Session I

Torrefied fuels

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 282826

Session I "Torrefied fuels" - Part 1: Torrefaction

- Execute series of lab/batch- and pilot tests in different torrefaction facilities in order to:
  - Further optimise torrefaction technologies (ECN, Umea Univ., CENER, Topell)
  - Broaden the feedstock range
  - Produce solid sustainable bioenergy carriers with properties that meet requirements set by subsequent densification, logistics and end-use

- Partners: CENER, ECN, OFI, Topell, UmU, VTT

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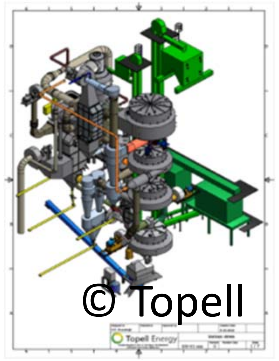
Torrefaction technologies

Different technologies

Moving bed*
(ECN)
pilot

Rotary drum / Auger
(Umeå University)
pilot

Rotary drum
(CENER)
pilot



Toroidal
(Topell Energy)
demo

Production with available **pilot scale facilities**
Typical test runs 50-100 hours
Typical production per test few tonnes
3-6 different feedstocks

Production with available **demo plant**
Continuous operation
Production of 100-200 tonnes
Specific feedstock

** And the resulting Andritz/ECN technology, successfully demonstrated in Denmark at a scale of 1 ton/h*

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Lab-scale torrefaction tests

- TGA measurements
  - On following feedstocks
    - ECN poplar, pine, spruce, bamboo
    - UmU pine, willow
    - CENER pine, straw
    - Bintuni mangrove
    - Viridis Energy PKS
    - Cradle Crops miscanthus
    - Anbenna sun flower husk
  - At following temperatures
    - 240, 260, 280, and 300°C

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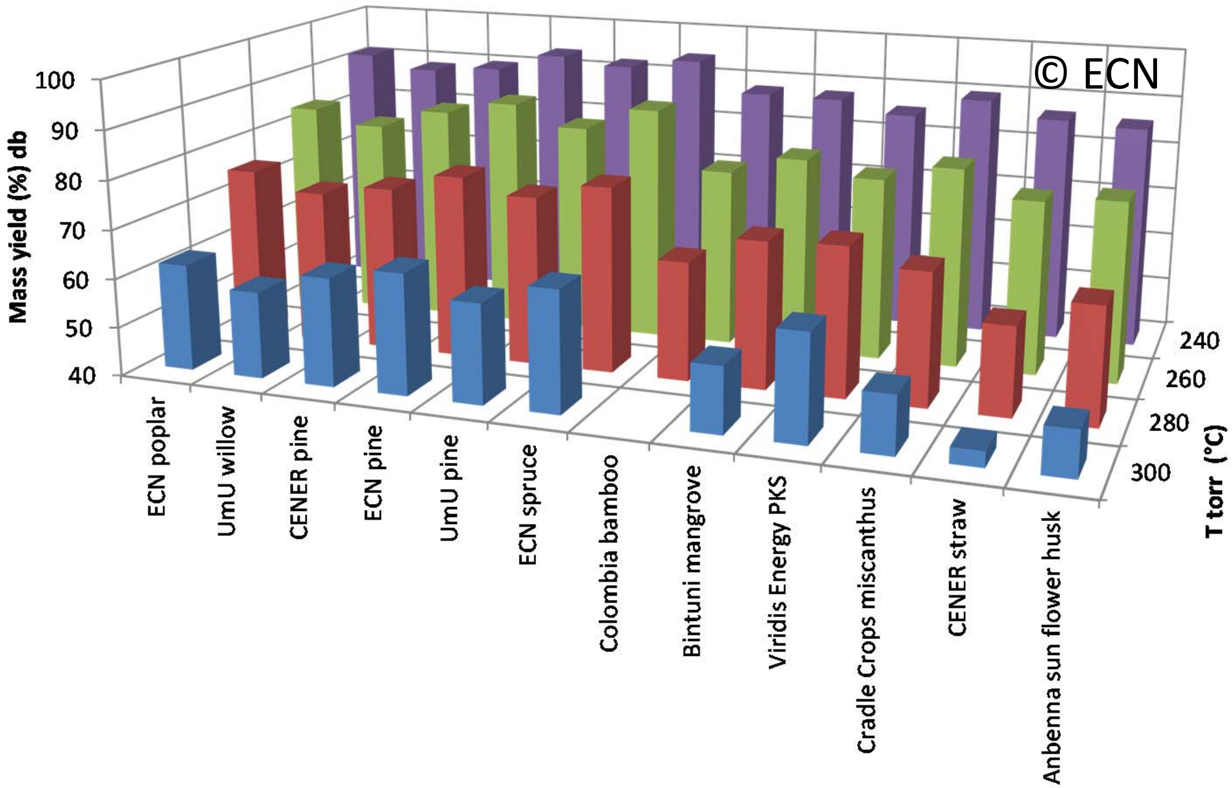
Lab-scale torrefaction tests

- TGA measurements
  - Mass yields at 45 min after reaching 200°C



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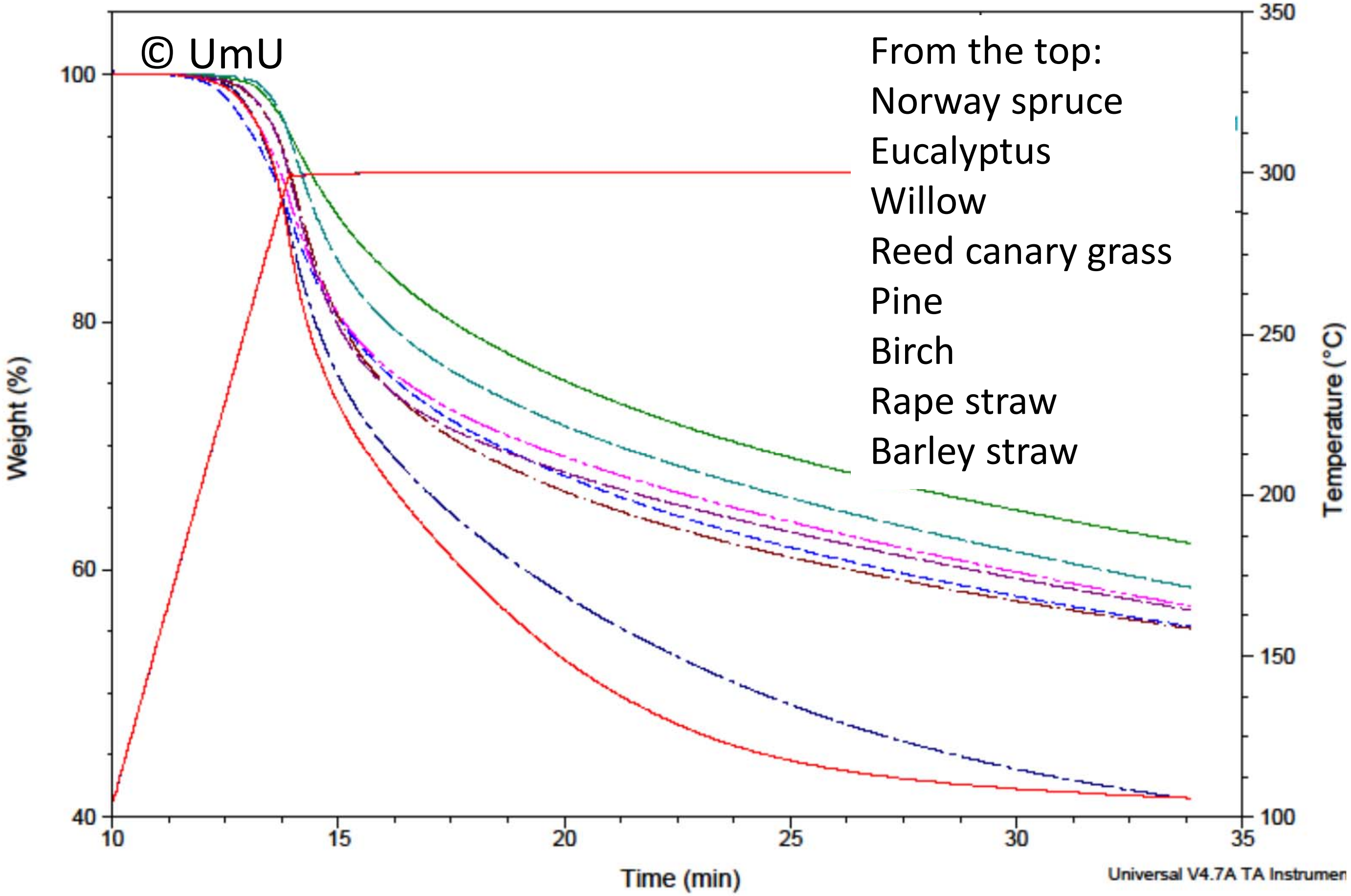
Lab-scale torrefaction tests

- Mass loss rate profiles (TGA experiments)



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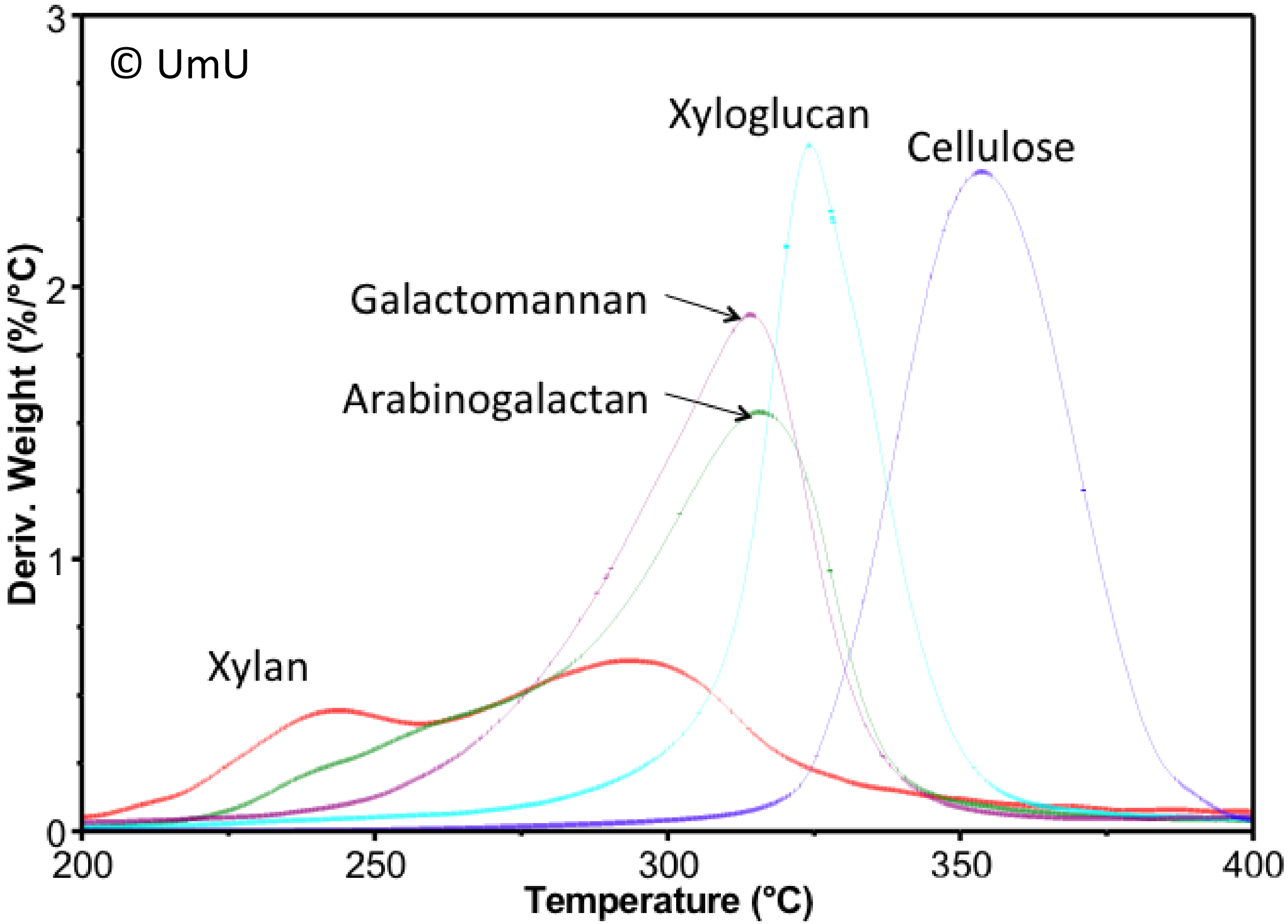
Lab-scale torrefaction tests

- Mass loss rate profiles (hemicelluloses)



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WP 3: Results Task 3.1

- Batch reactor tests
  - On following feedstocks
    - ECN poplar, pine, spruce, bamboo
    - UmU pine, willow
    - CENER straw
    - Bintuni mangrove
    - Viridis Energy PKS
    - Cradle Crops miscanthus
    - Anbenna sun flower husk
  - At following temperatures
    - 240, 255, 260, 270, 280, or 300°C

    (not all temperatures for all materials)

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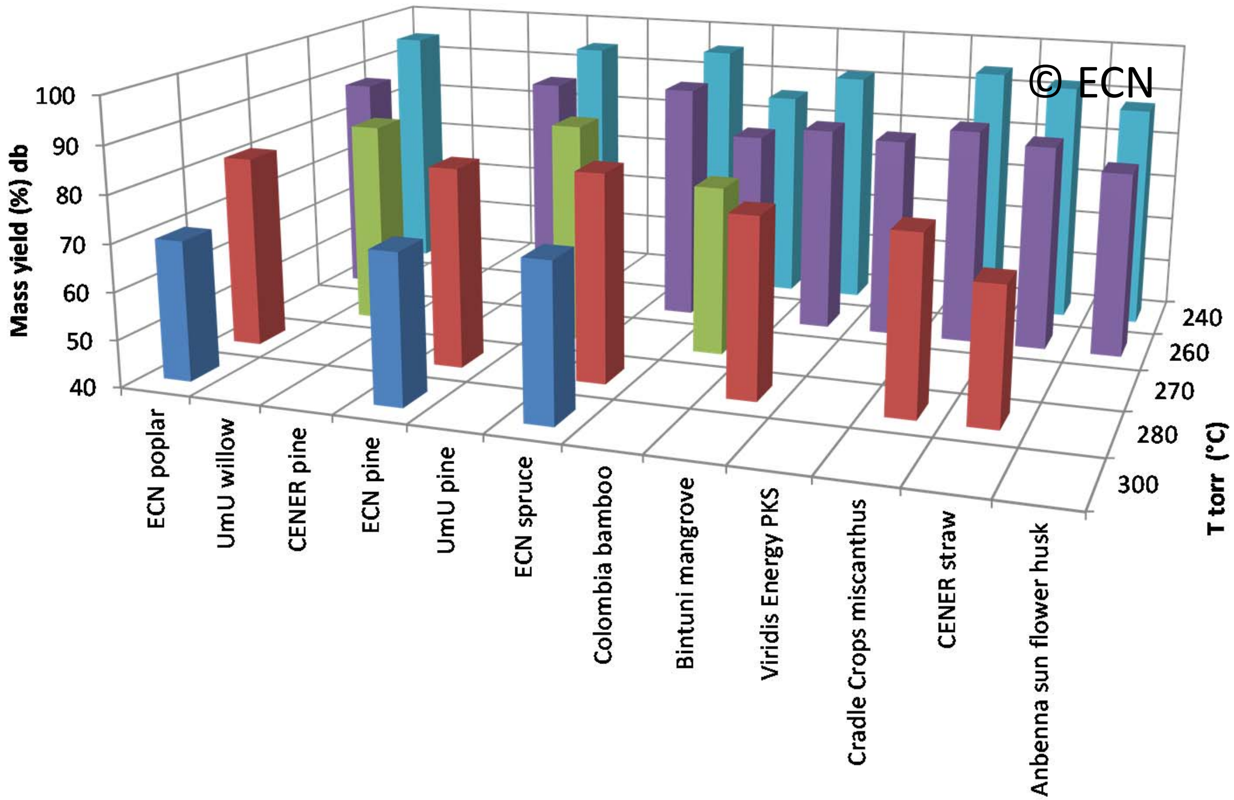
Lab-scale torrefaction tests

- Batch reactor tests
  - Mass yields at 45 min after reaching 200°C



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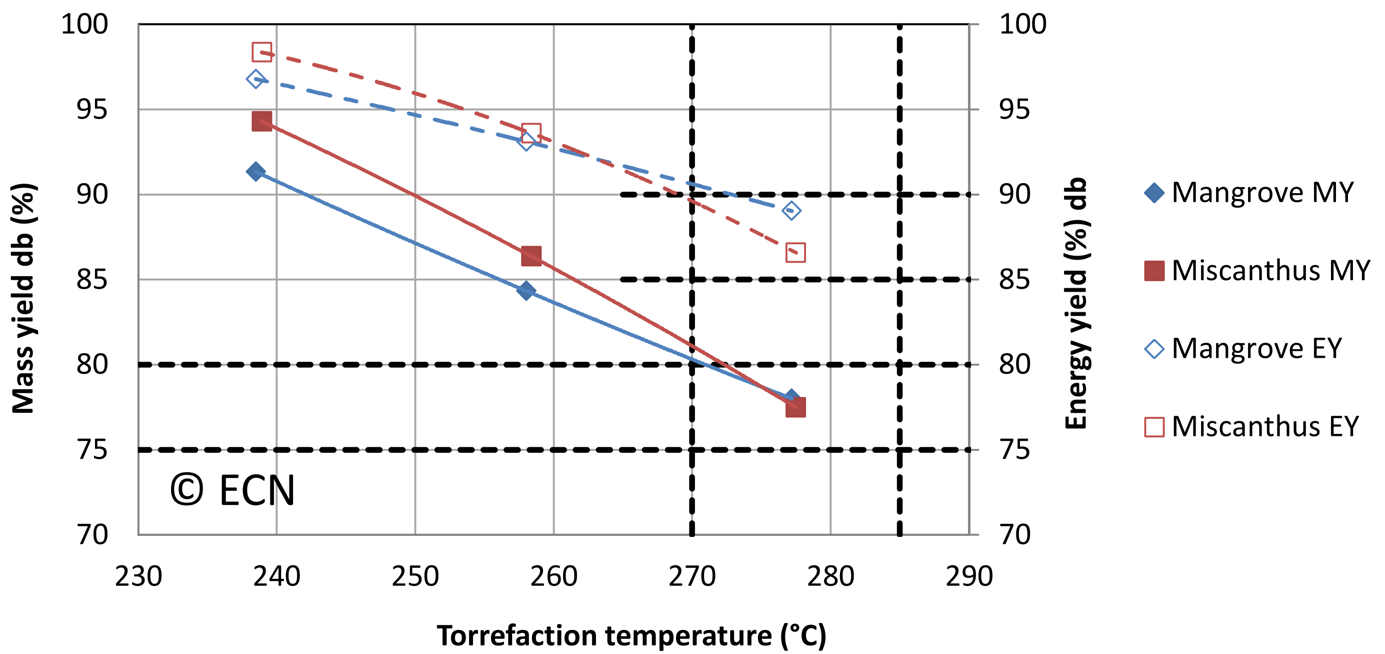
Lab-scale torrefaction tests

- Test results combined
  - Mass yields and energy yields for determining working window e.g. mangrove and miscanthus (from batch reactor tests)



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Pilot-scale torrefaction tests

No.	Selected feedstock	Partner responsible	Pilot test temperatures (ºC)	Pilot test production (kg)		
				CENER	ECN	UmU
1	Delimbed coniferous stem wood without bark, (Pine as reference raw material 1)	ECN, UmU, CENER	240, 270, 260, 280, 291, 300, 308, 315	15.341	3.738	3.400
2	Logging residue, coniferous	UmU	286, 308, 325	-	-	3.400
3	Delimbed broadleaves stem wood with bark, (Beech, reference raw material 2)	CENER	270	4.619	-	-
4	Poplar	CENER, ECN	270, 280, 290, 300	8.466	4.058	-
5	Straw (Oat and wheat, Southern conditions)	CENER	250, 260, 270	8.680	-	-
6	Prunings from olive trees –woody biomass	CENER	250, 260, 270	-	-	-
7	Eucalyptus	CENER	250, 260, 270	196	-	-
8	Paulownia	CENER	250, 260	6.052	-	-
9	Bamboo	ECN	245, 255, 265	-	1487	-
10	Bagasse	CENER	250, 260	Cancelled	-	-
11	Willow (Salix)	UmU	286, 308, 330	-	-	3.400
12	Spruce	ECN	240, 260, 280	-	16.973	-
			Subtotal	**43.354**	**26.255**	**10.200**
			TOTAL		**79.809**	

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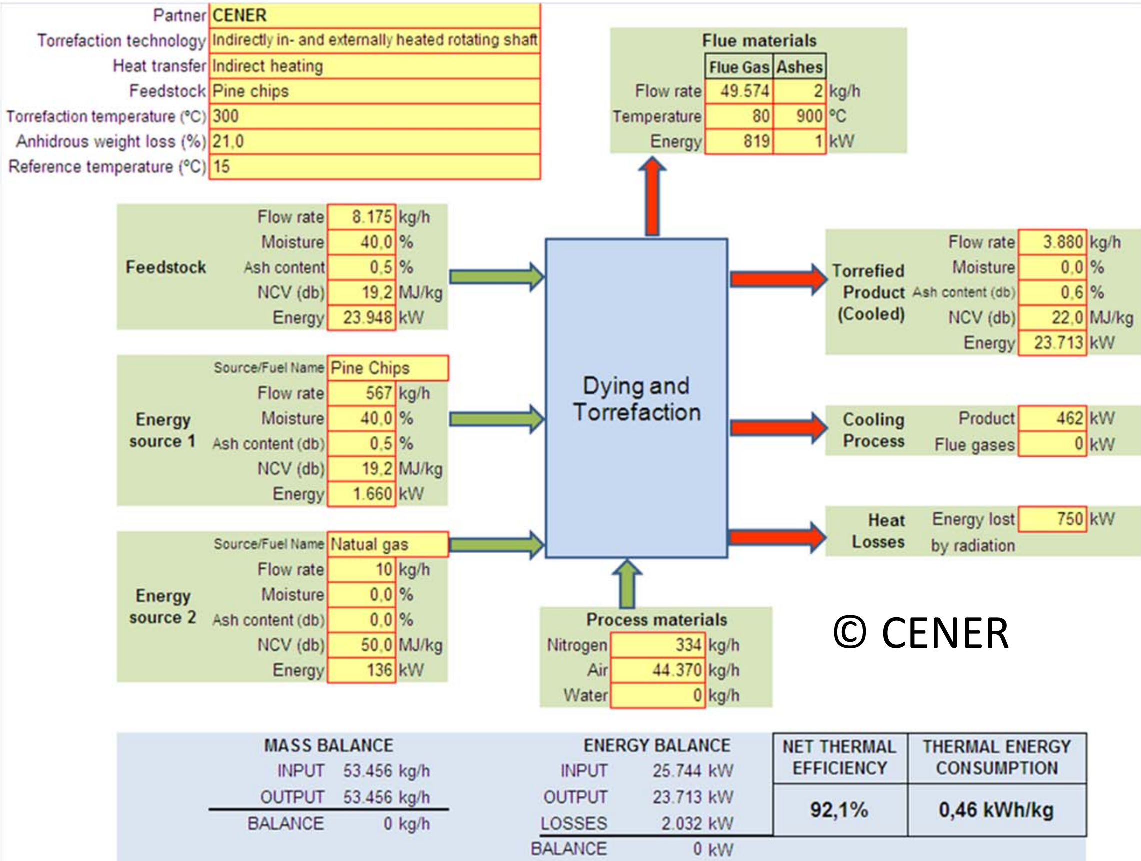
Pilot-scale torrefaction tests

- Mass and Energy balances prepared for pine by CENER, ECN & UmU



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Pilot-scale torrefaction tests

- Mass and Energy balances prepared for pine by CENER, ECN & UmU
- Net Thermal Efficiency (NTE) parameter is mainly influenced by biomass moisture content, mass yield of the torrefied product, energy integration and heat losses
- NTE values of cases including heat integration very similar

Partner	Torrefaction technology	Heat transfer type	Mass yield (% db)	Energy yield (% db)	Net thermal efficiency (%)	Thermal energy Consumption (kWh/kg[1])	Production capacity[2] (t/a)
CENER	Indirectly in- and externally heated rotating shaft	Indirect heating	79,0	90,5	92,1	0,46	31.041
UmU	Rotating drum	Indirect heating	75,7	87,9	83,6	0,30	114
ECN	Directly heated moving bed	Direct heating	81,3	87,6	92,4	0,34	112.682

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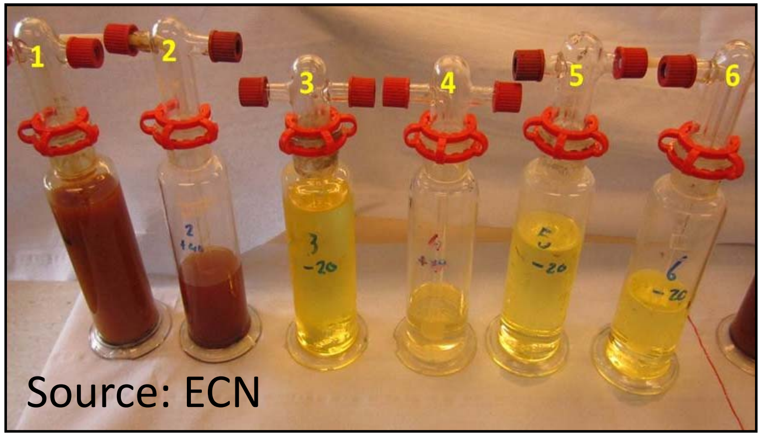
Feedstock and product analysis

- Gas composition during spruce torrefaction at 260 °C



Source: ECN

Component	vol.% wet gas
CO	1.5
CO_2	2.2
N_2	45.6
H_2O	50.6

Component	Average gas concentration (g/Nm³)
Acetic acid	39,5
Hydroxyacetone	15,8
Methanol	10,2
Hydroxyacetaldehyde	8,5
Formic acid	8,0
2-Furanmethanol	7,6
2-Furaldehyde	4,9
Isoeugenol	3,4
1-Hydroxy-2-butanone	2,9
5-(Hydroxymethyl)-2-furaldehyde (HMF)	2,9
2(5H)-Furanone	1,5
2-Methoxyphenol	1,1
2-methoxy-4-vinyl-phenol	1,1
Pyrocatechol	1,1
Total detectable organics	108,3

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Feedstock and product analysis

- Torrefied product homogeneity during pilot production

Homogeneity of the process: Sample analisys of each big-bag produced									
No.	Sample number	Big-bag code	production hours		Elemental analisys (% db)			Heat value (MJ/kg	
			Start	finish	C	H	N	HHV	LHV
1	230	12/007/TO03	10:45	11:45	54,0	6,0	0,18	21,68	20,43
2	231	12/007/TO04	11:45	12:36	53,8	6,0	0,13	21,65	20,40
3	232	12/007/TO05	12:36	13:22	53,7	6,1	0,16	21,63	20,38
4	233	12/007/TO06	13:22	14:09	53,4	6,1	0,16	21,39	20,14
5	234	12/007/TO07	14:09	14:55	53,4	6,1	0,11	21,55	20,30
6	235	12/007/TO08	14:55	15:41	53,4	6,1	0,13	21,44	20,19
7	236	12/007/TO09	15:41	16:20	53,4	6,0	0,13	21,51	20,27
8	237	12/007/TO10	16:20	17:11	53,3	6,1	0,11	21,44	20,19
9	238	12/007/TO11	17:11	17:55	53,5	6,1	0,14	21,53	20,27
10	239	12/007/TO12	17:55	18:37	53,5	6,1	0,13	21,51	20,26
11	240	12/007/TO13	18:37	19:23	53,3	6,2	0,14	21,37	20,08
12	241	12/007/TO14	19:23	20:08	53,1	6,1	0,12	21,41	20,15
Mean					53,5	6,1	0,14	21,51	20,25
Maximum					54,00	6,2	[illegible]	[illegible]	[illegible]
Minimum					53,10	6,0	[illegible]	[illegible]	[illegible]
Averaged desviation (%)					0,18	[illegible]	[illegible]	[illegible]	[illegible]
Maximun desviation (%)					0,52	0,12	[illegible]	[illegible]	[illegible]
Analysis acceptance repeatability criteria					0,39%	<0,2%	<0,03%	<0,12 MJ	

Differences are similar to analysis acceptance repeatability criteria

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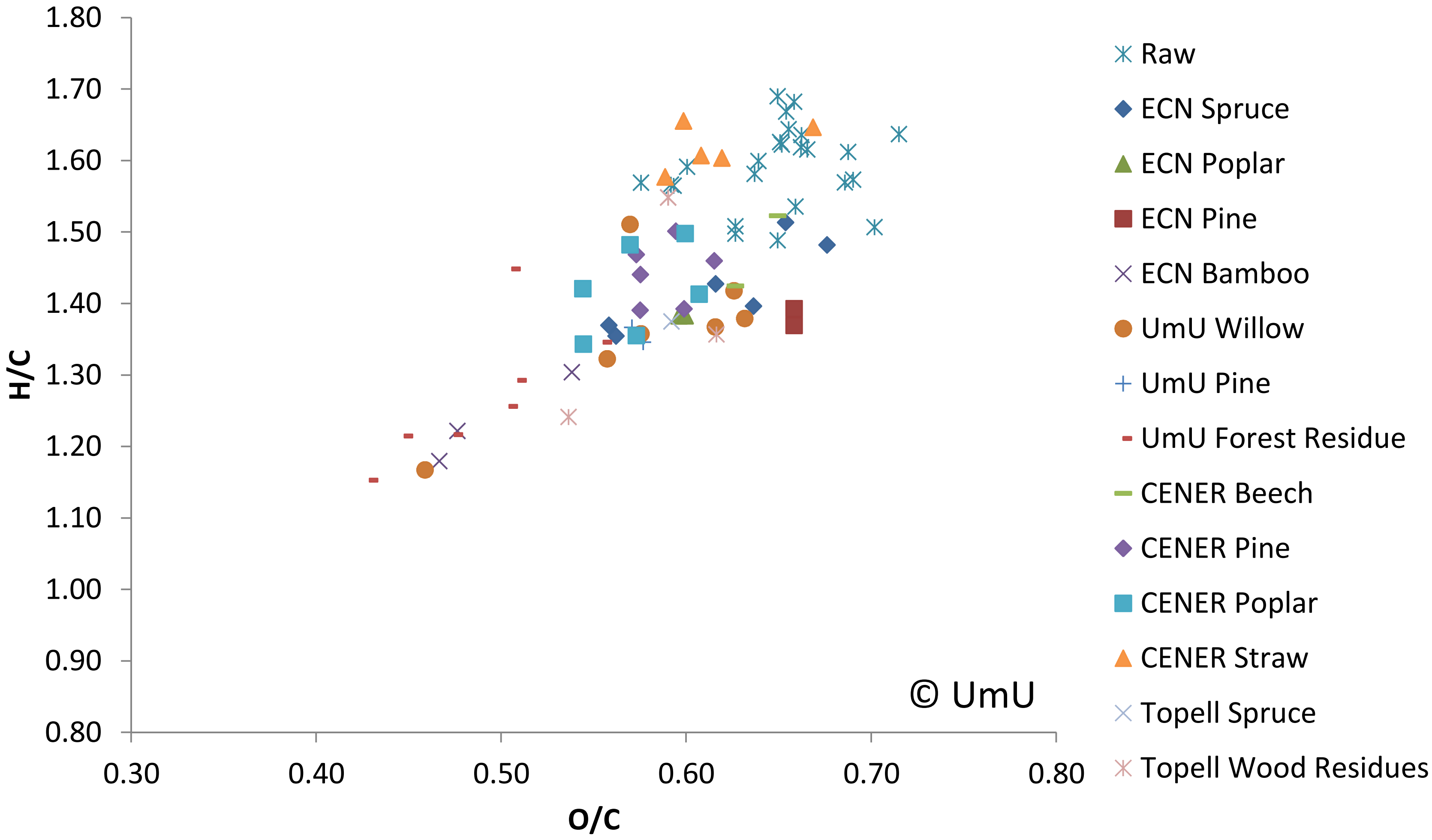
Feedstock and product analysis



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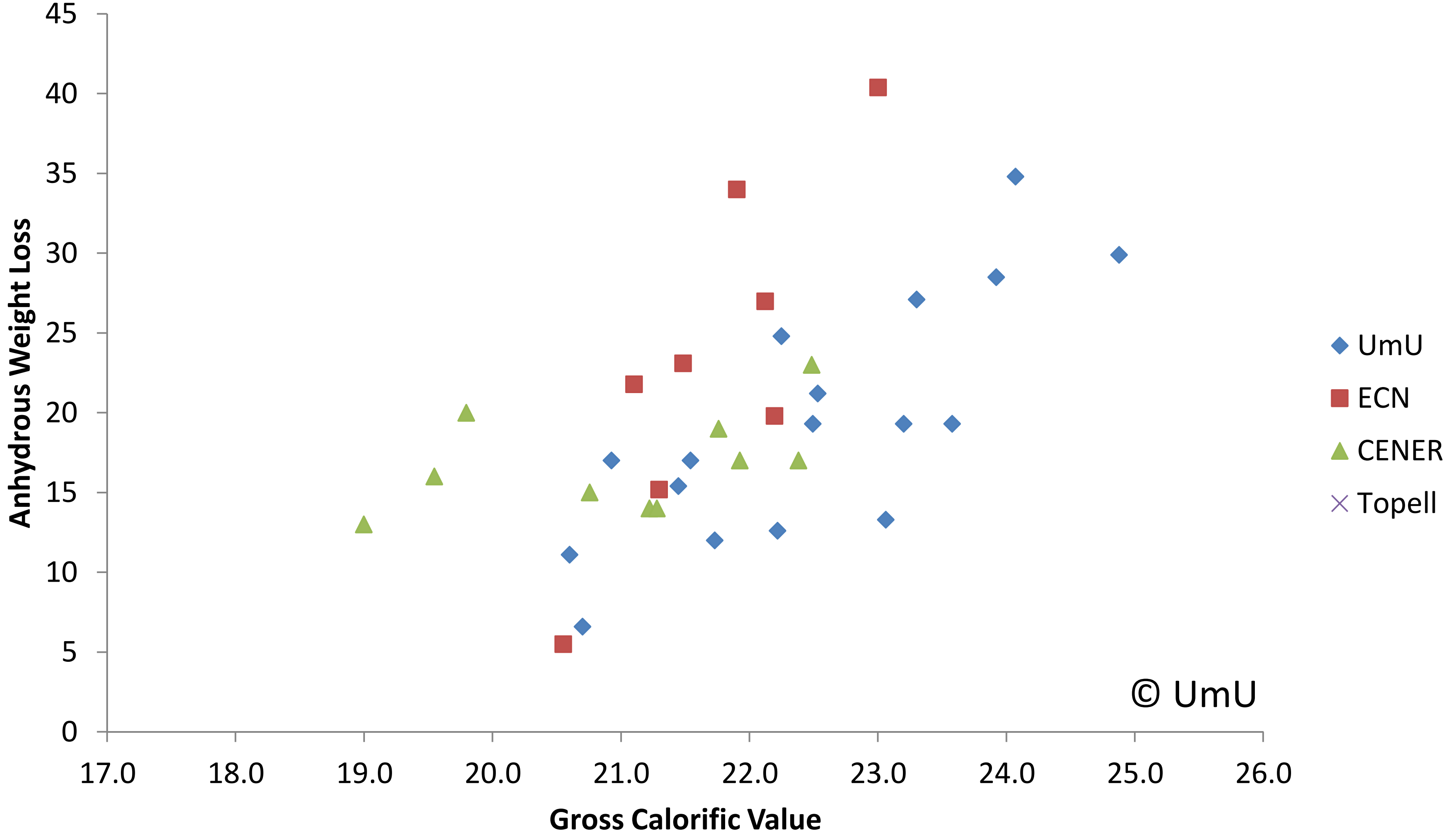
Feedstock and product analysis



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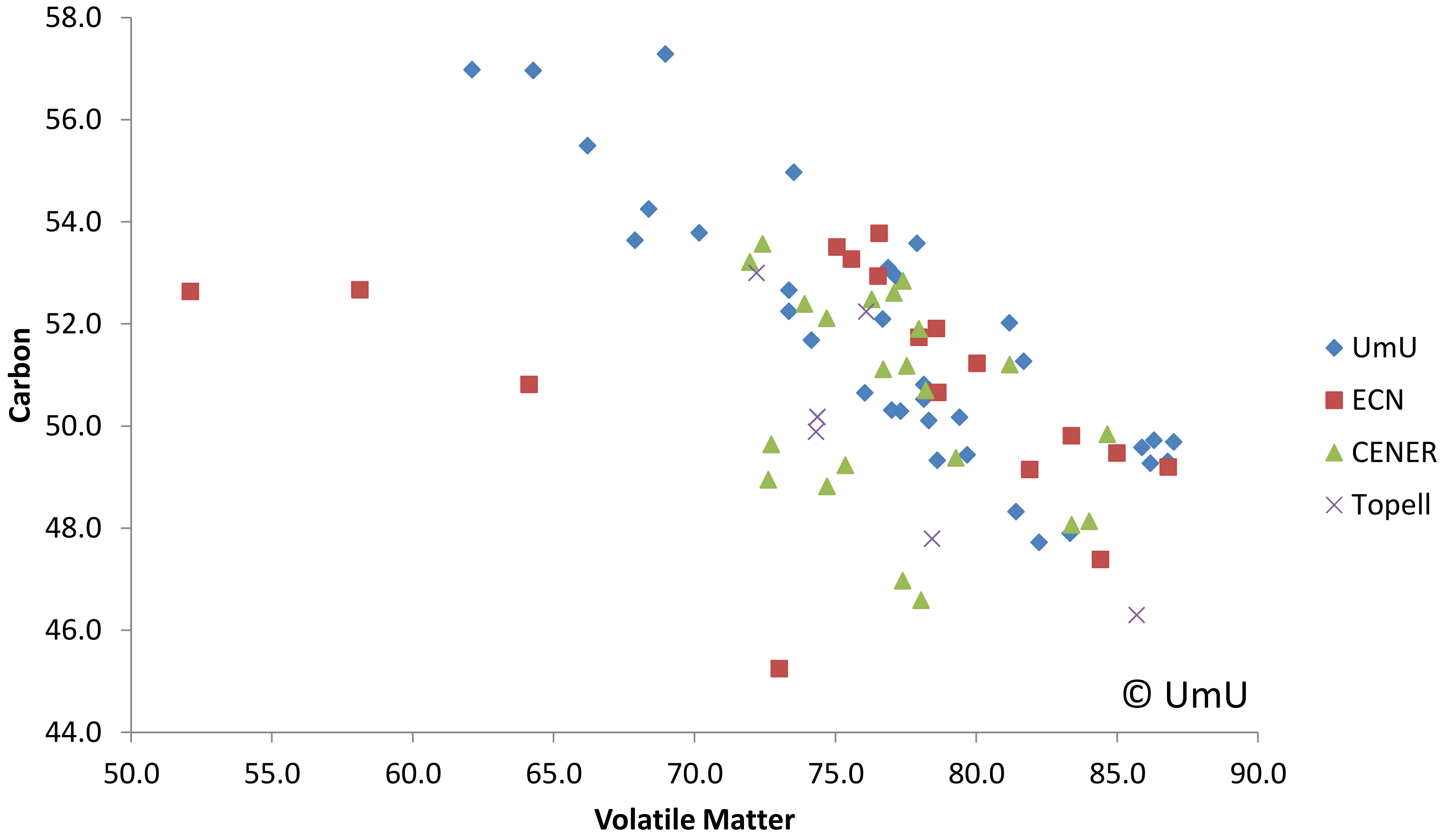
Feedstock and product analysis



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Torrefaction process optimisation/integration

- Harmonised mass and energy balances (with belt dryer) presented in flow sheets of ECN, Topell and CENER processes
- Three main integration options: Saw mill, CHP, P&P mill
- Black box mass and energy balance data for calculations about integrated torrefaction
- Both feedstock and energy integration was explored
- The energy production of integrated torrefaction plants was based on biomass use (no energy use of natural gas or oil based product)
- The main advantages of integrations:
  - front end: wood acquisition, logistics, wood handling and pretreatment
  - more efficient energy use compared to stand-alone plants
  - favorable power and heat prices
  - lower the production price of TOP-pellets (bigger boiler in integrated concepts, scaleup and efficiency benefits)

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Torrefaction process optimisation/integration

- Base Case: Stand-alone plant (50 MW_{th} torrefied wood pellets)
- Alternative 1:
  New sawmill and torrefaction integrated (158 MW_{th})
- Alternative 2:
  Existing sawmill and new torrefaction plant (72 MW_{th})
- Alternative 3:
  Existing CHP-plant (5 000 h/a) and new torrefaction plant (50 MW_{th})
- Alternative 4:
  Existing CHP-plant (3 500 h/a) and new torrefaction plant (50 MW_{th})
- Alternative 5:
  Existing pulp mill and new torrefaction plant (279 MW_{th})
- Alternative 6:
  Existing pulp and paper mill and new torrefaction plant (70 MW_{th})
- Alternative 7:
  Existing pulp and paper mill and new torrefaction plant (140 MW_{th})
- Alternative 8 & 9: Stand-alone plant in Nordic region and SE USA (343 MW_{th})

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Torrefaction process optimisation/integration

	Base Case	Alternative 1	Alternative 2	Alternative 5	Alternative 8	Alternative 9
Plant capacity, t torrefied pellets/a	72 800	231 600	101 100	407 200	500 000	500 000
Production costs of pellets, M€/a	19.3	48.8	24.3	82.5	104.2	87.6
Production costs of pellets, €/t	265	211	240	203	208	175
Production costs of pellets, €/MWh	43	34	38	33	34	29
Market price of wood pellets, €/MWh (PIX Pellet Nordic Index, 2012)	30	30	30	30	30	30
Price compared to base case, %	100	79	91	76	79	66
Price compared to market price, %	145	115	126	111	114	96

(orange)	Stand- alone plants
(blue)	Integrates

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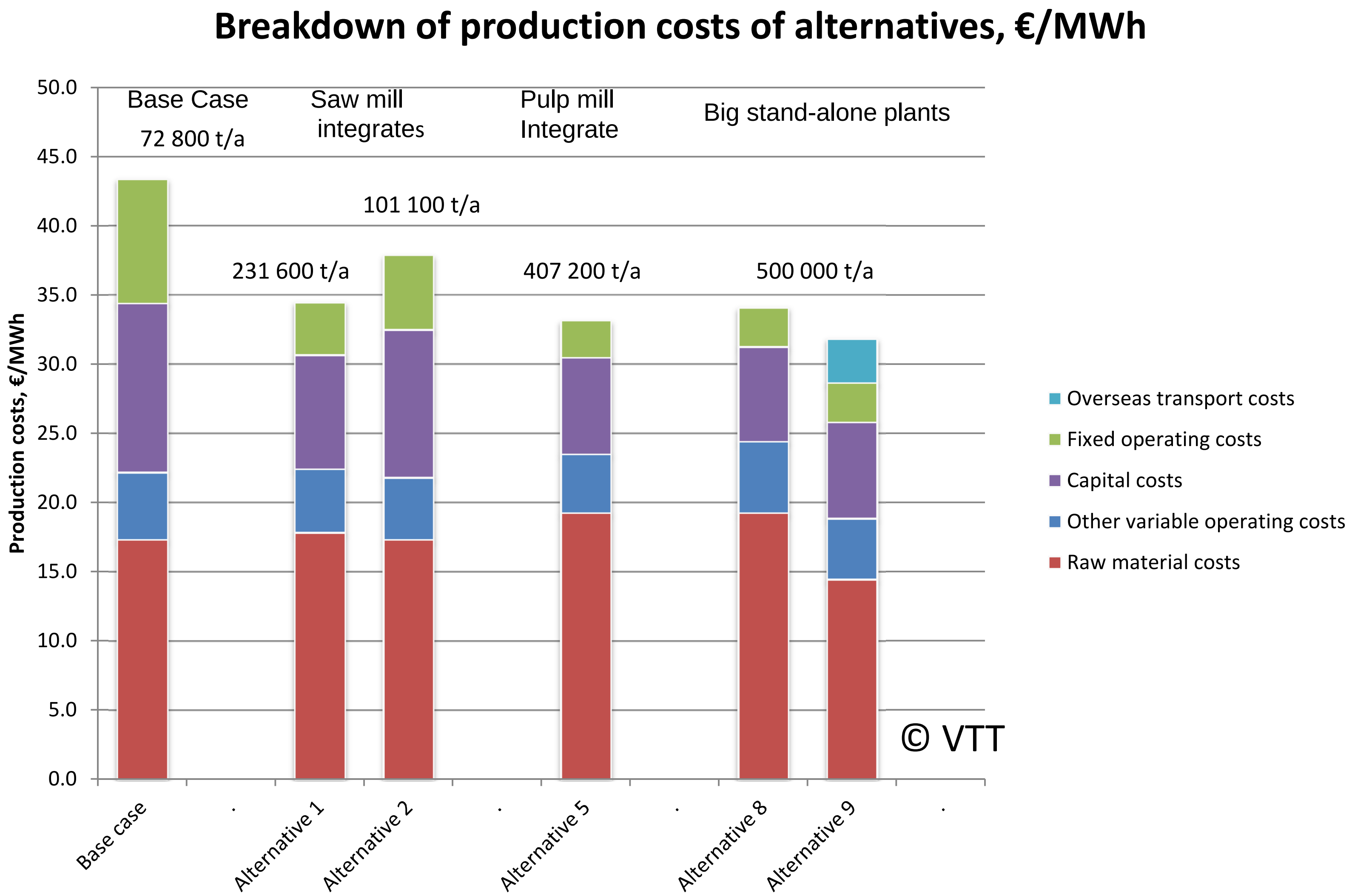
Torrefaction process optimisation/integration



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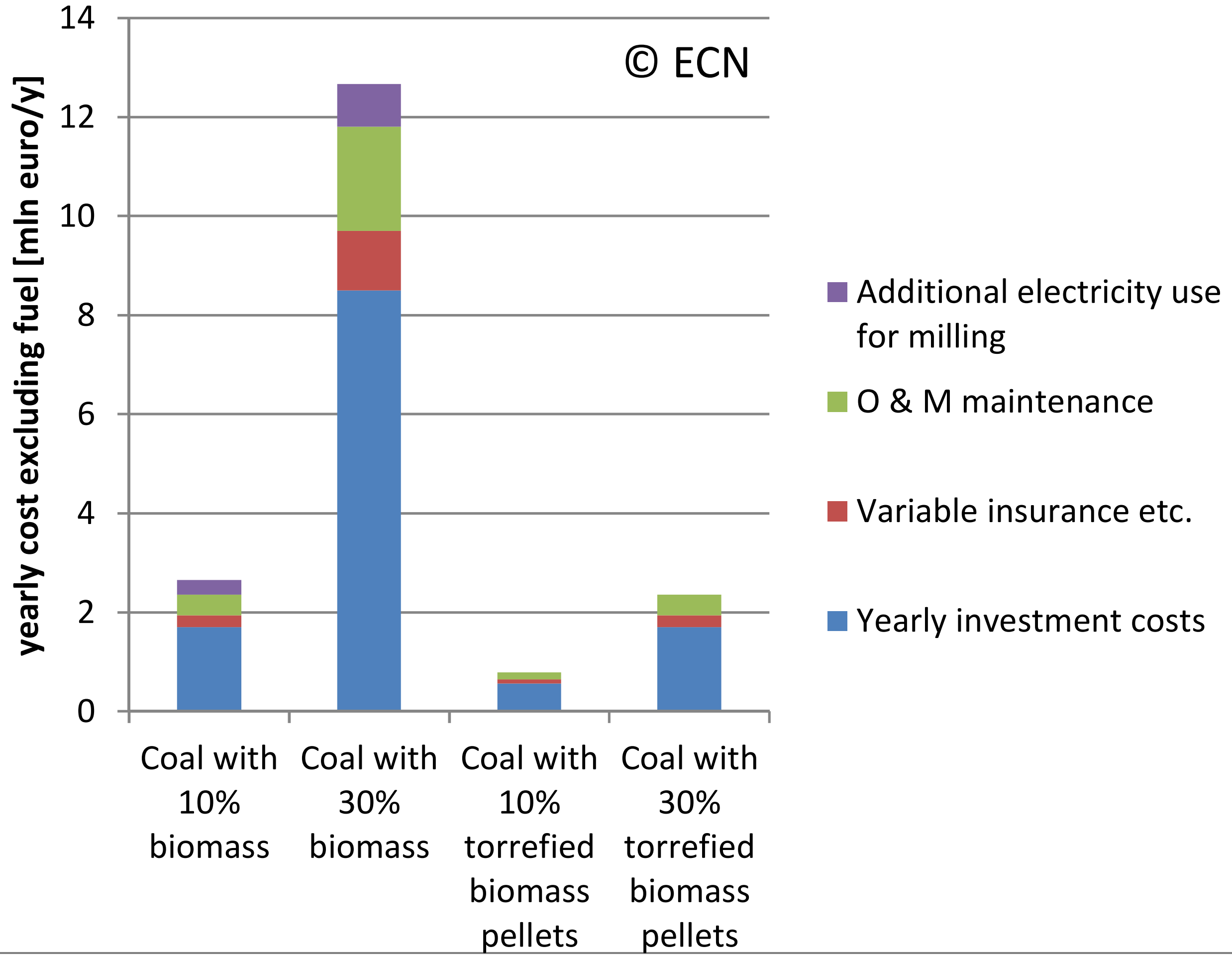
SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Torrefaction process optimisation/integration

- Purchasing power white wood vs. torrefied wood pellets



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Torrefaction process optimisation/integration

- Purchasing power white wood vs. torrefied wood pellets

		10% co-firing	30% co-firing
Cost difference between white wood and torrefied wood pellets	M€/y	1.86	10.31
Amount of biomass of pellets used	PJ	2.16	6.48
Price difference	**€/GJ**	**0.86**	**1.59**
Case 1: price difference at higher rate of return (12% → 15%)	€/GJ	1.08	2.02
Case 2: price difference at reduction of economic lifetime from 10 to 5 years	€/GJ	1.24	2.34

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Outlook

- A lot of experience gained within SECTOR
- Optimised recipes for integrated torrefaction and densification for mostly wood-based species
- Torrefied wood pellets can be a competitive alternative for white wood pellets
- Continue to broaden this experience for alternative feedstocks (agricultural residues, invasive species and other alternatives)
- Focus on upfront, in-situ or downstream removal of inorganic components

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