CTO of PyroCore Ltd. [2019-2024]

Background

I had previously done some work in 2015 for the first CEO of PyroCore Ltd., Linda Page, and she contacted me in June 2019 asking for some assistance with a small pyrolysis unit that had been built by 2 contractors – and was not working correctly. Linda had acquired ownership of the original company, DPS and changed the name to, "PyroCore Ltd." as pyrolysis was the core to the technological solution being offered by the company.

I therefore started off as an independent consultant to review an alleged 250 kg/h test rig located in Haybridge, west of Wells in Somerset and propose improvements, etc. to make it work better. The company who built the rig and were installing it were still onsite.

The Demonstrator [D1]

The D1 was built as a transportable, IED compliant system across 4 20' shipping Hi-cube containers. The 4 modules were:

1. Feed handling, PLC and entry to pyrolysis unit
2. Pyrolysis, gas oxidation and char removal
3. Heat recovery [steam boiler and condensation system]
4. Gas cleaning [ceramic candles with PAC/$NaHCO_{3(s)}$ dosing] and ID fan and CEMS

This is symbolised by the containers as shown in Figure 1 below and the overall flowsheet in Figure 2. One of the more unusual features of the system was that the kiln tube could be rotated, both directions, and the system had an internal screw. This presented sealing challenges.

An initial review of the system was made over a period of 3 months, with attempts to get it up and running and de-bug the system. The list of issues was extensive, here are some:

- Feed system did not seal well, and syngas would leak back out of the hopper.
- Kiln rotary seals simply failed to seal, despite being a "proprietary design". Seals had a very high expensive grease consumption to make them work.
- Feed system using a "proprietary" chain drag failed to work and constantly jammed.
- The CEMS package was very temperamental and required significant efforts to keep it operational and service engineers to replace parts- frequently.
- Char bins were fitted with nylon plugs on flanges leading to melting of these plugs, air ingress and one day, a bin deflagration.
- Dimensional changes in pipes cause feed blockages into the pyrolysis kiln.
- Char separator was not the right design to facilitate solids removal to char storage and fines removal from the syngas.
- Diesel burner was only low or high fire – zero modulation. When the burner came on, it would lead to a spike in emissions.

- Heat transfer to the kiln was poor – round tube in a square annulus. Combusted gas flow around the kiln was not evenly distributed so conversion rate was 100-150 kg/h and not 250 kg/h.
- Gas flow to gas cleaning had been grossly over-estimated – gas flow to the candles was poor and caused bad solids distribution.
- Char separator took days to heat up, leading to tar condensation and char accumulation on the walls. Lining was 20cm thick of refractory.

We spent months trying to debug the plant and make it work, but realised that a massive upgrade would be required to address various issues and failures A programme was agreed and modifications scheduled into Q3, 2020. The agreed list of upgrades of the D1 were also to coincide with the construction of a new Aganto building for the unit, which would be more permanent and have a much more secure facility and allow feedstock preparation inside the building. The list of upgrades included:

- New Untha shredder for those wastes not delivered to specification.
- New Coveya feed conveyor and hopper at ground level
- New feed system with 2x Vortex slide valves and dust extraction
- New syngas gas sampling to Gasmet DX-4000 FTIR analyser
- New kiln screw
- Modifications to Glosfume filtration system to improve solids distribution within the box to minimise lost reagents.
- Steam boiler overhaul
- Improvements to the syngas ducting
- Addition of more instrumentation around the pyrolysis kiln
- Rotating seals replaced with Eagle Burgmann seals.
- Gas fan replacement in 2022 after fan failure.
- Better servicing and maintenance of the CEMS package
- Modulating diesel burner
- Switching the PLC to a Siemens based system
- New stack flowmeter
- Verder dosing package for urea into the combusted gases
- New char colling screw from Ajax Equipment to drop char into UN oversize drums
- Numerous other minor upgrades

Most of this work was scheduled from June 2020, due to delays encountered over lockdowns for the CV-19 outbreak, so there were personnel delays on site access for months and work took place in June to August 2020 to get the new building finished and the 4 containers relocated. Two of the containers were outside the building: heat recovery and gas cleaning, while the feed handling, pyrolysis kiln and char recovery with cooling package were indoors with the Untha shredder. A "re-launch" of the new system took place in September, fully operational on wood and other materials. In order to expedite the re-build, the char separator was left and pre-heated during start-up.

Figure 1. **Pyrolysis kiln Demonstrator original layout, August 2019– 4 containers [L] and walking floor feed system [R]. Yes, that is myself**

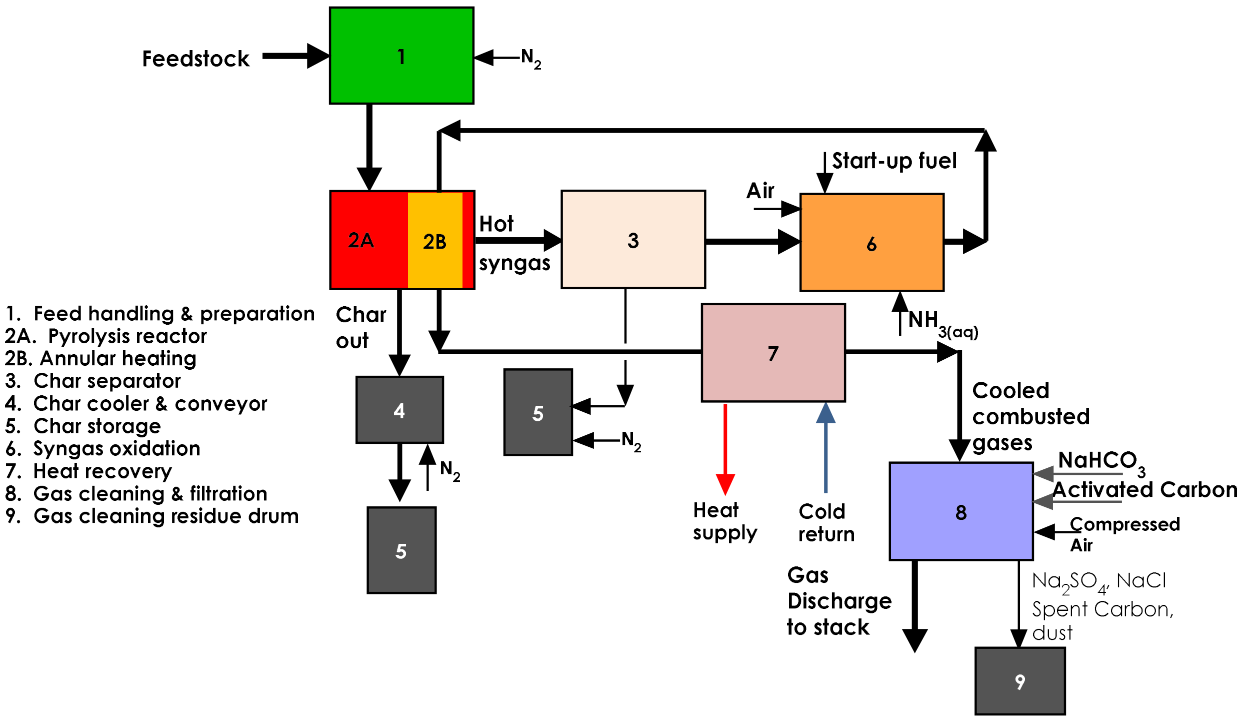

Figure 2. **Simplified Process Flowsheet for the Demonstrator**

Process Description for the PyroCore Process Demonstrator [D1]

Feedstock is delivered at ground level to a feed bin at the bottom of a belt conveyor. The feedstock is conveyed at a controlled rate into the lockhopper of the process [1]. This consists of 2 slide valves which meter feedstock into the pyrolysis process. Feedstock is metered into the pyrolysis reactor [2] where it is rapidly heated and achieves a final temperature of ~400-800+°C, subject to the objective of the process. This high temperature ensures rapid conversion of the material to a solid char, or charcoal and a combustible raw syngas.

The pyrolysis reactor is heated by the burnt raw syngas generated by the process. The raw syngas is oxidised and controlled to a temperature of >850°C with a residence time of >2s, subject to the material being processed. The hot gases pass into a char separator [3] and the hot char from the process drops onto a cooled char discharge screw [4] out of the pyrolysis kiln and into a an N_2 purged char receiver [5], allowing safe storage of the charcoal. The char is then removed to storage.

The remaining hot syngas is burned in the thermal oxidiser [6] with excess air and this excess air also controls the temperature of the burnt gases. For leather wastes or other high N containing wastes, $NH_{3(aq)}$ may be required to abate NOx.

The hot combusted gases are drawn through the process by the ID fan and passed through a heat recovery unit [7] where heat can be removed for other applications, e.g., district heating or used in an ORC for power generation. The heat recovery unit was a steam boiler generating steam at 14 bar g, which is immediately cooled upon generation and hot water returned to a hot well and subsequently back into the boiler.

Once the cooled gases exit the heat recovery, typically around 180-250°C, their composition is adjusted to remove acid gases by dosing reagents [sodium bicarbonate and/or activated carbon as required] into the gas stream prior to the recovery of the spent reagents in the gas cleaning system [8]. The spent reagents and dust are backpulsed off the candles using air and collected in a discharge screw, dropping the dust into a standard drum [9]. The drum is removed periodically based on its fill level. The char is then stored in drums prior to disposal or removal offsite for client use.

The filtered gases are then drawn into the ID fan and discharged to stack or atmosphere as required at a safe level. CEMS allows compliance of the emissions with national and international standards. Not all of the process streams are shown in Figure as there is no mass flow of $NaHCO_{3(s)}$ or activated carbon for waste wood.

Once re-installed over the summer, the unit was now in a purpose built structure and more capable of handling a wide variety of materials. This is shown in Figure 2 above.

A marketing suite/office was also installed at site for visitors and to allow tours of the unit and then any Q&A afterwards. This was much better than the previous arrangements in Portakabin's.

In late 2019, I was appointed as the full-time CTO for the company and took on a wide number of tasks, aside from upgrading the D1, my primary focus became the design and build of the next unit: a skid mounted, IED compliant, 500 kg/h [dry biomass] system with heat recovery and gas cleaning.

Figure 3. Pyrolysis kiln Demonstrator – new building and office/marketing suite

Figure 4. Coveya hopper and feed conveyor to feed hopper and Pyrolysis kiln, char cooling and recovery into barrels.

Char recovery into barrels allowed mass balances to be carried out in conjunction with syngas and stack gas analyses. Materials could also be shredded and weighed before being added to the Coveya hopper. This also allowed clients to come to site and monitor trials on their materials. Samples of char could also be provided on the spot to clients for their own testing and bulk samples later if needed.

The plant was moved to a new site in Avonmouth in July 2022 to consolidate activities on one site. The steam boiler was also replaced with a new de-superheater. The P1 started construction there in January 2021, completed September 2021 and commissioned.

D1 Feedstock testing

The D1 then entered an extensive testing phase of client enquiries for their feedstocks. The P1 was being designed and would not be ready for another year, so the D1 was the workhorse for testing materials – the list was extensive. Its not possible to review all of the feedstocks trialled, biomass types good, some wastes were terrible in terms of preparation and handling, but the onsite team carried out a wide range of trials, some for over 5 days as proof of processing and consistency, though the manpower commitment was tough. Some wastes and biomass types are noted below:



SRF	**RDF**	**Car seats**



Glass fibre composite	**Mixed plastics**	**Al scrap with plastics**



Wood chip	**Hemp**	**Cocoa shells**



Straw	**Miscanthus**	**Leather (wet blue)**

Other materials included whole tree chip [mixed hardwoods], arboriculture wastes, chicken litter, dried biodigestate, PAS100, pine, willow, wire wastes, shredded wire waste; PET, plastics bottles, cardboard, shredded wind turbine glass fibres, scrap Al wastes.

PyroCore Ltd. was awarded a mall Innovate UK grant to pyrolyse shredded wind turbine blade, which we managed to do and make a recovered glass fibre with a reasonable mechanical strength.

MoD: Prince of Wales and Queen Elizabeth – Aircraft Carriers

ST150 Pyrolysis machine was originally fitted to HMS Ocean in 2007 due to interest from the Royal Navy and Qinetiq. Royal Navy still keen on the idea of novel waste destruction techniques, and agreed to fit 2 pyrolysis machines to each of its aircraft carriers: their principle goal – to reduce waste volume only (waste destruction) Pyrocore Ltd., although not the OEM, are committed to support and assist important upgrades and maintenance to get fully functioning and safe plants.

PyroCore Ltd. had contracts with the Royal Navy/Ministry of Defence to upgrade the 4 pyrolysis plants on the 2 new aircraft carriers, the plants originally provided by DPS. As the units had been delivered to the MoD over 10 years ago, there was ongoing work to replace time obsolete parts and make improvements, which was handled internally. The unit designation was ST150 as the throughput was around 150 kg/h. The overall system is shown in Figure 5 below.

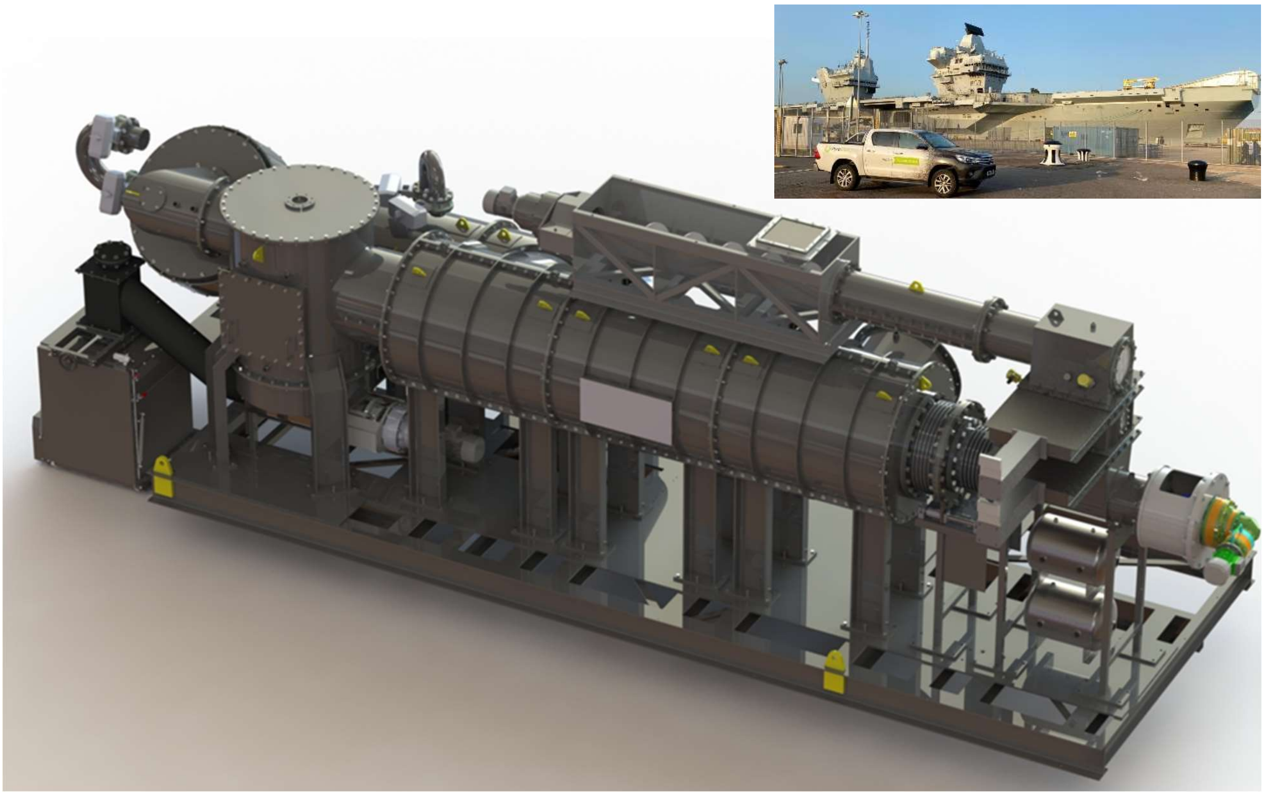

Figure 5 ST150 pyrolysis system for the MoD

The MoD has also publicly noted the success of these units and further information can be found here:

- https://www.royalnavy.mod.uk/news/2019/november/01/191101-carrier-green-waste-system
- https://scispace.com/pdf/vaporise-after-reading-pyrolysis-and-waste-management-on-2ly2ni8k.pdf

To investigate how the MoD shipboard wastes performed in terms of environmental compliance in the D1, wastes were processed with MoD staff present in July 2021 and full compliance under IED was achieved.

The 500 kg/h pyrolysis plant – the Phoenix [P1]

As note earlier, one of my primary roles was the process design of a larger plant, capable of at least 12 t/d dry biomass. I won't review the review and design process involved from concept to the detailed design, etc., but the overall process was to be capable of processing any wastes to comply with MCPD for clean/virgin biomass and related wastes and other categorised wastes under IED. The process flowsheet is given in Figure 6.

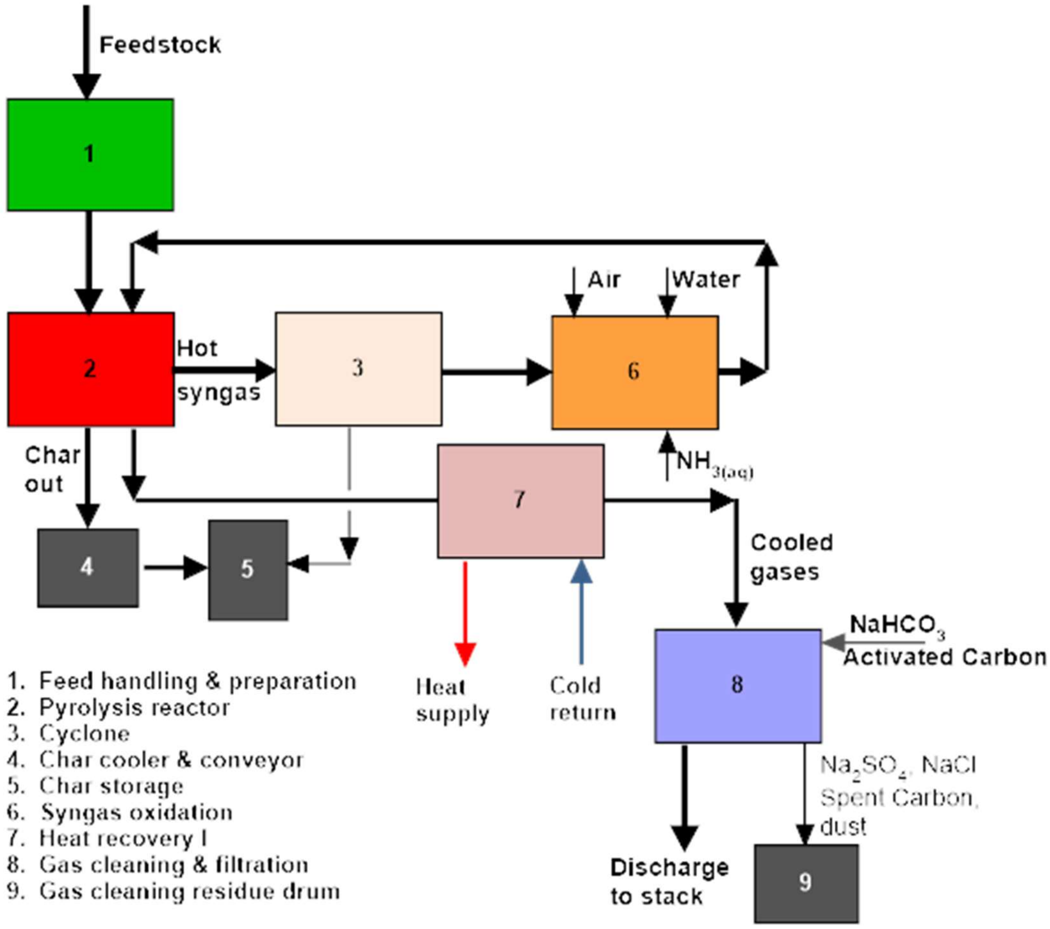

Figure 6. Process flowsheet: Phoenix 500 kg/h pyrolysis kiln [P1]

$NH_{3(aq)}$ dosing was added as some feedstock generate a lot of NOx in the raw syngas to reduce the final emissions from the thermal oxidiser. High N containing feedstocks definitely benefit from dosing into the exit of the oxidiser.

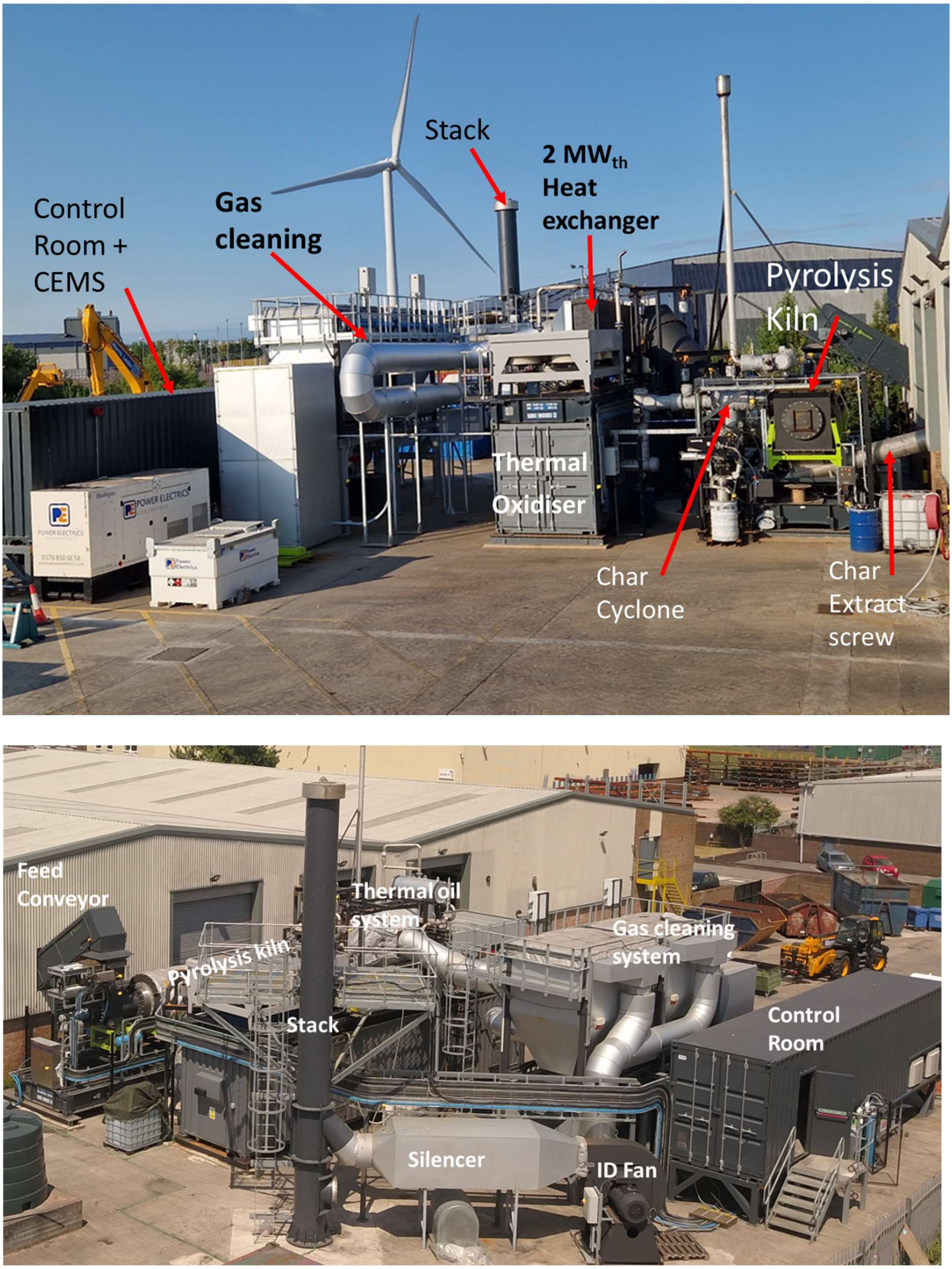

Figure 7. PyroCore Ltd: Phoenix 500 kg/h pyrolysis kiln [P1, 2021-2024]

Feedstock is delivered at ground level to a feed bin at the bottom of a belt conveyor. The feedstock is conveyed at a controlled rate into the lockhopper of the process [1]. Feedstock is metered into the pyrolysis reactor [2] where it is rapidly heated and achieves a final temperature of ~400-800+°C, subject to the objective of the process. This high temperature ensures rapid conversion of the material to a solid char, or charcoal and a combustible raw syngas.

The pyrolysis reactor is heated by the burnt raw syngas generated by the process. The raw syngas is oxidised and controlled to a temperature of >850°C with a residence time of >2s, subject to the material being processed. The hot gases pass into a cyclone [3] and the hot char from the process drops onto a cooled char discharge screw [4] out of the pyrolysis kiln and into a an N_2 purged char receiver [5], allowing safe storage immediately of the charcoal. The char is then removed to storage.

The remaining hot syngas is burned in the thermal oxidiser [6] with excess air and this excess air also controls the temperature of the burnt gases. For high N containing wastes, urea dosing in the thermal oxidiser may be required to abate NOx.

The hot combusted gases are drawn through the process by the ID fan and passed through a recovery unit [7] where heat can be removed for other applications, e.g., district heating or used in an ORC for power generation.

Once the cooled gases exit the heat recovery, their composition is adjusted to remove acid gases by dosing reagents [sodium bicarbonate and/or activated carbon as required] into the gas stream prior to the recovery of the spent reagents in the gas cleaning system [8]. The spent reagents and dust are backpulsed off the candles using air and collected in a discharge screw, dropping the dust into a standard drum [9]. The drum is removed periodically based on its fill level. The fine char is then stored in drums prior to use.

The filtered gases are then drawn into the ID fan and discharged to stack or atmosphere as required at a safe level. CEMS allows compliance of the emissions with national and international standards. Not all of the process streams are shown in Figure as there some mass flow of $NaHCO_{3(s)}$ or activated carbon for certain high S or Cl containing wastes and urea/NH_3 dosing for NOx abatement added as required.

SRF Pyrolysis at 600 kg/h

Following on from the theme of SRF pyrolysis, below is some data for the P1 operated on SRF. Over 25 feedstocks were processed by PyroCore Ltd. over 5 years and a number of mass and energy balances determined for client use from the trials. SRF was an interest to several European enquiries so this is of relevance.

One of my tasks was to collate all of the run data with the measured inputs, outputs and detailed product analysis. Along with the Gasmet DX-4000, a syngas analyser – SWG-100 from EiUK was used to measure H_2 and H_2S that could not be determined by FTIR. This was complex and analytical data for the feedstocks and chars was obtained from Marchwood, which required some interpretation as high ash feedstocks are prone to have erroneously high ash values due to oxidation of the reduced metals in the char subsequently oxidising.

Mass Balance in the P1 for pyrolysis of 600 kg/h SRF

Based on my calculations, the process could handle 600 kg/h of dry SRF, due to a higher bulk density and lower pyrolysis energy requirement. A summary for the SRF is given in Table 1 below. Its also shown in Figure 8 on the process flowsheet.

Table 1. SRF Mass and Energy Balance

Inputs			**Outputs**		
Waste	600	kg/h	Gases out	9772	kg/h
Water In	23	kg/h	Char	163.5	kg/h
Air in	9368	kg/h	Residues	13.1	kg/h
Cooling water	0	kg/h			
Reagents	24	kg/h			
N_2 Purge	2	kg/h			
Total:	**10015**	kg/h	**Total:**	**9949**	kg/h

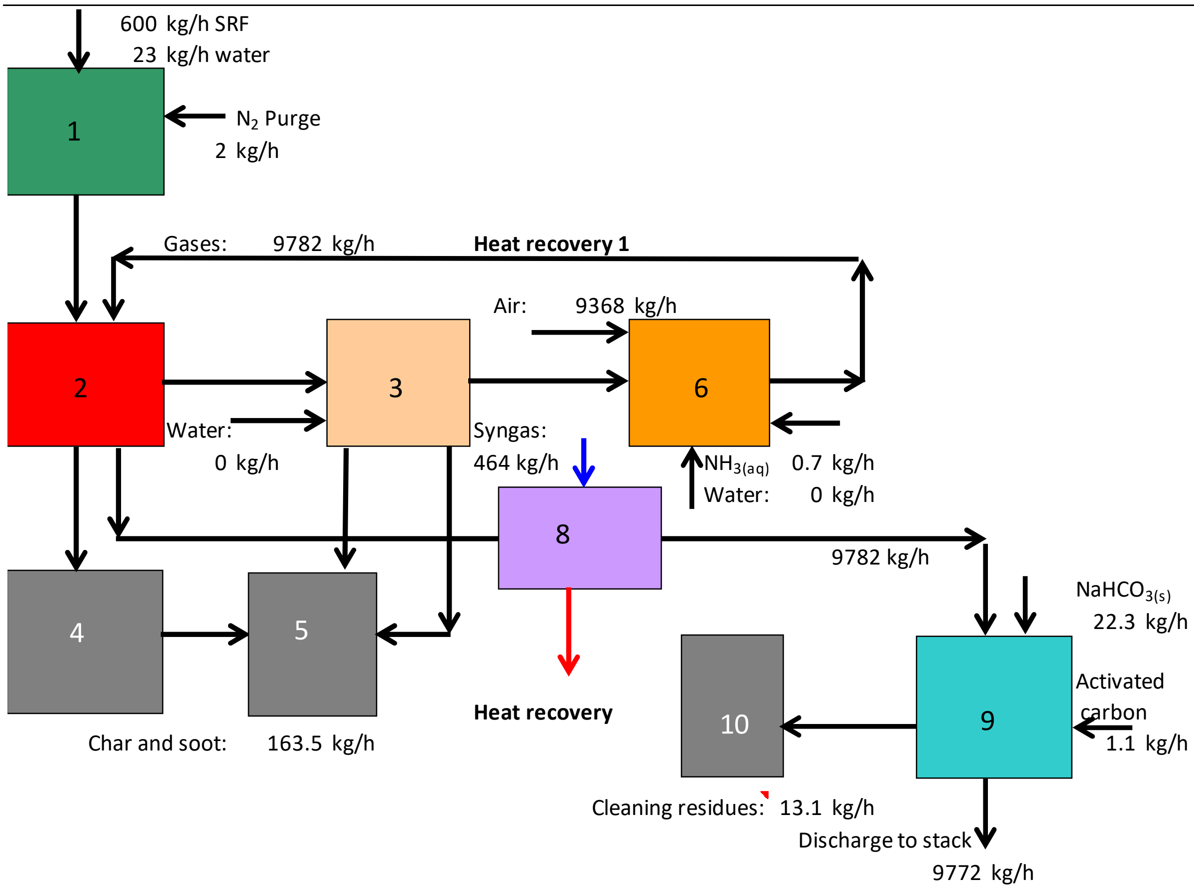

Figure 8. PyroCore Ltd Mass and Energy Balance on SRF [P1]

Energy Balance in the P1 for pyrolysis of 600 kg/h SRF

The overall energy balance for the SRF is given in Figure 9.

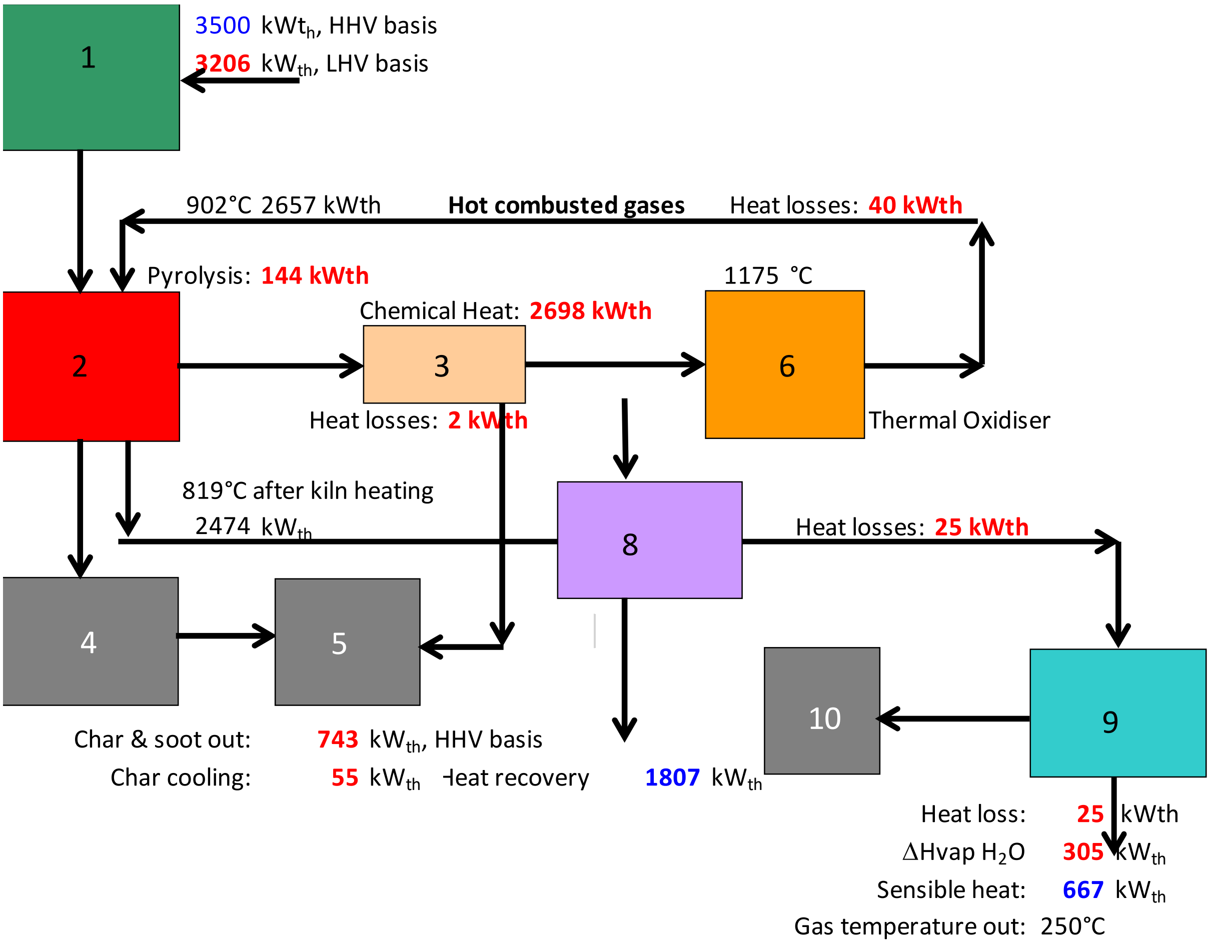

Figure 9. PyroCore Ltd Energy Balance on SRF [P1]

The SRF had an LHV of 20.3 MJ/kg dry. The ash content was high at 14.6 wt%. If there is not a commercial use for the char, options to oxidise the char were also considered and mass and energy balances constructed.

Heat recovery shows that 58% of the input waste energy can be recovered as heat and this can be improved by further gas cooling to recover DHvap H_2O and or utilise it elsewhere in the process, i.e, for drying if needed.

By combusting the char heat recovery can be further enhanced and disposal costs avoided for the char and the ash disposed of at a lower cost. The heat recovery would increase to 73% of the input feedstock CV.

Cost Models

A detailed cost model utilising the trial data was used to assist clients in making a commercial determination. As the work was generally carried out on the P1, the client would know that the results on their feedstock were the results that they would get.

Biochar and Properties

Due to the increasing demand for CDR, biochar is a priority material for CO2 credits and its use as a soil amendment. PyroCore Ltd. processed over 15 biomass types for biochar and had independent verification of the results were carried out by Eurofins in Germany, the only EBI accredited laboratory in Europe.

The results below were presented at the IrBEA Conference in Carrick-on-Shannon in May 2023. Note that the Eurofins report is over 15 pages long so only key data relating to H/C_{org} and Σ16 PAHs and dioxins/PCBs are presented.

The C_{org} is excellent at 89.4wt%, but the Severn Wye plant, a copy of the P1 has delivered char of > 92wt% C. The Σ16 PAHs is 7 mg/kg as shown in Figure 11, but the measurement error is quite high [±2.4 mg/kg], so may/not meet FeedPlus grade. As can be seen in Figure 12, the dioxins and PCBs are well below the limits.

Whole tree chip Biochar Analysis

eurofins | Umwelt

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											Description		G30 Woodchip Char - 27th February		
											Date and time of sample taking		2023-02-27		
				Limit values							Sample number		123034313		
Parameter	**Lab**	**Accr.**	**Method**	1) EBC-FeedPlus	2) EBC-Feed	3) EBC-Agro Organic	4) EBC-Agro	5) EBC-Urban	6) EBC-Consumer Materials	7) EBC-Basic Materials	**LOQ**	**Unit**		**ar**	**db**
Biochar properties															
Bulk density < 3 mm	FR		based on VDLUFA-Methode A 13.2.1									kg/m³	-	-	119
specific surface (BET)	SND2/o		DIN ISO 9277: 2014									m²/g	-	-	336.94
water holding capacity (WHC) < 2 mm	FR		DIN EN ISO 14238, A: 2014-03									%	-	-	245.6
Moisture	FR	F5	DIN 51718: 2002-06								0.1	% (w/w)	-	3.5	-
Ash content (550°C)	FR	F5	DIN 51719: 1997-07								0.1	% (w/w)	-	3.4	3.6
Ash content (815°C)	FR	F5	DIN 51719: 1997-07								0.1	% (w/w)	-	2.1	2.2
Total carbon	FR	F5	DIN 51732: 2014-07								0.2	% (w/w)	-	86.6	89.7
carbon (organic)	FR		Calculation									% (w/w)	-	86.3	89.4
Hydrogen	FR	F5	DIN 51732: 2014-07								0.1	% (w/w)	-	2.4	2.5
Total nitrogen	FR	F5	DIN 51732: 2014-07								0.05	% (w/w)	-	0.64	0.66
Sulphur (S), total	FR	F5	DIN 51724-3: 2012-07								0.03	% (w/w)	-	0.04	0.04
Oxygen	FR	F5	DIN 51733: 2016-04									% (w/w)	-	4.7	4.9
Total inorganic carbon (TIC)	FR	F5	DIN 51726: 2004-06								0.1	% (w/w)	-	0.3	0.3
carbonate-CO2	FR	F5	[illegible]								0.4	% (w/w)	-	1.1	1.2
H/C ratio (molar)	FR		Calculation										-	0.33	[illegible]
H/Corg ratio (molar)	FR		Calculation	< 0.4	< 0.4	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7			-	0.33	0.33
O/C ratio (molar)	FR		Calculation										-	0.041	0.041
Volatile Compounds	[illegible]	F5	DIN 51720: 2001-03								0.2	% (w/w)	-	9.5	[illegible]
gross calorific value (Ho,V)	FR	F5	DIN 51900-3: 2005-1								200	kJ/kg	-	32400	33600
net calorific value (Hu,p)	FR	F5	DIN 51900-3: 2005-1								200	kJ/kg	-	31800	33100

H/C_{org}

O/C_{org}

25

Figure 10. Eurofins data on whole tree chip biochar: *H/C_{org}* and *C_{org}* content

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Description	G30 Woodchip Char - 27th February
Date and time of sample taking	2023-02-27
Sample number	123034313

Parameter	Lab	Accr.	Method	1) EBC-FeedPlus	2) EBC-Feed	3) EBC-Agro Organic	4) EBC-Agro	5) EBC-Urban	6) EBC-Consumer Materials	7) EBC-Basic Materials	LOQ	Unit		ar	db
				Limit values											
Organic contaminents from toluene extraction acc. to EN 16181:2019-08 (method 2)															
Naphthalene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	4.1
Acenaphthylene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Acenaphthene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Fluorene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	0.2
Phenanthrene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	1.4
Anthracene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	0.3
Fluoranthene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	0.4
Pyrene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	0.4
Benz(a)anthracene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	0.1
Chrysene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	0.1
Benzo(b)fluoranthene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Benzo(k)fluoranthene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Benzo(a)pyrene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Indeno(1,2,3-cd)pyrene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Dibenz(a,h)anthracene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Benzo(g,h,i)perylene	FR	F5	DIN EN 16181:2019-08								0.1	mg/kg	-	-	< 0.1
Total 8 EFSA-PAH excl. LOQ	FR	F5	DIN EN 16181:2019-08	1	1	1	1	1	1	4		mg/kg	-	-	0.2
Total 16 EPA-PAH excl. LOQ	FR	[illegible]	DIN EN 16181:2019-08	6 1)		6 1)	6 1)					mg/kg	-	-	7.0
Benzo(e)pyrene	FR	F5	DIN EN 16181:2019-08	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.1	mg/kg	-	-	< 0.1
Benzo-(j)-fluoranthen	FR	[illegible]	DIN EN 16181:2019-08	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.1	mg/kg	-	-	< 0.1
Special analyses															
Plausibility check	FR												-	OK	-

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Figure 11. Eurofins data on whole tree chip biochar: PAH content

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Description	G30 Woodchip Char - 27th February
Date and time of sample taking	2023-02-27
Sample number	123034313

Parameter	Lab	Accr.	Method	1) EBC-FeedPlus	2) EBC-Feed	3) EBC-Agro Organic	4) EBC-Agro	5) EBC-Urban	6) EBC-Consumer Materials	7) EBC-Basic Materials	LOQ	Unit		ar	db
				Limit values											
1,2,3,4,7,8-HexaCDF	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.04	ng/kg 88% DM	< 0.04	-	-
1,2,3,6,7,8-HexaCDF	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.04	ng/kg 88% DM	< 0.04	-	-
1,2,3,7,8,9-HexaCDF	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.04	ng/kg 88% DM	< 0.04	-	-
2,3,4,6,7,8-HexaCDF	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.04	ng/kg 88% DM	< 0.04	-	-
1,2,3,4,6,7,8-HeptaCDF	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.22	ng/kg 88% DM	< 0.22	-	-
1,2,3,4,7,8,9-HeptaCDF	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.22	ng/kg 88% DM	< 0.22	-	-
OctaCDF	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.44	ng/kg 88% DM	< 0.44	-	-
WHO(2005)-PCDD/F TEQ (lower-bound)	SCT6/o	A04	Verordnung (EG) Nr. 152/2009									ng/kg 88% DM	0.00	-	-
WHO(2005)-PCDD/F TEQ (upper-bound)	SCT6/o	A04	Verordnung (EG) Nr. 152/2009	0.75	0.75						0.11	ng/kg 88% DM	0.11	-	-
WHO(2005)-PCDD/F+PCB TEQ (upper-bound)	SCT6/o	A04	Verordnung (EG) Nr. 152/2009	1.25	1.25						0.17	ng/kg 88% DM	0.17	-	-
Polychlorinated biphenyl (12 WHO PCB) by GC-HRMS															
PCB 77	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								4.4	ng/kg 88% DM	5.1	-	-
PCB 81	SCT6/o	A04	Verordnung (EG) Nr. 152/2009								0.40	ng/kg 88% DM	< 0.40	-	-

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Figure 12. Eurofins data on whole tree chip biochar: Dioxins an PCBs

Optimisation Throughput of the P1 for CDR

One of the important aspects is how to optimise a feedstock to get a high grade biochar and achieve a good throughput and not operate at extreme conditions. Figure 13 shows the effect of throughput, reactor temperature and the overall CO_2e sequestered.

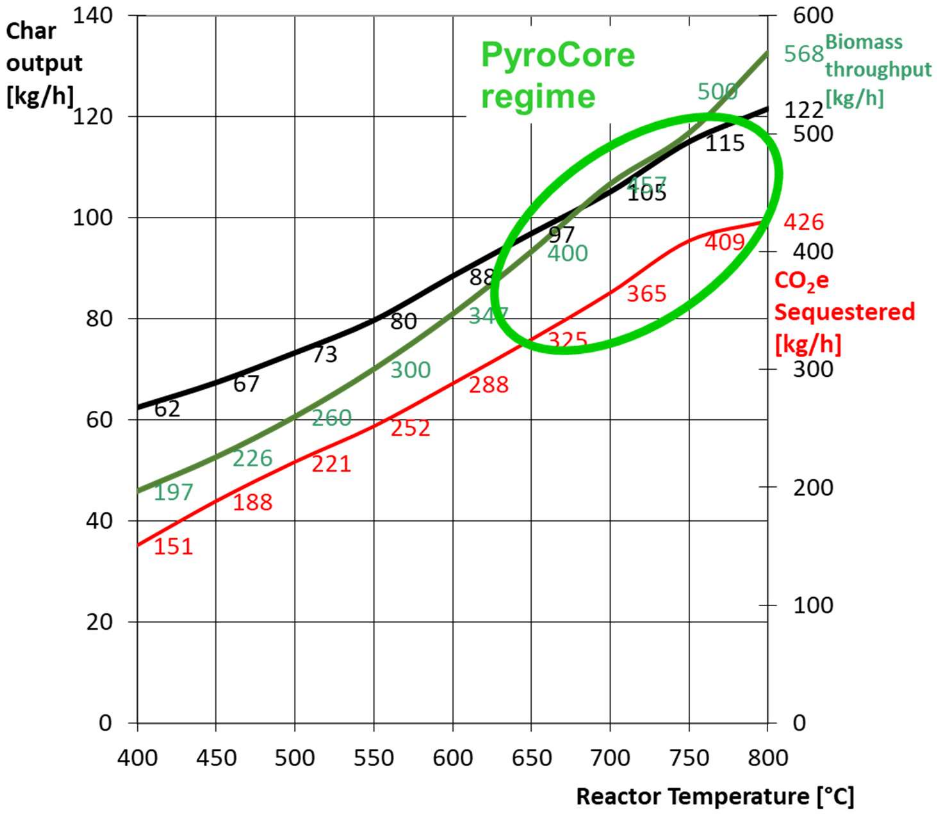

Figure 13. CO_2e sequestration as a function of biomass input, char yield and char C content

Pushing the process for more CO2e may not be worth it as the C content of the char reaches an asymptote and the energy efficiency of the process drops.

Conclusions

In my time at PyroCore Ltd., the company developed a TRL-9 IED and/or MCPD compliant pyrolysis system as evidenced by the commercial sale to Severn Wye/Mersy Biochar. I got to see the plant in operation in August 2025, running and making biochar.
The technical requirements were met, 2 plants we up and running. The plant operated at the 500 kg/h and was environmentally compliant and an LCA was needed to confirm its CDR credentials, but this was not done in my time.

Please check out the Severn Wye plant at:

https://merseybiochar.co.uk

https://biochartoday.com/blog/ibi-study-tour-day-1-severn-wye-biochar

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Severn Wye Biochar and site.