Welcome to BIORECAST / H2STEEL Online Joint Webinar “Defossilizing the Steel Sector„

JOINT ONLINE BIORECAST / H2STEEL WEBINAR "DEFOSSILIZING THE STEEL SECTOR”

18 June, 2025
Microsoft Teams

10:00 - 11:30

Co-funded by the European Union

H2Steel project Funded by the European Union under grant agreement 101070741. BioRECAST project has received funding from the European Union’s funding programme “The Research Fund for Coal and Steel” under grant agreement No 101112601. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Innovation Council. Neither the European Union nor the granting authority can be held responsible for them.

Register here!

Webinar Agenda

10:00 – 10:10

- **Welcome and introduction**

Dr. Rainer Janssen, WIP Renewable Energies, Germany

10:10 – 10:20

- **Hard to abate? Renewable Carbon and Hydrogen to defossilize the steel sector**

Prof. David Chiaramonti, Politecnico di Torino, Italy

10:20 – 10:35

- **BIORECAST: How the integration of a slow pyrolysis plant into the EAF can defossilize the metalluergy sector**

Prof. David Chiaramonti, Politecnico di Torino, Italy

10:35 – 10:50

- **H2Steel: Production of green hydrogen and biogenic carbon for the European steel sector**

Eng. Viviana Negro, Politecnico di Torino, Italy

10:50 – 11:10

- **Challenges in biocarbon production and usage in metallurgical industries**

Prof. Kentaro Umeki, Luleå University of Technology, Sweden, IEA Bioenergy Task 33: Gasification of Biogenic and Waste Feedstocks for a Sustainable Future

11:10 – 11:30

- **Q/A and Conclusions**

Webinar House Rules

- 🔴 The webinar will be recorded. If you do not wish to appear in the recording, please turn off your camera.
- 🎤 Please remain muted during the presentations to avoid background noise.
  After each presentation (unless delayed), the moderator will invite questions.
- ✋ To ask a question:
  Use the "Raise Hand" function.
  Wait until the moderator calls your name, then unmute to speak.
- 💬 You may also post your questions in the chat at any time. These will be addressed during the final Q&A session.
- 📅 The agenda will guide the flow — please be mindful of time and keep questions concise.

🙏 Thank you for your cooperation and enjoy the session!

Biochar and steel

Biochar perspectives as renewable substitute to defossilize steel making

David Chiaramonti

RE-CORD

Politecnico di Torino 1859

F4F

Fit4Foresight - Fuel

Opportunities for large scale deployment of biochar/biocoal in energy industries and agri

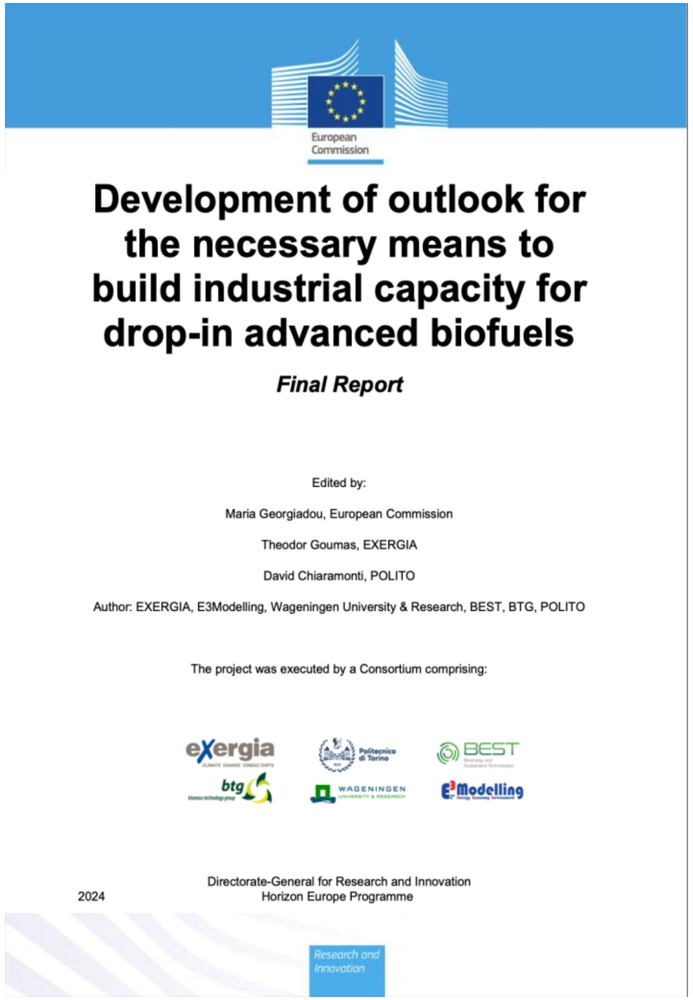
- **Steel**
- **Cement**
- **Farming (AD)**
- **Biofuels (road, aviation, maritime)**

H2Steel Bio RECAST Bio4A TULIPS

Remarks

- **Voluntary vs Mandatory Carbon markets**
- **EU legislations in force vs legislation under development.**
  - ✓ ***REDII-IR/REDII and EU ETS (Steel and Cement) in force. EU ETS: steel and cement the only cases of obligated market relevant for biochar***

The EU Dimension
Biomass is available


European Commission

Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels

Final Report

Edited by:

Maria Georgiadou, European Commission

Theodor Goumas, EXERGIA

David Chiaramonti, POLITO

Author: EXERGIA, E3Modelling, Wageningen University & Research, BEST, BTG, POLITO

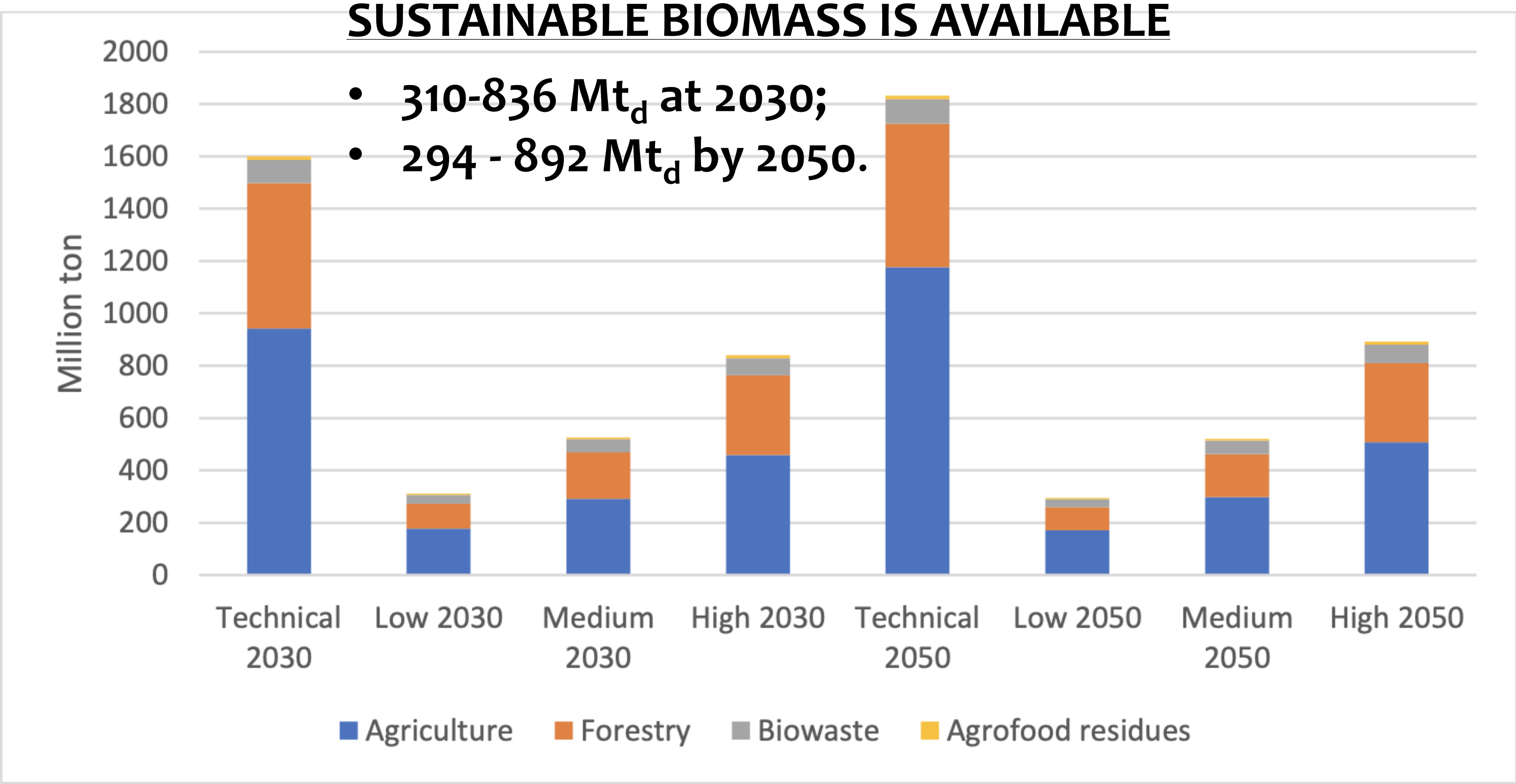
The project was executed by a Consortium comprising:

2024

Directorate-General for Research and Innovation
Horizon Europe Programme

Research and Innovation

Figure 3 Annex IX/A, B biomass potential in technical, low, medium, and high potentials in 2030 and 2050 and distribution over sectors delivering biomass



SUSTAINABLE BIOMASS IS AVAILABLE

- 310-836 Mt_d at 2030;
- 294 - 892 Mt_d by 2050.

1ST CHALLENGE: DEFOSSILIZING STEEL

126 Mt/y
EU 27 crude steel production[1]

56 Mt/y
fossil coal consumed[2]

183 Mt/y of CO_2 emitted[2]

(5% of EU GHG Emissions)

EU ETS regulation – "Polluters pay" principle

Source:elaborated from A.Salimbeni, 2025

EU COUNTRIES IN DESCENDING ORDER OF CRUDE STEEL PRODUCTION — TABLE ▪ 2023

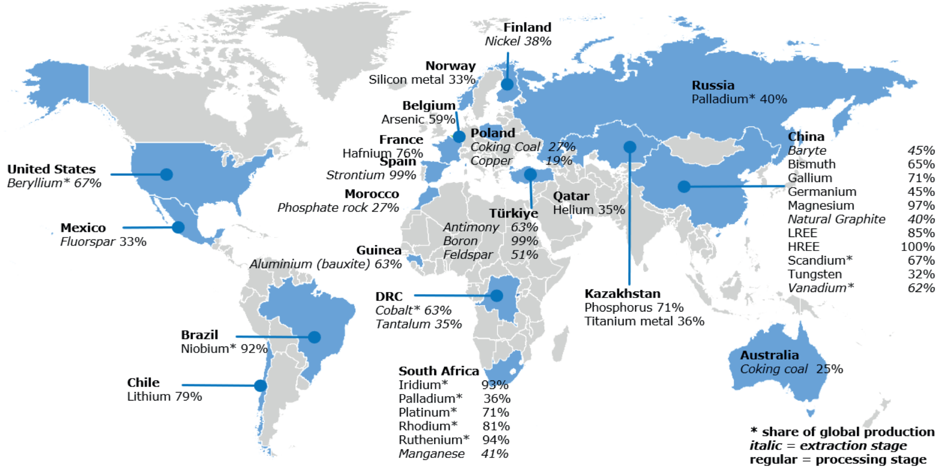
SOURCE: EUROFER

		2023	% shares 2023
1	GERMANY	35,438	28.1%
2	ITALY	21,055	16.7%
3	SPAIN	11,352	9.0%
4	FRANCE	10,011	7.9%
5	AUSTRIA	7,133	5.7%
6	POLAND	6,428	5.1%
7	BELGIUM	5,864	4.6%
8	NETHERLANDS	4,676	3.7%
9	SLOVAKIA	4,377	3.5%
10	SWEDEN	4,235	3.4%
11	FINLAND	3,811	3.0%
12	CZECH PUBLIC	3,369	2.7%
13	OTHERS	2,040	1.6%
14	LUXEMBOURG	1,900	1.5%
15	ROMANIA	1,622	1.3%
16	GREECE	1,181	0.9%
17	SLOVENIA	549	0.4%
18	BULGARIA	489	0.4%
19	HUNGARY	477	0.4%
20	CROATIA	212	0.2%
	TOTAL	**126,219**	**100%**

[1]EUROFER Statistical Report, 2024 (2023 figures)

[2]EU JRC Technical report – Greenhouse gas intensities of the EU steel industry and its trading partners, 2022 (2020 figures)

2ND CHALLENGE: CIRCULARITY & WASTE RECYCLING



Source: "European Commission, Study on the Critical Raw Materials for the EU 2023– Final Report"

EU Critical Raw Materials Act

at least 15% of the EU's annual consumption for recycling

Sludge
11 Mil dt/y

OFMSW
40 Mil dry t/y

Source: A.Salimbeni, 2025

Biochar & Steel (EU ETS)

Hints on PoliTO/RE-CORD R&D projects

✓BIORECAST

Coord PoliTO

✓H2STEEL

Coord PoliTO

✓H2LOOP

(starting June 2025)

1	VDEH-BETRIEBSFORSCHUNGSINSTITUT GMBH	DE
2	ROUGE H2 ENGINEERING AG	Austria
3	ACCIAIERIE D ITALIA SPA	IT
4	POLITECNICO DI TORINO	IT

✓THELMA

Coord PoliTO

(starting November 2025)

1	POLITECNICO DI TORINO	IT
2	CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE	IT
3	ArcelorMittal Hamburg	DE
4	ARCELORMITTAL MAIZIERES RESEARCH	FR
5	FERALPI SIDERURGICA SPA	Italy
6	TALLERES FELIPE VERDES SA	ES
7	MM SPA	IT

→ .... **National project and research contracts not listed here...**

https://www.cleanenergyministerial.org/

The Clean Energy Ministerial (CEM) is a high-level global forum to promote policies and programmes that advance clean energy technology, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. Initiatives are based on areas of common interest among participating governments and other stakeholders.

https://biofutureplatform.org/

Strategic goals of the CEM Biofuture Platform Initiative are to

1. Foster consensus on biomass sustainability, availability, and governance
2. Promote policy best practices and convergence
3. Enable supportive financing mechanisms
4. Promote cooperation on policy, regulations, and technologies

Reports, Papers, and Databases

Country Profiles

Dissemination Materials

Statements and Recommendations

Principles

Governance Frameworks

Thanks for your attention

David Chiaramonti

Politecnico di Torino

david.chiaramonti@polito.it

Bio RECAST

How the integration of a slow pyrolysis can defossilize the metallurgy sector

BIORECAST

BIObased REsidues Conversion to Advanced fuels for sustainable STeel production

Professor **David Chiaramonti**

Assistan Professor Viviana Negro

Politecnico di Torino

18/06/2025, IEA Webinar "Defossilizing the Steel Sector"

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BioRECAST - *OVERVIEW*

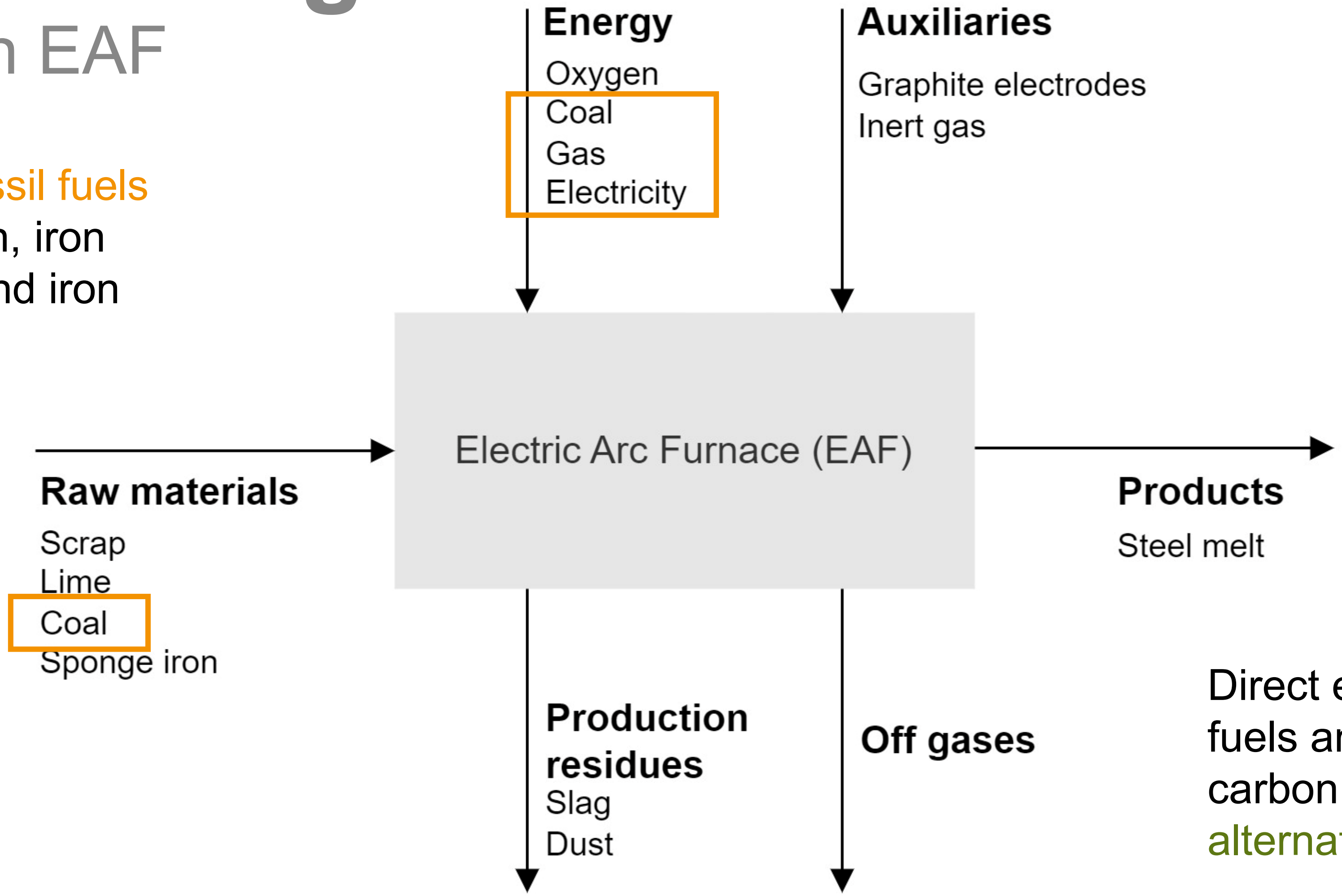
- **Project name**: BIO-based Residues Conversion to Advanced fuels for sustainable STeel production
- **Project acronym**: BIORECAST
- **Project coordinator**: Politecnico di Torino
- **Call**: RFCS-2022
- **42-month project**, KoM in November 2023
- **2.362.962,00 €** European funding

Project partners

WIP Renewable Energies · Politecnico di Torino · Politecnico Milano 1863 – Dipartimento di Meccanica · RE-CORD · Acciaierie di Calvisano · HTT · Sidenor · RINA

Steelmaking
Focus on EAF

Massive use of fossil fuels for heat generation, iron oxide reduction, and iron carburization.



Direct emissions from fossil fuels and indirect from grid's carbon footprint. Need for alternatives!

BioRECAST
Project framework

Main objective: foster the consumption of biowaste streams as renewable carbon and energy source for steel sector and, at the same time, to valorize the waste heat of EAF steelmaking.

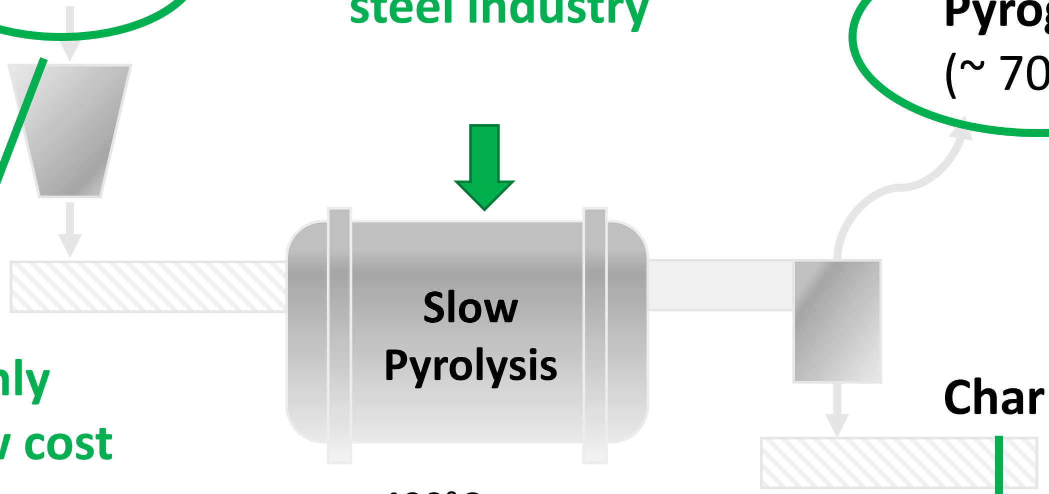
BioRECAST

Biomass

< 25-30% moisture content

Utilization of **highly available** and **low cost** biowaste streams

Waste heat from steel industry



>400°C;
20 °C/min;
~2h

Pyrogas (~ 70% w)

Condensable HC

Incondensable gases (CO, CO_2, CH_4, H_2)

Possibility to utilize it for:

- Direct combustion through innovative burners
- Source of renewable electricity and heat

Char (25-35%w)

Chemical leaching

Biocoal for steel industry

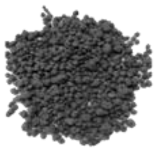
Valorization of **inorganic compounds** (Ca, P, N, Mg, K)

BioRECAST

Project framework

Urban biowaste
Organic fraction MSW
Green waste

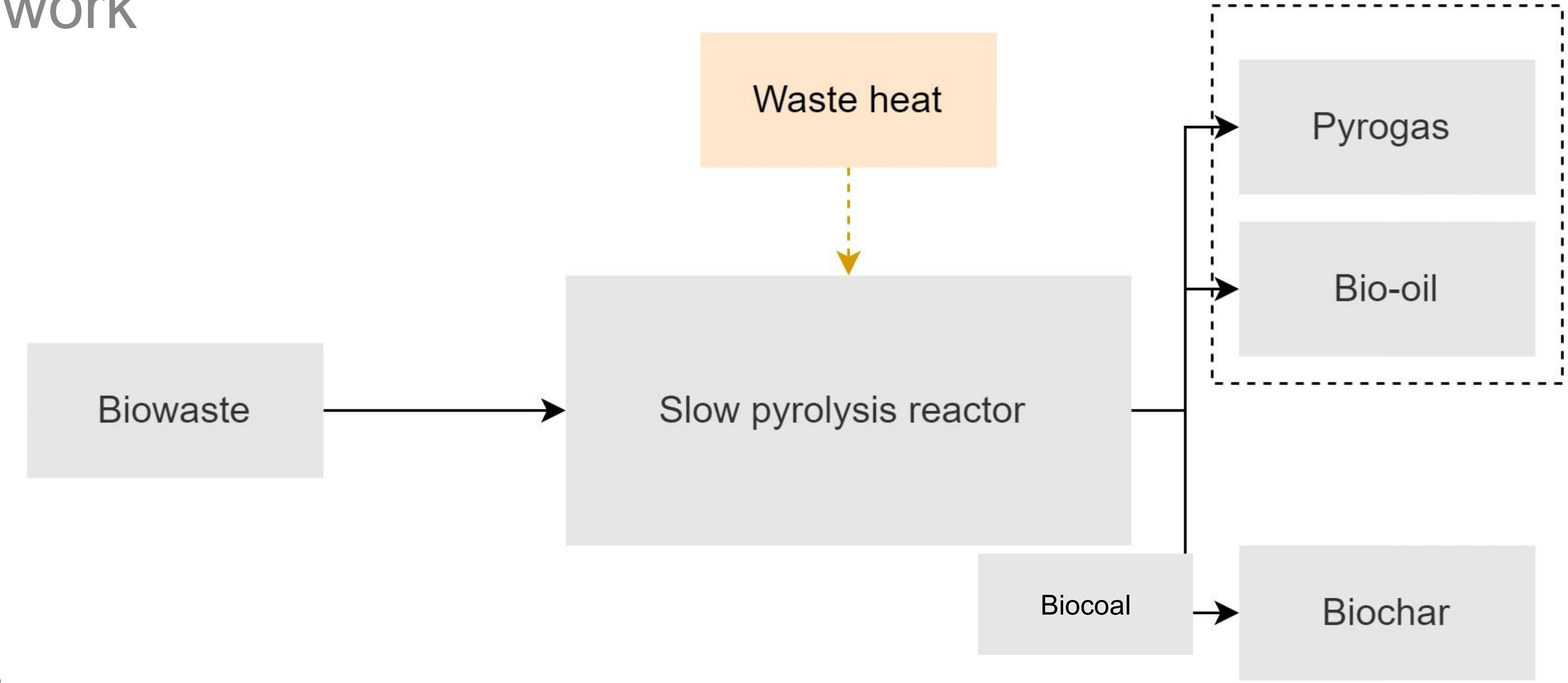
Industrial sludge
Pulper sludge
Food waste sludge



Sewage sludge
Digested sludge
Aerobic stabilized

Agricultural residues
Lignocellulosic residues
Digestate

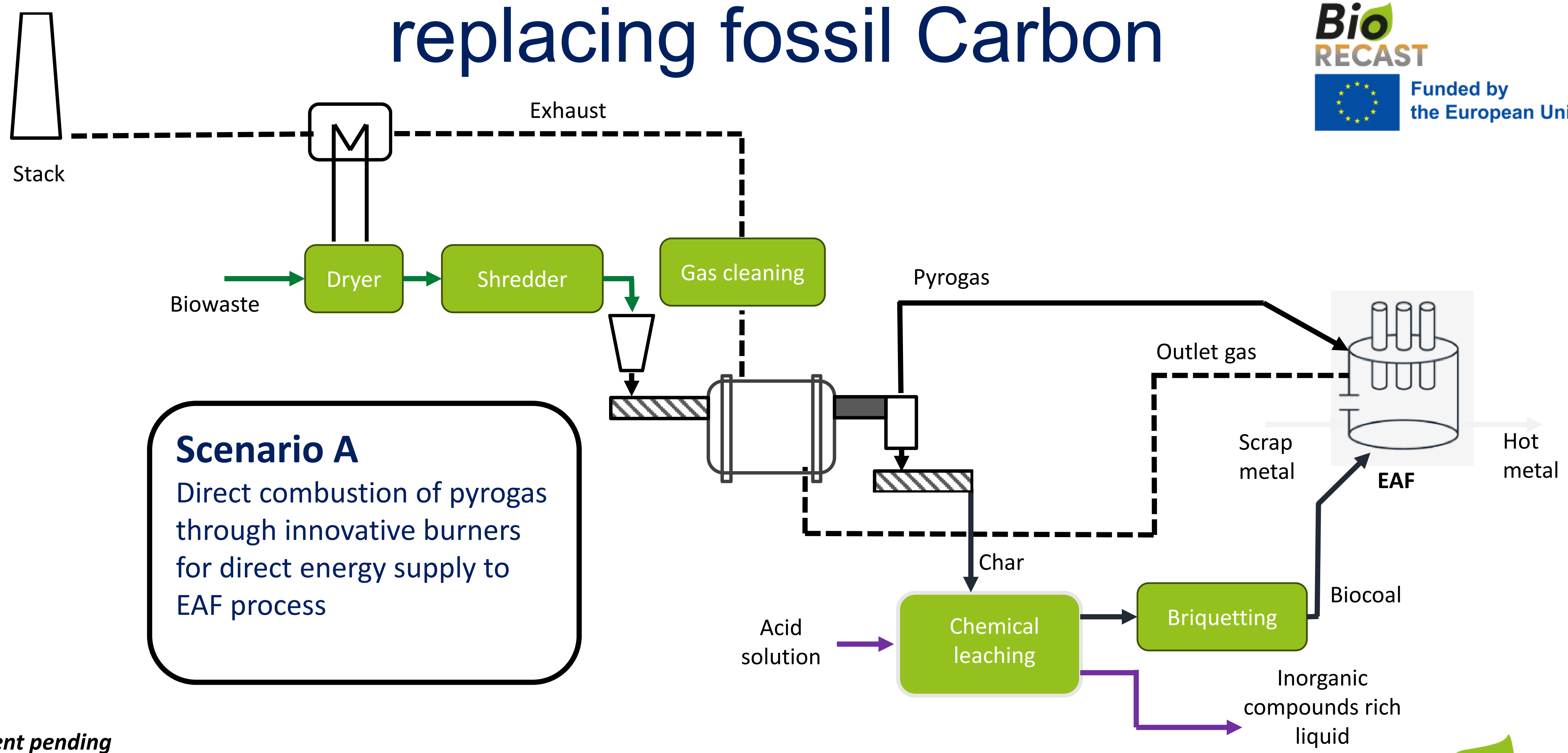
Gaseous phase
Possible source of
renewable energy



Solid phase
Possible source of
bio-based carbon and
valuable by-products.

BIORECAST - Biogenic/Waste Carbon replacing fossil Carbon

Funded by the European Union



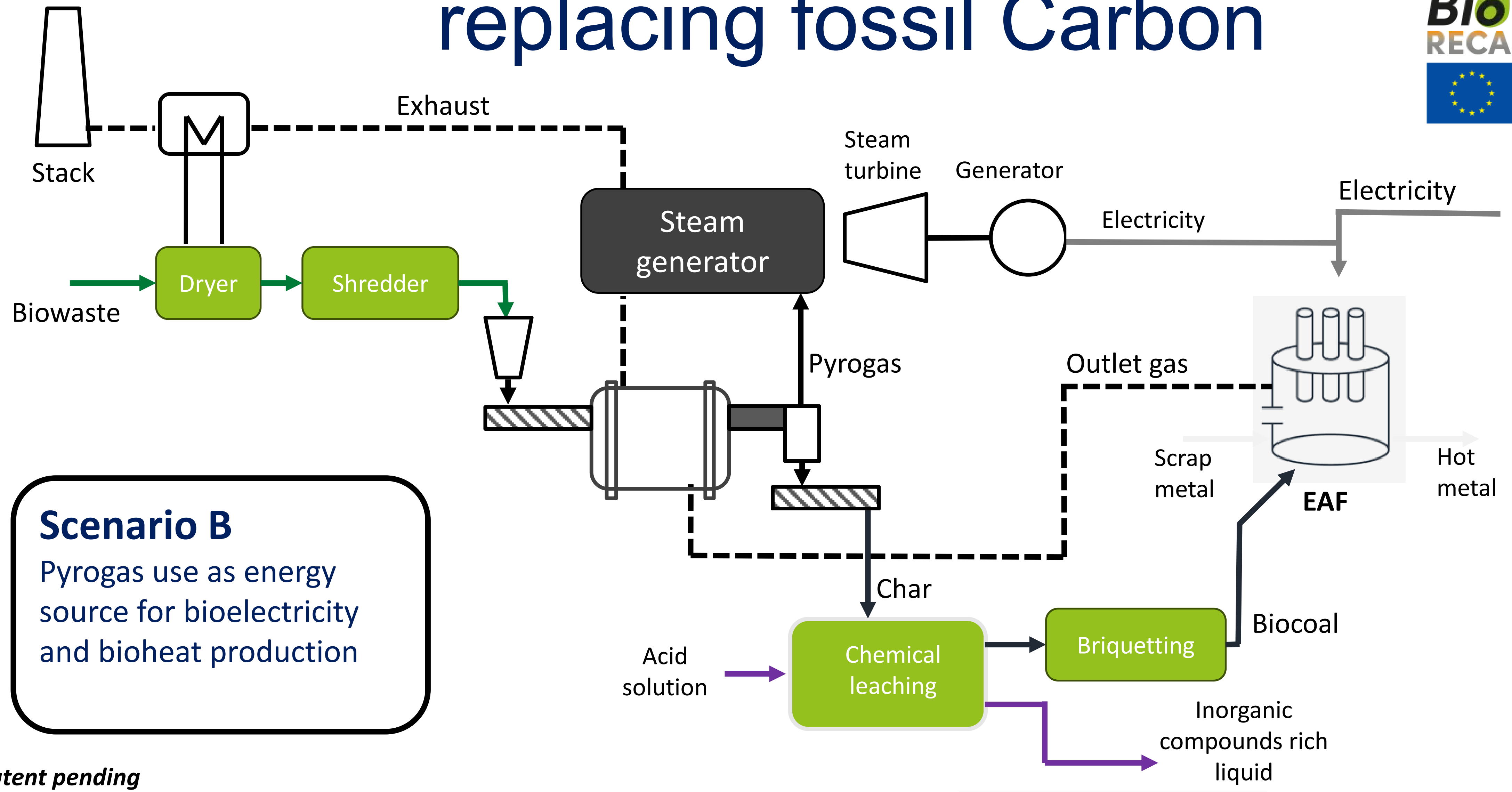
Scenario A

Direct combustion of pyrogas through innovative burners for direct energy supply to EAF process

Patent pending

BIORECAST - Biogenic/Waste Carbon replacing fossil Carbon

Funded by the European Union



Scenario B

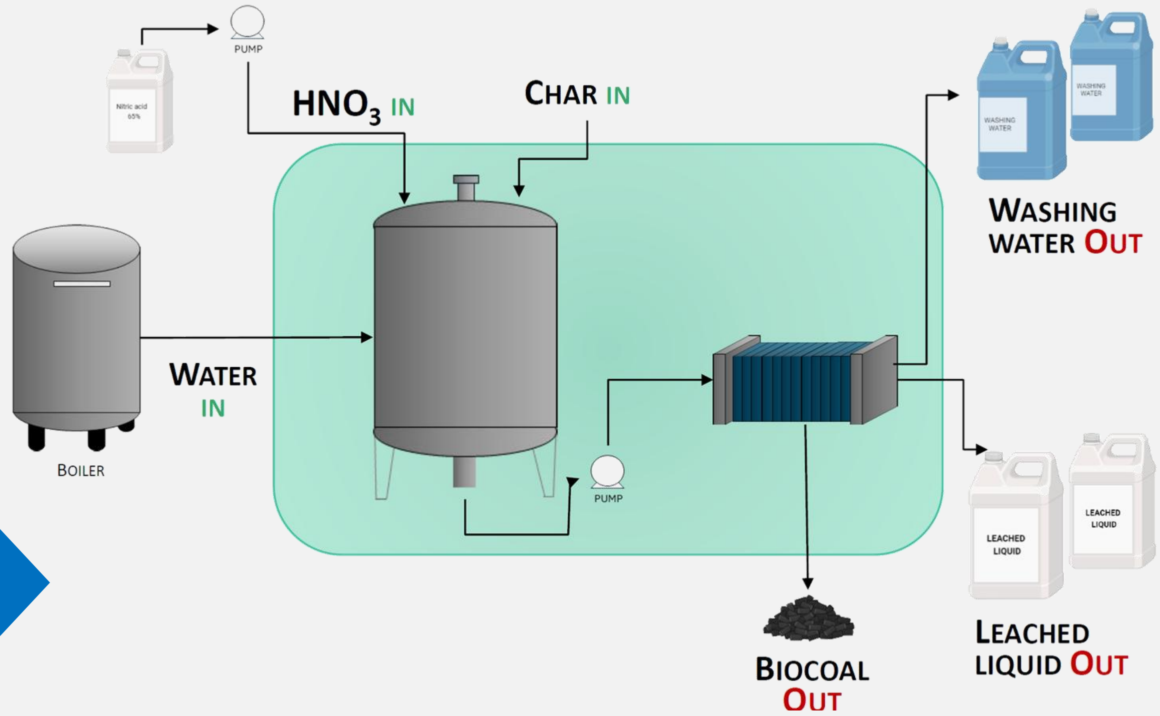
Pyrogas use as energy source for bioelectricity and bioheat production

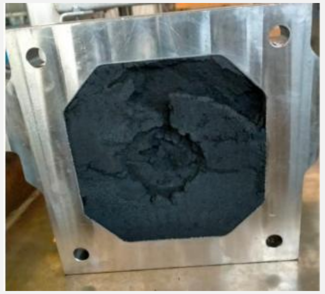
Patent pending

BioRECAST

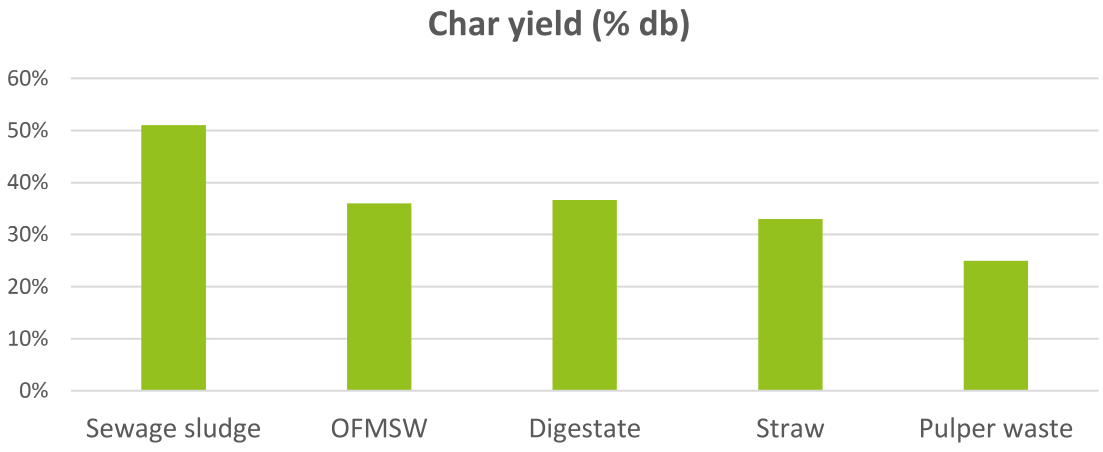
Objectives	Description
Production of high quality biocoal from waste	Optimization of thermo-chemical treatment plant with char chemical upgrading for high quality biocoal production from biowaste streams
Validate biocoal quality in industrial scale furnaces	Test and assess the biocoal applicability in Electric Arc Furnaces
Enable the utilization of pyrogas as bioenergy source for EAF steelmaking	Identification of most efficient and sustainable solution for slow pyrolysis pyrogas utilisation in EAF steelmaking site, system design and modelling the system energy balance
Maximize the reuse of EAF waste heat for pyrolysis process	Development of effective heat exchanging system to reuse EAF waste heat for slow pyrolysis process energy supply
Demonstrate economic and environmental benefits of the Pyro-EAF process	Evaluate the economic and environmental feasibility of the BioRECAST proposed solution for steel sector application, demonstrating the sustainbility of LCA and LCC studies in comparison with existing EAF steelmaking process

BioRECAST R&D methodology





BioRECAST COMPOSITION OF RAW CHAR AFTER SLOW PYROLYSIS



Parameter	Unit	S. Sludge char	OFMSW char	Digestate char	Straw char
Ash	% db	58.4	45.7	35.9	28.5
Volatiles	% db	17.4	18.1	12	12.2
C	% db	31.7	45.9	56.8	64.3
H	% db	1.38	1.3	1.6	2
N	% db	4.8	2.5	1.5	1.3
S	% db	0.26	0.2	0.3	0.1
Cl	% db	0.76	1.9	0.5	0.5
HHV	MJ/kg	12.7	16.4	20.9	24.4

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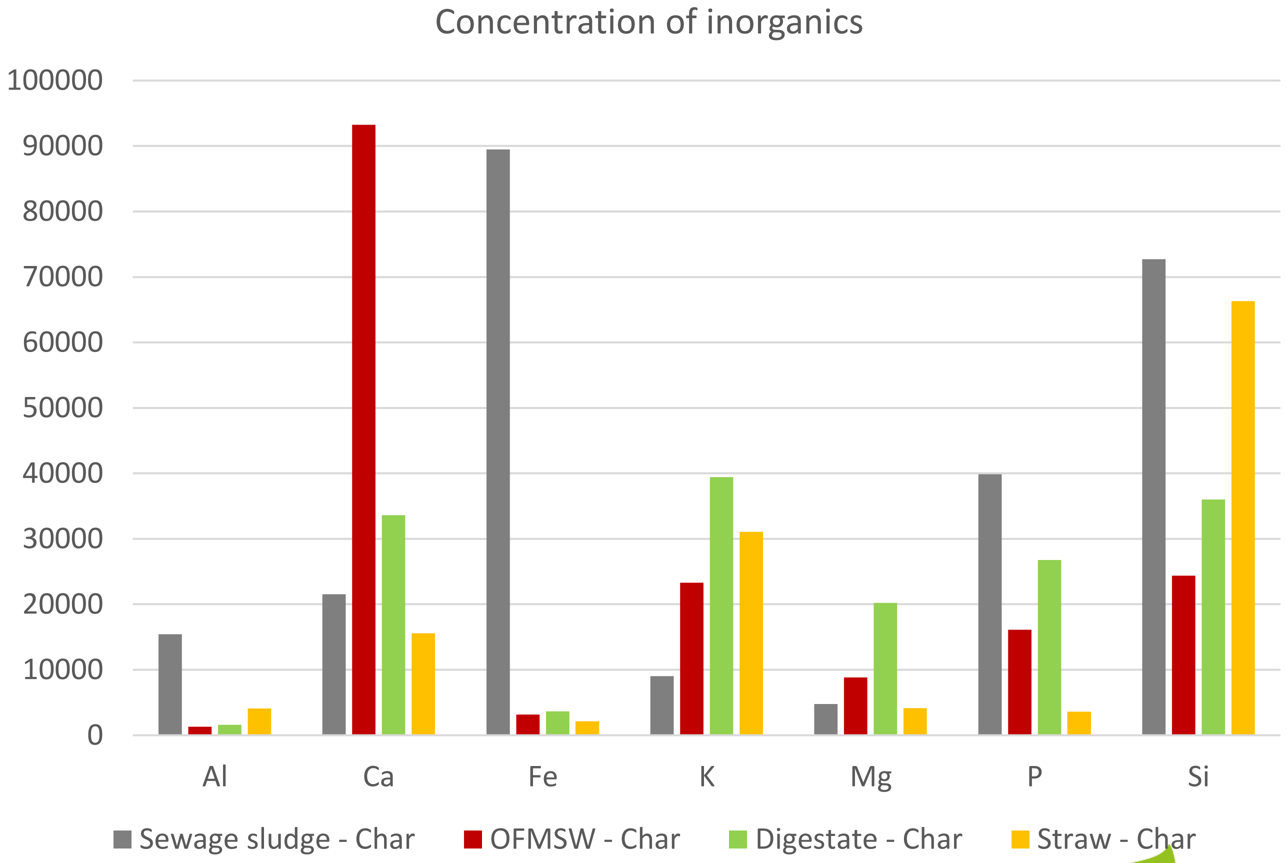
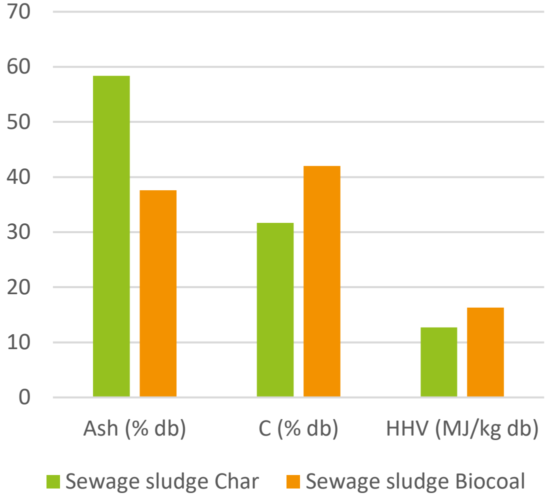


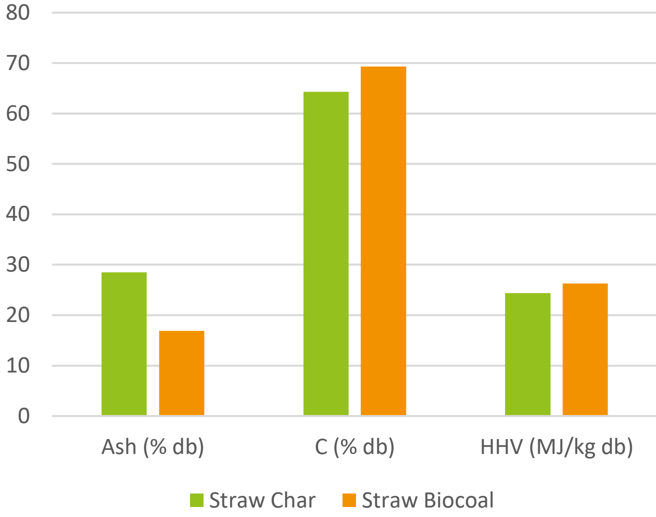
Reprinted from A.Salimbeni, 2025

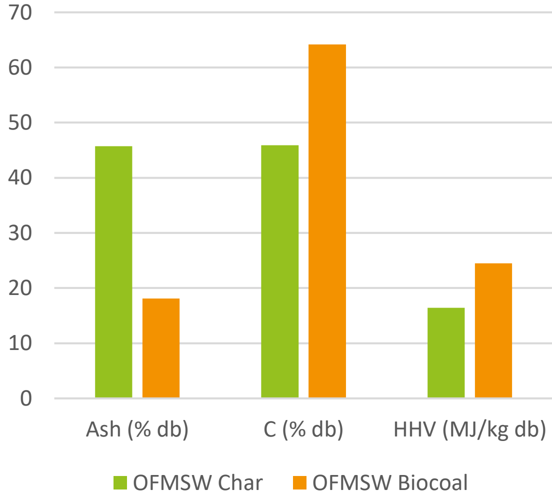
BioRECAST COMPOSITION OF OBTAINED BIOCOALS

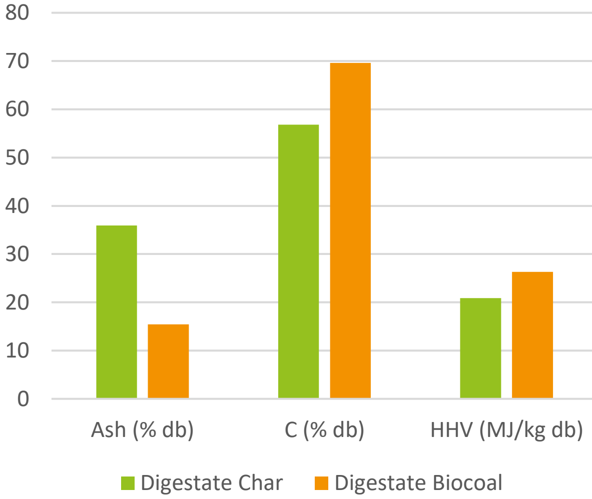
- C content increase of up to 60%
- P reduced to < 0.3%
- Cl reduced to < 0.4%

Parameter	BIOCOAL S. Sludge	BIOCOAL OFMSW	BIOCOAL Digestate	BIOCOAL Straw
Volatiles	19.5	20.1	18.7	16.9
Ashes	37.6	18.1	15.4	16.9
C	**42.0**	**64.2**	**69.6**	**69.3**
H	1.5	2.0	1.9	2
N	6.6	4.7	2.7	2
S	0.1	0.2	0.4	0.1
Cl	0.3	0.1	0.01	0.02
HHV	16.3	24.5	26.3	26.3









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BioRECAST

Conclusions

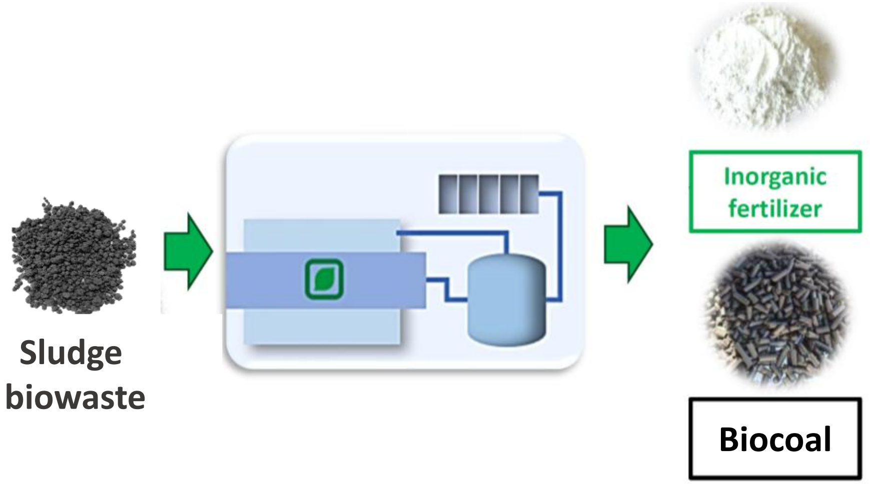
- The production of bio-coal from bio-waste could be a key player in the green transition of steel-making processes.

- Besides the environmental benefits of the solution, from an economic standpoint, this could be a game-changer. It opens up the possibility of benefiting from C credits associated with reduced CO_2 emissions in a sector covered by EU ETS.

- Further analysis will be conducted in the coming years to determine the optimal integrated solution.

BioRECAST
Conclusions

- A 95-99% P extraction efficiency is obtained
- Sludge ash is extraction can be by up to 90%
- Biocoal has reduced reactivity at high Temperatures
- Silica is not removed by the process
- Calorific value is increased from 15-20 to 24-27 MJ/kg
- Leaching process remove PAH, Cl, and > 50% ash from char
- Nutrients recovery improve the economic feasibility and sustainability
- Successful pelletisation tests



BioRECAST (and other projects)

Follow-up – coming soon......

3 tons + char production in 100 kg/h rotary kiln

PYROK rotary kiln

ADELE leaching unit

> 1.5 tons biocoal production in a 500 lt/h leaching unit

Thank you!

David Chiaramonti, Viviana Negro
Politecnico di Torino

david.chiaramonti@polito.it
viviana.negro@polito.it

Partners

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GREEN H2 AND CIRCULAR BIO-COAL FROM BIOWASTE FOR COST-COMPETITIVE SUSTAINABLE STEEL

Assistant Professor Viviana Negro
Professor David Chiaramonti
Politecnico di Torino

Funded by the European Union

Funded by the European Union - European Innovation Council - H2STEEL project - Grant Agreement nr.101070741. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Innovation Council. Neither the European Union nor the granting authority can be held responsible for them.

H2STEEL – OVERVIEW

- Project name: Green H2 and circular bio-coal from biowaste for cost-competitive sustainable Steel
- Project acronym: H2STEEL
- Call: HORIZON-EIC-2021-PATHFINDERCHALLENGES-01
- 3 year project, KoM in October 2022
- 2,368,910 € European funding

Funded by
the European Union

H2STEEL – CONSORTIUM

- Coordinator

Politecnico di Torino
Department of Energy "G.Ferraris"

- 5 partners

RE·CORD
I3P Incubatore Politecnico di Torino
ArcelorMittal
Universiteit Leiden Institute of Environmental Sciences
contactica innovation

- 1 associated partner

Imperial College London

7 partners from 5 countries

CATALYTIC METHANE PYROLYSIS

Catalytic Methane Pyrolysis is an environmentally friendly method of hydrogen production from methane that, unlike other conventional processes such as Steam Methane Reforming can convert methane into hydrogen **without emitting GHGs**.

$$CH_4 \rightarrow C + 2H_2$$

$$\Delta H^0(298K) = 74{,}9\,\frac{kJ}{mol}$$

Methane pyrolysis is the single-step process of methane conversion into hydrogen and carbon.
Endothermal reaction that occurs with and increase in the number of moles:
Thermodynamically favored at **high temperatures** and **low pressure**

Funded by the European Union

CATALYTIC METHANE PYROLYSIS

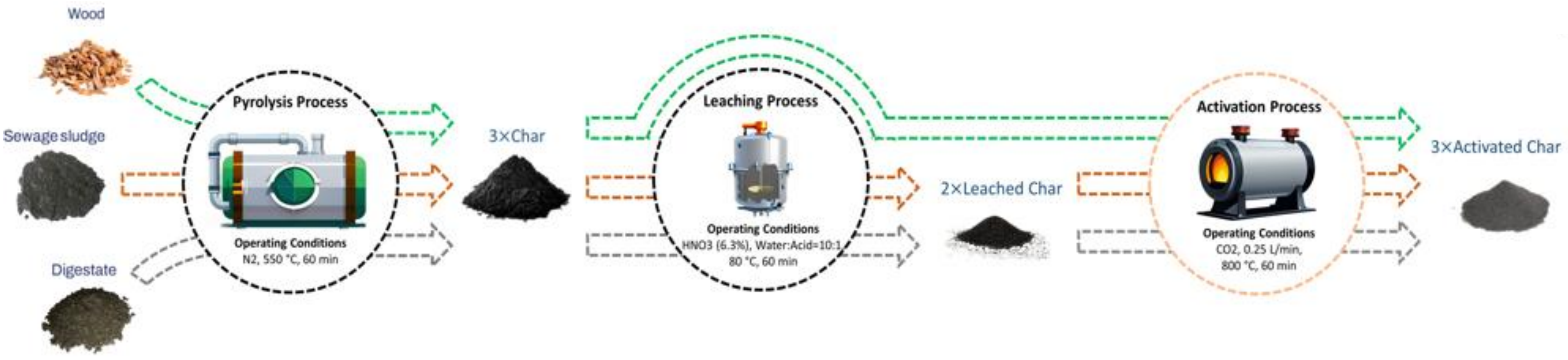
Carbon-based catalysts have been extensively assessed for Methane Pyrolysis process; however, the application of carbon-based catalysts derived from waste materials, like sewage sludge, has been rarely studied within this framework.

The conversion of sewage sludge into char through pyrolysis not only mitigates the challenges of waste management but also offers a promising catalyst for hydrogen production.

This work aims at developing a method to prepare a waste-derived carbon-based catalyst for methane pyrolysis.

Funded by
the European Union

CATALYST PRODUCTION

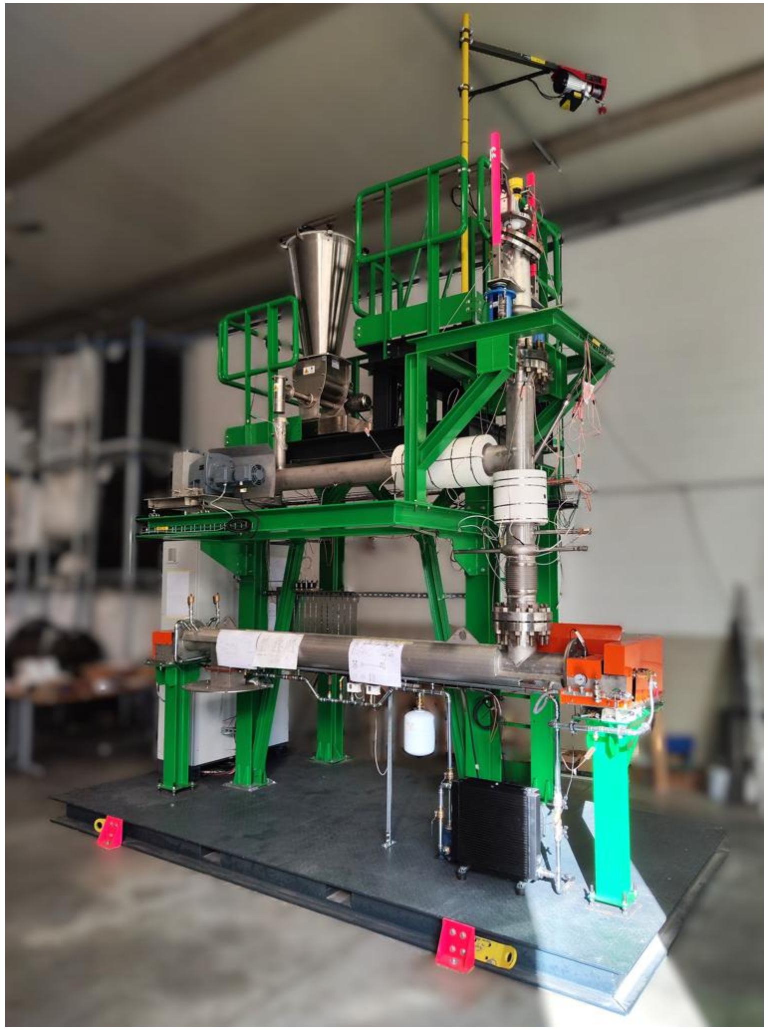


CATALYTIC METHANE PYROLYSIS: FROM LAB TO POC

RE·CORD

Politecnico di Torino

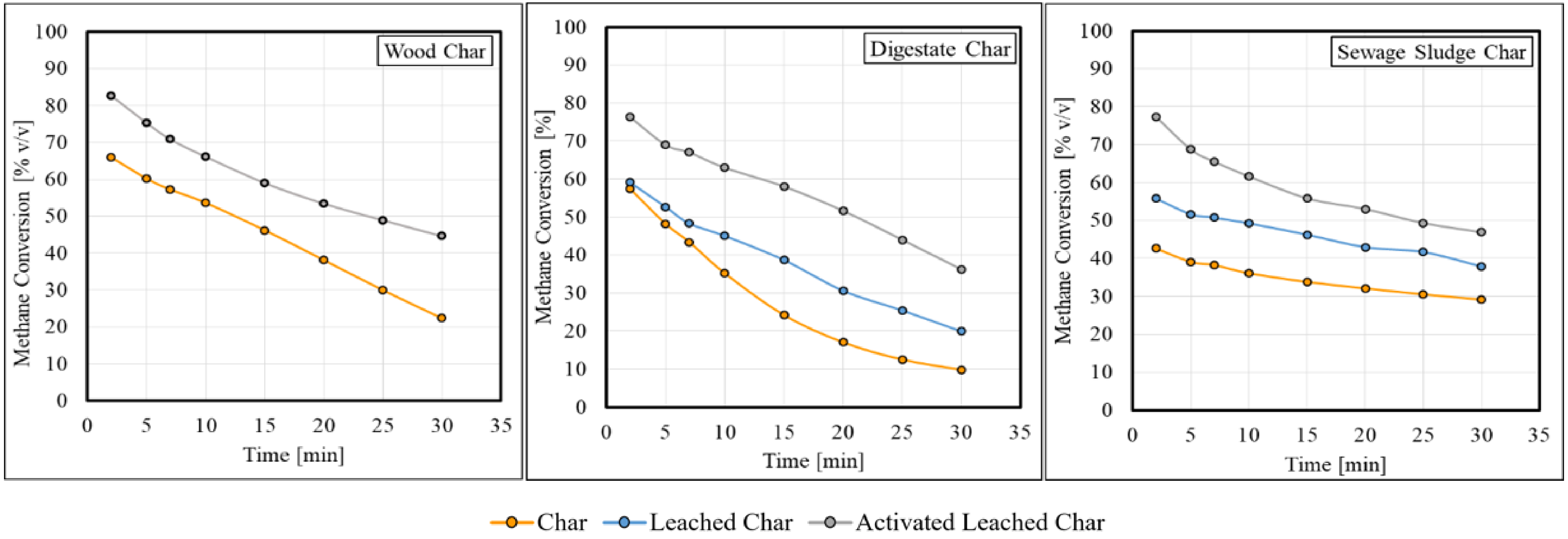
Department of Energy "G.Ferraris"



RE·CORD

CATALYTIC METHANE PYROLYSIS: RESULTS

Effects of catalyst origin and characteristics on methane conversion

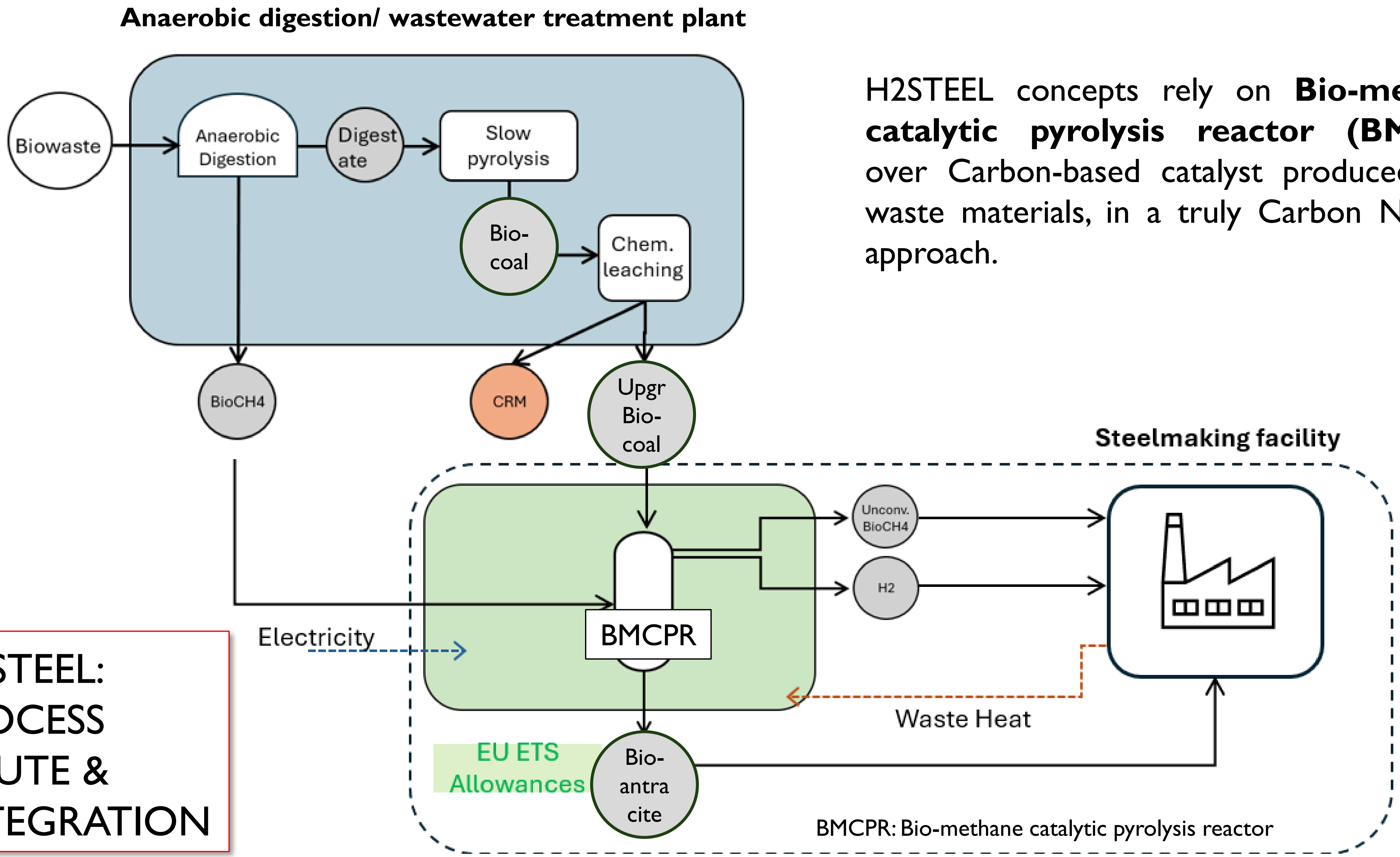


Comparing the results of using catalysts prepared from the slow pyrolysis of biowaste and wood indicated that carbon materials with **lower ash content** achieved **higher initial methane conversion.**

(Wood char > Digestate char > Sewage sludge char)

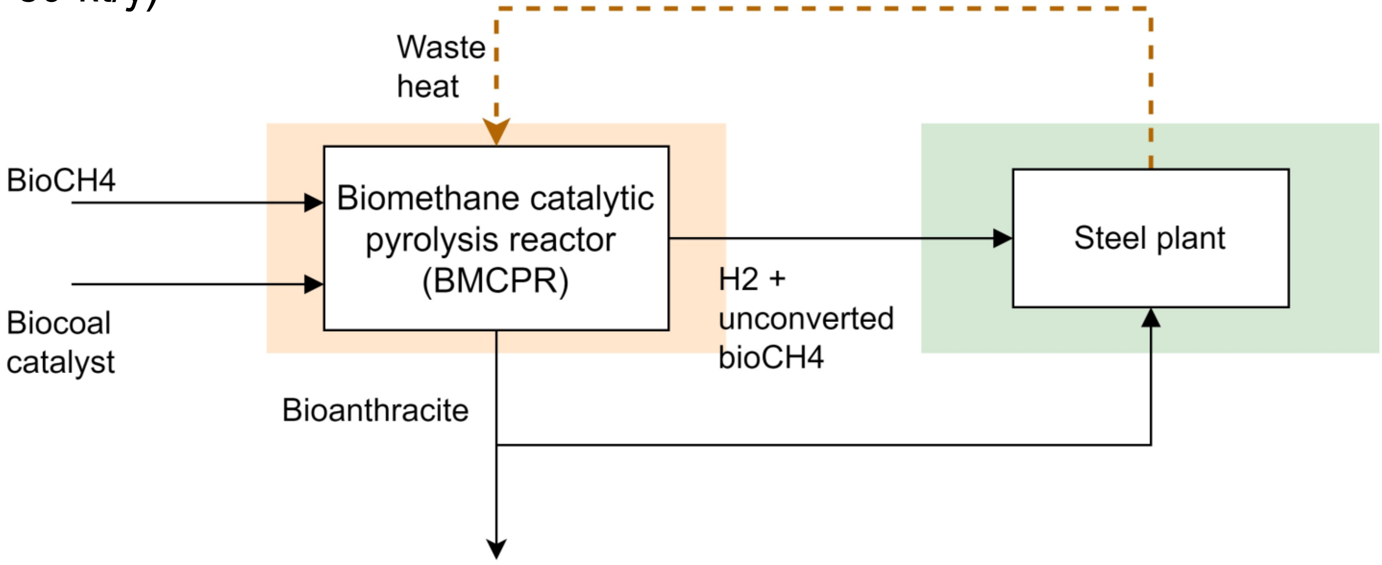
H2STEEL: PROCESS ROUTE & INTEGRATION

H2STEEL concepts rely on **Bio-methane catalytic pyrolysis reactor (BMCPR)**, over Carbon-based catalyst produced from waste materials, in a truly Carbon Negative approach.



TEA: PRELIMINARY RESULTS FOR LCOH

Steelmaking integrated unit (large scale 39 kt/y)



Further cases will be considered about the energy supply to the reactor:

1. Electrically heated
2. Internal recovery
3. Partial heat recovery from steel facility

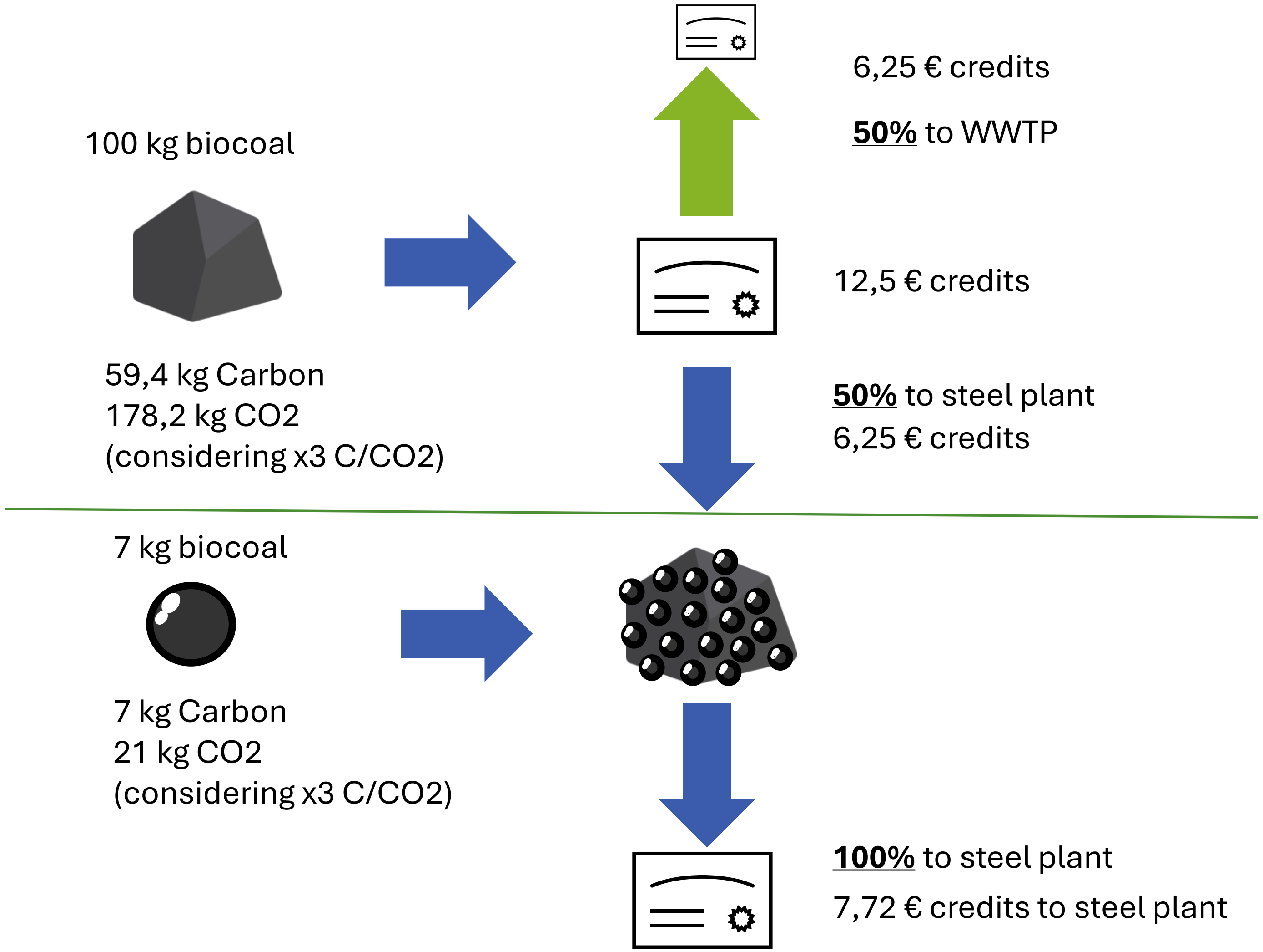
Funded by the European Union

TEA: ETS CREDITS CALCULATION METHODOLOGY

CO2 credit
70€/tCO2

Biocoal produced by the WWTP
(Carbonaceous fraction 59,4%)

Carbon deposited during
the pyrolysis
(100% carbon)



TEA: RESULTS

ETS credits-Electrical heating

Carbon credits	50%
Power source	Electricity
Heat recovery	No

	€/kgH2
Annualized CAPEX	0,49
Electricity	3,30
Methane	4,70
Catalyst	6,21
Other OPEX	0,02
Bioanthracite	8,88
Credits	2,02
NC Methane	1,88
LCOH (€/kgH2)	**1,95**

CAPEX	M€	120
Lifetime	y	20
WACC		6%
Electricity	€/MWh	137,3
Methane	€/MWh	45,7
Catalyst	€/t	150
Bioanthracite	€/t	200
CO2 credits	€/tCO2	70

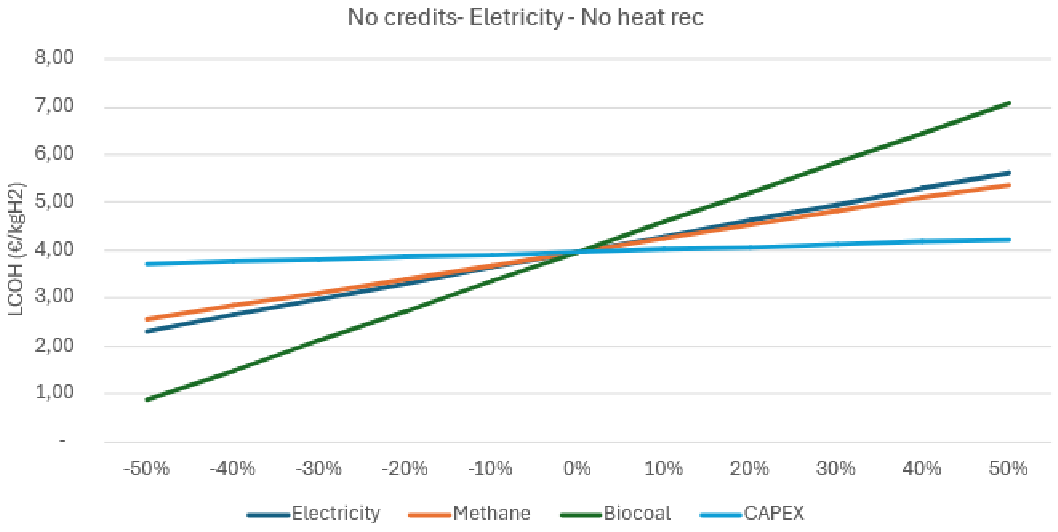
Electricity price (€/MWh)

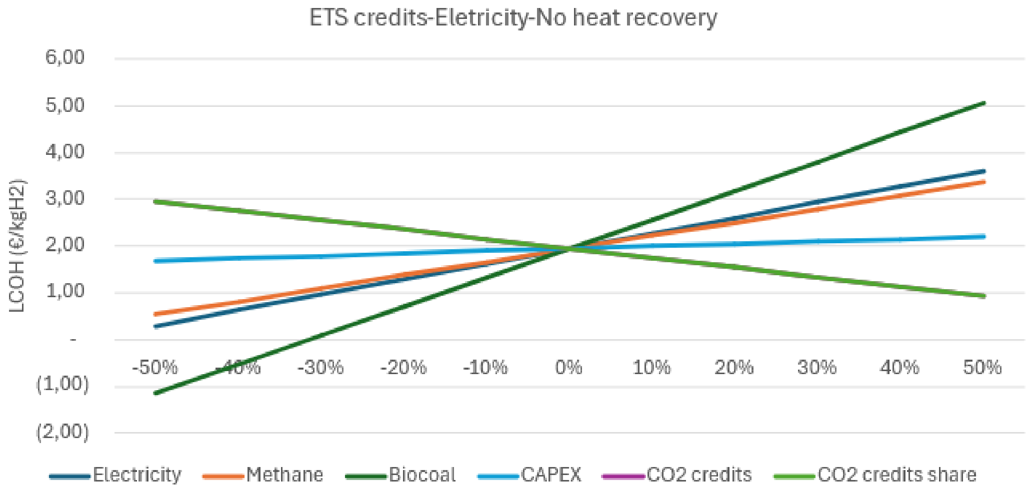
Biocoal price (€/t)	80	90	100	110	120	130	140	150	160
150	0,57	0,81	1,05	1,29	1,53	1,77	2,01	2,25	2,49
160	0,98	1,22	1,46	1,70	1,94	2,18	2,42	2,66	2,90
170	1,40	1,64	1,88	2,12	2,36	2,60	2,84	3,08	3,32
180	1,81	2,05	2,29	2,53	2,77	3,01	3,25	3,49	3,73
200	2,64	2,88	3,12	3,36	3,60	3,84	4,08	4,32	4,56
250	4,71	4,95	5,19	5,43	5,67	5,91	6,15	6,39	6,63
300	6,78	7,02	7,26	7,50	7,74	7,98	8,22	8,46	8,70
350	8,85	9,09	9,33	9,57	9,81	10,05	10,29	10,53	10,77
400	10,91	11,15	11,39	11,63	11,87	12,11	12,35	12,59	12,84

Carbon credits share (%)

Biocoal price (€/t)	5%	10%	20%	30%	40%	50%	60%	70%	80%
150	3,76	3,56	3,16	2,75	2,35	1,95	1,54	1,14	0,73
160	4,18	3,97	3,57	3,17	2,76	2,36	1,96	1,55	1,15
170	4,59	4,39	3,98	3,58	3,18	2,77	2,37	1,97	1,56
180	5,00	4,80	4,40	3,99	3,59	3,19	2,78	2,38	1,98
200	5,83	5,63	5,23	4,82	4,42	4,01	3,61	3,21	2,80
250	7,90	7,70	7,29	6,89	6,49	6,08	5,68	5,28	4,87
300	9,97	9,77	9,36	8,96	8,56	8,15	7,75	7,35	6,94
350	12,04	11,84	11,43	11,03	10,62	10,22	9,82	9,41	9,01
400	14,11	13,90	13,50	13,10	12,69	12,29	11,89	11,48	11,08

TEA: RESULTS


No credits- Eletricity - No heat rec
LCOH (€/kgH2)
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
-
-50%
-40%
-30%
-20%
-10%
0%
10%
20%
30%
40%
50%
Electricity
Methane
Biocoal
CAPEX


ETS credits-Eletricity-No heat recovery
LCOH (€/kgH2)
6,00
5,00
4,00
3,00
2,00
1,00
-
(1,00)
(2,00)
-50%
-40%
-30%
-20%
-10%
0%
10%
20%
30%
40%
50%
Electricity
Methane
Biocoal
CAPEX
CO2 credits
CO2 credits share

CONCLUSIONS

- The combined production of biocoal and hydrogen from bio-waste could make the green transition of the steel process possible.
- Hydrogen costs could be significantly reduced thanks to the valorization of biocoal and related carbon credits.
- The proposed value chain would favour circularity, by deploying unexploited wastes as urban wwt sludges.
- Industrial symbiosis would be stimulated by the integrated approach.

THANK YOU FOR THE ATTENTION

viviana.negro@polito.it

Funded by
the European Union

Challenges in biocarbon production and usage in metallurgical industries

Kentaro Umeki
Div. Energy Science
Luleå University of Technology

Agenda

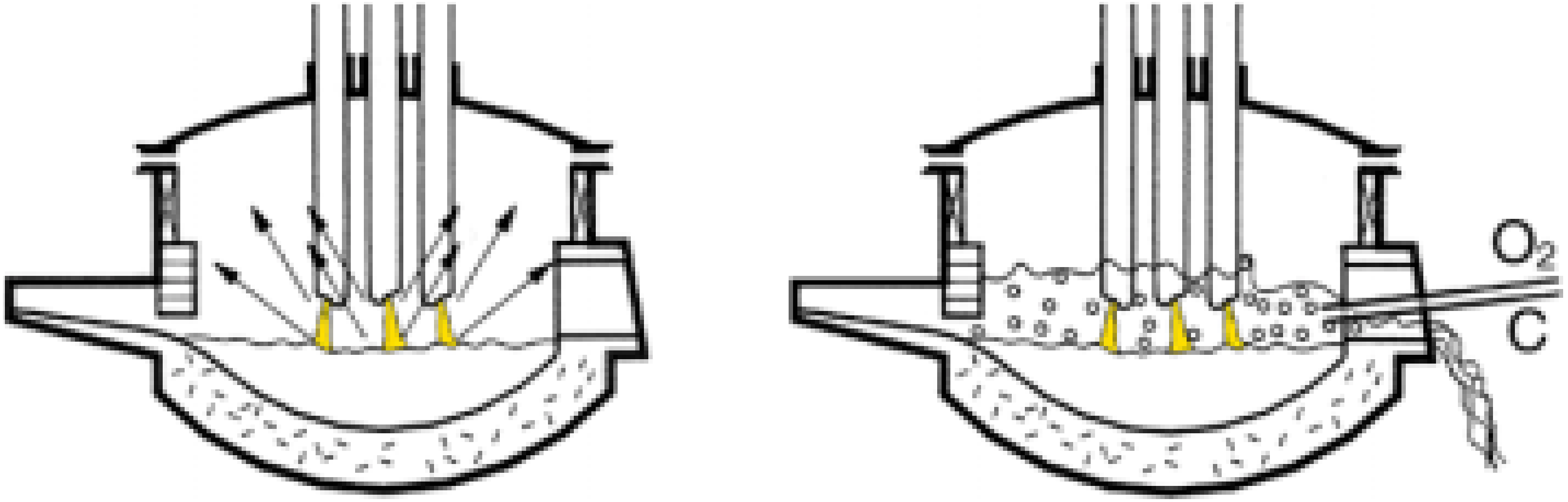
- Why do we need biocarbon in metallurgical industries?
- Major (technical) challenges in biocarbon production and usage
- Some potential solutions (research summary)
- Outlook

Chemistry of metallurgy 101

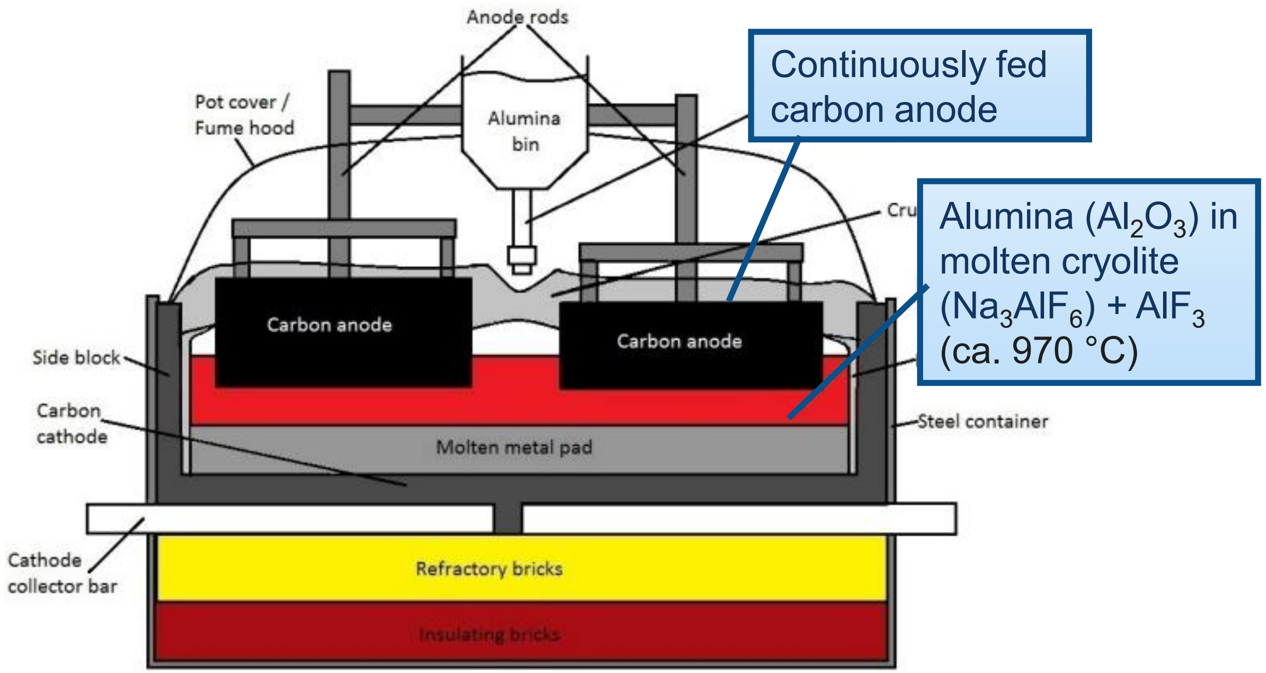
- First goal is to produce pure metals
  - $M_xO_y + A \rightarrow \boldsymbol{x}\mathbf{M} + B$
- Typically, A = CO and/or H_2, and B = CO_2 and/or H_2O
- Traditionally, A (reduction media) was produced by
  - C (coal/coke) + $CO_2 \rightarrow 2CO$
  - CH_4 (natural gas) + $H_2O \rightarrow CO + 3H_2$
- Relevant for blast furnace (BF-BOF route) and direct reduction (DRI-EAF route)
- Renewable alternatives: biocarbon, H_2 with renewable electricity

Electric arc furnace

- Arc between iron/steel and graphite **carbon** electrodes (1-2 kg-C/ton-steel)
- Foamed slag protects refractory from high intensity arc.
  - generated by CO from solid **carbon**: $C+1/2O_2 \rightarrow CO$ (12 kg-C/ton-steel)
- Solid **carbon** also used for carburization (up to 20 kg-C/ton-steel)



Aluminium and silicon production processes



Hall-Héroult process for aluminium production

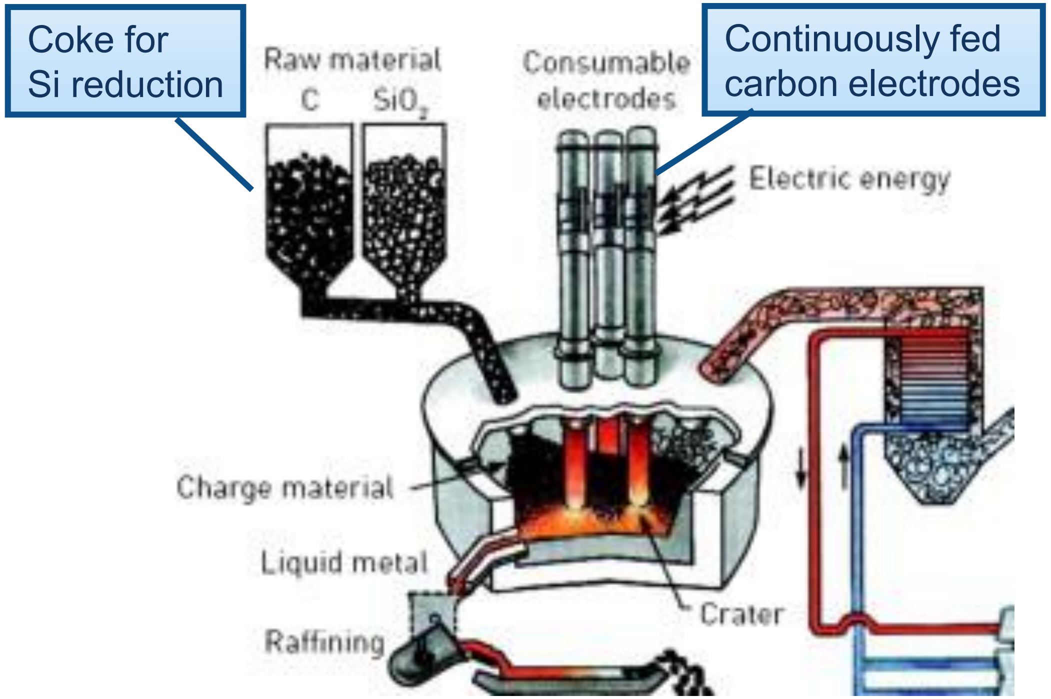
Overall: $Al_2O_3 + 3C \rightarrow 2Al + 3CO$

or $Al_2O_3 + 1.5C \rightarrow 2Al + 1.5CO_2$

Cathode: $Al^{3+} + 3e^- \rightarrow Al$

Anode: $C + O^{2-} \rightarrow CO + 2e^-$ *or* $C + 2O^{2-} \rightarrow CO_2 + 4e^-$

J. Haraldsson and M.T. Johansson, RSER 93 (2018) 525



Submerged arc furnace (SAF) for silicon production

Overall: $SiO_2 + 2C + O_2 \rightarrow Si + 2CO_2$

Outer zone (1550 °C): $SiO(g) + 2C \rightarrow SiC + CO$

Inner zone (>1800 °C): $SiO_2 + SiC \rightarrow Si + SiO(g) + CO$

Freeboard: $CO + 0.5O_2 \rightarrow CO_2$ and $SiO(g) + 0.5O_2 \rightarrow SiO_2$

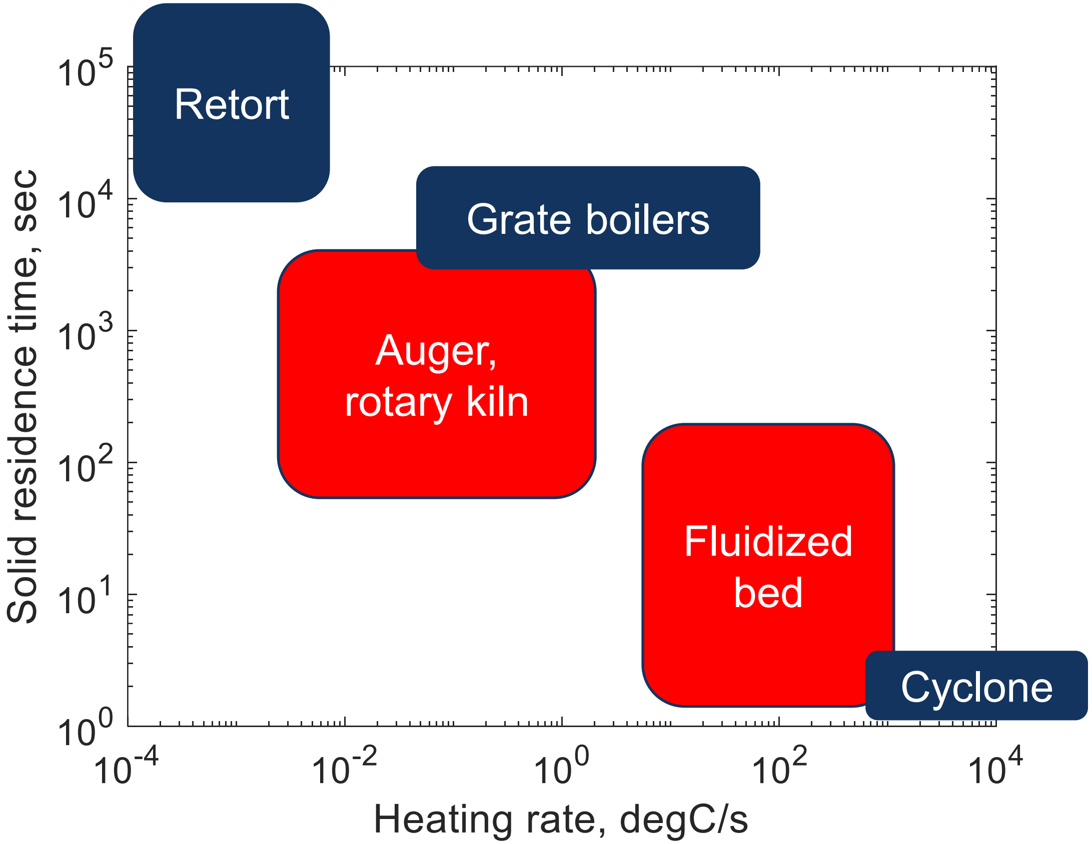
M. Takla et al., Energy 58 (2013) 138-146

Agenda

- Why do we need biocarbon in metallurgical industries?
- Major (technical) challenges in biocarbon production and usage
- Some potential solutions (research summary)
- Outlook

Biocarbon production technologies

- Traditional retort
- Modern pyrolysers
  - Auger (screw) reactors
  - Rotary kiln
- Non-conventional (co-production)
  - Fluidized bed
  - Cyclone reactor
  - Grate boilers

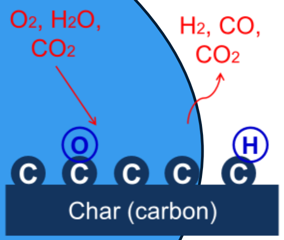


They look the same… But are they really?

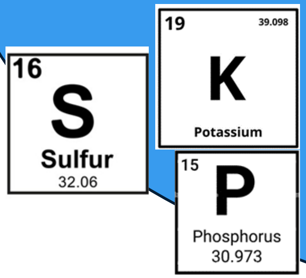
Some key RD&I issues for biocarbon

Heterogeneous biomass

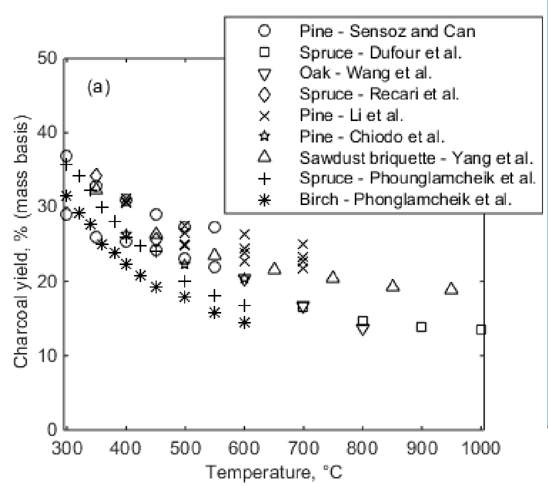
Self-heating, ignition, dusting



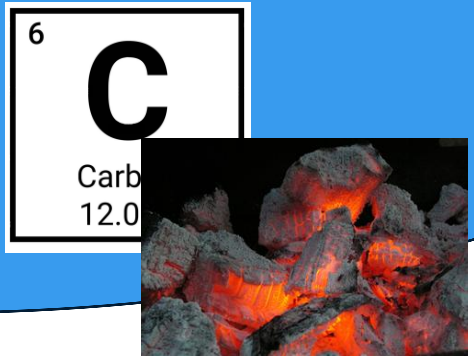
Control of reaction rates



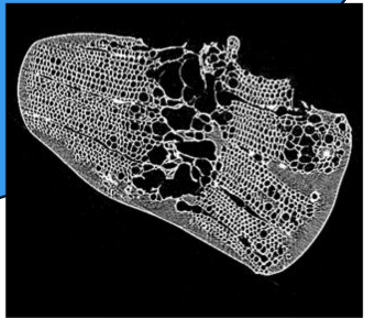
Harmful elements



Low yield (profitability)



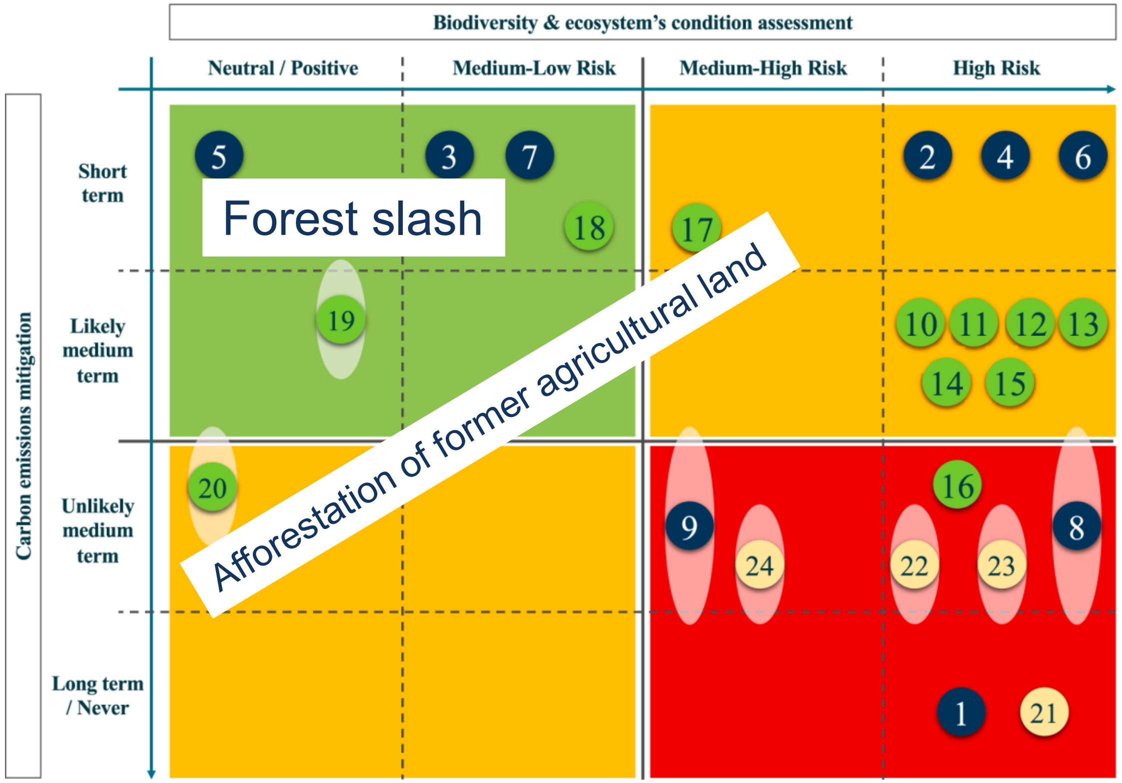
C & fix-C content



Low density

Feedstock issues

- Highest quality wood – stemwood, wood pellets
  - Expensive
  - Reserved for traditional material use (sawn goods, pulp and paper)
  - Short-to-medium CO_2 emission & ecosystem risks
- Residual biomass – agricultural, forest slash, etc.
  - Heterogeneous
  - Spatially spread availability
  - Often low quality (high ash content, low density)



[J. Giuntoli et al., RSER 2022]

Harmful elements

- Many elements abundant in biomass (Zn, Pb, K, Na, P, and S) are harmful for metallurgy
  - Effects on the process equipment
  - Effects on the process operatability
  - Effects on the product quality
- Biomass in waste streams almost always have higher content than coke
- During pyrolysis, elemental content can be further increase by 3-4 times.

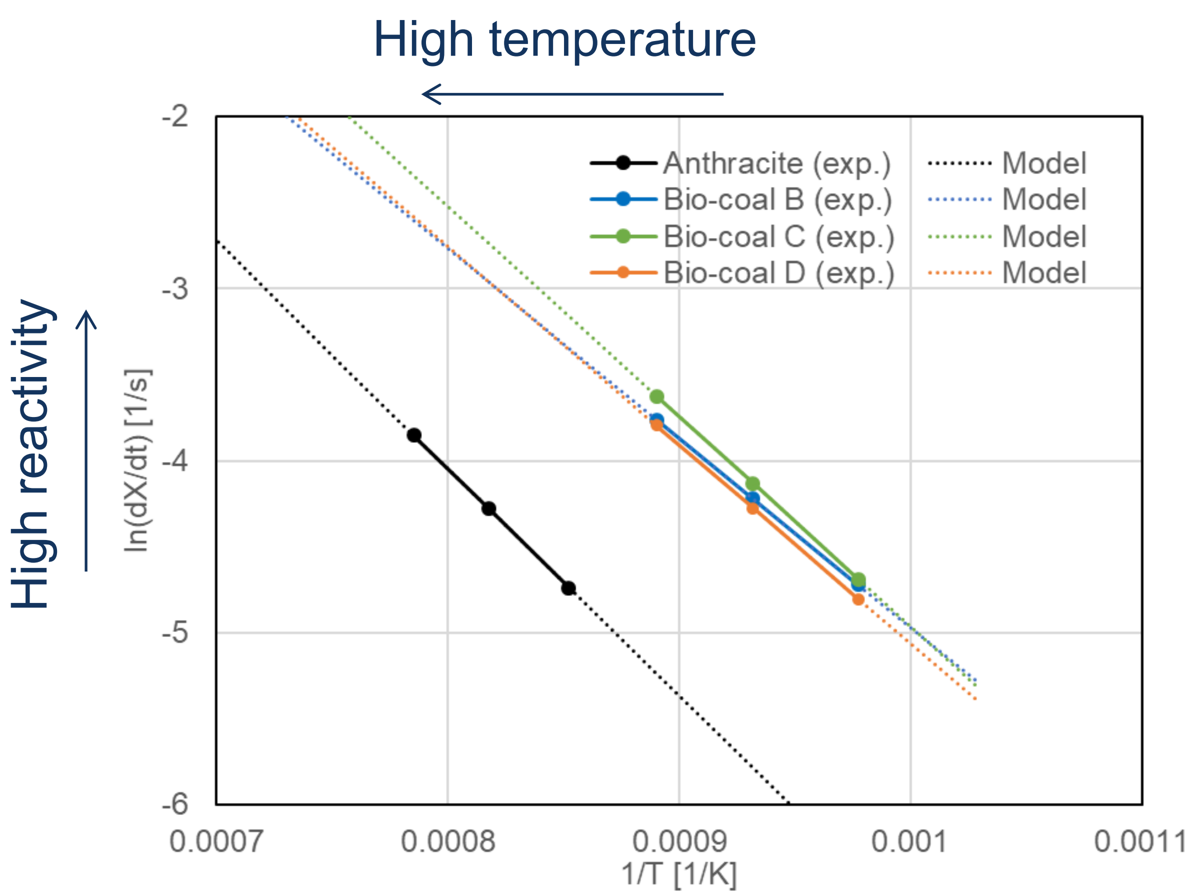
Type biomass	Origin	S	K	Na	P
Coke		6000	1000	300	300
Stem-wood	Softwood	300	332	27	59
	Hardwood	300	872	53	231
Grasses	Alfalfa	1900	14127	124	1583
	Switch grass	1200	4593	194	1194
	Mischantus	600	3246	51	396
Straws	Corn	1000	3164	129	759
	Rice	1300	18686	584	878
	straw	1200	10910	108	780
Bark	Bark-general	500	2133	128	415
	Pine	700	1827	95	609
Husk/ shells	Rice	800	4735	235	374
	Sunflower	1800	9162	92	1272
	Walnut	1000	5966	175	641
Manure	Pig	5700	14600	3443	11792
	Chicken	8800	31300	4675	20000
Others	Sugar bagasse	800	1487	281	474
	Black liquor	22900	9150	183000	60
	Sewage sludge	20000	4164	1425	30973

[A. Bach-Oller, PhD thesis, LTU 2018]

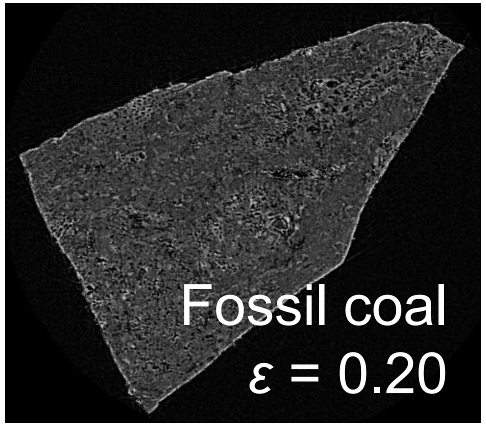
Reactivity of biocarbon

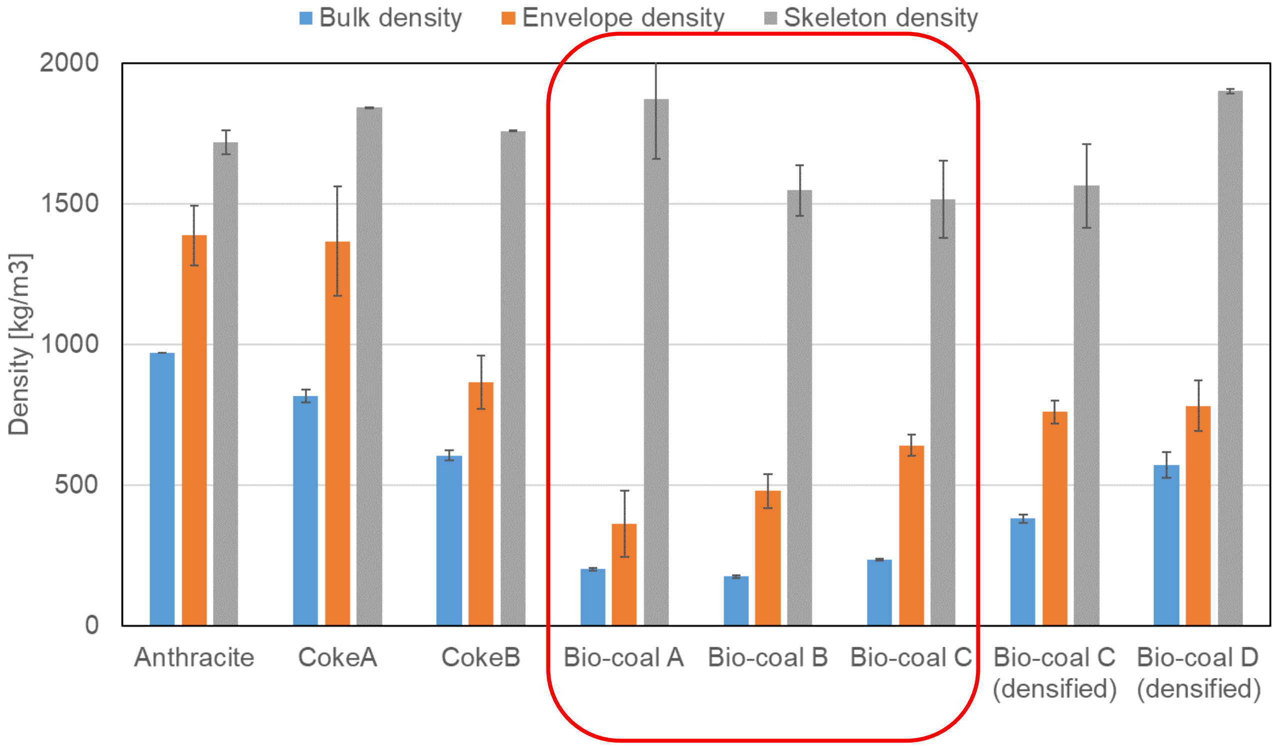
- Large difference between fossil coal and biocarbon
- Biocarbon produced at lower temperatures is slightly faster
- Need to decrease the reactivity by…
  - physical means (e.g. densification)
  - Chemical means (e.g. calcination, ash leaching)

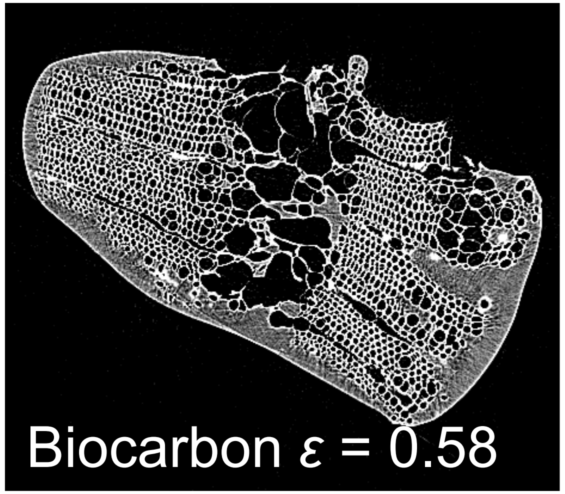
Arrhenius plot ($C+CO_2 \rightarrow 2CO$)

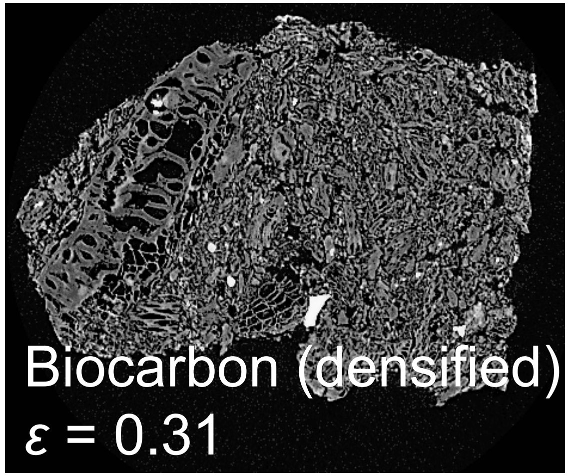


Density of bio-carbon









Bulk Envelope Skeleton

Self-heating and self-ignition of biocarbon

- Traditional problems in coal and biomass

- Not well documented for biocarbon…
  →but, almost all the developer producing >100 kg biocarbon experienced self-heating/-ignition problems

1. Ignition temperature can be <100 °C

2. Raw biomass, pyrolysis temperature and storage conditions affect self-heating

- Many developers ended up using big bags for storage and transport instead of larger containers

Agenda

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- Major (technical) challenges in biocarbon production and usage
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Previous and ongoing projects of biocarbon at LTU

Biomass pyrolysis

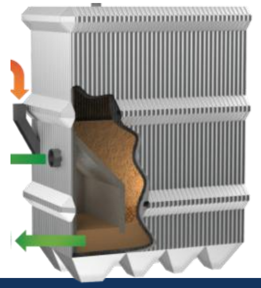
Fundamental work

2015-19: RENEPRO (EU Interreg)
2015-19: Bio4Metals (TVV)
2019-21: Bio4Steel (SEA)

Scale up (auger reactor / rotary kiln)

2019-25: MICO (SEA)
2023-26: BioKolMet (SEA)
2022-26: FINAST (EU just transition fund)
2024-2027: 2StgePyro (VINNOVA)

Scale up (fluidized bed)



2022-26: FluidBioKol (SEA)

Biocarbon use in industry

SSAB 2019-25: MICO – blast furance (SEA)

Höganäs

2019-23: SusHI (SEA)

eraMeT Elkem Hydro

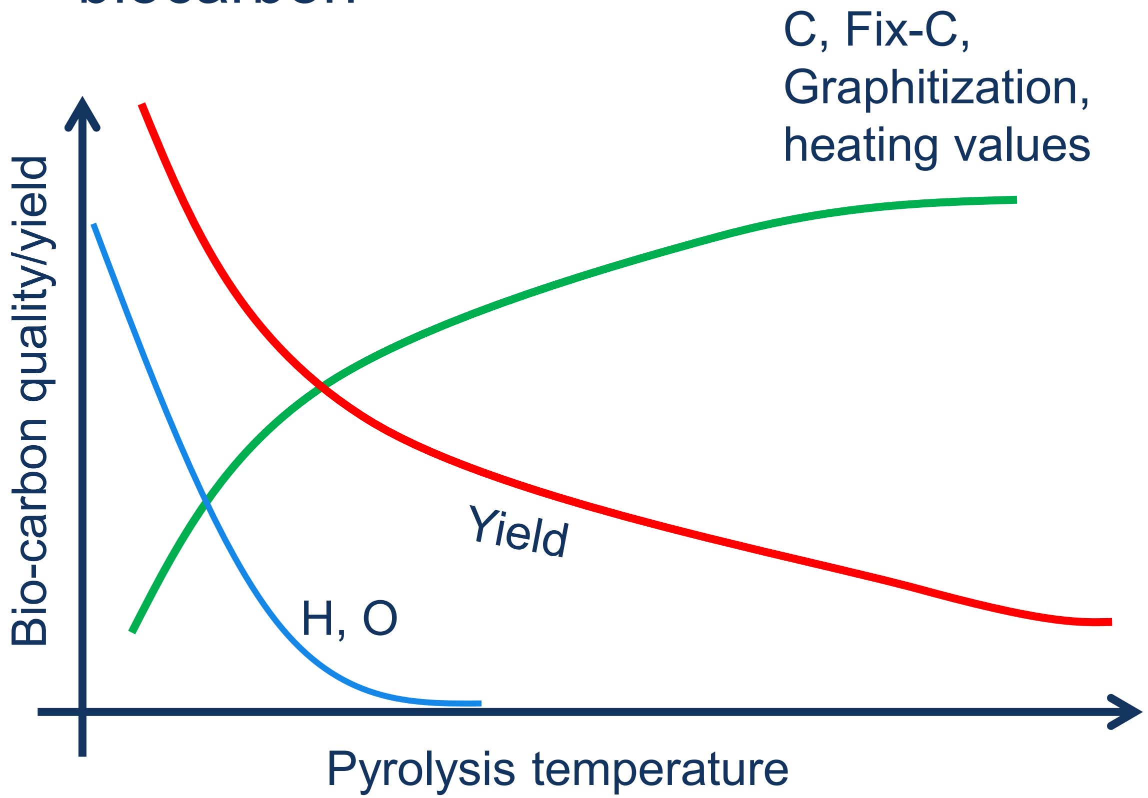
2023-26: BioCarbUpgrade
2025-28: EnergyProSafe
(Norwegian Research Council)

2023-27: GreenCarbon, within BEST 4.0 (Austrian Research Promotion Agency)

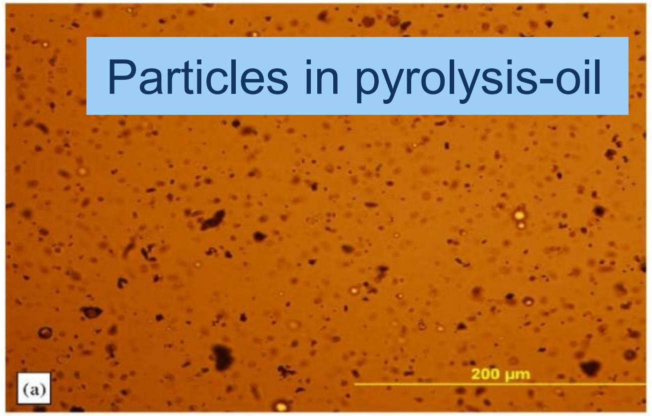
SEA: Swedish Energy Agency, TVV: Swedish Agency for Economic and Regional Growth, VINNOVA: Sweden's innovation agency

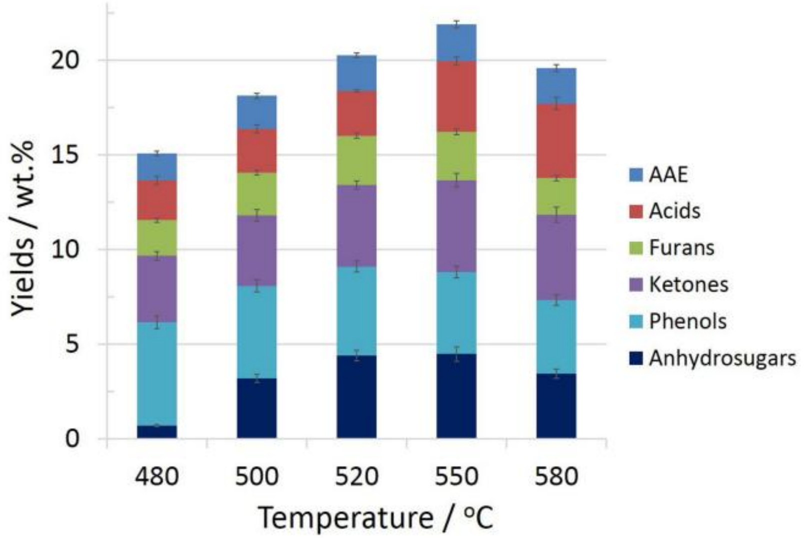
The problem to be solved

- Dilemma of quality and quantity of biocarbon

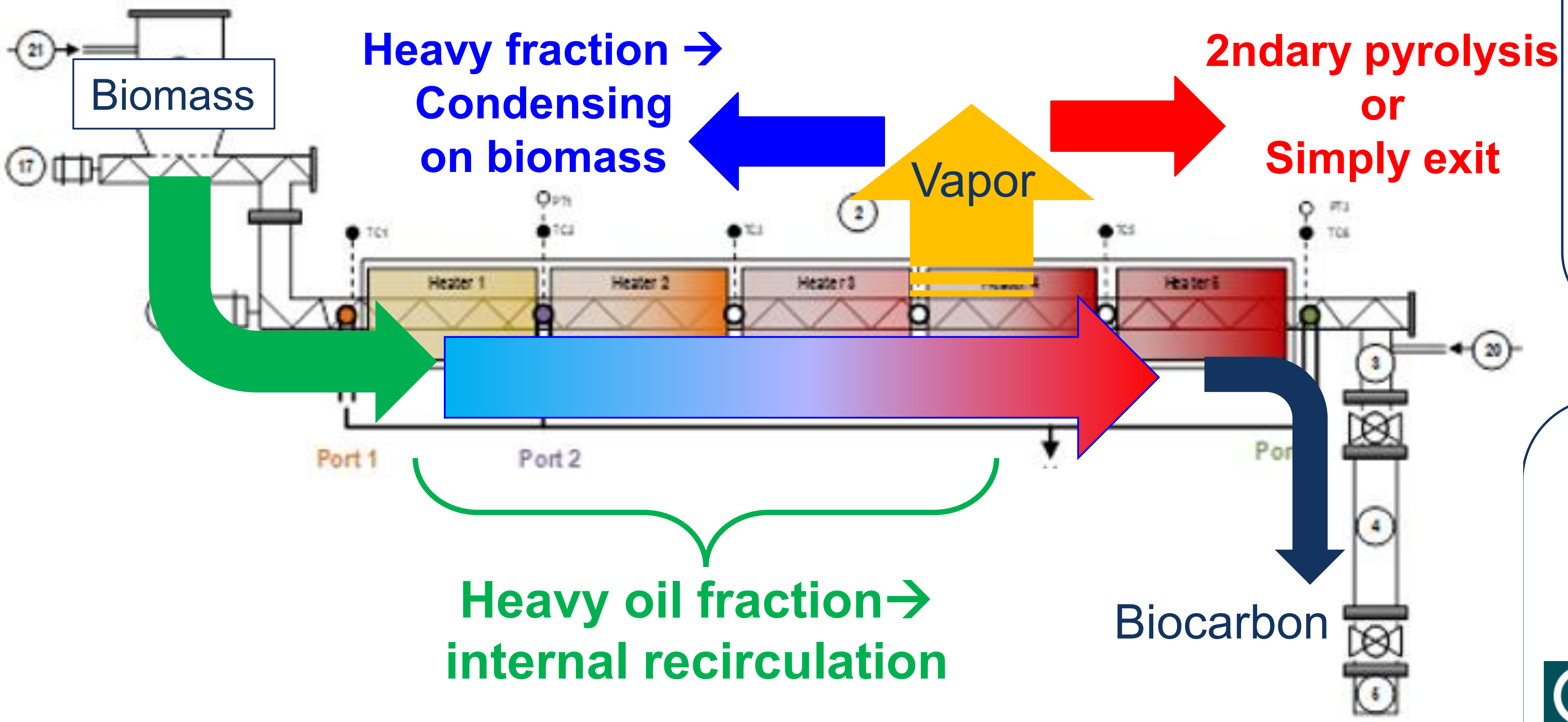


- Particles and composition of pyrolysis-oil.





Alternative 1:
Internal recirculation of pyrolysis oil (reactive distillation)



Biokolmet project

Swedish Energy Agency

FUTURE ECO NORTH SWEDEN AB

LULEÅ UNIVERSITY OF TECHNOLOGY

Harads Arctic Heat AB

Biocarbupgrade project

The Research Council of Norway

Elkem

eramet

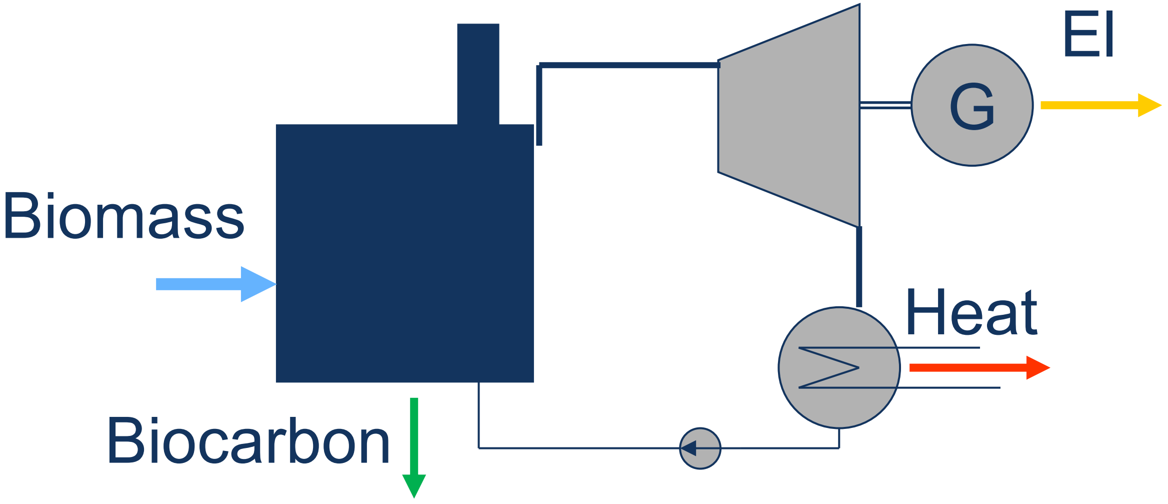
Hydro

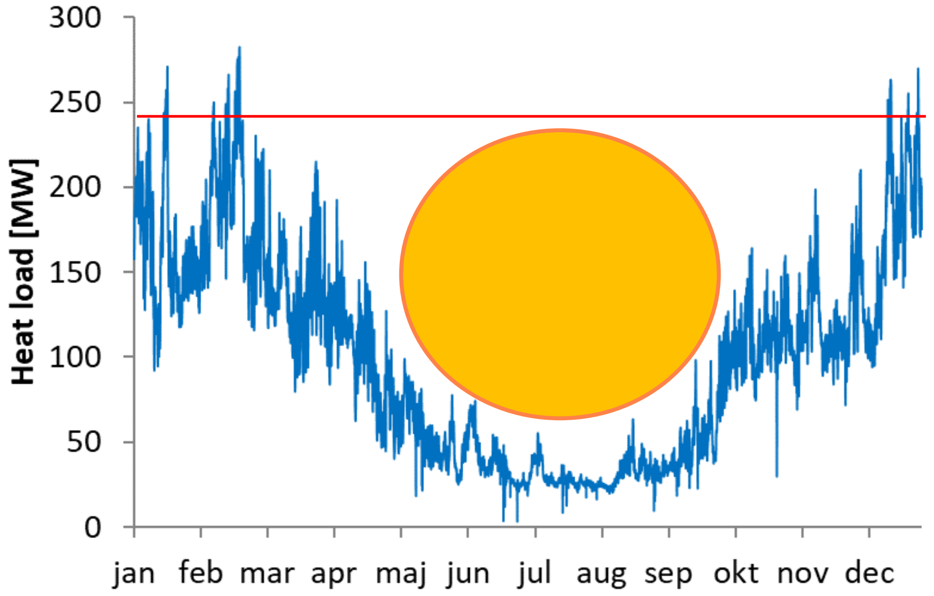
EYDE CLUSTER NCE EYDE Norwegian Center of Expertise Sustainable Process Industry

NORSKbiobrensel ET SELSKAP I ergon nordic

WAI Environmental Solutions

Alternative2:
Co-production of biocarbon from existing boilers





- Heating and CHP plants are operated at reduced load most of the year.
- Use of excess capacity in boilers to co-produce biocarbon
- Fluidized bed materials for heat supply
- Volatiles returned to the boiler and combusted for heat

BiokolFluidBed project

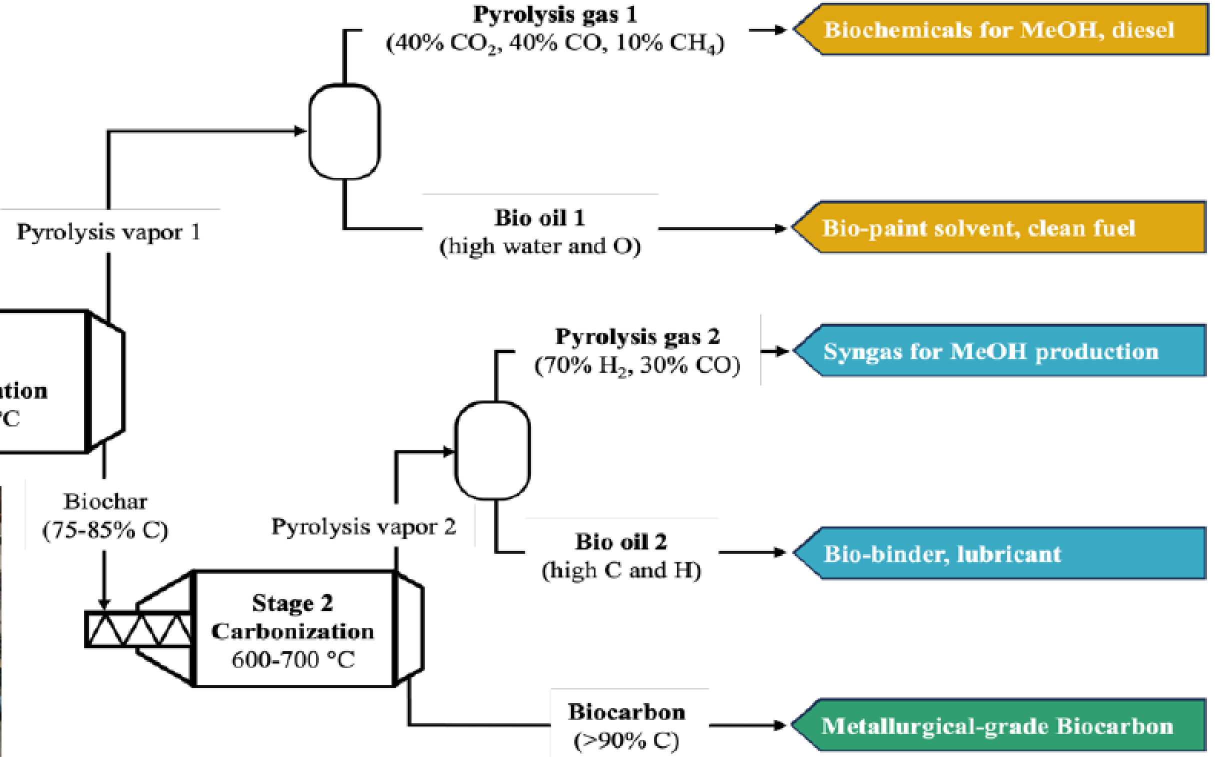
Swedish Energy Agency
CHALMERS UNIVERSITY OF TECHNOLOGY
SSAB
BIOSHARE
RISE
LULEÅ UNIVERSITY OF TECHNOLOGY
e.on
Höganäs

Alternative 3: 2-stage pyrolysis

- Low temperature devolatilization
  - increase final biocarbon yield by slower heating rate and selectivity of reactions
  - Mainly release O-containing gas and oil
- High temperature carbonization
  - Increase C and fix-C content of biocarbon
  - Release near O-free bio-oil

2StagePyro project

VINNOVA, envigas, outokumpu, LULEÅ UNIVERSITY OF TECHNOLOGY, STENA RECYCLING, SWERIM



Other on-going RD&I activities at LTU

- Manipulation of carbon nanostructures for reactivity controls
- Reduction of ash-forming elements by
  - Attrition in fluidized bed with partial oxidation
  - Post-pyrolysis leaching with targeted chemical properties of ash
- Improvement in bio-oil characterization
  - Molecular weight distribution (GPC) and fingerprint analyses (NMR)
- Avoidance of self-heating and ignition
  - Correlation with biocarbon properties
  - 3D numerical simulation of long-term storage

Comments on non-technical issues

- Metallurgical industry wants reliable, established biocarbon producers with large production capacity (>10 000 t/year).
- Large forest companies seem to be interested but hesitate to own production processes.
- Most biocarbon producers are start-up SMEs.
  - Dependent on the near-future possibility of gaining a large long-term contract.
  - Challenges: Muscles (financial and technical competence) to overcome the valley of death and technical challenges during the commissioning of FOAK plants.
- Strong commitment to ownership structures (either from the upstream or downstream side) is necessary.

Takehome messages

- Biocarbon is essential for future metallurgical processes no matter what technologies we use for defossilization
- Biocarbon production (pyrolysis) technologies are about to be commercialized with ca. 10- 20kt/year production plants
- Many technical challenges still exist, but also many potential solutions to them
- Academic-industry collaboration is essential to utilize science-based problem-solving during commissioning

Acknolwedgement

- Current and former group members
  - Aekjuthon ”Phai” Phounglamcheik
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  - Yusuf Tolunay Kilic
  - Zahra Ghasemi Monfared
  - Wenxuan Jia
  - Yasemin Gökyildiz
- Past and current collaboration partners
- All the funders!

Q & A