SOLID RECOVERED FUEL AS COAL SUBSTITUTE IN THE ELECTRICITY GENERATION SECTOR

by

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According to the 1999/31 EC Directive, municipal solid waste should not be disposed for landfill from 2005. In this way, more environmental friendly waste management options are promoted towards the volume reduction and limitation of negative consequences. In this context, attention is focused on the utilisation of solid recovered fuels derived from the waste treatment as coal substitute in large-scale power plants. Such activities are realized within an EU-funded project RECOFUEL, in which the solid recovered fuels co-combustion with brown coal is demonstrated in two commercial-scale PF-boilers at RWE Power's power plant site in Weisweiler, Germany. During testing the thermal share of solid recovered fuels in the overall thermal input was adjusted to some 2%, resulting into a feeding rate of about 2   12.5 tons per hour. NTUA-LSB in cooperation with IVD-University of Stuttgart, Germany, is responsible for the boiler measurements and the characterization of boilers operational behaviour. Among the main activities are the technology transfer of co-combustion practice in the Balkan countries and the perspectives of its future application in the Greek region, with respect to the special characteristics of the Greek brown coal and municipal solid waste. Co-combustion tests of brown coal and solid recovered fuels, that have been taken place up to now, have been successfully performed and the strict European emission limits are kept. The waste quantities in Greece that can be utilized are estimated in 200,000 Mg/year while their utilization in existing thermal plants is expected to bring savings of 3% lignite use and avoidance of up to 200,000 Mg CO_2 per year.

Key words: *co-combustion, waste, environmental legislation*

Introduction

The need for more efficient and environmental friendly waste treatment methods becomes gradually clear in all the EU countries. Co-combustion of solid recovered fuels (SRF), which mainly consists of biogenic components like paper, cardboard, wood (50-70%) and of plastics, in existing coal-fired power plants, may bring significant economic and environmental benefits. To be more specific, SRF is proven as a very advantageous substitute fuel, due to its low production cost and its high thermal value – about double than the thermal value of Greek brown coal. Moreover, its utilization in existing plants normally requires low investment costs. The use of SRF results in savings of the valuable non renewable energy sources and to reduction of CO_2 emissions, as well as of waste quantities that are disposed to landfill. Special attention has to be paid on the emission limits according to the EU legislation and especially on the compounds derived from the recovered fuels' combustion, *i. e.* dioxins, furans, and heavy metals.

Mandated by the EU-Commission the standardisation and classification work of SRF by CEN TC 343 started in 2002 [1].

Legislative framework

EU legislation

Environmental protection and the assurance of public health stay as one of the priorities in EU policy. Main targets concerning EU legislative framework about waste are:
– Implementation of measures and politics that will lead to the reduction of municipal solid waste (MSW) quantities, according to the prevention principle.
– Gradual reduction of the allowed quantities that are disposed of to landfill with priority given to the biodegradable material, from which the high calorific fraction (HCF) has to be recovered.
– Implementation of stricter operating prescriptions for MSW-incinerators and other types of thermal plants (*e. g.* cement kilns, power plants), where utilization of SRF as substitute fuel is taking place.

Specific measures targeting to the reduction of waste quantities land filled, are source separation, mechanical and biological treatment, SRF and compost production and alternatively MSW incineration. The main European Directives [2, 3] which define the guidelines in the subject of waste treatment are:
– Directive 1999/31 EC: It sets as main target the reduction of biodegradable quantities material and used tires that are disposed to landfills,
– Directive 2000/76 EC: It is the new Directive on waste incineration. Permission procedures are defined, and stricter limits for SRF co firing in thermal plants are set, which come closer to the incinerators emission limits, and
– Directive 2001/77 EC about renewable energy sources: It promotes the use of biomass and HCF of MSW as substitute fuels for brown coal, in order to reduce green house gases emissions.

It is worth to be mentioned that recycling is considered as a preferable process in comparison with incineration or mechanical treatment, because higher quality products and therefore higher resources savings can be achieved. Furthermore, the use of mechanical treatment allows a better logistic management of waste in comparison with incineration, because there is no demand on continuous feeding, which allows the better quality control of the whole process.

To sum up main priority of European legislation in the subject of waste treatment is the prevention of waste production and the reduction of the MSW quantities land filled, concentrating efforts on their recycling and the recovery of their thermal content.

Greek legislation

Following the European Legislative Framework, the Greek legislation defines waste treatment through a number of laws. The most important among them is the National Plan of Solid Waste Treatment [4]. Some of its targets that derive from the EU legislation are:

- for packaging waste, the end of 2005 stays as a time limit, up to which procedures for waste recovery have to be implemented, that will lead to: recovery of the 50% of its weight and accordingly recycling/reuse of the 25%,
- gradual decrease of biodegradable waste quantities, that are disposed of to landfill. Having as reference year 1995 it is expected for the following target years: 2010 a decrease to 25%, 2013 to 50%, 2020 to 65%,
- the spreading, modernization and optimisation of the MSW collection and transportation network targeting to the reduction of necessary logistic times, and
- the closing and restoration of all uncontrolled landfills, which are the majority in the Greek area.

Waste quantities that can be utilised in the greek area

Present situation

The progress of MSW production in Greece is presented in fig. 1. A constant increase in all the previous years is observed and based on estimations this will continue in the coming years. The main portion of the produced quantities is concentrated in the two

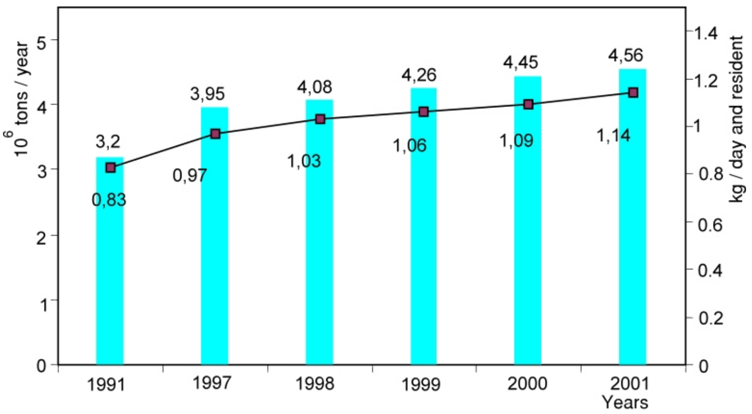

Figure 1. Annual production of MSW in Greece; Source: Ministry of Environment

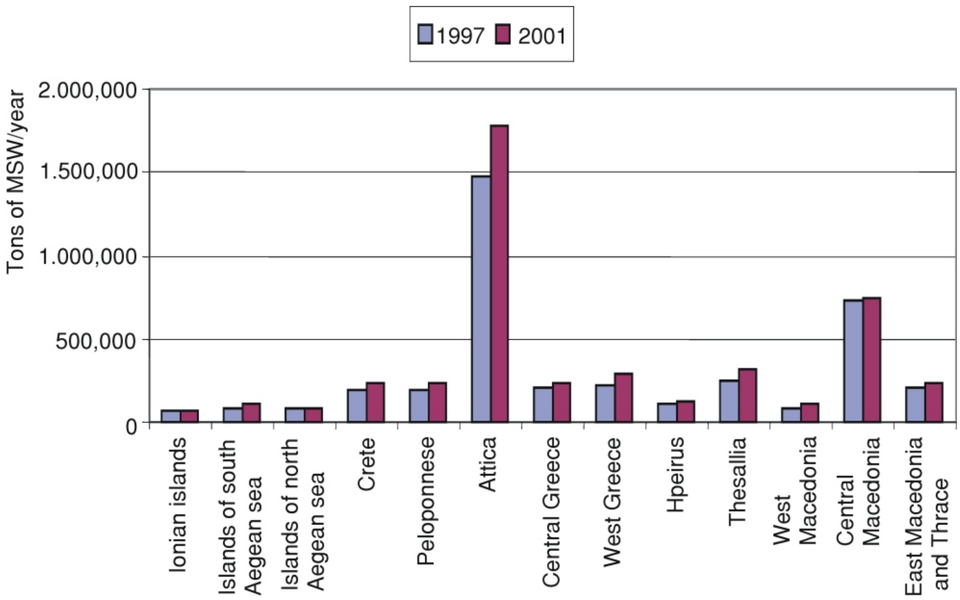

Figure 2. Geographical distribution of MSW production in Greece; Source: Ministry of Environment

biggest Greek cities, Athens and Thessaloniki (fig. 2). Taking also into consideration that no MSW incinerators or mechanical treatment units operate today in Greece, which could decrease the waste volume, then the waste management problems and the hazards for the public health become more intensive.

The composition of Greek waste, fig. 3, slightly differs from the European average. The organic fraction is higher and the moisture content lays up to 40% [5, 6]. The direct application of successful technological practicies from other European countries in Greece, without having studied the special demands of the region, is therefore not recomended. The direct waste incineration for example, although now allowed according to Greek legislation, should not be a favourable solution, due to the high moisture content of Greek waste. Otherwise, biological treatment processes, which have not been advantageous in northern European countries could be successfully applied in the Greek region, due to the high organic fraction of Greek waste. However, it is proven, that compost product, derived from mixed-unsorted waste has usually low quality and is contaminated with toxic compounds such as heavy metals. Source segregation should be therefore of prime importance. The amount of MSW collected at source in Greece is 5-10% of the whole produced MSW, whereas in other EU countries exceeds 20%. Through these actions the recovery of products, such as organic, paper, glass, and metalls directly from the households is possible. The higher logistic efforts will be balanced through the better qualities of input streams and accordingly the improved quality of recovered products – compost and SRF.

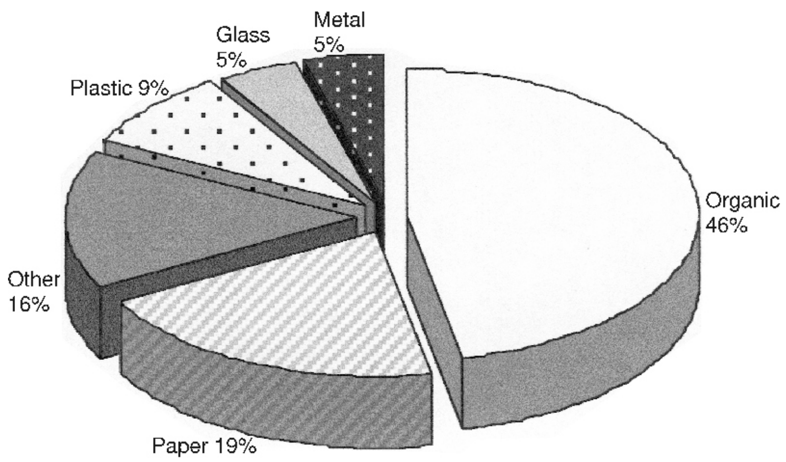

Figure 3. MSW composition in Greece; Source: National Plan for Solid Waste Treatment 2003

Necessary actions

Taking into account the current situation on waste management in Greece, it is of utmost importance to increase the source segregation until this becomes common practice in the most Greek households. The organic fraction, which is highest share in the Greek MSW should be separately collected. Furthermore, the need for waste recovery and volume decrease of waste disposed to landfills leads to two major options.

The first one is the direct waste incineration, where a drastic volume decrease and simultaneous power production is achieved. The low efficiency of this process is however expected in the Greek area, due to the high moisture content of MSW. Additionally, the public acceptance of this technology is not very high. The second one is the Mechanical and Biological Treatment, where a mass recovery primarily takes place. The output stream usually consists of compost and SRF. Possible advantage of this method is the improved quality of the products and the potential use of the produced streams in various industries, such as cement kilns and power plants for SRF and agricultural industries for compost. Considering that the main lignite deposits are concentrated in West Macedonia and Peloponnese, the utilization of SRF as substitute fuel in existing power plants should be explored.

The case of Attica

Attica is the most densely populated Greek region and faces various problems concerning waste treatment. The new Mechanical and Biological Treatment unit in Ano

Liosia runs under nowadays a test period. The daily quantities of input and output streams as well as an overall balance are shown in tabs. 1-3. The daily SRF production of the unit in Ano Liosia may be used as substitute fuel for the cement industry in the Attica region. It can be calculated that the combustion of 1 kg SRF replaces about 1 kg of solid fuel at minimum and that ca. 1 kg CO_2 emissions/kg SRF can be prevented [8].

Table 1. Input stream; Source (5)

Materials	Quantity [t/day]
MSW	1 200
Sewage sludge	300
Forest residues	130

Table 2. Output stream; Source (5)

Materials	Quantity [t/day]
Compost	300
SRF	340
Fe	35
Al	5
Waste	350
Water	500
Volatiles	100

Table 3. Overall balance of output materials; Source (5)

Materials	Percentage
Commercial products	47
Rejects to sanitary landfill	20
Process losses	33

The case of West Macedonia

The distinct of West Macedonia has planned and adapted an integrated solid waste management system, fig. 4. The total MSW of the region according to the plan is brought to a central position – optimised from the logistical point of view, where the mechanical treatment unit and the landfill are located. This site is close to the thermal power

Figure 4. Geographical position of the various MSW transfer stations and of the landfill site in West Macedonia

plant in Kardia. The landfill already operates in this area and the mechanical treatment unit is in the plan phase.

Table 4. Composition of products coming from the mechanical treatment unit

Final products	Amount [t/year]	Percentage
To be recycled	3,593	3.4
Ferrous metalls	2,727	2.6
Aluminum	358	0.3
Glass	509	0.5
SRF	19,571	18.5
Compost	22,896	21.6
Waste to landfill	28,730	27.1
Water and volatiles	31,057	29.3
Sum	105,848	100.0

According to the solid waste treatment plan the estimated quantity of annual MSW production is 106,000 tons. The SRF annual production is estimated to 19,500 tons. Taking into consideration that the mentioned SRF quantity will be produced very close to the power plant in Kardia region, the scenario of SRF co-combustion becomes realistic. It is calculated, that 2-3% of lignite can be substituted through SRF in one of the four units with nominal power production 300 MW. This action would not cause operational problems to the unit due to the low substitution rate. Furthermore 40,000 tons of lignite and about 20,000 of CO_2 can be saved per year. It is, thus, concluded that even a low substitution rate can bring high saving in lignite consumption, due to the high availability of these units.

The case of Peloponnese

Concerning Peloponnese region, MSW production is calculated to be 235,000 tons per year [9]. Assuming that in a future mechanical treatment unit the SRF production is equal with 20% of the input stream mass flow, the daily produced SRF quantity is estimated to be 100 tons. This quantity could also be used as substitute fuel in the thermal power station of Megalopolis, which is located in the area.

Demonstration of co-combustion tests at commercial scale

Introduction

First trails have taken place in the RWE Power's site at Weisweiler, which is located 50 km far from Cologne in the Rheinish brown coal area. The Weisweiler site consists of six units with total installed capacity some 2,060 MW_e. Two of these units, with 600 MW_e nominal capacity each, already utilise paper sludge for co-combustion (fig. 5).

The co-combustion tests are scheduled in two stages. First, a short one day pre-trail was prepared and conducted in July 2004. The pre-trail focussed mainly on fuel handling, conveying and feeding issues and should also give first indications about ignition, burnout, and changes in emission levels. The share of SRF to the overall thermal input started from 2% and was increased up to 8.5%, in order to detect possible restrictions even during test duration limited to some 24 hours. The main co-combustion trials are to be realized in 2005. The thermal share of SRF to the overall fuel mixture will be kept to the level of about 2%, which is the expected share in normal operation. The two 600 MW_e units were used in the co-firing campaign because they employ after-burning-grids, despite of the initial planning to apply the co-firing in one of the 150 MW_e units. As a result, the percentage of SRF in the fuel mixture could be decreased and operational problems would be avoided. In addition, the initially expected SRF quantity could be doubled, since lager units were used.

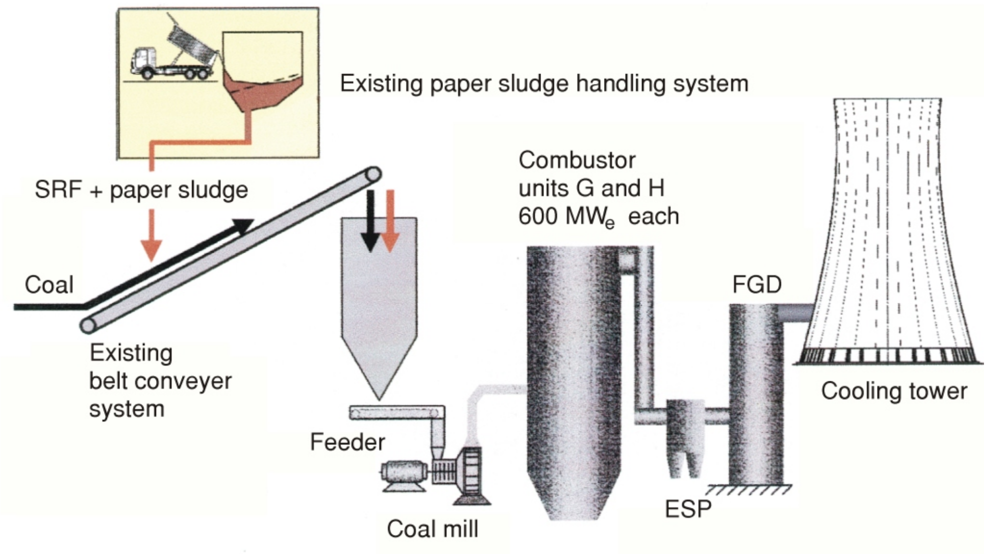

Figure 5. SRF/ paper sludge supply system to the boiler; Source: RWE Power

Data about SRF

The recovered fuel is produced by REMONDIS (coordinator of the RECOFUEL-projekct) and its lower heating value equals to 15.4 MJ/kg, which is about double compared to the one of Rheinish brown coal. Its production is based on positive sorting methods, where only a small amount, mainly paper fractions, biogen fibre material and some plastic – about 30% mass of the input stream of MSW – is sorted out and utilized. The material sorted out from MSW is called HCF and is afterwards treated (*i. e.* multistep particle size reduction, FE/NF-separation) with orther in order to meet special chemical and physical prescriptions of the power plant. Towards the distinction of different types of SRF REMONDIS developed the trade marks BPG® for SRF coming from industrial wastes (Brennstoff aus produktionsspezifischen Gewebeabfällen in German nomenclature) and SBS® (Substitutbrennstoff) coming from HCF's of MSW. The positive sorting methods guarantee the high quality of the produced SBS® in comparison with the traditional waste treatment methods, where the whole MSW input stream is utilized and low quality products are achieved at the end. It should be however also mentioned that about 50% of the MSW which is not utilized during positive sorting has to be incinerated.

Fuel and ash analyses of the Rheinish brown coal and SBS® are presented in tabs. 5 and 6, respectively.

Table 5. Proximate and ultimate analysis of the Rheinish brown coal in comparison with SBS® during the pre-trail in July 2004; Source: RWE Power and REMONDIS

Component	Units	Rheinish brown coal	SBS®
H_l	MJ/kg	8.15	15.4
Moisture	%	58.8	30.2
Ash	%	3	12.9
Cl	%	~0	0.21
Volatiles	%	55	54
C	%	24.8	33
H	%	2.2	5.9
O	%	10.6	18.5
N	%	0.4	0.5
S	%	0.2	0.2

Results of the pre-trails in July 2004

The tests were successful with no severe operational problems. Specifically, the unloading was successful due to the good weather conditions. In case of stronger winds a spreading of the fluffy SBS® material from the transportation trucks to the area might occur and, therefore, the construction of a windshield could be necessary. The SBS® transportation from the unloading area to the coal bunkers and afterwards to the boilers happens through the conveyor belts together with brown coal. Some stainings of SBS® in parts of the transportation system were observed, due to low density of SBS® (0.1 kg/l loose on the belt, 0.25 kg/l compressed). During the tests, a small increase of the power production was observed due to the increased heating value of the fuel mixture, while no changes in the flue gas emissions was observed. The amount of unburnt SBS® in the wet bottom ash was neglectable. After the pre-trail some aluminum deposits were observed on the second row of pre-beater arms in the coal mills which were obviously case by the metal aluminum available in the SBS®.

Concerning combustion behaviour, SBS® share was raised during the pre-trail up to 8.5% of the overall thermal input. Due to the higher heating value of SBS®, the performance of the beater mills (milling and drying) was improved and therefore the overall power production could be raised to some extend. Flue gas emissions remained were not

Table 6. Chemical analysis of ash samples of Rheinish brown coal and SBS® obtained from the pre-trails in July 2004 Source: RWE Power and REMONDIS

Component	Units	Rheinish brown coal	SBS®
Al_2O_3	%	5	45.9
CaO	%	35	20.8
Fe_2O_3	%	15	1.2
K_2O	%	1	1
MgO	%	16	1.5
Na_2O	%	5	2.7
P_2O_5	%	–	1.2
SiO_2	%	7	23
SO_3	%	16	0.9
TiO_2	%	–	1.6

effected. Small changes in NO_x and CO were not significant and could be attributed to differentiations in the brown coal quality and the beater mill operation.

When inspecting the beater mill after the pre-trail, some aluminum layer were found on the second row of the pre-beater arms, where the relative stream velocity is expected to be low. The depositions had a thickness of up to 3 cm and weigh up to 1.1 kg, figs. 6 (a) and (b). They have high mechanical hardness and constitute mainly of layers

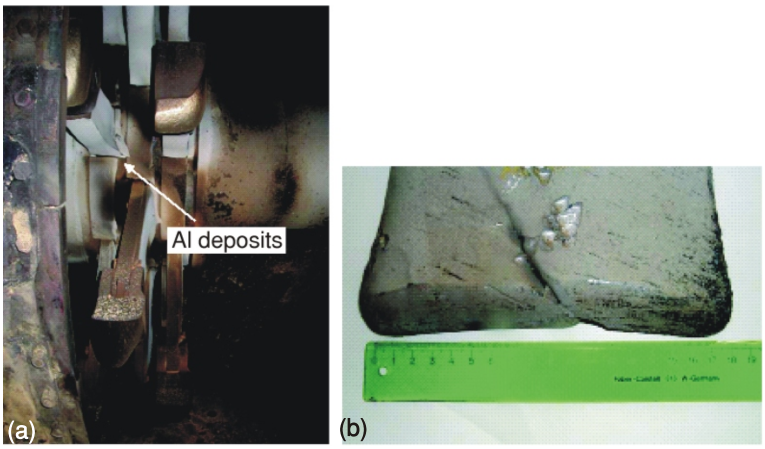

Figure 6. (a) aluminum deposits inside the beater mill; (b) aluminum deposit (weight 1.1 kg)

from metal aluminum and aluminum oxides. The reason of their appearance is the high content of metal aluminum in the SBS® of July 2004 and in the meantime these values have been reduced on an acceptable level. During SRF co-combustion tests in Vattenfall's power plant Jänschwalde [10] no similar affect on the mill was observed. The difference lays on the SRF quality, *i. e*. Al_2O_3 content in SRF in the Jänschwalde power plant was reported to be in the level of 10% while in Weisweiler is 40%. The reduction to less than 20% Al_2O_3 solved the problems in Weisweiler.

The second test campaign in March 2005

During these co-combustion trials, the corrosion phenomena in the boiler walls and the heat exchanger surfaces were further investigated. Fuel, ash and gypsum were sampled and analysed. Extensive mill balance and boiler performance measurements were undertaken. Two main measuring positions were determined and the first one was located at the end of the boilers radiative part, before the superheater surfaces. At this point, profile measurements (T_{gas}, O_2, CO_2, CO, NO_x, SO_2) as well as fly ash particle sampling were performed. The second position was in the flue gas path before the air preheater. Gas temperature and concentration was measured as well as HCl and fly ash according to isokinetic sampling method. The purpose of these measurements was to investigate the influence of SBS® in the combustion phenomena. Additionally, the extensive database from boiler measurements gives the opportunity for validation of CFD models. Extensive emission measurements and detailed analyses of the fuel, ash, and gypsum properties were also conducted. The overall results and conclusions of this extensive measurement campaign will be published in an international journal, as soon as the postprocessing analysis and evaluation of the whole data set is completed.

Conclusions

The perspective to use SRF as substitute fuel in brown coal power plants is still being investigated and has to be demonstrated in further trials. The current situation and the waste potential in Greece showed, that although the main MSW production is located in the two biggest urban centers, Athens and Thessaloniki, there is still the possibility of using SRF in plants of Macedonia and Peloponnese. Significant environmental benefits would be brought in that way, such as the savings of solid fuels and the avoidance of landfilling. In order to investigate the effects of SBS® co-combustion with brown-coal, a two week campaign is to be performed in a German power station. Results up to now show that SBS® co-combustion is a feasible and environmentally beneficial process, while all the environmental requirements (*e. g*. pollutants) are met. Finally, it is worth noting that future research efforts should deal with SRF standardization, which is a topic still under investigation.

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