WASTE IS A RENEWABLE SOURCE OF ENERGY

Turnkey design & build and services

For:
- Household waste
- Commercial and industrial waste
- Biomass
- Fuels derived from waste

To produce:
- Recyclable materials
- Compost
- Energy (heat and electricity)

Leeds (UK)
Energy-from-Waste plant 160,000t/a
Image courtesy of Thomas Graham - Arup

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Municipal Solid Waste is an important valuable source of low-carbon renewable energy. Thermal treatment technologies are efficient to recover Energy from Municipal Solid Waste (MSW) and produce heat and power. Energy-from-Waste (EfW) plants contribute to the diversion of biodegradable municipal waste from landfill and secure a noteworthy reduction of greenhouse gas emissions.
The objective of this paper is to understand the variability in waste feedstock and the opportunities and interests for pre-processing them.

Throughout the world, Municipal Solid Waste is a fuel with some general common characteristics concerning physical, biological, chemical and thermal aspects. Its heterogeneity in size and in composition and its high content in moisture and inert are among them.

Reliable and mature technologies have been developed in the last decades to deal with these specific topics and to guarantee a perfect combustion and energy recovery from this sustainable fuel.

By nature, Municipal Solid Waste is also presenting high physical and chemical feedstock variability, according to the location or the season for example. Cultural differences, climate, social and economic conditions have also an impact on MSW changing quality. Nevertheless, one may observe a tendency to an increase of its variability. Selective collection and material recovery are modifying the compositions. Raw municipal wastes are now often replaced by residual wastes after sorting and/or preparation and they could be mixed with clinical wastes, sewage sludge or Commercial & Industrial wastes.

To integrate successfully this new feedstock, some questions are pending:

- What impacts on calorific values or chemical compositions could we note about MSW residual fraction?
- Are the existing technologies flexible enough to accept greater variability of the fuels?
- Are pre-processing required to obtain more homogeneous feedstock?
- What are the opportunities using feedstock production techniques for high calorific fuels with all various acronyms such as RDF (Refuse Derived Fuels), SRF (Solid Recovered Fuels), CDR, CSS, CSR or EBS?
- What are the repercussions on thermal treatment technologies design, operation and costs?
- What are the effects on the global net energy recovery efficiency or the environmental impact?
- What are the overall benefits of improving the quality of the feedstock for the EfW plant?

The goal of this paper is to develop awareness to understand this fuel input variability and to evaluate the impacts and interests of waste pre-processing, such as waste pre-treatment or Refuse Derived Fuel use.

Is the game worth the candle?

1. Municipal solid waste characteristics

1.1. MSW general characteristics

Municipal Solid Waste (MSW) is generally a complex mixture of several materials different in physical and chemical characteristics as well as extremely variable in size.
MSW general characteristics are the following:

- **Physical**: heterogeneous and variable size,
- **Biological**: contains pathogens,
- **Chemical**: high moisture and high ash content, corrosive species and chemical pollutants,
- **Thermal**: mostly renewable combustible, with heating value similar to wood chips.

### 1.2. MSW variability

Due to cultural differences, climate, social & economic conditions, MSW changes in quality and quantity:

- on different time scales:
  - daily with the example of the food market (packaging in the morning vs. spoiled fruits in the afternoon)
  - seasonal (summer vs. Christmas)
  - long term basis (decades) with new material appearing (plastics…) and some disappearing (coal ashes…),
- with different geographic locations:
  - wet with high organic content in Asia
  - low inert content in Japan because of burnable/non-burnable selection
  - very high calorific value in Switzerland
- with the mixture with other types of solid wastes such as:
  - Clinical waste
  - Sewage sludge
  - Commercial & Industrial
- Depending on the waste management process upstream such as:
  - Selective collection and sorting impact (glass, packaging, bio-waste…)
  - Pretreatment with Mechanical Biological Treatment (MBT)
  - Fuel preparation for Refuse Derived Fuel (RDF) or Solid Recovered Fuel (SRF) production.

### 1.3. MSW thermal treatment

Because of these general characteristics and variability, some efficient technologies have been developed to deal with Municipal Solid Waste thermal treatment and energy recovery. In particular, the large and variable size of fuel elements affects the time required for their combustion. Therefore, the completion of combustion takes longer time for MSW than for other solid fuels.
The technological answers to these set of problems are the following in general:

- **Physical**: Grate combustion system, with specific fuel handling, strong mixing process and large combustion chamber size
- **Biological**: Complete combustion at high temperature during long residence time with high excess air for full oxidation
- **Chemical**:
  - Large boiler design, with adapted steam conditions, material protection and ash handling for corrosion and clogging prevention
  - Complete Flue gas treatment because of waste pollutants content
- **Thermal**: Smaller scale than fossil fuel power plant (in MW) with adapted thermal efficiency

To try to avoid or limit these constraints, some pretreatment or fuel preparation are foreseen.

### 2. Pretreatment objectives

In Europe, the energy transition and circular economy packages have the ambitions to disconnect the link between economic growth, raw materials consumption and waste disposal. Including ambitious objectives for renewable energy production, European directives and national laws require:

- drastic reduction of landfill disposal,
- minimum recycling rates for non-hazardous waste,
- extended producer responsibility (EPR) for specific waste flows management
- implementation of selective collection and sorting for some waste flows such as paper, plastic bottles, glass…,
- source separation for biowaste
- or even preparation and use of RDF

As indicated above, material or energy recovery from solid waste is facing some difficulties, linked to the presence of pollutants or unwanted substances which are going to reduce the material recovery rate or the efficiency of thermal treatment facilities (such as heavy metals or chlorine etc.), or cause health risks or greenhouse gas emissions.

The goal of pretreatments is to extract the compounds considered as polluting or non-recoverable, in order to transform the waste into a secondary raw material, to use in the industrial process of material and energy production.

In order to improve material or energy valorisation, the pre-treatment processes should have the targets to reduce the pollutants load, which is defined there as the elements which do not allow the valorisation, mainly in environmental terms.
This preparation stage may also consist in conditioning the waste by removing its non-recoverable part (or recoverable by other sectors), by increasing its dryness or removing elements, substances or organic compounds whose presence is forbidden by the technical specifications of secondary use.

Following the waste treatment hierarchy and considering material recovery as priority, this is meaning that high quality material recovery should avoid pollution of secondary materials by hazardous compounds.

This important topic has been emphasized by environmental organizations such as the European Environmental Bureau in their recent study *Keeping it clean: How to protect the circular economy from hazardous substances.* [6]

Depending on the waste management value chain, this is meaning that if this pollutants load should be avoided in some material or specific energy recovery process, it will have to be treated *elsewhere* in a good technical and economical manner. Depending on the end energy users, this is meaning that RDF should avoid any pollutants load (case with chlorine in cement plants) or could accept a *concentration* of these pollutants if RDF is corresponding to the residual part of high quality material recovery.

### 3. RDF value chain

Figure 1 is showing the full value chain of Refuse Derived Fuels. A good mix balance between these different flows should be considered to obtain a technical and economical optimization.

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**Record:** Utilisation des CSR et des RDF en Europe – synthèse bibliographique et situations administratives rencontrées sur le terrain (use of SRF and RDF in EUROPE), May 2018
Each flow or stakeholder has its own technical specifications and requirements depending on its process. Depending on energy users or national situation, RDF term does not have the same meaning. Let us try to clarify.

4. Terminology and standards

In order to avoid confusion, it is important to maintain the difference among a long list of abbreviations and acronyms:

- RDF/SRF are general abbreviations, used in Europe.
- CSR (Combustibles Solides de Récupération) refers to the fuel that corresponds to the French framework.
- CDR (Combustibili Derivati da Rifiuti) or CSS (Combustibili Solidi Secondari) in Italy.
- EBS (Ersatzbrennstoffe) or SBS (Sekundärbrennstoffe) in Germany.
- …

In general, RDF are solid non-hazardous waste prepared for energy recovery, derived from either municipal waste, commercial and industrial waste or from construction and demolition waste.

The term SRF has been chosen to refer to solid fuel, prepared from non-hazardous waste, and compliant with European standard EN 15359 or an equivalent national standard (or regulation).

European standard EN 15 359 defines a classification, specification and quality management system for standardized RDF as presented in Table 1. It does not define a quality threshold. The European standard is seldom used in practice.

Table 1: Classification system for SRF according to EU standard EN 15359

<table>
<thead>
<tr>
<th>Classification characteristic</th>
<th>Statistical measure</th>
<th>Unit</th>
<th>Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net calorific value (NCV)</td>
<td>Mean</td>
<td>MJ/kg (ar)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 25</td>
<td>≥ 20</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>Mean</td>
<td>% (d)</td>
<td>≤ 0.2</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>Median 80th percentile</td>
<td>mg/MJ (ar)</td>
<td>≤ 0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 0.04</td>
<td>≤ 0.06</td>
</tr>
</tbody>
</table>

Example of classification: SRF having a mean net caloric value of 19 MJ/kg (ar = as received), a mean chlorine content of 0.5 % (d = dry) and a median mercury content of 0.016 mg/MJ (ar) with a 80th percentile value of 0.05 mg/MJ (ar) is designated as: Class code NCV 3; Cl 2; Hg 2.

In France, the regulatory regime (Decree No. 2016-630) concerning the preparation of CSR and the quality control of CSR received by users is rather unique. It defines the CSR as an RDF that meets certain requirements with thresholds – Net Calorific Value (NCV), halogens, mercury content… –, requirements relating to quality control and an obligation to respect waste hierarchy.
With the exception of France, Italy and Austria have set up a regulatory definition of RDF, but these countries do not define the minimum quality to be achieved. These countries have also introduced the possibility of RDF End of Waste status, but none seems to be currently applied in practice for RDF.

Germany has also a national standard for RDF (RAL-GZ 724), mainly aimed at power plants, cement kilns and limekilns, but it is not used by facilities dedicated to energy recovery from RDF. In Germany, Austria and Sweden, RDF energy recovery plants are not constrained to recover only RDF; they can recover other non-hazardous waste if the technical conditions allow it. Figure 2 summarizes the situation.

In general, the quality of RDF is not covered by the regulations. Figure 3 is showing the repartition between standardized RDF and non-standardized RDF production (which is the majority) in different European countries.

In any case, the local authorities could apply extra requirements in the environmental permits. The quality of the RDF is often defined by agreements between producers and users according to technical criteria in order to respect emission limit values. The parameters concern at minimum NCV, moisture content, density and ash content. Ferrous metal, Sulphur and chlorine content, granulometry and heavy metals concentration (especially mercury) could also be subject to threshold values.

Although RDF prepared from household waste is not a priority in the French projects, this category comprises the majority of the European RDF market. In other countries, the notion of RDF is used to refer to non-hazardous waste prepared by mechanical or mechanical biological sorting for energy recovery. Let us make a focus on RDF market in Europe.
5. RDF market situation in Europe

5.1. RDF production and use quantities

Around 18 to 20 millions of tons of RDF are produced and used in Europe per year. The following graph shows the distribution and the comparison between production and use of RDF by country.

The difference is made up by some import/export flows between the countries.
5.2. RDF import/export

Gate fee differences in waste thermal treatment plants between European countries has caused the development of an import and export market for combustible waste. The main import-export flows of RDF are shown in Figure 5. The main exporting countries are the United Kingdom, the Netherlands, Italy, Norway and Germany. The main importers are the Netherlands, Germany and Sweden with the help of their available capacities and their need for energy.

Let us focus on the UK case with Figure 6 and 7.

The evolution of the situation of UK RDF export from the UK to the continent is firstly linked to the landfill tax increase in this country and to a certain imbalance in the speed of construction of waste management infrastructure in their domestic market. Nevertheless, everyone could now observe a stabilization or even a slowdown in these export flows due to the BREXIT impact. It has reduced the value of the Pound Sterling against the Euro and the economic interest of this export.

France, Finland and Belgium remain relatively out of this RDF trade market.

![Figure 5: Main RDF import and export flows](https://www.entreprises.gouv.fr/files/files/directions_services/etudes-et-statistiques/Analyses/2019-02-ANALYSECombustibleSolidesRecuperation.pdf)

**Figure 5:** Main RDF import and export flows


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![Figure 6: Photo of wrapped UK RDF delivery by boat to a WtE plant](https://www.ea.gov.uk/media/785/energy-from-waste/KN/2017-05/001/KN201705001_01.jpg)

**Figure 6:** Photo of wrapped UK RDF delivery by boat to a WtE plant

Source: EA/DEFRA

![Figure 7: RDF export from the UK versus UK landfill tax evolution](https://www.tolvick.com/assets/2017/05/UK-RDF-Export-and-Landfill-Tax.jpg)

**Figure 7:**

RDF export from the UK versus UK landfill tax evolution

Source: Tolvick: UK RDF Export Market
5.3. RDF production in Europe

In general, the production of RDF is based on pretreatment process of MBT or just Mechanical Treatment (MT) types. This is mainly depending on the inlet flow nature and its organic content and on national laws and standards. Figure 8 shows the quantities of RDF produced by country with the distribution between the two main types of waste inlet: MSW or Commercial & Industrial Waste (C&IW).

![Figure 8: RDF production source between MSW and C&I Waste](source)

Source: Record: Utilisation des CSR et des RDF en Europe – synthèse bibliographique et situations administratives rencontrées sur le terrain (use of SRF and RDF in EUROPE), May 2018

The quality and the NCV of the RDF in Europe are depending on the type of waste used to prepare RDF (MSW, C&IW or rejects from separately collected waste) and on the pretreatment process type corresponding to the end user specifications. Nevertheless, the NCV of RDF prepared from C&IW is generally higher and in a narrower variation range than from MSW inlet. The RDF NCV could vary from 8 to 20 MJ/kg for RDF prepared from MSW. The quantity of produced RDF is strongly depending on this level of NCV.

6. RDF produced quantity versus quality

The recovery rate of a certain defined RDF quality will depend on the input waste quality and the multiple stage RDF production process applied. In some cases, this may lead to a conflict of interest between quantity (amount of RDF produced out of a certain type of input waste) and quality required by customer or the environmental constraints.

In general, the higher NCV of RDF is required; the lower is the recovery rate of RDF. As shown in Figure 9, the Pomberger study (2008) determined the relationship between the NCV (net calorific value) and the yield (recovery rate) when processing MSW or Commercial & Industrial Waste (CW) by a RDF processing plant.
For instance, if the NCV of 22 MJ/kg is required for RDF for example for cement industry typical requirement, the recovery rate will be only about 7 % with MSW as original substance. This is meaning that 93 % residual waste is coming out this RDF preparation process and is requiring some other final sink. This cement RDF use might only help to solve a very small part of the waste management problem. This recovery rate increases up to 20 % with C&IW.

In conclusion, there is a conflict of interest between a high RDF recovery rate and high quality (high NCV) of the RDF produced. The suitable end use for the produced RDF must be designed based on the specific case.

7. RDF use in Europe

RDF can be used as a substitute for fossil fuel in co-incineration plants (coal-fired and brown coal-fired power plants, cement kilns, limekilns), in municipal Waste-to-Energy plants (WtE/MSW-Incineration – MSWI) or in dedicated RDF units for energy production.
User facilities fall into two main categories: first in incineration, (the main purpose of which is waste management) and then in co-incineration, (whose main objective is the production of energy or material). Non-standardized RDF is mainly intended for dedicated facilities or WtE and standardized RDF for cement kilns and coal-fired plants.

In the Netherlands, the RDFs used are of low quality (extraction of the mixed waste recycling fraction and imports from the United Kingdom).

The majority of the facilities in operation in Europe function by combustion, with gasification only occupying a very minor role (a few percent of the facilities identified).

**Figure 10:**

Repartition of RDF use in European countries


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**Figure 11:**  
CDR (SRF) - to-Energy dedicated Termovalorizzatore Pozzilli, Italy

Credit photo: Hera
Fluidized-bed furnaces and grate furnaces share the market, with fluidized beds mainly used when the facility does not only use RDF but also a mixture of homogeneous different flows of waste (biomass, sludge, bone meal, etc.) or high quality RDF with a high NCV and a good preparation.

Nevertheless, CNIM has also a major experience with high quality SRF with a grate combustion. The Pozzilli plat in Italy is running since 2008 with high quality CDR (RDF in Italy) which has a nominal NCV around 15 MJ/kg. The CNIM/MARTIN reverse acting grate technology (VARIO Grate) allows the combustion of this rich fuel without any water-cooling.

Test have been done with RDF NCV up to 19 MJ/kg with this robust technology without any problems. This is a cold grate by principle as explained in the paper [4].

8. RDF impact on WtE costs

8.1. Thermal treatment costs

A major point to understand is that thermal treatment plant costs are mostly related to its thermal power in MW_{th} rather than its mass capacity or tonnage in t/h.

Let us consider a WtE plant n°1, designed for a capacity of 10 tons of MSW per hour with a nominal NCV of 9 MJ/kg. It will have a thermal power input of 25 MW_{th}. Let us now compare this facility with a WtE plant n°2 of an equivalent thermal power input of 25 MW_{th}, but treating 7.5 t/h of RDF at 12 MJ/kg

In first approximation, as the thermal power input is equivalent, most of the parameters of these two plants are similar in particular:

- the total power production in MW_{e},
- the total flue gas flow in Nm^3/h,
- the CAPEX
- and also most of the OPEX main topics
The main exception is concerning the residues quantities such as bottom ashes, which are more related to the quantities rather than thermal power. Even Air Pollution Control costs could be very similar as the pollutants concentrations could increase in relation with NCV, as the total quantity is often remaining in the residual part after pretreatment compared to the original flow.

Therefore one should not hope to reduce drastically the different costs CAPEX and OPEX or increase energy revenues by treating 25 % less fuel (7.5 t RDF/h in our example instead of 10 t MSW/h) if the thermal power input does not change (25 MWth). This a common misunderstanding.

8.2. MSW pretreatment impact on costs

One should not consider the thermal treatment part alone, but the waste management system with the whole sequence of processes. This was the goal of the research lead by Pr Consonni from Politecnico di Milano [2, 3]. This study aim was to understand if

Figure 13: Residual MSW strategies considered

the preparation of residual waste ahead of combustion in dedicated waste-to-energy plants could either increase efficiency or reduce environmental impact or reduce the cost of energy recovery.

This research assesses different strategies for energy recovery from MSW based on mass, energy, environmental and economic considerations.

The considered feedstock is the residual fraction after selective collection and material recovery (RMSW). The four alternative strategies shown in Figure 13 correspond to the options often considered by several municipalities to recover energy from MSW. In strategy 1, the RMSW is fed directly to a combustion furnace. In strategy 2, the RMSW is first pretreated by light mechanical treatment. Strategies 3 and 4 are including biological treatment for the organic fraction (MBT); the RMSW is converted into RDF, which is then combusted in dedicated combustion system.

To examine the relevance of scale, they considered two sizes of waste management system (small/large).

As shown in Figure 14 and considering the whole sequences of these waste management strategies, it appears that:

- pre-treating the RMSW in order to increase the heating value of the feedstock fed to the WtE plant has marginal effects on the energy efficiency of the WtE plant,
- the more important the pre-treatment, the smaller the amount of energy recovered per unit of RMSW,
- pre-treatment of RMSW ahead of the WTE plant does not provide any environmental benefits as RDF production worsens almost all impact indicators,
- the cost of all strategies with pre-treatment is always higher. The benefits of improving the quality of the feedstock to the WTE plant do not compensate the cost of such improvement,
- scale-up impact between small and large systems is much more important than pretreatment strategies,
- total disposal cost is always very sensitive to the electricity sale price.

In conclusion, the most viable option according to this study is the one based on direct combustion of RMSW in a large-scale grate combustion plant (Strategy 1L). NB: the different figures in Figure 14 should be considered in relative values between the different scenario and not absolute regarding the price evolution.
The RDF production option might gain some interest when its energy content might be recovered with a significantly higher efficiency than what can be obtained in a traditional WtE plant, as it could be the case for co-combustion in suitable coal-fired power plants or cement kilns. However, the RDF quality requirement on NCV and pollutants contents in these processes is limiting hugely the treated RDF quantity and therefore is leaving a majority of residues to deal with from this high quality RDF preparation.

9. Drivers behind the development of RDF

In most countries in Europe, facilities producing and those using RDF are not in general the result of a public policy whose goal was to develop a RDF sector. They emerged mainly in the last 2 decades through a combination of the following factors:

- climate of high and increasing fossil fuel prices, pushing energy consumers to look for alternatives;
- combustible waste available at a competitive price, resulting from the implementation of public policy instruments aimed at reducing landfill in the form of bans and/or dissuasive taxation
- European system of CO₂ quotas favouring alternative energy overall compared with the most carbon fossil fuels;
- for some countries, placing dedicated RDF facilities in the incineration category as renewable energy, thus exonerating RDF energy production from CO₂ quotas.
- national energy investment or operational subsidies or regulatory conditions can apply to facilities using RDF and encourage the economic model.

10. Conclusion

This paper is presenting this MSW fuel input variability and trying to evaluate the impacts and interests of waste pre-processing, such as waste pre-treatment or Refuse Derived Fuel use with a benchmark in different European countries.

The cost of landfill, influenced by the existence of taxes and/or the existence of bans on sending certain types of waste to landfill (raw waste, combustible waste) explains the preparation of a RDF/SRF market. The high cost of landfill or the ban on landfilling raw waste encourages waste producers to reduce the amount they send to landfill. In most countries with high RDF use, the cost of sending non-hazardous waste to landfill exceeds 100 EUR/t and/or that there were landfill bans in force.

The energy end-consumer is usually the driver behind the construction of the RDF use site.

The European RDF market has developed thanks to a demand for competitive renewable energy (context of rising prices before crisis, CO₂ quotas); and an offer in fuel prepared from waste, the consequence of national policies aimed at reducing landfill. However, the economic model of the facilities is very sensitive to the price of waste and energy.

One should evaluate if the game is worth the candle in its local situation.
Do We Need Pretreatment or Refuse Derived Fuel for Energy-from-Waste?

11. Literature


[8] Record: Prétraitements avant valorisations matière et énergie des déchets solides (Pretreatments prior to matter and energy recovery of solid waste) – August 2017

[9] Record: Utilisation des CSR et des RDF en Europe – synthèse bibliographique et situations administratives rencontrées sur le terrain (use of SRF and RDF in EUROPE), May 2018


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Due to recent alterations in the legal framework in Germany, the market for utilisation of sewage sludge will be fundamentally changing in the near future. On the one hand, the application in agriculture as fertiliser will be largely restricted. On the other hand, the political will to strengthen the circular economy will be provided. Regarding the sewage sludge the focus lies on the recovery of phosphorous, which is due to the European Commission designated as a critical raw material since 2014.

Numerous procedural approaches considering the recovery of phosphorous from primary sludge or from the residues of thermal treatment exist but with different development status. Against the background of a manifold industrial sector regarding the specification (dimension, stages of treatment steps) and the periphery (urban, rural, local options for utilization) of the sewage plants, many operators seek for meaningful technical solutions and economic concepts. The book will be released accompanied to the “Berliner Klärschlammkonferenz” (Berlin Sewage Sludge Conference) in November 2018 and will give a review to the altered legal framework as well as to innovative procedures and experiences in practice.