Hydrogen and Strategic Energy Reserve

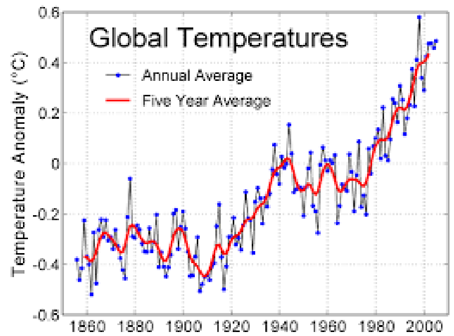
Paulo Brito

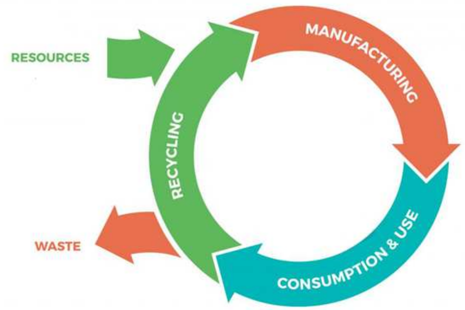
Sumary

1. Overview
2. Waste-to-gas
3. Power-to-gas
4. Conclusions

Goals

1. Reduction of carbon emissions
2. Wastes valorization
3. Energy storage





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New fuels

- Non-food biomass
- Cellulose and vegetable fibers
- Microalgae
- Waste




Types of wastes/effluents

- Municipal Solid Wastes
- Demolition and Construction wastes
- Forest residues
- Industrial and Agro industrial effluents and residues
- Wastewater treatment plants and Sewage Sludge
- (…)

Municipal waste	Agricultural Waste	Forest Waste	Animal Waste	Agroindustry waste
food waste, waste oil, sewage, plastics, paper and cardboard, textiles and leather, Construction and Demolition Waste.	crop residues, green waste, straws, leaves, stalks stovers, prunings, wood chips.	Nut shells, sawdust, splinter, fibers, dead trees, leaves, branches, etc.	fat, tallow, lard, intestines, blood, processing waste, manure.	wastewaters and waste from: cork, wineries, olive oil mill, coffee torrefaction, paper pulp industry.

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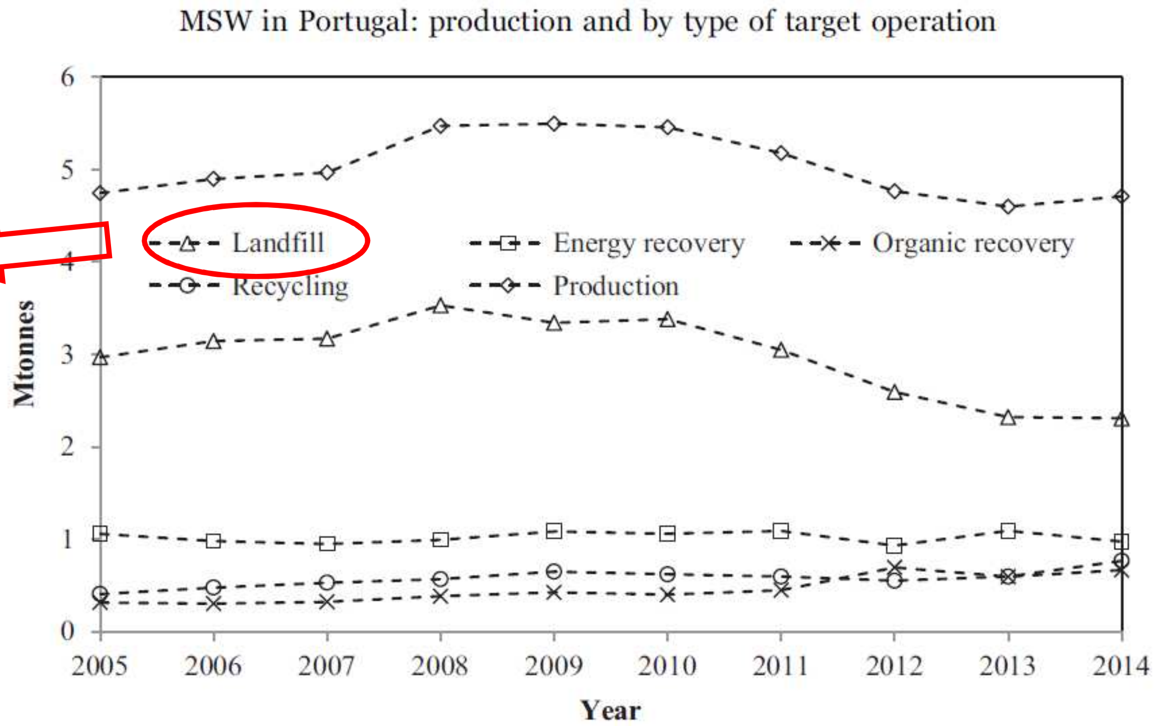
Biomass - Waste



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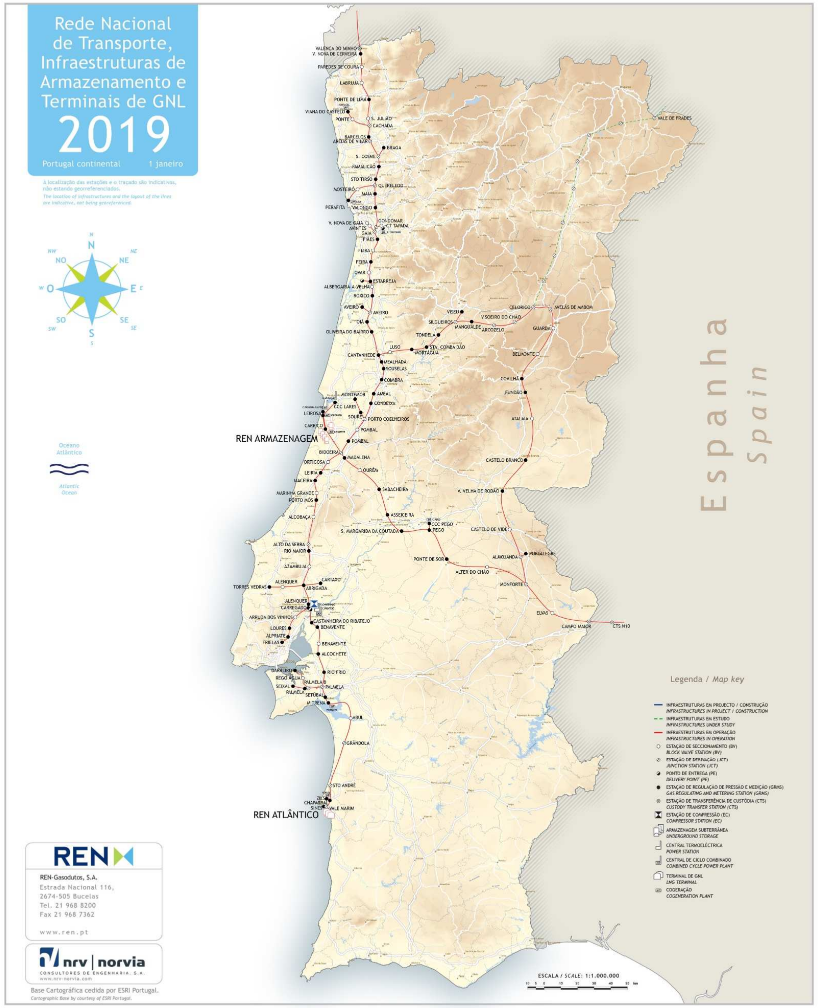
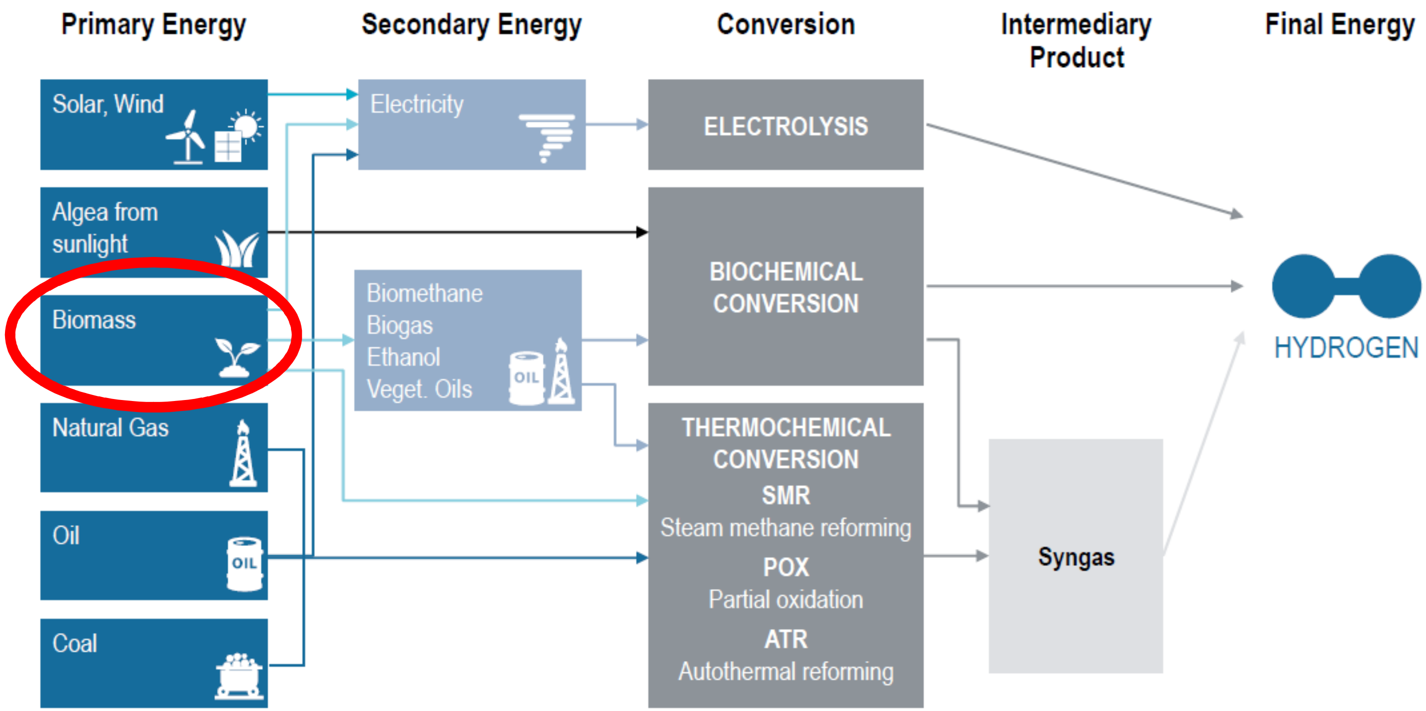
Bio resource	Potential GWh/year
Animal manure	1,088
Forest residues	11,578
Agriculture residues	4,528
Wastewater treatment plants	207
Municipal solid wastes	1,600
Energy crops	8,378
Total	27,379

10% of the energy demand

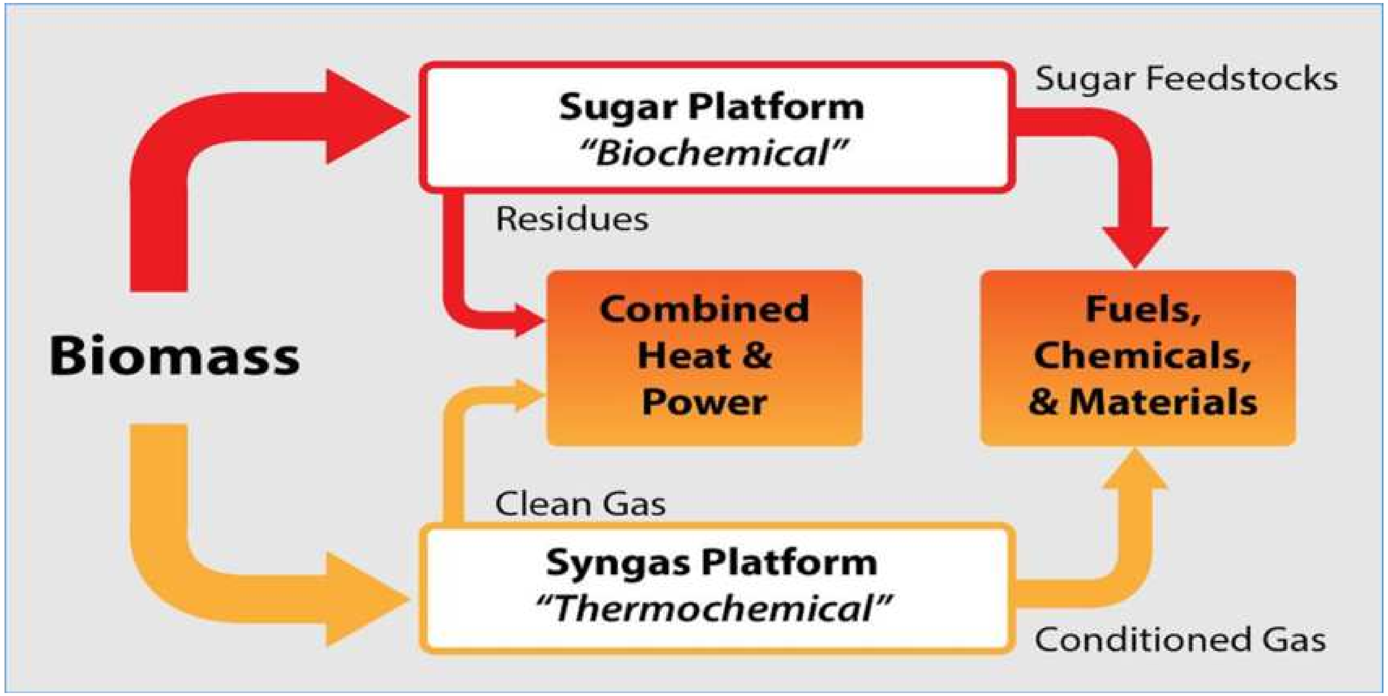
Hydrogen and Strategic Energy Reserve



Hydrogen production



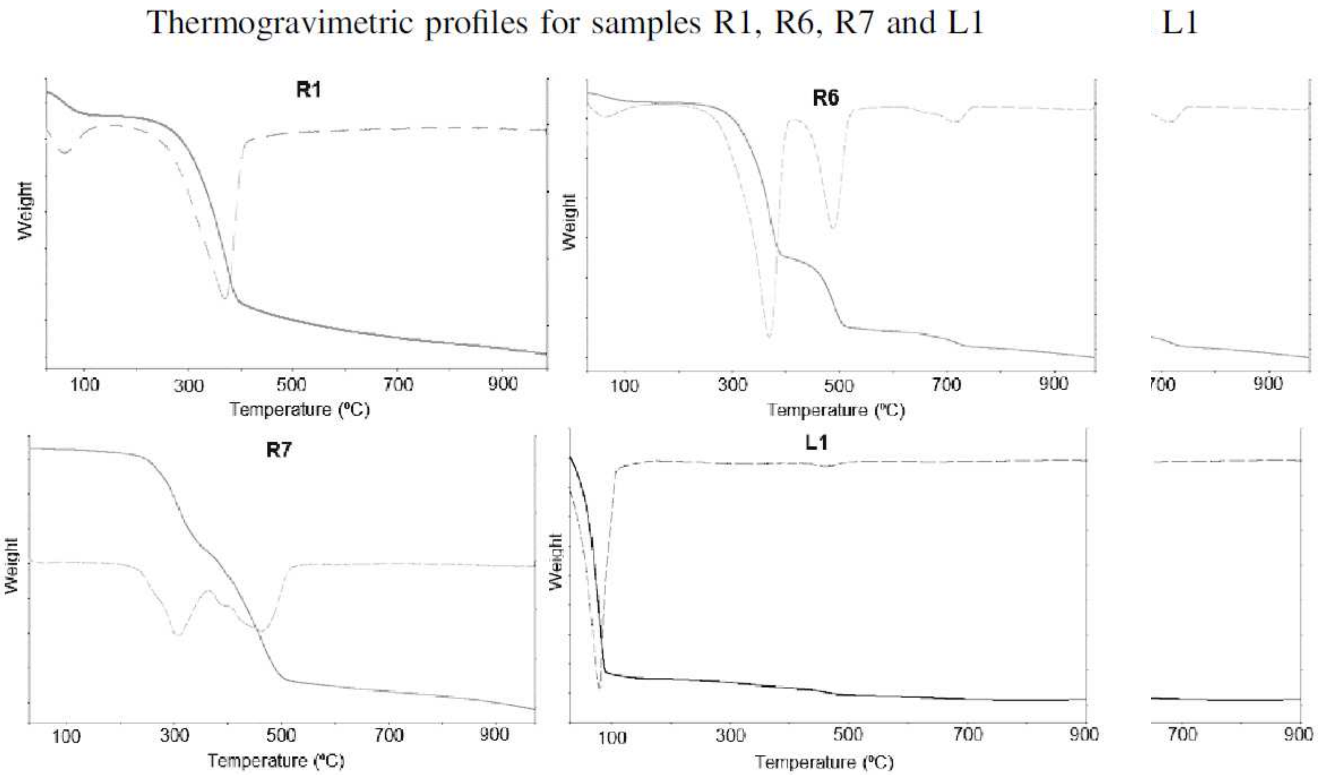
Biorefinery



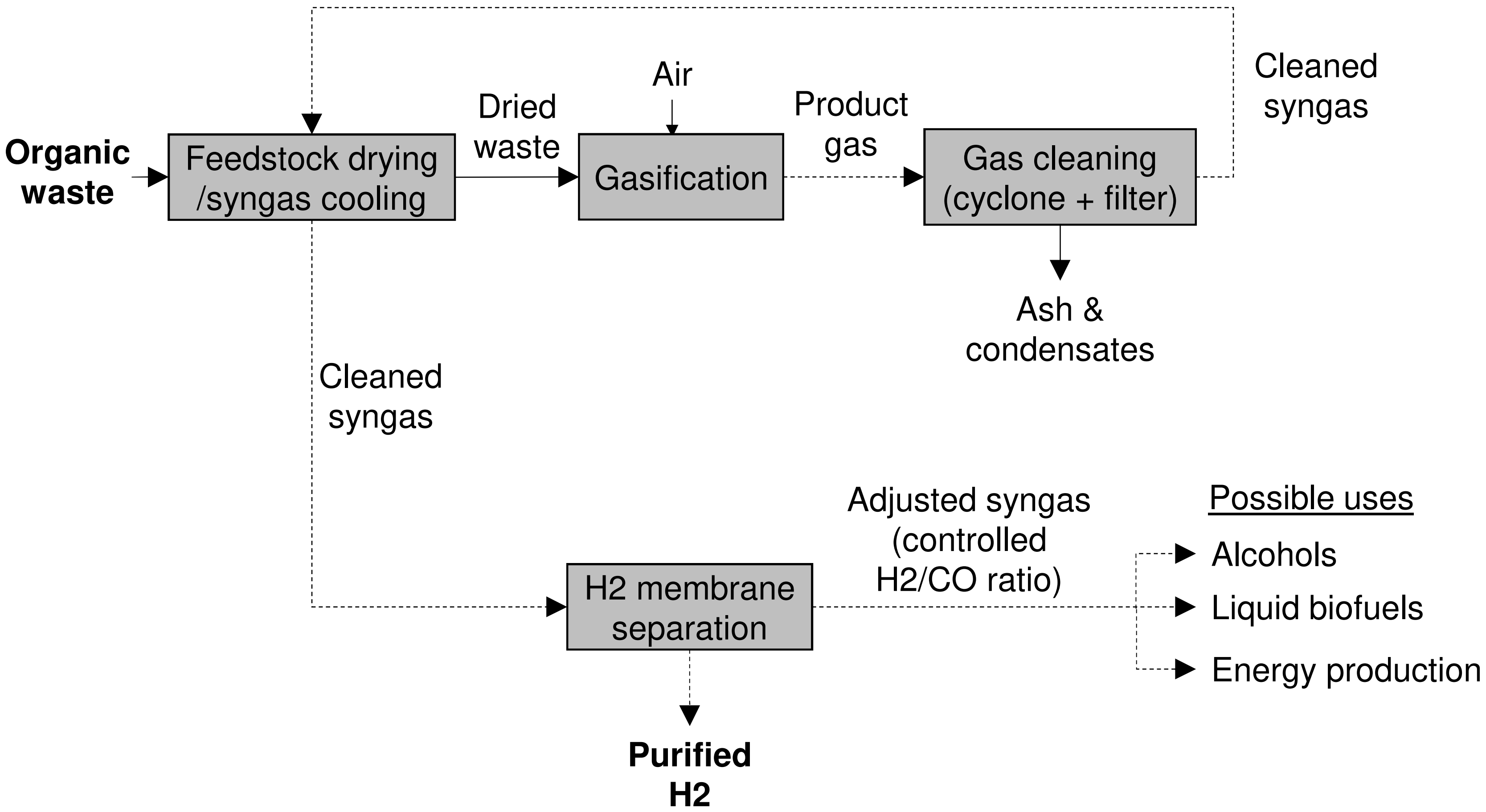
Thermochemical processes

Technology	Benefits	Limitations	Products	Applications	Technological Readiness Level
Combustion/ Incineration	Reduction of mass (70%) and volume (80%), Fast and simple process, energy recovery of waste with good LHV	high capital cost, public opinion objection, produces toxic slag, air pollution, dioxin emission	Combustion in boilers and furnaces	Heating, Electricity and transportation	TRL-9
Gasification	Wide range of applications and feedstocks, High conversion efficiency	High capital cost, high sensibility processes, low flexibility, risk of mechanical failure, condensate production	Syngas rich in hydrogen and carbon monoxide	Heating, Electricity, transportation, fuels and high value chemicals	TRL-7
Explosive decompression	Transformation of lignite, solubilization of hemicellulose	Production of toxic compounds, partial degradation	Sugars, digestible products	Heating, Electricity, transportation, fuels and high value chemicals	TRL-4
Pyrolysis	High yield, reduced syngas treatment, reduction of waste volume (90%)	High capital costs, high maintenance and operation costs, high viscosity of the produced oils	Bio-Oils, BioChar, Syngas	Additives, high value chemicals, transportation, heating and electricty	TRL-6
Hydrothermal Liquefaction	Higher LHV Bio-Oil and low moisture content	Low conversion efficiency (20-60%), higher pressure equipment and higher capital cost	Heavy oil, intermediate value chemicals	Additives, high value chemicals, transportation, heating and electricty	TRL-4
Torrefaction	Homegeneous and stable products, easy pelletizing, high LHV, hydrophobic	Low energy Density, high ash quantity	Torrefied biomass	Heating, electricity	TRL- 8

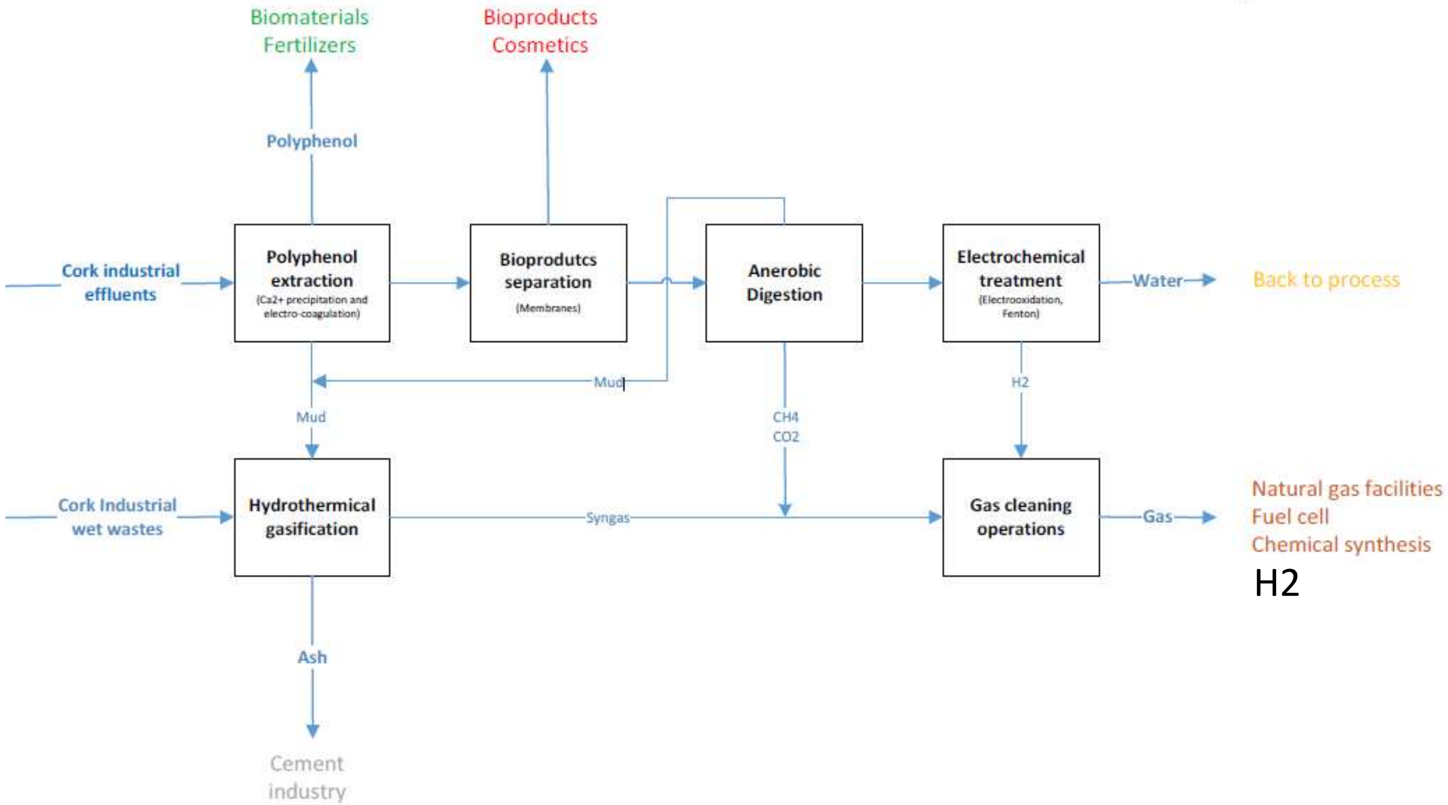
Torrefaction



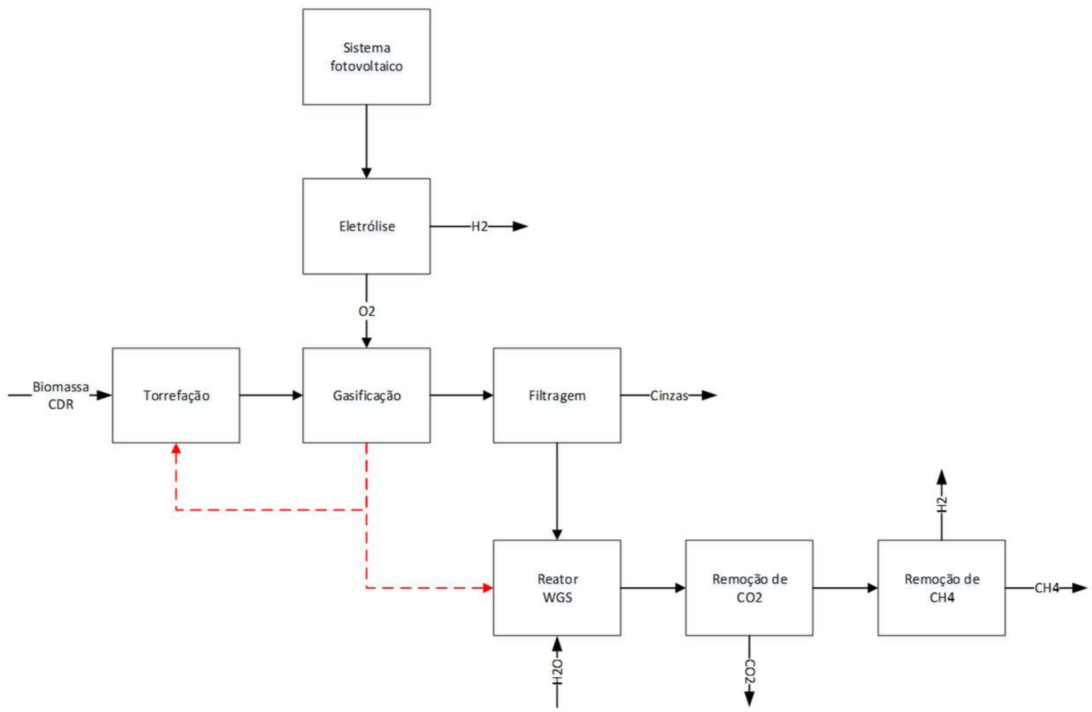
Hydrogen production from biomass



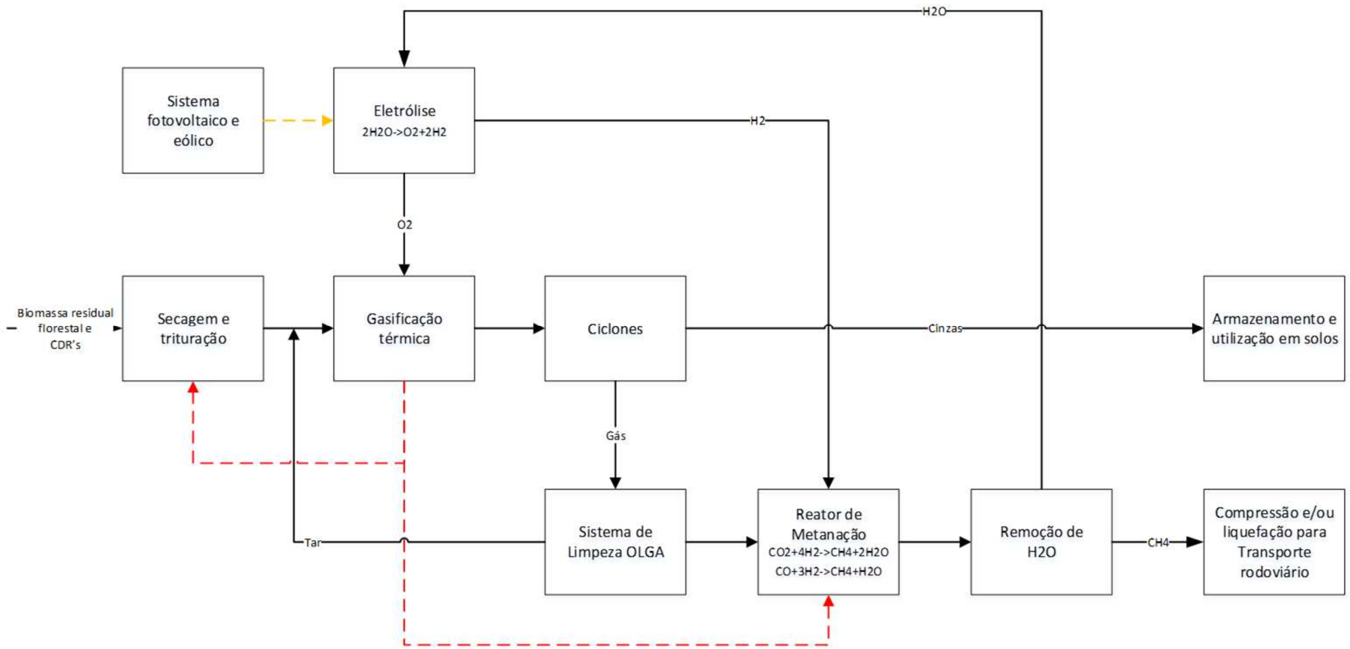
Cork Wastewater Biorefinary



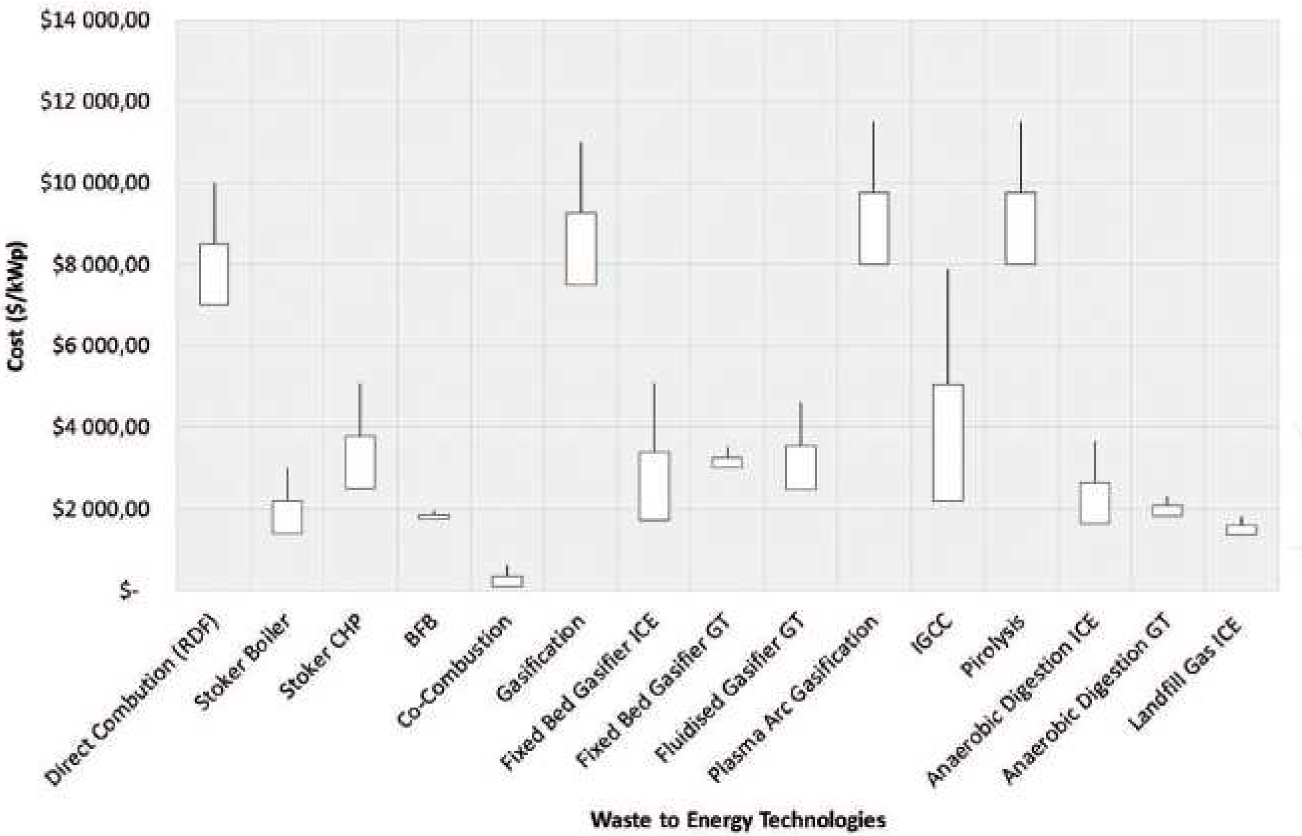
Hydrogen production from Biomass



Methane production from Biomass



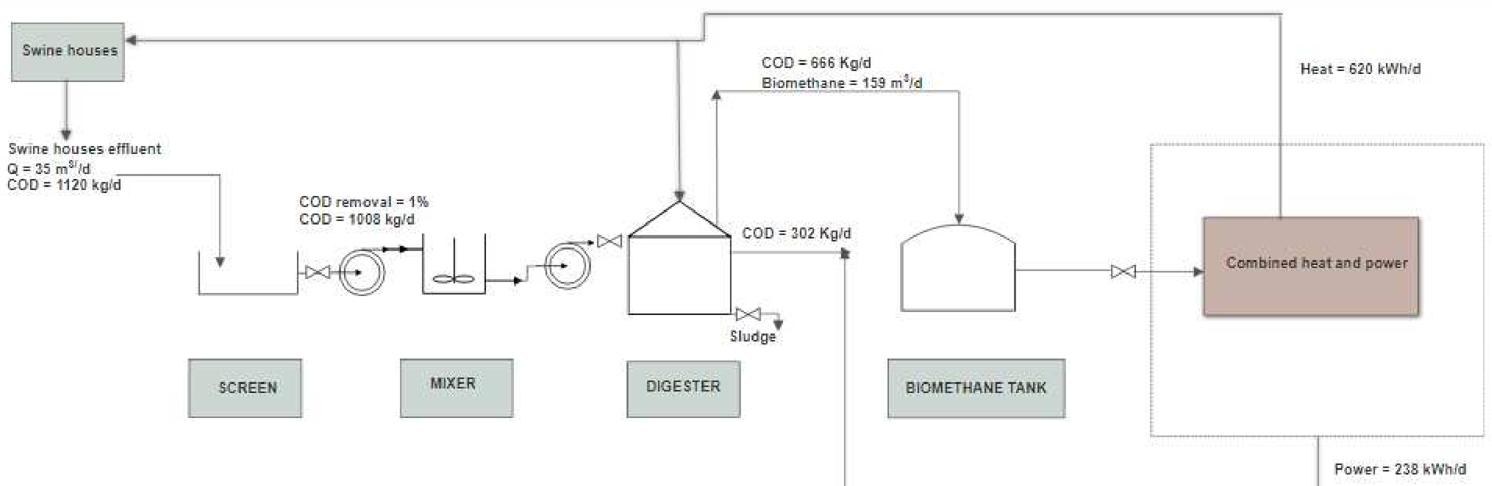
Costs


$14 000,00
$12 000,00
$10 000,00
$8 000,00
$6 000,00
$4 000,00
$2 000,00
$-
Cost ($/kWp)
Direct Combution (RDF)
Stoker Boiler
Stoker CHP
BFB
Co-Combustion
Gasification
Fixed Bed Gasifier ICE
Fixed Bed Gasifier GT
Fludised Gasifier GT
Plasma Arc Gasification
IGCC
Pirolysis
Anaerobic Digestion ICE
Anaerobic Digestion GT
Landfill Gas ICE
Waste to Energy Technologies

Biochemical Process

Technology	Benefits	Limitations	Products	Applications	Technological Readiness Level
Anaerobic Digestion	Solid waste reduction, high moisture content feedstock, methane and carbon dioxide rich biogas, low cost organic fertilizer as by-product	Need to treat and clean the biogas, unstable system, large facilities are unattractive	Biogas, bio digestate	Heating, Electricity, transportation, fuels and high value chemicals	TRL-9
Fermentation	Does not contribute to increase of greenhouse gas emissions	Limited to sugar, starch or cellulose rich feedstocks	Liquids and CO_2	Additives, high value chemicals, transportation, heating and electricty	TRL-9
Photo-Fermentation	the photosynthetic bacteria are capable of using a range of the electromagnetic spectrum	Low-efficiency, inhibited in the presence of oxigen	Hydrogen, Carbon Dioxide, organic acids	Additives, high value chemicals, transportation, heating and electricty	TRL-4
Dark Fermentation	capable of converting a wide range of wastes, scalable technology , independent of light	Low theorical limit, imature technology	Hydrogen, Acetic Acid	Additives, high value chemicals, transportation, heating and electricty	TRl-3
Enzyme Treatment	Low power consumption, low by products production, does not require toxic catalysts, can result in a reduced solvent	High cost of the enzimes, slow reactions, necessity of high purity, limited in temperature and ph range	Ethanol, amino acids	high value chemicals, transportation, heating and electricty	TRL-8
Microbial electrolysis	Hydrogen Production, low energy consumption, effluent degradation	High internal resistance, high capital cost, production greatly affected by substrate composition	Hydrogen, Methane, Acetate, formic acid	Wastewater treatment, high value chemicals, transportation, heating and electricty	TRL-4

Biological step



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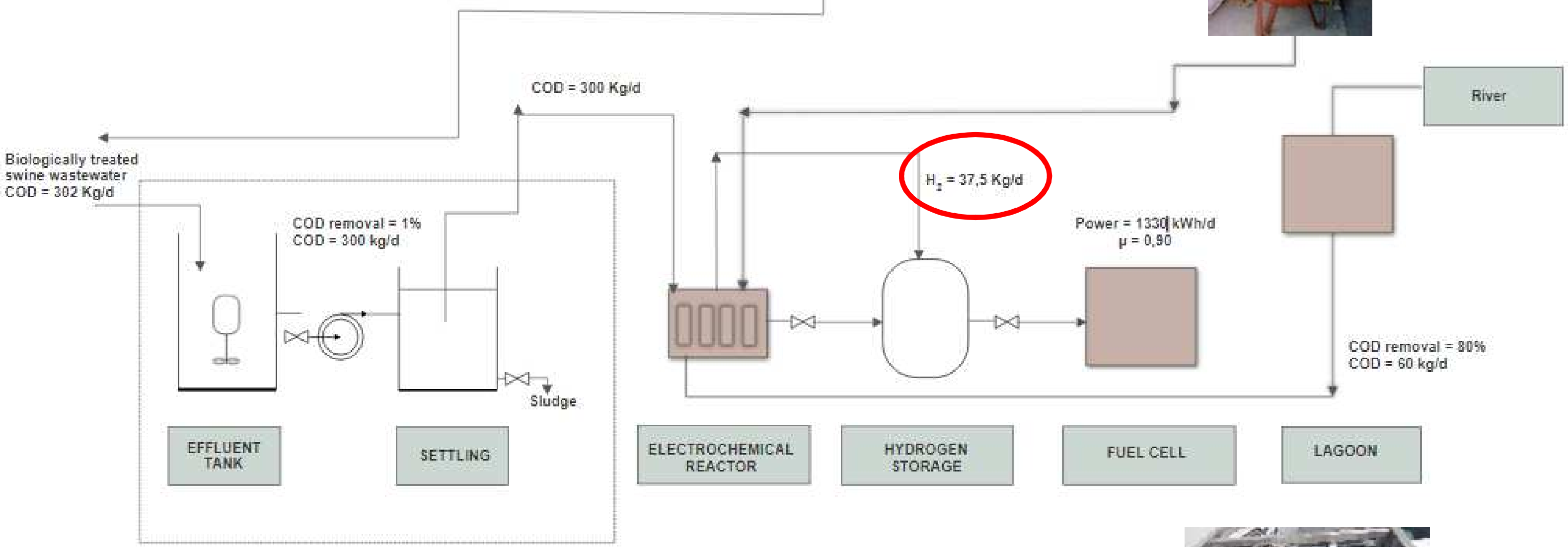
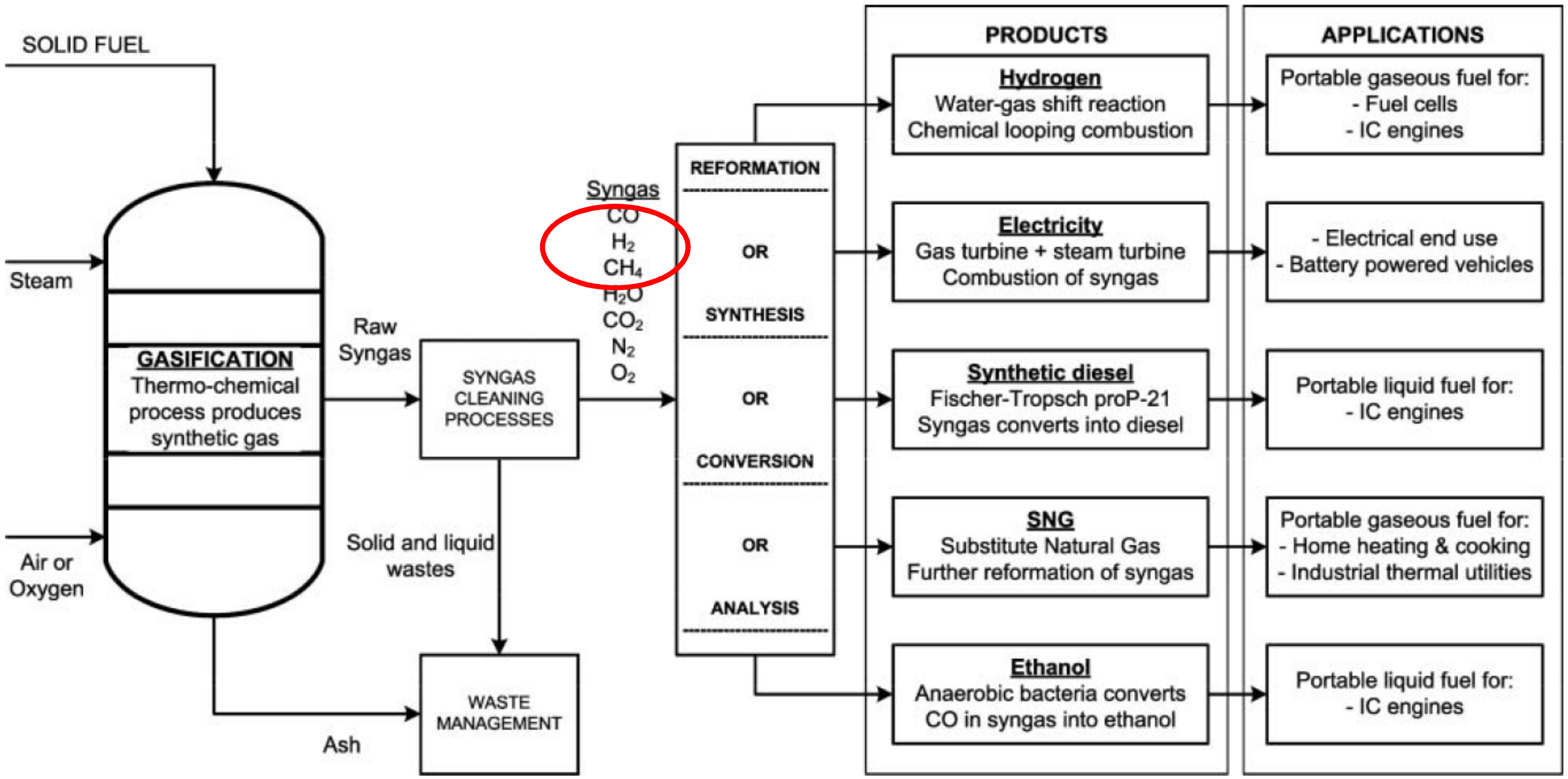
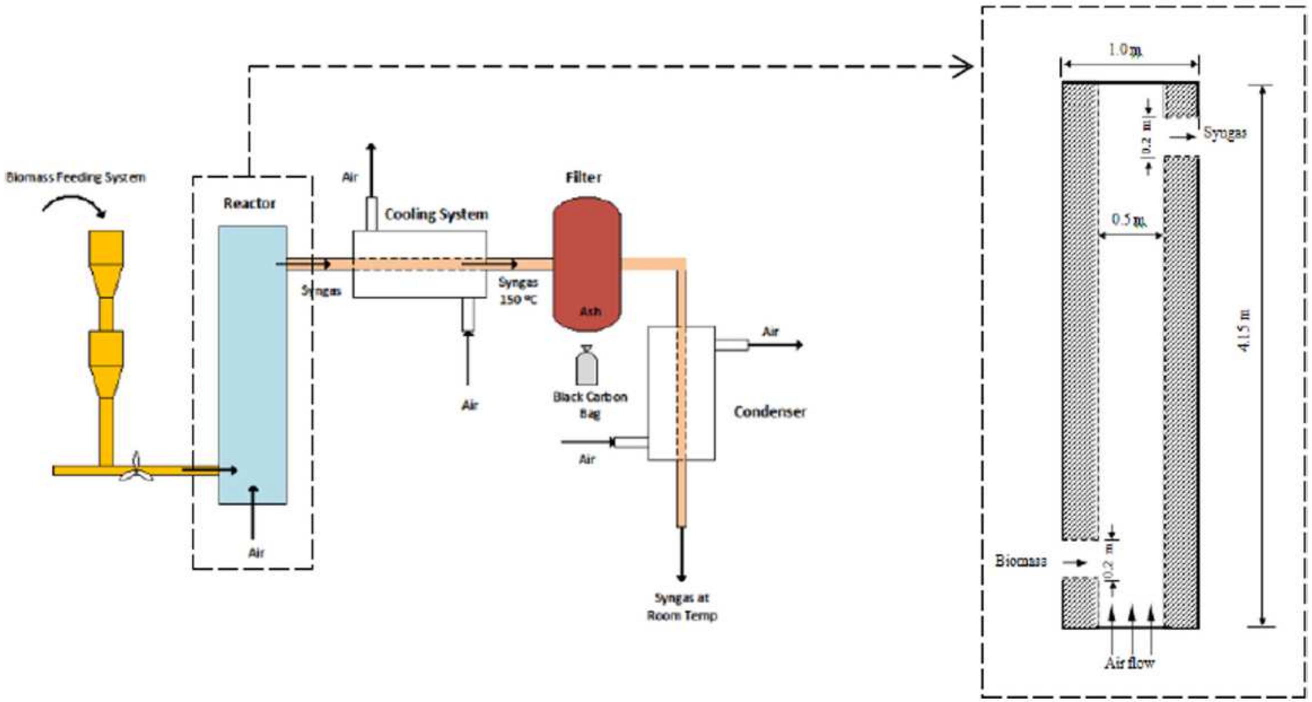
Electrochemical step



Thermal gasification



Pilot gasification plant
Bubble fluidized rector



Properties of some biomasses and residues

Parameter	Unit	Biomass											
		Pine	Acacia	Hemp	Rice husk	Peach pit	Dried timber	Pine bark	Olive stone	Olive press-cake	Meat and bone	Tires	Plastics
Moisture content	wt% ar*	8.6	7.8	7.9	9.8	13.3	0	16.7	9.4	8.9	8.8	0.8	0.2
Volatile matter	wt% ar	80.6	75.7	71.9	59.9	66.4	80	57.6	57.8	70.97	50	64.5	78.3
Fixed carbon	wt% ar	8.2	12.5	4.2	14.7	19.3	19.4	24.5	19.7	19.48	8.3	29.6	20.9
Ash	wt% ar	2.6	4.0	16.0	15.6	1	0.6	1.2	13.1	0.65	32.9	5.1	0.6
Lower heating value (LHV)	MJ/kg	17.1	17.6	23.1	13.88	16.18	16.31	16.42	16.36	20.3	15.2	38.6	31.6
Carbon	wt% ar	51.6	44.2	45.7	38.8	45.49	52.0	46.24	43.22	53.87	30,6	75.5	69.2
Hydrogen	wt% ar	6.0	5.4	7.1	4.6	6.26	6.3	5.92	5.56	8.8	5.2	7.1	7.4
Nitrogen	wt% ar	2.8	1.4	3.5	1.3	0.73	0.4	0.19	1.86	2.03	8.1	0	0
Oxygen	wt% ar	22.8	33.1	15.2	29.6	33.22	40.5	29.75	26.86	26.51	52.2	11.8	23.4

*ar—as received basis.

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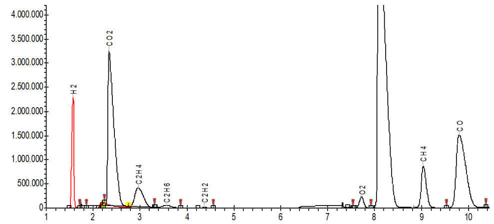
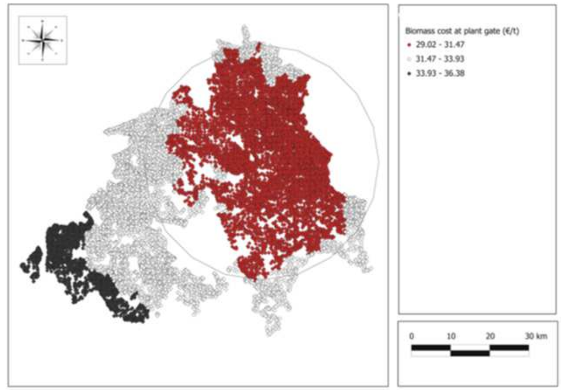
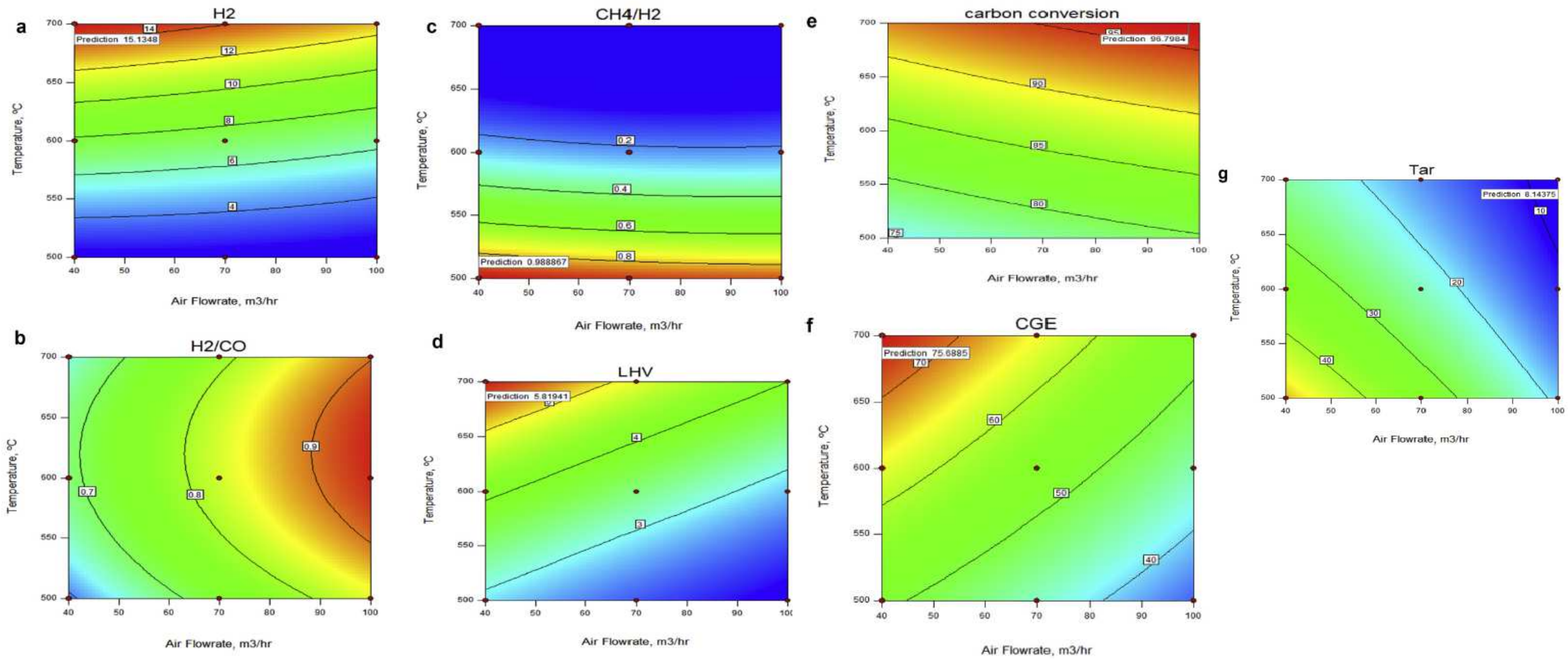
Experimental conditions and syngas analyses.

Experimental conditions	Forest residues			Coffee husk			Vines pruning		
Temperature (°C)	815	815	790	815	790	790	790	790	815
Admission Biomass (Kg/h)	63	74	63	28	28	41	25	55	55
Air Flow Rate (Nm^3/h)	94	98	98	75	72	80	52	40	40
Ratio $O_2/O_{2\ Stoichiometric}$	1,11	0,99	1,16	2,63	2,52	1,96	2,96	0,58	0,58
Syngas flow rate (Nm^3/h)	106	94	100	106	88	116	107	108	102
Syngas fraction (dry basis)									
H_2	8,2	8,4	7,6	12,4	7,6	7,5	5,1	10,4	12,7
CO	18,6	18,0	17,9	11,4	11,1	10,6	8,3	11,7	14,1
CH_4	4,6	4,4	4,4	1,6	2,4	2,4	1,1	2,4	2,3
CO_2	16,7	17,1	17,1	18,7	17,0	18,5	16,5	20,1	17,9
N_2	48,0	48,2	49,2	52,3	54,2	55,2	56,4	51,2	49,1
Syngas composition (g/kg dry biomass)									
CO	438	323	399	711	572	506	855	328	375
H_2	14	11	12	55	28	25	38	21	24
CH_4	62	45	56	56	71	65	63	39	36
CO_2	620	483	602	1836	1380	1390	2675	888	751
Syngas NHV									
MJ/Nm^3	5,16	5,02	4,93	3,34	3,20	3,07	1,99	3,46	4,02
KWh/Kg	1,13	1,09	1,07	0,73	0,65	0,63	0,37	0,73	0,89
Cold Gasification Efficiency	0,41	0,30	0,37	0,60	0,47	0,42	0,95	0,4\5	0,49





Two-dimensional Computational Fluid Dynamics (CFD) model - MSW

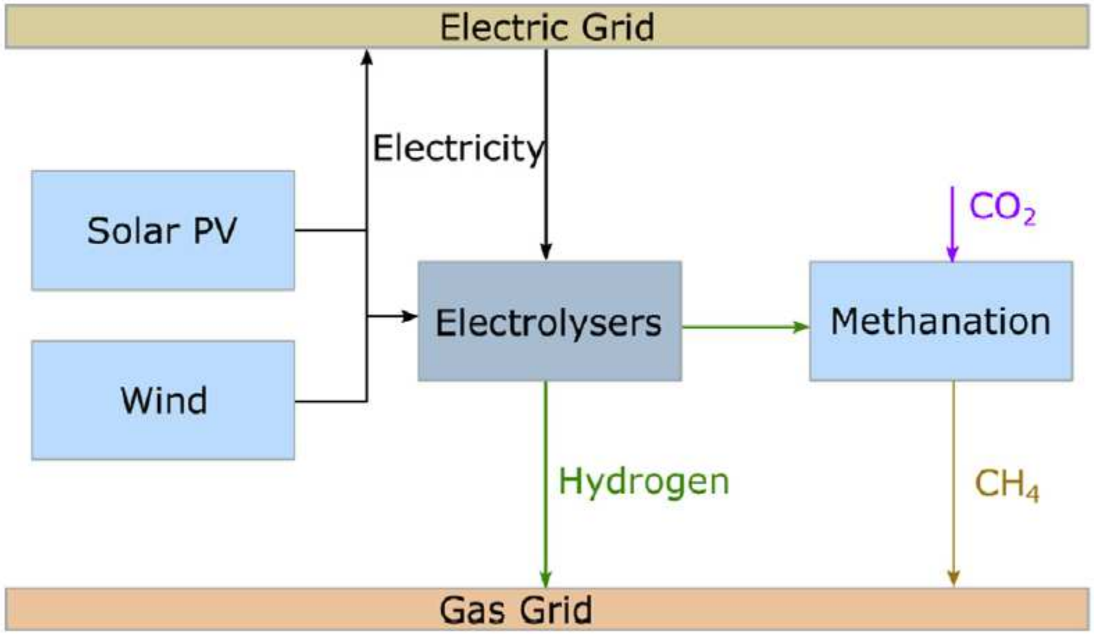


Economical Evaluation – CDW + Forest residues

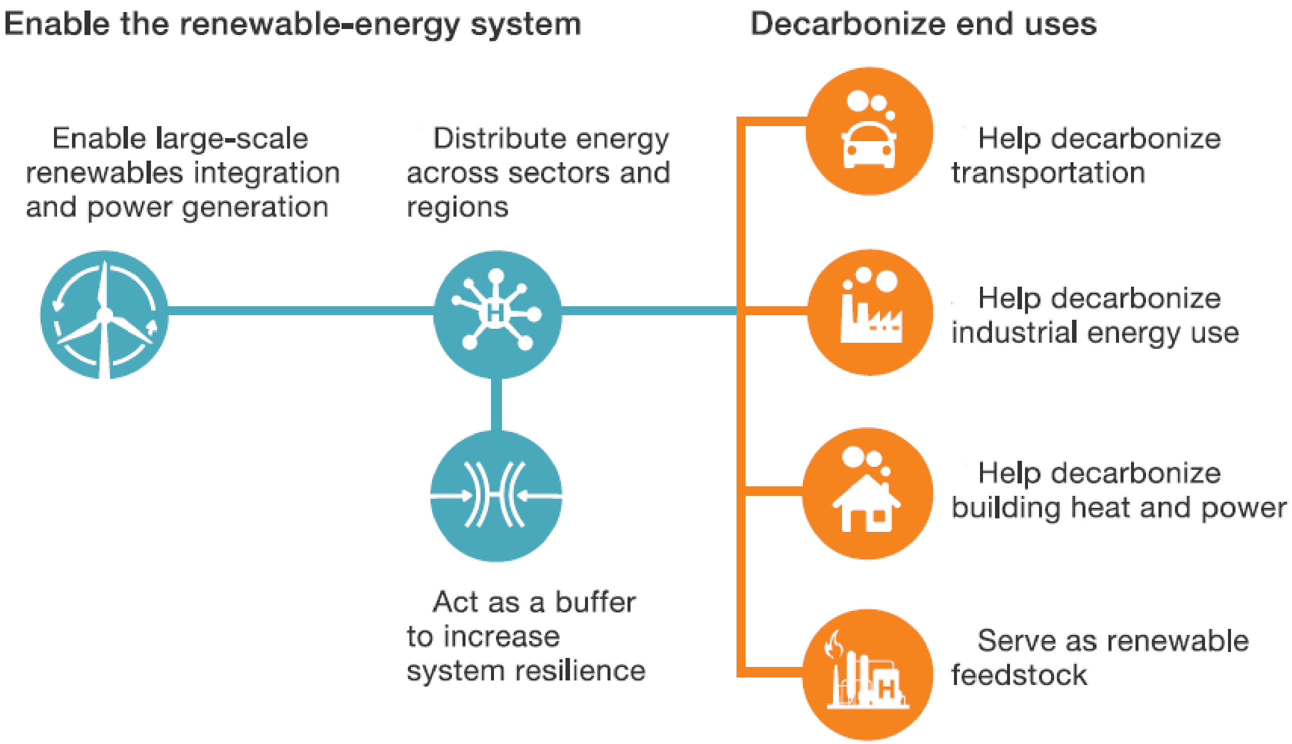
System Parameters	
Type of gasifier	Fixed bed
Operating yield (%)	16 - 18
Operating time (h)	12
Days of the month	21
Days of the year	252
Feedstock	
PCEC	
Amount (ton/year)	226,8
Price for landfill (€/ton)	9,9
Annual readjustment of landfill	1,12
Forestry material	
Amount (ton/year)	2041,2
Price of the chip (€/ton)	25
Economic parameters	
Investment (€/kW)	2000
Price of electricity produced (€/kWh)	0,2
Price of electricity consumed (€/kWh)	0,29
Operating costs (% investment)	1%
Life time (year)	30

Parameter	Test 90% pine + 10% PCEC
PCI (MJ/m³)	5,2
Volume produced (m³/h)	21,93
Biomass consumption (kg/h)	6
Energy contained in biomass (kWth/ kg)	5,28
Energy produced in one year (kWe.month)	179606,7
Current costs	
Deposition in landfill (€ton/year)	2245,32
Energy spent per month (kWh)	39884,5
Expenses with the installation of a gasification plant	
Investiment	2565810
Maintenance costs (€/year)	25658,1
Costs with forest biomass (€/year)	51030
Income	
Non-referral to landfill (€/year)	2245,32
Electric power saved (€/year)	138791,1
Sale of residual energy (€/year)	35921,34
Time of return (year)	8

Waste-to-gas (P2G)



Hydrogen in Energy transformation



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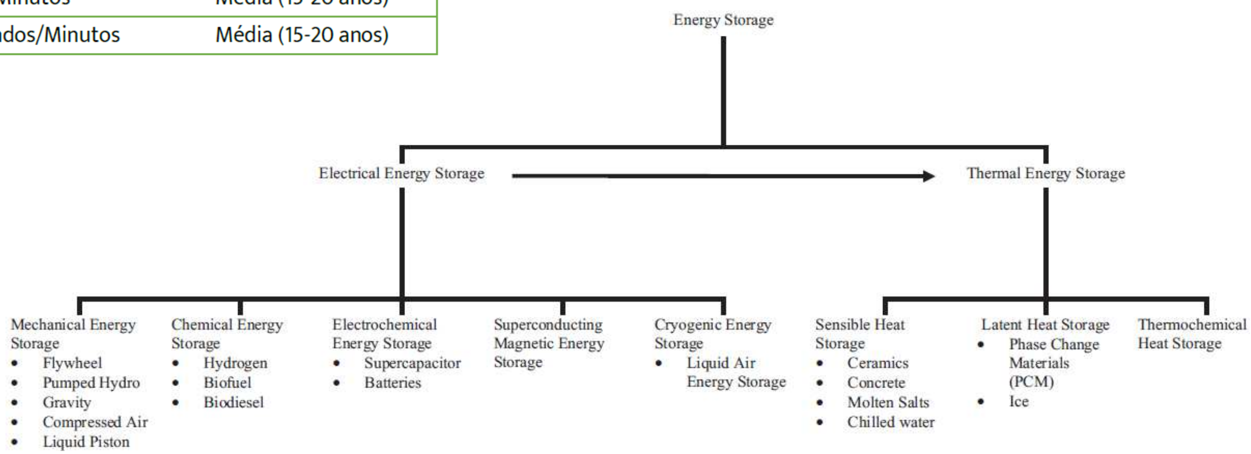
Armazenamento de energia

Cenário comparativo entre as formas de armazenamento de energia

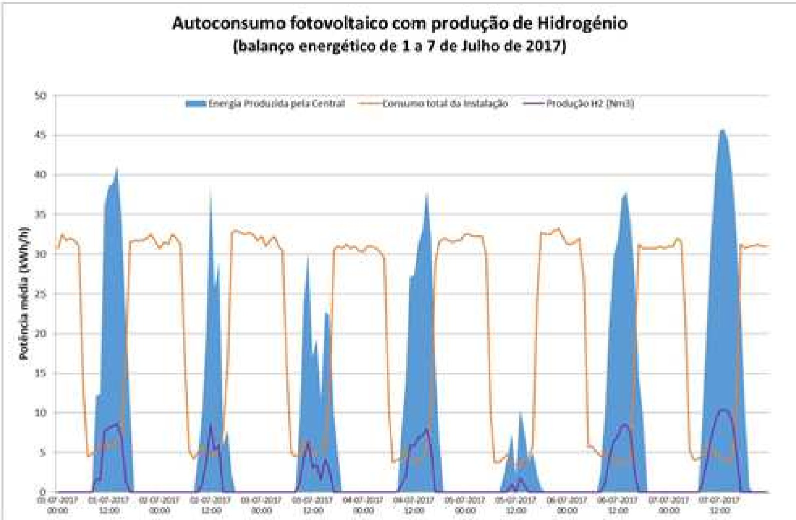
Forma de Armazenamento de Energia	Custo	Tempo de resposta	Vida Útil
Eletroquímica	Baixo/Elevado	< Segundos	Baixa (2-10 anos)
Elétrica	Médio	< Segundos	Média (15-20 anos)
Cinética	Elevado	Segundos/Minutos	Média (15-20 anos)
Potencial	Baixo	Segundos/Minutos	Elevada (40-60 anos)
Térmica	Baixo/Médio	Minutos	Média (15-20 anos)
Química	Médio	Segundos/Minutos	Média (15-20 anos)



Hydrogen and Strategic Energy Reserve

Energia [kWh/ano]		Rácios		Produção de H2	
Consumo total da Instalação	153.141	Energia Produzida/ Energia Consumida	59%	Excedente de Energia(kWh)	67.156
Energia produzida pela central	90.642	Energia Autoconsumo/ Energia Produzida	25,9%	Eficiência Eletrólise(%)	25%
Energia para autoconsumo	23.487	Excedente/ Energia Produzida	74,1%	**Potencial de Produção H2 (Nm3)**	**16.789**

Energia Térmica do H2: **181,32 GJ**



Avaliação económica

	Eletricidade		Hidrogénio			
Tipo de célula	PEM		PEM			Alcalina
Ano	2020		2020		2030	2020
Potência	36	360	36	360	36	36
Caso de Estudo - A						
VAL (euros)	-5 499	326 586	49 354	833 682	12 871	57 444
PRI (anos)	>15	6	6	3	9	5
TIR (%)	1,2%	18,3%	16,4%	38,2%	8,6%	20,9%
Caso de Estudo - B						
VAL (euros)	-33 913	6 570	-4 040	270 298	-11 869	6 171
PRI (anos)	>15	15	>15	8	>15	13
TIR (%)	-6,8%	3,3%	2,0%	13,7%	-1,5%	4,7%
Caso de Estudo - C						
VAL (euros)	-4 649	163 786	23 962	427 686	5 462	28 436
PRI (anos)	>15	6	7	3	9	5
TIR (%)	0,2%	17,2%	15,0%	36,0%	7,4%	19,4%
Caso de Estudo – D						
VAL (euros)	-6 854	-5 466	-1 974	37 190	-2 833	-103
PRI (anos)	>15	>15	>15	9	>15	>15
TIR (%)	-8,3%	1,5%	0,3%	11,3%	-3,1%	2,8%
Caso de Estudo – E						
VAL (euros)	-38 598	-58 991	-16 563	130 671	-17 753	-6 825
PRI (anos)	>15	>15	>15	10	>15	>15
TIR (%)	-9,8%	-0,2%	-1,6%	8,8%	-4,7%	0,9%

Conclusion

The Waste Biorefinary with Thermal Gasification rout is a good alternative for descarbonization and waste valorization by permitting:

- Production of alternative sustainable fuels and hydrogen;
- The promotion of waste recovery technologies;
- Alternative technologies for waste combustion/Incineration that are more Green.

Waste and Renewables are an National Energy Strategic Reserve!

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BIOREF
Laboratório Colaborativo para as Biorrefinarias

Technology-based incubator

Pilot units

Thank you for your attention

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