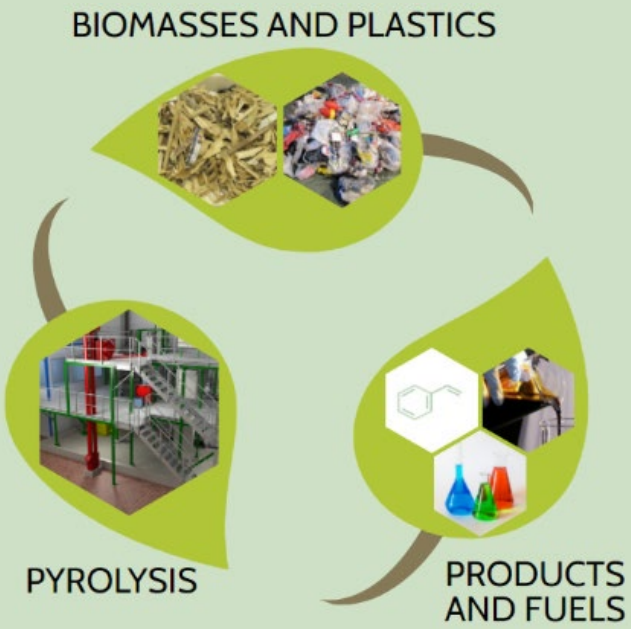

Fast pyrolysis of biomass – Past, present and future, A European perspective

TCBiomass, September 10, 2024

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Content

- Intro
- Experiences in scaling-up fast pyrolysis
- Enablers
- Wrap-up

Historical Review on VTT Fast Pyrolysis Bio-oil Production and Upgrading. Oasmaa, A., Lehto, J., Solantausta, Y. & Kallio, S., 2021, In: Energy & Fuels. 35, 7, p. 5683−5695. 10.1021/acs.energyfuels.1c00177

VTT briefly

VTT is a visionary research, development and innovation partner for companies and society, and one of the leading technical research organisations in Europe.

We bring together people, business, science and technology, to solve the world's biggest challenges, creating sustainable growth, jobs and wellbeing.

We promise to always think beyond the obvious.

2,355
employees

284 M€/a
operating income

488
scientific articles/a

450
patent families

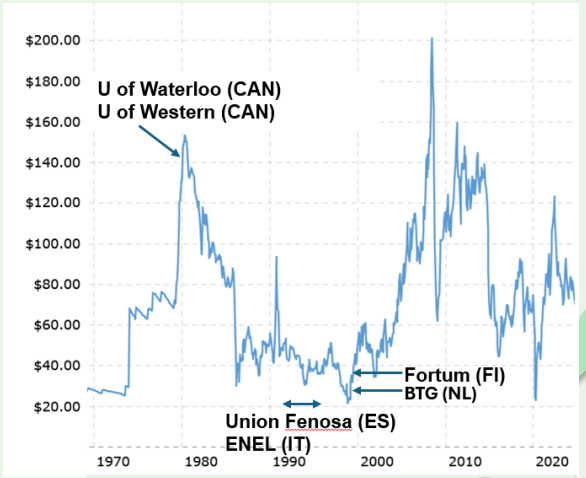
Scaling-up biomass fast pyrolysis – TRL 1-3

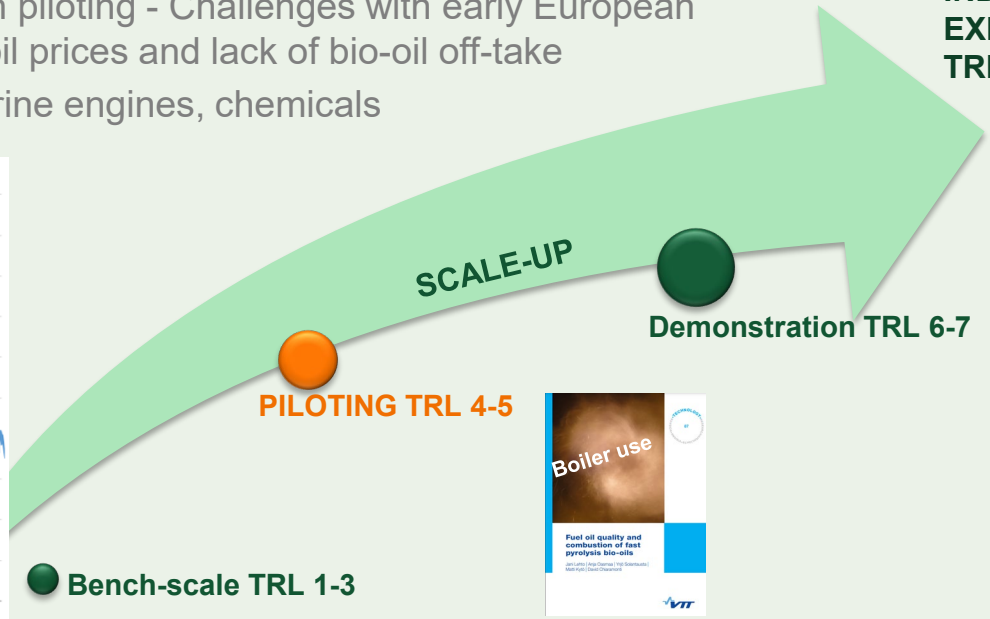
- **Networking - national and international projects**
  - Optimizing process parameters, scaling-up plans

- **International collaboration promoted early development in the 80s, e.g. IEA Bioenergy**

Scaling-up biomass fast pyrolysis – TRL 4-5

- **Piloting of biomass fast pyrolysis and end-use applications**
  - Valuable expertise gained with piloting - Challenges with early European piloting included low mineral oil prices and lack of bio-oil off-take
  - Application tests - boilers, marine engines, chemicals





- **Early industrial consortia promoted piloting**

https://publications.vtt.fi/pdf/technology/2013/T87.pdf

Scaling-up biomass fast pyrolysis – TRL 6-7

- **Demonstration of biomass fast pyrolysis**
  - Bio-oil demonstration plants
  - Bio-oil to replace fossil feed in boilers and refineries
  - Chemicals production

SCALE-UP

Bench-sc

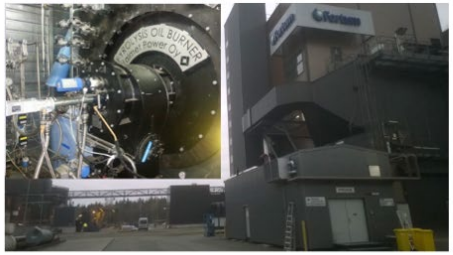
Piloting TRL 4-5

INDUSTRIAL EXPLOITATION TRL > 8

DEMONSTRATION –
Industry lead supporte

ENSYN

Valmet



Fortum, Joensuu, FI, **10 MWth**

Fortum, Vermo, FI, **50 MWth**

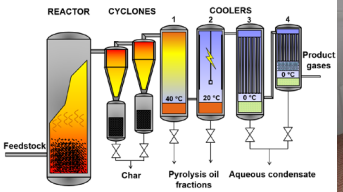
E.ON, Karlshamn, S,**174 MWth**

➢ **Product end-use and markets must be defined and available for demonstration**

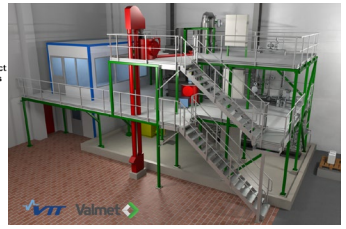
Fast pyrolysis for chemicals

Valmet & Circa – New pyrolysis technology paves the way for fossil-free solvent production

VTT helped Circa and Valmet to scale up new pyrolysis technology for fossil-free solvent production. The development started small and was scaled up at VTT's pilot facilities once the results from the smaller-scale tests looked promising. When the pyrolysis process started working on a larger pilot-scale, Circa had sufficient proof to build the plant in France.



Bench scale optimization



Pilot scale concept testing

Data for scale-up

Scale-up

"This was the first bigger-scale trial that we did on the setup for the ReSolute plant. It was very helpful in confirming theoretical values like the product yield, which was even better than we had calculated."

Philipp Morgenthaler
Head of Manufacturing
Circa

"Our aim is always commercial viability, and we know we can trust VTT to help us reach that. VTT has wide-ranging expertise from their projects with other companies, which benefits us. They also have more R&D staff than us, which is a valuable resource."

Jari Niemelä
Director of New Technologies
Valmet

https://www.vttresearch.com/en/news-and-ideas/circa-valmet-renewable-chemical-production-piloting

Enablers – Markets, legislation

- Investment environment – markets, legislation
- Market development is as crucial as technology development
- EU Decarbonization Targets: Aims for carbon neutrality by 2050, 55% reduction in emissions by 2030 (compared to 1990 levels), and 62% reduction for EU ETS (Emissions Trading System) sectors (compared to 2005 levels).
- The 2023 IMO* GHG Strategy predicts a reduction in carbon intensity of international shipping by at least 40% by 2030. The 2023 IMO GHG Strategy also includes a new level of ambition relating to the uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources which are to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030.

** International Maritime Organization*

Enablers – Norms, standards

- Norms and standards are needed for market introduction
  - Development of analytical methods for physico-chemical characterisation of FPBOs
  - International validation of methods by round robins
  - REACH registration in EU

ASTM D7544, EN 16900, REACH
Work on-going in Europe and USA

- ASTM and EN standards for boiler use, Technical Specification for diesel-engine use, work is on-going in Europe and USA to cover other applications
- REACH registration for FPBO available

https://task34.ieabioenergy.com/; https://www.nrel.gov/bioenergy/bio-oil-analysis.html
https://publications.vtt.fi/pdf/publications/2010/P731.pdf, https://www.nrel.gov/docs/fy00osti/27613.pdf

Enablers – Experimental research, resources

- Research infra important for proof-of-concept and support for demonstration
- Experiments combined with CFD modeling for technology development / scale-up
- Resources: (i) innovative project management; (ii) critical mass of experienced people; (iii) long-term public and industrial funding
- IPR

https://www.vttresearch.com/en/technology-infrastructures/vtt-bioruukki-pilot-centre

CFD = Computational fluid dynamics

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Enablers - Funding

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BUSINESS
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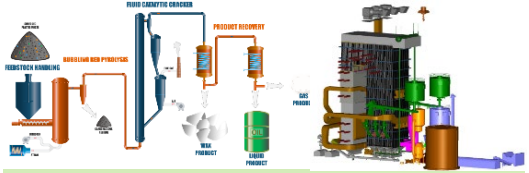
- Steady funding critical (European – National)
- The EU provides financial assistance to support EU policies
  - grants – ‘call for proposals’
  - subsidies managed by national or regional authorities
  - loans, guarantees and equity
- National funding, e.g. in Finland BF is funding over 20 ecosystems of leading companies, serve as means to accelerate research, development, and commercialization.
- Demonstration funds for industrial investment
- Private investments

Fast pyrolysis of biomass – Focus in Europe

LOW-COST SUSTAINABLE REDIII FEEDSTOCKS

- ✓ **Wood wastes, agricultural residues, biogenic waste***
- ✓ **Biodiversity, ecological aspects**
- ✓ **Impurity removal**
- ✓ **Feedstock pretreatment**

LOW-EMISSION PYROLYSIS TECHNOLOGIES



- ✓ **Thermal/Catalytic pyrolysis**
- ✓ **New reactor designs**, negative-emission technologies
- ✓ **Process integrations**
- ✓ **CFD-modelling, scaling-up**
- ✓ **Catalyst development**
- ✓ **Hydroprocessing upgrading**

HIGH-QUALITY SUSTAINABLE PRODUCTS

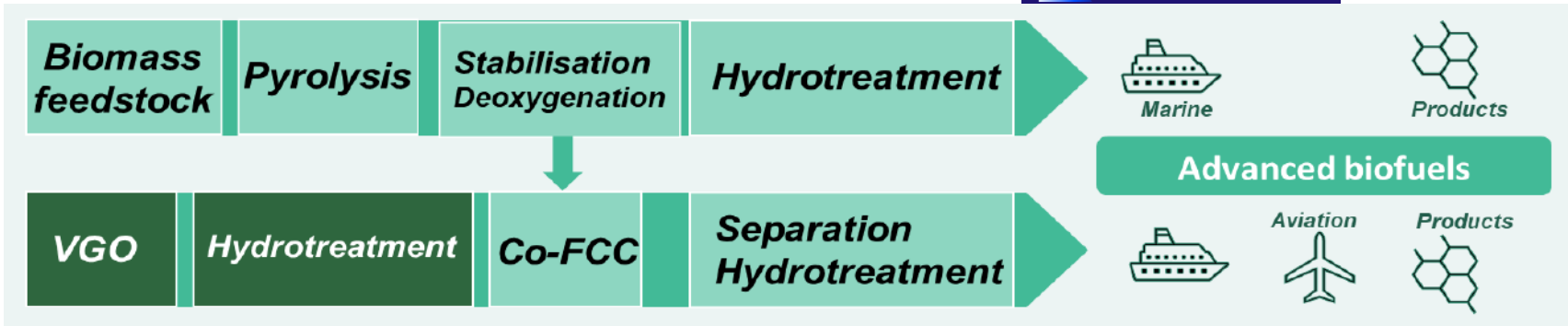
- ✓ **Co-refining / Refinery feeds**
- ✓ **Chemicals, materials**
- ✓ **Advanced liquid biofuels**
- ✓ **Analytical methods, standards, REACH, IPR**
- ✓ **TEA, LCA, EHS**

** Biogenic waste: Biowaste, MSW, Residual waste, Sewage sludge, Green waste, Manure, Agricultural waste.*

Fast pyrolysis to advanced bio-oils

Refinery integration, scale-up and certification for aviation and marine biofuels production

REFOLUTION
Unlocking the potential of biofuels
2023 - 27



Virtual Special Issue of Recent Advances in Biofuel Production via Co-refining Route. Oasmaa, A., Elliott, D. C. & Prins, W., 18 May 2023, In: Energy and Fuels. 37, 10, p. 6875-6878 4 p. Access to Document: 10.1021/acs.energyfuels.3c01384

Co-processing of Biocrudes in Oil Refineries. Lindfors, C., Elliott, D. C., Prins, W., Oasmaa, A. & Lehtonen, J., 19 Jan 2023, In: Energy and Fuels. 37, 2, p. 799-804 6 p. Access to Document: 10.1021/acs.energyfuels.2c04238

Hydroprocessed FPBO (~ 5 wt. % O) quality

PROPERTY		Upgraded FPBO's	Marine distillate ISO 8217:2017	Marine residual ISO 8217:2017
Density at 15 °C	kg/m3	**912**	max. 900	991
Viscosity at 40 °C	cSt	6.37	2.00 –11.0 (40 °C)	330 (50 °C)
Cetane number/index/CCAI		**22.2**/-/860	-/Min. 35/-	-/-/Max. 870
Sulphur	mg/kg	5.2; 38.0	Max. 5000	Max. 5000
Flash point	°C	**< 40**	Min. 60	Min. 60
Pour point	°C	-36	Max 0/6 w/s	Max. 30
Cloud point/CFPP	°C	-/18	- / -	
HFRR lubricity 60 °C	µm	140	Max. 520	
Acid number	mg KOH/g	0.08 (SAN < 0.1)	Max. 0.5	Max. 2.5
Water	wt-%	**0.59**	Max. 0.30 (Vol-%)	Max. 0.50 (Vol-%)
Total sediment	wt%	<0.01	Max. 0.1	Max. 0.1
Carbon residue	wt%	**0.70**	Max. 0.3	Max. 18
Oxidation stability	g/m3	too viscous	Max. 25	
Oxidation stability	min	50.5; 53.3	No spec	No spec
Ash (775 °C)	wt%	<0.001	Max. 0.01	Max. 0.1
V/Na	mg/kg	<0.5/0.8	-	Max. 350/100
Al+Si	mg/kg	<0.5+<0.5	-	Max. 60
Ca/Zn/P	mg/kg	<0.5/<0.5/<0.5		Ca>30, Zn or P >15

- Most of the properties are in line with ISO 8217 standard
- No changes in properties of upgraded FPBO and its 30% blends with marine fuels in one year storage time
- Improvements needed in
  - Density
  - Cetane number
  - Flash point
  - Water content
  - Carbon residue
- Method development needed in
  - Oxidation stability
  - Lubricity
  - Cl, S
  - Blending protocols

Ohra-aho et al. Quality and storage properties of upgraded fast pyrolysis bio-oil for marine transport. Accepted to Energy&Fuels 2024.
https://task34.ieabioenergy.com/wp-content/uploads/sites/3/2023/12/PyNe54-komplett.pdf

Fast pyrolysis for marine fuels

- There are various approaches for FPBO to be used as marine fuel blend, e.g.
  - Co-refining route
  - Hydroprocessing upgrading to decrease the O content for blending with marine fuels
  - FPBO fraction (sugar fraction) emulsified with water and marine fuel by BTG Bioliquids and Quadrise
- To be demonstrated:
  - Standardized large-scale production of hydroprocessed bio-oil and its blends
  - Increasing the bio-part in the blend, additives
  - Adequate fuel properties and storage quality of the bio-oil blend
  - Long-duration large-scale engine tests
  - Validated analytical methods, blending and feeding protocols
  - Standards and norms

** FPBO = fast pyrolysis bio-oil*

Wrap-up

- Market development is as crucial as technology development.
- Enablers for commercialization of new bio-oil/product:
  - Analytical methods, standards and norms early-on
  - Industrial consortia early-on
  - Investment environment – private and public funding, markets, legislation
- Pyrolysis oil to boilers to replace fossil fuels and small-scale chemical production already on the markets.
- Future larger scale applications:
  - Co-feeding to the FCC, increase the share of bio-oil
  - Gasification of pyrolysis oil in existing gasifiers
  - Advanced bio-oils for marine and aviation
  - Chemicals

Thank you! Questions?

Acknowledged: Valmet - Joakim Autio; BTG-BTL – Gerhard Muggen, Ardy Toussaint; Sintef – Duncan Akporiaye; VTT – Jarmo Ropponen, Elmeri Pienihäkkinen, Taina Ohra-aho, Päivi Aakko-Saksa, Riikka Reitzer

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