Process analysis of flexible gasification-based thermochemical conversion concepts of biogenic residues and wastes into biomethane and biochar

Konstantinos Atsonios, Panagiotis Tatoulis, Sanna Tuomi, and Panagiotis Grammelis

CERTH
CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

CPERI
Chemical Process and Energy Resources Institute

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FlexSNG in brief

- **"Flexible Production of Synthetic Natural Gas and Biochar via Gasification of Biomass and Waste Feedstocks"**
- Horizon 2020 Research and Innovation || 01/06/2021 – 31/12/2024 || EU funding: ~ 4.5 M€
- 12 partners from 8 countries (Finland, Greece, Italy, Denmark, Sweden, Germany, UK, Canada)

Main aim: to develop and validate (TRL5) a **flexible and cost-effective gasification-based process** for the production of **pipeline-quality biomethane**, **high-value biochar** and **renewable heat** from a wide variety of **low-quality biomass residues and biogenic waste feedstocks**.

FlexSNG in brief

Optimization of feedstock supply chains

Development of the gasification process

Optimized utilization of end-products & detailed case studies in Europe and Canada

Biomass, waste

Biomethane — Energy, transport sectors & industrial use

Biochar — Energy, soil amendment, activated carbon, etc.

Heat — District heating, industrial use

FlexSNG approach – ”one plant, two modes”

a) Maximization biomethane production mode

Biomass, waste

Biomethane

Heat

b) Co-production mode

Biomass

Biomethane

Biochar

Heat

- Switch between operation modes to adapt to market signals and feedstock availability and price
- Biochar can be used as co-feed to ”upgrade” more challenging feedstock as suitable feeds for gasification
- Makes possible to convert a much wider range of lower quality, low-cost biomass residues and biogenic waste feedstocks into added-value products in comparison to state-of-the-art gasification technologies

Scope and methodology of this study

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- To present new, gasification based pathways that handle biogenic residues and wastes such as bark and SRF for the production of biomethane, biochar and heat
- To perform the process analysis at system level and compare it with conventional gasification based pathways in terms of mass and energy yields

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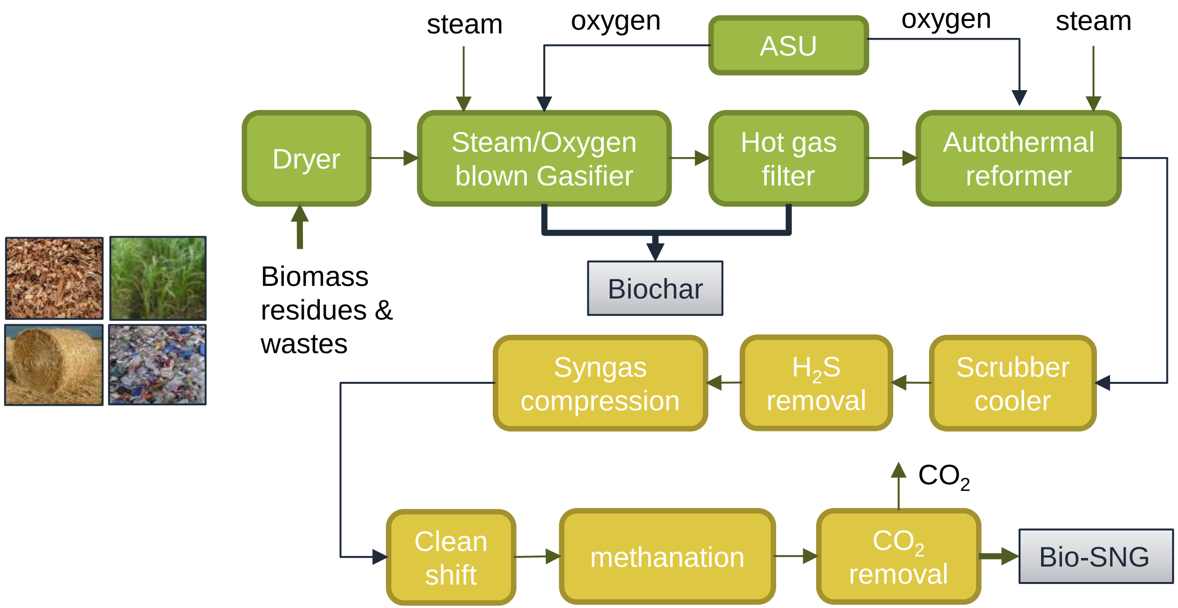
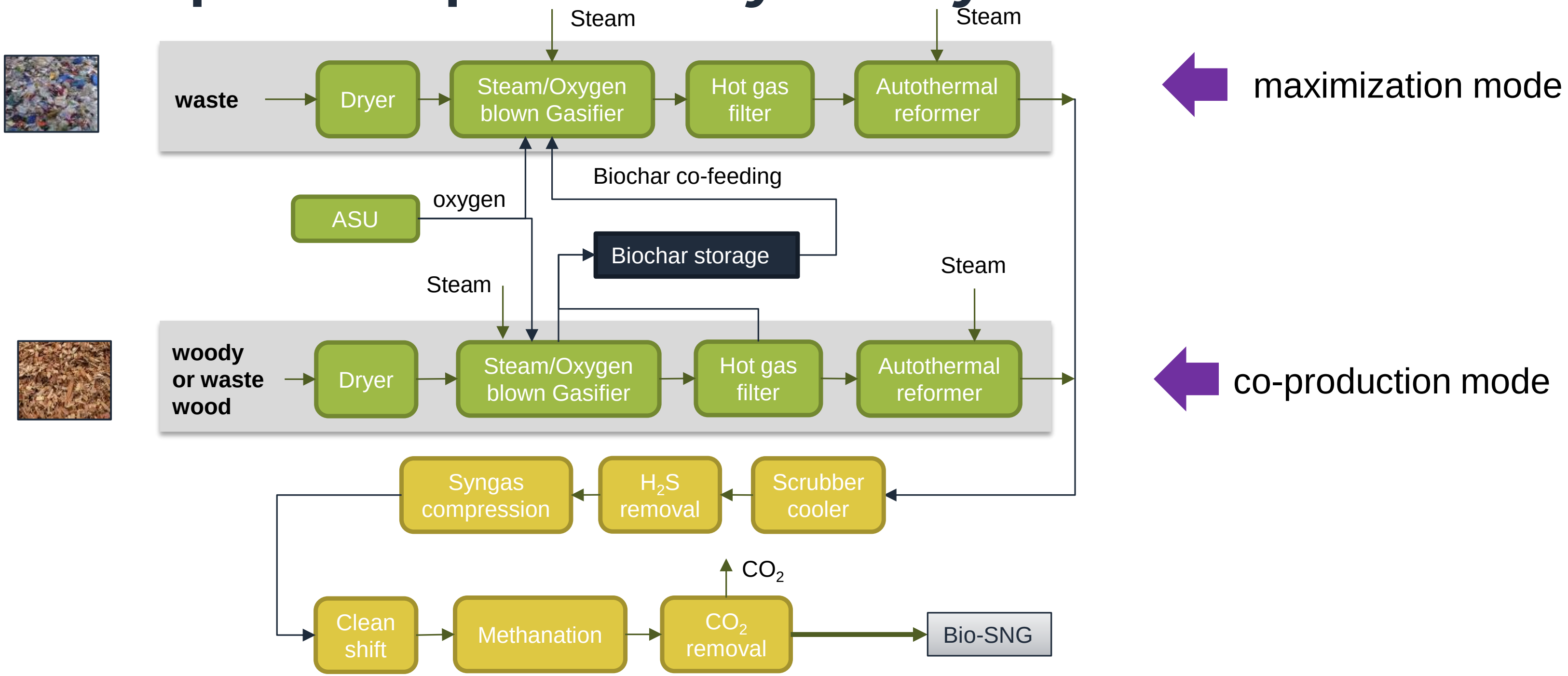
- Development of the integrated process models for the examined cases in Aspen Plus
- Perform the material and energy balance analysis

Concepts description – “Biorefinery”



- Biomass drying (belt dryer) where necessary
- Able to operate at both maximization and co-production mode
- H_2S removal via adsorbents
- CO_2 removal after methanation

Concepts description – "Cityrefinery"



- Two operation modes in parallel (2 separate gasifiers) or consecutively (in 1 gasifier)
- Biochar co-feeding with low grade feedstocks
- Common bio-SNG production section for both gasification lines
- Suitable for cases with low biomass availability or low grade feedstcock

Concepts description – "Hybrid"

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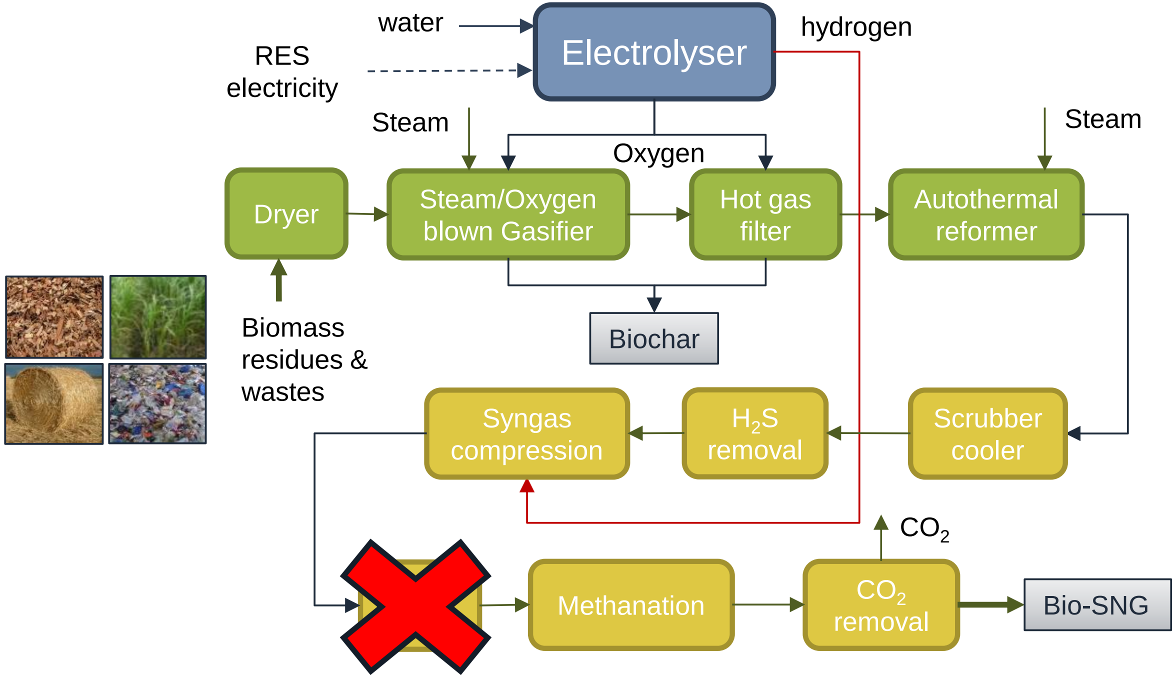
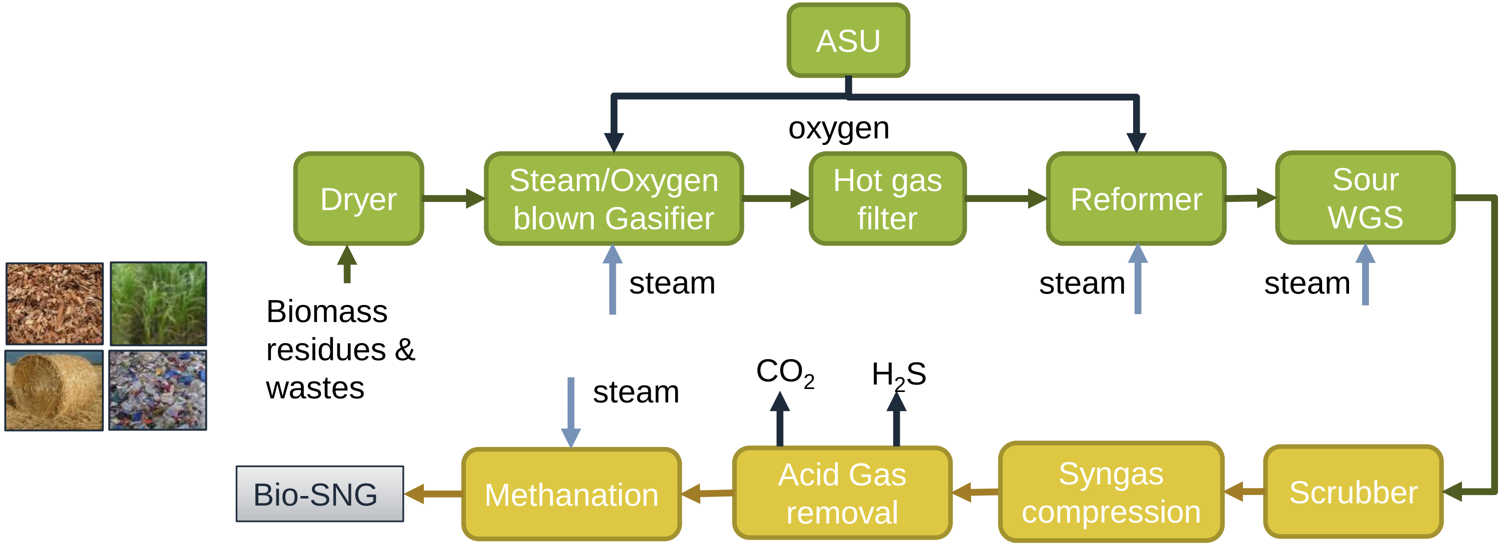


- Electrolytic H_2 to increase the H_2/CO ratio
- No clean shift is required prior methanation
- Able to operate at both maximization and co-production mode

Concepts description – Reference case



- Based on past VTT studies[1,2]
- Acid Gas removal: separate CO_2/H_2S separation via Rectisol process
- Methanation process: TREMP developed by Haldor –Topsoe

[1] Hannula dissertation 2015
[2] Hannula Biomass and Bioenergy 74 2015 26-46

Model description

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A. Gasifier and reformer

		BIOREFINERY			HYBRID		CITYREFINERY
		Max	Co-prod	Straw	Max	Co-prod	Max + Co-prod
Gasifier Temperature	°C	880	820	850	880	820	880
Gasifier Pressure	bara	1.5					
Gasifier Steam-to-oxygen ratio	kg/kg	1.2	1.5	1.3	1.2	1.5	1.2
Carbon conversion to gas+tars	%	98	90	93	98	90	98
Heat losses	%LHV	1.0	1.0	1.0	1.0	1.0	1.0
Filter Temperature	°C	600	600	550	600	600	550 + 600
Reformer Temperature	°C	870	870	900	870	870	920 + 870
Reformer Steam-to-oxygen ratio	kg/kg	0.8	0.8	0.8	0.8	0.8	1.2

- Equilibrium based model for main products prediction
- For the non-equilibrium conversions (H2S, HCl, HCN, COS, HCs), C, S, N distribution at fly/bottom ash, empirical information from the respective pilot runs during the project was considered

Model description

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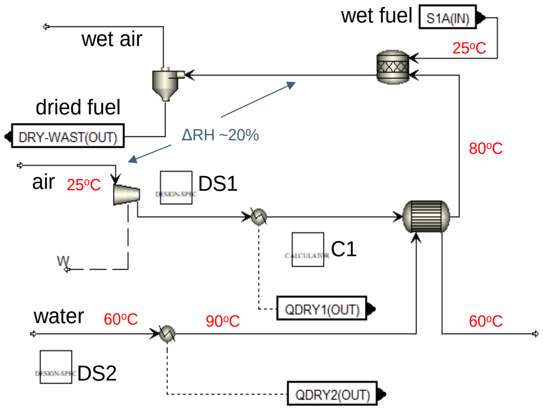
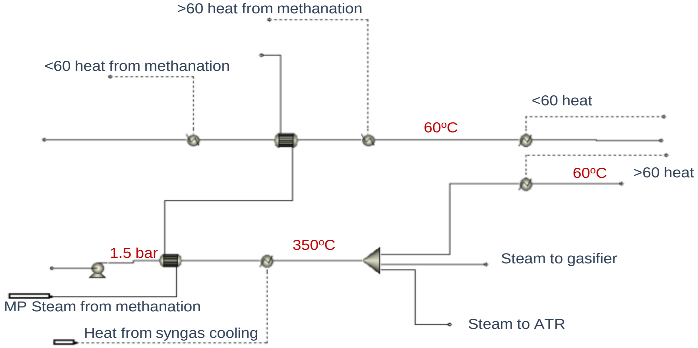
B. Dryer



C. Heat integration



- Similar to the reference case, (atmospheric belt dryer)
- hot water (90 °C in, 60 °C out) to heat the air
- dry the feedstock from 50 wt.% to 12 wt.%
- heat requirements: 1100 kWh/t of evaporated moisture
- power consumptions:115 kJ/kg of dry biomass

Excess heat for:

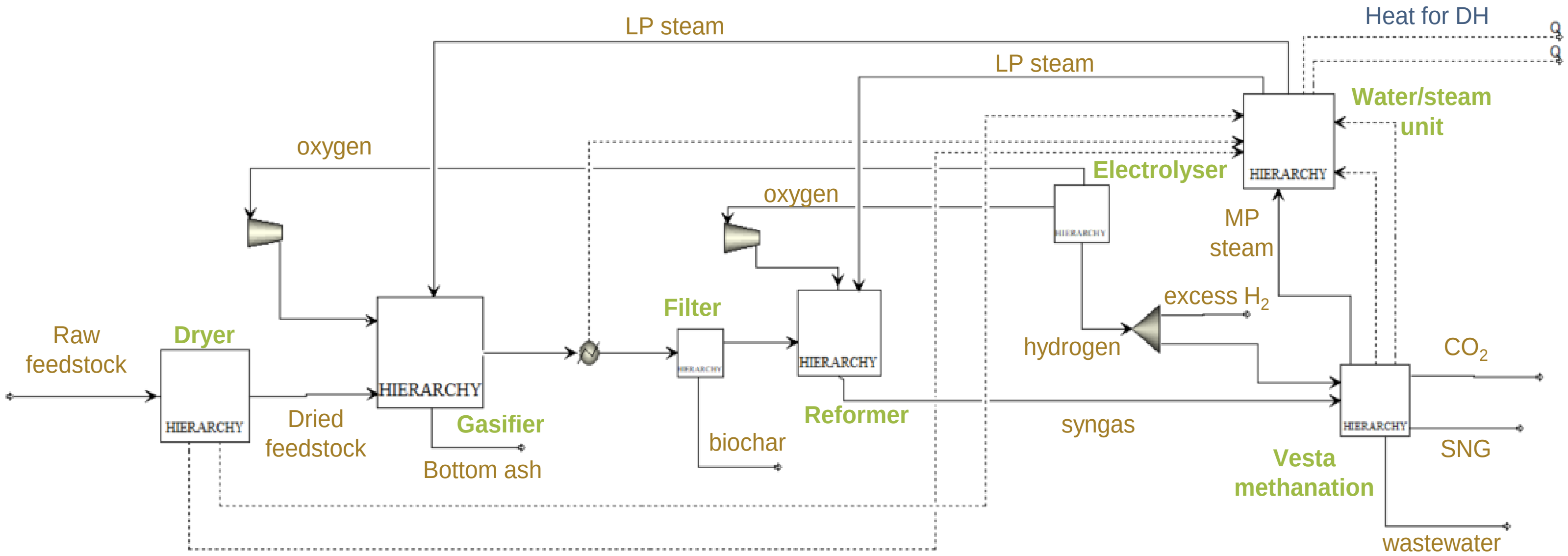
- Drying
- Steam production for gasifier and reformer
- >60 district heating
- <60 district heating

D. Syngas cleaning, conditioning & methanation

- Energy and mass balance data provided from the methanation technology provider

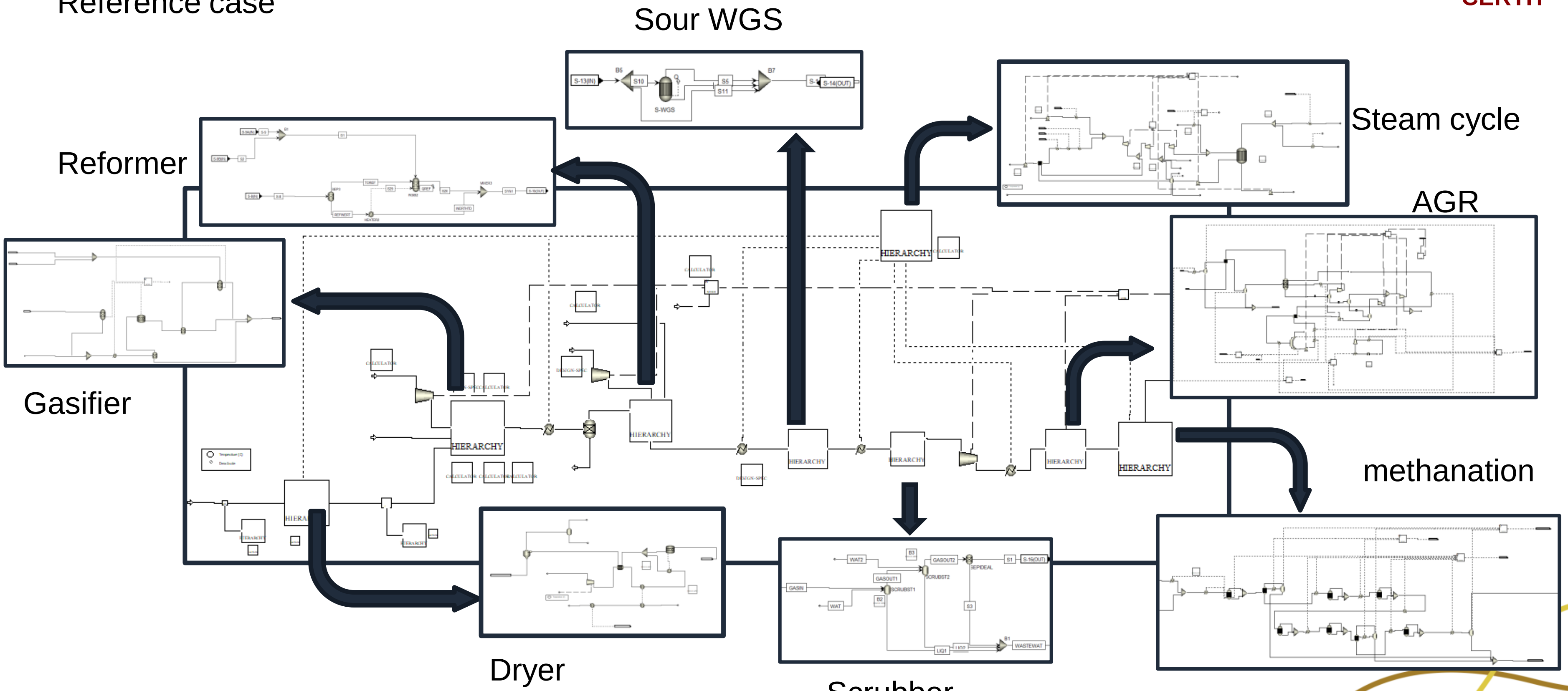
Model description

Process integration



Model description

Reference case



Case studies description

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Case	Feedstock	Thermal input (MW)	Concept	Gasification mode
Reference	Bark	100	Biorefinery	Maximization
1	Bark	100	Biorefinery	Maximization
2	Bark	100	Biorefinery	Co-production
3	Straw	100	Biorefinery	Max.
4	Bark+SRF	50+50	Cityrefinery	Co-prod. & Max.
5	Bark	100	Hybrid	Maximization
6	Bark	100	Hybrid	Co-production

Process simulations results

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1. Mass balance

CASE	Ref	1	2	3	4		5	6
					line 1	line 2		
inlet streams (kg/s)								
wet biomass	11.63	11.63	11.63	11.84	5.82	3.17	11.63	11.63
dried biomass	6.84	6.61	6.61	6.58	3.31	2.70	6.61	6.61
steam for gasifier	1.90	2.48	2.66	2.46	1.33	1.35	2.48	2.66
O_2 for gasifier	1.90	2.07	1.78	1.89	0.89	1.12	2.07	1.78
steam for ATR	1.24	0.65	0.68	0.69	0.12	0.58	0.65	0.68
O_2 for ATR	1.24	0.81	0.85	0.87	0.19	0.49	0.81	0.85
steam for methanation	0.10	0	0	0	0		0	0
cooling water	914.40	261.10	280.56	175.00	313.89		300.00	291.67
outlet steams (kg/s)								
CO_2 stream	6.82	7.2	6.57	6.32	6.31		5.11	4.97
ash	0.24	0.3	0.14	0.67	0.60		0.33	0.14
SNG	1.31	1.4	1.29	1.14	1.27		2.11	1.87
biochar	0.00	0.00	0.39	0.00	-0.19		0.00	0.39
wastewater	68.64	264.9	284.74	179.45	318.14		305.48	297.16

increased steam for gasification

low steam & O_2 for reforming

$y_{SNG, case1} > y_{SNG, ref}$ because of improved ATR performance

$y_{SNG, case1} > y_{SNG, case 4}$ because of better feedstock characteristics

Process simulations results

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2. Energy balance

CASE		Ref.	1	2	3	4	5	6
Heat streams								
Biomass to dryer (LHV)	MW_{th}	100.2	100.0	100.0	100.9	100.2	100.0	100.0
Dried biomass to gasifier	MW_{th}	111.4	111.6	111.6	100.9	111.5	111.6	111.6
Moisture inlet/outlet	%	50/15	50/12	50/12	10	50, 25/12	50/12	50/12
Dryer heat demands	MW_{th}	19.00	19.91	19.91	0	11.58	19.91	19.91
Syngas after reformer	MW_{th}	80.36	84.39	77.87	76.10	38.94	84.37	77.87
SNG heat input (LHV)	MW_{th}	62.78	67.11	62.30	61.18	60.67	103.05	90.92
Biochar heat input (LHV)	MW_{th}	0	0	9.45	0	-4.60	0	9.45
District heat	MW_{th}	7.26	7.65	6.29	14.09	5.46	13.79	13.03
Waste heat	MW_{th}	38.40	38.44	35.60	40.95	33.26	7.57	6.65
On-site electricity consumption								
Dryer	MW_e	0.78	0.81	0.81	0.00	0.47	0.81	0.81
O_2 production	MW_e	2.97	2.73	2.48	2.61	2.77	66.69	60.77
O_2 compression	MW_e	0.56	0.12	0.11	0.11	0.12	0.14	0.11
Syngas compression	MW_e	2.88	7.21	6.99	6.82	6.82	11.64	10.40
Acid Gas Removal	MW_e	3.62	0	0	0	0	0	0
Electricity production	MW_e	8.45	0	0	0	0	0	0
Net electricity	MW_e	-2.36	-10.87	-10.40	-9.54	-10.18	-79.29	-72.09

Process simulations results

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2. Energy balance

- Drying is a heat demanding processing (20% of LHV) where is necessary
- No improvement on gasification efficiency is observed. Considerable improvements at catalytic reformer
- Although straw enters the gasifier with less moisture content (CASE 3), the syngas yield is lower than that from the woody biomass (CASE1)
- Case 2 and Case 6, which are the cases that biochar is considered among the products, present the lowest waste heat
- Comparing Case 1 and Case 4 as the two ways for maximizing SNG production without the assistance of the electrolytic hydrogen, Case 1 (Biorefinery) configuration leads to a higher biomethane synthesis than Cityrefinery because of the better gasification performance, owed to the better feedstock type

Process simulations results

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3. Basic performance indicators

CASE	Ref.	1	2	3	4	5	6	
Plant heat input (MW_{th})	100.2	100.0	100.0	100.9	100.2	100.0	100.0	
Gasifier heat input (MW_{th})	111.4	111.6	111.6	100.9	111.5	111.6	111.6	
Total oxygen demand (kg/MWh)	101.59	92.88	84.64	98.35	94.38	92.90	84.65	lower O_2 demands and ASU consumptions
ASU consumptions (MW_e/MW_{th})	0.0267	0.0244	0.0223	0.0259	0.0248	-	-	
Total steam demand (kg/MWh)	101.59	101.00	107.82	112.4	116.4	101.02	107.83	
CGE after filter	82.8%	82.6%	76.7%	85.2%	76.2%	82.6%	76.7%	Similar gasifier performance
CGE after reformer	72.2%	75.6%	69.8%	75.5%	68.3%	75.6%	69.8%	Improved ATR performance
H_2/CO ratio after reformer	1.34	1.43	1.61	1.6	1.6	1.44	1.61	
Total electricity consumption (kWh_e/kWh of biofuels)	0.172	0.162	0.145	0.156	0.156	0.769	0.718	Lower specific el. demands
Conversion efficiency to bioSNG	56.4%	60.1%	55.8%	60.6%	54.4%	66.5%	62.2%	Improved bioSNG yield
Conversion efficiency to biomethane, biochar and heat	69.4%	67.0%	70.0%	74.6%	63.6%	65.5%	71.3%	Highest for straw (no dryer)
Total carbon utilization	31.8%	33.5%	41.0%	30.4%	43.3%	51.5%	55.3%	Better C utilization

Conclusions and outlook

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- Process simulation study of new process configuration concepts for the production of biomethane, biochar and heat
- The proposed advancements in the biomass conversion into biomethane and biochar can achieve higher bioSNG yields and lower oxygen demands compared to a conventional gasification based pathway, mainly owed to the improved performance of the catalytic ATR.
- High conversion efficiency and good performance are also observed when more challenging feedstock are used such as SRF and straw.
- The co-production mode is a promising approach to produce bio-SNG and biochar with quite high overall efficiencies.
- The hybrid concept can reach up to 70% overall efficiency and >50% total carbon utilization. The electricity demands for H_2 production are very high and comparable to the respective feedstock heat input (0.67 $kW_e/kW_{th,\ feed}$)

Thank you!

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www.flexsng.eu

info@flexsng.eu

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