Liquefaction technologies at Valmet

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Bio4Fuels seminar

Helsinki 12th June 2024

Content

- Valmet today
- Valmet R&D of Thermo-Chemical Conversions
- Valmet fast pyrolysis product
- HTL at Valmet
- BL2F
  - Introduction
  - Major results
  - Conclusion of BL2F
- Conclusion - the liquefaction of biomass at Valmet

Valmet

Valmet today

Progress built on 220 years of industrial history

From cloth making to high-tech processes

- 1797 Jokioisten Verkatehdas
- 1841 Götaverken
- 1856 Tampella
- 1858 Beloit
- 1860 KMW
- 1868 Sunds Defibrator

1942
Rauma-Raahe

1951
Valmet

1968–1996
Several M&As:
1986 KMW
1987 Wärtsilä paper finishing machinery
1992 Tampella Papertech

1999
Metso created through merger of Valmet and Rauma

Acquisitions
2000
Beloit Technology
2006
Kvaerner Pulping
Kvaerner Power
2009
Tamfelt

End of 2013
Demerger to Valmet and Metso

2015
Metso Process Automation Systems to Valmet

2019
Valmet acquires GL&V and J&L Fiber Services Inc

2020
Valmet acquires PMP Group

2021
Valmet acquires EWK Umwelttechnik and ECP Group

2022
Neles merged into Valmet
Valmet acquires Coldwater Seals

2023
Valmet acquires NovaTech Automation’s Process Solutions business and Körber’s Business Area Tissue

2024
Valmet acquires Siemens’ Gas Chromatography Business

This is Valmet

Unique offering

- Market's widest offering combining process technologies, services and automation, consisting of automation systems and flow control solutions
- Research and development spend EUR 114 million in 2023

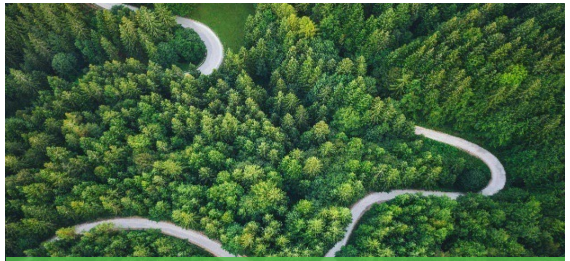
Market leadership

Strong market position

- Pulp #2
- Energy #1–3
- Board #1
- Tissue #1
- Paper #1
- Services #1–2
- Automation
  - Automation Systems #1-4[1)]
  - Flow Control #1[1)]

Strong global presence

- Approx. 130 service centers
- Approx. 50 production units
- 29 R&D centers
- More than 19,000 professionals



Leader in sustainability

- Ten consecutive years in Dow Jones Sustainability Index
- Highest ranking in Ecovadis sustainability assessment
- Highest AAA ranking in MSCI ESG rating

Illustrative figures of the combined company.
1) In pulp and paper.

Valmet's R&D addresses global megatrends

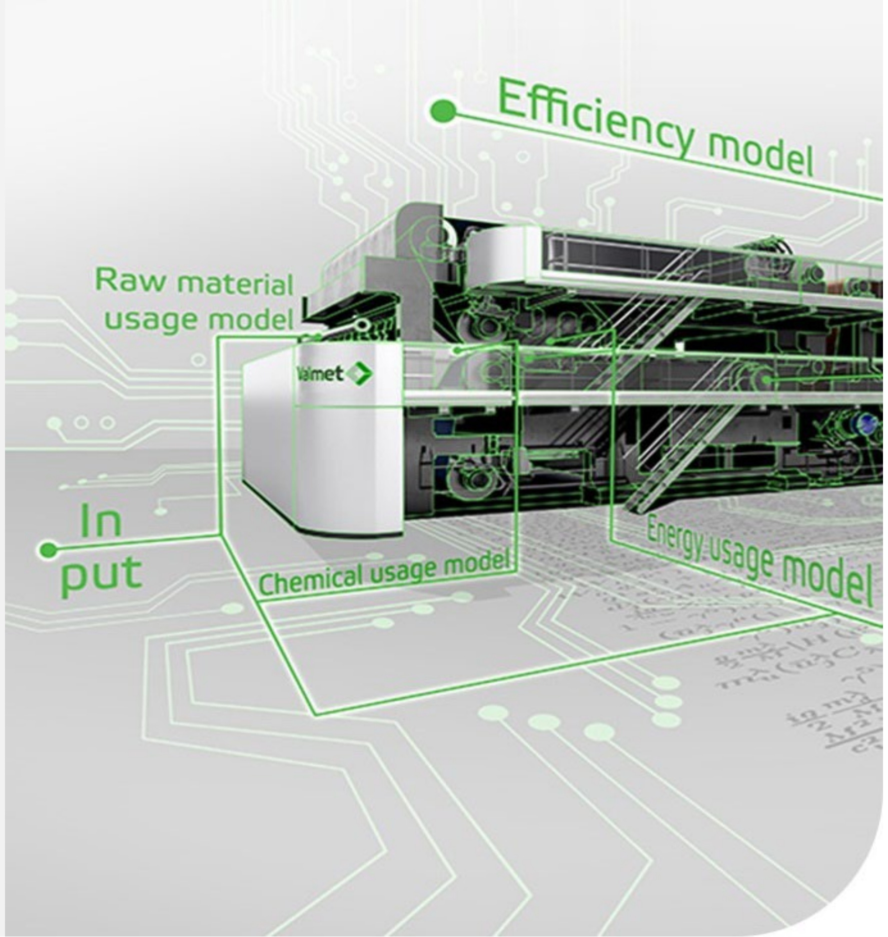
R&D focus areas

- Promotion of renewable materials
- Raw material, water and energy efficiency
- Emission reductions
- Circularity
- Productivity and environmental improvements with digitalization

29
research and development centers

EUR **114** million
R&D spending in 2023

~1,300
protected inventions



Illustrative figures of the combined company.

Valmet – R&D of Thermo-Chemical Conversions

Strategic direction towards more valuable products

Resources

Biomass
- Forest residues
- Agro residues

Plastics
- Mixed plastic waste (Polyolefins)
- Polystyrene

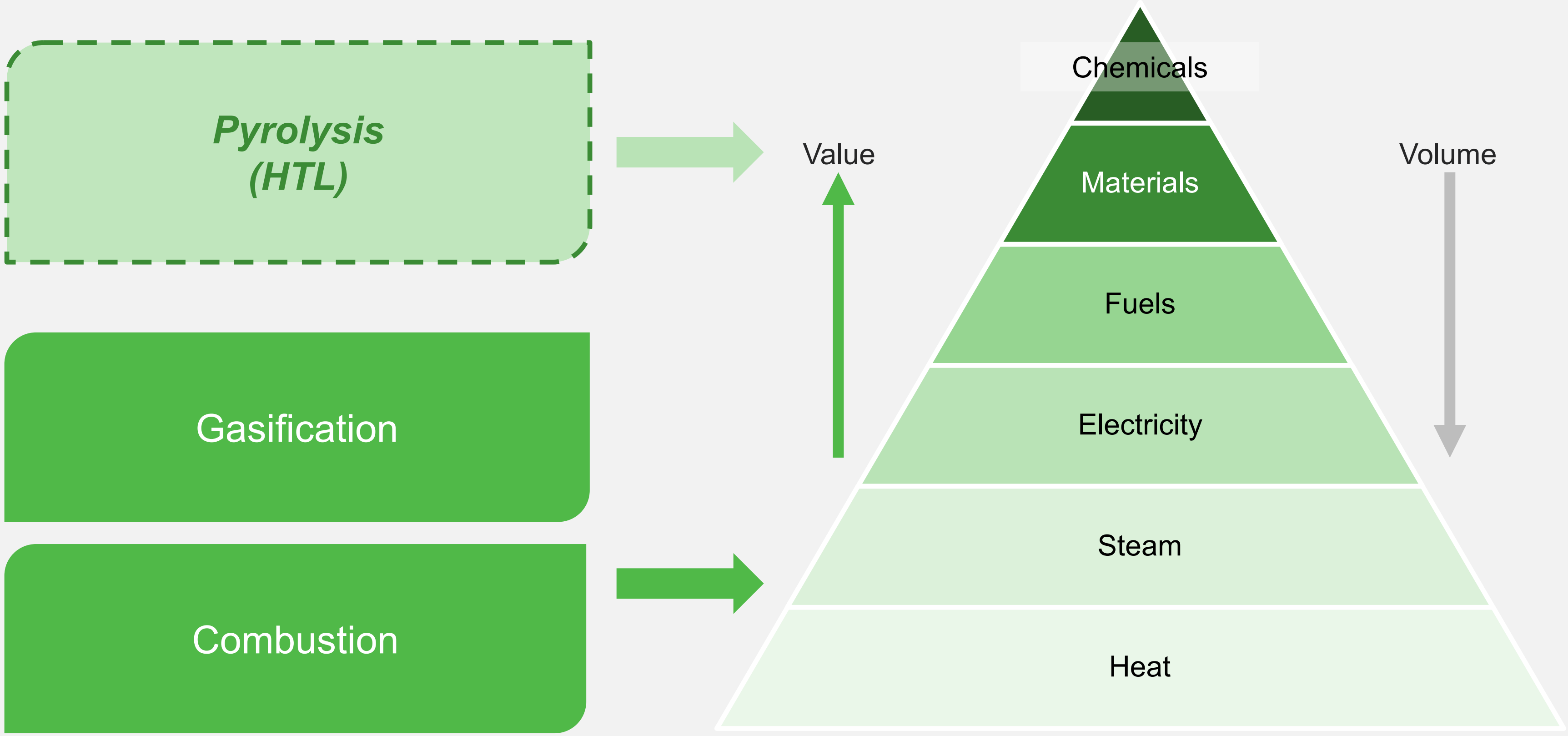
Industrial residual wastes
- Pulp & Paper
- Mechanical forest industries
- Process industries

Municipal solid waste (MSW)
- Refuse derived fuels (RDF)

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

Thermo-Chemical Conversion

Value



Catalytic pyrolysis pilot plant commissioned successfully

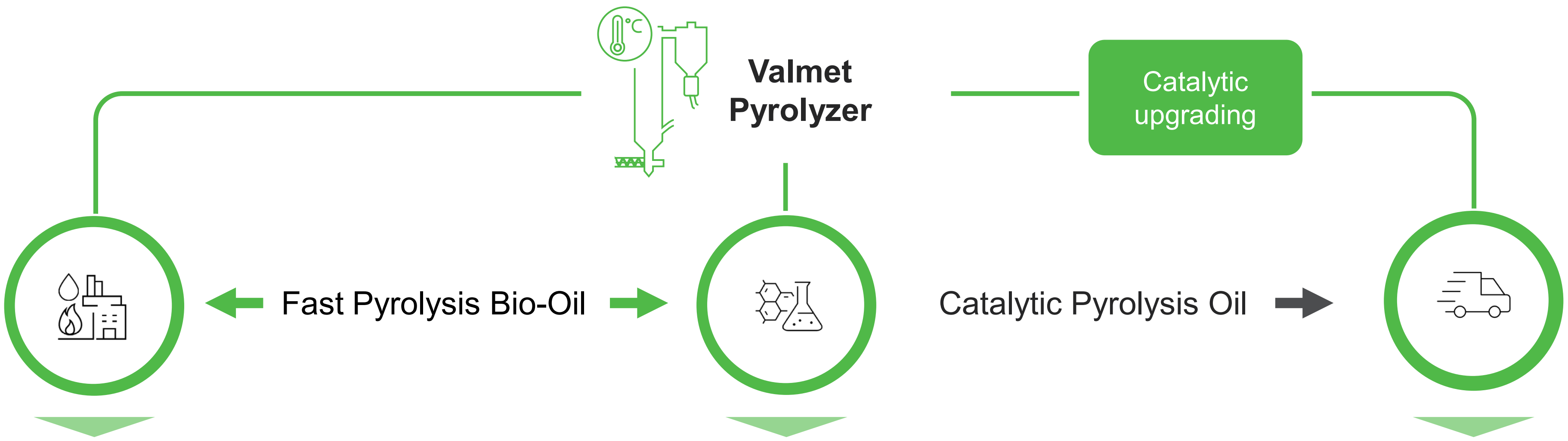
Valmet Energy R&D Center (Tampere, Finland)

- Pyrolysis pilot with continuous catalytic treatment of pyrolysis vapors
  - Design of demo/commercial unit, Feeds 10 tons/d
  - Utilizes commercially available catalyst
- Separate pyrolysis and catalytic upgrading stages
- Product yield & quality in line with targets[1]
  - Feedstocks: dried & milled biomass
  - Energy yield > 40% to liquid products
- Product liquid properties
  - Low oxygen content: 10-20 %
  - Low acidity: TAN 10-30
  - High heating value: > 35 MJ/kg
  - Distillable[2]

[1]Based on previous and current pilot scale
[2]According to batch distillation / Simdist

Valmet

Fast pyrolysis at commercial scale, focus now on catalytic pyrolysis



FPBO

TRL 9

- Fast pyrolysis system proven in operational environment
- Commercial plant (50 kt/a) started 2013 (Joensuu, Finland)

Specialty chemicals

TRL 8

- Circa small industrial plant to produce commercial bio-solvent, Cyrene™
- Pyrolyzer input 2 t_{DS}/h, start-up 2025

Transport fuels

TRL 7

- Piloting ongoing on small industrial scale (400 kg/h feed)
- Target to reach readiness for 5 t/h in 2024 and 50 t/h by 2027
- Commercial target: 100 kt/a product

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HTL at Valmet

Long history

- Already studied at Chalmers University of Technology in early 2010's
  - Valmet build there a bench-scale research system
- Biomass alternatives were explored in 2014 – 2017
- Participation in BL2F and an IIT Madras R&D projects
- Support for piloting equipment EHTA at Tampere University
- HTL technology has a monitoring status in Valmet – participating in selected projects

Valmet

BL2F

Main results and lesson learned

Bio4Fuels seminar
12 June 2024, Tero Joronen, TAU/Valmet

BL2F
Transforming Black Liquor to Biofuel

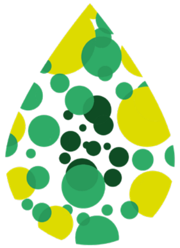
This project has received funding from the European Union Grant Number 884111

Valmet

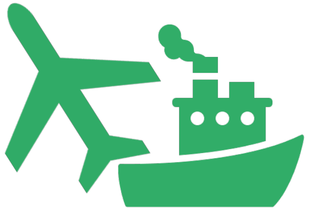
Basics revised and recalibrated

This project has received funding from the European Union Grant Number 884111

Project Goals



Create a high-quality drop-in biofuel



Decrease carbon emissions from aviation and shipping

Decrease the use of fossil fuels

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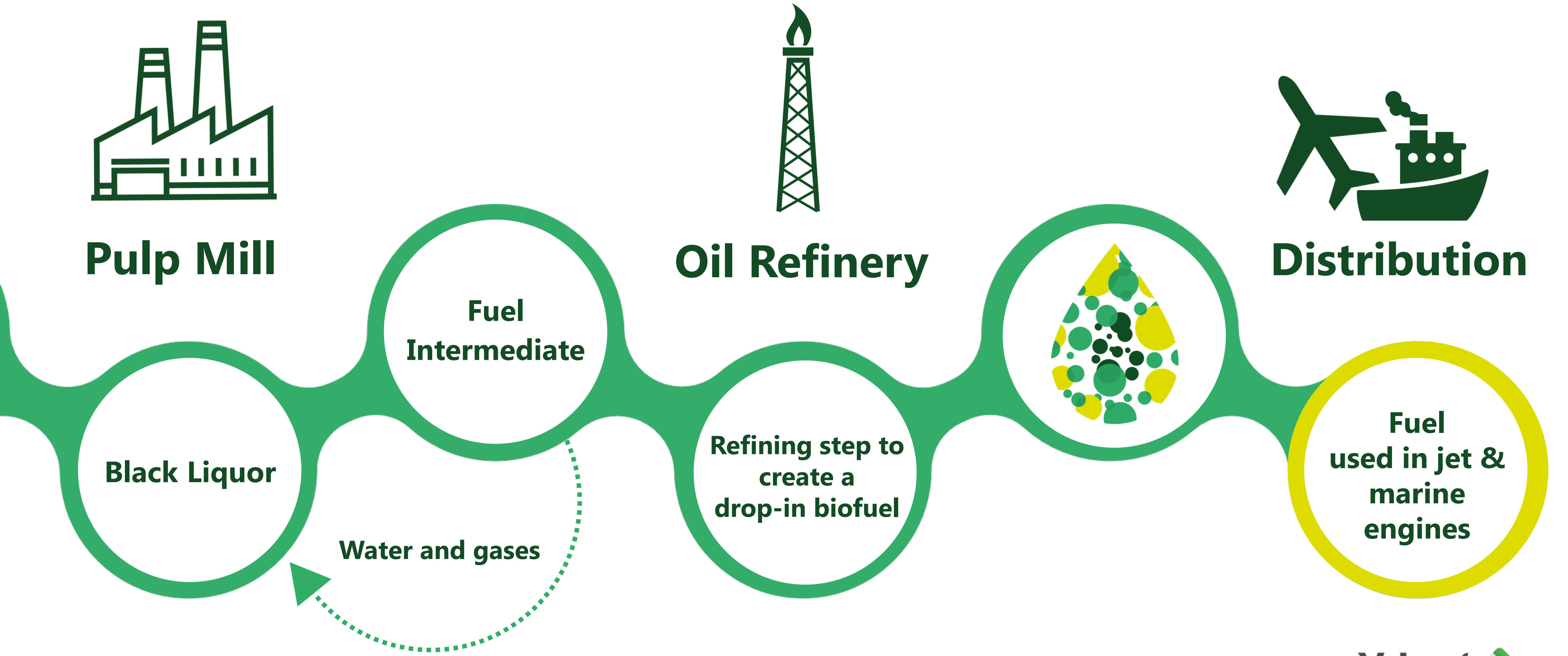
Valmet

The BL2F Process



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Pulp Mill Integration
- Great benefit, but also a challenge

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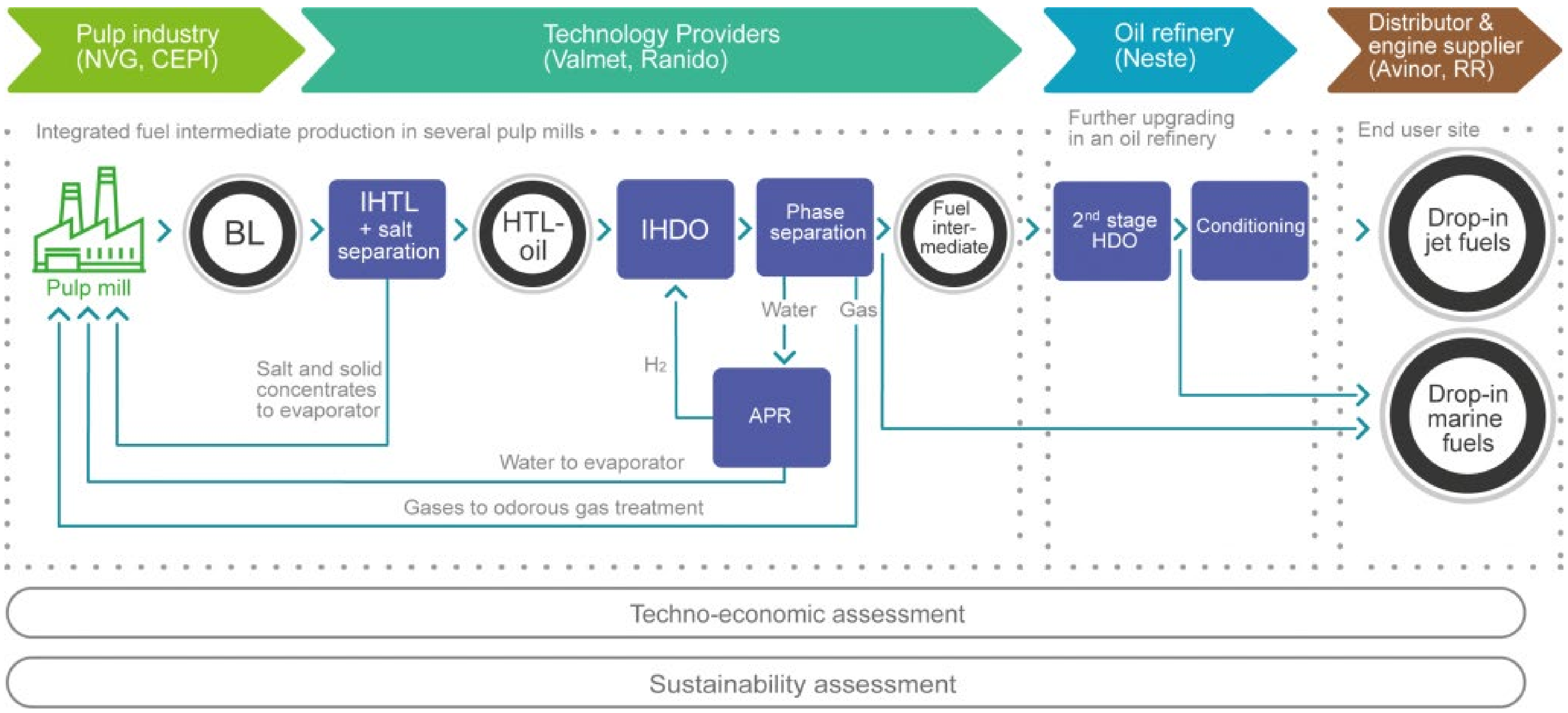
The BL2F value-chain



1. Salt separation
2. Solids/salt handling
3. Water handling
4. Gas handling
5. Hydrogen production

This project has received funding from the European Union Grant Number 884111

Reactor design

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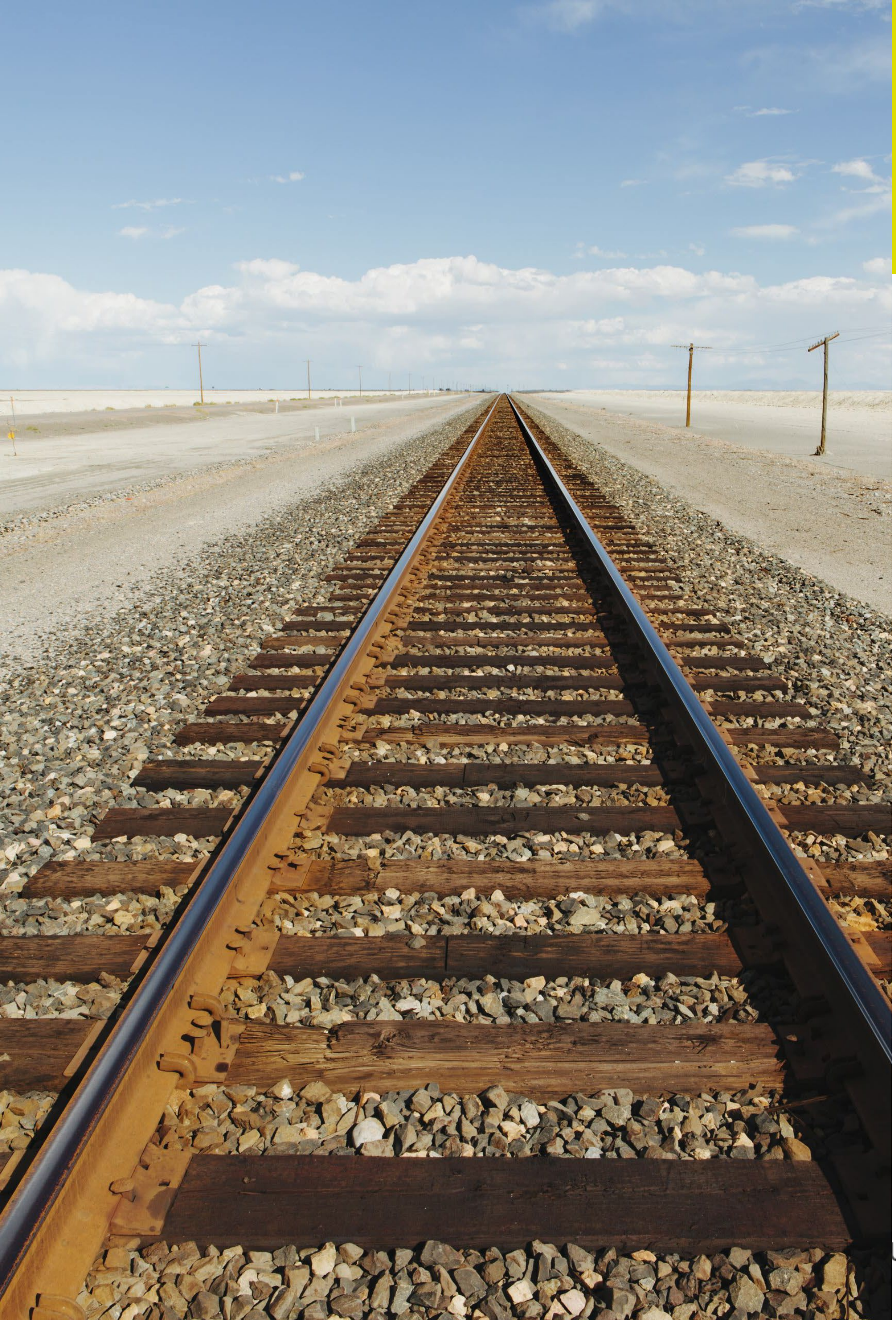


Requirements

HTL reaction in supercritical conditions

Salt separation from product (SC conditions)

- Separation of salts (> 90 %)
- Enough residence time for HTL reaction
- Extraction of the brine

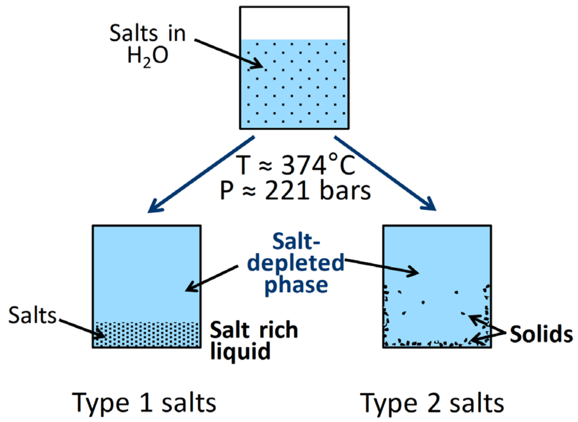
Heating

Union Grant Number 884111

Salt separation Integrated-HTL (IHTL)

- Salts have limited solubility in supercritical water
- Salts 1 and 2 behave differently
- Black liquor contains both types

Ions	HO^-	Cl^-	CO_3^{2-}	SO_4^{2-}
Mg^{2+}	2	1	2	2
Ca^{2+}	2	1	2	2
Na^+	1	1	2	2
K^+	1	1	1	2



Lappalainen, Jukka, David Baudouin, Ursel Hornung, Julia Schuler, Kristian Melin, Saša Bjelić, Frédéric Vogel, Jukka Konttinen, and Tero Joronen. "Sub-and Supercritical Water Liquefaction of Kraft Lignin and Black Liquor Derived Lignin." *Energies* 13, no. 13 (2020): 3309

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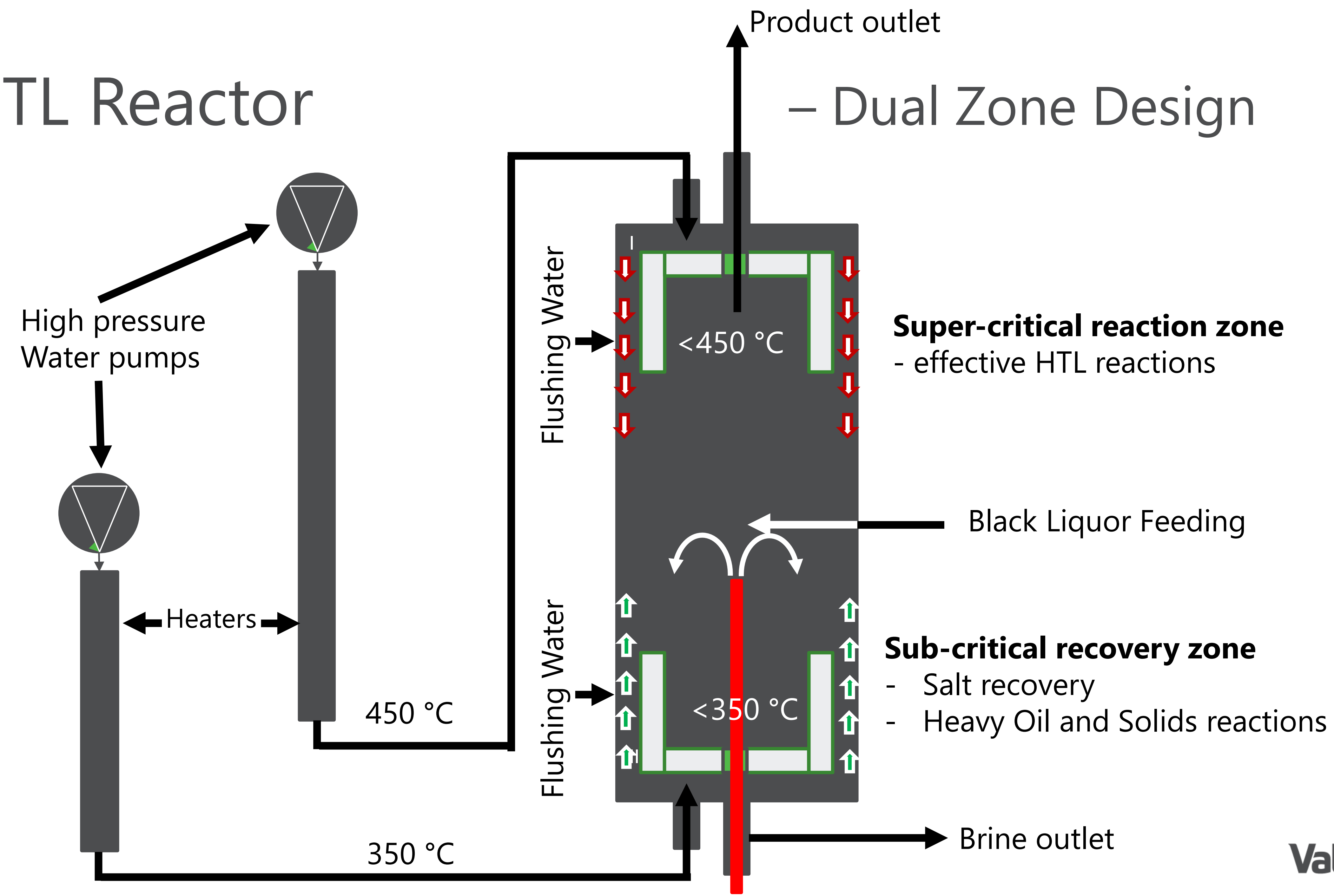
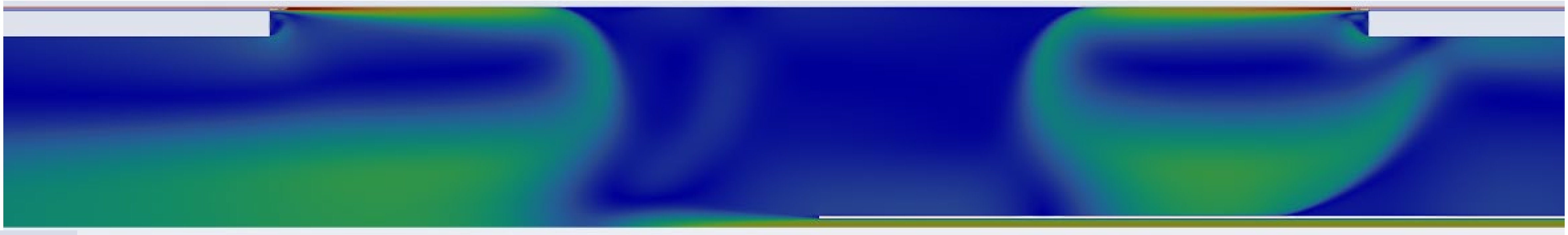
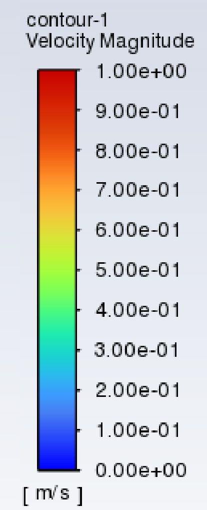
Valmet

IHTL Reactor – Dual Zone Design

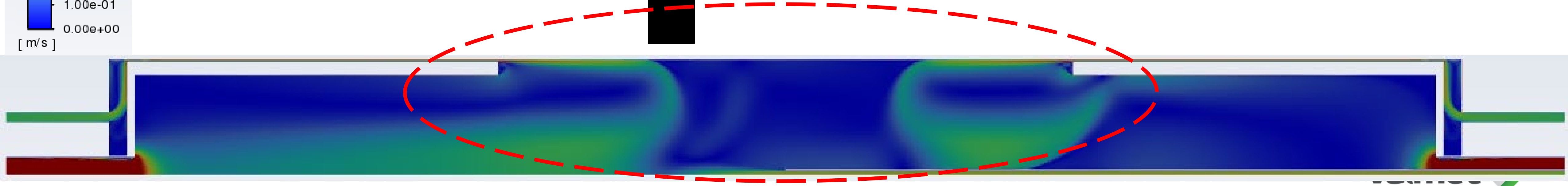


Simulation-1 Result – Velocity Magnitude

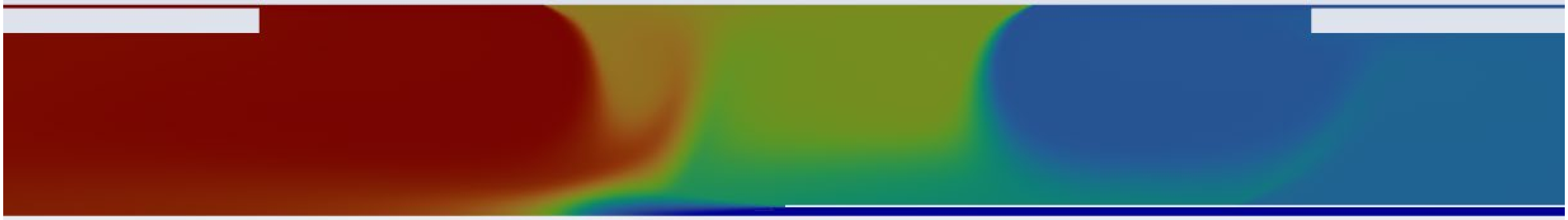


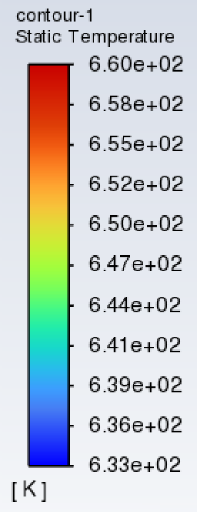


Simulation Conditions	
Velocity	Temperature
Flushing (Top) – 0.4m/s (3 L/hr)	Flushing (Top) – 387.1 °C
Flushing (Bottom) – 0.4m/s (3 L/hr)	Flushing (Bottom) – 364.6 °C
Feed – 0.49m/s (3 L/hr)	Feed – 360.3 °C



Simulation-1 Result – Temperature





Simulation Conditions	
Velocity	Temperature
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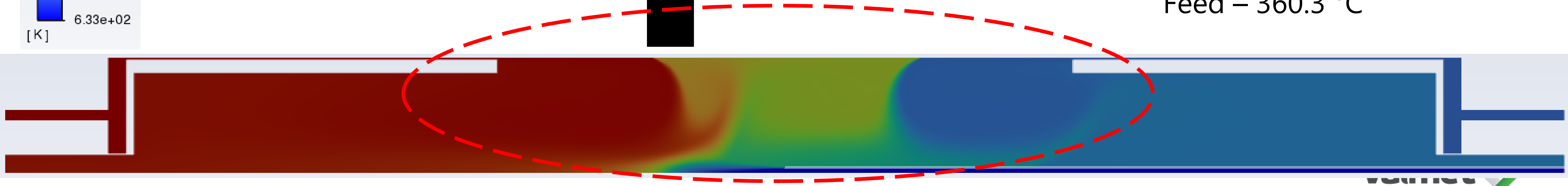
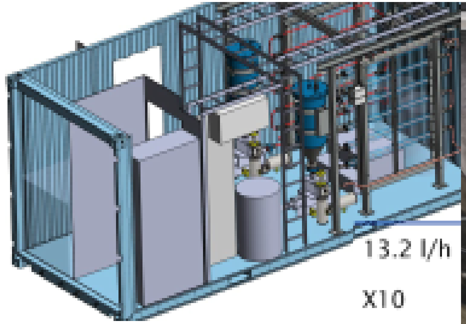




13.2 l/h

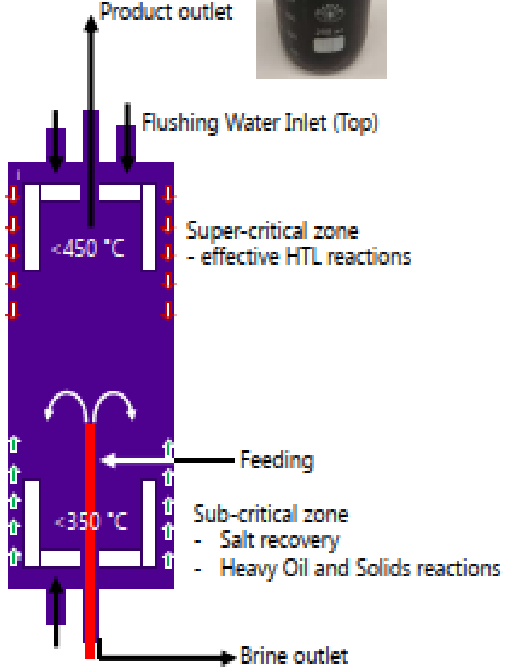
X10

400 °C

30 MPa

EHTA

Equipment for HydroThermal Applications



Benefits of HTL

- Good yield (Energy >80%, mass >45%)
- Good quality (O_2 <10%, HHV >37.5MJ/kg)
- Refinable product, flexible wet feedstock
- Fast reaction <10 min

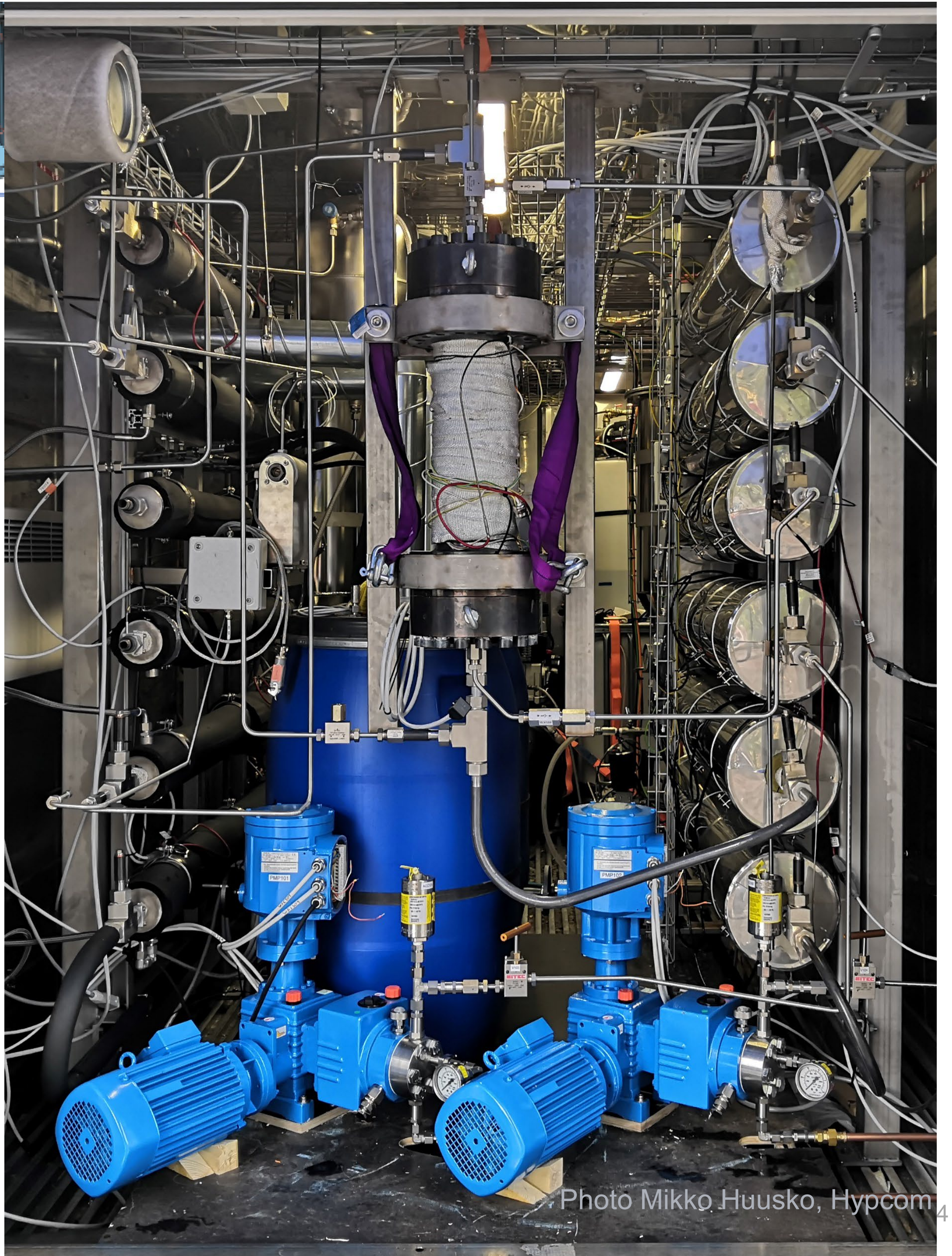
Features of EHTA

- Continuous
- Special separator reactor design
- Corrosion resistant (X10)
- High temperature and pressure (SC)
- CE marked, fully automated, mobile system

Feedstocks and projects at TAU

- Biomass
- Municipal solid waste
- Textile waste
- Plastic waste
- Black Liquor
- Pretreated biomass

EHTA (TAU)
ILPO (EAKR)
BL2F (H2020)
Bio4All (BF)



Analytical methods and results

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Analysis of feedstock and HTL products

Feedstock analysis

- Ultimate analysis ☑
- TGA ☑
- HHV

Bio-crude analysis

- GC-MS ☑
- Ultimate analysis ☑
- TGA ☑
- HHV

Aqueous phase analysis

- TOC

Hydro-char analysis

- Ultimate analysis ☑
- TGA ☑
- HHV

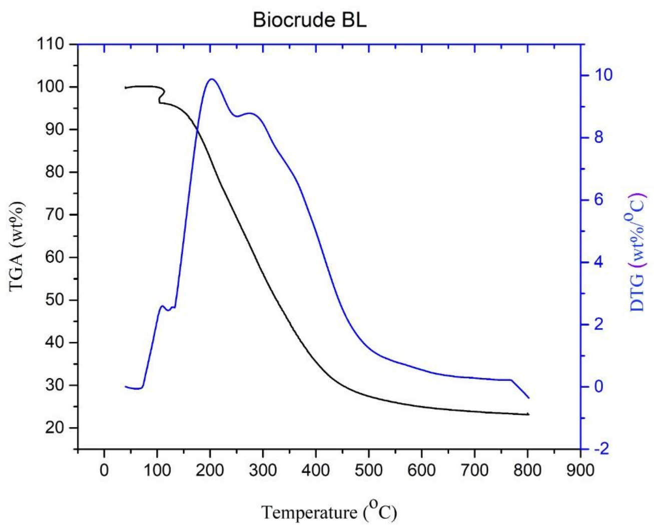
Example of elemental analysis of Lignin, Hydrochar, and Biocrude

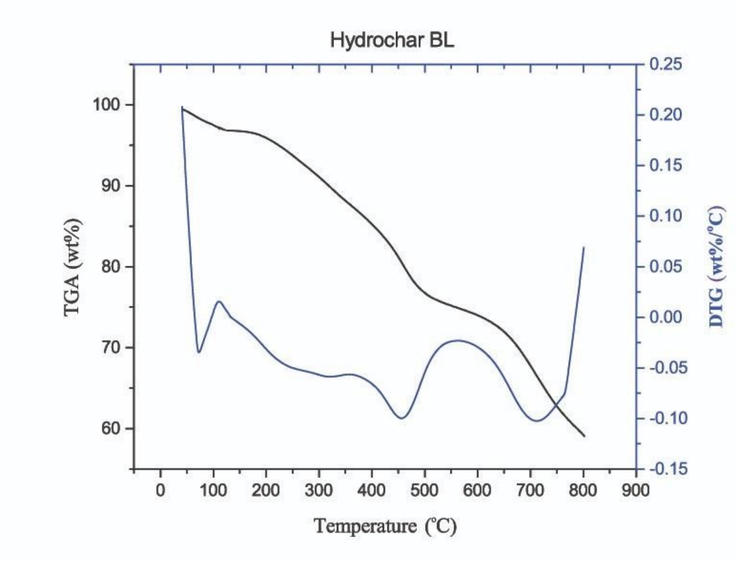
Sample	N	C	H	S	O	Ash	HHV
Lignin	0.47	53.64	5.8	4.85	35.4	0.08	29.556
Hydrochar	0.25	48.4	3.208	0.972	21.44	25.72	23.14
Biocrude	0.412	80.247	7.135	1.127	8.88	2.3	37.52

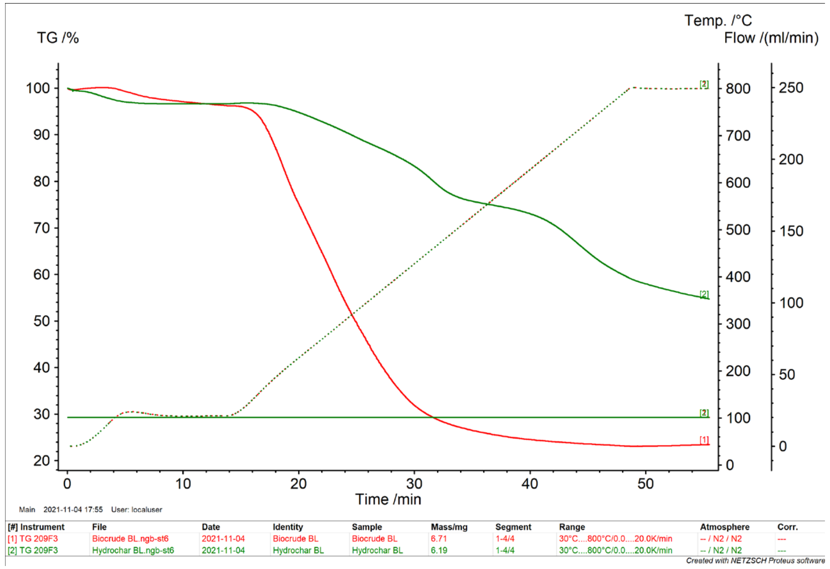
Babak Arjmand, TAU

Higher heating values (HHV) were calculated according to Boie's formula:
HHV = 0.3516 C +1.16225 H + 0.1109 O + 0.0628 N

TGA analysis (Biocrude & Hydrochar)







Babak Arjmand, TAU

	Moisture	VM	FC
Biocrude	5	71	24
Hydrochar	4	35	61

50 °C to 800 °C in N_2 for 90 min (ramp of

Feasibility

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the European Union Grant Number

Valmet

Financial estimate of PM integration

Integration to a pulp mill

- Abundant and Pumpable feedstock
- Homogenous quality
- Thermal integration (steam system of recovery boiler)
- Evaporator for preheating/ concentration
- Solids, water and gas handling
- Existing operation and maintenance personnel

Biomass conversion technology		IHTL	HTL
Technology development level			R&D
Plant size	1000t/a	150	180
O&M	M€/1000t	0.40	0.22
Investment	M€/1000t	0.73	2.00
Total	M€/1000t	1.23	2.22

45 % saving

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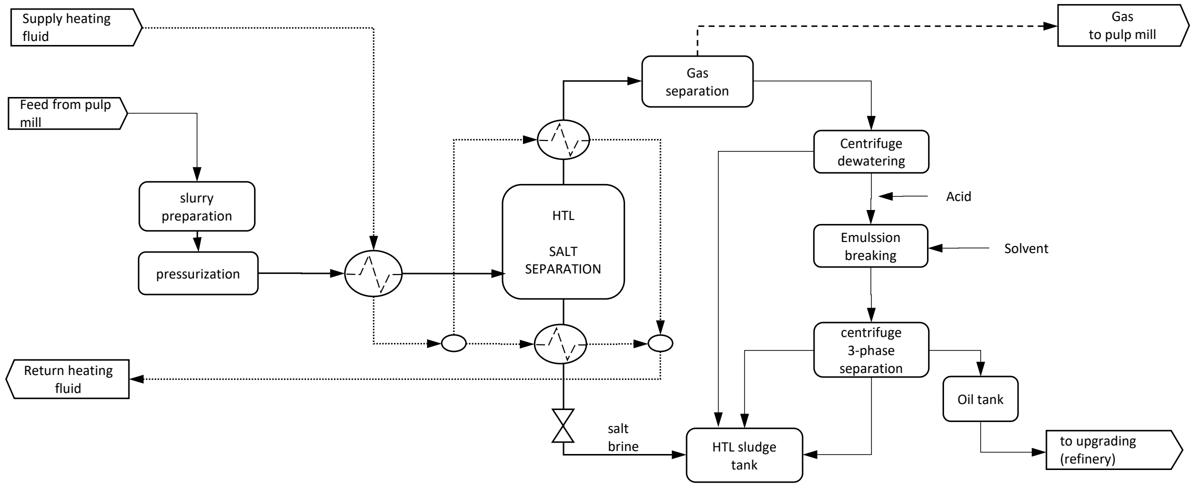
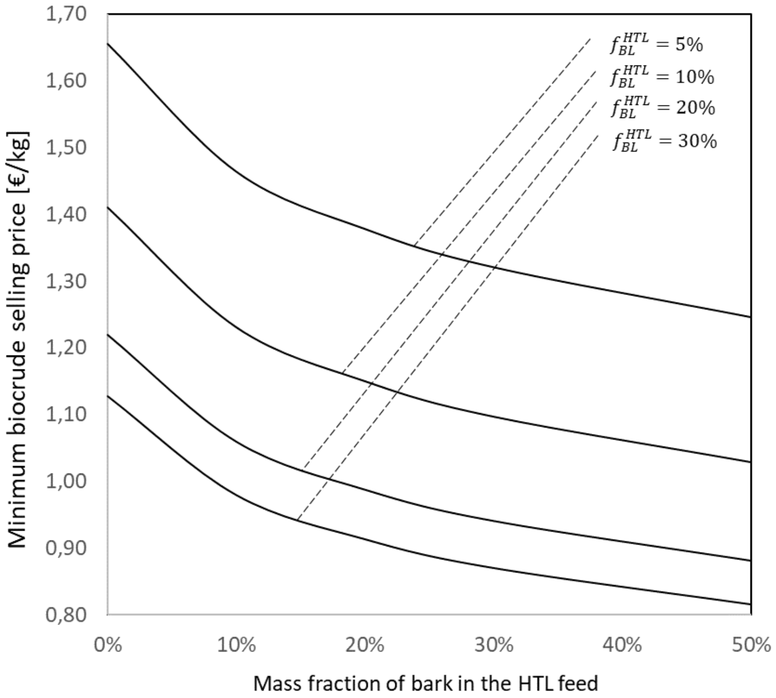
Realized estimates in the BL2F study





Minimum biocrude selling price as a function of the fraction of the black liquor diverted from the pulp mill and the mass fraction of black liquor in the feed to the HTL plant.

Gonzalo del Alamo (SINTEF), Adéola Jaiyeola (LGI), Feasibility assessment of integrating the production of HTL biofuels in conventional pulp mills Deliverable 4.3 of BL2F, 2024

This project has received funding from the European Union Grant Number 884111

HTL of Black Liquor

Lessons learned from BL2F project for Valmet

- Black Liquor is abundant and interesting feedstock
  - Available in a point source, relatively constant quality
  - Cooking chemicals require salt separation, IHTL concept approach promising
- The quality of HTL-oil meets requirements (< 10 m-%O_2)
- Salt separation at EHTA > 90 % (PSI tests > 98 %)
- The mechanical development need further studies
- Integration to Pulp Mill reduces the production cost of fuel intermediate (Price < 1 €/kg_Biocrude)
  - Potential to use other streams like bark and sludges
- Side streams of HTL have potential for further utilization
- IHTL on a simplified version remains interesting technology for further development

Liquefaction technology at Valmet

- Biofuels are in the core of Valmet's R&D
- Valmet has strong position in liquefaction technology
- Pyrolysis is in main focus currently
  - Fast pyrolysis commercial
  - Cirka project under construction
  - Development in the Catalytic pyrolysis, readiness for 5 t/h in 2024 and 50 t/h by 2027
- HTL at monitoring status
  - BL2F reached significant results
  - Salt separation successfully run
  - Low oxygen content (9 – 10.5 %), high heating value > 37 MJ/kg, feasible price for biocrude (< 1€/kg)
  - Technology requires further development in demonstration

Valmet
FORWARD