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Gasificazione di scarti di biomassa in reattore pilota a letto fluidizzato per la produzione di H_2: variabili di processo e validazione nel progetto europeo HYIELD

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MASOL Continental Biofuel

Gasificazione di scarti di biomassa in reattore pilota a letto fluidizzato per la produzione di H_2: variabili di processo e validazione nel progetto europeo HYIELD

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Outlines

1. Introduzione
   - Da problema ad un asset
   - HYIELD
   - Rilevanza di HYIELD nel contesto europeo

2. Gasificazione
   - Cos'è la gasificazione di biomassa
   - Tecnologie e soluzioni reattoristiche
   - Principali aspetti tecnologici
   - KPIs ed altri aspetti rilevanti

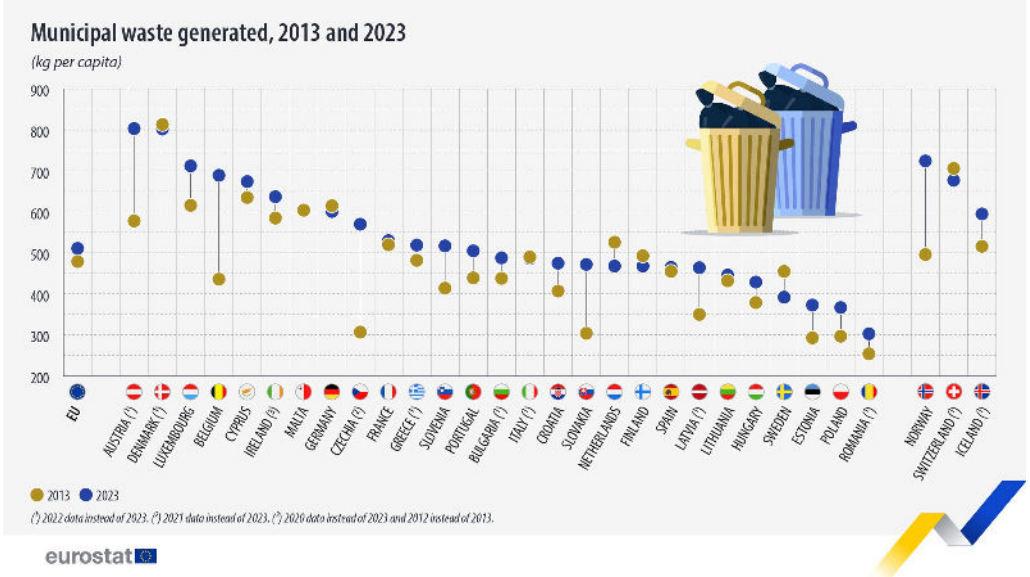
3. Validazione su scala pilota in ICB-CSIC

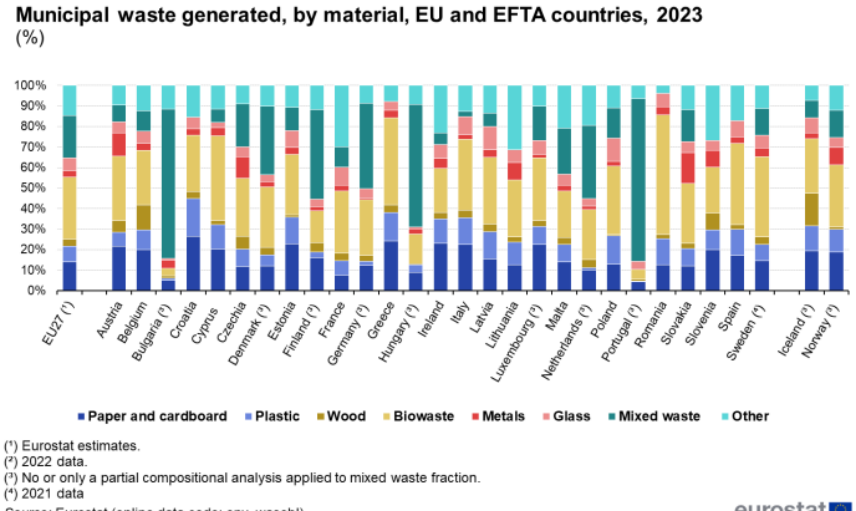
4. Conclusioni

Introduzione

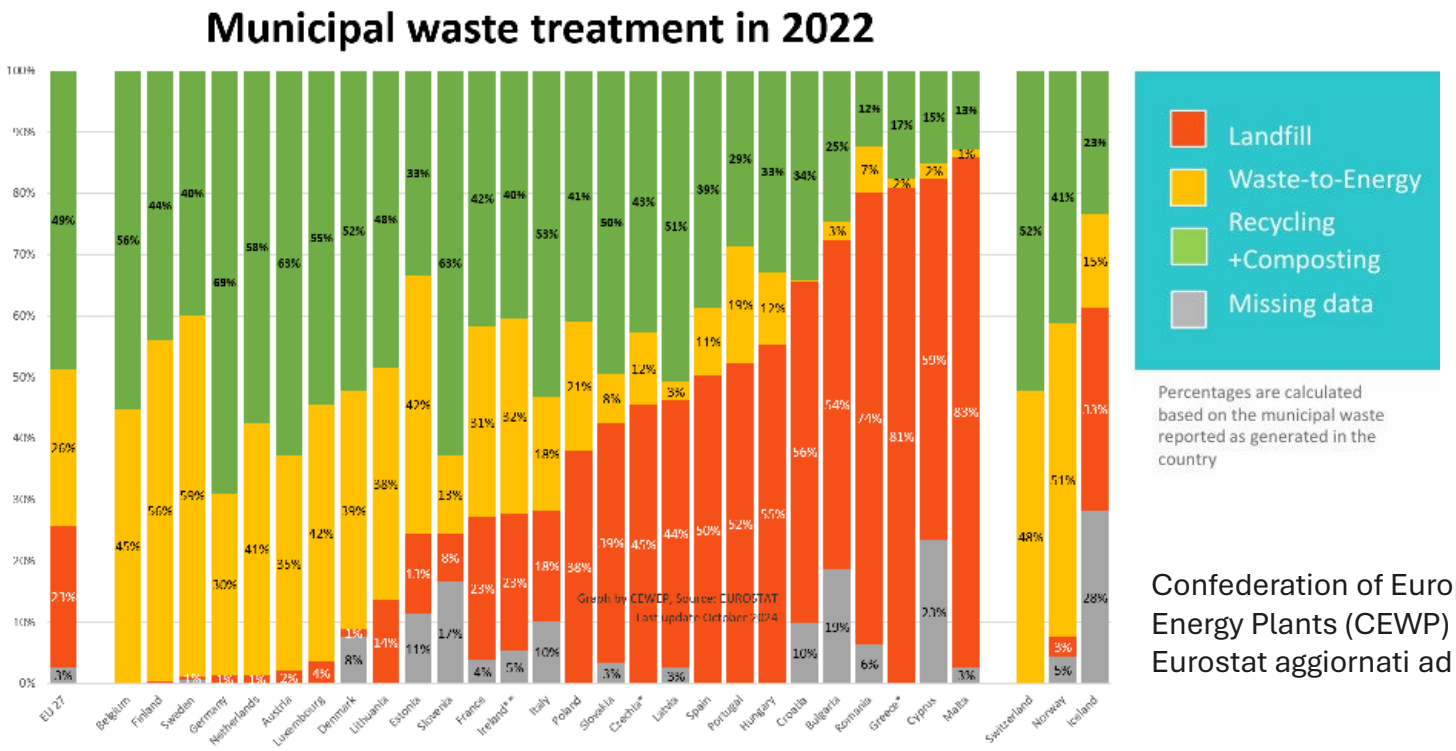
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Consumiamo sempre di più...





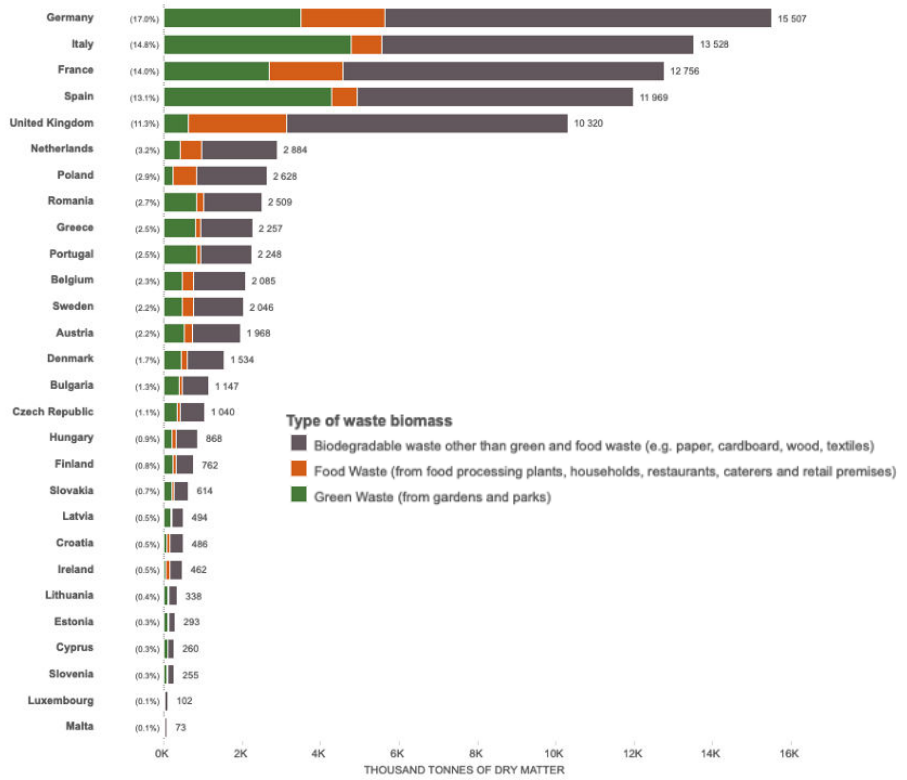
… ma quasi il 25% si butta



Confederation of European Waste-to-Energy Plants (CEWP) – basato su dati Eurostat aggiornati ad ottobre 2024

Da un problema...

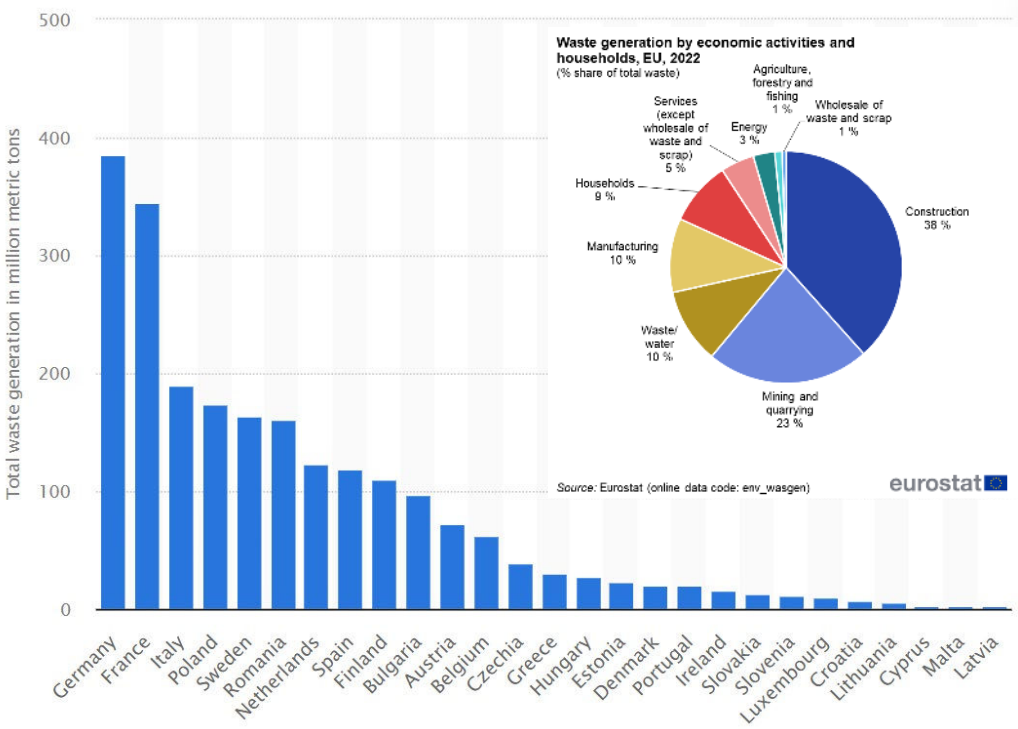
Biomassa di scarto
Biogenic carbon
Renewable feedstocks
Residuo da agricoltura, foreste e filiere industriali



Source: Elina Griniece, Alasdair Reid and Vladimir Cvijanović, High-level value chain mapping in the Baltic Sea Region: Pilot exercise on circular bioeconomy, June 2020

Da un problema...

Waste (rifiuto)
Non (o difficilmente) riciclabile
Refuse-Derived Fuel (RDF)
Solid Recovered Fuels (SRF)
Plasmix
Mix di rifiuti recalcitranti ai pretrattamenti



Source: Eurostat (figura da Statista)

… ad asset strategico

Biomassa
Biogenic carbon
Renewable feedstocks
Residuo da agricoltura,
foreste e filiere industriali

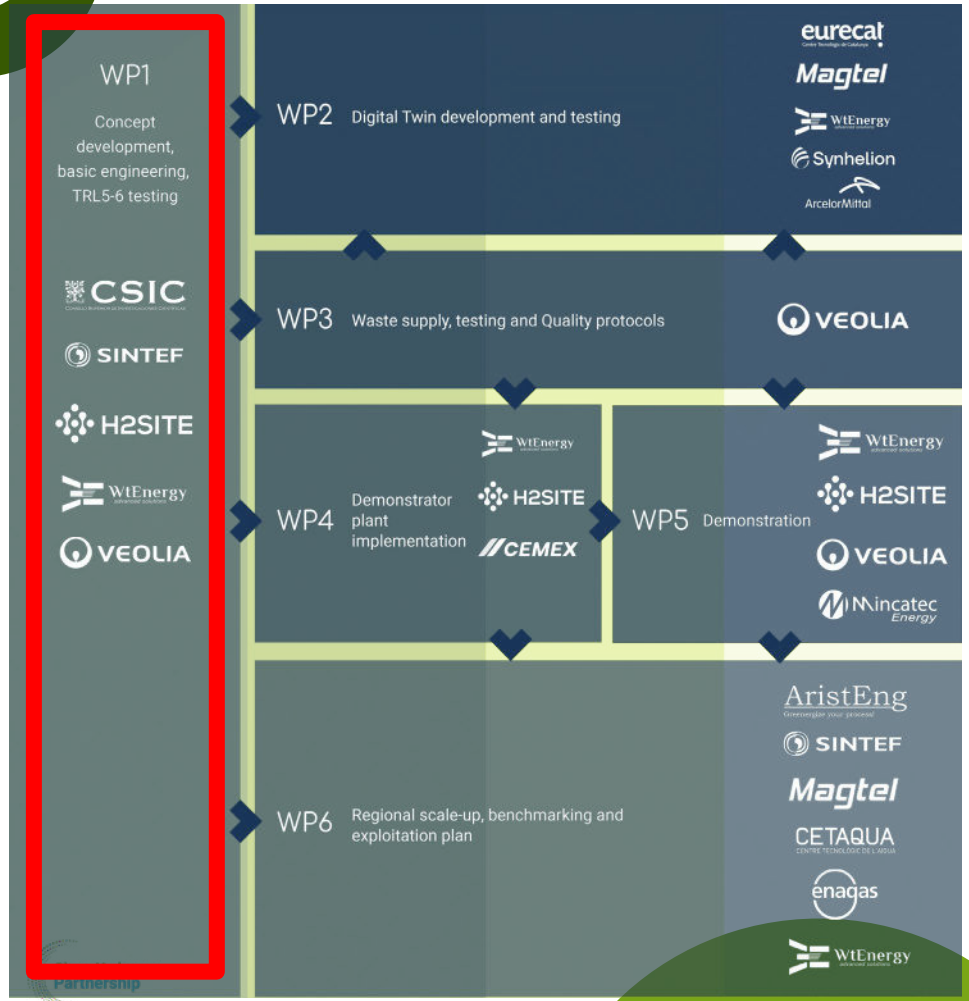
Waste (rifiuto)
Non (o difficilmente) riciclabile
Refuse-Derived Fuel (RDF)
Solid Recovered Fuels (SRF)
Plasmix
Mix di rifiuti recalcitranti ai pretrattamenti

Syngas o H_2



Valore strategico
1. Minore dipendenza da fonti fossili
2. Produzione di heat & power
3. Syngas-to-X (SNG, methanol, fuel da FT)

Cosa serve
1. Purificazione efficiente del syngas
2. Pre-trattamento della carica

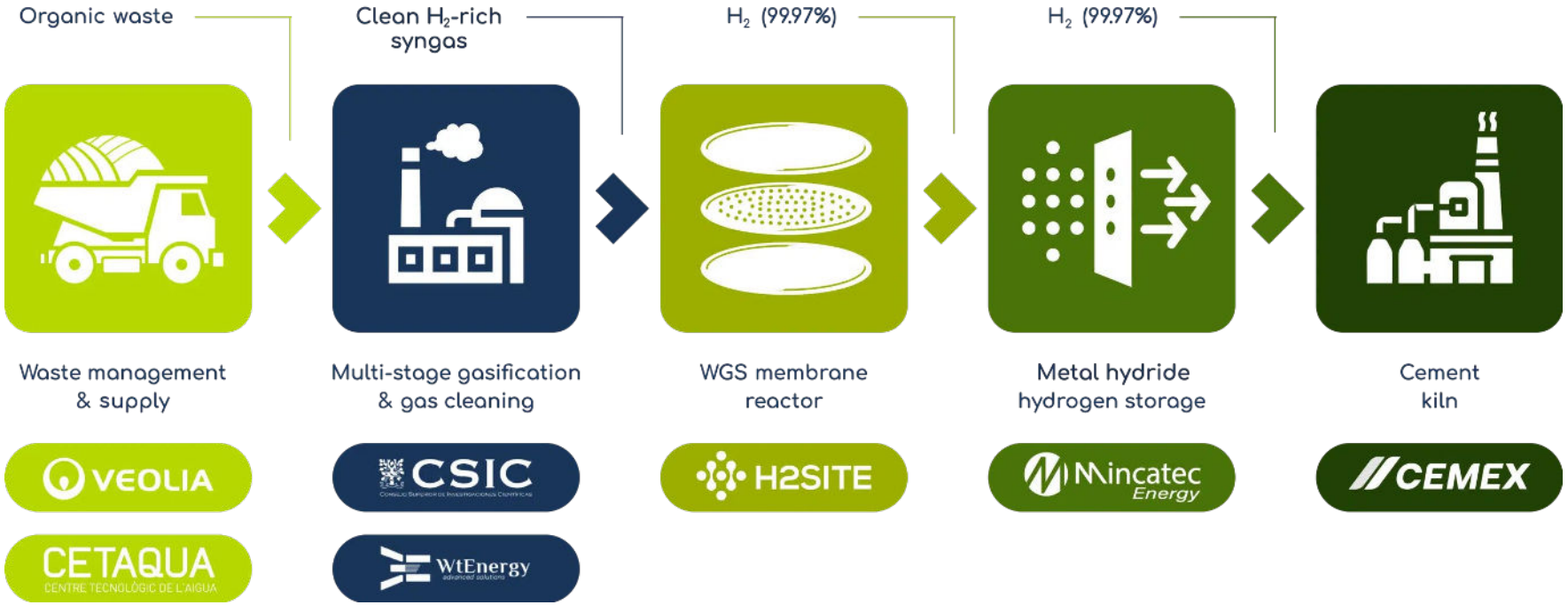


Cos'è HYIELD?

A novel multi-stage steam gasification and syngas purification demonstration plant for waste-to-hydrogen conversion

HORIZON-JTI-CLEANH2-2023-01-05 - Waste to Hydrogen demonstration plant
HORIZON-JU-IA - HORIZON JU Innovation Actions

Overview


Organic waste
Clean H_2-rich syngas
H_2 (99.97%)
H_2 (99.97%)
Waste management & supply
Multi-stage gasification & gas cleaning
WGS membrane reactor
Metal hydride hydrogen storage
Cement kiln
VEOLIA
CETAQUA
CENTRE TECNOLÒGIC DE L'AIGUA
CSIC
WtEnergy
H2SITE
Mincatec Energy
CEMEX

Cos'è HYIELD?

A novel multi-stage steam gasification and syngas purification demonstration plant for waste-to-hydrogen conversion

Perché HYIELD è importante?

- Valorizzazione di biomassa di scarto difficilmente utilizzabile/riciclabile
- Produzione di "clean H_2"
- FOAK pilot con integrazione di multistage gasification, purificazione H_2 e stoccaggio temporaneo

In questa presentazione

- Validazione su **scala pilota presso ICB-CSIC**
- Focus sulla tecnologia **bubbling fluidized bed gasification** and specifiche/caratteristiche del syngas
- Valutazione e discussione dei **principali KPIs** della soluzione utilizzando biomassa di scarto locale.

Key point: H_2 (altamente puro) per applicazione industriale diretta/decarbonizzazione di processi produttivi hard-to-abate

Tieniti aggiornato!

Visualizza la pagina web ed iscriviti alla newsletter di HYIELD!

Gasificazione

Tecnologia e alcuni valori di riferimento

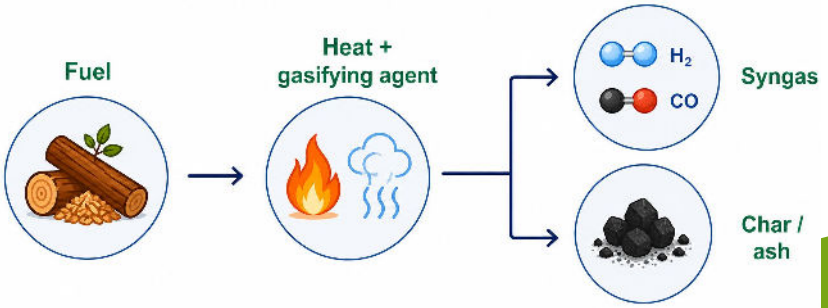
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Fondamentali

- Conversione di un combustibile solido e/o liquido in syngas (o miscela ricca in H_2)
- Agente ossidante/gasificante (steam e/o O_2) substechiometrico;
- Punto operativo (ER = 0.2-0.4 per steam gasification)
  - Sopra la pirolisi
  - Sotto la combustione

Step
Drying (essicamento)
Devolatilizzazione/pirolisi
Reazioni di ossidazione (parziale)
Tar cracking e reforming
Gasificazione del char

Mix
H_2
CO
CO_2
CH_4
C_{2+}
Tar
NO_x
SO_x
H_2S



Reazioni

Pirolisi/devolatilizzazione

Biomassa → tars + precursori char (C) + light gas

Fortemente endotermica

Partial oxidation

$CH_4 + 1.5\ O_2 \rightarrow CO + 2H_2O$

$C + 0.5\ O_2 \rightarrow CO$

Esotermiche

Water-gas shift

$CO + H_2O \rightleftharpoons CO_2 + H_2$

Debolmente esotermica ed equilibrium-driven

Boudouard

$C + CO_2 \rightleftharpoons 2CO$

Endotermica

Combustioni

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$C + O_2 \rightarrow CO_2$

$H_2 + 0.5\ O_2 \rightarrow H_2O$

Fortemente esotermiche

Steam reforming/tar reduction

$CH_4 + H_2O \rightleftharpoons CO + 3H_2$

$C + H_2O \rightleftharpoons CO + H_2$

$Tar + aH_2O \rightleftharpoons bCO + cH_2$

$Tar + aCO_2 \rightleftharpoons bCO + cH_2$

Fortemente endotermiche

Cracking

$Tar \rightleftharpoons Light\ tar + C + CH_4 + 3H_2$

$Tar \rightleftharpoons C + CH_4 + 3H_2$

Fortemente endotermiche

Reazioni

Partial oxidation
$C + 0.5\ O_2 \rightarrow CO$
Esotermiche

Boudouard
$C + CO_2 \rightleftharpoons 2CO$
Endotermiche

Steam reforming gasification
$C + H_2O \rightleftharpoons CO + H_2$
Fortemente endotermiche

Combustioni
$C + O_2 \rightarrow CO_2$
Fortemente esotermiche

Le reazioni gas-solido soffrono di forti limitazioni di **mass-transfer**

Tutte le reazioni che coinvolgono il char (C) sono spesso lente rispetto a tutte le altre di devolatilizzazione e reforming/cracking → **limitazioni nella conversione globale del solido**

Agente ossidante

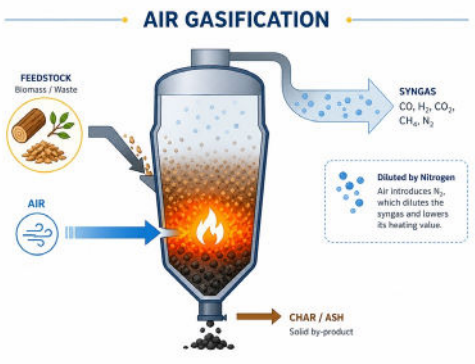
Air gasification

Semplice ed economica

N_2 diluente → basso LHV

Combinabile con heat/CHP

Parzialmente autotermico



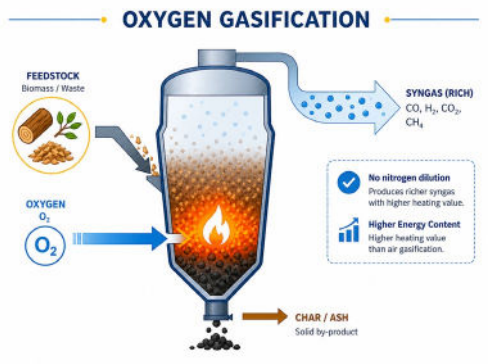
O_2 / O_2-steam gasification

No N_2 diluente

Alto tenore CO + H_2

Moderato LHV del syngas

O_2 da fornire



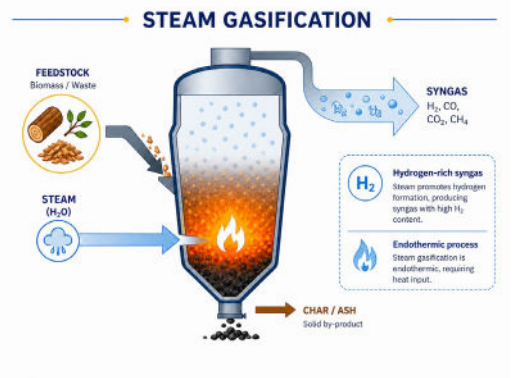
Steam / allothermal gasification

Favorisce H_2

Spinge reforming e shift

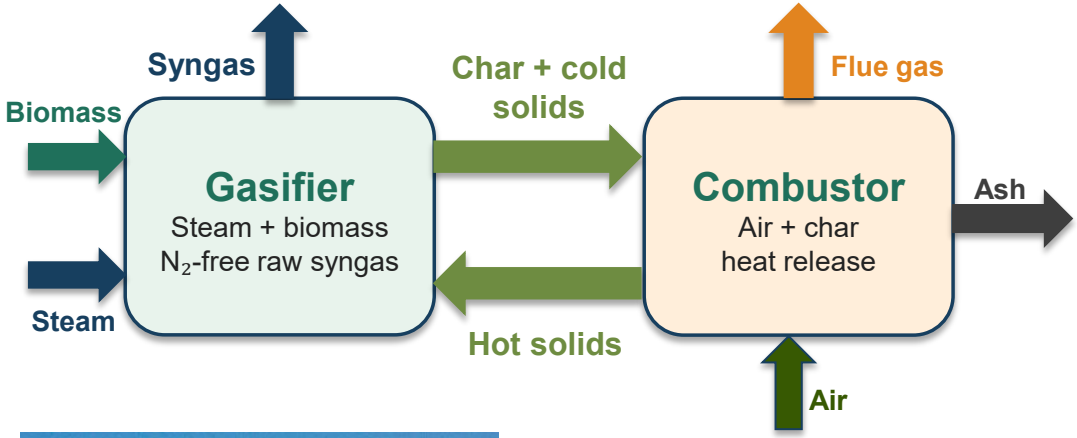
Fortemente endotermica

Supply di steam e calore



Ma opportunamente controllare trasferimento di ossigeno e calore

Indirect Gasification



	% vol. dry
H_2	40
CO	25
CO_2	20
CH_4	10
N_2	5



Indirect gasification plant in Güssing (Austria)

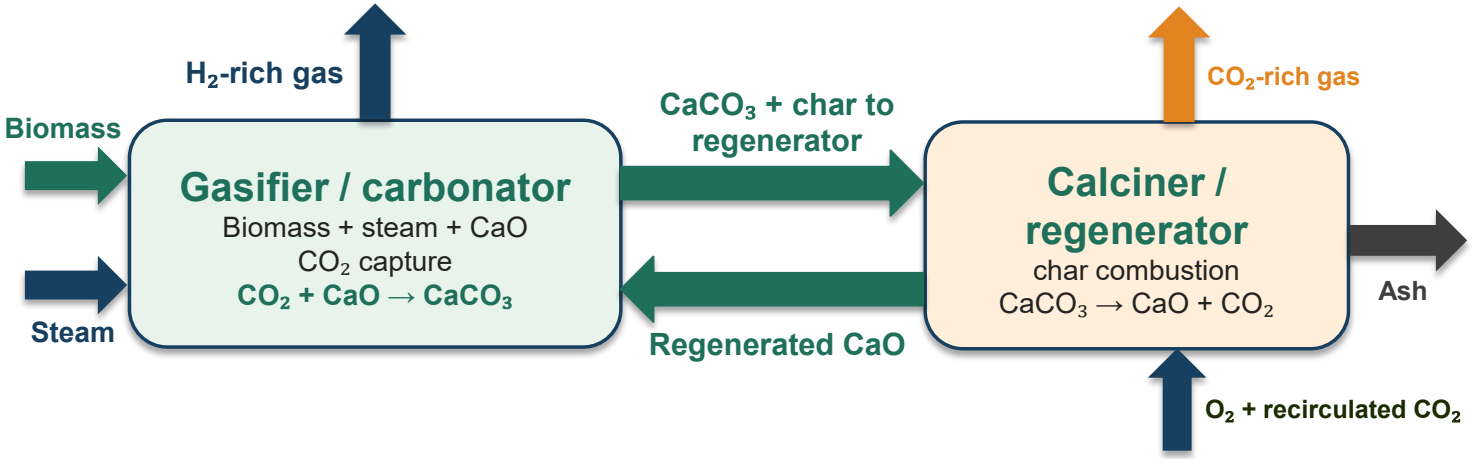
Why it is useful
Steam gasification without direct air dilution.

Main advantage
Higher-quality syngas with no N_2 dilution.

Key point: the gasifier produces syngas, while char is combusted in a separate reactor to reheat the circulating heat carrier, typically olivine or another bed material.

Main challenge
Solids circulation and heat-transfer control.

Sorption Enhanced Gasification (SEG)



	% vol. dry
H_2	70
CO	7
CO_2	7
CH_4	12
N_2	4

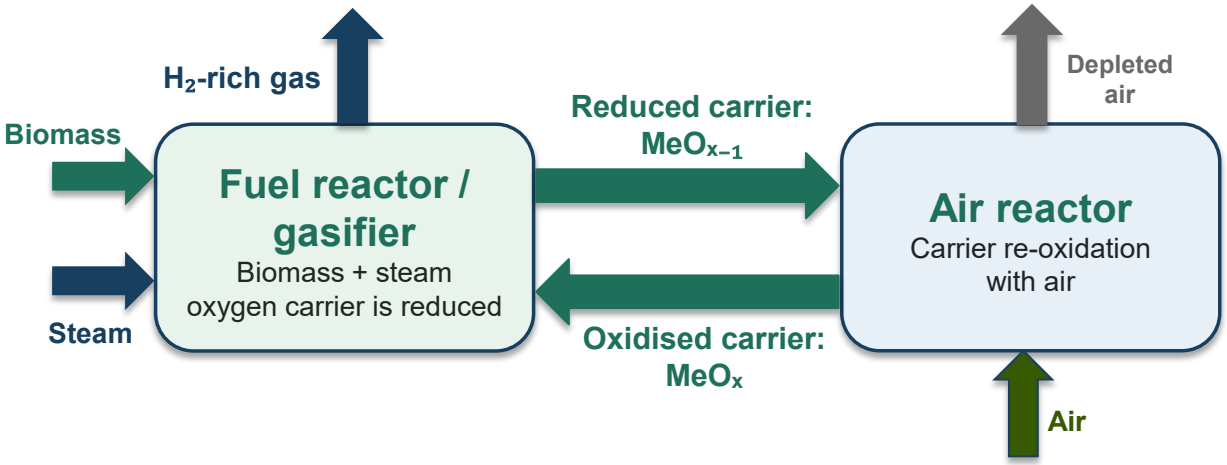
Effect in the gasifier
CO_2 removal favours H_2 production

Regeneration step
$CaCO_3$ is calcined back to CaO.

Heat supply
Char combustion can provide regeneration heat

Key point: the $CaO/CaCO_3$ loop combines gasification, CO_2 capture and sorbent regeneration, producing a hydrogen-enriched gas in the gasifier and a concentrated CO_2 stream from the calciner

Chemical Looping Gasification



	% vol. dry
H_2	30
CO	30
CO_2	22
CH_4	8
N_2	2

Concept
Oxygen is supplied by a solid metal oxide.

Main advantage
Air and syngas are never directly mixed.

Control parameter
Oxygen carrier circulation and reactivity.

Key point: chemical looping controls the oxygen potential through a circulating solid carrier, enabling partial oxidation/gasification while avoiding nitrogen dilution of the syngas.

Confronto

Component (% vol. dry)	Air	O_2	O_2 + steam	Indirect	SEG	CLG
H_2	15	30	45	40	70	30
CO	20	40	25	25	7	30
CO_2	15	20	20	20	7	22
CH_4	3	4	8	10	12	8
N_2	47	1	0 - 2	5	4	2

Diluted fuel gas
Air operation is simple and autothermal, but the high N_2 content strongly lowers gas quality.

Synthesis-oriented gas
O_2 and indirect routes produce low-N_2 syngas with higher heating value and easier upgrading.

H_2 / CO_2 management
SEG boosts H_2 and creates a CO_2-rich regeneration stream; CLG tunes oxidation without air mixing.

Note: actual gas composition depends on feedstock, equivalence ratio, steam/biomass ratio, temperature, pressure, residence time and bed material/catalyst activity.

Key message: the oxygen and heat supply strategy determines whether the product is a diluted fuel gas, a synthesis gas or an H_2-rich gas with CO_2-capture potential.

Configurazioni

Fixed or moving bed gasifiers



LOW MIXING

Main characteristics

- **Simple and robust** reactor concept, often used at small to medium scale.
- Fuel **particles move slowly** through drying, pyrolysis, oxidation and reduction zones.
- Strong axial gradients; tar level depends strongly on updraft/downdraft configuration.

Bubbling fluidized bed gasifiers



INTENSE MIXING

Main characteristics

- **Excellent gas–solid contact** and nearly **uniform bed** temperature.
- Very suitable for heterogeneous biomass and waste feedstocks.
- Requires **bed material**, distributor design, cyclone separation and agglomeration control.

Configurazioni

Circulating fluidized bed gasifiers



SOLIDS RECYCLE

Main characteristics

- High throughput and **better scale-up potential** than bubbling beds.
- Continuous solids circulation **improves heat transfer and carbon conversion**.
- More **complex operation**: cyclone, loop seal, erosion and fines management

Entrained-flow gasifiers



HIGH TEMPERATURE

Main characteristics

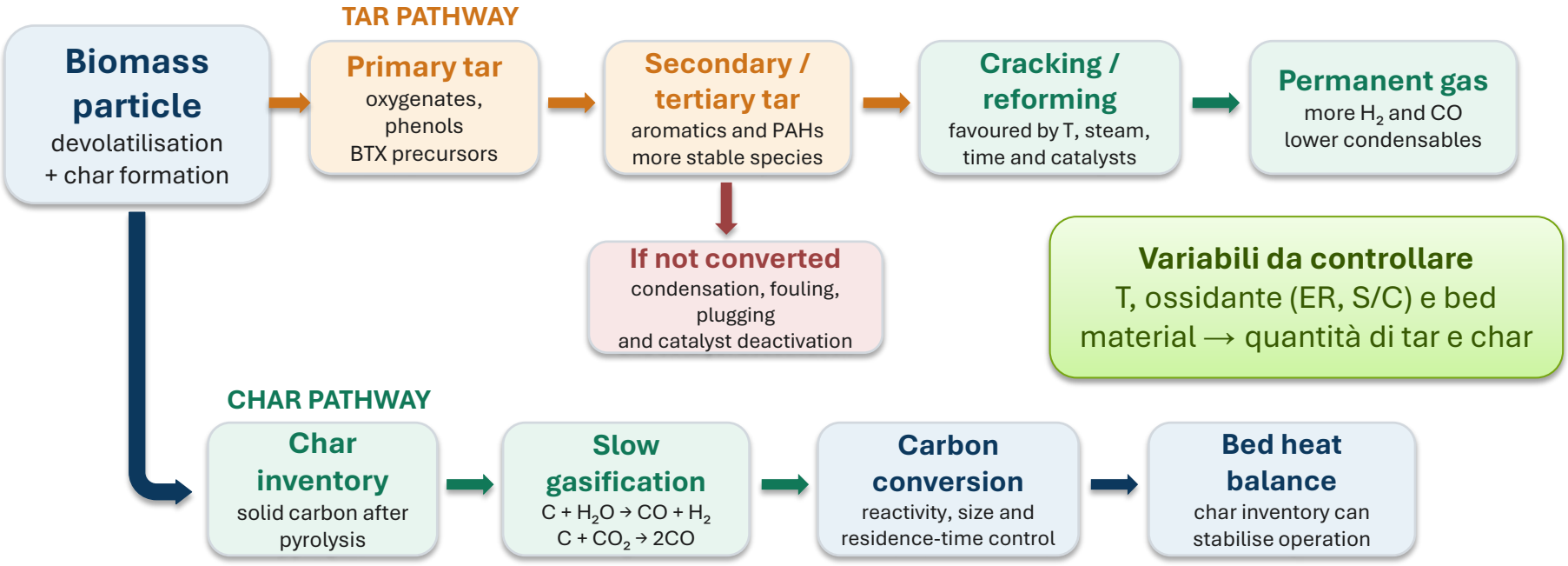
- Very **short residence time** and **high carbon conversion** at **high temperature**.
- **Low tar formation**; product gas is suitable for downstream synthesis after cleaning.
- Demanding feed preparation, **oxygen supply** and high-temperature ash/slag handling.

Configurazioni

- Aumentare la velocità del gas migliora lo scambio termico e di materia, ma rende complesso gestire il solido sia in camera che nel ricircolo

- La soluzione reattoristica migliore è sempre un compromesso tra
  - Flessibilità
  - Variabilità della biomassa
  - Scala
  - Controllo del tar (residence time e agente ossidante)
  - Conversione del solido
  - Costo della purificazione

Gestione del tar e char



Key message: good gasification requires simultaneous control of tar formation, char conversion and contaminant release.

Syngas cleaning

Raw syngas may contain particles, alkali species, H_2S, HCl, NH_3, tars and condensable organics

Particles and solids

Cyclones
Hot ceramic / candle filters
Bag filters or polishing filtration

Tar removal after cooling

Quench and condensation
Water / venturi scrubbers
Oil scrubbers or wet ESP

Inorganic / acid contaminants

H_2S, HCl, NH_3, alkalis, trace metals
Wet scrubbers
Sorbent beds / activated carbon

Hot tar conversion

Catalytic beds: dolomite, olivine, Ni
Thermal cracking
Thermal plasma

Why cleaning matters

- avoids plugging, fouling and condensation
- protects catalysts, membranes and synthesis units
- limits corrosion, emissions and downstream instability
- tailors gas quality to H_2, MeOH, SNG or FT routes

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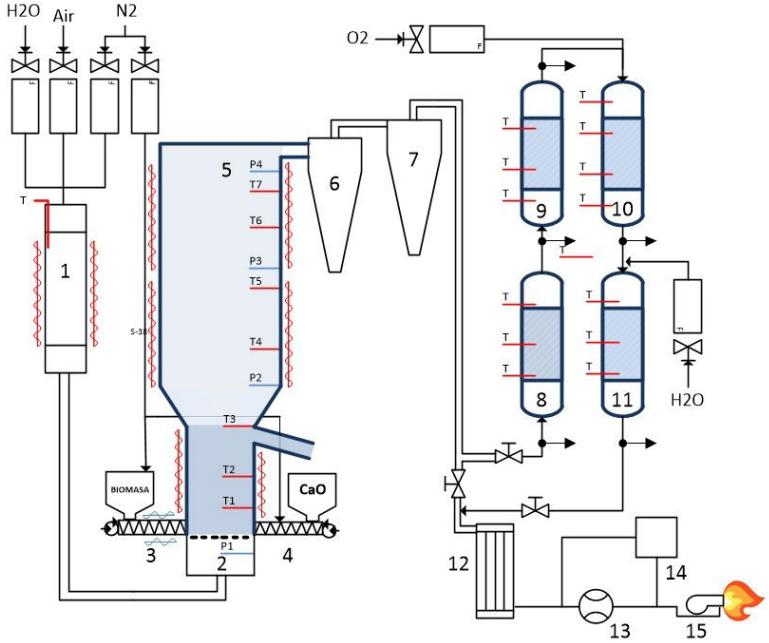
Validazione di oxy-steam gasification di waste a TRL-5

Pilota esercito da ICB-CSIC

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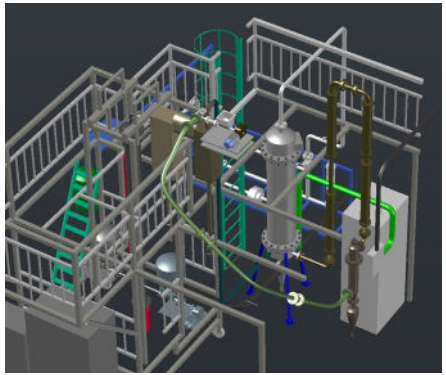
Bubbling fluidised bed gasifier





1- Evaporator
2- Distributor plate
3- Biomass screw feeder (water-cooled)
4- Bed screw feeder (insulated)
5- Fluidised-bed gasifier
6/7- Cyclones
8- Chlorine removal reactor
9- Sulphur removal reactor
10- Tar reforming reactor
11- WGS reactor
12- Condenser
13- Flow meter
14- Online gas analyser
15- Flare stack



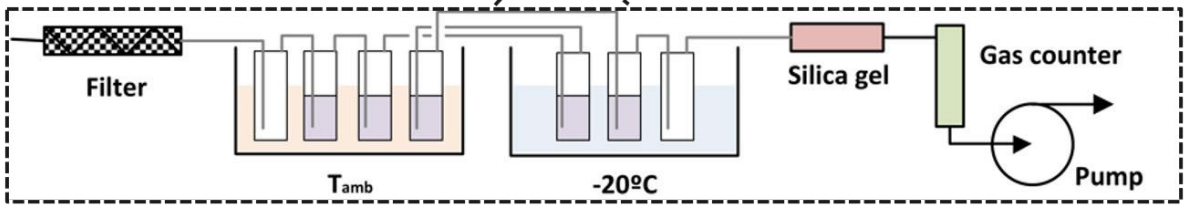


Tar sampling

- Standardized cold sampling train downstream of the gasifier
- Particle filter + impingers at Tamb and −20 °C

Tar sampling system

- Isopropanol used as solvent
- Gas flow controlled by pump and gas counter

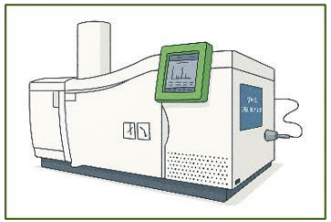


Collectable tar

- 23 representative compounds (BTX, phenols, PAHs)



GC–MS

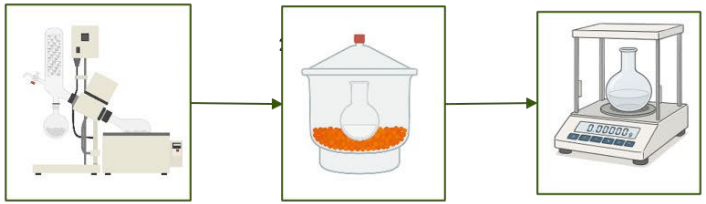


Gravimetric tar

Rotary Evaporator

Drying 24 h (Silica Gel)

Analytical Balance



Experimental matrix

Run	Feedstock	Bed	T (ºC)	S/C	ER
1	Structurant	Olivine	650	1.5	0.14
2	Structurant	Olivine	750	1.5	0.13
3	Structurant	Olivine	850	1.5	0.20
4	Structurant	Olivine	650	2	0.12
5	Structurant	Olivine	650	1	0.15
8	Olive stone	Olivine	650	1.5	0.13
11	Sewage sludge	Olivine	650	1.5	0.14
14	Grape seeds	Olivine	650	1.5	0.15

Caratterizzazione del solido



Structurant



Olive stone



Sludge



Grape Seeds

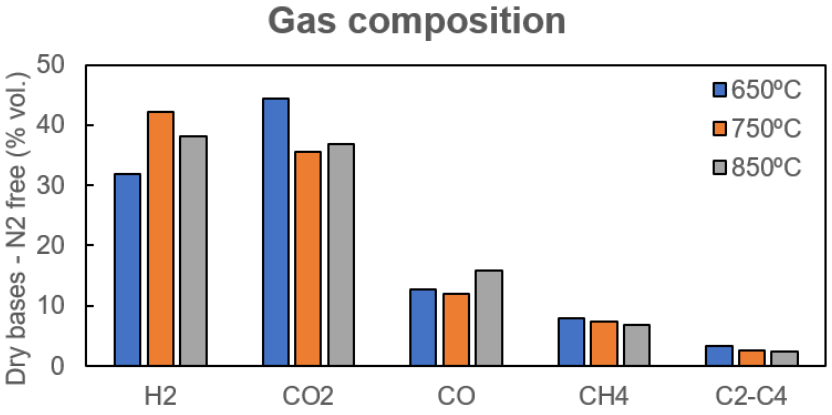
(%)	Structurant	Sludge	Grape Seeds	Olive stone
Moisture	7.7	6.5	7.8	8.61
Volatile Matter	64.4	48.0	67.7	72.96
Ash	12.8	42.1	3.1	0.42
Fixed carbon	15.2	3.4	21.5	18.01

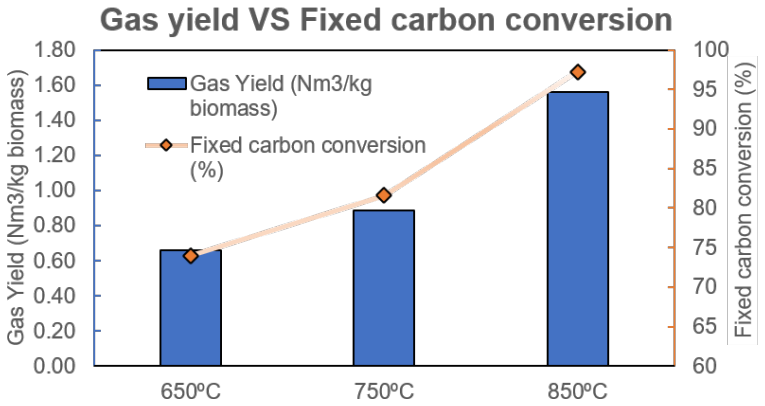
(%)	Structurant	Sludge	Grape Seeds	Olive stone
C	41.6	28.0	51.7	46.66
H*	5.89	4.49	6.94	5.21
N	0.75	3.86	1.74	0.13
S	<0.1	1.8	0.1	<0.1
O**	31.16	13.25	28.62	38.87

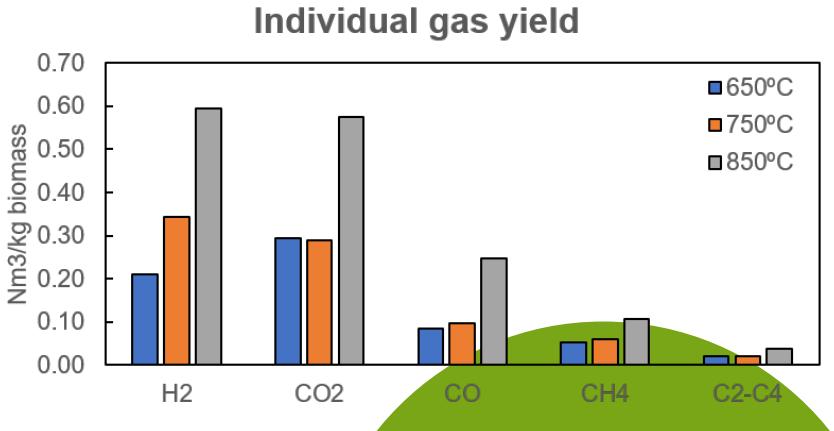
Parameter (MJ/kg)	Structurant	Sludge	Grape Seeds	Olive stone
HHV	15.96	11.93	21.75	18.77
LHV	14.72	10.99	20.32	17.35

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Effetto della temperatura

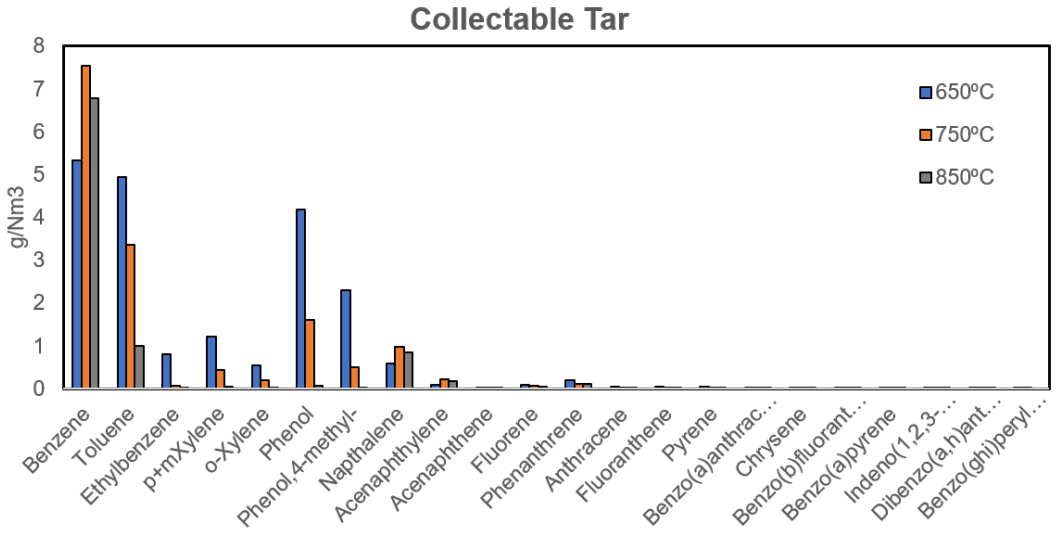






Operating conditions

- Bubbling fluidized bed gasifier
- Structurant biomass
- Constant S/C ratio



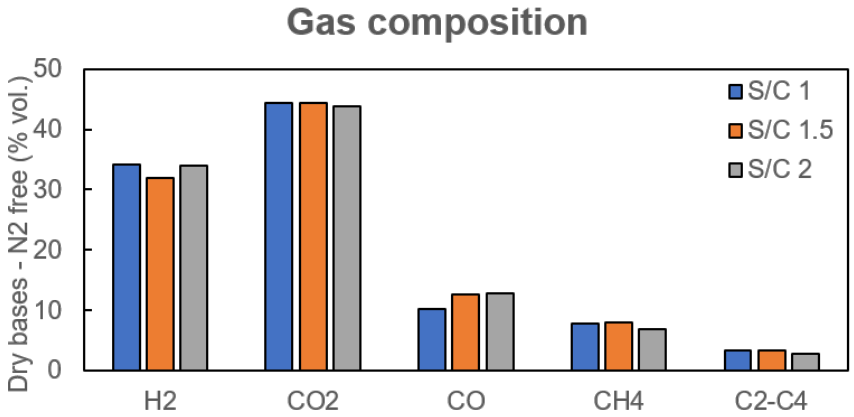
- **650 °C:** Maximum tar production, dominated by phenols and BTEX.
- **750 °C:** Phenols decrease; BTEX remains but in lower amounts; PAHs start to decline.
- **850 °C:** Minimum tar; heavy compounds (PAHs) almost disappear.

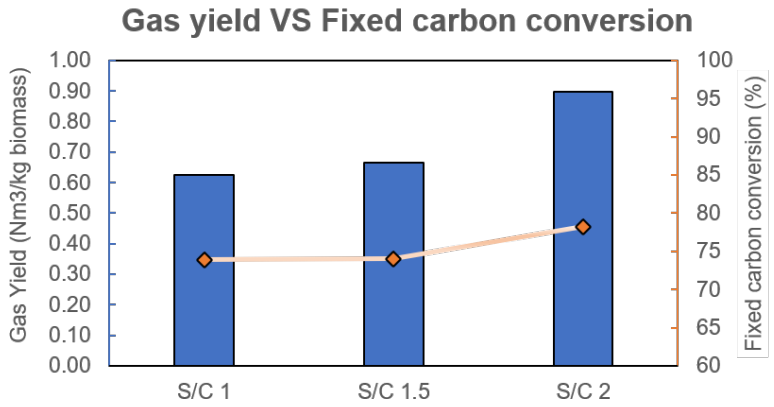
	Collectable tar		
	650ºC	750ºC	850ºC
TOTAL (g/Nm³)	20.54	15.12	9.16
	Gravimetric tar		
	650ºC	750ºC	850ºC
TOTAL (g/Nm³)	35.16	6.85	2.39

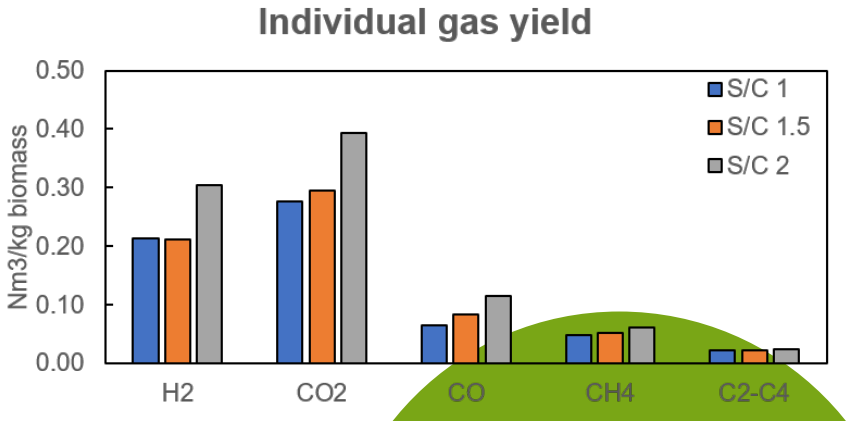
	Sulfur compounds (ppmv)		
	650ºC	750ºC	850ºC
COS	7.53	6.55	11.53
H_2S	516.05	594.60	544.41
CS_2	0.00	0.00	0.00
CH_4S	20.84	0.00	0.00

The main **sulfur compound** detected is H_2S, which remained relatively stable at around **500 ppm**.

Effetto del S/C ratio

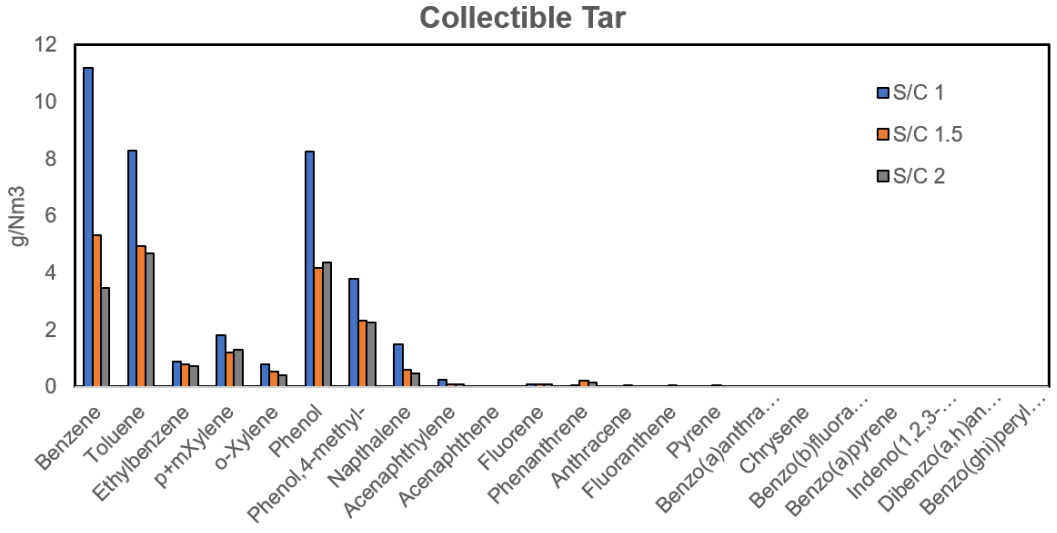






Operating conditions

- Bubbling fluidized bed gasifier
- Structurant biomass
- T = 650°C assegnata



- H_2S is the main sulfur species detected in all cases.
- At high S/C (2.0), H_2S concentration decreases probably due to dilution effects.

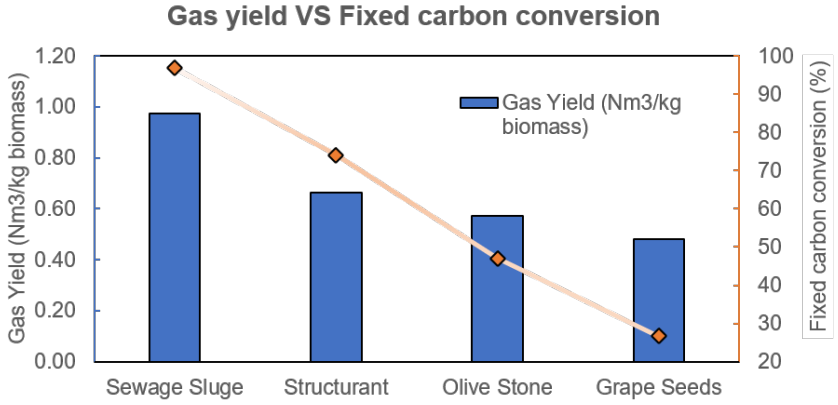
	Collectible tar		
	S/C 1	S/C 1.5	S/C 2
TOTAL (g/Nm³)	37.00	20.54	18.26

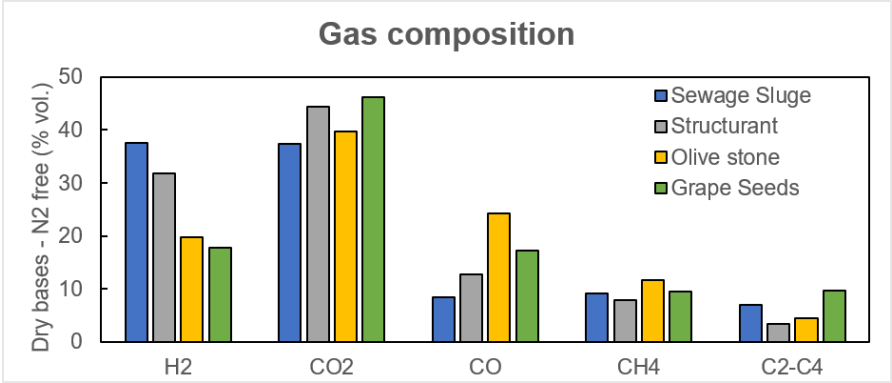
	Gravimetric tar		
	S/C 1	S/C 1.5	S/C 2
TOTAL (g/Nm³)	37.27	35.16	21.50

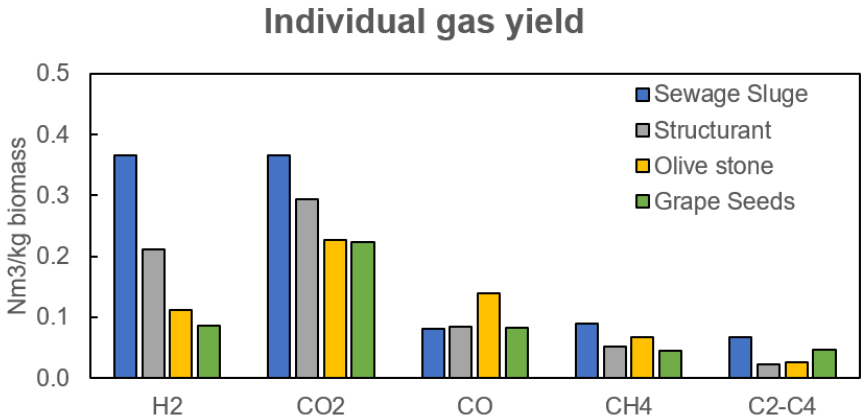
	Sulfur compounds (ppmv)		
	S/C 1	S/C 1.5	S/C 2
COS	9.48	7.53	3.02
H_2S	509.47	516.05	276.31
CS_2	0.00	0.00	0.20
CH_4S	10.73	20.84	1.69

Effetto del feedstock

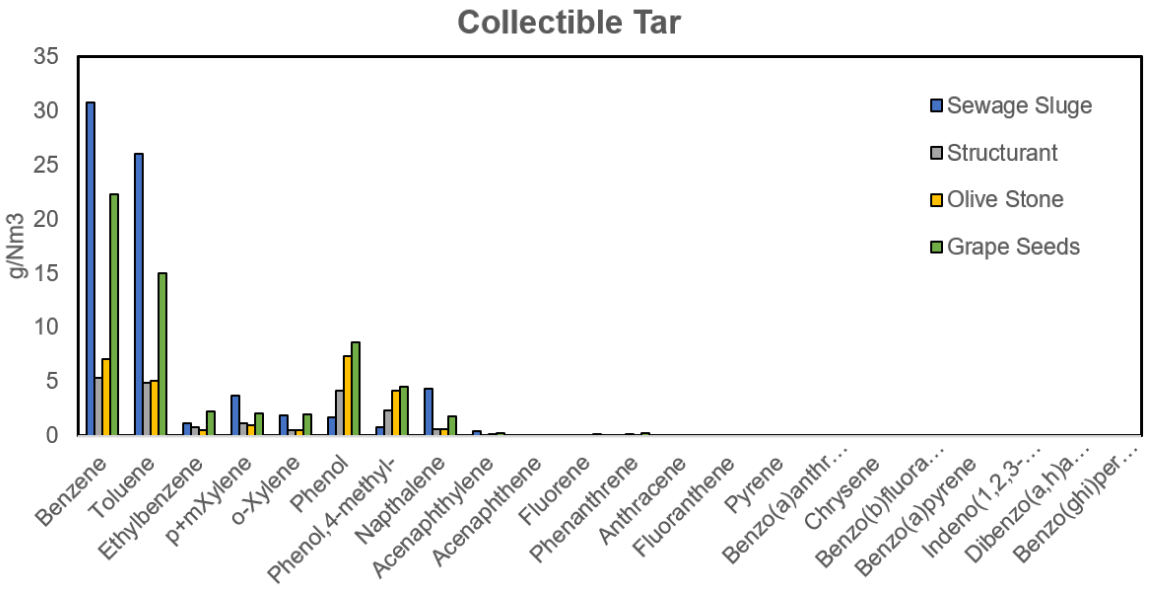
	Structurant	Olive Stone	Grape Seeds	Sewage Sludge
T (ºC)	645	654	658	651
S/C	1.56	1.42	1.83	1.52
ER	0.15	0.13	0.15	0.14







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	Collectible tar			
	Structurant	Olive Stone	Grape Seeds	Sewage Sludge
TOTAL (g/Nm³)	20.54	26.79	59.41	70.92
	Gravimetric tar			
	Structurant	Olive Stone	Grape Seeds	Sewage Sludge
TOTAL (g/Nm³)	35.16	66.73	124.82	33.56

	Sulfur compounds (ppmv)			
	Structurant	Olive Stone	Grape Seeds	Sewage Sludge
COS	7.53	2.36	34.90	9.61
H_2S	516.05	101.02	52.43	6480.74
CS_2	0.00	0.00	0.00	8.80
CH_4S	20.84	1.67	23.30	108.40

Conclusioni

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Key messages

- In Europa produciamo enormi quantità di rifiuti
- Della sola frazione «solid municipal waste» ne accumuliamo (in discarica) il 25%
- La questione **rifiuti da problema** deve diventare **un asset europeo**

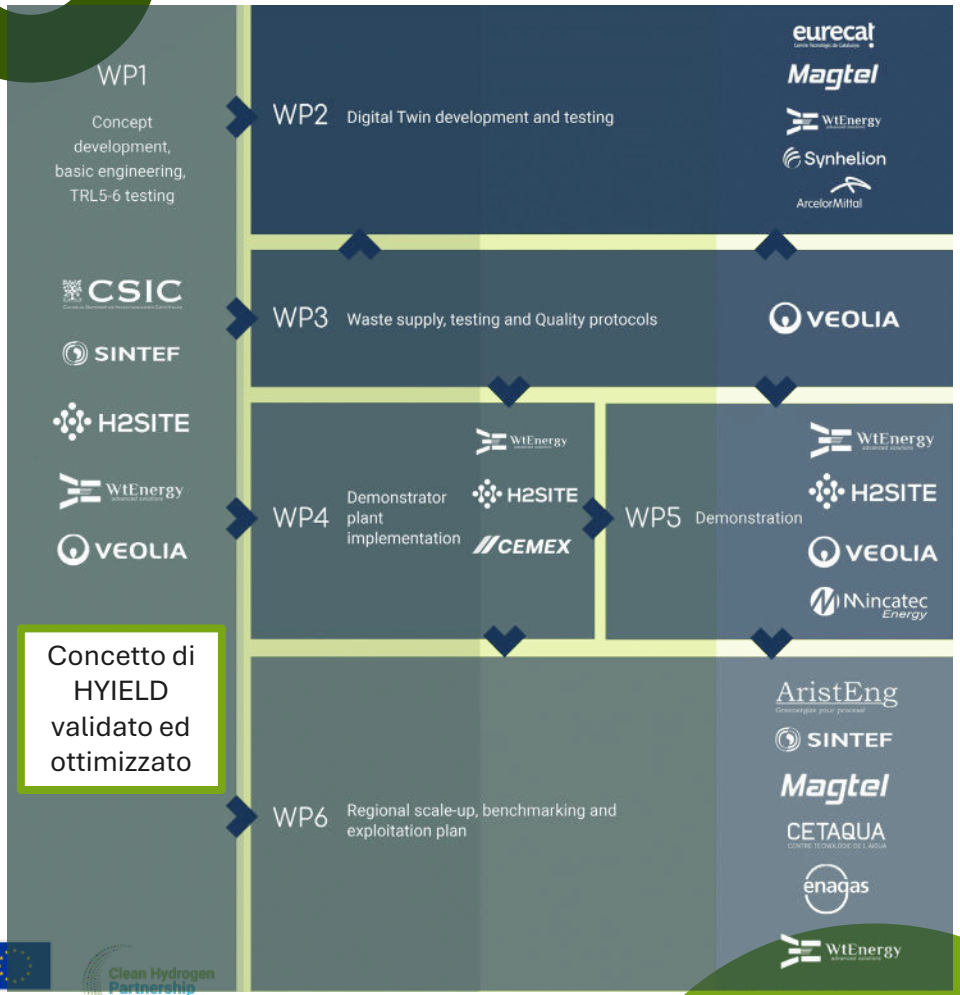
- Gasificazione consente
  - **Valorizzare scarti** difficilmente utilizzabili/riciclabili
  - Produrre biosyngas...
  - ... ma questo biosyngas deve subire **post-trattamenti (cleaning)**
  - Circolarità significa **nuove tecnologie**... o **riadattare l'esistente** (con modifiche)

- **HYIELD** vuole dimostrare che **waste-to-H_2** tramite **oxy-steam gasification** è possibile e **può diventare competitivo**

Conclusioni

La campagna sperimentale usando biomassa di scarto e rifiuti (waste) ha evidenziato

- Il **feedstock** ha un ruolo chiave nella qualità del (bio-)syngas prodotto
- Le **impurezze** nel (bio-)syngas dipendono dalla carica
- La **resa e carbon conversion** dipendono dalle condizioni operative
- «Harsh» operating conditions non si riflettono necessariamente in una maggiore qualità del syngas finale
- Il punto di ottimo dipende da **tanti fattori**: carica, condizioni operative, agente ossidante, target di produzione, cleaning a valle etc



Concetto di HYIELD validato ed ottimizzato

Cosa mi devo aspettare da feedstock diversi?

Quale tipo di scarto genera l'industria o può raccogliere e utilizzare?

Quali sono le prestazioni del processo su scala pilota?

Quale è la fattibilità economica (TEA) e il reale beneficio ambientale?

Esiste una scalabilità e come impatta a livello regionale?

Conclusioni

HYIELD riflette questo **complesso ecosistema**... fatto di domande e risposte che bisogna dare

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Thank you for your time!

Non esitate a visitare la webpage e contattateci per qualsiasi richiesta!

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