CLC of waste-derived fuel and biomass in a 150-kW pilot unit

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The "CLC-SRF" project is funded by Gassnova through the Norwegian CLIMIT-Demo programme (grant No. 620066)

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Background

- Carbon dioxide removal (CDR) technologies are needed to a large extent (IPCC, IEA)
- Bioenergy with carbon capture and storage (BECCS) can play a major role as CDR technology
- CLC is a highly relevant BECCS technology
  - Can provide negative CO_2 emissions at high efficiency and low cost using biomass and waste-derived fuels containing biogenic carbon

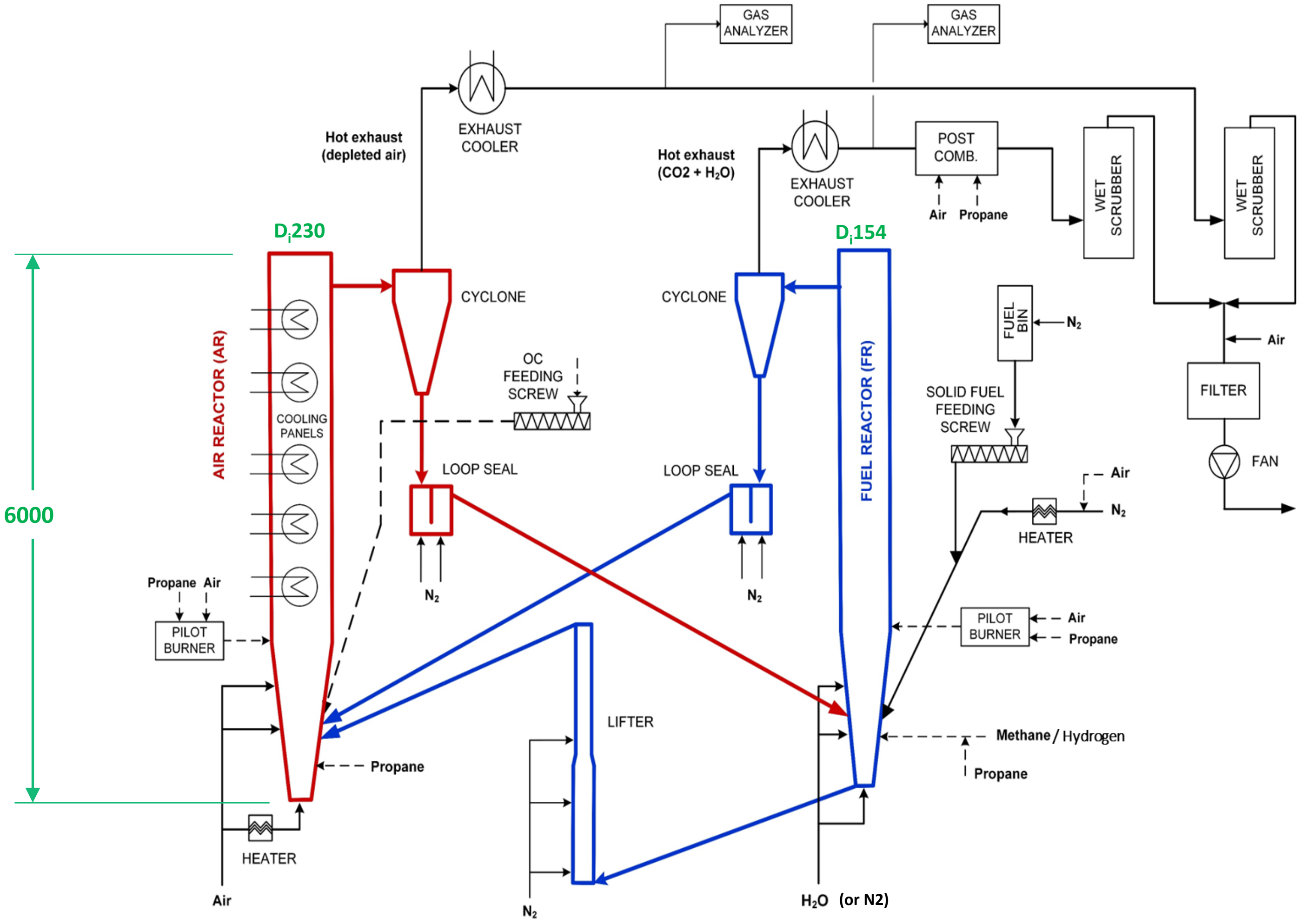
- Scope of this study
  - Test SRF waste-derived fuel in the 150 kW_{th} pilot unit at SINTEF Energy Research
  - Compare performance with biomass as a reference fuel
  - Evaluate CO_2 capture rate in view of the reactor design, which is without a carbon stripper

- *IPCC (2018) Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels.* ***CDR 3.5–16 Gt CO2/year in 2050***.
- *IEA (2021) Net Zero by 2050 - A Roadmap for the Global Energy Sector.* ***CDR about 1.9 Gt CO2/year in 2050***.
- *IPCC (2022) Working Group III report to Sixth Assessment Report.* ***Larger contribution on CDR compared to previous assessments***.

Reactor system

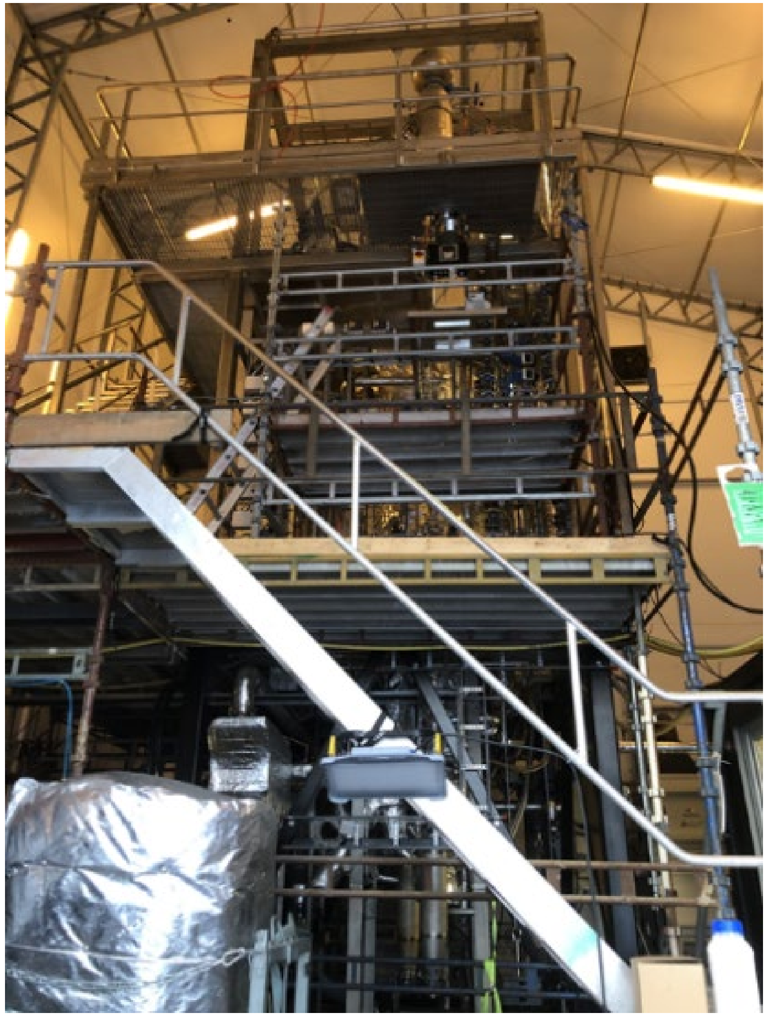
Gas analyzis

- Fuel reactor outlet gas ($CO2$,CO ,$O2$,$H2$,$N2$,$CH4$,$C2H_X$,He)
- Air reactor outlet gas (CO_2 ,CO ,O_2)



In addition: FR and AR exhaust OC collecting buckets plus low velocity settling chambers

Pictures



Fuels and oxygen carrier material

SRF waste-derived fuel

Loose form

16 mm pellets

8 mm pellets

Biomass fuel

8 mm pellets

Milled and sieved

Milled and un-sieved

Fuel composition (wt-% a.r.), Φ_0 , and lower heating value
(For the SRF waste, about 40-50% of the carbon is biogenic)

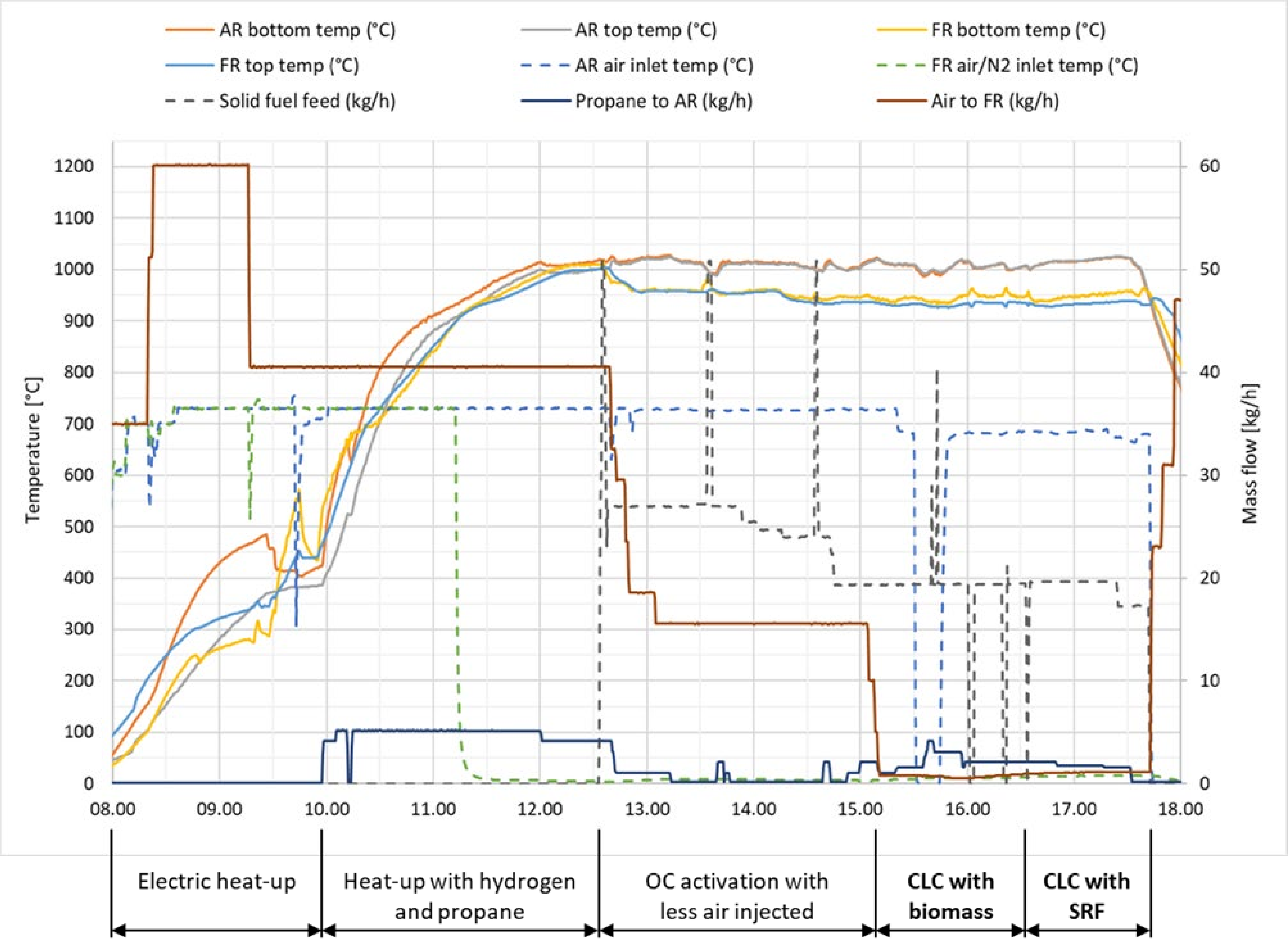
	C	H	O	N	S	Cl	Moisture	Ash	Φ_0 (*) (mol/mol)	LHV (MJ/kg)
SRF waste	51.6	8.9	20.5	1.2	0.14	0.49	2.76	14.4	1.35	20.4
Wood pellets	50.7	5.8	38.1	0.01	< 0.01	< 0.01	4.9	0.5	1.06	19.0

Ilmenite from Titania used as OC
Sieved to 120 – 200 µm
(normally using 40 – 120 µm)

Performance parameters

Fuel carbon conversion	$X_{fuel-C} = \frac{\left(x_{CO_2,FR} + x_{CO,FR} + x_{CH_4,FR} + 2x_{C_2H_y,FR}\right) F_{total,dry}^{FR}}{carbon\ in\ fuel\ feed\ to\ FR},$
FR oxygen demand	$\Omega_{OD} = \frac{0.5x_{CO,FR} + 2x_{CH_4,FR} + 0.5x_{H_2,FR} + 3x_{C_2H_y,FR}}{\Phi_0 \left(x_{CO_2,FR} + x_{CO,FR} + x_{CH_4,FR} + 2x_{C_2H_y,FR}\right)},$
FR gas conversion efficiency	$\eta_{gas} = 1 - \Omega_{OD}.$
CO_2 capture rate	$\eta_{CO2\ capture} = \frac{carbon\ in\ fuel\ feed\ to\ FR - carbon\ out\ from\ AR}{carbon\ in\ fuel\ feed\ to\ FR}.$
AR theoretical riser mass flow	$\dot{m}_{riser} = \frac{A}{g}\frac{\Delta p}{\Delta h}(u_0 - u_t)$

Overview of the test day

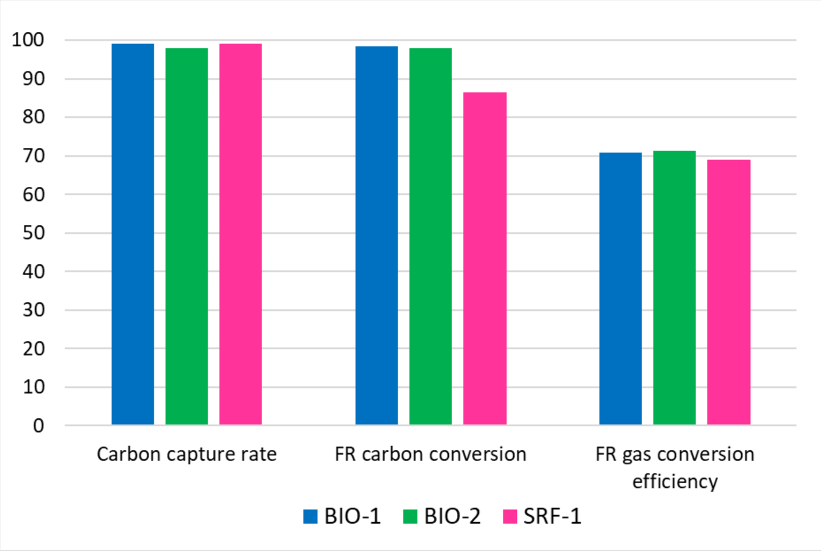


Only a short test due to limited amount of SRF

Results

Capture rate, FR carbon conversion and FR gas conversion efficiency

		BIO-1	BIO-2	SRF-1
Main operating parameters				
Solid fuel feed rate	kg/h	19,4	19,4	19,6
Solid fuel power	kWth	102,5	102,4	111,2
FR bottom temperature	°C	940	948	949
FR specific inventory	kg/MW	261	256	228
AR riser mass flow	kg/s	3,62	3,85	3,56
Performance parameters				
Carbon capture rate	%	99,0	97,9	99,1
FR carbon conversion	%	98,5	98,0	86,5
FR gas conversion efficiency	%	70,8	71,2	68,9

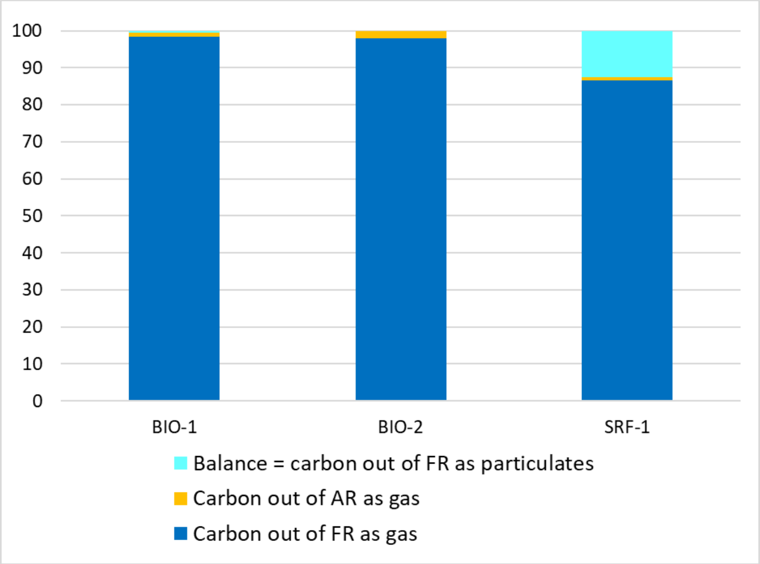


- High capture rate of about 98 %
- Rather low FR gas conversion efficiency, about 70 %
- The SRF case shows lower fuel carbon conversion than the biomass cases
- It seems to be more carbon-containing particulates leaving the FR in the SRF case compared to the biomass cases

Results

Carbon balance

		BIO-1	BIO-2	SRF-1
Carbon balance				
Carbon fed with solid fuel	kg/h	9,84	9,83	10,14
Carbon fed with solid fuel	%	100	100	100
Carbon out of FR as gas	%	98,4	98,0	86,5
Carbon out of AR as gas	%	1,0	2,0	0,9
Sum carbon out FR + AR as gas	%	99,4	100,0	87,4
Balance = carbon out of FR as particulates	%	0,6	0,0	12,6



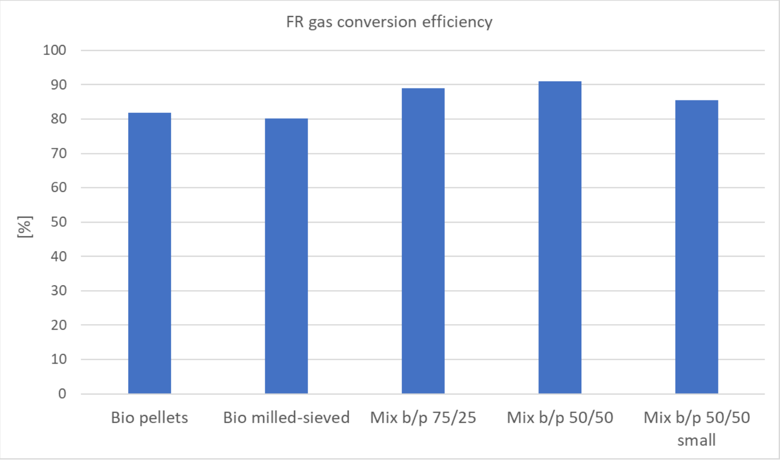
- The carbon balance illustrates the same:
  More carbon-containing particulates seem to leave the FR in the SRF case compared to the biomass cases
- But they were not found in the OC collecting bucket or the low-velocity settling chamber in the FR exhaust line
- Most likely they are captured in the wet scrubber, as experienced earlier using petcoke as fuel

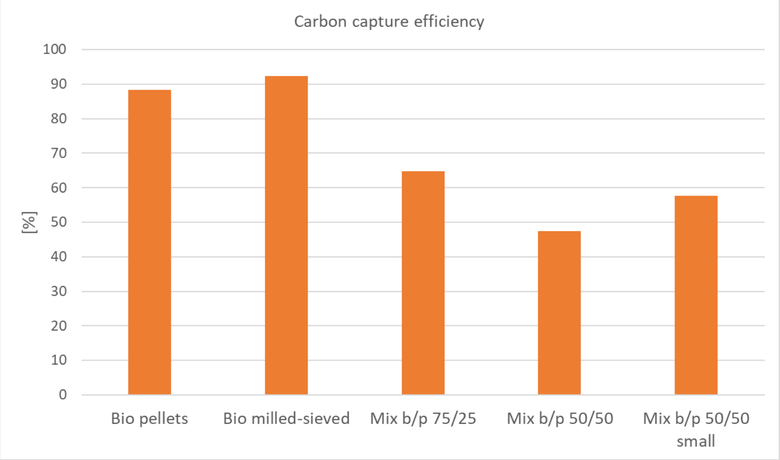
Comparison with earlier results

Biomass milled and sieved + petcoke 315-500 µm

Biomass milled and un-sieved + petcoke 100-315 µm plus fines

		Biomass pellets	Biomass milled and sieved	Mix bio/petcoke 75/25	Mix bio/petcoke 50/50	Mix bio/petcoke 50/50 smaller
Main operating parameters						
Solid fuel power	kW_{th}	108,6	99,7	80,5	93,1	109,4
FR bottom temperature	°C	996	976	973	974	966
FR specific inventory	kg/MW	253	122	249	243	262
AR riser mass flow	kg/s	7,4	3,4	4,7	4,8	4,8
Performance parameters						
Carbon capture rate	%	88,3	92,3	64,8	47,5	57,6
FR gas conversion efficiency	%	81,9	80,2	89,1	90,9	85,5





- Earlier tests with <u>smaller ilmenite size</u>, higher FR temperatures and generally higher AR riser mass flow
- The earlier tests show about 10 %-points higher FR gas conversion efficiency, and about 8-9 %-points lower capture rate

Summary and conclusions

- SRF waste fuel in form of pellets was injected without problems such as clogging etc., and operation in CLC mode was stable
- The carbon capture rate was high both for the SRF case and the reference biomass cases, about 98 %. This was higher than expected based on some earlier results using biomass
- The FR gas conversion efficiency was just about 70 %. This was lower than expected based on the earlier results
- The SRF case showed significantly lower FR carbon conversion than for the biomass cases (86.5 % versus 98 %). Uncertainties (e.g., fuel feed rate and fuel composition) can likely not explain such large difference
- The tests needed some propane firing in the AR but still the FR temperature was not as high as earlier tests
- The pilot unit does not include a carbon stripper. For reactive fuels, such as SRF and biomass, the results show that a high capture rate can still be obtained in this reactor design
- Further tests will be performed with longer duration (more fuel available) and a new and smaller size ilmenite oxygen carrier
  - to possibly improve the FR carbon conversion and gas conversion efficiency
  - to further evaluate the difference in FR carbon conversion between SRF and biomass
  - to possibly improve the heat balance, FR temperature and reduce AR propane firing
  - to assess the impact of ash

Thank you for your attention!

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Acknowledgements

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(New tests with SRF and biomass)

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(Earlier tests with biomass and petcoke)

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