BEST PRACTICES

IN THE ADOPTION OF RESOURCE RECOVRY STRATEGIES

Gasification: a flexible process for resource recovery from waste

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RESOURCE RECOVERY PARTNERSHIP CONFERENCE 2018

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5th Anniversary

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Gasification: a flexible process for resource recovery from waste

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Outline

1. From *Flue* to *Fuel gas* technologies

2. Types of gasification processes

3. Case studies of waste valorization by gasification

4. Conclusions

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From ***Flue*** to ***Fuel gas***

technologies

to increase flexibility

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Thermochemical conversion processes

1. **combustion**, where the fast and complete oxidation of the waste organic fraction occurs in presence of an adequate excess of oxygen. The resulting *flue gas* contains only completely oxidised products.
2. **gasification**, where a series of endothermic reactions occurs in presence of a gasifying agent (oxygen, steam or carbon dioxide). The resulting *fuel gas* contains large amounts of not completely oxidised products, which can be utilised in different sites and times.
3. **pyrolysis**, where a thermal degradation of the waste occurs in the almost total absence of oxygen or other reagents, through a direct or indirect heat supply. The (solid, liquid and gaseous) products have a very high

Gasification: *a Fuel Gas Process*

The gasification of a solid fuel (waste, biomass or coal) leads to the formation of a producer gas made of some major components (CO, H_2, CH_4, CO_2, H_2O) and different organic (tars) and inorganic impurities and particulates:

solid fuel → CO, CO_2, H_2, CH_4, (N_2), C_nH_m, H_2O

→ char, ash/slag (…, alkali metals), tar

→ HCN, NH_3, H_2S, HCl, COS

Gasification converts the chemical energy contained in the fuel into chemical energy contained in the gaseous products and sensible energy of the produced gas.

Gasification: a flexible *Fuel Gas Process*

Gasification has a wider flexibility and potentially important advantages, when compared to conventional direct combustion:

- reduction of gaseous emissions (of CO_2, PCDD/F, NO_x and SO_x)
- reduction of gas volumetric flow rate (lower cost of APC system)
- potential of higher electrical energy conversion efficiency
- possible production of recyclable slags and metals
- reduction of the amount of residues to final disposal (extension of the lifetime of existing landfills)
- wider fuel flexibility (co-gasification)
- wider range of products (electricity and thermal energy from

Gasification: *large flexibility in input*

Not only biomass and MSW:

Bottom Ash from WtE

Mixed wastes

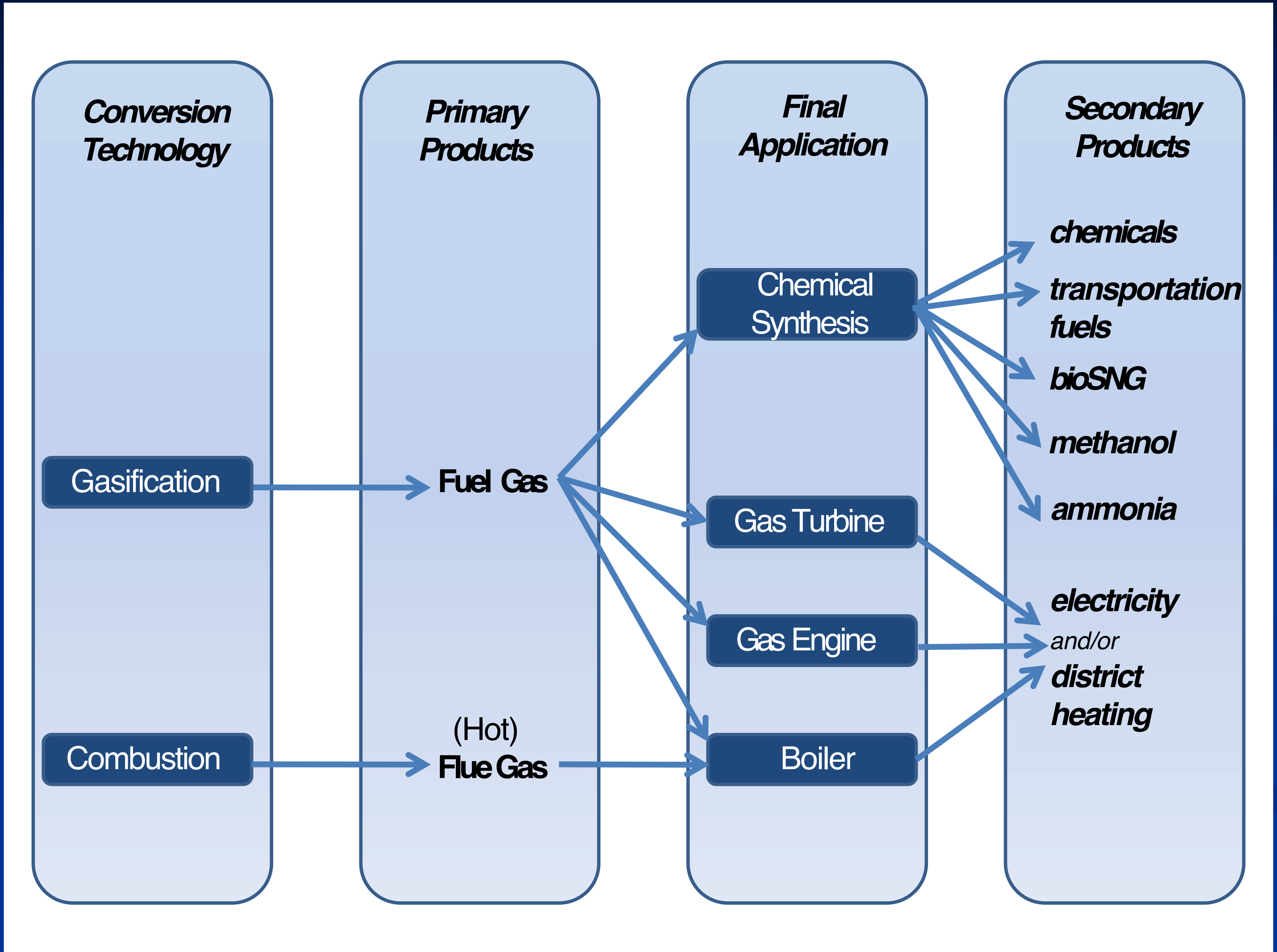
Incombustible residues

Landfill/Reclamation Waste

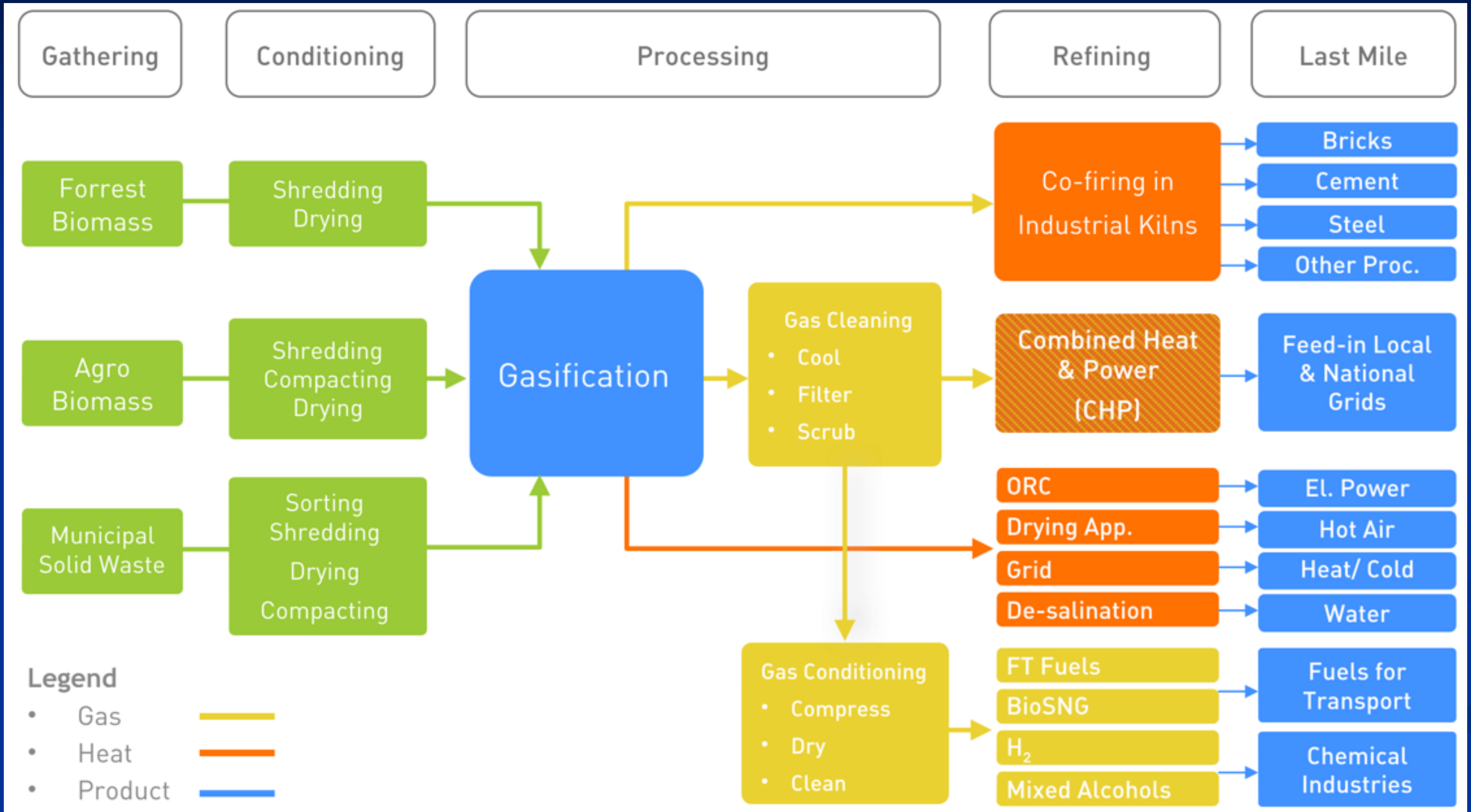
Sewage sludge

Disaster refuse

Gasification: *large flexibility in output*

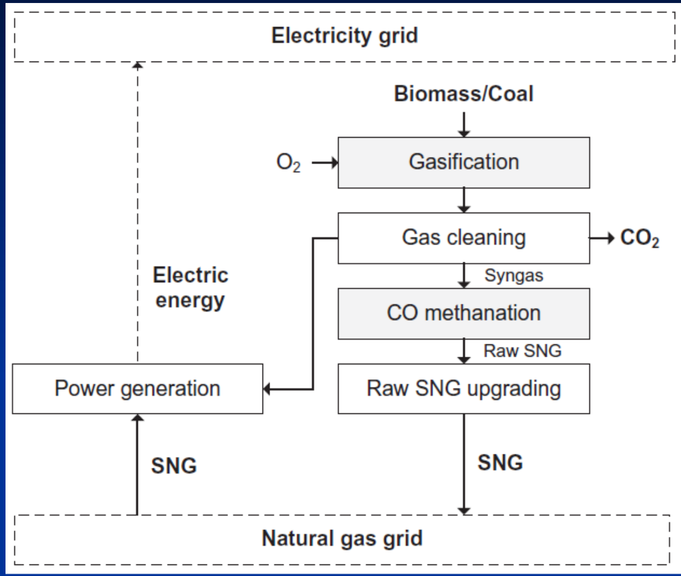


Gasification: *large flexibility in output*

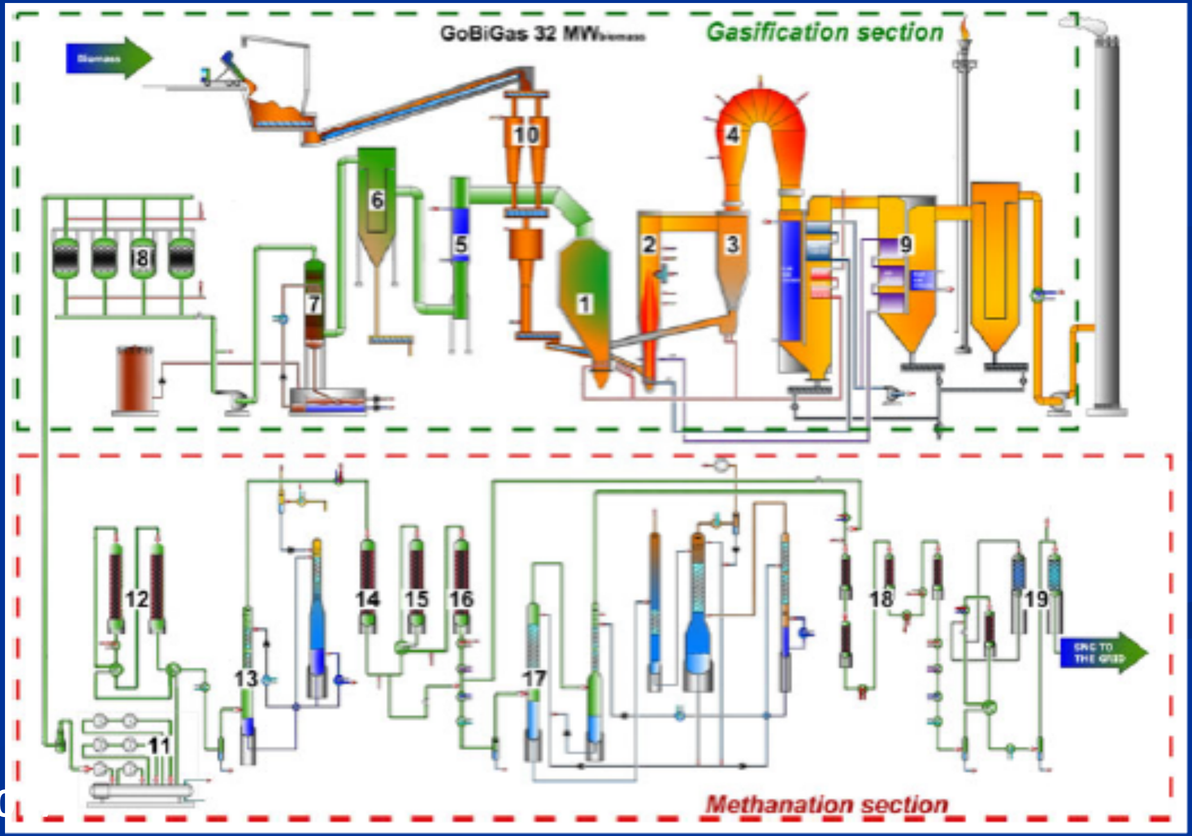


Source: *http://gussingcleanenergy.com/technology/*

Gasification: *large flexibility in output*



Source: *Ronsch* et al., FUEL, 2016



Source: *Alamia* et al., IJEnRes, 20

Gasification: *large flexibility in output*

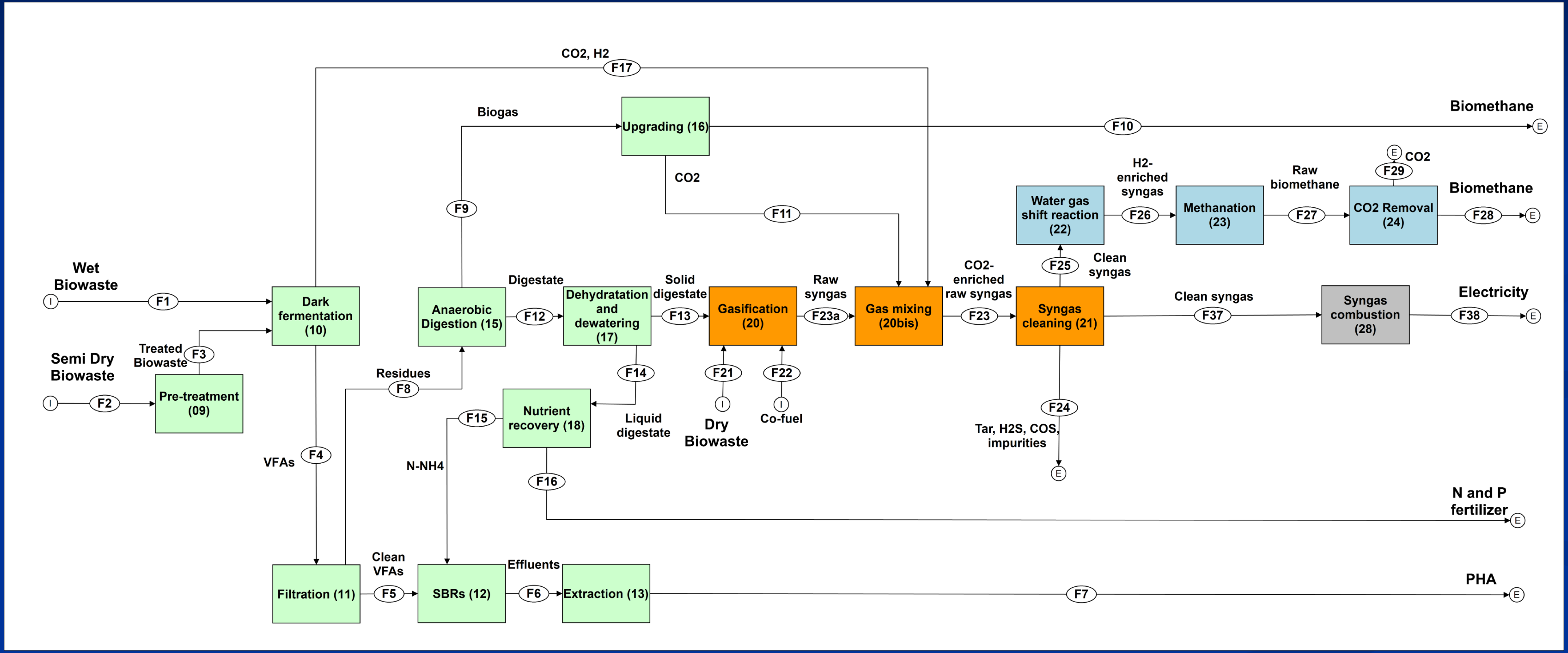
Gasification also allows polygeneration strategies, the production of more than one product in a combined process, to improve process efficiency, economic viability and overall sustainability of biowaste utilisation. Examples are:

- Combined Heat and Power (CHP)
- Solid Oxide Fuel Cells (SOFCs) in combination with Micro-Gas Turbine (MGT)
- Combined SNG, heat and power production
- Biofuels, heat and power production
- Hydrogen and heat production

Polygeneration offers flexibility with regard to changes of market demands.

But higher flexibility comes with higher capital investment costs as well as higher operation and

Gasification: *IN/OUT large flexibility*



Gasification: *IN/OUT large flexibility*

Gasification is a potential great process for:

- waste-to-energy (thermal and/or electric)
- waste-to-fuels (bioSNG, H_2, F-T fuels)
- waste-to-products (chemicals, bio-chemicals)

Gasification opens the way to a Carbon Recycling Economy

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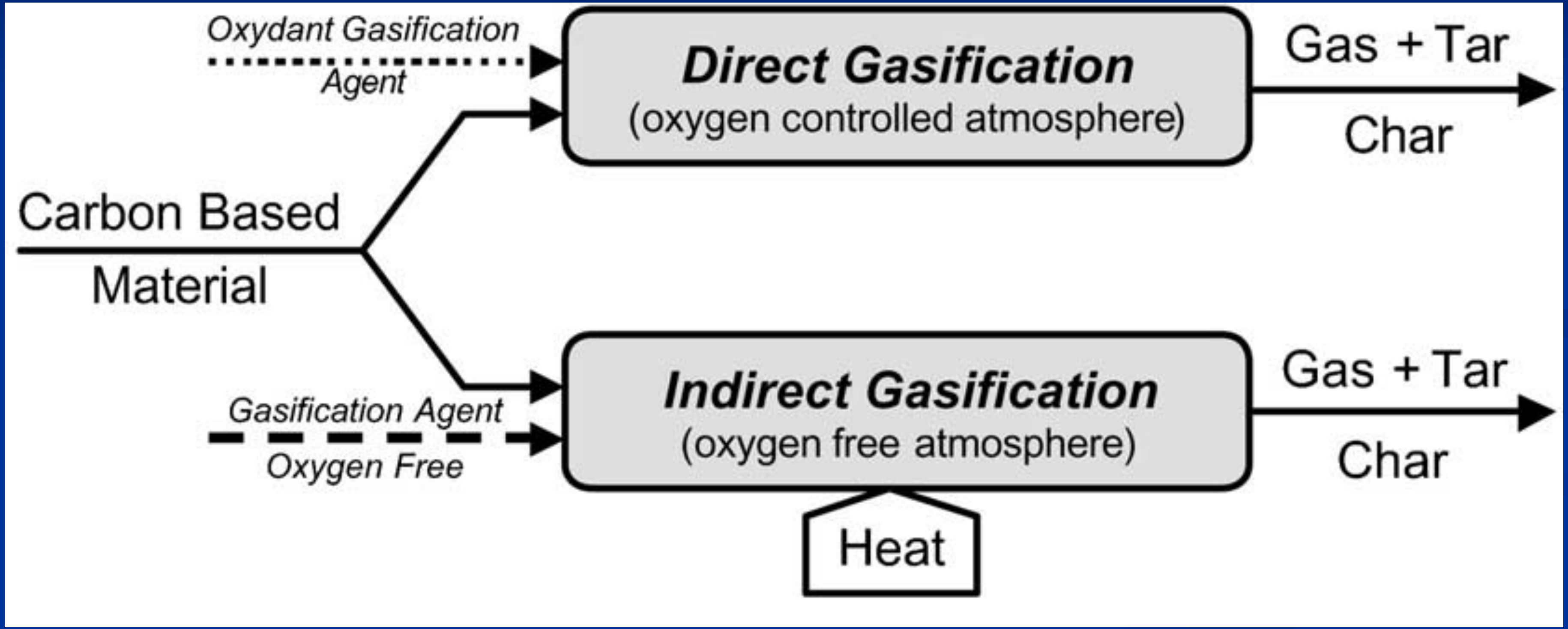
Types of *gasification processes*

Types of gasification processes

Auto-thermal processes



Allo-thermal processes

Types of gasification processes

Auto-thermal processes (direct gasification): the heat is provided by the partial oxidation of the fuel in the gasifier itself. The gasification agent can be air or O_2, even though steam can also be added to these oxidants.

- **Partial oxidation with air**

  Syngas LHV: 4-7 MJ/m^3_N, suitable for energy production by a boiler, a gas engine and new generation gas turbines.

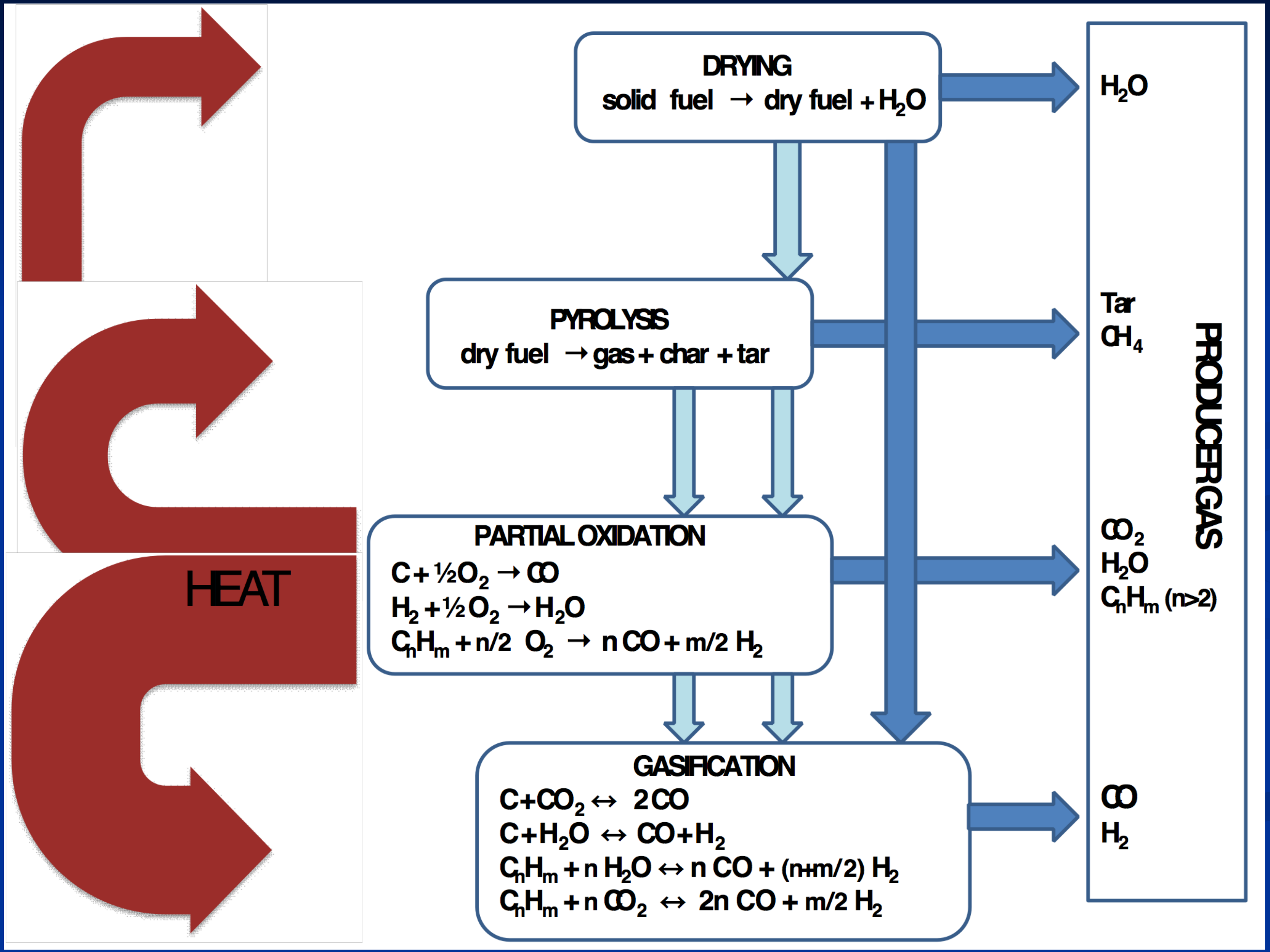
- **Partial oxidation with O_2-enriched air**

  Syngas LHV: 7-10 MJ/m^3_N, that makes possible to carry out auto-thermal processes at higher temperature, without expensive consumption of oxygen.

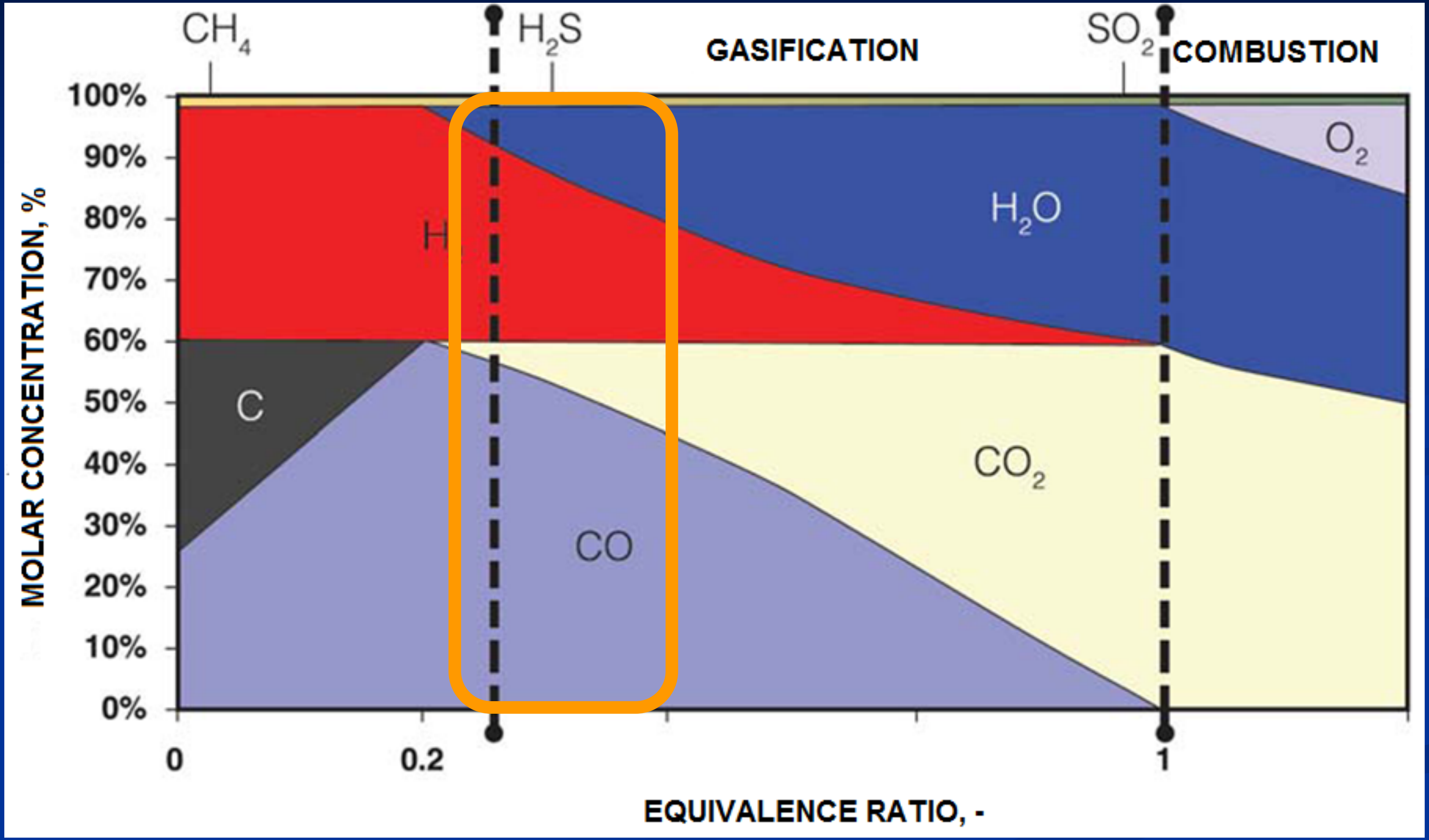
- **Partial oxidation with pure O_2**

  Syngas LHV: 10-15 MJ/m^3_N, almost free of atmospheric N_2, which can also be suitable for pipeline distribution or as a basis for production of transportation fuels.

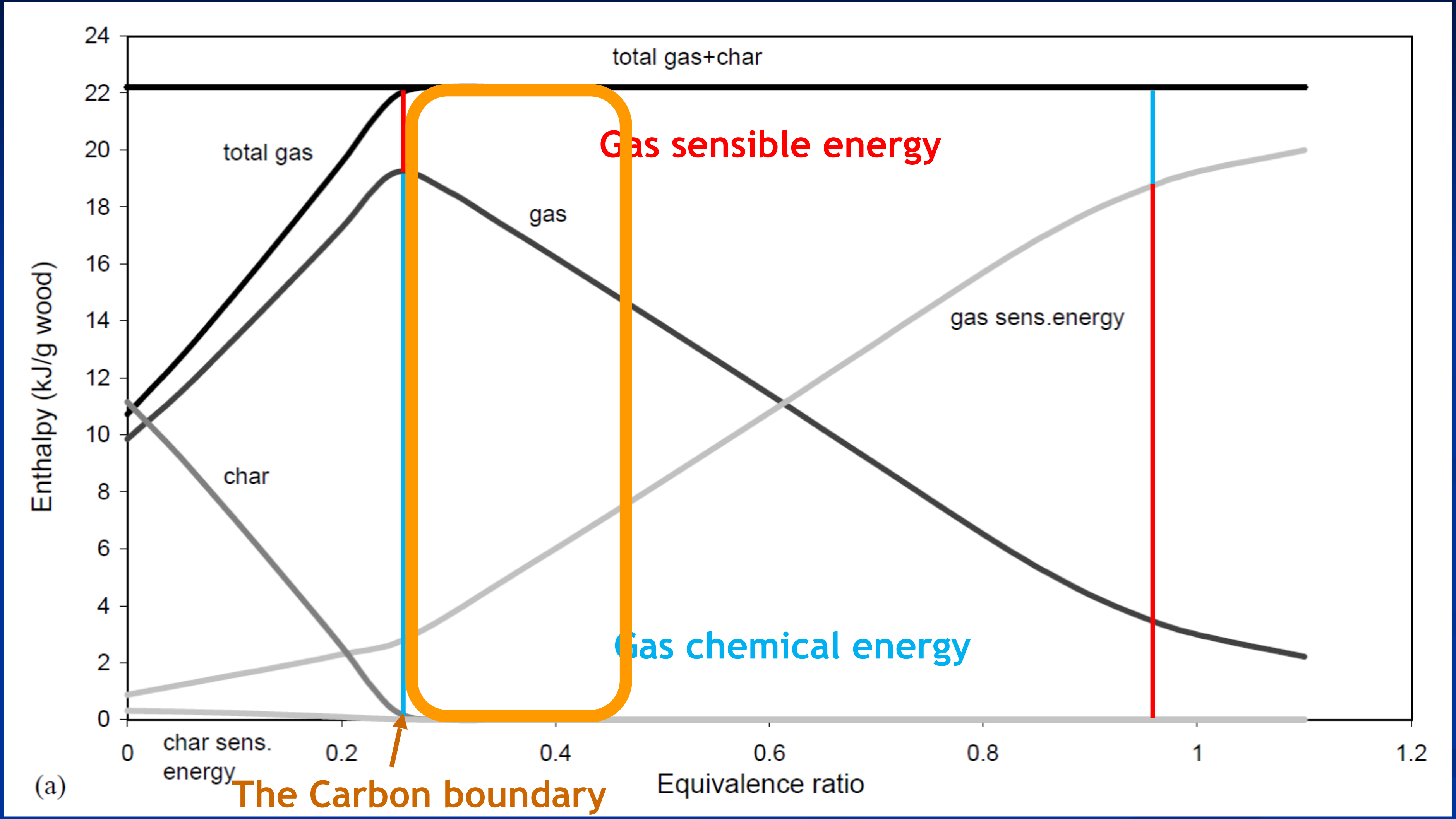
Autothermal gasification: process steps



Autothermal gasification



Autothermal gasification



Source: *Prins* et al., CES, 2003

Types of gasification processes

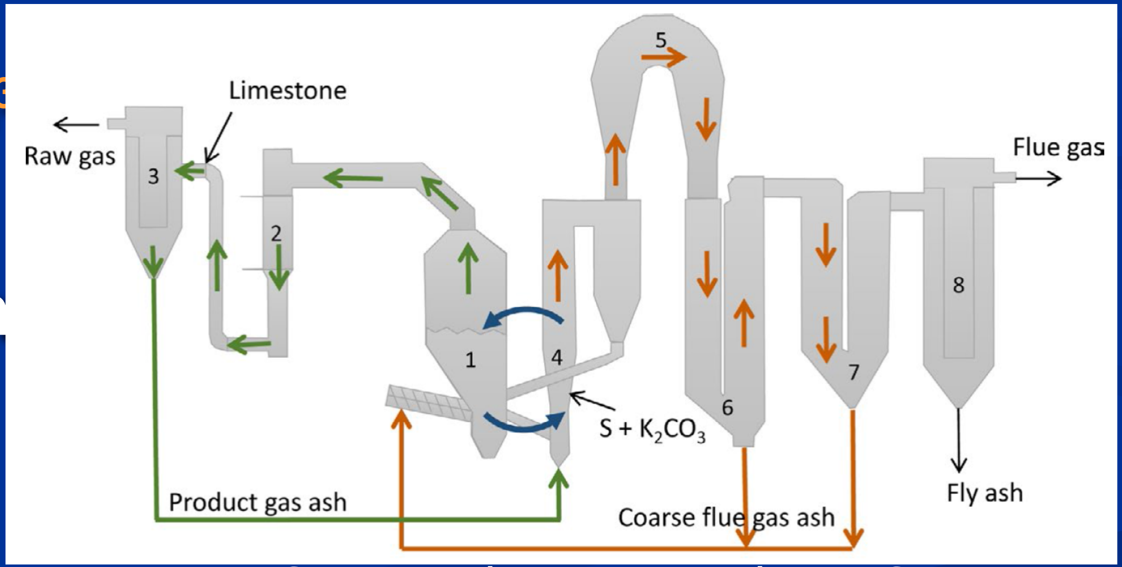
Allo-thermal processes (indirect gasification):

steam is generally the only gasifying agent (but CO_2 can also be used), the process does not include exothermic reactions and then it needs an external source of energy for the endothermic gasification reactions.

- **by internal recirculation of gas and char**

Steam gasification

Syngas LHV: 15-20 MJ/m^3



(Source: Thunman et al., EnScEng, 2018)

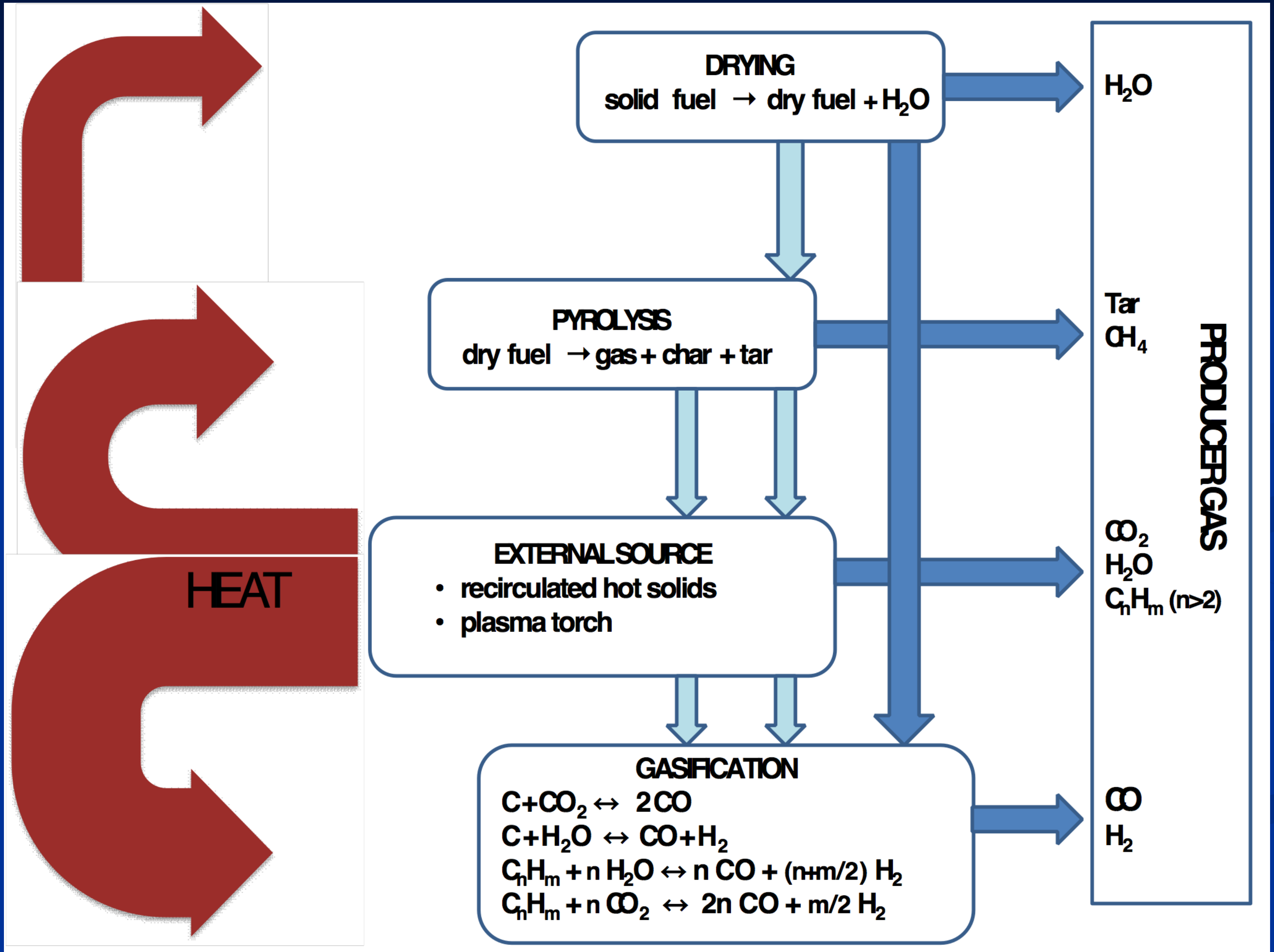
- **by external addition of heat**

Plasma gasification

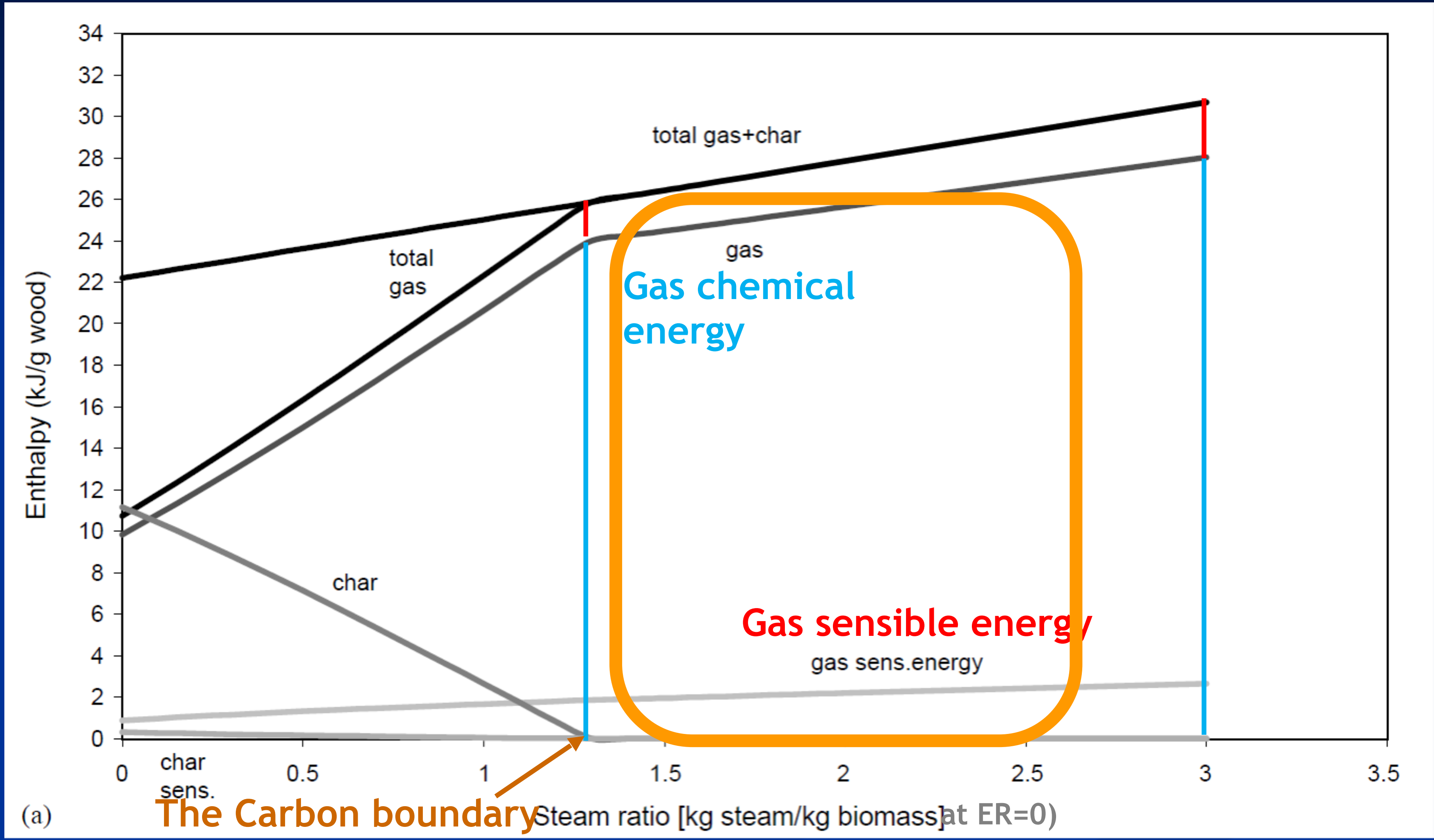
Syngas LHV: 10-15 MJ/m^3_N

Possibility to accept fuel without pretreatments

Allothermal gasification: process steps



Steam gasification process



Source: *Prins* et al., CES, 2003

Types of gasification processes

Co-gasification processes (co-feeding of different biomass or wastes): the flexibility of some gasification technologies (mainly, vertical shaft and FB reactors) allows useful co-feedings into the gasifier:

- **to maximise the process performance**, since the potential synergy between products and intermediates of co-fed fuels can
  - Increase the feedstock energy content (and the reactor temperature)
  - Increase the syngas energy content (then the C losses in particulates and tars)
  - Reduce the ecological footprint of the process
- **to increase the role of thermal treatments in sustainable WM systems**, since waste/biomass co-feeding can
  - Allow to treat difficult materials, for which is not easy to find adequate site for their disposal
  - Minimise the final amount of residues sent to final disposal
  - Reduce emissions of CO_2 (renewable character of biowaste) and those of N_2 and S (low contamination content of biomass)

Potential co-gasification fuels

BIOMASS	Diversity
Wood and woody biomass	Stems, branches, leaves, bushes, chips, lumps, pellets, briquettes, sawdust, …
Contaminated biomass and industrial wastes	MSW, demolition wood, sewage sludge, paperboard, fiberboard, plywood, wood pallets and boxes…
Herbaceous and agricultural biomass	Grasses, flowers, straws, stalks, fruits, fibers, shells, husks, pits…
Animal and human wastes	Bones, meat-bone meal, chicken litter, animal manure, sponges….
Aquatic biomass	Marine or freshwater algae, macroalgae, microalgae, seaweed, lake weed, water hyacinth…
WASTE	
MSW	Paper, cardboard, metals, textiles, organics, wood
Commercial and IW	Packaging, paper, metals, tires, textiles, biomass…
RDF, SRF	Residues of sorting/recycling process, non-combustibles…
ASR	Rubber, foam, glass, wood, paper, leather, textile, metals….
Bottom ash from WtE	**Bottom and boiler ashes from conventional incinerators**
Other wastes	**Disaster waste, Hospital waste, Reclamation waste**

Adapted from: *Ramos et al.*, RSER, 2018

Taxonomy of gasification processes

Criterion	Types
Heat supply	▪ auto-thermal (directly heated) ▪ allo-thermal (indirectly heated)
Gasification agent	▪ air ▪ oxygen enriched-air ▪ oxygen ▪ steam ▪ carbon dioxide
Bottom ash status	▪ dry bottom ash ▪ vitrified slag (melting system)
Final application	▪ waste-to-resources (th/el. energy, landfill space) ▪ waste-to-fuels (bioSNG, H_2, F-T fuels) ▪ waste-to-products (chemicals, bio-chemicals)
Number of	▪ gasification

Case studies

of waste valorisation

by gasification

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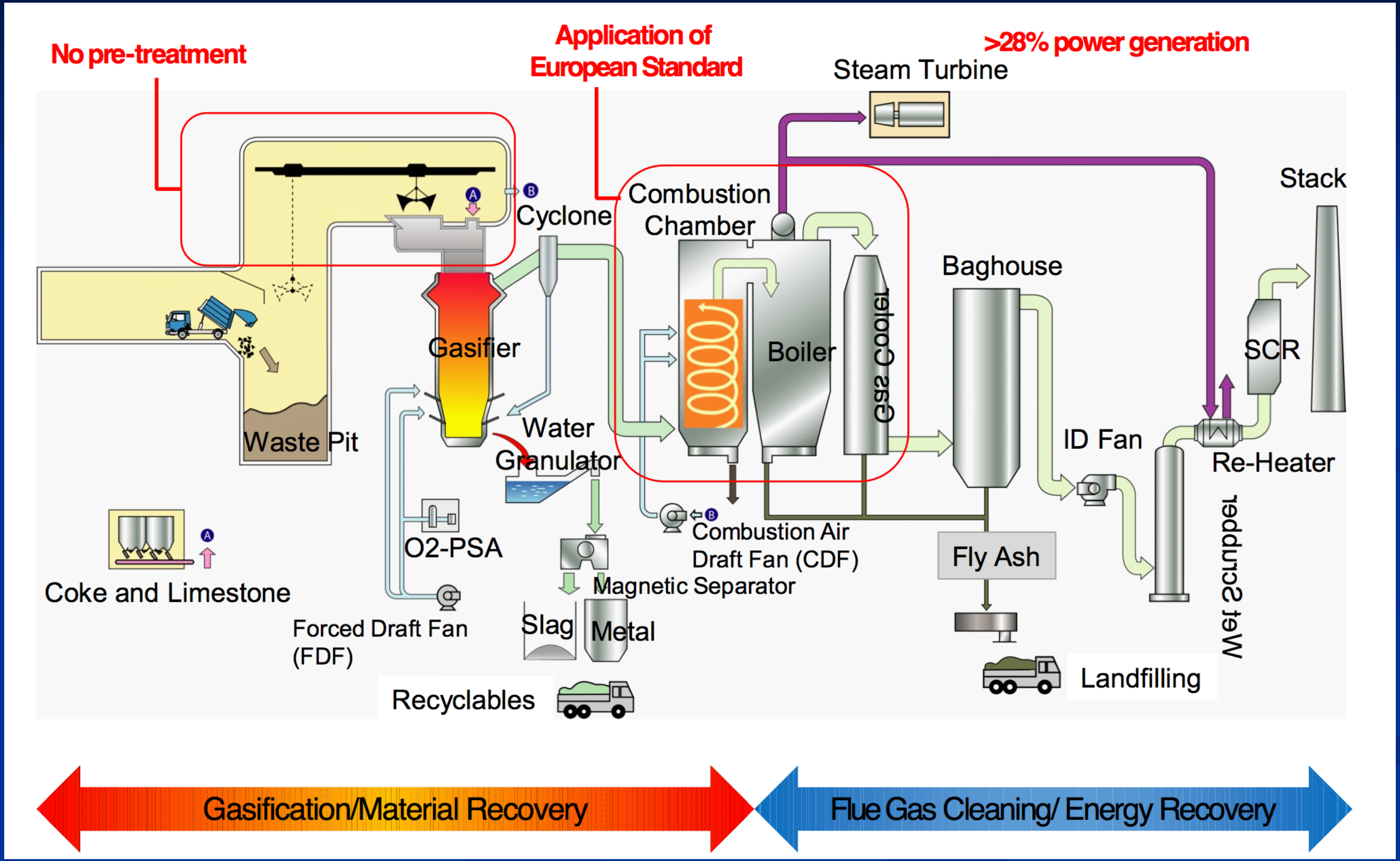
Nippon Steel&Sumkin Engineering DMS



Courtesy of Nippon Steel&Sumikin Eng. Co., *Tanigaki 2015*

Direct Melting System

➢ **Waste Flexibility**

No Pretreatment (Max. 800 mm)

Co-gasification

Sewage sludge

Bottom ash

Landfill Waste

Clinical Waste

➢ **High Syngas LHV**

Continuous syngas measuring

Stable combustion

Approx. 5.9 MJ/m^3_N based on 9.1 MJ/kg-waste

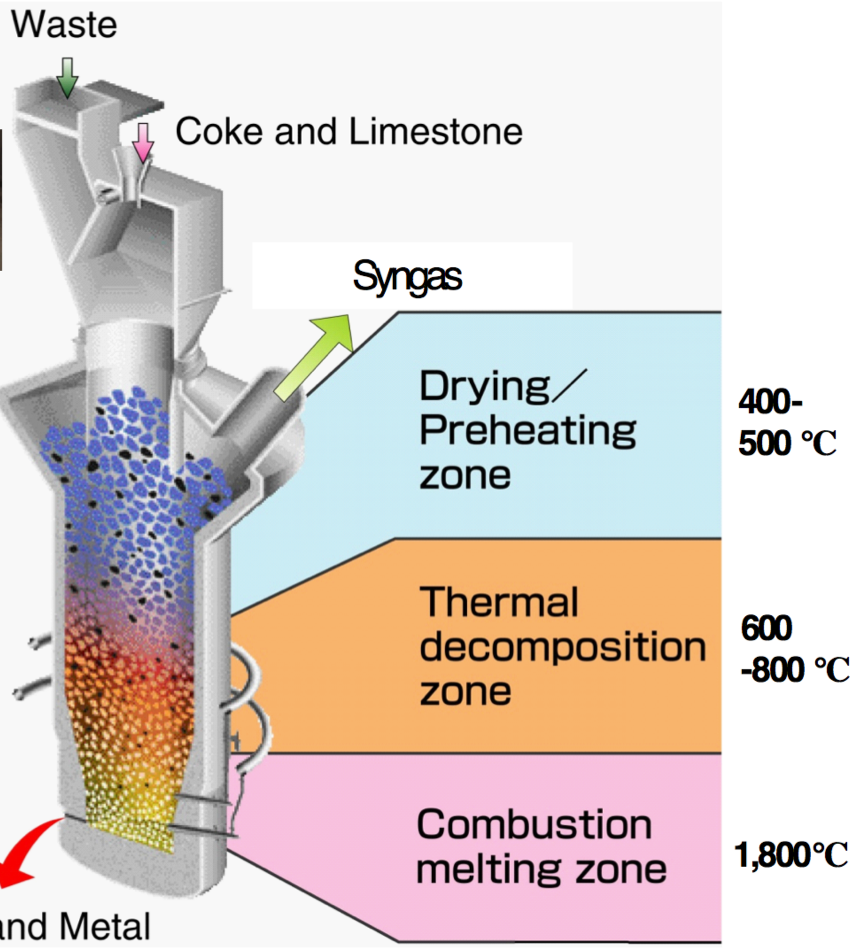
Tanigaki et. al. ***Waste Management, 2012***

➢ **High Temperature & Reducing Atmosphere**

Produced by coke burning heat.

Toxic heavy metals are volatilized and distributed to APC residues.

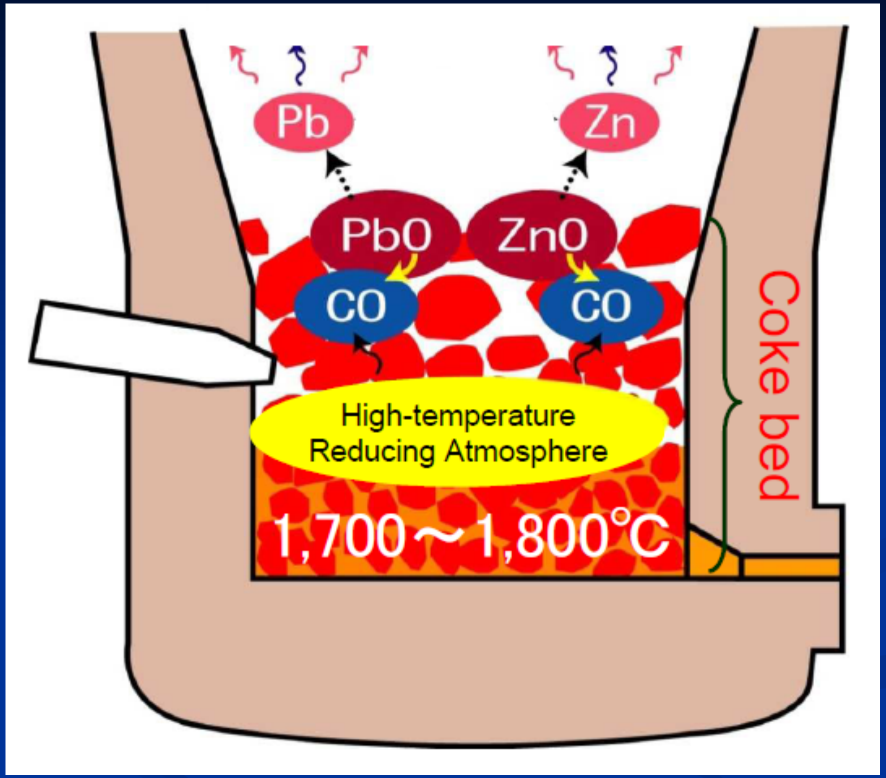
Few toxic heavy metals remain in slag and metal.



Material and Energy Recycling from Waste

Courtesy of Nippon Steel&Sumikin Eng. Co., *Tanigaki 2015*

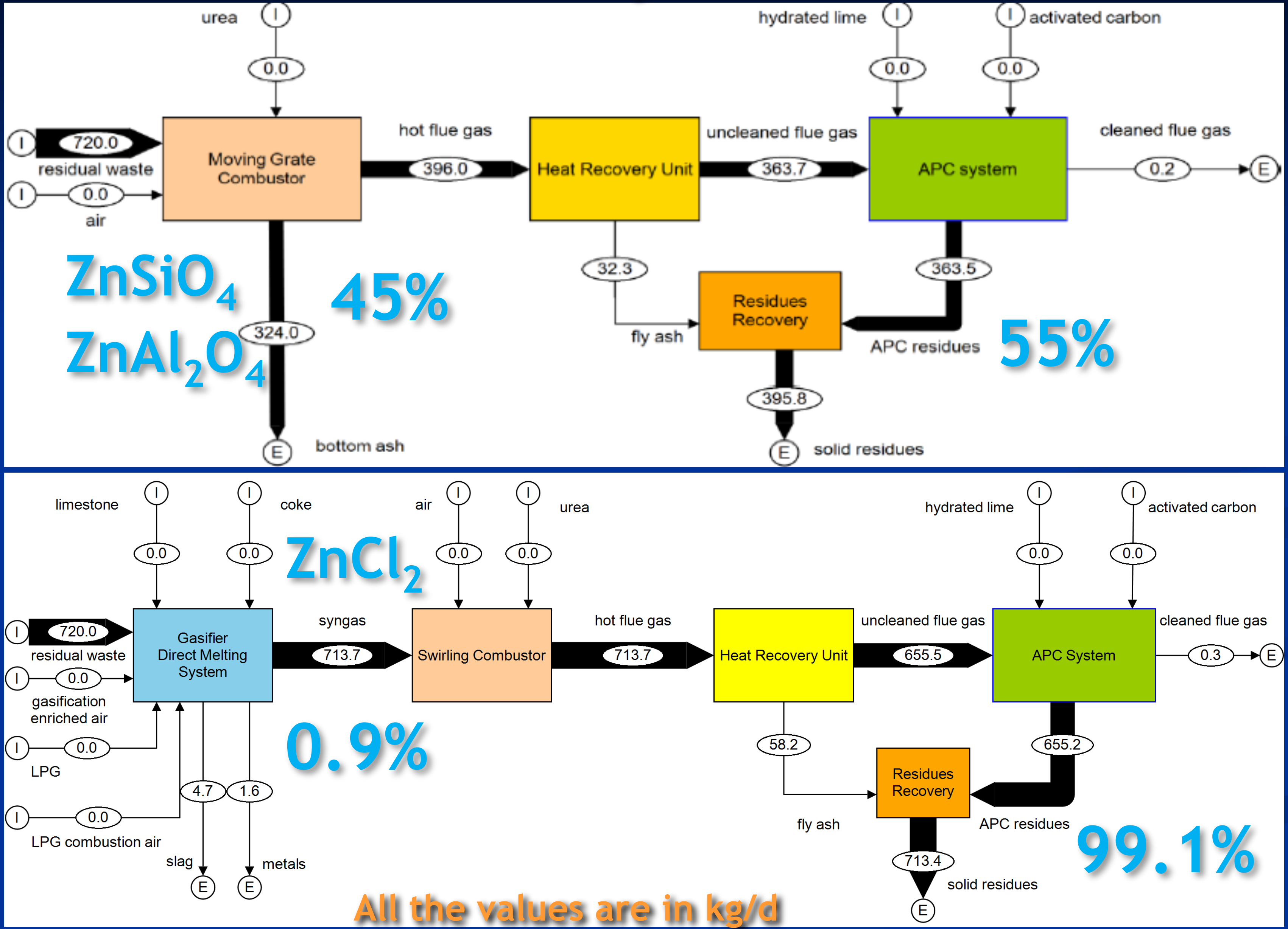
Direct Melting System



Courtesy of Nippon Steel &SUMIKIN ENG. Co., *Tanigaki 2015*

1. Effect of coke-bed layer
   → formation of high-temperature melting zone
   - ➢wide range of treatable wastes: bottom ash (1400˚C), glass (1670˚C); iron (1570˚C)
2. Intermittent slag tapping → long residence time
   - ➢complete melting and homogenization of molten matter
3. High-temperature reducing atmosphere → heavy metals are mainly distributed to APC residues
   - ➢slag has no hazardous heavy metals

DMS: fate of heavy metals



All the values are in kg/d

(Source: Arena et al., WM,

Direct Melting System: co-gasification

Shin-Moji Plant

Location
Kitakyushu City, Japan

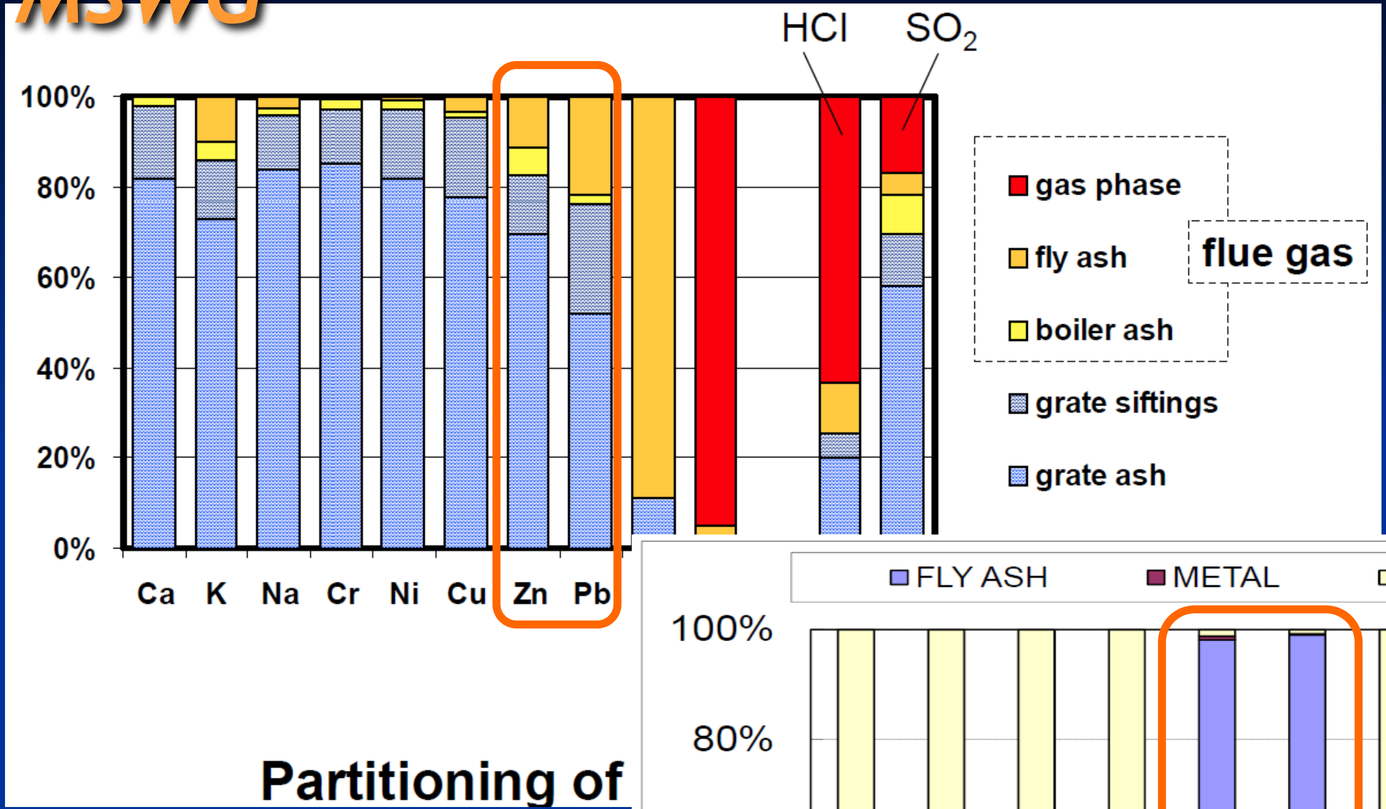
Co-gasification of:
Municipal solid waste
Incombustibles
Sewage sludge

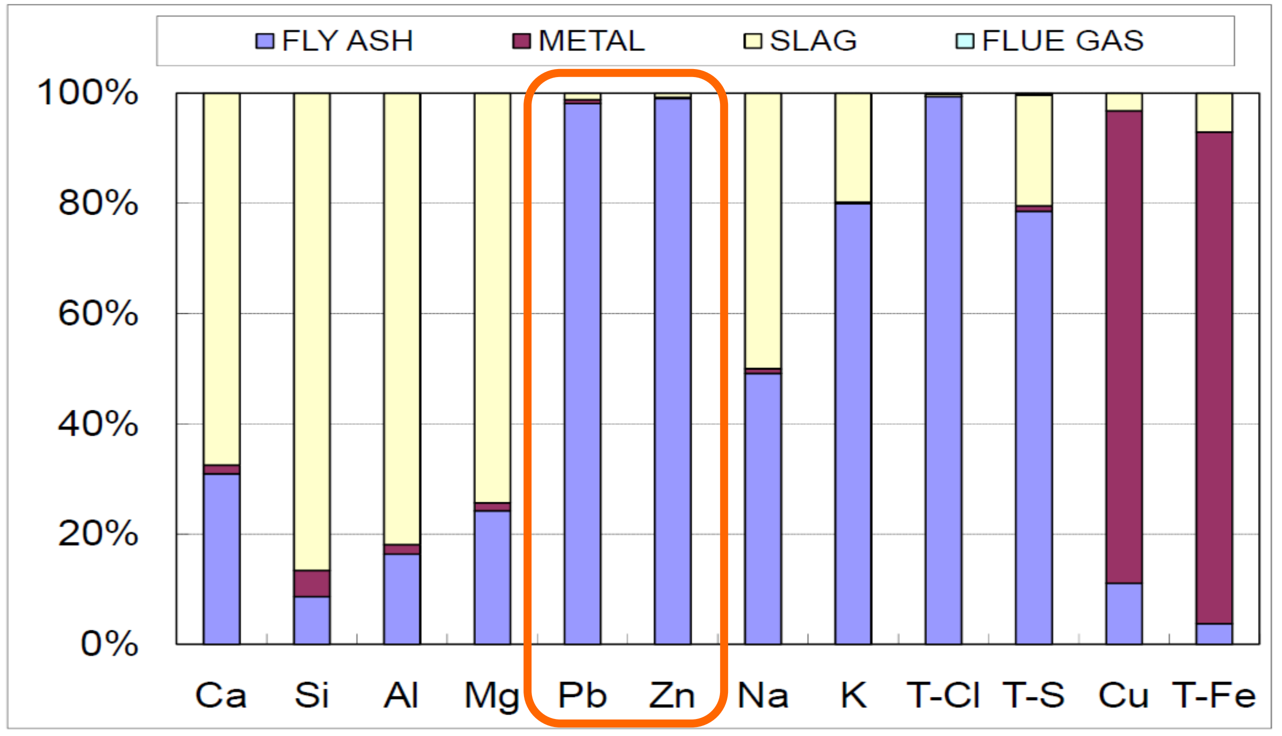
Capacity
3 x 10 t/h
9 100 - 12 000 kJ/kg
Largest gasification Plant in operation

Year of Start Up
2007

Courtesy of Nippon Steel&Sumikin Eng. Co., *Tanigaki 2015*

Heavy metals partitioning: *MSWI vs MSWG*



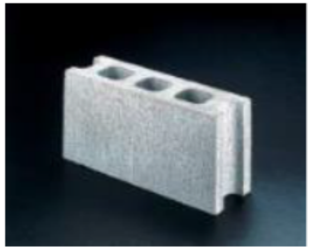


Metal distribution, Shin-moji Plant (720t/d)

Direct Melting System: co-gasification

Produced Slag is 100% recycled and is sold as “Eco-Sand”, not only for secondary materials but also marine block or soil.

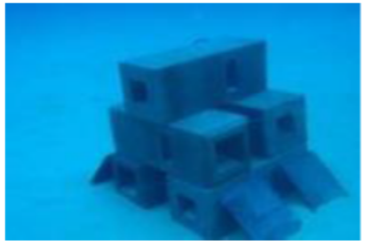
Conventional Application



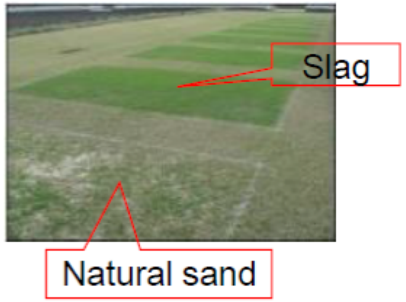
Concrete block

Interlocking block

Asphalt paving



Marine Block



Soil

Further Application (Fertilizer)

R&D activities for further application of Eco-Sand has been done, especially as fertilizer, because silica contained in Eco-Sand makes plants come well.

In March 2017, Eco-Sand (Slag) is ad interim registered as “Fertilizer”.

With Eco-Sand

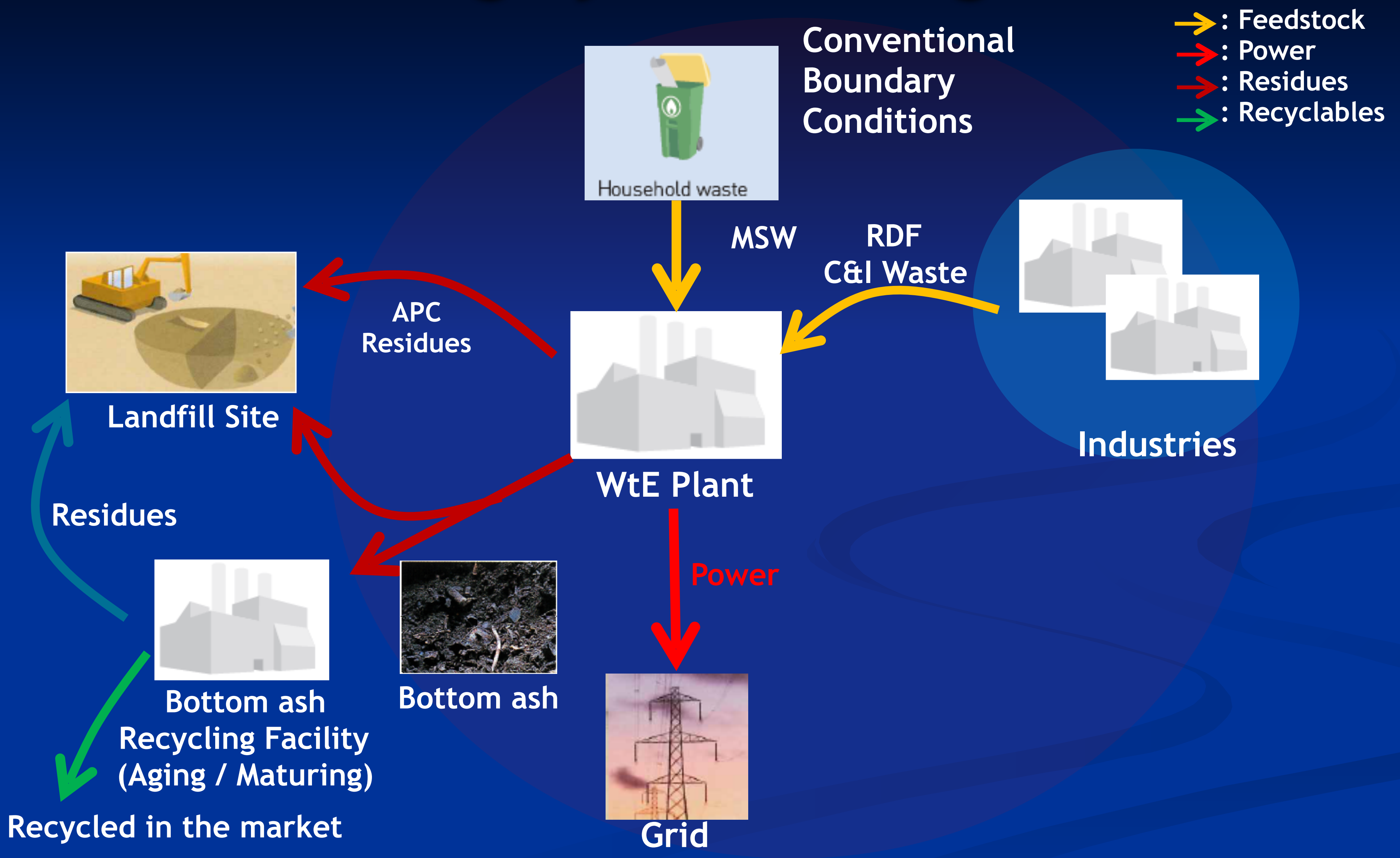
Without Eco-Sand

Interim registration Certificate for Fertilizer

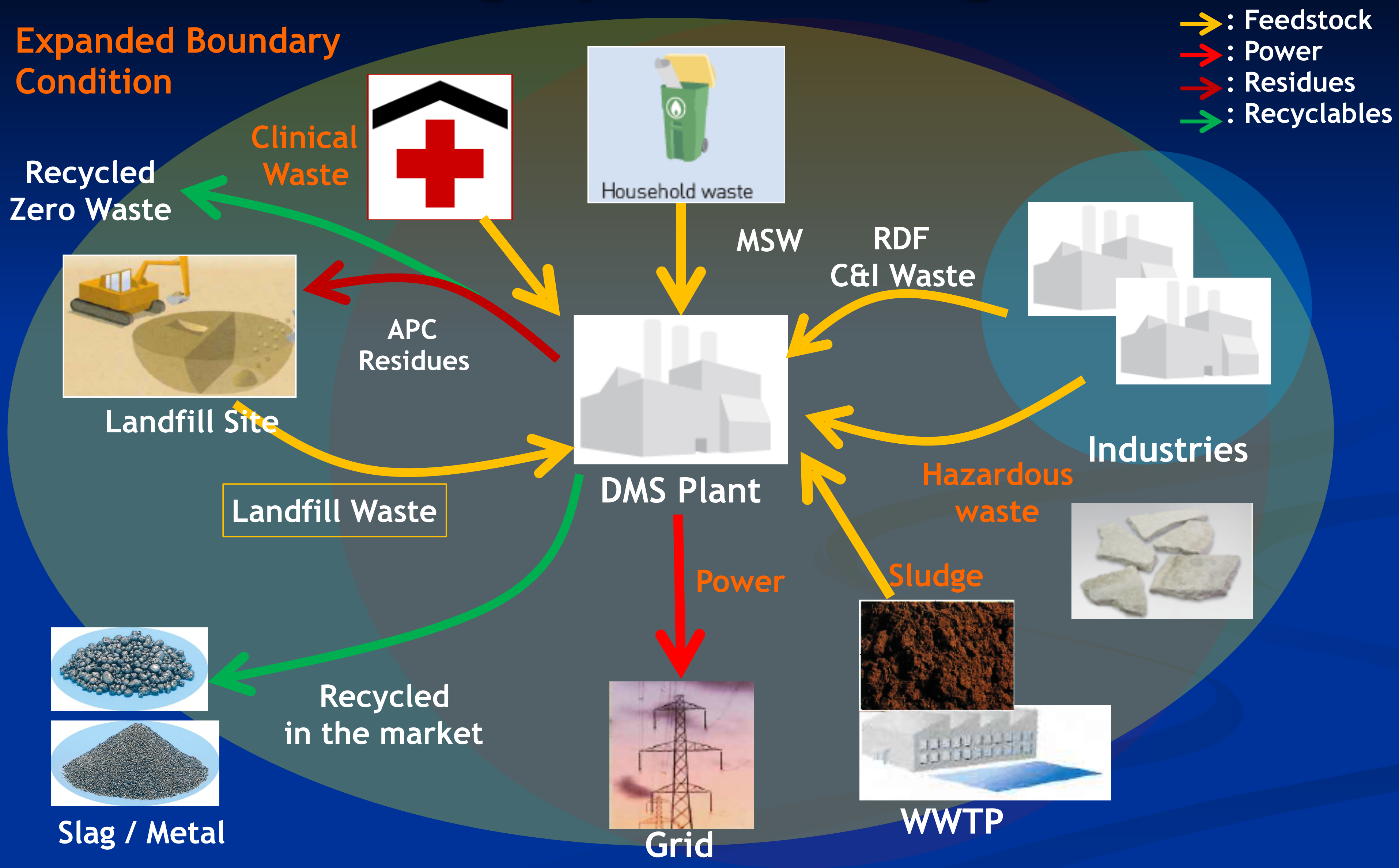
www.steinmueller-babcock.com

Courtesy of Nippon Steel&Sumikin Eng. Co., *Tanigaki 2015*

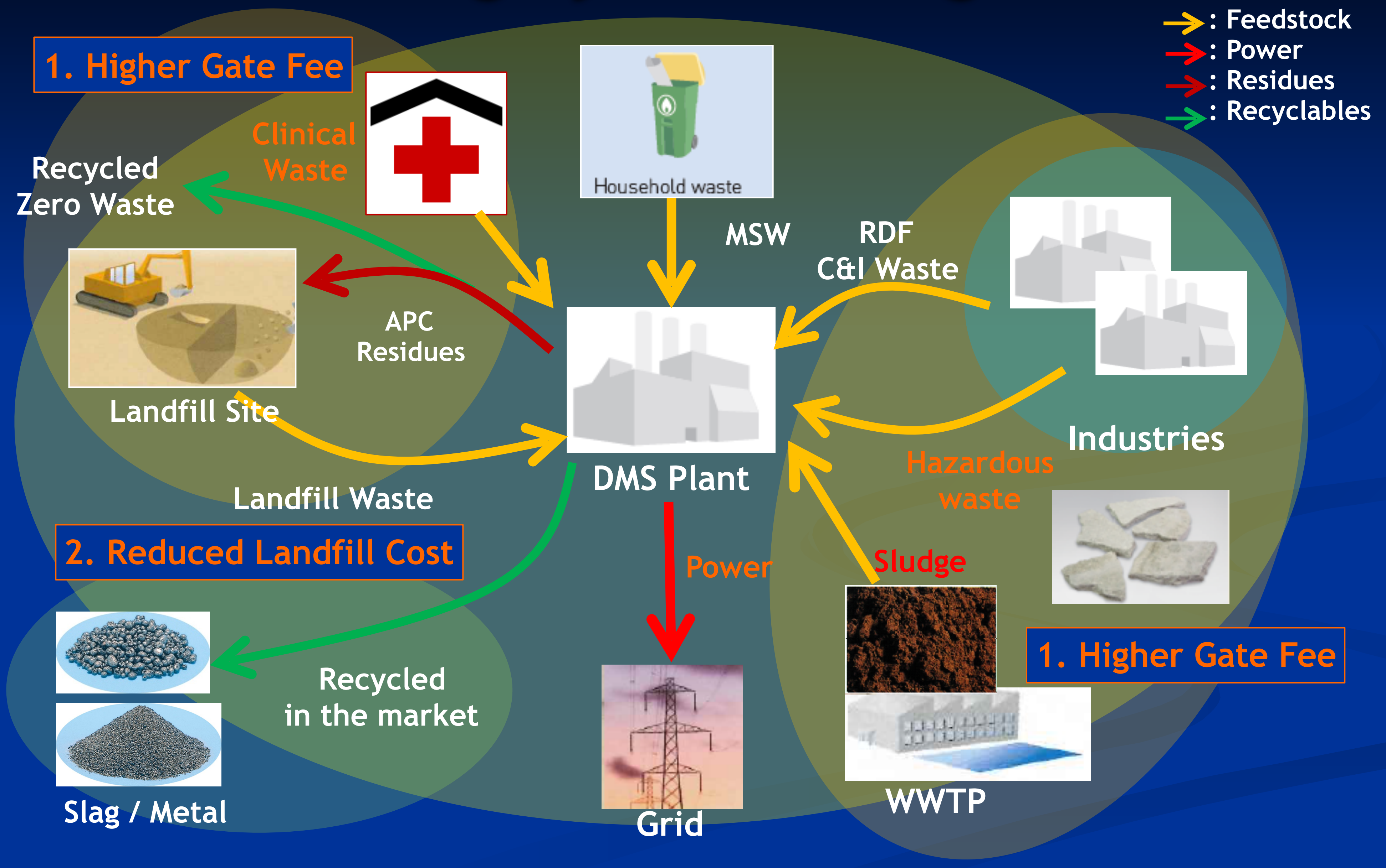
Direct Melting System: co-gasification



Direct Melting System: co-gasification



Direct Melting System: co-gasification



Direct Melting System: co-gasification

Narumi Plant

Location
Nagoya City, Japan

Co-gasification of:
Municipal solid waste
Bottom ash
Incombustibles
Combustibles

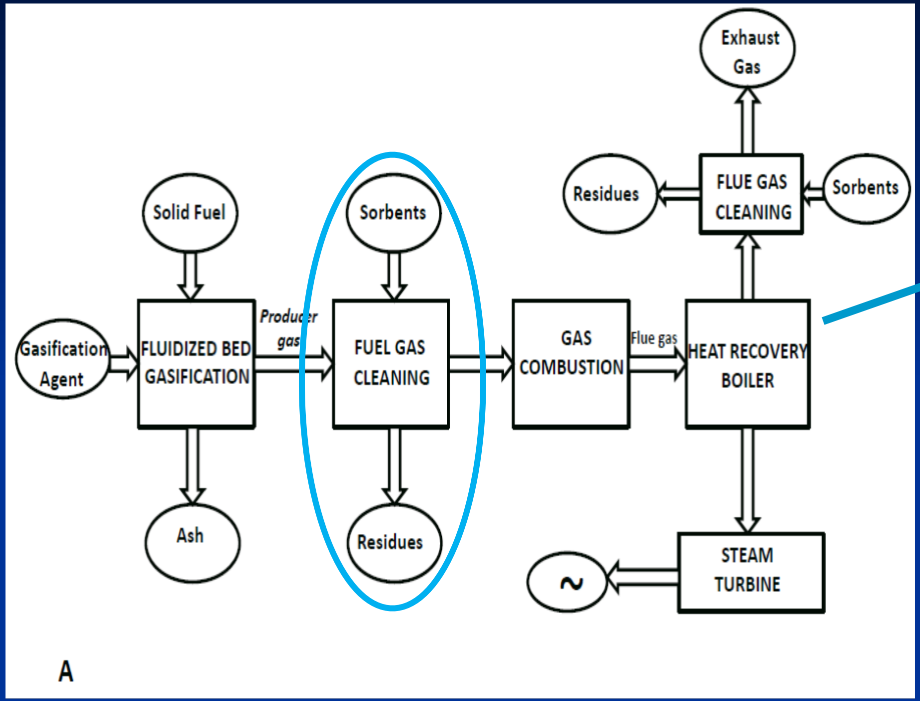
Capacity
2 x 11 t/h
6 500 kJ/kg

Year of Start Up
2009

✓ Bottom ash recycling is not allowed. The municipality has no landfill site.
⇒ ***Need solutions. Co-Gasification and recycling***
⇒ ***87% reduction of final landfill amount***

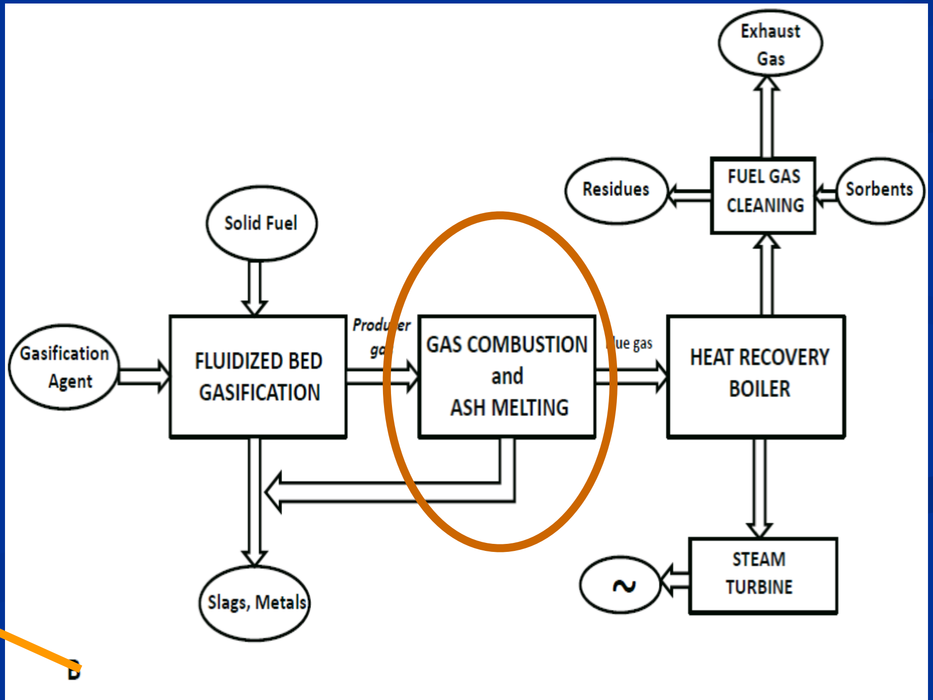
Courtesy of Nippon Steel&Sumikin Eng. Co., *Tanigaki 2015*

Fluidized bed gasifiers



Valmet

Kobelco
Hitachi Zosen

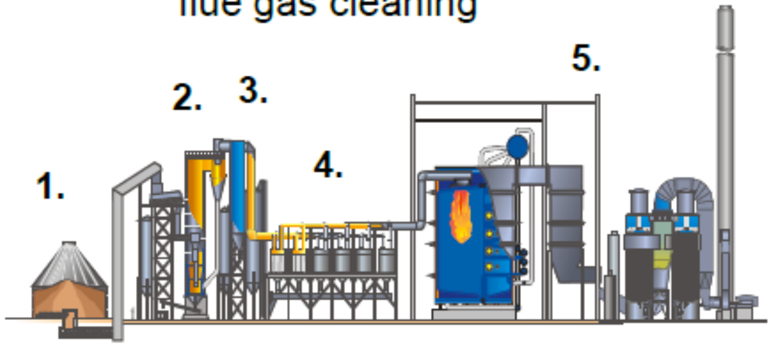


Valmet CFBG *Nice-and-Clean*

Lahti Energia - solid waste gasification

- 160 (2x80) MW, 250 000 tn/a
- Total investment 160 M€
- Contract signed November 2010
- Start up April 2012

1. Fuel handling
2. Gasifier
3. Gas cooling
4. Gas filter
5. Gas boiler and flue gas cleaning



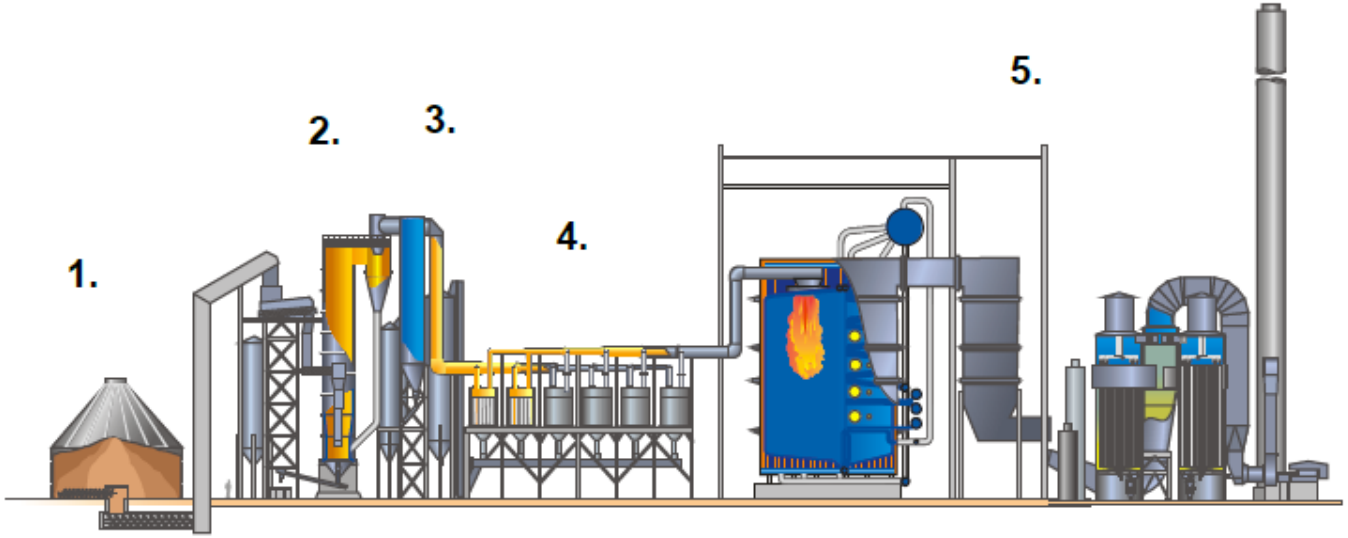
Courtesy of Valmet Group, *Honkola, 21FBC 2012*

Valmet: CFB co-gasification

Technical concept of the waste gasification plant

- Gasify waste at 850-900 C
- Cool it down to about 400 C
  - all corrosive components, alkalichlorides, Pb, Zn will be in solid form
- Filter all dust out so the resulting gas is clean
- Burn clean gas in gas fired boiler

1. Fuel handling
2. Gasifier
3. Gas cooling
4. Gas filter
5. Gas boiler and flue gas cleaning

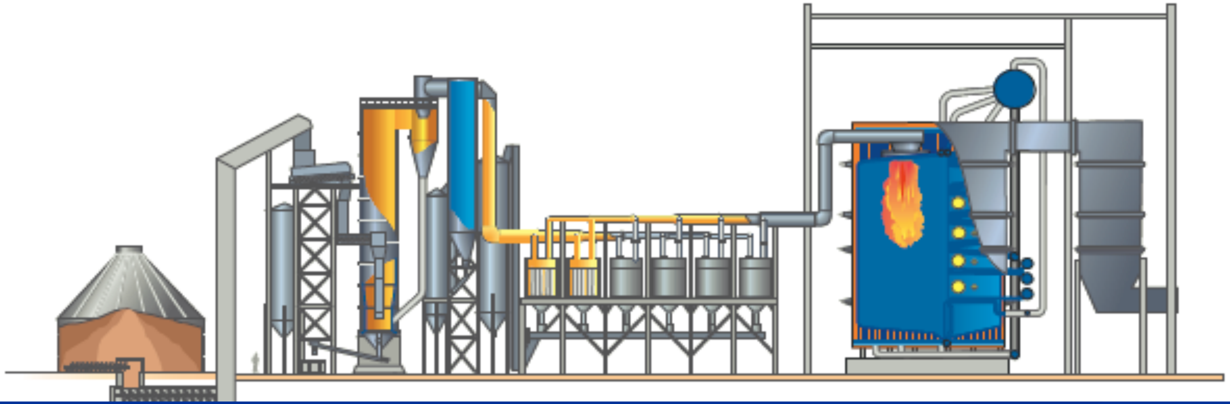


Courtesy of Valmet Group, *Hankola, 21FBC 2012*

Valmet: CFB co-gasification

Benefits of waste gasification

- High steam parameters → higher efficiency
  - Lahti 160 MW fuel => 50 MWe + 90 MW district heat
  - Lahti 120 bar, 540 C live steam
  - Technology can offer even higher electricity efficiency
- Lower grade waste as a fuel → lower fuel cost
  - Lahti fuel : Household waste (origin sorted), Industrial waste, demolition wood, waste wood from industry
  - LHV 14 -24 MJ/kg, dry ; Moisture< 30 %, Cl < 0,4 %
- Tolerance for fuel quality → multiple fuel sources
- Less corrosion → less expensive materials in the boiler

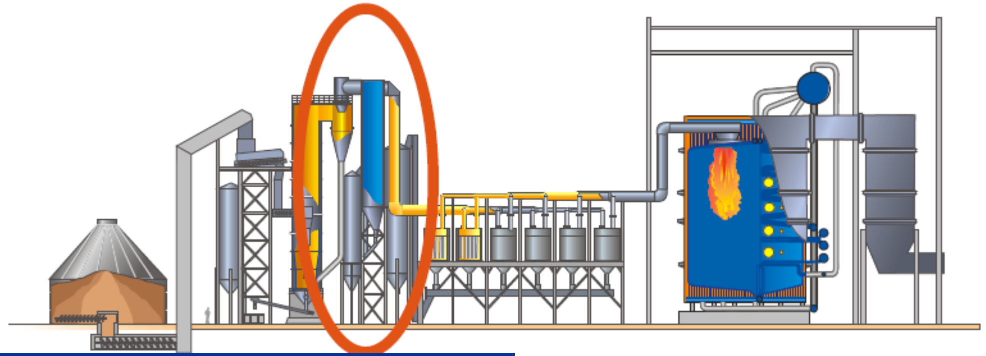


Courtesy of Valmet Group, *Hankola*, *21FBC 2012*

Valmet: CFB co-gasification

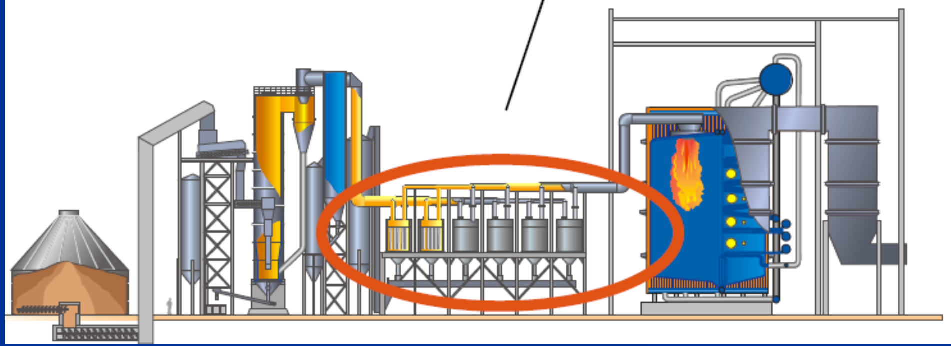
All water walls cooled with boiler feed water

- Avoid risk of corrosion in cooler
- Condensate harmful components on particles
- Avoid tar condensation in cooler
- Still reasonable size cooler to reach right gas temperature



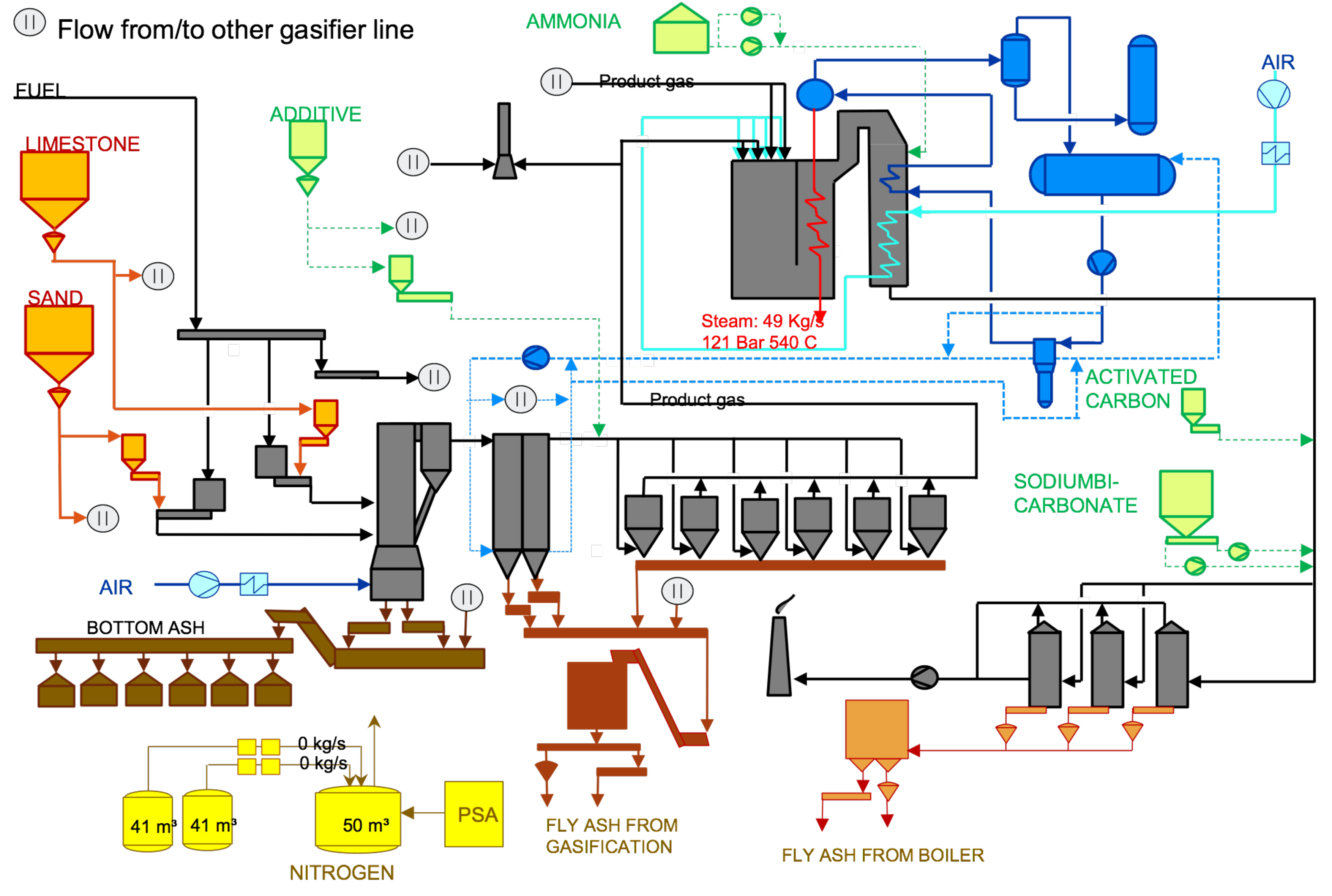
High temperature ceramic fiber filters

- Filter can tolerate high temperatures
- Tar condensation can be avoided
- Filter can be recovered if needed



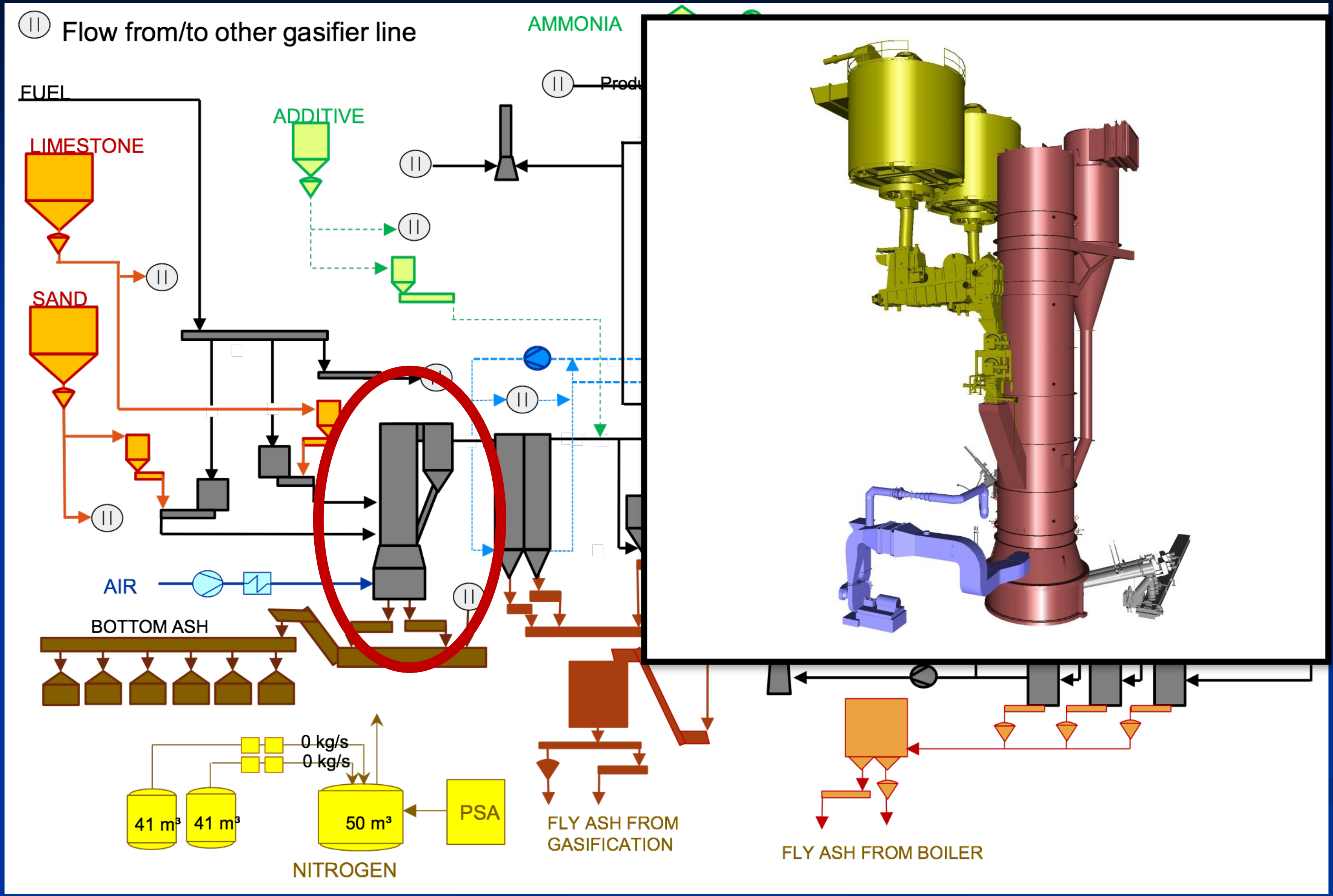
Courtesy of Valmet Group, *Hankalin, Sardinia 2011*

Valmet: CFB co-gasification



Courtesy of Valmet Group

Valmet: CFB co-gasification



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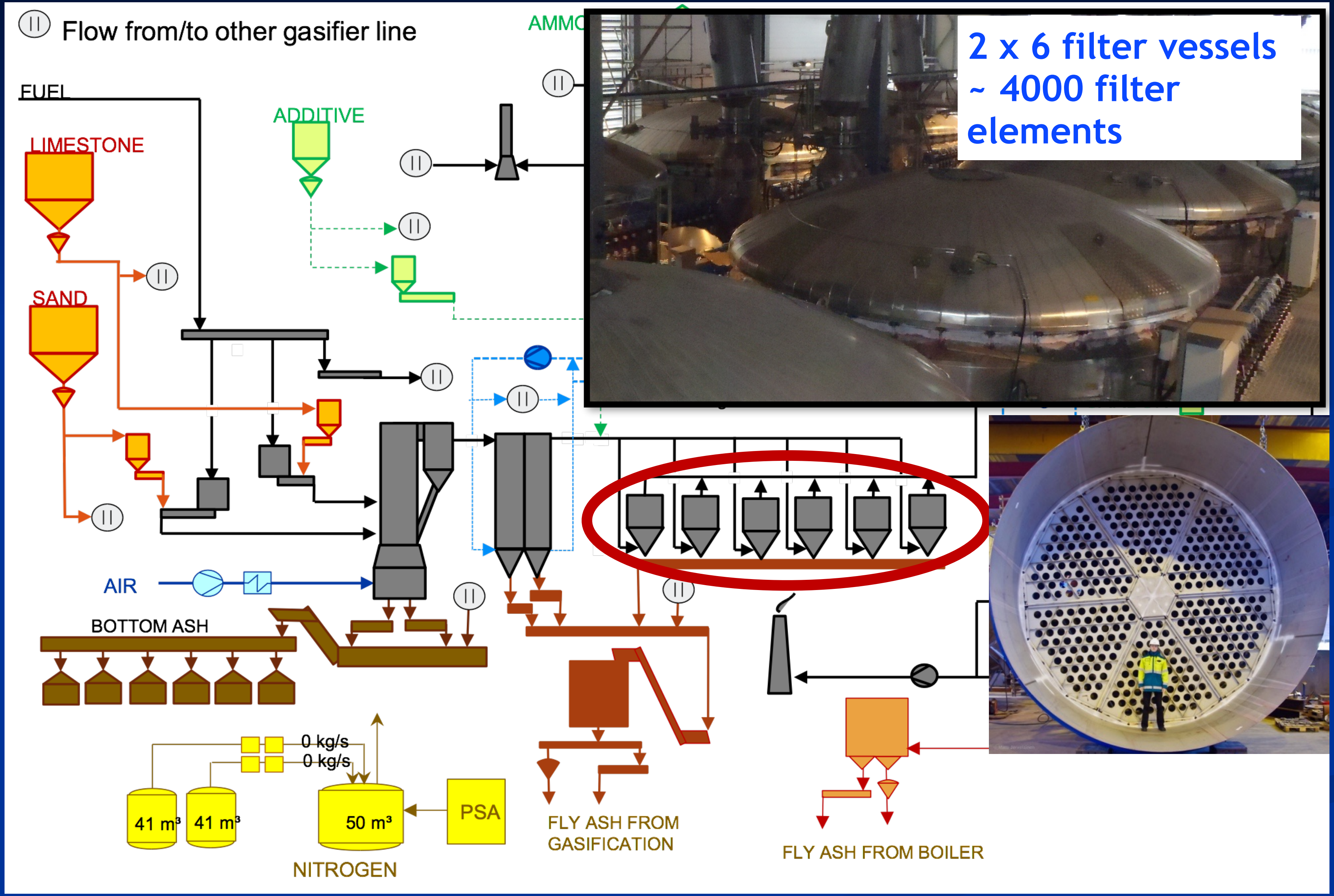

Courtesy of Valmet Group

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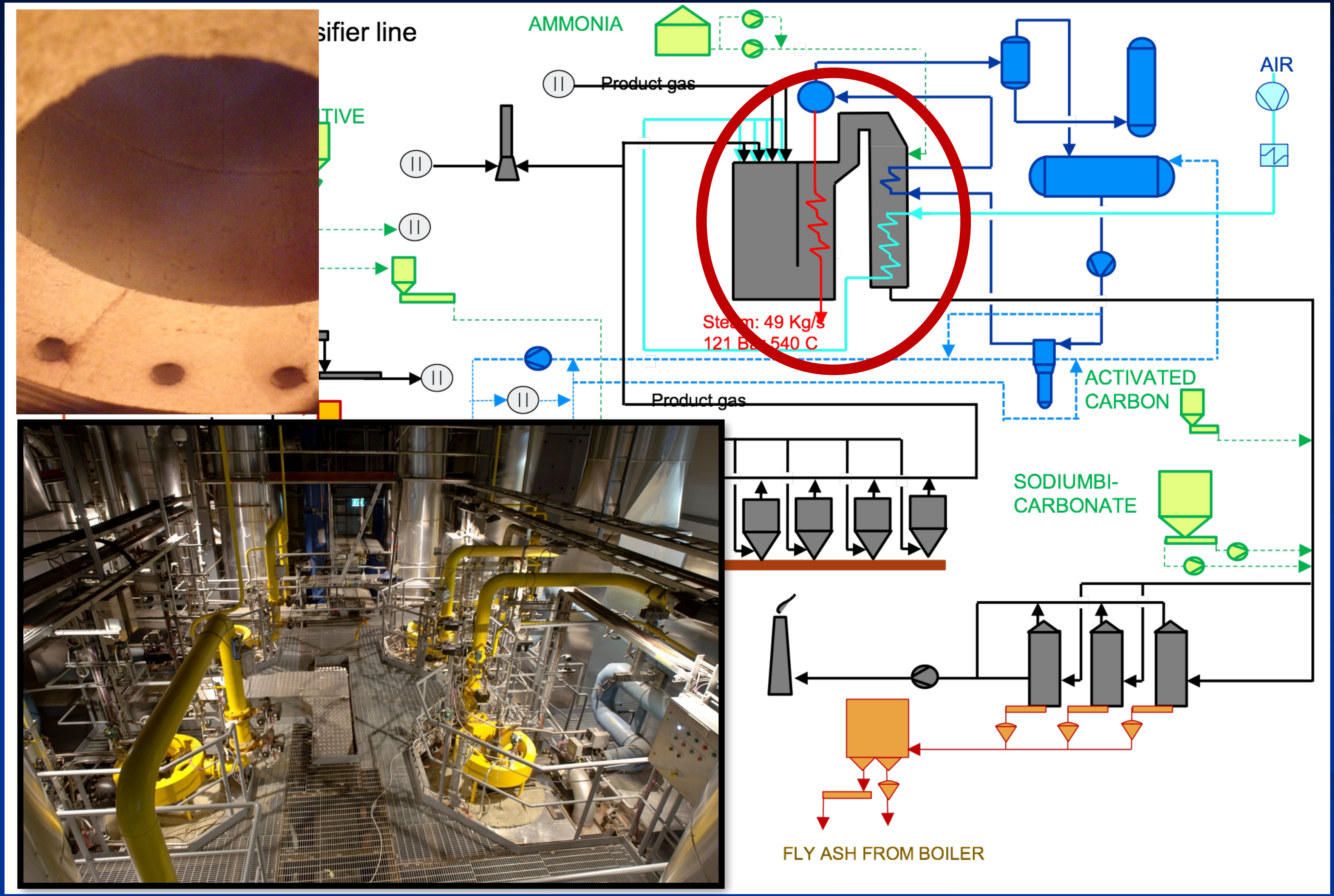
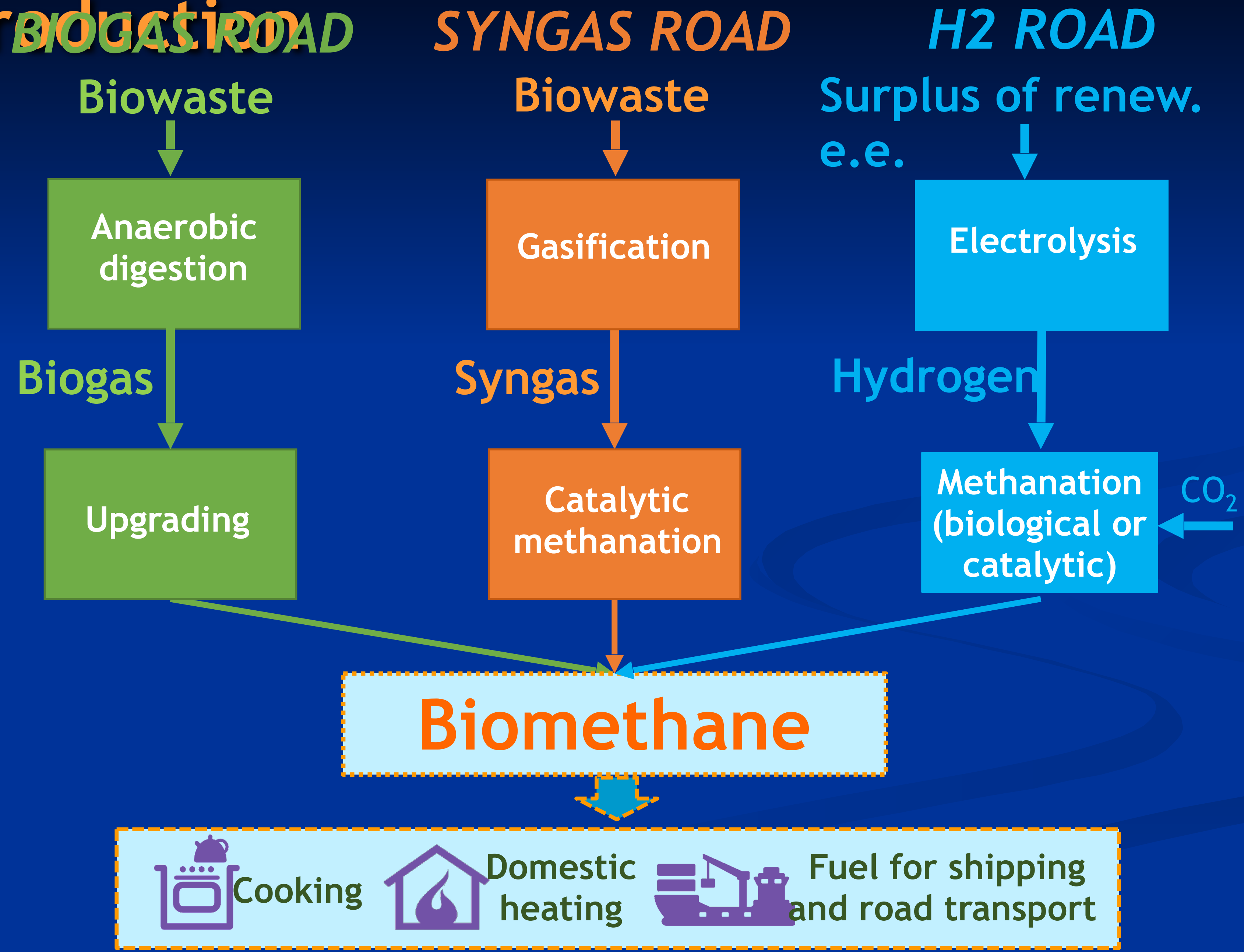


Courtesy of Valmet Group

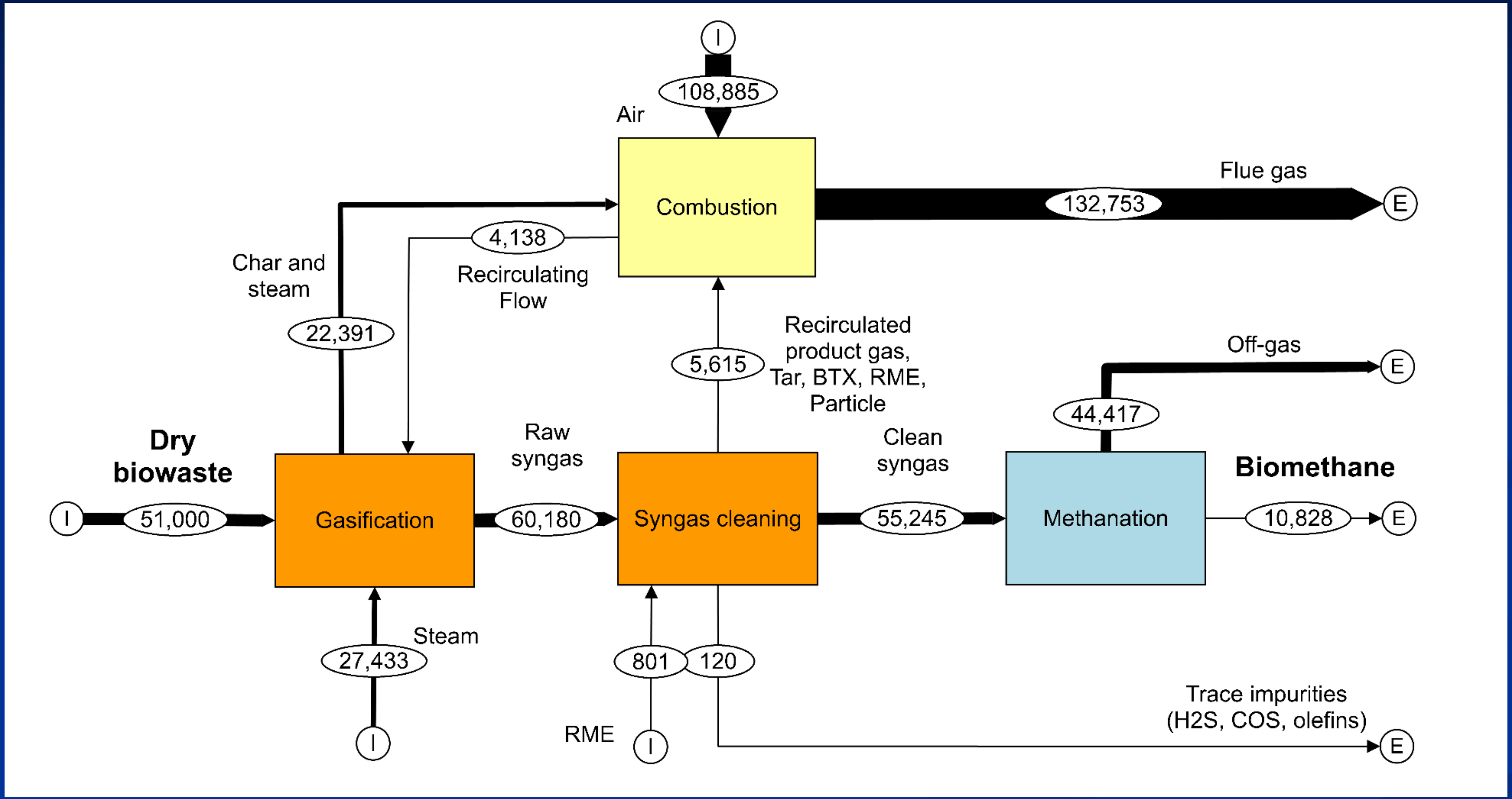
Alternatives strategies for bioSNG production



Comparison of two strategies

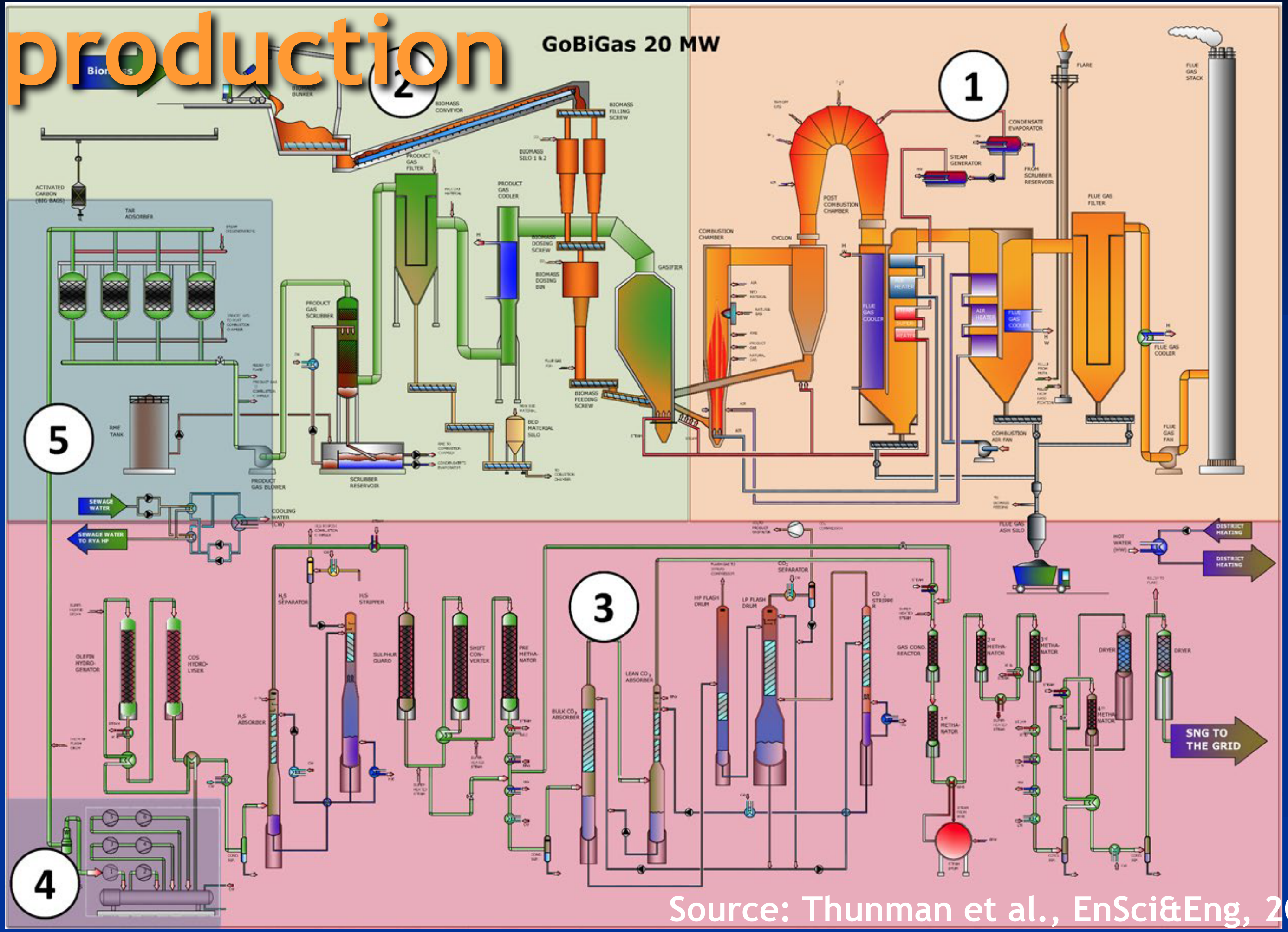
	Biological pathway	Thermochemical pathway
Energy OUT		
Typical plant capacity, MW	2-15	20-(100)
Specific output energy, MJ/$t_{biowaste}$	1800	11000
Biomethane OUT		
Specific bioSNG production, $m^3{}_N/t_{biowaste}$	45-75	300-320
Energy IN		
Feedstock energy IN, PJ/y	0.15-1.1	0.8-(4)
Biowaste IN		
Specific biowaste energy, MJ/$kg_{biowaste}$	4-5	16-18
Process efficiency		
Energy efficiency, -	0.3-0.6	0.6-0.7
C-to-bioSNG efficiency, -	0.13-0.25	0.34-0.37
Plant availability, h/y	8400	8000

BioSNG thermochemical pathway



Source: Ardolino and Arena, 2018

GoBiGas project for bioSNG production



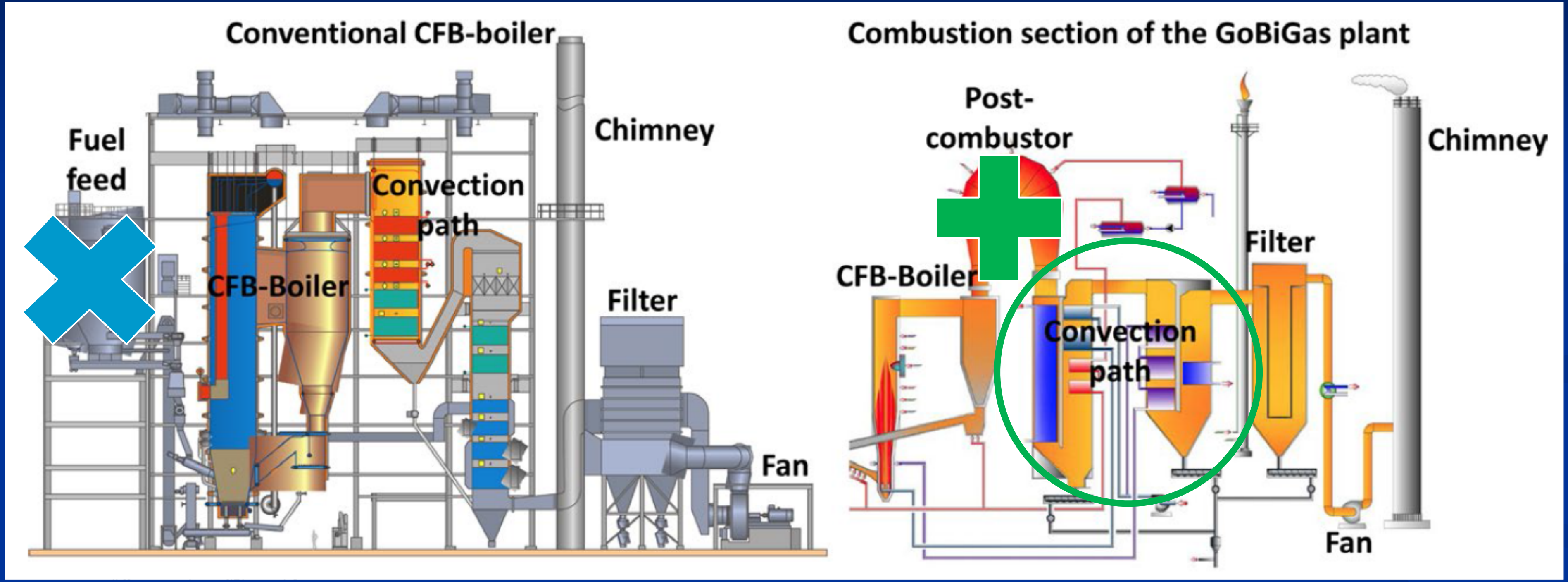
Source: Thunman et al., EnSci&Eng, 2018

Gothenburg
Biomass
Gasification

1. Heat generation
2. Gasification
3. Synthesis
4. Compression
5. BTX removal

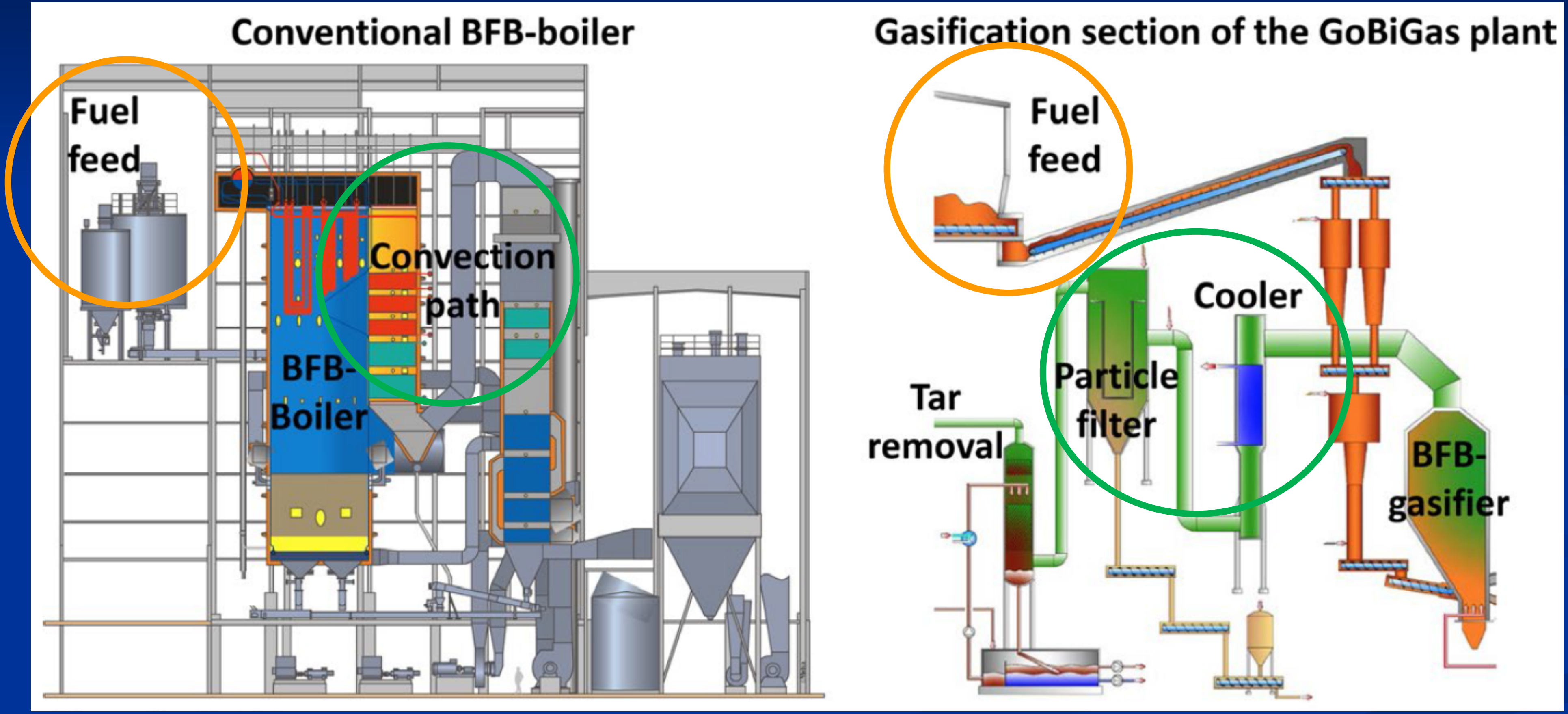
- ✓ Input: Dry (or semi-dry) biomass
- ✓ Technology readiness level: 6-7
- ✓ Treatment capacities: 50,000 $t_{biowaste}$/y, 20 $MW_{biomethane}$

GoBiGas project for bioSNG production



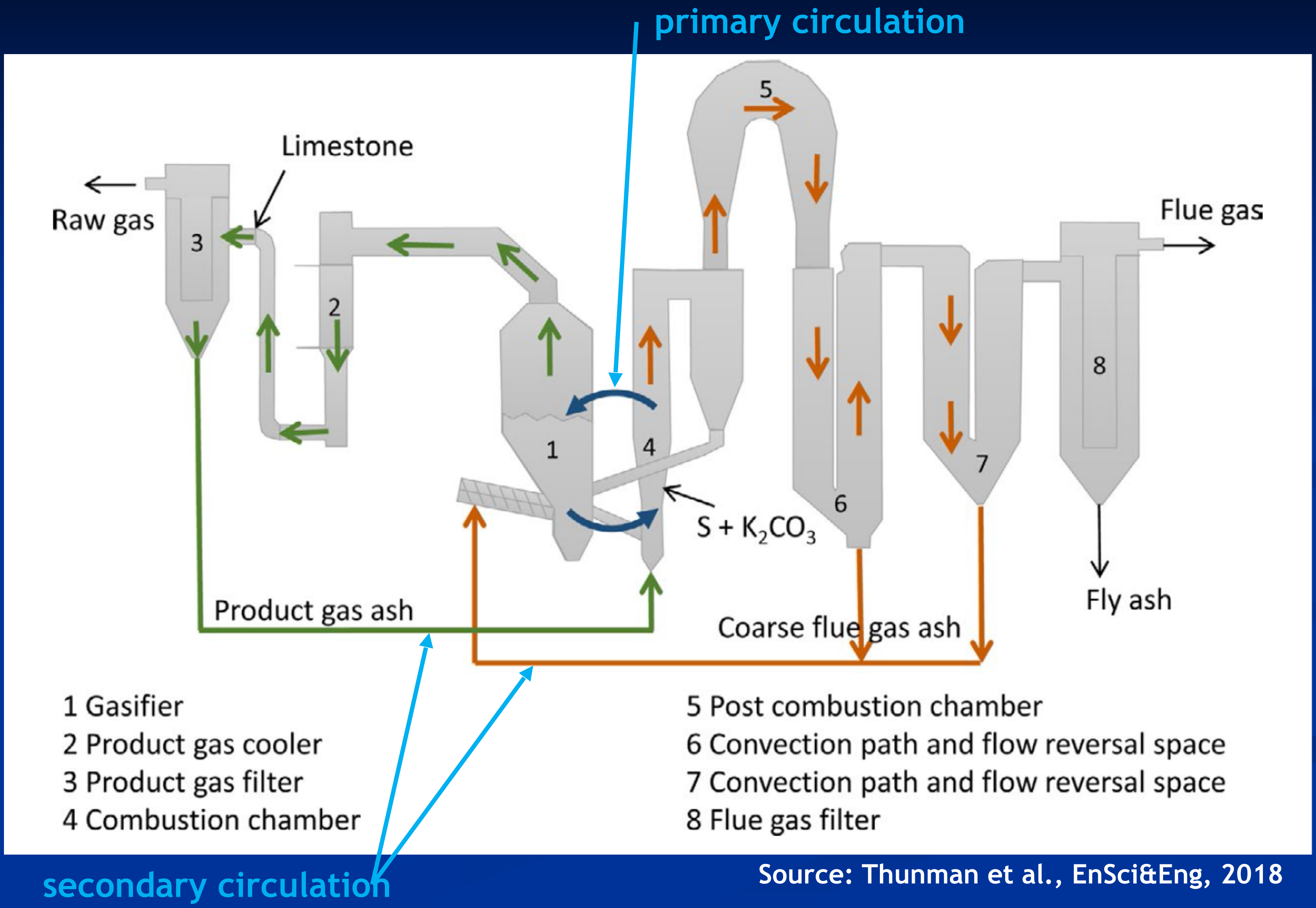
Source: Thunman et al., EnSci&Eng, 2018

GoBiGas project for bioSNG production



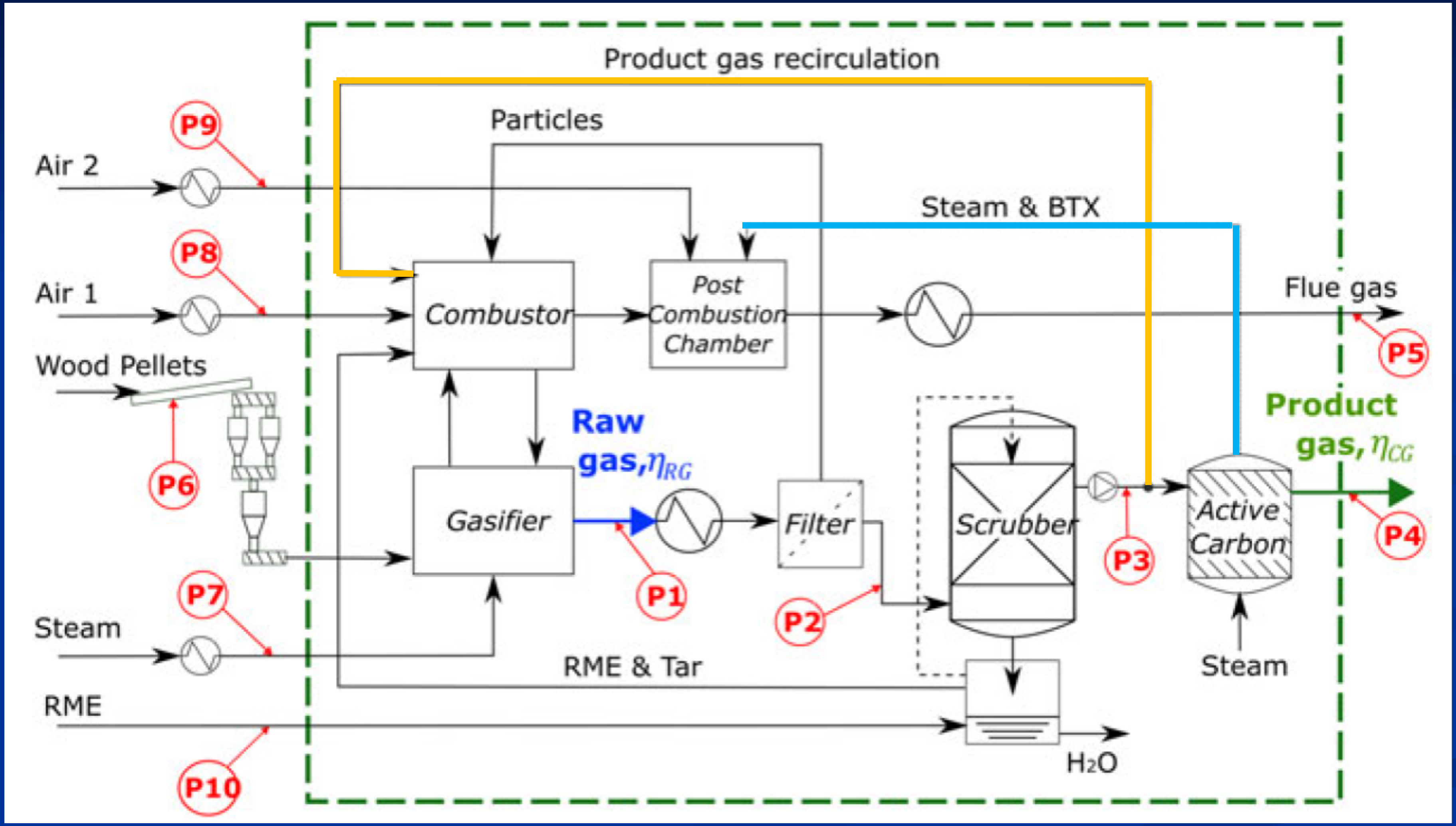
Source: Thunman et al., EnSci&Eng, 2018

GoBiGas project for bioSNG production



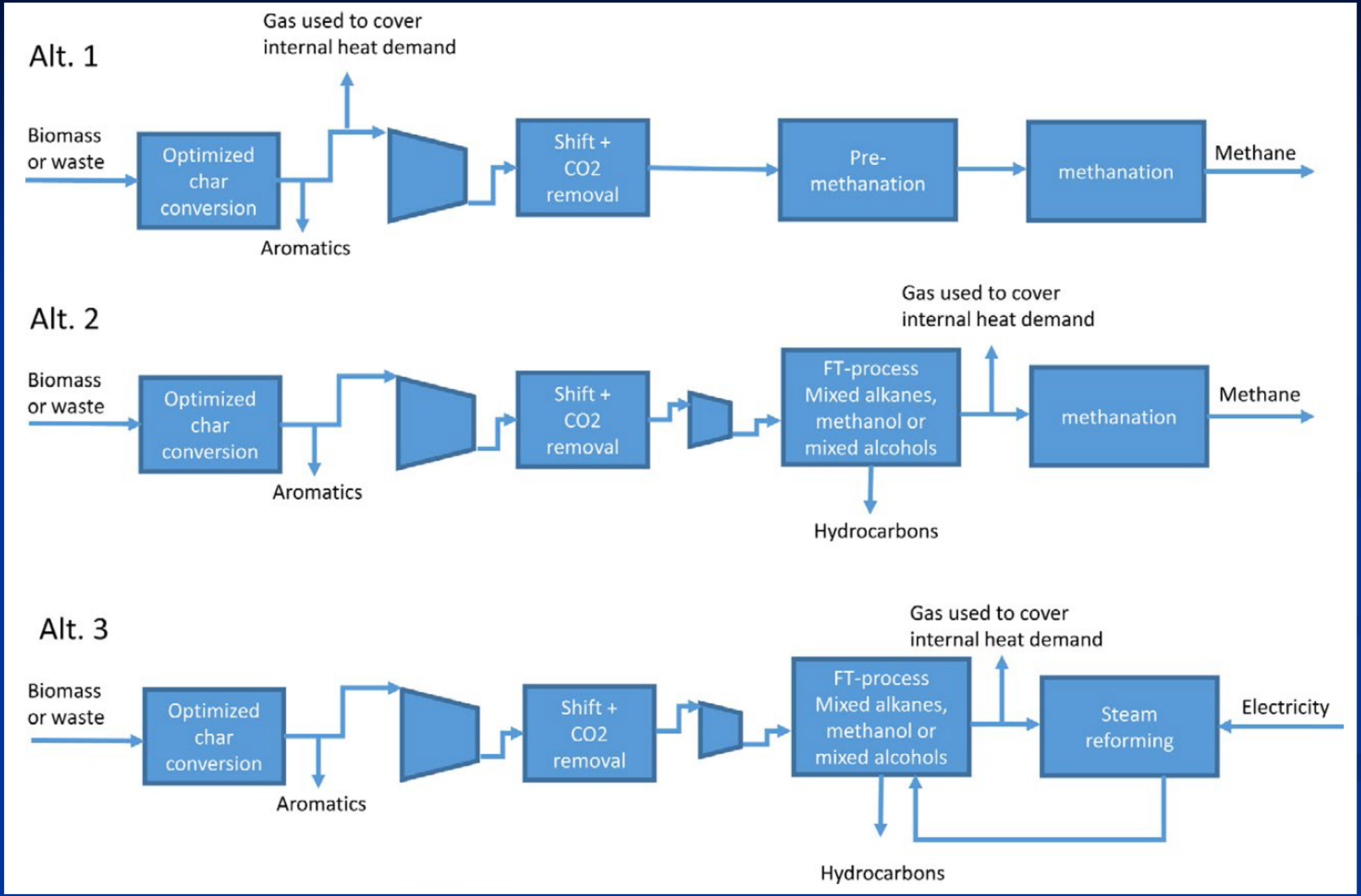
Source: Thunman et al., EnSci&Eng, 2018

GoBiGas project for bioSNG production



Source: Alamia et al., IJER, 2017

GoBiGas project for bioSNG production



Source: Thunman et al., EnSci&Eng, 2018

CONCLUSIONS

- Gasification plants may accept a wide variety of wastes and biomass (including bottom ash from incinerators, uncombustible residues, landfilling wastes, etc.)
- Gasification appears suitable for waste-to-resources (thermal/electric energy and landfill space); waste-to-fuels (bioSNG, H2, F-T fuels); and waste-to-products (chemicals, bio-chemicals) processes
- Gasification is the thermochemical conversion process that supports a Carbon Recycling Economy (allowing combinations and integrations with biological treatments and industrial production processes).

THANK YOU
for your kind attention

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degli Studi
della Campania
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