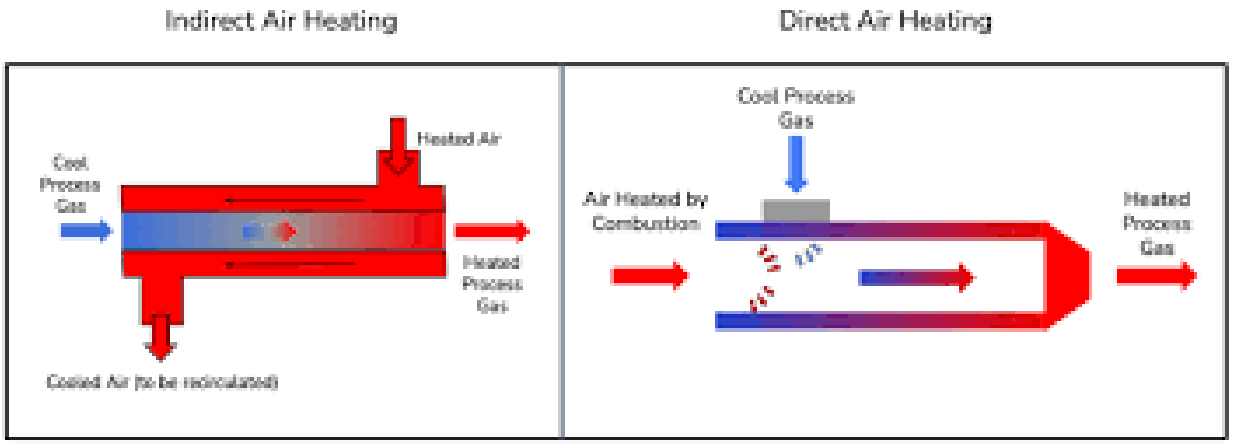
Condensation units







Indirect vs. direct heat exchangers



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Pyrolysis at Valmet

Valmet's Pyrolysis R&D, in co-operation with partners

1980's VTT
First Finnish R&D laboratory studies on pyrolysis (VTT)

1990's
First R&D projects including Finnish companies

2007
Technology development consortium formed

Cold model tests at Valmet R&D Center in Tampere

2009
FPBO pilot tests at Valmet R&D Center start

2013
Consortium formed to develop technology for production of advanced biomass-based fuels
Catalyst study and process benchmarking program starts at CPERI/CERTH

CPERI Chemical Process and Energy Resources Institute

2013
Commissioning and commercial operation of Joensuu plant

2014 JM
Catalyst development and performance evaluation program with Johnson Matthey

2018
Catalytic pyrolysis pilot construction at VTT Bioruukki facilities

2019
Catalytic pyrolysis piloting starts at VTT (20 kg/h)

2020
Case-studies in biochemical production with pyrolysis

Chemical recycling with pyrolysis

2021
Scale-up preparation in catalytic pyrolysis

2022
Agreement in biochemical production with Circa Group

circa

2023
Catalytic pyrolysis piloting starts at Valmet R&D Center

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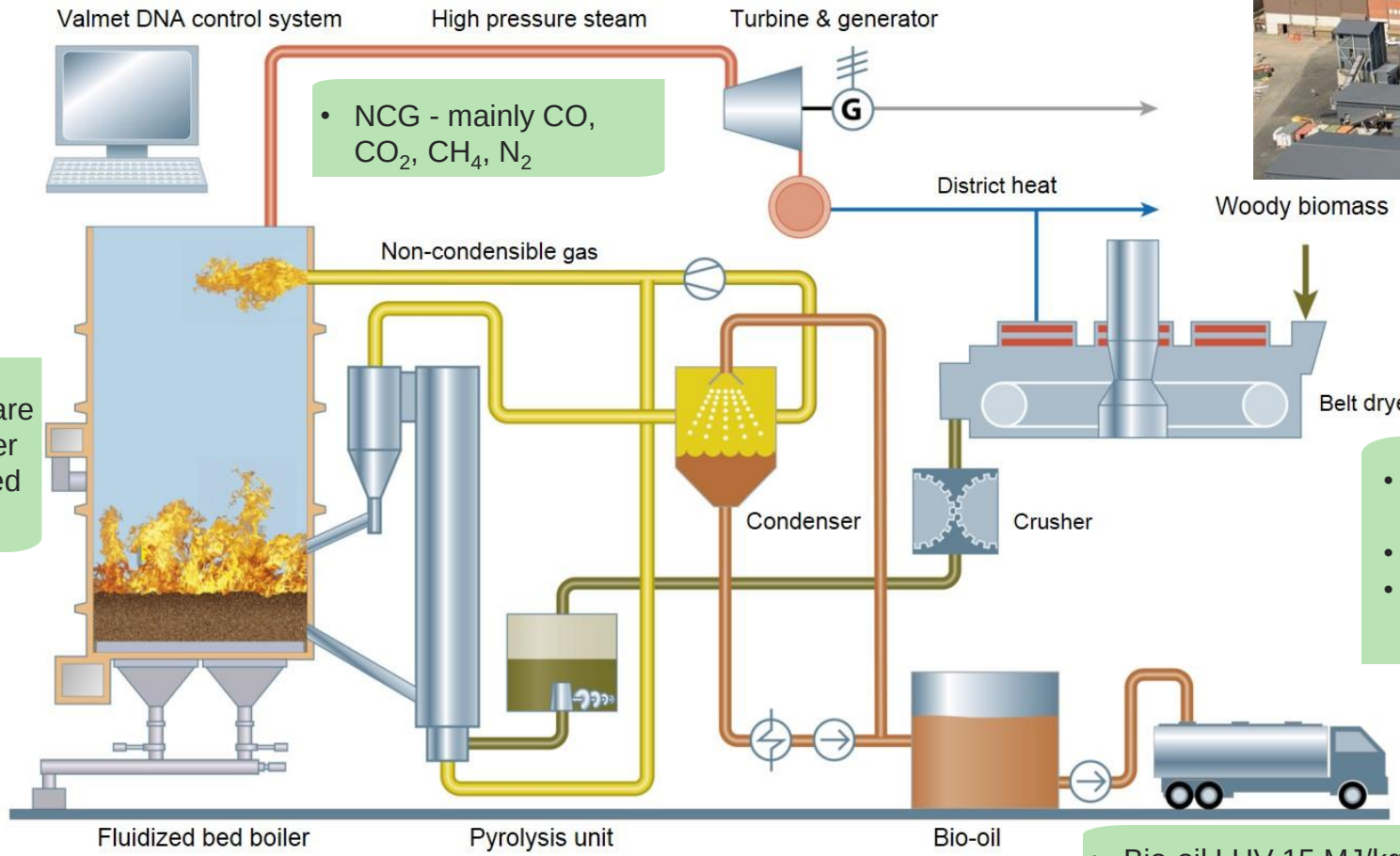
Valmet Fast Pyrolyzer

Technical description: fluidized bed boiler integrated fast pyrolysis

Fortum plant, 50 kt Bio-oil per annum



- NCG - mainly CO, CO_2, CH_4, N_2

- Residuals (char & NCG) are combusted in the FB boiler
- Excess energy is produced

- Feedstocks: woodchips, forest residue, sawdust

- Dryer uses process excess heat, district heat, LP-steam
- Drying to < 10 % H_2O
- Milling to < 5 mm size

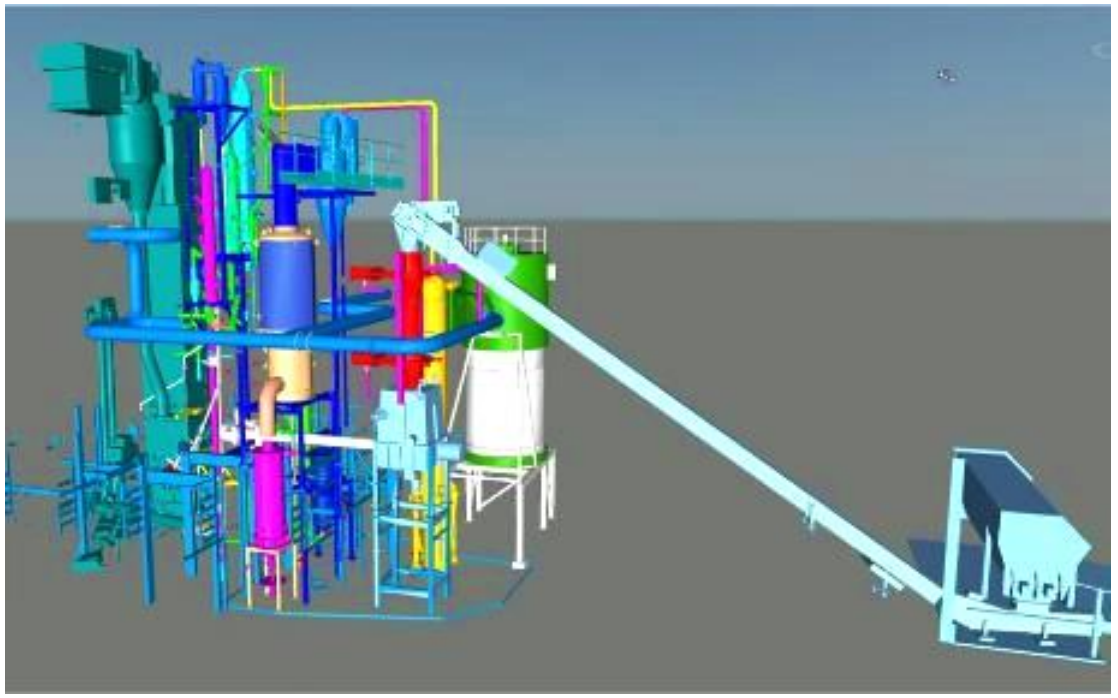
- Reactor temperature 460 - 500 °C
- Continuous circulation of hot bed material

- Bio-oil LHV 15 MJ/kg
- Water content 25 %
- pH: 2-3

Valmet Pyrolyzer – development streams

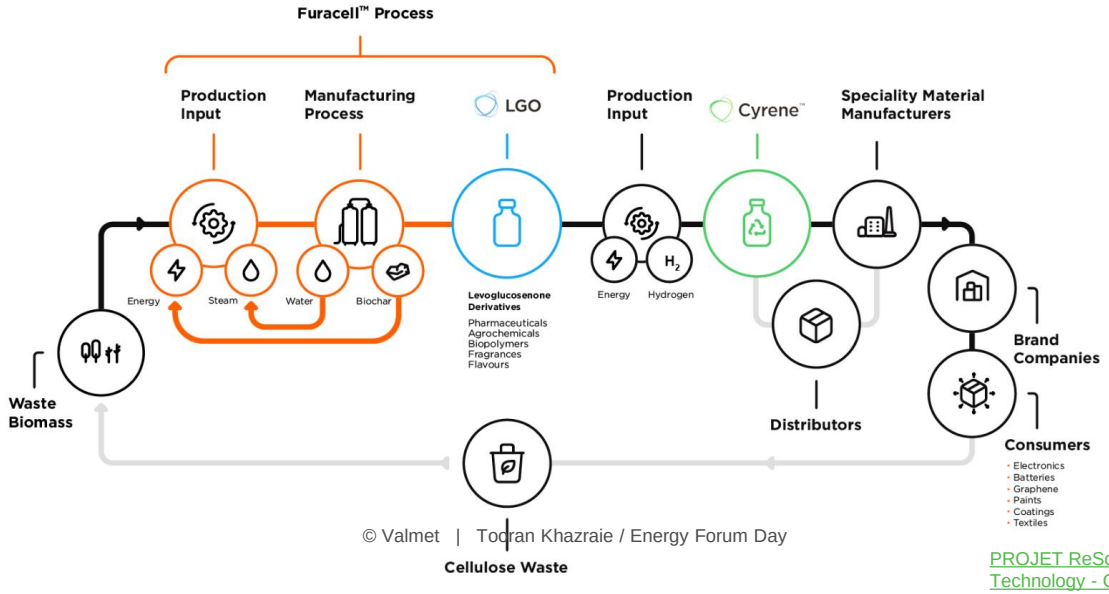
Pyrolysis is Valmet's technology solution for:

- Biomass to chemicals
  - Pyrolysis liquid can be utilized as a raw material for renewable chemicals (for instance solvents)
- Biomass to traffic fuels
  - Catalytic pyrolysis of biomass can produce renewable feedstock to oil refinery (= biocrude)
- Chemical recycling of waste plastic
  - Pyrolysis can be applied also for plastics, targeting a feedstock for new plastics and chemicals



Biomass to Chemicals

- Circa Group produces biochemicals through pyrolysis
  - Different platform chemicals in the product liquid
  - For instance, Circa converts LGO to Cyrene, environmentally friendly solvent
    - Cyrene could be a replacement for NMP or DMF solvents
- Valmet delivers the key equipment of the pyrolyzer to the ReSolute project in Carling, France
  - Feed input: 2 t DS/h
  - CFB boiler: 10 MW



PROJET ReSolute CIRCA CEH SAINT-AVOLD – YouTube
Technology - Circa Group AS (circa-group.com)

Development of Valmet Pyrolyzer with Catalytic Upgrading

Scale-up of catalytic pyrolysis of biomass from laboratory to industry

Evaluation, development & comparison

Catalytic pyrolysis technologies

In-situ and ex-situ catalyst

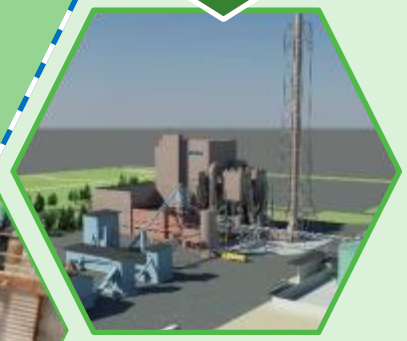
Pilot I tests: selected upgrading technology & catalyst

Phase II: Scaling up to industrial pilot

10's x pilot I

Scaling up to industrial demo plant

200x pilot I



Commercial upgrading technology available

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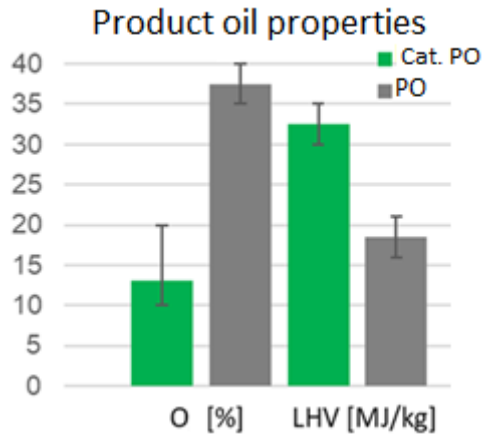
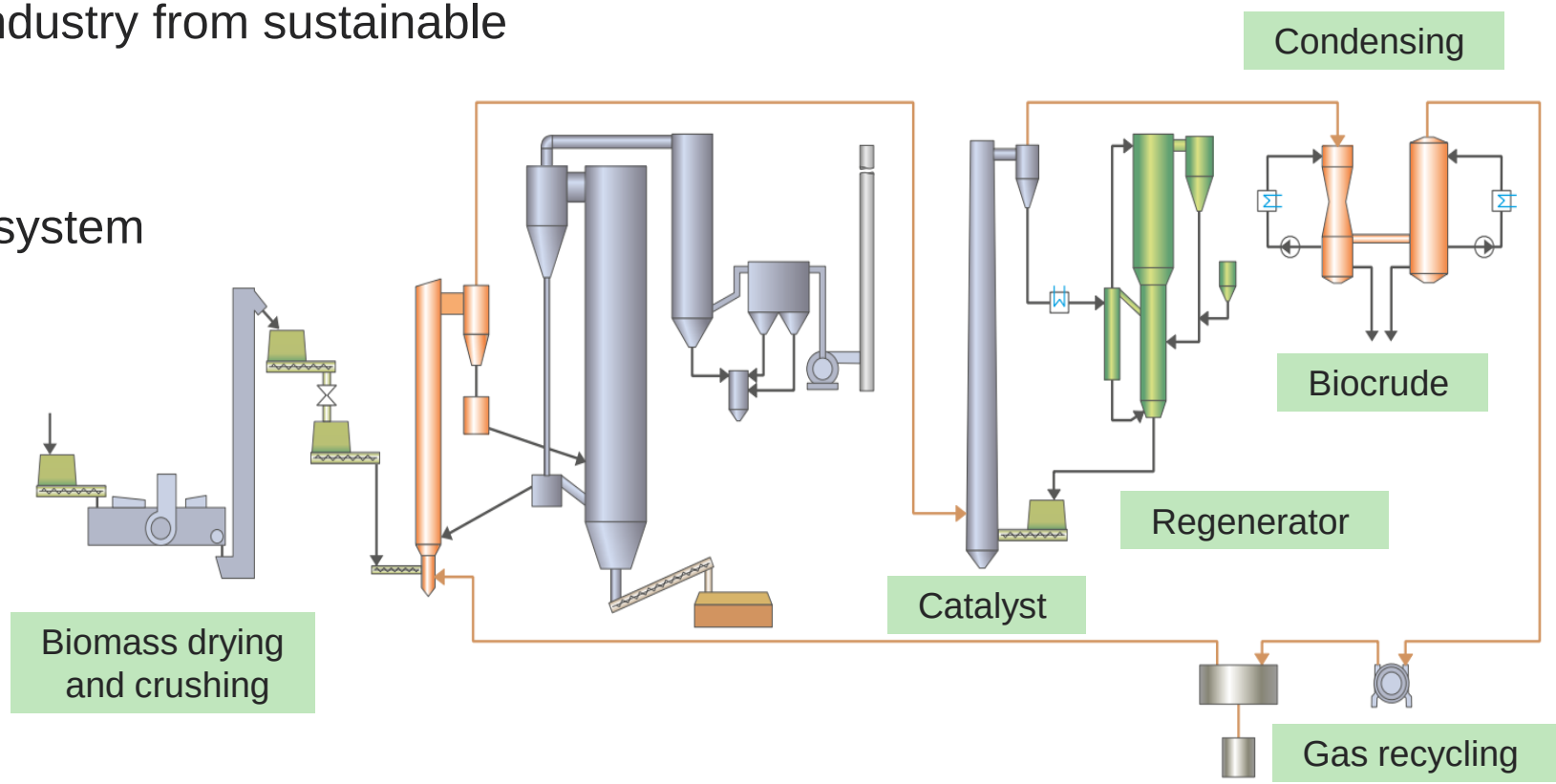
Biomass to traffic fuels – pyrolysis with catalytic upgrading

- Target: to produce renewable feedstock (biocrude) to refineries and petrochemical industry from sustainable biomass sources
- Technology:
  dual reactor Valmet Pyrolyzer system
  - First stage: Fast pyrolysis
  - Second stage: Catalytic upgrading with catalyst regeneration





Catalytic pyrolysis pilot plant commissioned successfully!

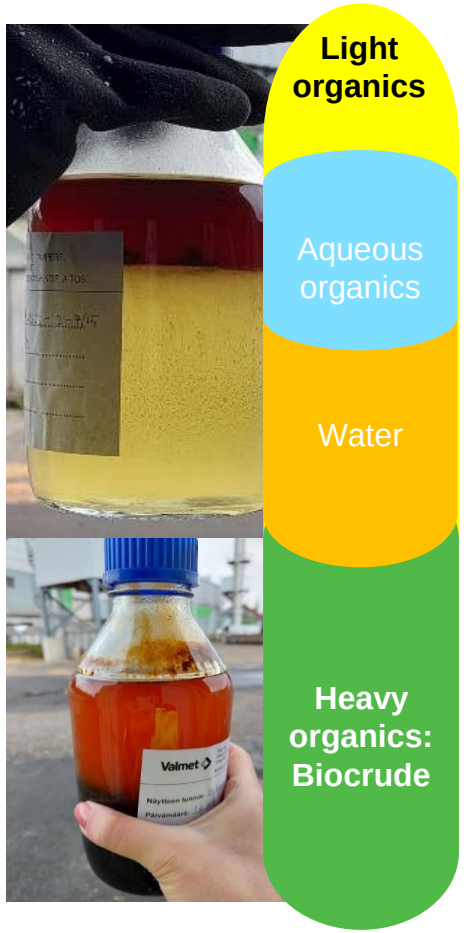
Valmet Energy R&D Center (Tampere, Finland)

- **Revamp** of existing fast pyrolysis pilot to include continuous catalytic treatment of pyrolysis vapors
  - Design of demo/commercial unit + down-scaling to pilot
  - **Pre-engineering** started late 2021, **hot commissioning** completed June 2023
  - Feed capacity **400 kg/h**, production rate several tons of liquids/day
  - Various biomass feedstock can be tested
  - Utilizes commercially available catalyst
  - Operates at atmospheric pressure
- Separate pyrolysis and catalytic upgrading stages
  - Catalyst *contamination reduced* significantly
  - Independent parameter control, e.g.:
    - Pyrolysis and catalytic stage temperatures & residence times
    - Catalyst flow rate to upgrading stage
    - Catalyst regeneration temperature & time
- Reference plant for process and concept development

Preliminary results from commissioning

Catalytic pyrolysis oil properties and yields

- Feedstock: pine sawdust (dried)
- Product liquid properties
  - Oxygen content: 10-20 %
  - TAN: 10-40
  - Heating value >35 MJ/kg
- Product liquid energy yield ~40 %
- Carbon recovery to product liquids > 40%
  - Char separation under development to enable carbon negative operation

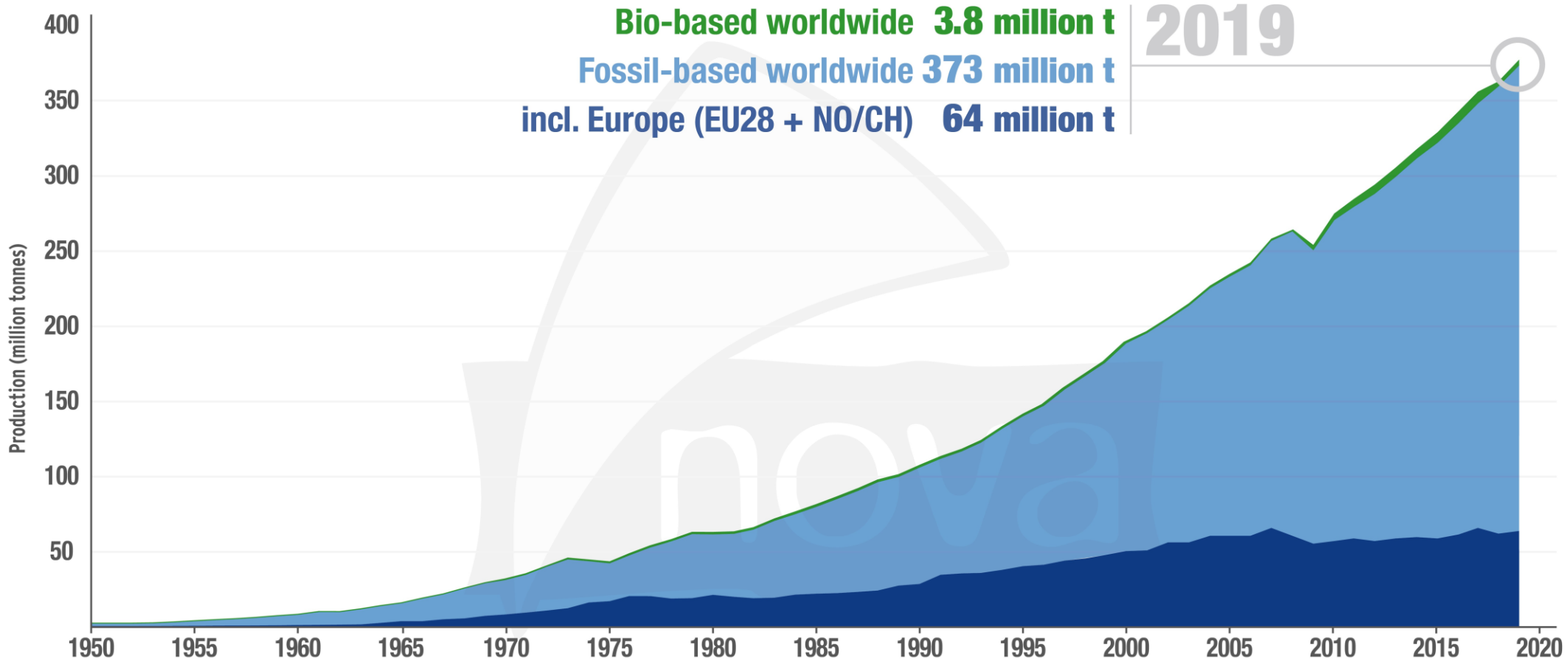


Why is plastic chemical recycling needed?

- EU is aiming at 50 % recycling rate of all plastic packaging by 2025 and 55 % by 2030.
- Waste hierarchy:

- Mechanical recycling has priority over chemical recycling
- Mechanical recycling output material has limited use cases

Plastics production from 1950 to 2019



available at **www.renewable-carbon.eu/graphics**

Includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and PP-fibres. Not included PET-, PA-, and polyacryl-fibres.

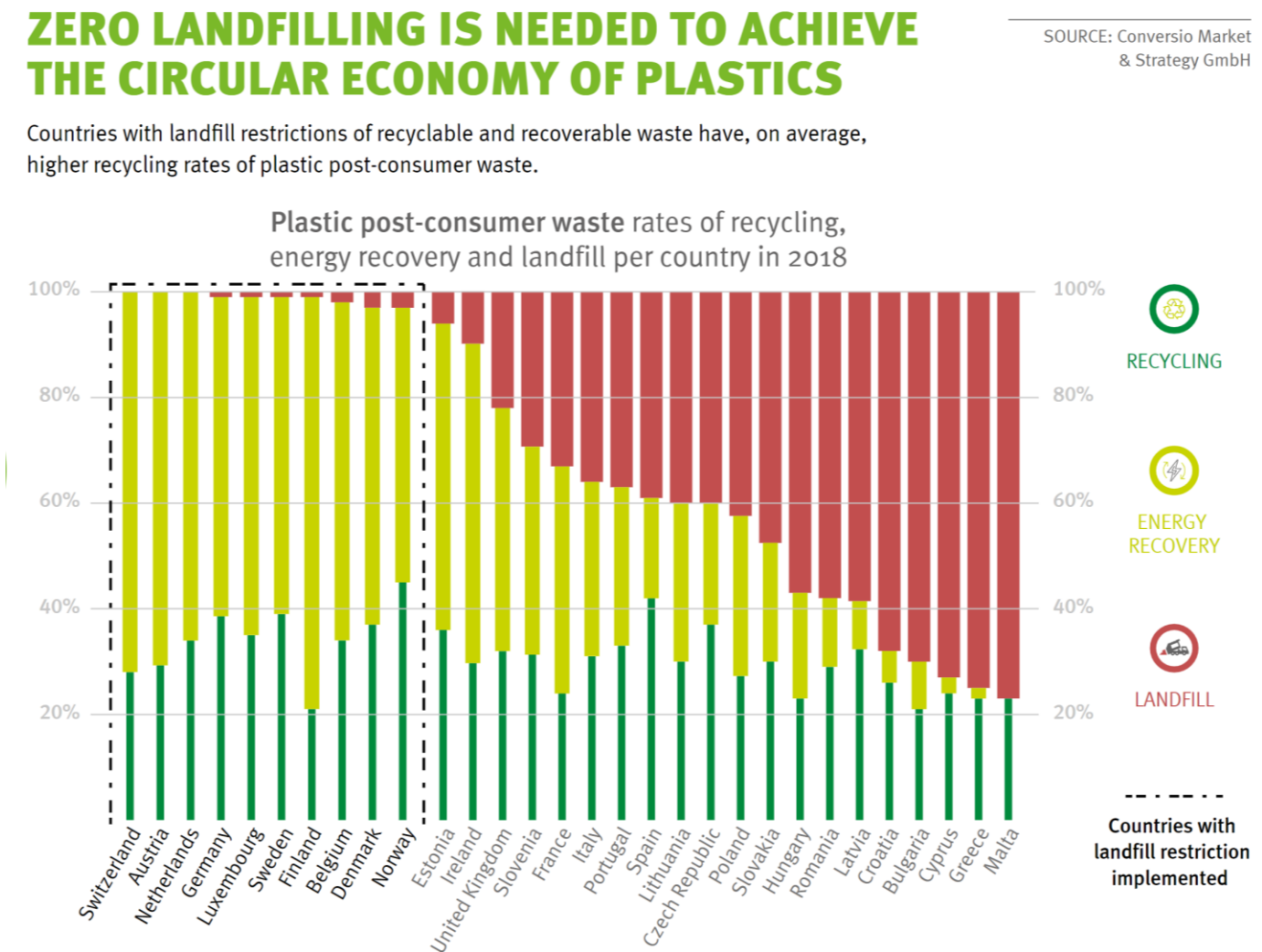
Data sources: PlasticsEurope, Consultic and nova-Institute

Suurin osa kodeissa lajitellusta muovijätteestä päätyi poltettavaksi – MOT selvitti, kuinka hyvin muovin kierrätys onnistuu

Fortumin antamat luvut muovinkierrätyksen onnistumisesta eivät ole vastanneet totuutta viime vuosina.

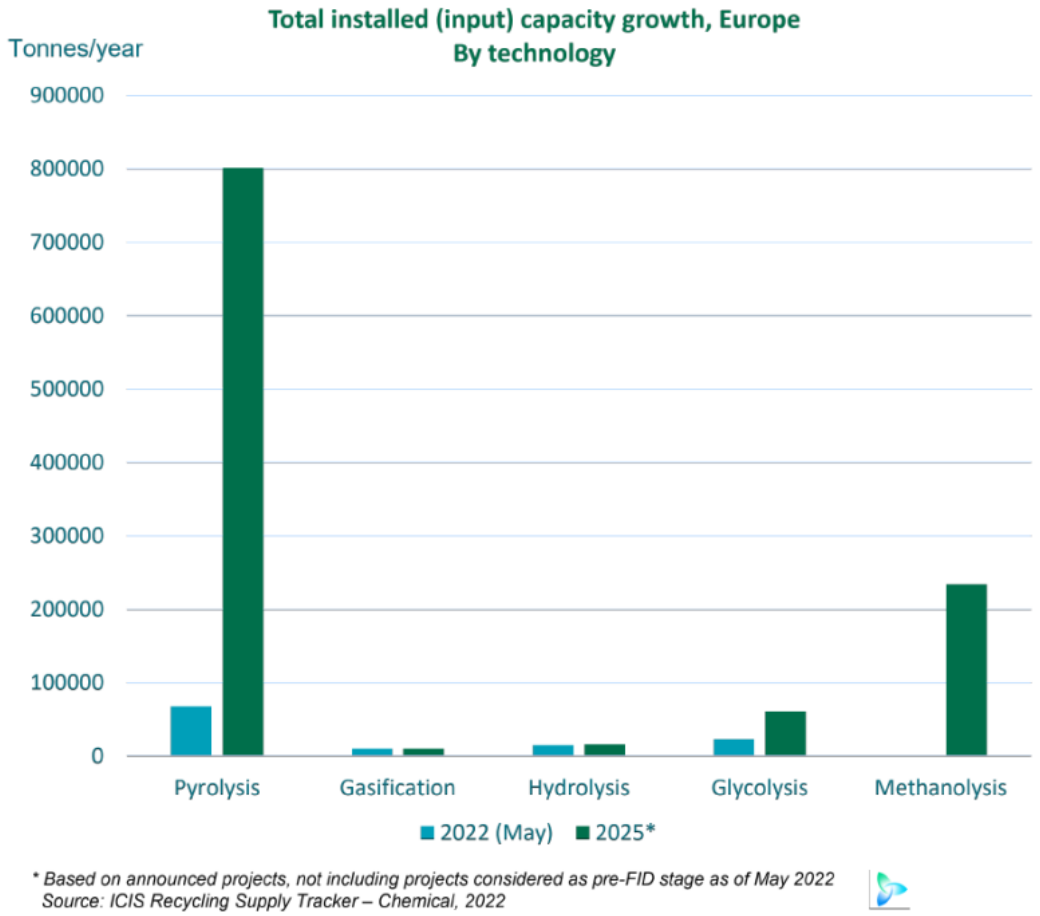
Nämä jätemuovipaalit ovat matkalla Saksaan, koska kotimainen kapasiteetti ei riitä kaiken suomalaiskotien muovijätteen käsittelyyn. Kuva: Janne Järvinen / Yle

Fortum has managed to mechanically recycle only 37 % of collected plastic waste. Rest is incinerated.

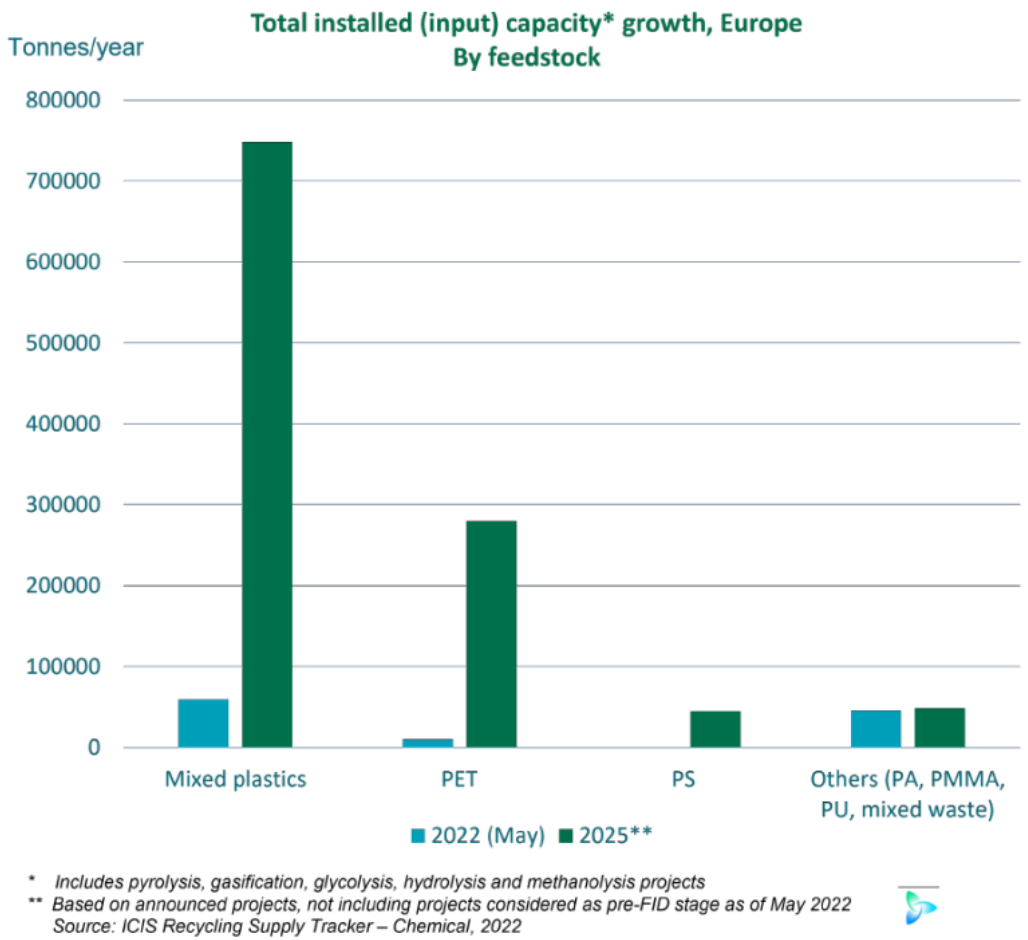


Plastics – there are many different kinds of them

Plastic Chemical recycling industry in Europe



* Based on announced projects, not including projects considered as pre-FID stage as of May 2022
Source: ICIS Recycling Supply Tracker – Chemical, 2022

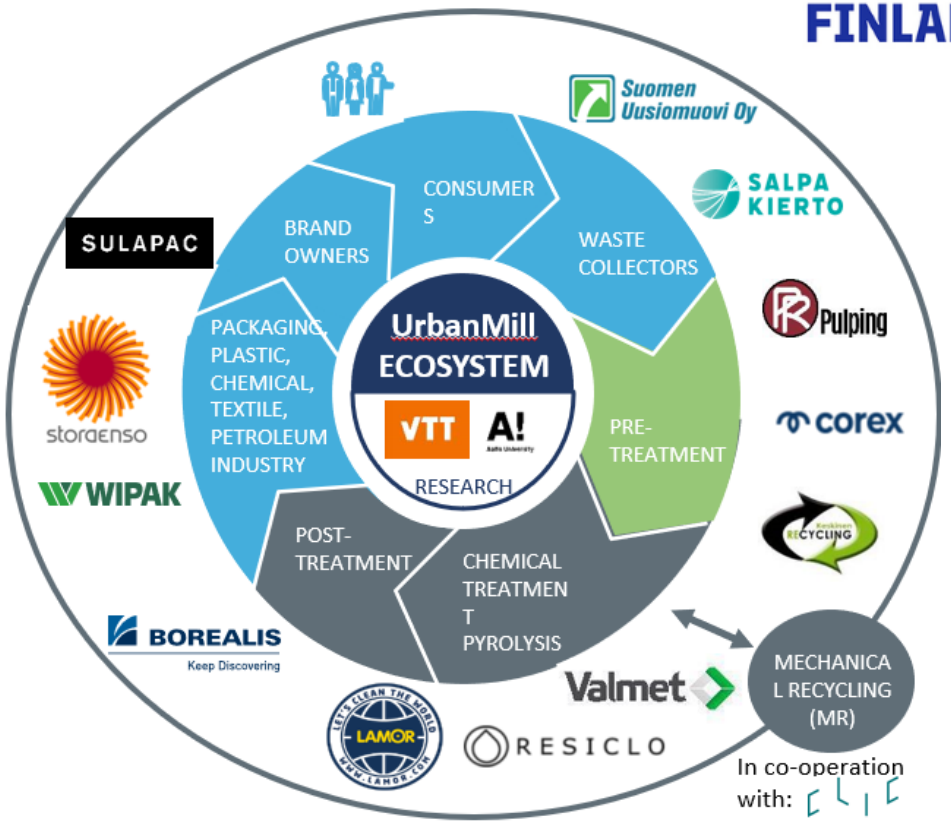


* Includes pyrolysis, gasification, glycolysis, hydrolysis and methanolysis projects
** Based on announced projects, not including projects considered as pre-FID stage as of May 2022
Source: ICIS Recycling Supply Tracker – Chemical, 2022

Source: PlastPyro seminar, Mika Härkönen, VTT

UrbanMill in a nutshell

- Two-year project of 3 M€, Funded by Business Finland
- Aims to **develop** a pyrolysis-based industrial **chemical recycling concept** for plastic waste
  - Targeted feedstock: highly mixed plastic waste
  - Targeted product: intermediate for high-quality plastic material



Chemical Recycling with Plastic Pyrolysis

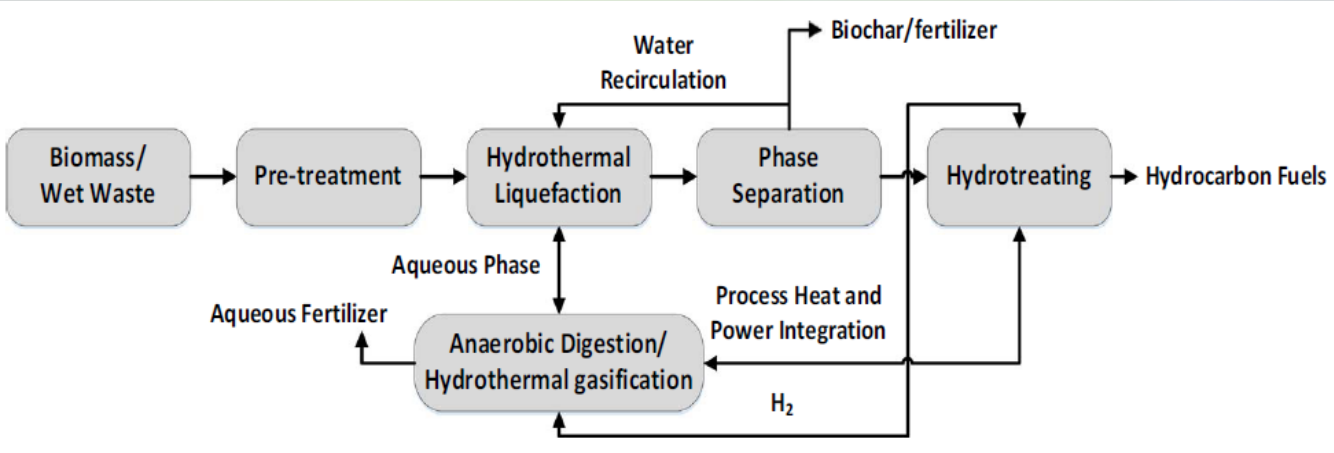
- Plastic recycling
  - Mechanical
  - Chemical
    - Pyrolysis is identified as a key promising technology

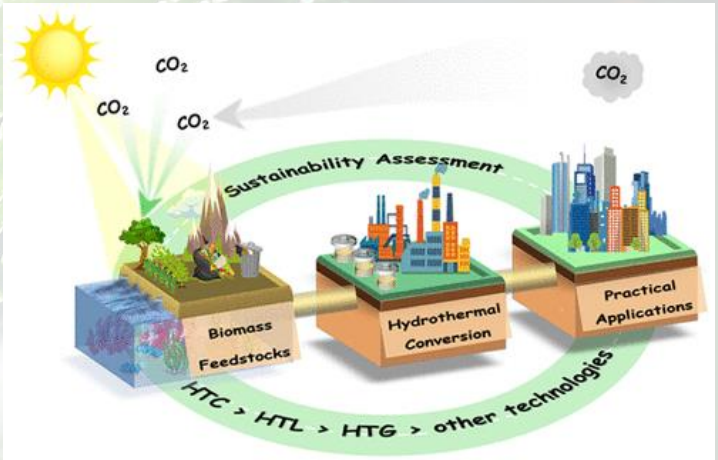
- Research currently in the piloting scale to verify scale-up potential. Investigations on
  - Suitable feedstock
  - Feeding method
  - Removal of impurities and volatiles
  - Reactor type
  - Handling the side products
  - Post treatments: Fractionation and catalytic upgrading
  - Interesting final products

[Pyrolysis and Catalytic Conversion of Plastics - YouTube]

HTL is a promising pathway for wet wastes

- HTL is one of the most promising new technologies to convert **wet** feedstocks to renewable fuels
- Wet feedstocks
  - Agro waste
  - Algae
  - Municipal solid waste
  - Bio waste/Food waste
  - Sludges
  - Black liquor
- The oil as the final product
  - Has high heat value
  - Has low oxygen
  - Can be separated from the aqueous phase
  - Is stable
  - Needs post-treatment (refining)





Comparison of HTL and Pyrolysis

	Fast pyrolysis	Catalytic Pyrolysis	Hydrothermal liquefaction
Oil's oxygen content %	35-45%	10-35%	10-20%
Complexity	Low	Medium/High	High
Suitable feedstock	Dry biomass, plastic	Dry biomass, plastic	wet feedstock, biosludge, black liquor, algae, biomass and plastic
Challenges	Upgrading to fuel	Low oil yield	High-temperature pumps and handling the aqueous phase

Technology plays a key role in mitigating climate change

Valmet is actively developing pyrolysis technology towards biochemical and biofuel applications

- We are capable of industrial piloting with catalytic pyrolysis to produce feedstock for biofuels or -chemicals
- Next step is to bring catalytic pyrolysis into demonstration and commercial scale
  - Valmet has deliveries & experience in commercial scale FP
  - Catalytic pyrolysis technology ready for demo development
  - Alternative feedstocks are of interest and will be evaluated
  - Value stream development is enabled by large scale piloting and sample production in sufficient volumes
- Adaptation potential of the fast pyrolysis process
  - Commercial scale delivery for biochemical production
  - Development in chemical recycling progressing
- We are open to joint development utilizing pyrolysis for different end products (confidential or public projects)


Valmet
FORWARD