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► **To cite this version:**

P.-A Maitre, L Bertier, J Cren, F Ducros. End of life of Solid Recovered Fuels: could the gasification of waste compete with its incineration, answer by techno-economic and environmental analysis for the French case. EUBCE 2024 - 32 nd European Biomass Conference & Exhibition, Jun 2024, Marseille, France. cea-04794918

**HAL Id: cea-04794918**

**<https://cea.hal.science/cea-04794918v1>**

Submitted on 21 Nov 2024

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## End of life of Solid Recovered Fuels: could the gasification of waste compete with its incineration, answer by techno-economic and environmental analysis for the French case

P.-A. Maitre<sup>1</sup>, L. Bertier<sup>1</sup>, J. Cren<sup>1</sup>, F. Ducros<sup>1</sup>

**Abstract:** Considering the future context of uncertainty on price and supply of gas and electricity from renewables, as well as the urgent need to reduce the global emissions of fossil greenhouse gases, finding safe and steady replacement sources of energy to fossil ones has become a paramount goal of modern society. Therefore, it might become environmentally and economically desirable to change the end of life in landfills of Solid Recovered Fuel (SRF) in order to extend its valorization to the production of more electricity or Synthetic Natural Gas (SNG). Different scenarios of SRF valorization involving a first step of gasification to allow more flexibility on the final utility production (heat, electricity, SNG) were modelled and compared to the base case of incineration. The study revealed a significant variation in overall energy yield and energy vectors from 80 % (amongst which 25 % goes to electricity and 55 % goes to heat generation) for the simplest incineration down to 57 % in the case the SRF is firstly gasified before burning the syngas for power (55 %) and heat (30 %) generation. The economic performance of all scenarios was assessed, it showed that depending on the retail price of gas and electricity, the most profitable scenario may vary. In the case of equivalent price for electricity and gas, the SNG production is the best, in the case electricity is higher than 80 €/MWh for low gas remuneration (< 60 €/MWh<sub>LHV</sub>) the CHP system is the best option. Finally, in the unlikely eventuality that grid electricity is low price (< 60 €/MWh) and gas high (> 80 €/MWh<sub>LHV</sub>), the production of SNG via an electrified process involving electrolysis is the way to go as long as the electricity is low carbon.

**Keywords:** Waste to energy, SNG, gasification, multi-energy system, carbon assessment

### 1 Introduction

Solid Recovered Fuel (SRF) (Figure 1) consists of a blend of several non-hazardous waste such as paper, card, wood, textiles and plastic. The production of SRF operates in parallel with the recycling industry by providing an alternative to fossil fuels for some industries. The most common sectors of SRF valorisation are in cement kilns for heat production and in communal incinerators for district heat generation, sometimes along with electricity.

The present environmental French policy aims at reducing waste landfilling so that 2.5 Mt/y of SRF are predicted to be produced from 2025. In the current context of uncertainty about gas and electricity prices and supplies, the SRF feedstock appears as a strong opportunity to increase tenenergy sovereignty by extending its valorisation to more

electricity generation and Synthetic Natural Gas (SNG).

However, switching from a very simple process consisting of one elementary step (an incinerator) to a more complex one for the production of SNG, might not be economically feasible nor desirable.

In order to unravel the economical / technical conditions whereby a switch in the SRF valorisation could be worthwhile, a techno-economical survey is



Figure 1: SRF: a blend of paper, card, wood, textiles and plastic (LHV: 18 -25 MJ/kg)

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performed considering 4 different scenarios of valorisation based on the size of a typical communal incinerator. The size of the plant is therefore set to 10 t/h of SRF with a LHV of 20.2 MJ/kg, corresponding to a thermal inlet power of 56 MW.

## 2 SRF end of life: considered pathways

All the different pathways considered in the study are presented in Figure 2.

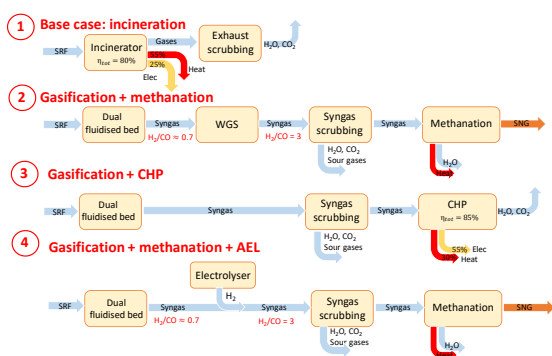


Figure 2: Block scheme of the considered pathways

1) **Base case scenario, the incineration** of the SRF feedstock. In this scenario, the combustion is supposed to perform at a total yield of 80 %, of which 25 % is channelled into electricity generation and 55 % into heat, distributed via a district heating network.

2) **Gasification + methanation.** The SRF is supposed to be gasified in a dual-fluidised bed, producing a syngas with a  $H_2/CO$  of approximately 0.7, the gasifier is modelled at equilibrium by minimizing Gibbs energy at 850 °C, considering a shift in temperature of 150 °C to account for the fact that equilibrium is not reached at 850 °C in an industrial reactor. The  $H_2/CO$  ratio is then further adjusted in a WGS ( $CO + H_2O \rightarrow CO_2 + H_2$ ) reactor to a value of 3 to ensure a maximum conversion of CO (99 %) in the final methanation reactive step. A small production of fatal heat can be recovered from the methanation reactor, after integration of all the needs of the plant.

3) **Gasification + CHP.** The syngas obtained from the gasification step is combusted in a CHP system that runs with a similar overall yield than the incinerator (85 %), but produces more electricity (55 %) over recoverable heat (30 %).

4) **Gasification + methanation + AEL.** In this scenario the syngas  $H_2/CO$  ratio is adjusted by the addition of  $H_2$  coming from an electrolyser

(supposed to be an alkaline electrolyser with an energy electricity to  $H_2$  yield of 66 %). This process has the advantage to avoid CO consumption so that the total carbon yield is improved compared to the non-electrified version. However, to operate the electrolyser, electricity that is supposed to come from the French grid is imported.

## 3 Results

### 3.1 System performance results

The performance of the different scenarios are

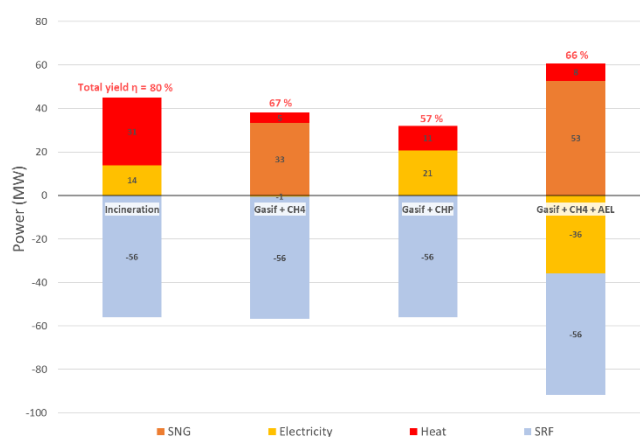


Figure 3: Power balance of the whole system for all scenarios, power consumption are counted negatively and power productions are counted positively

firstly compared in terms of power balances (Figure 3).

The best overall yield (80 %) is obtained with the incineration scenario thanks to its simplicity, almost no power is lost from the 56 MW of thermal power coming from the SRF. However, it produces mostly heat, which is the less valuable form of energy considered in this study (see 3.3).

Both scenarios producing SNG reach a similar overall yield of about 67 %, mostly due to the cold gas efficiency of the primary gasifier of about 70 %. However, it is important to note here that the electrified version imports 36 MW of electricity, which will have a substantial consequence on its OPEX (see 3.3).

Finally, the worst overall energy yield (57 %) is obtained with the gasification + CHP scenario as both the gasification and the conversion in the CHP have non-perfect yields. However, contrary to the incineration scenario, it produces more higher-value added electricity than heat.

### 3.2 Carbon assessment

The present study encompasses several types of energy and all the considered scenarios provide final utilities (heat, electricity, SNG) in different proportions. In order to compare them, a global perimeter that includes all types of utilities, is considered (see Figure 4).

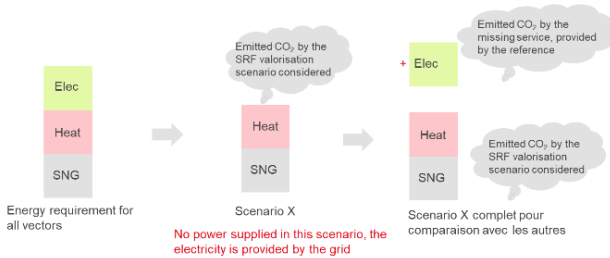


Figure 4: Carbon assessment method for a multi-utilities system

In this approach, a global demand for all utilities corresponding to the energy production across 8000 h/y of the maximum utility production obtained from 56 MW of SRF in the different scenarios is considered:

- Heat: 31 MW in the incineration scenario → the target for all scenarios is 249 GWh/y of heat
- Electricity: 21 MW in the gasification + CHP scenario → 166 GWh/y
- SNG: 53 MW<sub>LHV</sub> in the electrified SNG scenario → 422 GWh/y

Given that no scenario produces all utilities, the carbon footprint of the French grids for all utilities is considered to complement the production when required (electricity, 70 % nuclear powered: 56 kgCO<sub>2</sub>/MWh, heat from district heating: 111 kgCO<sub>2</sub>/MWh, natural gas: 227 kgCO<sub>2</sub>/MWh<sub>LHV</sub>). The normalised results, all types of utilities considered, are presented in Figure 5.

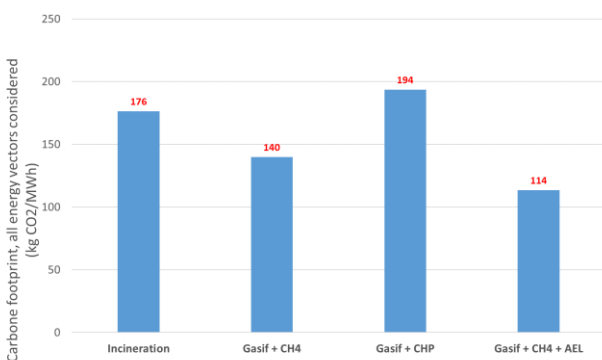


Figure 5: Carbon footprint of the scenarios, all utilities considered

The Gasif + CH<sub>4</sub> + AEL scenario, despite requiring 288 GWh/y electricity to perform the production of SNG on top of the 166 GWh/y required in the considered perimeter, remains the least carbon-intensive scenario (114 kgCO<sub>2</sub>/MWh). This is due to the fact that the taken reference electricity for the case of France is low carbon. The Gasif + CH<sub>4</sub> scenario allows decarbonizing compared to the incineration case (140 vs 176 kgCO<sub>2</sub>/MWh) as less natural gas has to be added (156 GWh/y) compared to the incineration scenario (422 GWh/y) that does not produce SNG. Finally, the gasification and CHP scenario increases the normalized carbon footprint as it requires a significant input of reference natural gas (422 GWh/y) and district heating (160 GWh/y), which are the most carbonated utilities in the reference. All these results are extremely dependent on the references that are considered. Typically, electrified scenarios would be greatly disadvantaged in countries where electricity is more carbon emitting.

### 3.3 Economical evaluation

The economic feasibility of all scenarios is firstly assessed by comparing their main CAPEX and TOTAL OPEX (Figure 6).

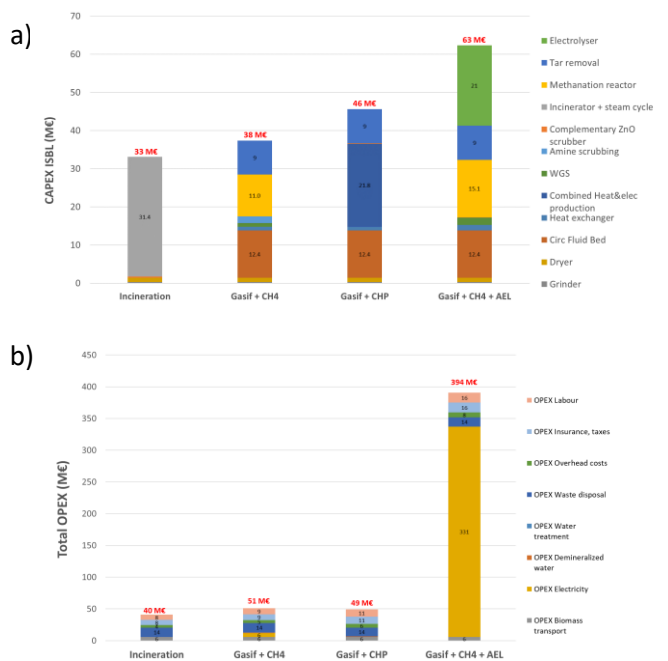


Figure 6: a) CAPEX ISBL of the plant, b) Total OPEX

The incineration scenario, due to its simplicity has by far the lowest CAPEX of all (33 M€), most of the costs are due to the incinerator and the steam cycle

and turbine. The Gasif + CH<sub>4</sub> scenario is the second lowest in terms of investments (38 M€), among which the gasifier, the methanation reactor and the tar removal are the most important investments. The gasification and CHP scenario requires more investment than the gasification and methanation as the CHP system is comparatively more expensive than a methanation reactor. Finally, it is important to note that the gasif + CH<sub>4</sub> + AEL scenario is significantly impacted by the investment in the electrolyser (21 M€), which makes it the scenario with the highest CAPEX (63 M€).

The total OPEX of all scenarios are very similar except for the Gasif + CH<sub>4</sub> + AEL which is about 10 times higher due to the cost of electricity from the grid (80 €/MWh considered as a base case scenario).

In order to compare the economic performance over the whole duration of a hypothetical plant (20 years), the Net Present Value (NPV) of all the scenarios was calculated considering a discount rate of 5 %. For this analysis, the selling price of electricity and SNG (the most valuable utilities) were varied from 0 €/MWh up to 160 €/MWh, whilst the selling price of heat was kept at a value of 20 €/MWh. The scenario giving the highest NPV, e.g. the scenario generating the most net revenues are presented in Figure 7.

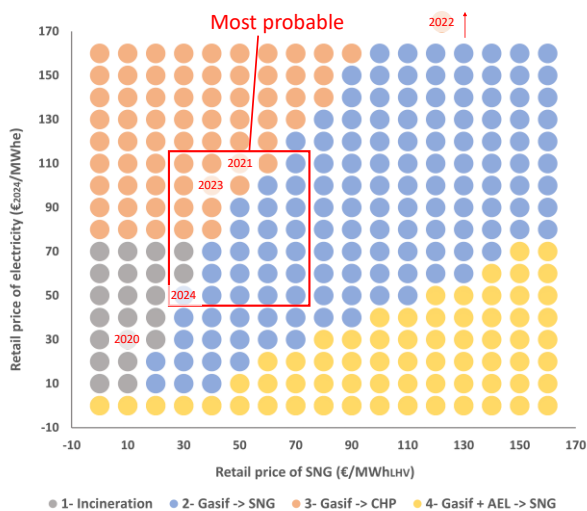


Figure 7: Sensitivity of scenarios to variations in price of electricity and gas, the coloured dot depicts the scenario with the best NPV for the couple gas / electricity prices considered

Depending on the couple gas / electricity prices, all scenarios can become the most profitable one. Overall, the Gasif + CH<sub>4</sub> scenario is the most frequent one with 40 % of intermediate cases

whereby electricity and gas are sold /bought at about the same price per MWh. In the case electricity is cheaper than 60 €/MWh and gas sold at a higher price than 60 €/MWh<sub>LHV</sub>, it can be interesting to invest in an electrified SNG plant as it allows to produce more SNG than the non-electrified version, therefore increasing the profits in the long run. In the case electricity remains expensive (> 80 €/MWh) and gas isn't sold higher than 60 €/MWh<sub>LHV</sub> it seems that the gasification and CHP system is the most relevant option.

## 4 Conclusion and prospects

Alternative ends of life to incineration for SRF have been modelled and compared in a technical, economic and environmental manner. This study was performed considering 3 utilities that can be obtained from the valorisation of SRF: heat, SNG and electricity, this in different scenarios producing them in different proportions, using different elementary steps.

A significant variation (from 57 % up to 80 %) on the overall energy yield has been observed, which mostly depended on the complexity of the process, as more intermediate steps tend to decrease subsequently the yield by energy losses.

The carbon assessment revealed that for an equivalent utility perimeter, the electrified production of SNG is the pathway that allows the most decarbonizing, however this conclusion is tied with the hypothesis of a low-carbon electricity.

The economical performance of all scenarios was assessed by calculating their NPV for various prices of gas and electricity. It revealed that the subsequent production of SNG after gasification might be the safest option in a world where electricity and gas would have the same price (60-80 €/MWh). In the case electricity is expensive (> 80 €/MWh) and gas is not (< 60 €/MWh), the gasification + CHP is the most profitable solution, whilst the SNG production with an electrolyser was the best if electricity happened to be economical (< 60 €/MWh) and gas expensive (> 80 €/MWh).