Modelling the integration of slow pyrolysis of residual biomass in the steelmaking sector: a techno-economic analysis

A. Salimbeni[1,2], G. Talluri, D[1,2]. Chiaramonti[3], A.M. Rizzo[1,2]

1. *RE-CORD: Renewable Energy Centre for Research and Demonstration*
2. *University of Florence*
3. *Polytechnic of Turin*

Achieving Net Zero Carbon Goals – the Role for Biomass

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Market Uptake Support for Intermediate Bioenergy Carriers

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Introduction

Volumes and CO_2 emissions of Steel sector*

World steel production	1.691 Mt
Europe Steel production	177.2 Mt
Italian Steel production	24 Mt

**data referring to year 2019*

CO_2 emission per ton of steel produced by Blast Furnaces — 2.3 t CO_2/t steel

Steel sector contribution to global CO_2 emisisons — 6%

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Introduction

Coal use in the steelmaking sector

Coal and coke are generally used into the blast furnaces, either as C-source to remove oxygen from iron oxides to produce steel, or to provide heat to the process.

- coke-making for production of bio-coke;
- sintering process for production of bio-sinter;
- pelletizing/briquetting for use in EAF;
- partial replacement of PCI injected into the blast

Property	Value	Measure Unit
Carbon Content	88.83	%wt
Ash Content	10.20	%wt
Volatiles	0.57	%wt
S	0.49	%wt

Table 1. Coke properties for a sample used in a polish plant.

To replace fossil coal, renewable carbon in the form of charcoal from pyrolysis and pyro-gas is considered

Property	Value	Measure Unit
Carbon content	77.38	%wt
Ash Content	15.02	%wt
Volatiles	13.21	%wt
S	0.90	%wt

Table 2. Proximate analysis of a coal used as PCI in BF steelmaking.

To increase the process efficiency and sustainability, reuse of excess pyrogas for bioenergy generation is also considered

2. Description of the steelmaking site

The Steelmaking site in Taranto (Italy)

The steel plant in Taranto is a fully integrated facility with 5 blast furnaces, of which 3 are operational.

Total **hot metal production** in 2018 was approximately **4.5 Mton/year**, with the potential capacity of **6 Mton/year of** hot metal.

The equivalent fossil coal rate is about 595 kg/ton hot metal, of which:

- **335 kg**/thm coke
- **170 kg**/thm PCI

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Coal quality and consumption of plant Blast Furnaces

Assuming that the charcoal would be replacing PCI, and that all the PCI could be theoretically replaced, the coal, or charcoal consumption in BFs is estimated

Current operations

$0.170\ t_{coal}/t_{hm} \times 4.5\ Mt_{hm}$ = 765,000 ton/year of coal

Full capacity

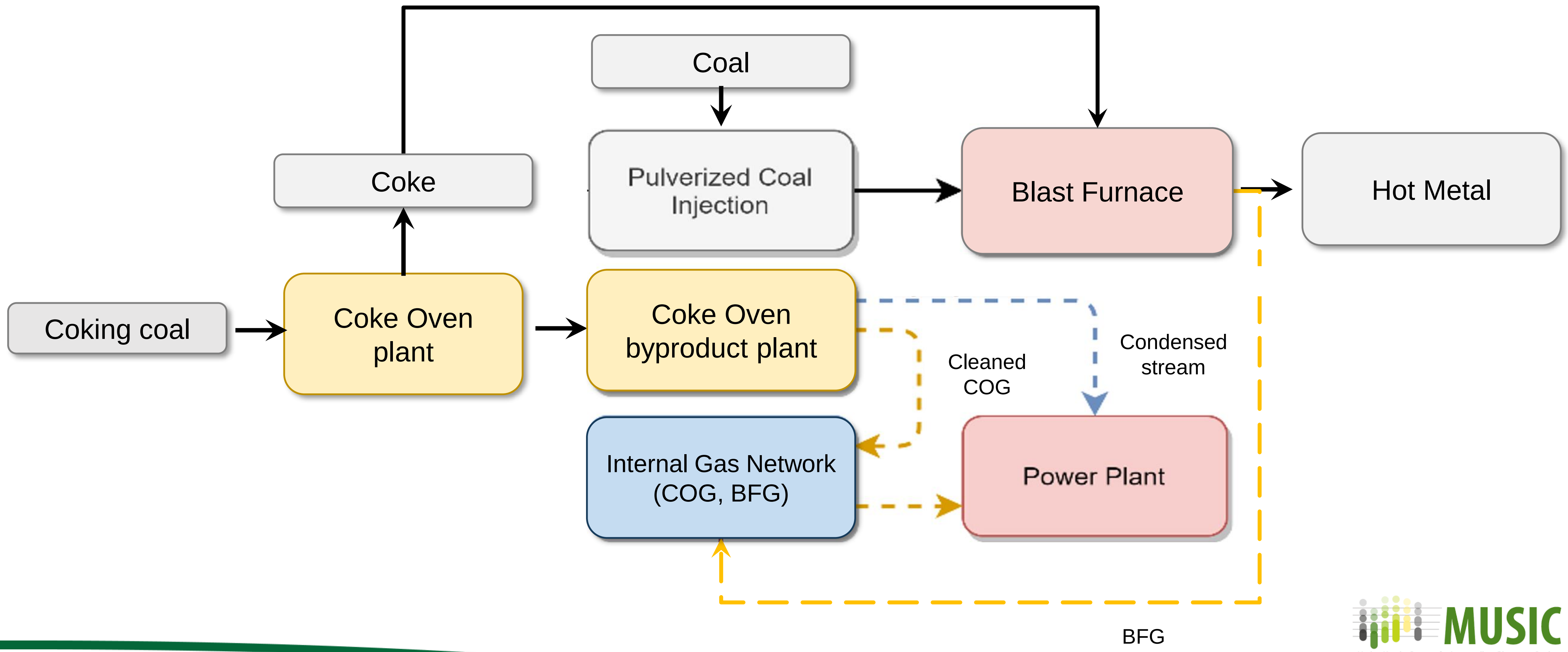
$0.170\ t_{coal}/t_{hm} \times 6\ Mt_{hm}$ = 1,020,000 ton/year of coal

Feature	Anthracite	Australian Coal Sample	North American Coal Sample	Measure Unit
C	77.38	79.22	75.62	$\%wt_{db}$
H	3.61	3.53	3.57	$\%wt_{db}$
O	1.35	3.56	1.60	$\%wt_{db}$
N	0.86	1.66	0.86	$\%wt_{db}$
S	0.90	0.43	0.82	$\%wt_{db}$
Ash content	15.02	9.10	5.08	$\%wt_{db}$
Fixed Carbon	70.93	64.87	67.00	$\%wt_{db}$
Volatile matter	13.21	18.03	19.92	$\%wt_{db}$

Quality of three different coal qualities used in as PCI, which can be considered as a quality target for the obtained charcoal

Description of the steelmaking site

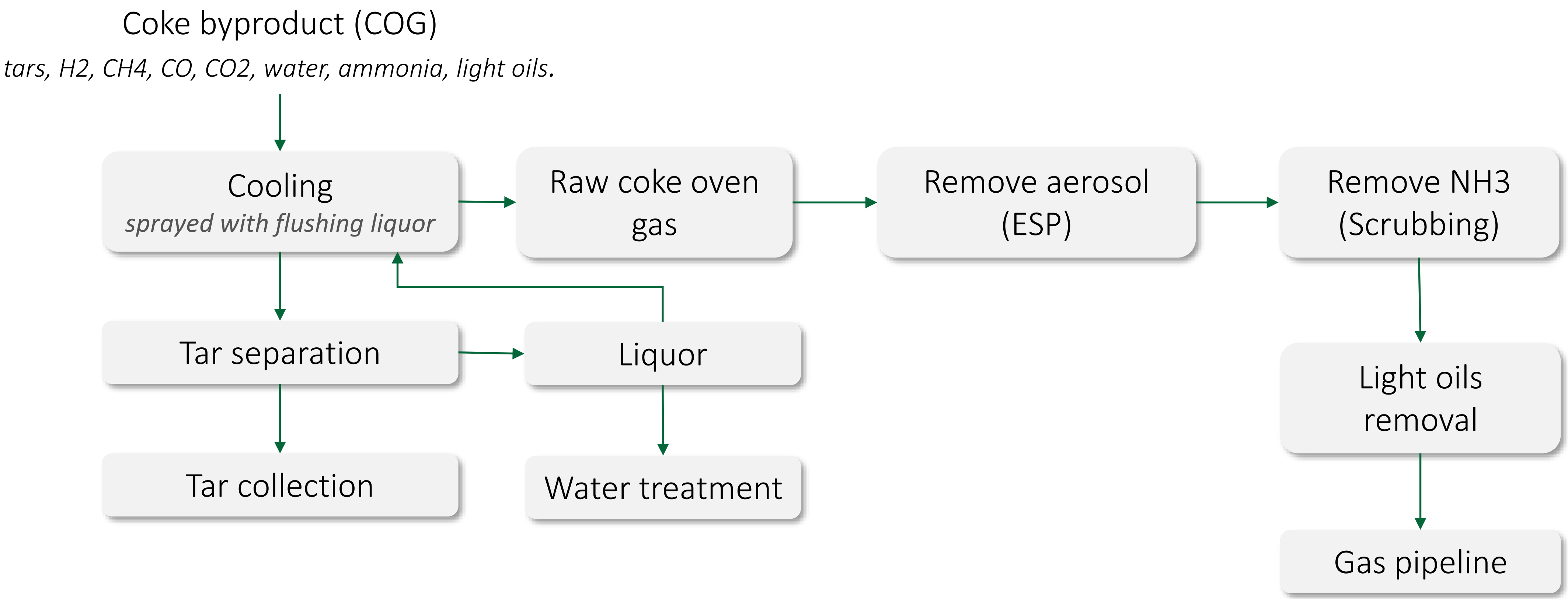
Scheme of the steelmaking plant



Description of the steelmaking site

The coke oven byproduct plant

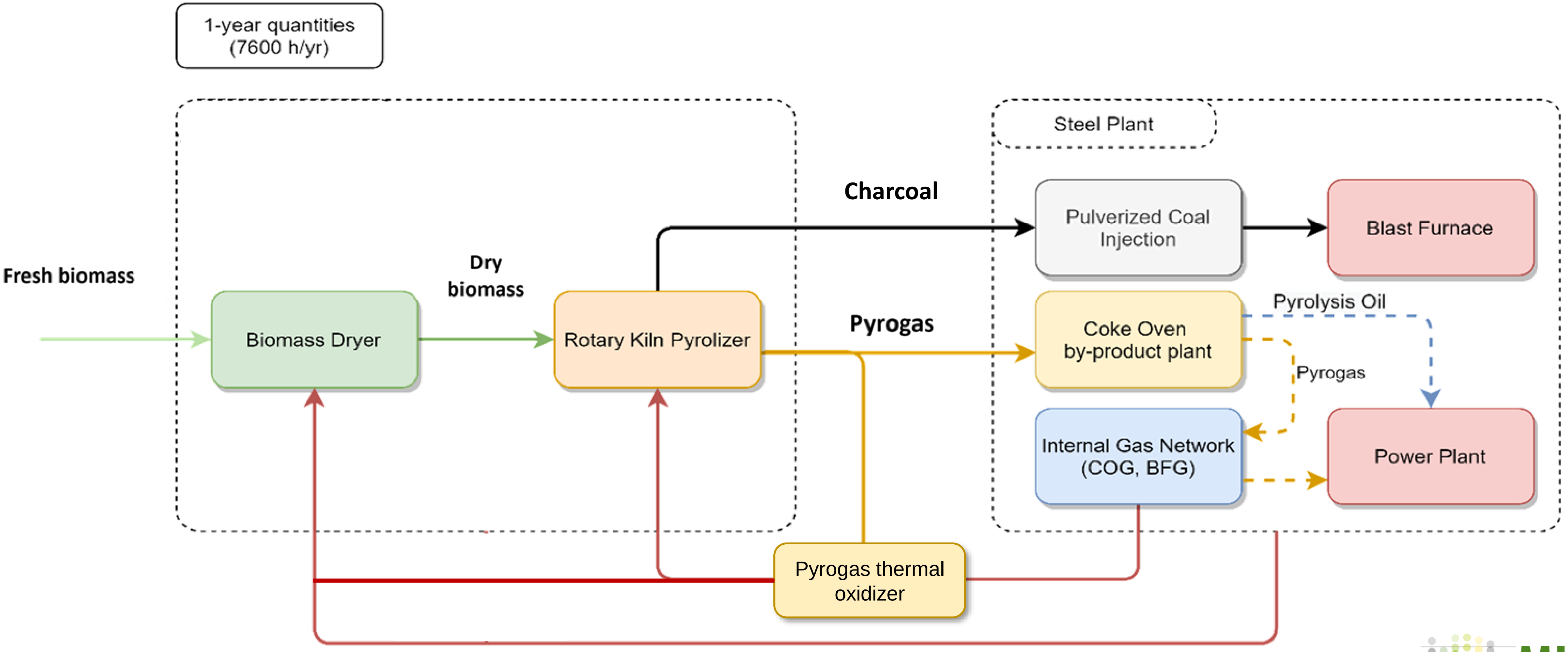
Coking (coal pyrolysis) - heating of coal in the absence of oxygen at more than 600° C



3. Description of the integrated solution

Description of the integrated solution

Integrated plant



Experimental trials

Input Biomass (Arundo donax)

Feedstock characterization	Value	Reference method
Volatile matter (wt.% db)	77.1	UNI EN 15148
Ash (wt.% db)	3.4	UNI EN 14775
Fixed carbon (wt.% db)	19.5	UNI EN 1860-2
C (wt.% db)	50.2	UNI EN 15104
H (wt.% db)	5.6	UNI EN 15104
N (wt.% db)	0.2	UNI EN 15104
Lower heating value (db, MJ kg^{-1})	18.4	UNI EN 14918

Charcoal

Feedstock characterization	Value	Reference method
Volatile matter (wt.% db)	12.3	UNI EN 15148
Ash (wt.% db)	15.6	UNI EN 14775
Fixed carbon (wt.% db)	72.1	UNI EN 1860-2
C (wt.% db)	79.7	UNI EN 15104
H (wt.% db)	2.3	UNI EN 15104
N (wt.% db)	0.8	UNI EN 15104
Lower heating value (db, MJ kg^{-1})	26.9	UNI EN 14918

Process parameters

- Temperature: 550°C
- Residence time: 1 hour
- Heating rate: ~ 10°C/min

Mass balance

Parameter	Value
Biocoal (wt.%feed db)	30.7
Liquid (wt.%feed db)	27.2
Permanent gas (wt.%feed db)	42.1

Description of the integrated solution

Availability of selected biomass

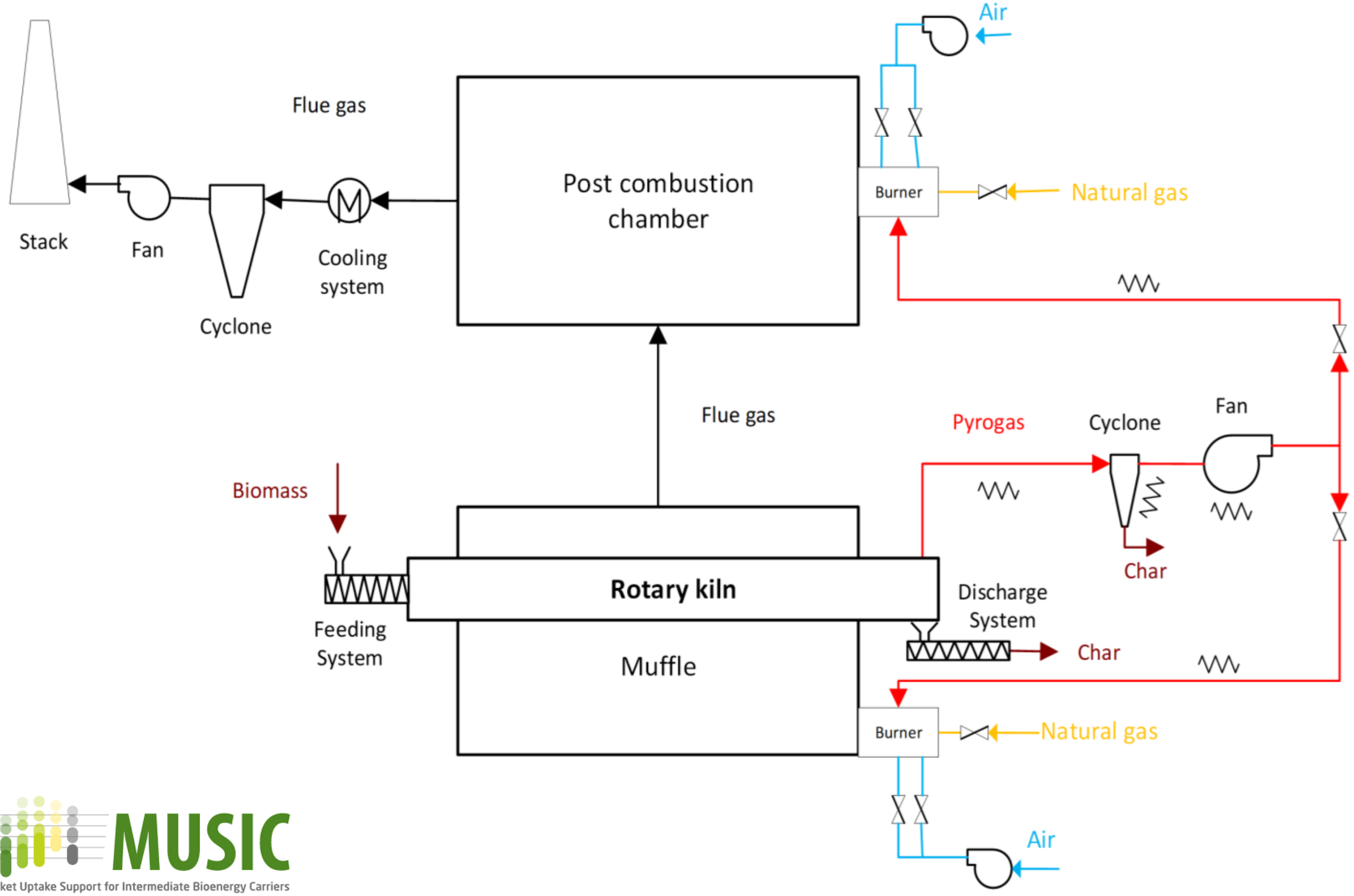
Biomass (t/y)	Fresh	Moisture content	Dry basis	10% MC
Total	336.974	37%	206.381	229.312
Straw bales	99.974	25%	74.981	83.312
Arundo	108.000	50%	54.000	60.000
Olive trees	129.000	40%	77.400	86.000



Description of the integrated solution

Slow Pyrolysis technology (adopted for modelling)

The RE-CORD carbonization plant (PYROK) is a slow pyrolysis, indirectly heated, rotary kiln that allows to convert up to 100 kg/h of biomass in charcoal and heat.



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4. Modelling plant energy and mass balance

Modelling plant energy and mass balance

Structure of the modelling tool

Plant sizing

- Calculate the required biocoal capacity of slow pyrolysis plant
- Set the working condition of rotary kiln
- Define the dimensions of the kiln to be heated by flue gases

Energy modelling

- Calculate the mass and energy balance of the slow pyrolysis plant
- Evaluate the possibility of using Steelmaking flue gases for slow pyrolysis energy supply
- Quantify the composition and the energy content of slow pyrolysis gases

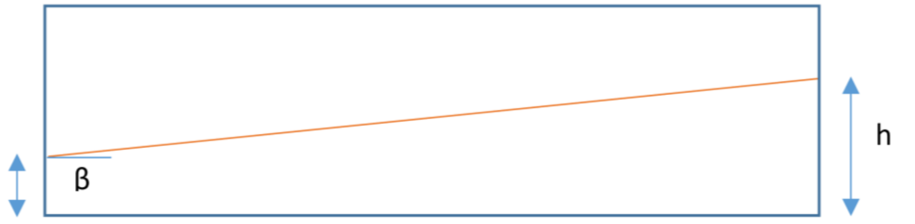
Economic feasibility

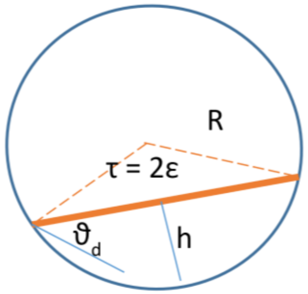
- Set key parameters influencing economics
- Perform economic assessment and estimate payback time
- Perform sensitivity analysis considering market drivers

Modelling plant energy and mass balance

Energy balance of slow pyrolysis process (5t/h unit)

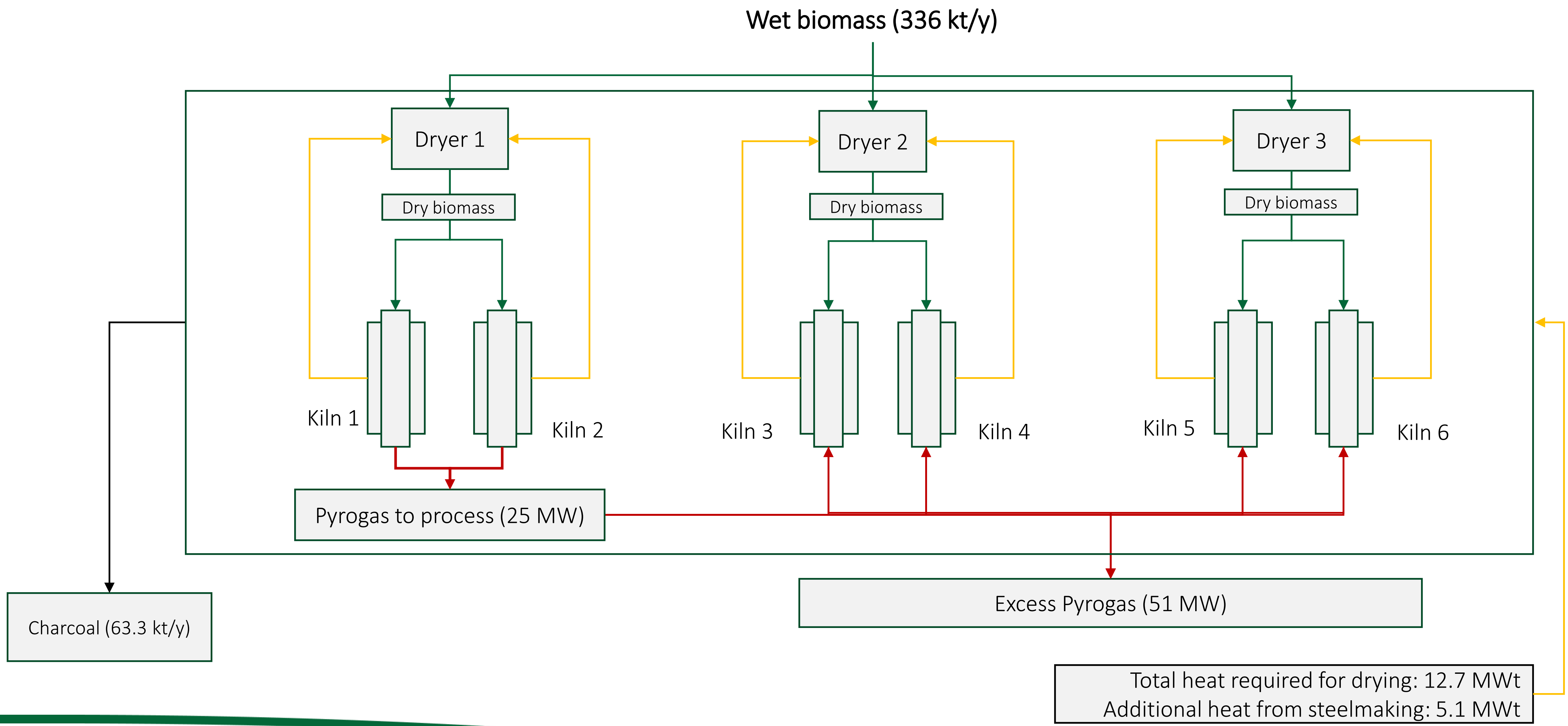
Process Parameters		
Pressure	bar	atmospheric
$T_{process}$	°C	550
$T_{ambient}$	°C	25
Char Yield	%	30.7
Process Efficiency (heat transfer)	%	60
Mean Retention Time	min	60
Mass Balance – Feedstock Input & Product Output		
Operating Time	h/yr	7,600
Moisture Content	%	10
$m_{biomass\_dry}$	t/h	4.53
m_{char}	t/h	1.39
$m_{pyrogas}$	t/h	3.64
Energy Balance – Process heat and Product Output		
$P_{heat\ for\ pyrolysis}$	MW	4.25
$P_{pyrogas}$	MW	12.75
P_{Char}	MW	10.38





Estimated Kiln Geometry and Sizing		
Internal Diameter	2.5	m
Extenal diameter	3.5	m
Length	27	m
Volume	132	m3
kiln slope angle	0.5	°
Rotational Speed	2	rpm
Filling Coefficient	20%	
Exhaust gas T	650° C	

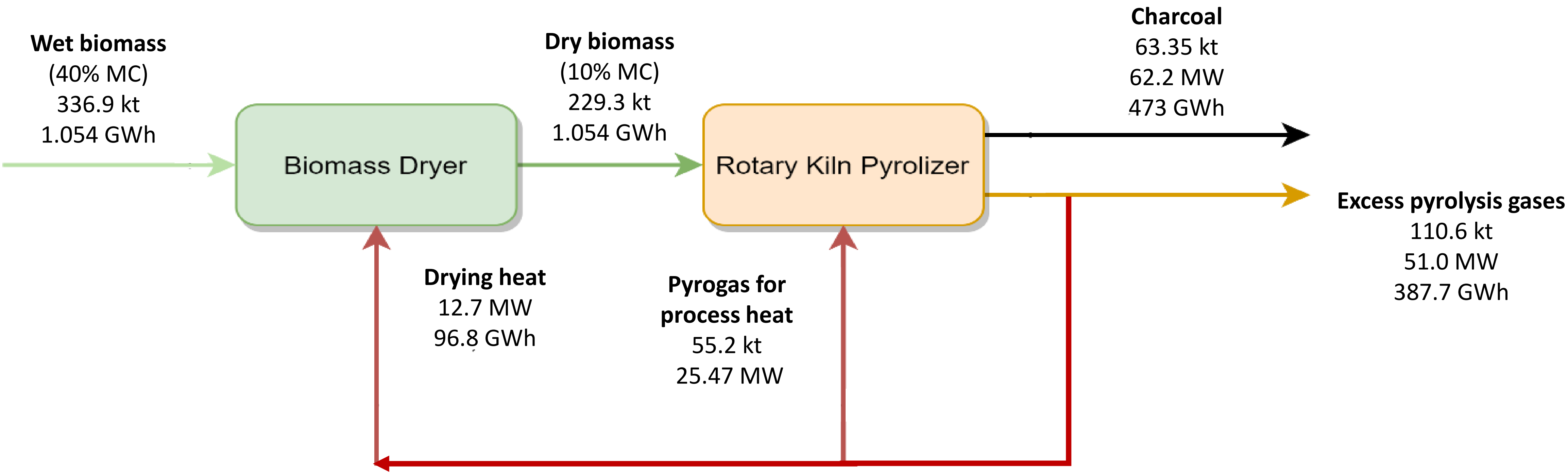
Modelling plant energy and mass balance



Modelling plant energy and mass balance

Mass & energy balance of slow pyrolysis unit

Charcoal production: 63.3 kt/yr → 6% of consumed PCI → 10% of biocoal x ton of Hot metal



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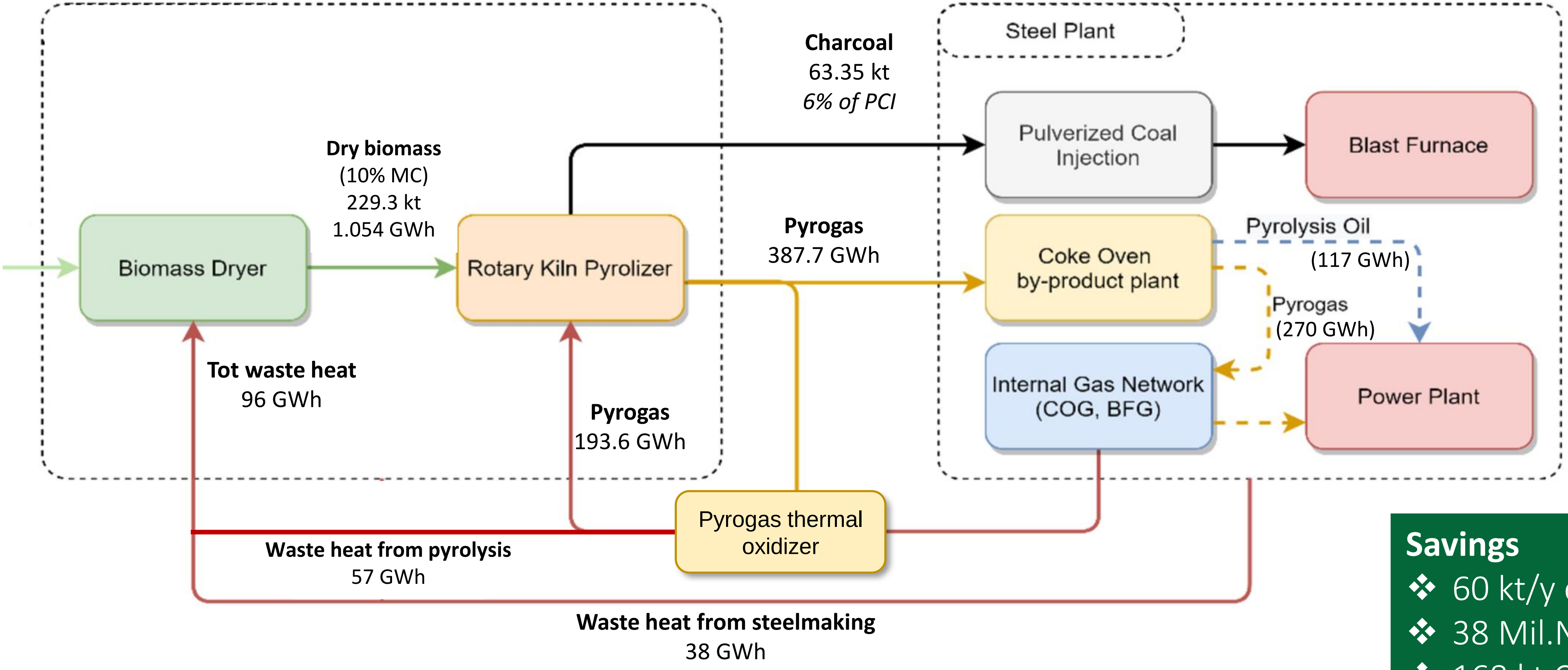
Mass & energy balance of integrated plant



Savings

- 60 kt/y coal
- 38 Mil.Nm3 CH_4/y
- 168 kt CO_2/y from biocoal
- 78 kt CO_2/y from Nat. gas

5. Economic assessment

Economic assessment

Biomass costs

Biomass	Dry basis	Wet basis	Moisture	Cost (€/wet t)
Total av.	206.381	336.974	37%	48.4
Straw bales	74.981	99.974	25.0%	62
Arundo	54.000	108.000	50%	34
Olive trees*	77.400	129.000	40%	50

The selected processes for biomass collection and pre-treatment, at farm level, are:

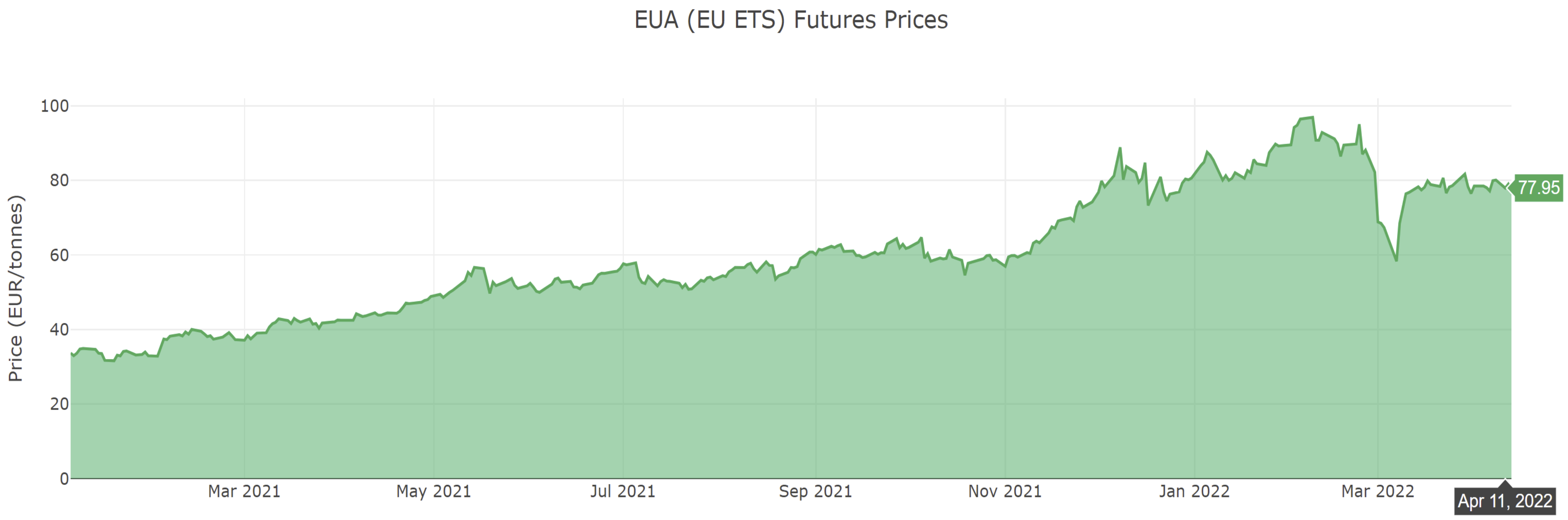
- harvesting of the residues distributed in the plot;
- chipping of the ligno-cellulosic residues and energy crops
- the use of bales for the herbaceous residues.

*As far as the olive tree pruning is concerned, the price of wood chips on the market was considered, assuming the sure presence of a chipper on the farm. From market surveys we have found that the purchase of a chipper is a sustainable cost for the farmer

Economic assessment

CO_2 price based on EUA ETS price and forecasts

EUA price on 11 April 2022: 77.95 €/t



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Economic assessment

Payback time calculation of integrated plant

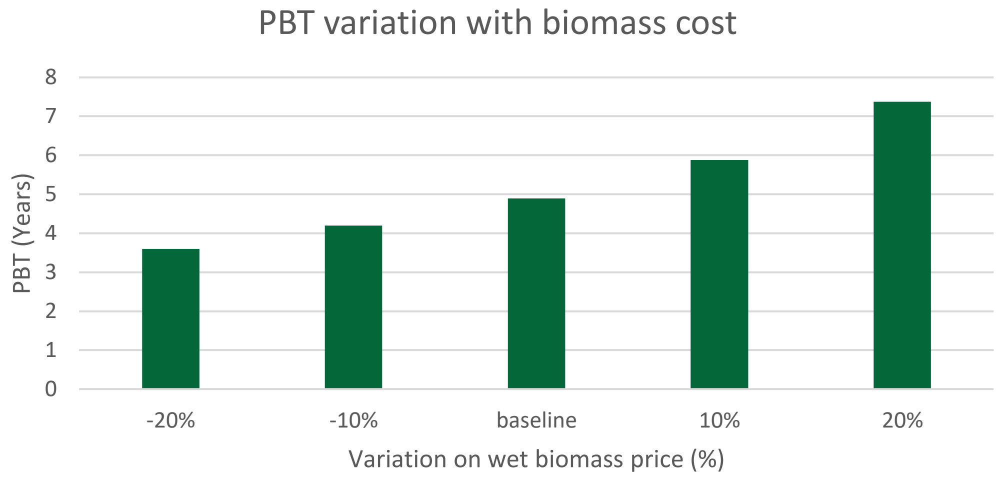
CAPEX		
Slow Pyrolysis plant	31.067.658	€
Installation, auxiliaries, civil	7.766.914	€
Dryer	2.007.795	€
Oxydation unit and heat exchangers	6.750.000	€
OPEX		
Personnel	720.000	€
Biomass	16.320.417	€
Electricity	2.322.461	€
Maintenance	2.297.751	€
SAVINGS		
Coal purchase	6.695.680	€
ETS on Coal CO2	10.112.084	€
ETS on Nat.Gas saving CO2	4.690.420	€
Nat gas. purchase	9.721.159	€
EBTDA	9.721.213	€
Payback time	4.9	years

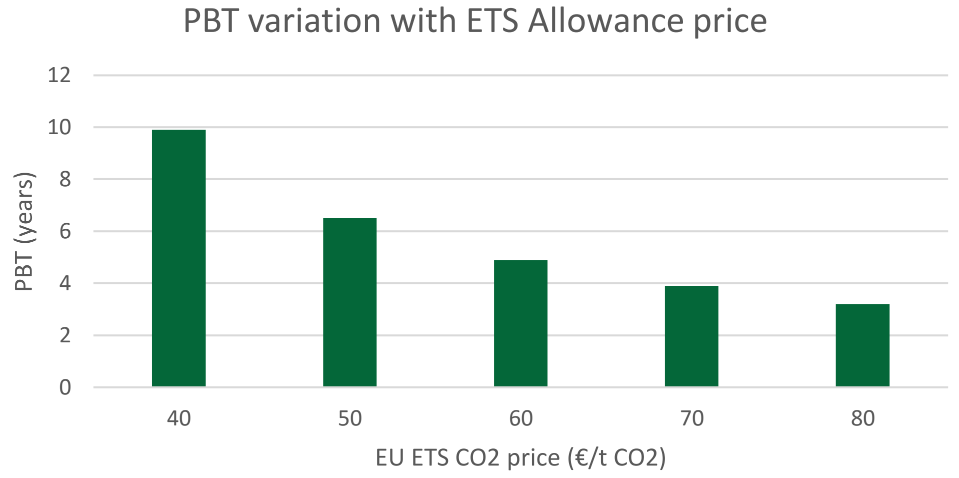
Cost and saving items		
Coal price	110	€/t
CO2 price	60	€/tCO2
Biomass price (dry)	79	€/t
Biomass price (wet)	48	€/t
Nat Gas price	0.25	€/Nm3
Electricity	0.1	€/kWh

6. Conclusion

Conclusion

- The solution brings to saving **246.000 t CO2** per year
- Savings on Nat. Gas consumption (38 Mil.Nm3 CH4/y) represents 25% of revenues
- Avoiding consumption of 60.000 t fossil coal per year represents 20% of total revenues
- Total ETS Allowances (both Nat. Gas and coal) **represents 54% of expected revenues**
- Savings on coal-derived ETS allowances amount to **37% of total revenues**
- Biomass purchase represents **75%** of total operating costs





Thank you for your attention!

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Andrea Salimbeni
Head of Unit | Raw materials & carbon recycling
andrea.salimbeni@re-cord.org
www.re-cord.org