

**CLEAN UTILIZATION OF MUNICIPAL SOLID WASTES  
AND ALTERNATIVE FUELS DERIVED FROM IT**

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**Abstract.** For the municipal solid waste (MSW) to be used in a proper way, it is necessary to implement clean technologies capable of thermal treatment of MSW and RDF in order to produce heat and electricity while meeting current ecological requirements. Nowadays, a number of technologies for MSW/RDF thermal treating are being used worldwide. Among them, the most proven technologies, applicable for industrial introduction, have been considered while analyzing their advantages/ disadvantages accounting for local conditions of Ukraine.

**Key words:** wastes, fuel, MSW, RDF, utilization, energy, incineration, combustion, gasification

## 1. Introduction

According to official statistics, the amount of municipal solid wastes (MSW) in Ukraine in 2018–2019 was in the range of 50–60 mln m<sup>3</sup> (about 12 mln t). In 2019 only 5.4 % of MSW was treated and utilized in Ukraine, 1.7 % of which was burnt out and 3.7 % went to recycling points and waste treatment facilities.

At the same time, thermal utilization of waste, having a lack of attention to special features of morphological and elemental analysis of MSW, can lead to the formation of extremely dangerous compounds for the humans (polychlorinated hydrocarbons – dioxins and furans, the maximum permissible concentrations of which are picograms).

To prevent unsafe combustion of MSW, strict directives (2010/75/EU, 2000/76/EU and others [1–3]) related to regime parameters of new thermal facilities to utilize MSW/RDF were introduced in the EU.

Local Ukrainian legislation which is being developed also facilitates stepwise replacing the combustion of unsorted MSW at incinerators with the combustion of RDF of guaranteed quality or with other technologies of thermochemical processing.

Disposal of almost 95 % of untreated MSW at landfills leads to annual losses of a significant amount of energy and valuable materials in waste.

According to preliminary estimates, the heat of low heating value (LHV) of MSW for the cities of Ukraine is 4.8–7.0 MJ/kg, it is similar to the LHV of peat and brown coal (in the EU–6–16 MJ/kg). As to RDF, the LHV is higher approaching the value of 12–18 MJ/kg.

MSW sorting does not solve the problem of complete utilization of waste. The separated part of the waste, having organic compound, should be used for the production of electricity and heat in an environmentally friendly way.

Thus, the development and implementation of environmentally friendly methods to utilize MSW and alternative fuels based on them, in particular RDF, is an urgent problem to be solved using the holistic and scientifically sound approach.

Among the modern clean technologies which are being developed or are assumed as proven on the industrial scale, it is worth to highlight the experience of implementation of the following typical processes: direct combustion technologies in furnaces having a proper level of temperatures and equipped with advanced systems of emission removal (e.g. based on carbon filters); technologies of steam-oxygen blown entrained flow gasification of unsorted MSW; RDF gasification in a circulating fluidized bed (CFB); RDF gasification in an air-blown internally circulating fluidized bed (IC-FB); RDF combustion in a CFB. For the above technologies to be implemented in the future in Ukraine, it is necessary to find out an optimal technical solution while accounting for local fuel properties and world experience.

The aim of the study is to analyze the experience of implementation of typical thermal treatment technologies for utilizing MSW/RDF/SRF used at the industrial level; define their advantages and disadvantages,

select the most promising for the introduction in Ukraine accounting for local conditions (relative to waste properties and the needed productivity of the plant), and develop proper recommendations.

## 2. Comparative analysis of typical large-scale plants to utilize MSW and RDF

### 2.1. Bulk combustion of not-sorted MSW in a grate-based incinerator

Among the widely spread typical technologies used for a long time to utilize MSW (usually not-sorted), it is necessary to pay attention to combustion in a fixed bed (moving by grate bed) or also known as Stoker firing (incineration) [4].

Before combustion, the fuel is not actually crushed or dried. Due to the high moisture content of the source fuel, it is not possible to achieve high temperatures in the furnace to comply with the requirements for holding combustion products for at least 2 s at temperatures above 1200 °C without the use of supplementary fuel – natural gas. In some cases, the addition of oxygen is also used.

However, despite the obvious disadvantages of the process, the use of such incinerators (based on Stoker firing) for not-sorted MSW remains the most widely spread technology over the world.

*The key advantages* of the technology are: no sorting of solid waste is required (no sorting costs, except for the removal of metal and large items); no extensive fuel handling system is needed (such as fuel crushing) except for magnetic separation.

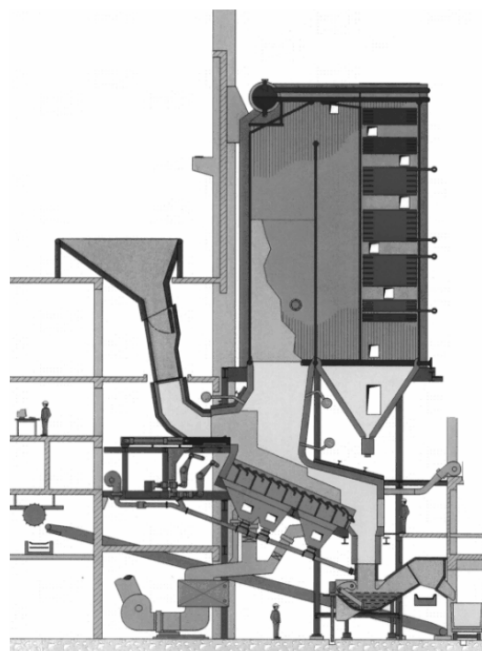
*The key disadvantages* of the technology are: no way to extract valuable products for secondary (non-energy) use; formation of extremely harmful (carcinogenic) combustion products having dioxins and furans; limited use of slag.

*Experience of industrial realization.* Despite the obvious problems of MSW direct incineration without the use of modern methods of deep cleaning of combustion products, the share of incineration plants in the world remains quite high (more than 60 %), although there is a tendency to gradually decrease.

To meet the environmental requirements, the above plants should be equipped with an advanced emissions removal system.

In Ukraine, the method is currently being used for incineration of not-sorted MSW at the “Energiya” plant (Kyiv) (currently the only powerful MSW incineration plant in Ukraine).

*Prospects for implementation in Ukraine.* The above method is obsolete. It requires significant consumption of natural gas for waste incineration, leads to an increase in the morbidity of the population in the areas adjacent to incinerators and does not ensure the necessary quality for slag to be further used.

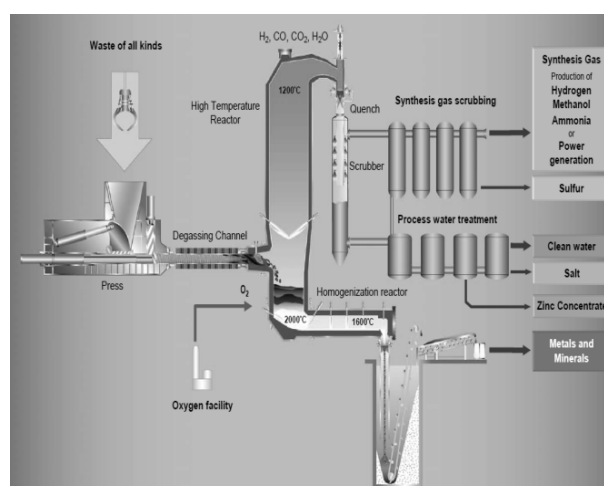


**Fig. 1.** Typical incinerator to burn bulk not-sorted MSW in a fixed bed using grate-based (Stoker) firing technology

It seems more feasible to burn RDF instead of not-sorted MSW using such technology (fixed bed combustion).

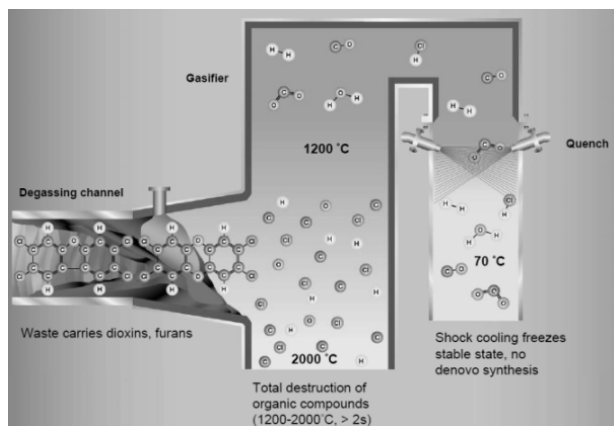
### 2.2. Gasification of not-sorted MSW in an steam-oxygen blown entrained flow (based on Thermoselect technology) [4, 5].

Among the promising technologies for the utilization of not-sorted MSW, the technology of steam-oxygen blown entrained flow gasification was considered for some period. A key feature of the process was the use of oxygen blown in the lower part of the gasifier to achieve high temperatures in this area of about 1600–2000 °C in order to form liquid slag.

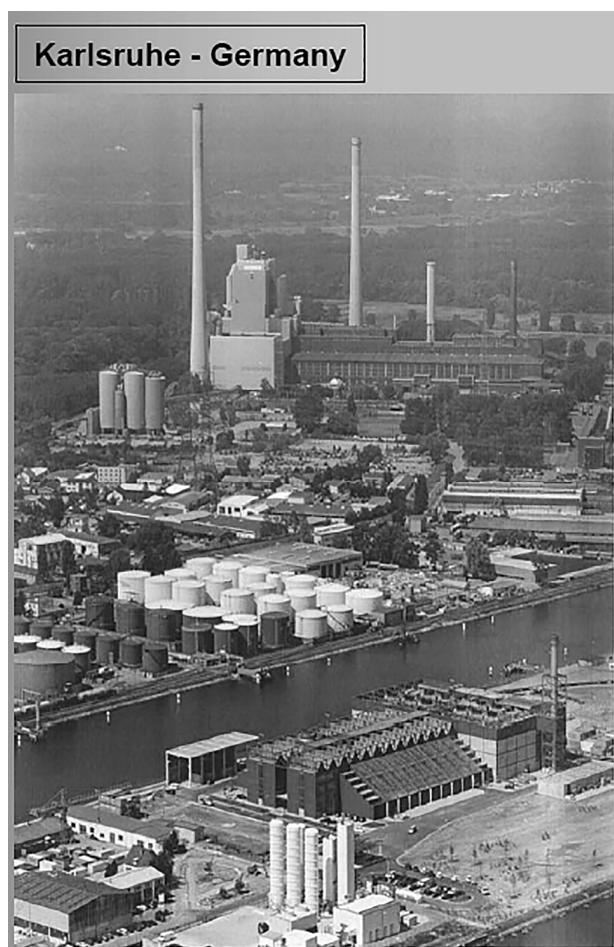


**Fig. 2.** An example of the use of oxygen-blown entrained flow gasification to treat not-sorted MSW (based on Thermoselect technology) [4, 5]

At the same time, the syngas temperature at the outlet of the gasifier was close to 1200 °C providing decomposition of polychlorinated hydrocarbons due to the required residence time of syngas (over 2 s) within the zone of elevated temperatures (over 1200 °C).



**Fig. 3.** Principle of operating the upper part of Thermoselect gasifier and chlorinated hydrocarbons decomposition



**Fig. 4.** Industry-scale implementation of Thermoselect technology to gasify not-sorted MSW (Karlsruhe factory; MSW productivity: 247.5 ths t/year) (red-colored facility)

In addition, the injection of water to sharply cool down the syngas at the outlet of the gasifier doesn't allow for polychlorinated hydrocarbons to be recovered.

The synthesis gas obtained at the outlet was cleaned up and further used for various purposes: for direct combustion to obtain heat or electricity; to produce valuable chemical products (hydrogen, methanol, ammonia, etc.) etc. The slag in the form of metals, formed from the inorganic component of waste, could be used in the future.

The technological scheme should include oxygen plant consuming high part of CAPEX (in some cases up to 30 %).

*Experience of industrial realization.* There are several powerful gasification plants in the world for processing municipal solid waste using this technology.

For example, in Germany: in Karlsruhe; the TESS plant (Thermoselect Stuwest) was built; commissioning took place in 1999; solid waste processing capacity: 247.5 thousand tons / year; plant includes: three lines, each with a capacity of 11 tons / hour; use of synthesis gas: combustion in a heat recovery steam generator (HRSG) to produce steam for a steam turbine (district heating).

The above technology was improved and mostly used in Japan.



**Fig. 5.** Industry-scale implementation of Thermoselect technology to gasify not-sorted MSW (Kawasaki Steel Chiba factory; MSW productivity: 110.0 ths t/year)

For example, Kawasaki Steel Corporation has Kawasaki Steel Chiba Plant; start up day was on September 1999; capacity to treat MSW: 110 thousand t/year; plant has: 2 lines, each with productivity of 6.88 t/hour; syngas is used to fuel Jenbacher GasEngine as well as at Chiba Work.

*The key advantages* of the technology are: no solid waste sorting is needed (no sorting costs); slag can be used as sub-product; low emissions (that meets EU requirements); lack or negligible dioxin / furan emissions; partial extraction of valuable products (molten metals) for secondary (non-energy) use (recycling).

*The key disadvantages* of the technology are: significant capital expenditures (CAPEX); significant operating costs (OPEX); the complexity of the process.

*Prospects for implementation in Ukraine.* Despite the attractiveness to obtain synthesis gas and by-products (metals, etc.), the implementation of the above technology in Ukraine now is considered to be not feasible (or extremely limited) since poor ability of integrating into the concept of “separate collection” and significant financial costs (OPEX / CAPEX).

### 2.3. Air-blown gasification of refuse-derived fuel (RDF) in a circulating fluidized bed (CFB) (based on Metso/ Foster Wheeler technology as an example) [6].

Circulating fluidized bed gasification technologies are well established, at least for coal. The peculiarity of the gasifier reactor is the operation at relatively low temperatures of 900–920 °C and multiple circulation of the material through the cyclones – over the gasifier loop (gasifier- cyclone-gasifier) (externally to the reactor).

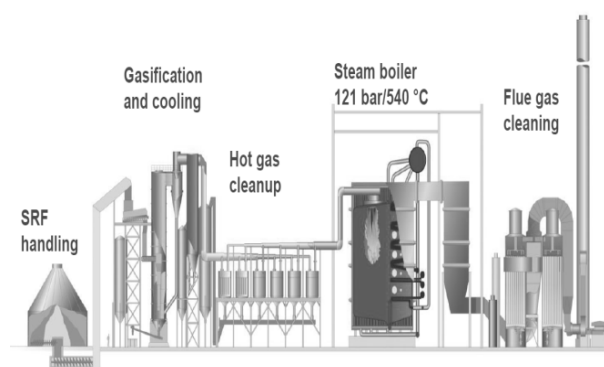


**Fig. 6.** Uploading of typical RDF to be used as fuel for CFB gasification at FW's gasifier

The fuel for gasifier should be properly handled before feeding into the reactor: separated from metal

objects and shredded to 1–5 cm. RDF is gasified in the reactor resulting in syngas formation that goes to hot-gas clean-up system. Once cleaned it is burned in a boiler to produce steam used further for district heating and/or electricity generation.

*The experience of industrial implementation.* A typical technological scheme of RDF / SRF gasification is shown in Fig. 7. The technology was realized in industrial scale at Lahti CHP (combined heat at power plant), Finland (Metso and Foster Wheeler technologies used).



**Fig. 7.** Scheme of technological process of air-blown gasification of RDF to produce heat and electricity at Lahti CHP plant (annual RDF consumption: 250 ths t/year)

CHP Lahti Energia II key data: the use of RDF/SRF gasification (Metso) in CFB; productivity to treat RDF – 250 thousand tons/year; heat capacity of CHP – 90 MW for district heating; electric capacity – 50 MW; CHP has two CFB gasifiers with heat capacity of 80 MW each.

*The key advantages* of the technology are: low emissions (meets EU requirements); integration into the concept of “separate collection” and “sorting”.

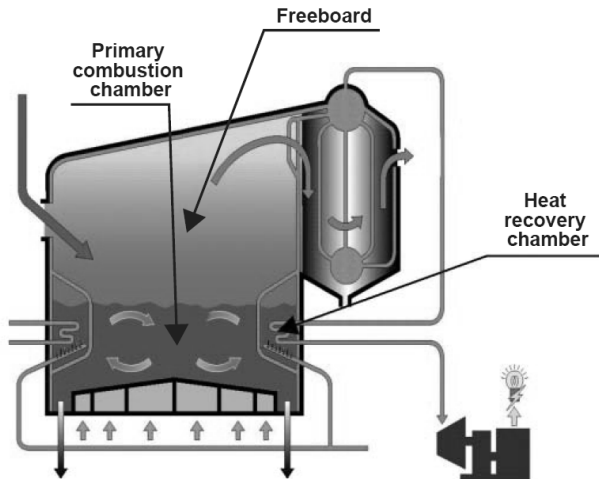
*The key disadvantages* of the technology are: the need to handle primary feedstock (to separate from metal and to shred); complexity of the process compared to bulk MSW combustion at Stoker incinerator; there is a question of ash utilization; larger CAPEX / OPEX (compared to Stoker-firing).

*Prospects for implementation in Ukraine.* In the case of the development of RDF market in Ukraine, the above technology can be considered as attractive option (having moderate feasibility) for implementation.

### 2.4. Air-blown RDF gasification in a internally circulating fluidized bed accompanied with ash melting system (based on Ebara IC-FB technology of Japan as an example) [7–9].

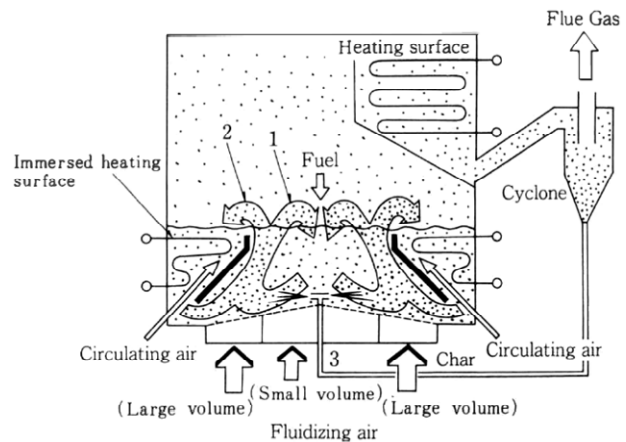
The above technology has original approach and taking into account the shortcomings of the previously

considered processes. A feature of the proposed fluidized bed reactor is the extraordinary internal circulation of the bed material due to the specific geometry of the lower part of the reactor and the organization of the air distribution under the grate causing high internal circulation of the bed inventory.



**Fig. 8.** Principle of operation of Internal Circulation Fluidized Bed reactor – IC FB (Ebara technology) [8]

Another feature is that evaporating surfaces is placed in heat recovery chamber where low fluidizing velocity is maintained to avoid corrosion issue.



**Fig. 9.** Principle of air distribution through the reactor (Ebara technology)

The properties of fuel used in commercial plant in operation are as follows:

Table 1

**Municipal waste properties (Particle sizes are under 0.05 m)**

Net Heat Value, MJ/kg	Moisture, %	Density, kg/m <sup>3</sup>	Constituent distribution, %						
			Paper	Wood Bamboo	Plastic	Kitchen waste	Textiles	Metal Glass	Other
8.3	55.4	148	36.7	1.1	20.7	24.3	5.4	7.1	4.7

In addition, an important option of the technology is the use of low-calorific synthesis gas to convert fluidized bed fly ash to a “glassy” slag while melting it at high temperatures for further suitable usage. The last process takes place in an ash melting furnace.

The flue gas resulted from syngas combustion can be further used at heat recovery steam generator to produce steam for district heating.

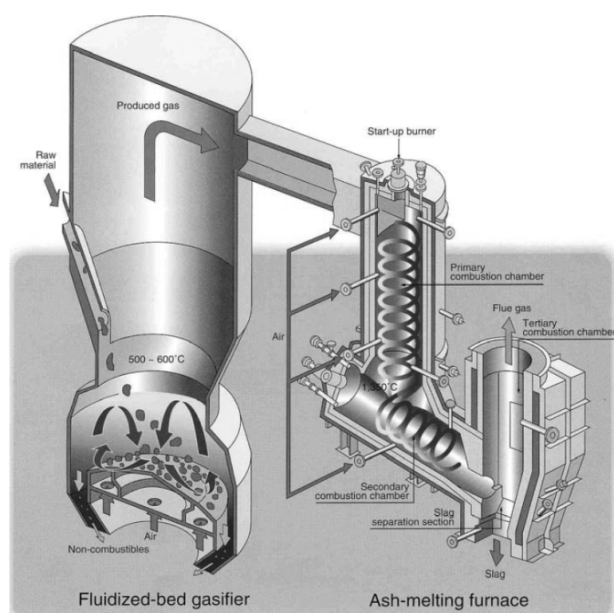
*Experience of industrial implementation.* This technology has been widely spread at industrial level in Japan mainly on boilers of low and medium steam productivity (20–50 t/hour).

*The key advantages of the technology are:* low emissions (meets EU requirements); integration into the concept of “separate collection” and “sorting”; the possibility to use molten ash (slag) in the future; the ability to use coarse RDF/MSW particle to feed reactor.

*The key disadvantages of the technology are:* the need for fuel preparation; the complexity of the process compared to simple incineration; low steam capacity of boilers involved in the technological scheme; higher CAPEX / OPEX (compared to combustion technologies).

*Prospects for implementation in Ukraine.* The above technology is considered to be feasible for

implementation in Ukraine within the range of proven gasifier size and corresponding steam boiler capacities.



**Fig. 10.** Principle of ICFB fly ash melting to produce glass-type slag suitable for further common use (Ebara technology) [9]

## 2.5 RDF combustion in a circulating fluidized bed (CFB)

Circulating fluidized bed combustion technologies are widely used over the world for various fuels. The achievable electrical capacity of power units that has coal fired CFB steam generators is 300–600 MW. There is also enough experience to burn RDF / SRF.

The CFB combustion process takes place in the combustion chamber at relatively low temperatures of 850–880 °C compared to fixed/moving bed in Stoker incinerator. The temperature of the inert circulating material (ash usually served as furnace inventory) is uniform over the furnace height compared to high difference over the bed for grate combustion (450–1500 °C). The intensive circulation of the bed inventory is used over the circulating loop: furnace – cyclone – standpipe – seal pot – furnace). The fuel should be crushed to a size of 1–5 mm. An special feature of CFB is that the input fuel feed (flux) is greatly (by 20–40 times) less than those flux of recirculating material, which makes bed thermally inert and practically insensitive to fuel properties (such as high water content and/or ash content). Low temperature favors low NO<sub>x</sub> emissions compared to Stoker-firing, which simplifies NO<sub>x</sub> removal system design (if needed at all).

*Experience of industrial realization.* The CFB technology is proven one and widely used all over the world at steam boilers having steam productivity up to 900–950 t / hour. The steam capacity of the boiler to burn RDF/SRF is less.

*The key advantages of the technology are:* low emissions (meets EU requirements); integration into the concept of “separate collection” and “sorting”; the possibility to use coarse RDF/ MSW particles.

*The key disadvantages of the technology are:* the need for fuel handling and preparation; limited possibility to use ash mainly bottom ash (the research is required).

*Prospects for implementation in Ukraine.* The implementation of CFB combustion technology for RDF/SRF can be considered as promising (feasible) option for medium to large scale application (boilers with steam productivity of more than 50 t/hour).

## 3. Results and discussion

The analysis of the results of the morphological composition of MSW as typical for Ukraine is given in Table 1 (for Kyiv). It is seen from the given data that the share of more than 40 % (by weight) corresponds to highly moist food and garden waste.

Table 2

**Morphological composition of MSW obtained from multistoried houses (Kyiv city)**

No.	MSW component name	%, average by weight
1	Cardboard	4.04
2	Paper	6.21
3	PETF bottle, boxes	2.07
4	Polymer films	3.97
5	Plastics	2.63
6	TetraPak package	0.86
7	Black metals	1.03
8	Colored metals	0.15
9	Glass	12.09
10	Skin, resign	1.12
11	Textile	2.39
12	Wood	0.89
13	Food & garden wastes (for compost)	42.32
14	Hazardous wastes	0.0066
15	Unsorted combustibles	15.21
16	Unsorted incombustibles	4.42

After MSW treating the LHV of the RDF/SRF can range within the 6–16 MJ/kg. The choice of the technology to implement should be based on the key following technical factors: availability of wastes (annual amount), type of feedstock (MSW, sorted MSW, RDF/SRF), local ecology requirements, places to store ash/slag or the option to use it.

Here we may summarize the following general trends existing in the area of waste management in Ukraine.

The recommendations are as follows.

1. By the moment Ukraine has accumulated significant amount of unsorted solid waste / MSW (bulk Municipal Solid Waste, MSW), which is stored in

thousands of landfills, most of which are unauthorized landfills.

2. The amount of solid waste generated annually is approximately 300–400 kg/person. The amount of RDF that can be derived from MSW is about 15–30 % (typically 25 %) by weight of MSW. These estimate can be used to make energy potential analysis of wastes annually generated in Ukraine.

3. Currently, direct incineration of unsorted MSW in a fixed/moving bed (Stoker firing) dominates (over 60 % by productivity) as a cheap technology for waste utilization.

4. At the same time, there is a steady trend in the world to use the technologies of “separate collection” and “sorting” of solid waste.

5. Usually to achieve complete sorting (100 %) of wastes is not possible and the share of energy valuable refuse-derived fuel (SRF / RDF) can be high ranging the 15–30 % of initial MSW. Beside this, the LHV of RDF/SRF can reach 9–16 MJ / kg, which is comparable to low grade fossil fuel (brown coal, lignite, etc).

6. Thus, in Ukraine there is a need to develop and implement new environmentally friendly technologies for thermal processing of MSW and/or secondary derived fuel, which could be used to generate heat and electricity.

The analysis given below allows us to sum up the recommendations regarding the feasibility to implement typical thermal treatment technologies for utilizing MSW and fuel, derived from it, in Ukraine based on technological parameters, ecological performance and worldwide experience of technology implementation.

*Incineration of unsorted MSW in fixed/moving bed on the grate (Stoker firing) should be considered obsolete. In most cases it is necessary to use natural gas (and spend corresponding cost) as supplementary fuel to maintain stable incineration.*

The technology does not provide necessary quality of slag for further use and doesn't correlate well with principle of “separate collection” and “waste sorting” declared by “National Strategy on Waste Management in Ukraine by the year of 2030” (Strategy). It could be used exceptionally following deep removal of all hazardous impurities and gas emissions or in the case of shift from MSW to RDF.

Despite the proven industrial size of plants in operation ensuring the treatment of about 300 ths t of MSW annually, the implementation of steam-oxygen gasification of unsorted MSW (similar to Thermoselect process) in Ukraine is also considered to be not-feasible (or extremely limited) bearing in mind poor integration into the concept of “separate collection” set in the

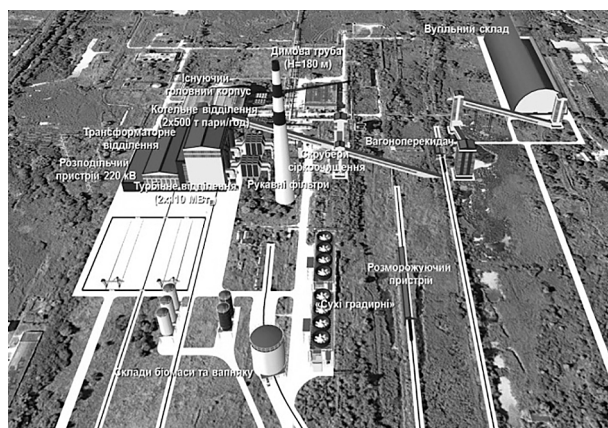
Strategy and significant financial costs (on OPEX / CAPEX) to be spent on technology introduction.

In the case of the development of RDF market in Ukraine, the air-blown gasification of refuse-derived fuel in circulating fluidized bed (CFB) is considered to be feasible for individual plant aimed at treatment of 150–200 thousand of RDF annually, which applicable for large cities producing about 0.7–1.0 mln t of MSW/year.

The implementation in Ukraine of *air-blown gasification of RDF in an internally circulating fluidized bed with ash melting* (similar to IC-FB) is considered to be reasonable for small to medium size plants designed to treat up 30–50 thousand t of wastes annually.

The combustion of *RDF in a circulating fluidized bed* should consider as very promising one for the implementation in Ukraine for large scale plant application (aimed at treatment of equal or more than 200 ths t of RDF annually derived from more than 1 mln t of MSW).

As part of the given analysis, the authors together with SC “Vuglesyntezgaz of Ukraine” (VSGU) identified opportunities and developed reference plant design for the implementation of RDF CFB combustion (as an example, area of Lviv CHP-2 was chosen). The result of reference plant layout is shown in Fig. 10



**Fig. 10.** Plant layout for CFB-boilers (2x110 MW) for joint combustion of coal and RDF (e.g. for Lviv CHP “Pivnichna”), developed jointly by SC “VSGU” along with CETI)

*Advantages of the project implementation:* low emission level (meets EU requirements) [10–12]; CFB technology, where RDF is used, is integrated into the concept of “separate collection” and “sorting”; insensitive to waste quality; co-incineration with coal is possible.

*Disadvantages:* RDF should be available on site in proper amount; the need to remove chlorine-

containing compounds (less than 1 %); the need to address the use of ash (e.g., for road construction).

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