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A comprehensive comparative assessment of energy recovery from MSW in “dedicated” and “non-dedicated” plants

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Summary

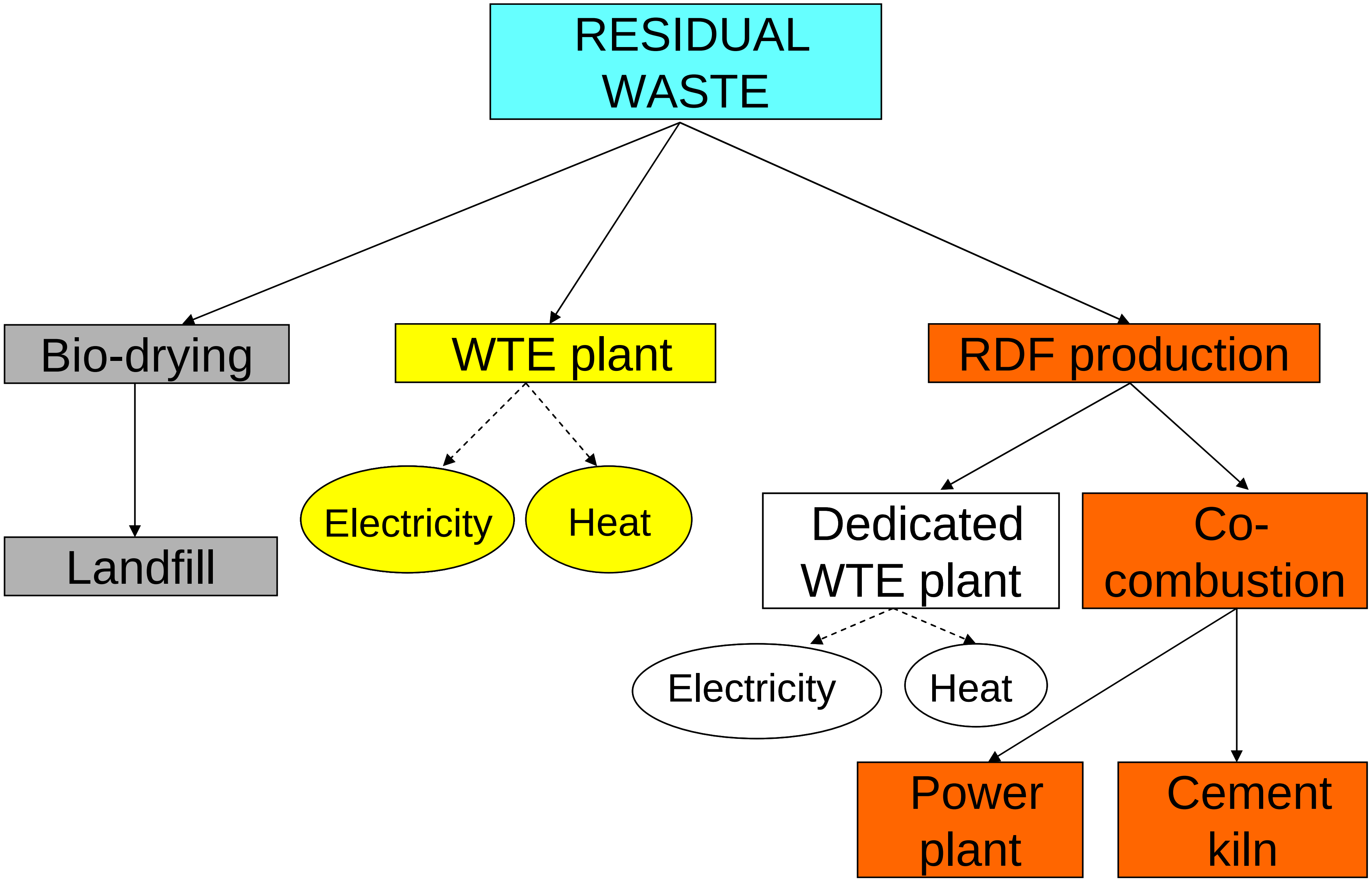
Disposal of MSW in Italy

1. Effort to reduce landfill use by enhancing material and energy recovery from waste
2. Material recovery has been given higher priority (although optimal role of material vs energy recovery has yet to be identified)
3. Energy recovery by combustion in WTE plants takes care of about 12% of Residual Waste (RW) production
4. Endorsement of energy recovery through the production of an intermediate energy carrier: Refuse Derived Fuel (CDR = Combustibile Derivato dai Rifiuti)
5. Recent years have witnessed an increasing production of RDF, even if only a fraction of it actually goes to energy recovery

Framework of this research

1. Since 2000, Federambiente (the federation of Italian municipal companies managing environmental services) has sponsored research at Politecnico di Milano to assess benefits and caveats of alternative strategies for energy recovery
2. First study on "dedicated" plants completed in 2002
3. This presentation illustrates the study on "non-dedicated" plants carried out in 2004-06
4. The study focuses on the co-combustion of RDF in large-scale power stations and cement kilns
5. Results based on relatively limited sets of experimental data. As such, they must be regarded as preliminary. Further data acquisitons being discussed with Federambiente and plant operators.

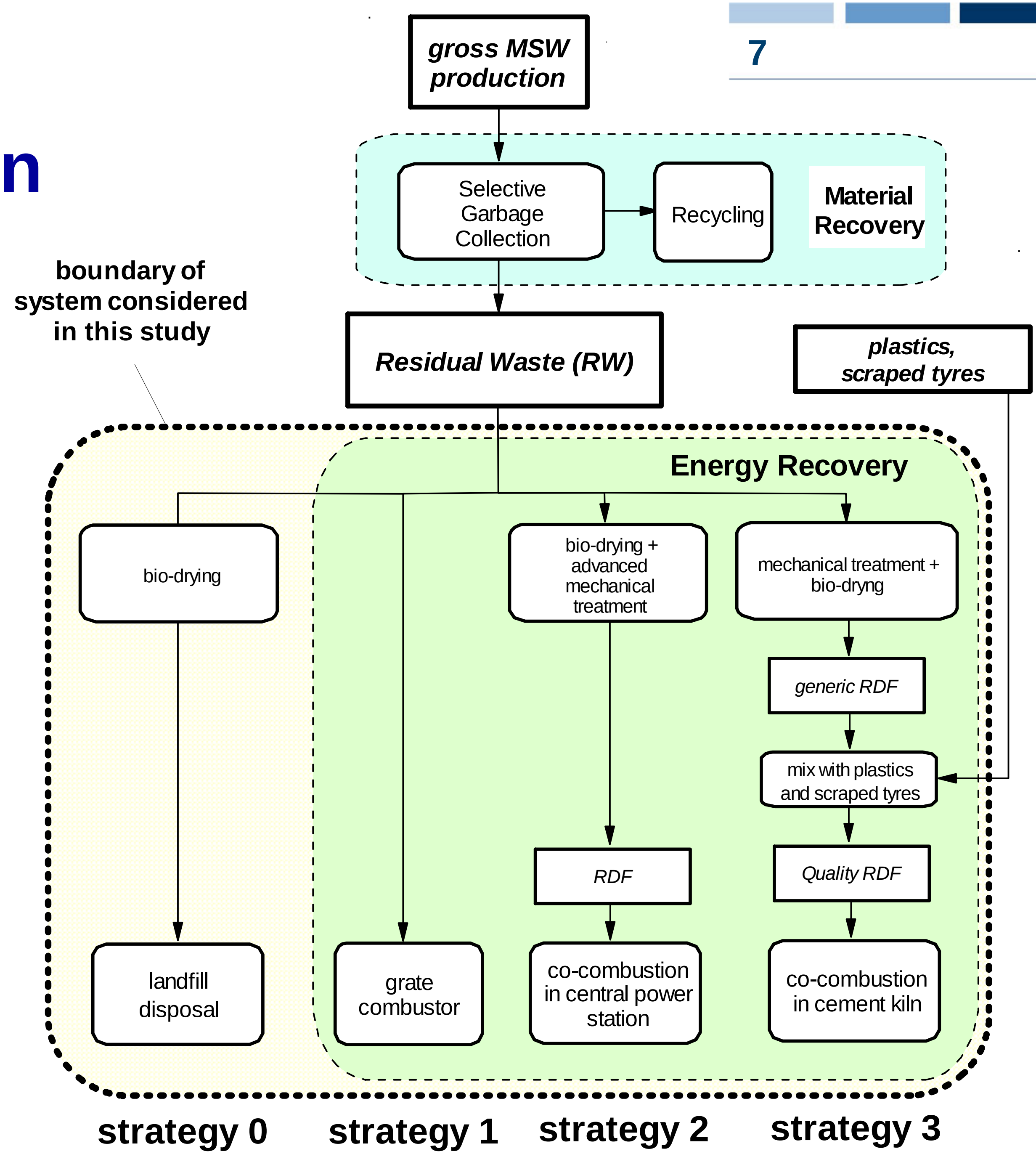
Systems of interest



Basic conclusions on RDF + dedicated plants

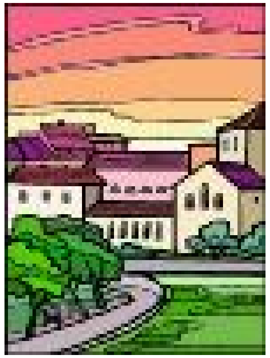
1. Producing RDF to subsequently use it in dedicated plants appears to offer no advantage over the "direct" use of Residual Waste in grate combustor WTE plants
2. Compared to "direct" energy recovery, strategies with {RDF+dedicated plants} reduce energy savings by 10-40%, reduce environmental indicators by up to 90% and increase costs by up to 80%.
3. The more sophisticated and complex is the process adopted to produce RDF, the higher the losses
4. Economies of scale give a very strong advantage to large Waste Management Systems
5. For dedicated plants, best option is large cogenerative WTE plant with "direct" feed of Residual Waste

Strategies considered in this study



Reference systems

MSW production

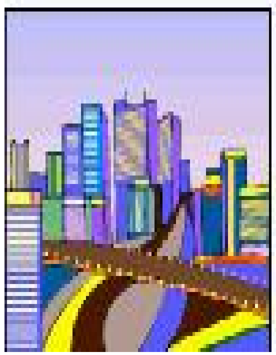


"SMALL"

200.000 people

100.000 t/yr gross

65.000 t/yr downstream of selective garbage collection



"LARGE"

1.200.000 people

600.000 t/yr gross

390.000 t/yr downstream of selective garbage collection

Scenarios for the evauation of avoided energy consumption and emissions

Scenario 1 Eletricity generated from WTE plant (or landfill gas) substitues electricity generated by a Steam Cycle (SC) fed with 50% nat. gas + 50% oil. Heat generated from WTE plant substitues heat generated by boiers fed with fuel oil

Scenario 2 Electricity generated from WTE plant (or landfill gas substitutes electricity generated by a Combined Cycle fed with nat. gas. Heat generated from WTE plant substitues heat generated by boilers fed with nat. gas

Scenario 3 Eletricity generated from WTE plant (or landfill gas) substitues electricity generated by a Steam Cycle (SC) fed with coal. Heat generated from WTE plant substitues heat generated by boiers fed with fuel oil

Specific technologies considered in this study

Bio-drying + landfill	Biodrying + disposal into landfill with electricity production from landfill gas by Otto engines
WTE plant	Grate combustor with integrated boiler and steam Rankine cycle. Electricity only or cogeneration
RDF production	Biodrying in closed cells + mechanical treatment. Exhaust air is combusted with nat. gas in a system with regenerative heat recovery
Energy recovery from RDF	Co-combustion with coal into the ENEL 320 MWel steam power station in Fusina (Venice) Co-combustion with pet-coke into the Buzzi Unicem cement kiln of Robilante (Cuneo)

Residual Waste (RW)

Composition of Residual Waste (RW) downstream of 35% by weight selective garbage collection

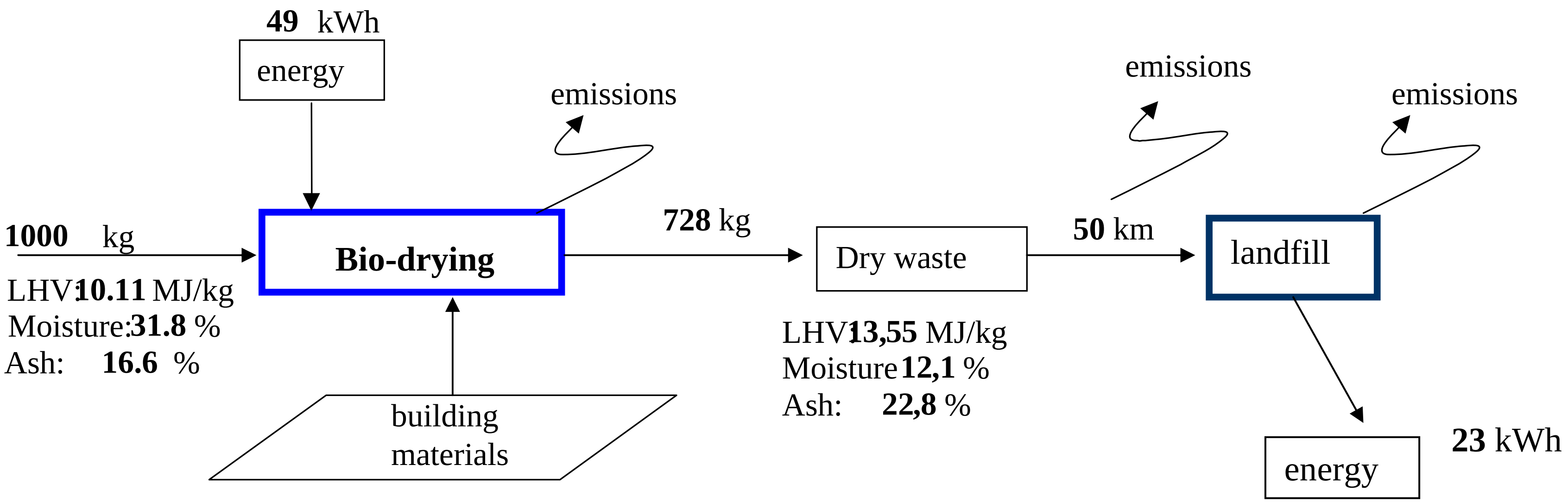
constituent	content in RW	composition: moisture	composition: ash	composition: volatile fraction	carbon content: total	carbon content: % renewable	LHV
	% by weight						MJ/kg
paper & cardboard	24.5	14.0	5.0	81.0	37.6	100	13.22
wood	6.0	22.0	1.5	76.5	37.6	100	13.87
plastic	19.0	6.0	9.0	85.0	55.5	0	26.18
glass & inert material	3.5	2.5	95.0	2.5	1.0	0	-0.061
metals	3.5	5.0	92.5	2.5	1.0	0	-0.122
organic fraction	31.5	70.0	9.0	21.0	9.6	100	1.719
fines	12.0	30.0	35.0	35.0	20.5	60	4.395
Residual Waste	**100**	**31.8**	**16.6**	**51.6**	**27.6**	**16.0**	**10.11**

volatile fraction % by weight of total	
C	27.6
Cl	0.64
H	3.49
O	19.7
N	0.15
S	0.06
Total	**51.6**

Values in table are representative of Northern Italy conditions

System configuration

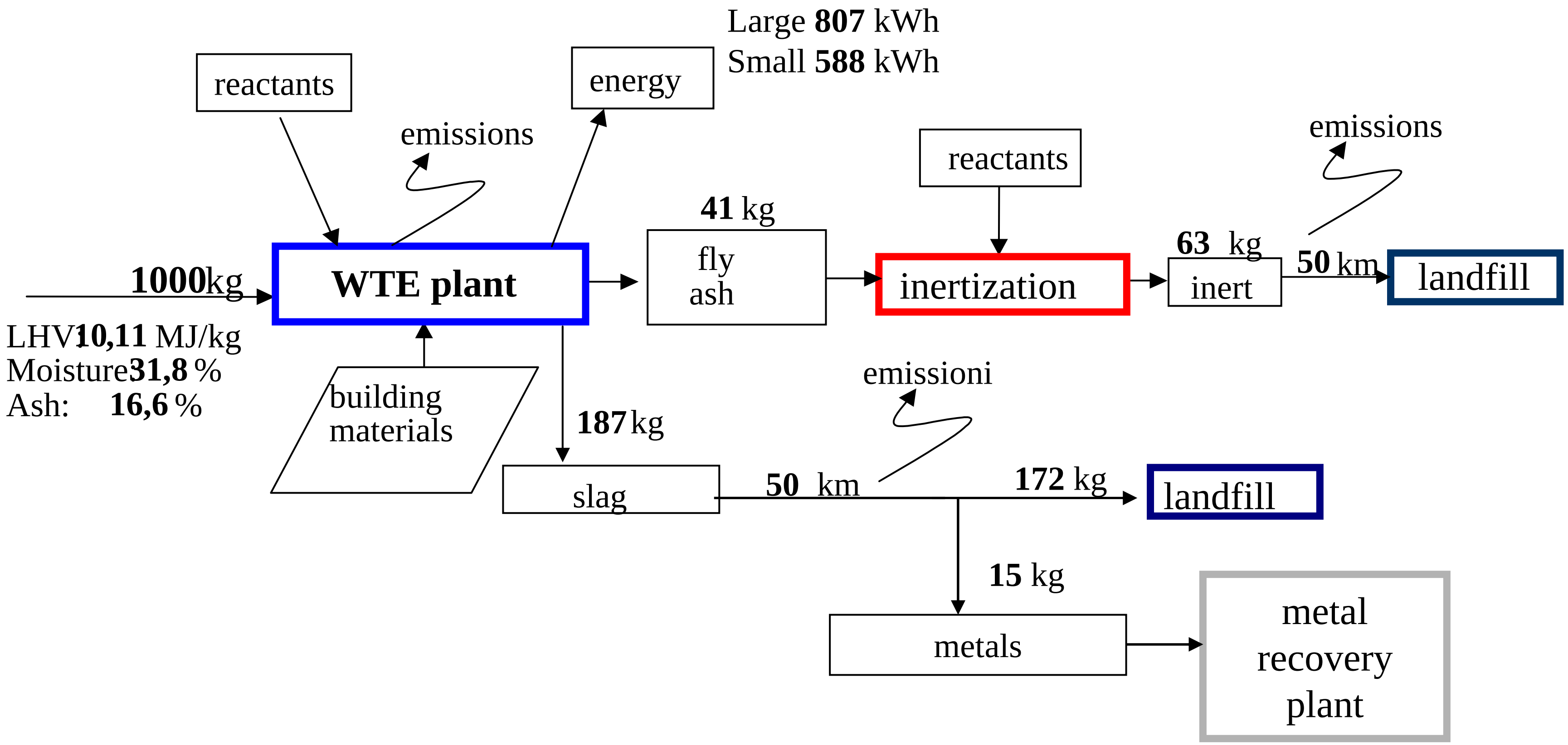
Strategy 0: bio-drying + landfill



– bio-drying carried out on the whole mass of Residual Waste (RW)
– biogas from landfill feeds internal combustion engines

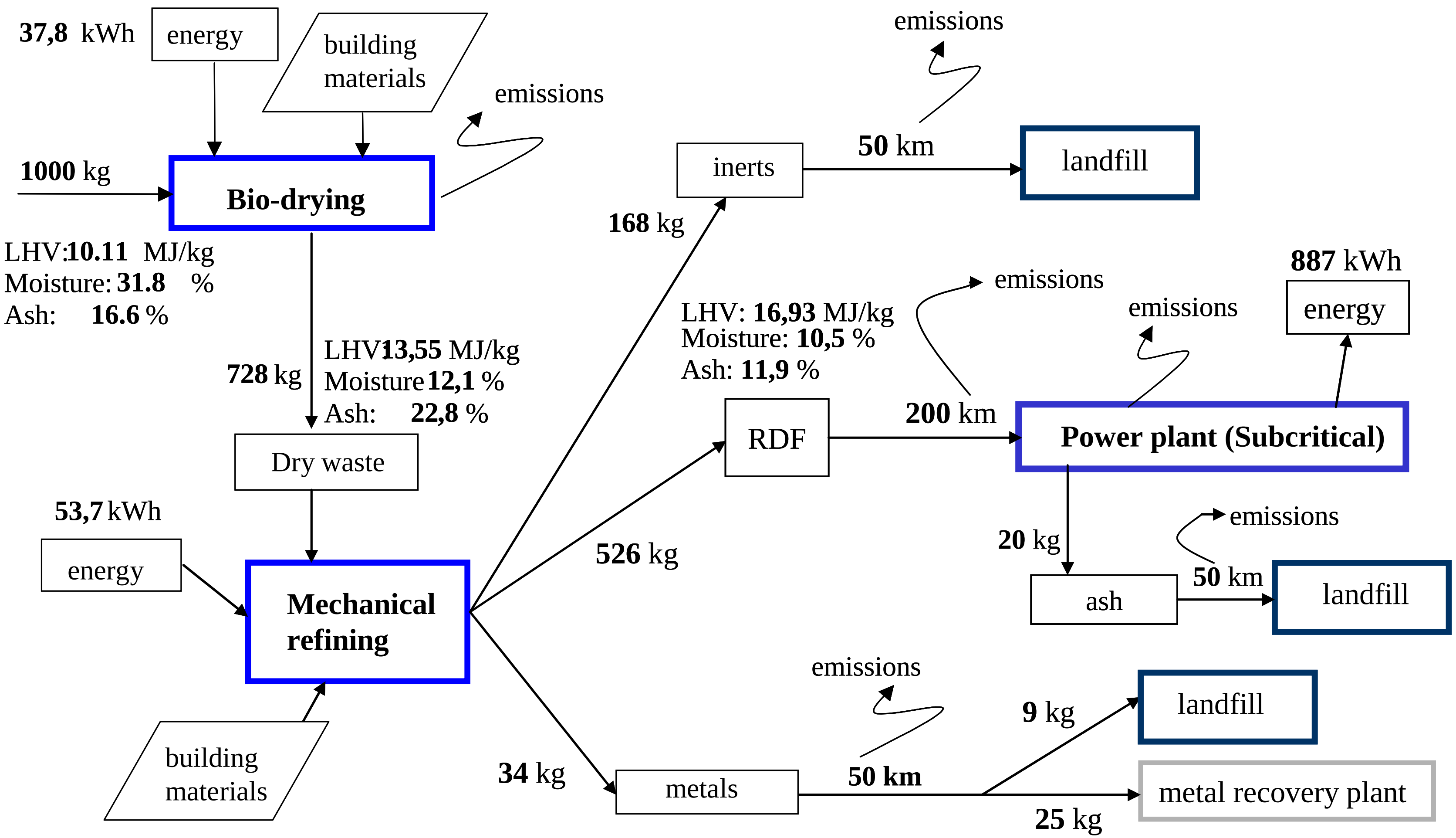
System configuration

Strategy 1: Residual Waste fed directly to a dedicated WTE plant with grate combustor



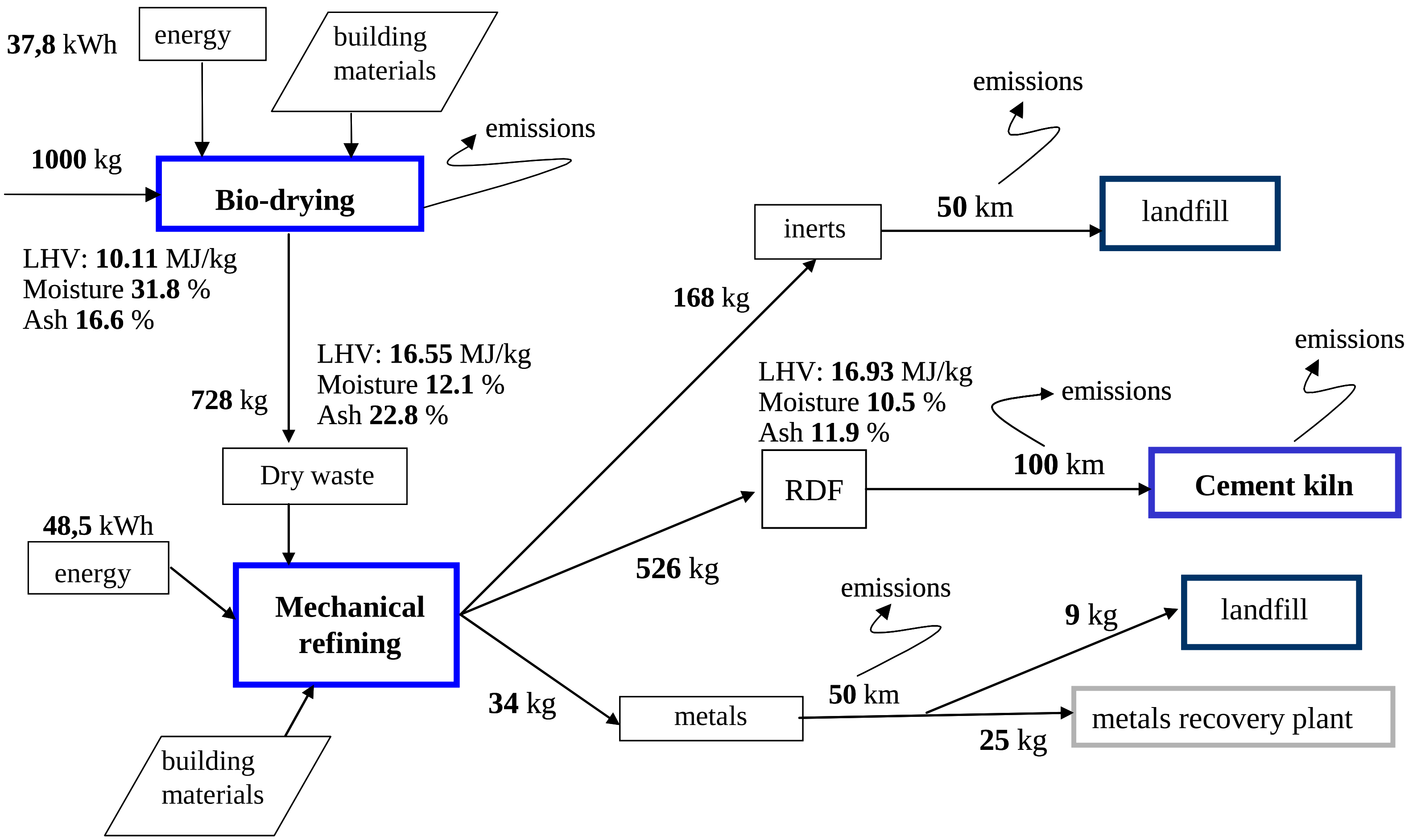
System configuration

Strategy 2: produce RDF and then feed it into a non-dedicated fossil-fuel-fired power station



System configuration

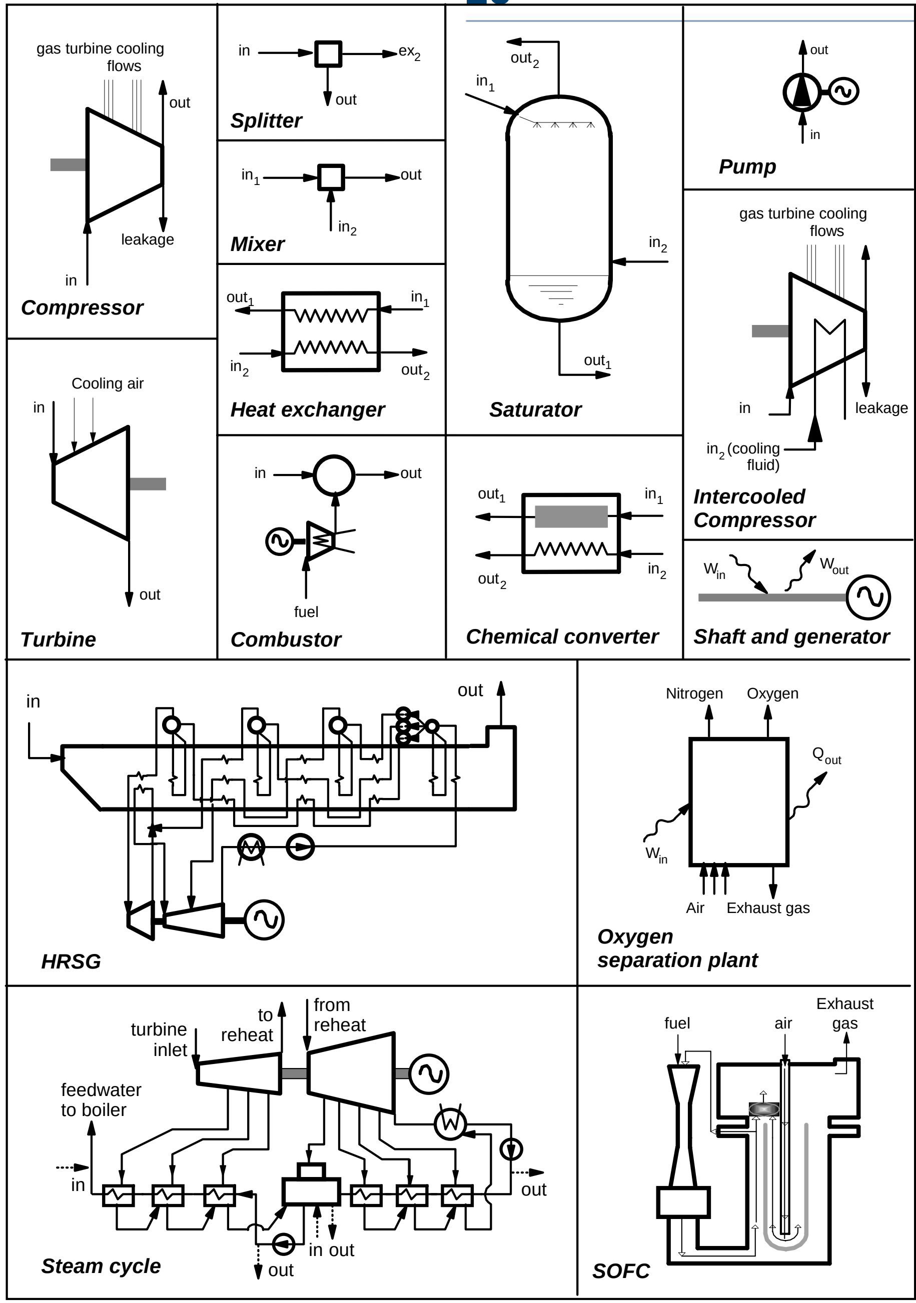
Strategy 3: produce RDF and then feed it into a <u>non-dedicated</u> cement kiln



Simulation of energy conversion processes

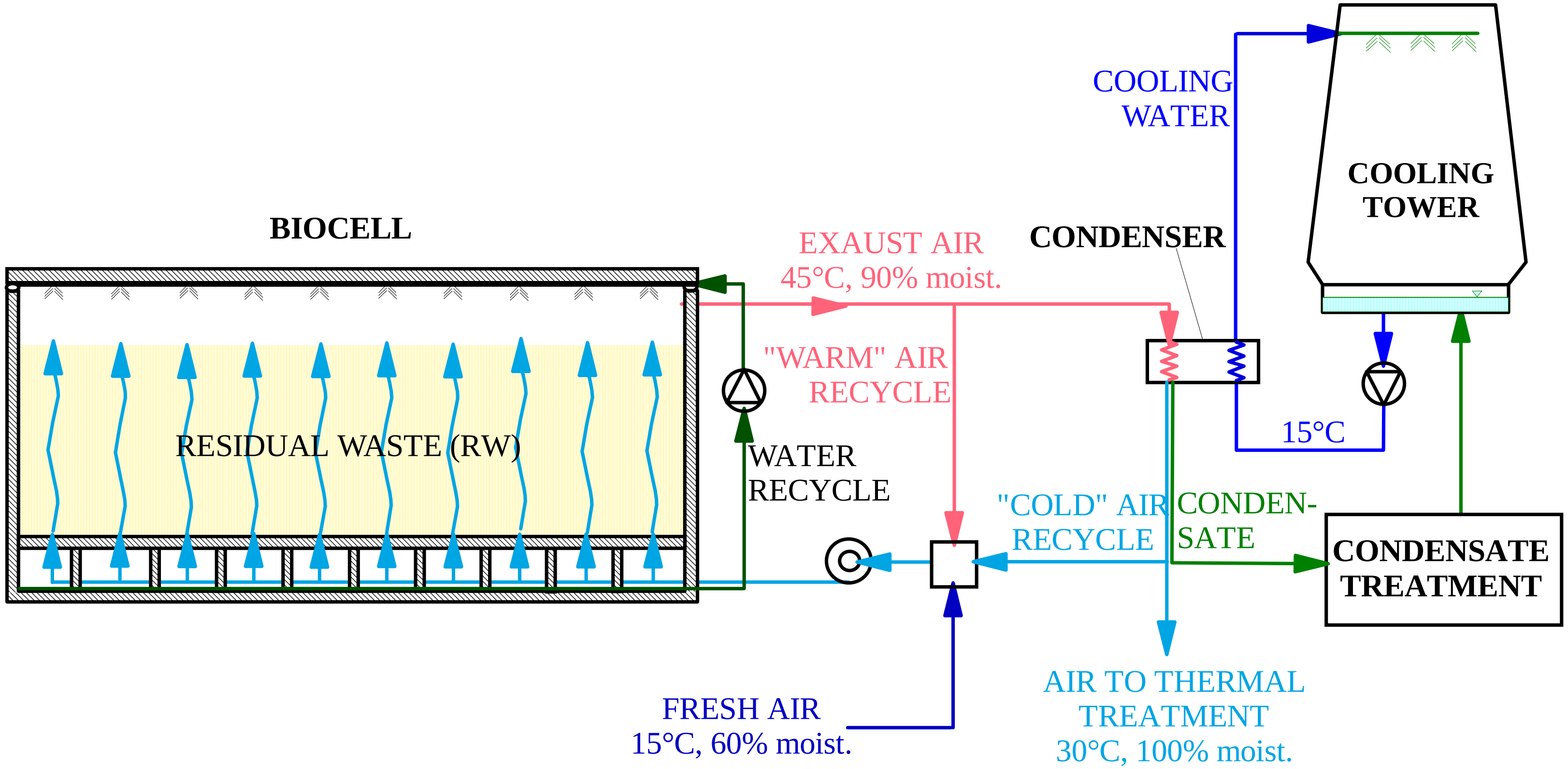
Energy and mass balances of bio-drying, WTE plants, steam plants operating in co-combustion been evaluated by a modular computer code developed at Politecnico di Milano.

System is defined as an ensemble of basic components, with characteristics and interconnections defined by user.



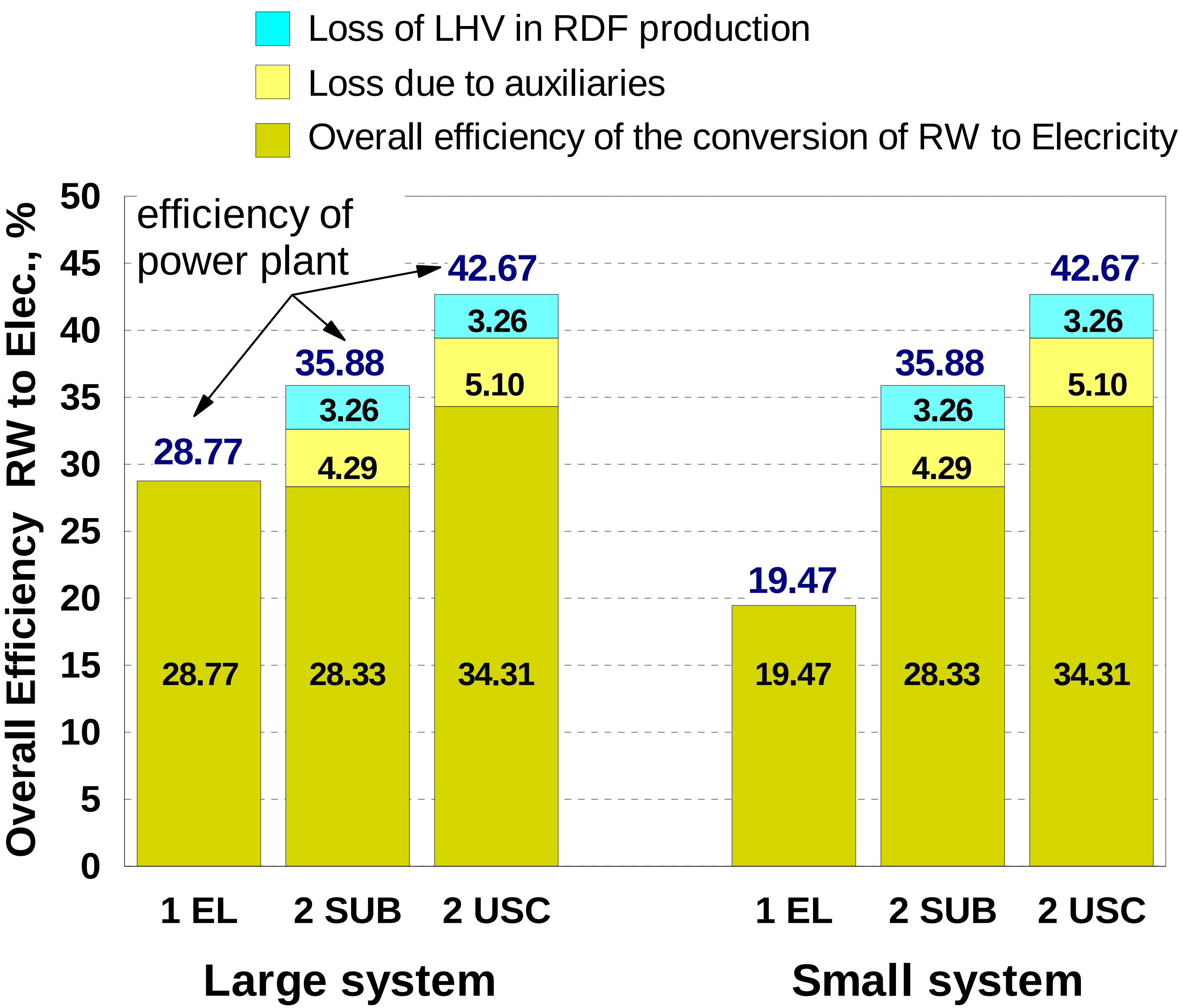
RDF production: bio-drying

equivalent (time-averaged) steady-state mass and energy balances carried out by code developed at Dept. of Energy Engineering



configuration similar to the one adopted in the Vesta plant (Venice)

Electricity production



1 EL = WTE plant fed with RW

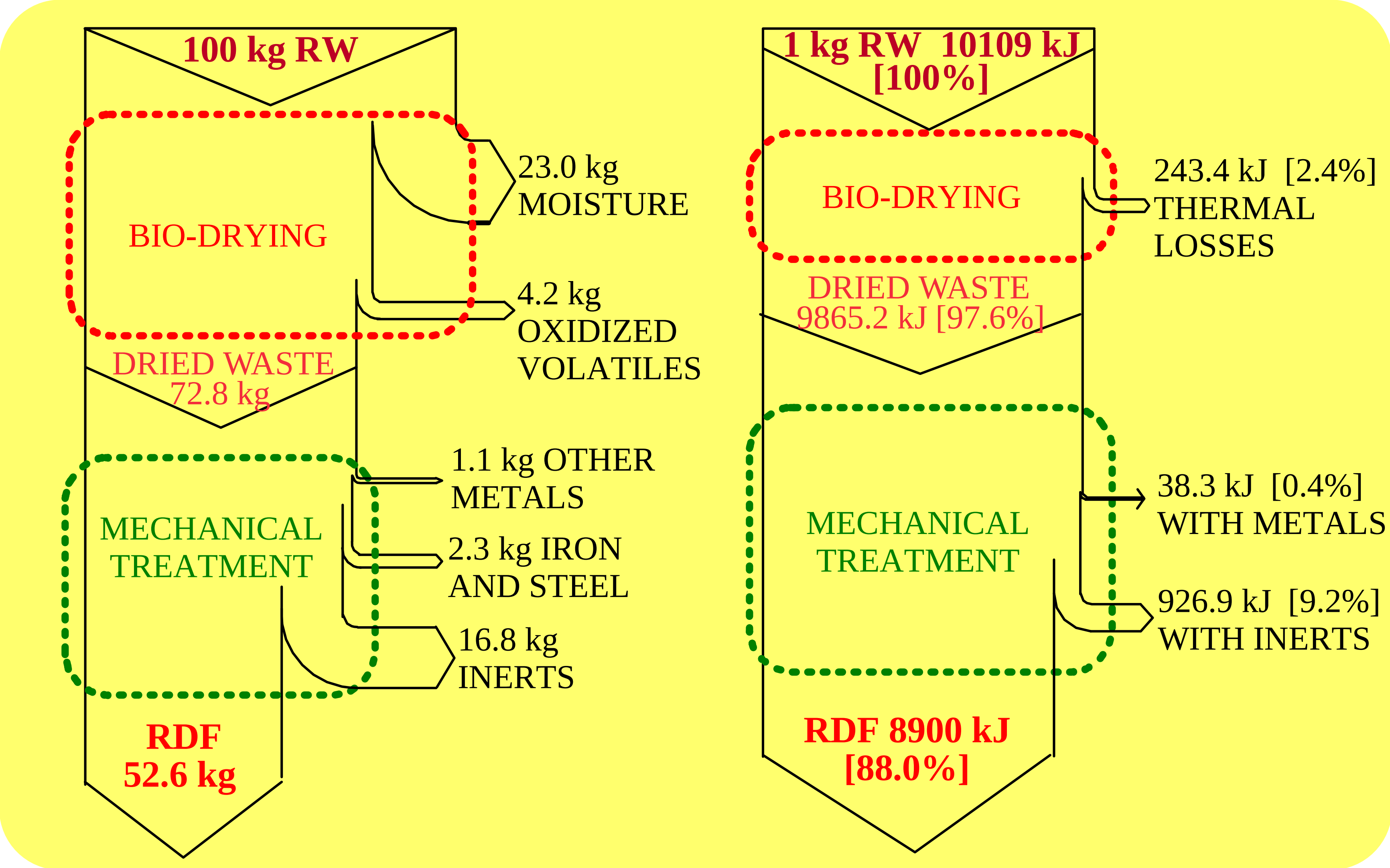
2 SUB = RDF fed to a subcrtical Steam Cycle

2 USC = RDF fed to a Ultra-super-critical Steam Cycle

Balances of RDF production

Mass

Energy (LHV)



Estimate overall balances

1. Account for all energy losses, auxiliary power consumption and emissions between the delivery of Residual Waste to the disposal of inert materials in landfill
2. Account for fuel consumption and emissions from transport
3. Account for avoided fuel consumption and emissions of electricity and/or heat production
4. Convert all energy consumptions (or savings) to Tons of Oil Equivalent (TOE)
5. Convert all relevant emissions to the same unit adopted to quantify each impact indicator (kg of CO_2 equivalent for GWP, kg of SO_2 equivalent for the Acidity Potential, etc.)

Overall energy balance

Primary energy savings

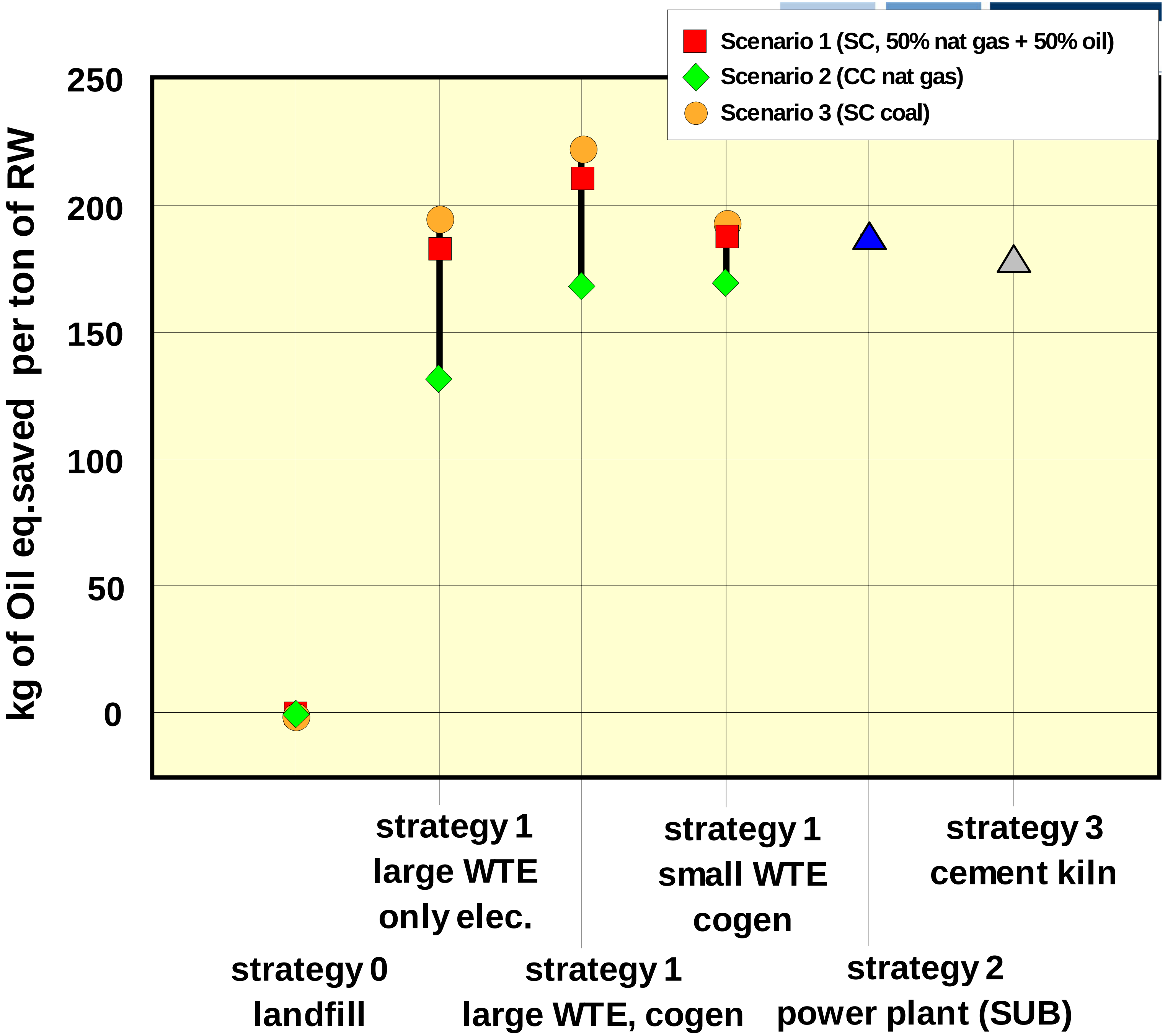
	kg of oil equivalent saved per ton of Residual Waste (RW)					
	STRATEGY 1			STRATEGY 2		STRATEGY 3
	Large system		Small system	SUBcritical steam plant	USC plant	Cement kiln
Cogeneration	No	Yes (30%)	Yes (60%)	-	-	-
Scenario 1	183	211	188	187	187	178
Scenario 2	132	168	169			
Scenario 3	195	222	193			

Scenario 1: dedicated plants substitute steam plants fed with 50% nat. gas and 50% oil, as well as domestic boilers fed with fuel oil

Scenario 2 dedicated plants substitute combined cycle plants fed with nat. gas, as well as domestic boilers fed with nat. gas.

Scenario 3: dedicated plants substitute coal-fired plants, as well as domestic boilers fed with fuel oil

Primary energy savings



Environmental Impact Indicators

The environmental balance has been carried out by a LCA approach, taking into consideration all direct and indirect atmospheric emissions.

LCA was based on the CML Guidelines. The SimaPro5® commercial software was utilised for the final calculations of the emission inventory and of the four major impact indicators:

- **Global Warming Potential (GWP – kgCO_2 eq.)**
- **Human Toxicity Potential (HTTP – kg 1,4-DCB eq.)**
- **Acidification Potential (AP – kgSO_2 eq.)**
- **Photochemical Ozone Formation Potential (POFP – kgC_2H_4 eq.)**

Assign emissions to impact categories

Emission	Greehouse effect (GWP)	Human Toxicity (HTP)	Photochemical Ozone Depletion (PODP)	Acidification (AP)
CO_2 (fossil)	X			
SO_x (as SO_2)				X
COV NM			X	
CH_4	X		X	
NO_x (as NO_2)		X	X	X
propane, butane, eptane			X	
formaldheid			X	
benzene		X	X	
toluene			X	
IPA		X		
heavy metals		X		
dioxins (I-TEQ)		X		
ethilene			X	
HF		X		
NH_3		X		X
HCl		X		
N_2O	X			
CO			X	

Data collection: a word of caution

A wide array of estalished a data is available for dedicated plants, continuously updated based on the experience being gained in hundreds of plants operating all over the world.

Data for non-dedicated plants are scarce and difficult to get, even more for the comparison fossil fuel feed vs co-combustion feed

In this study we have referred to:

→ Experimental emission data taken from ARPAV (“EPA” of Veneto, the region of Venice) for the Fusina power plant.

→ A single experimental data set for the emissions of the cement kiln of Robilante (Cuneo) fed with Pirelli Ambiente RDF

No reliable experimental data on the energy balance were available

It follows that:

- results and indications of this study must be regard as **preliminary**
- **more experimental data are needed** to support the conclusions presented here

Emissions from WTE plant

Emission		Strategy 1 2002 study	Strategy 1 this study	Italian law 133/05
NH_3	$mg\ m_n^{-3}$	2	3,9	
CO		10	10	50
Total dust		2	0,32	10
HCl		7	2	10
HF		0,7	0,05	1
N_2O		14	14	
VOC		3,3	3	
NO_x		140	70	200
SO_x		8	2	50
As	$\mu g\ m_n^{-3}$	0,06	0,04	
Cd		10	0,015	50 (1)
Hg		10	0,425	50
Pb		99,5	0,5	
PAH		0,05	0,0025	100
Dioxin	$ngI\text{-}TEQ\ m_n^{-3}$	0,05	0,01	0,1 (2)
Sum of Pb, Cu, Cr, Co, As, Sb, Mn, Ni, V	$mg\ m_n^{-3}$	0,161	0,001	0,5

(1) sum of Cd and Tl

(2) 8 h sampling

Emissions from coal-fired power station

Emission		type of operation: coal-fired	type of operation: co-combustion	difference
Total dust	$mg\ m_n^{-3}$	9,1	2,9	-6,2
HCl		1,3	2,3	1,0
HF		4,3	4,9	0,6
NH_3		0,002	0,13	0,128
TOC		0,05	0,2	0,15
Sb		0,002	0,001	-0,001
As		0,002	0,001	-0,001
Cd		0,0005	0,0005	0
Co		0,002	0,0005	-0,0015
Cr		0,005	0,0005	-0,0045
Mn		0,027	0,008	-0,019
Hg		0,0006	0,003	0,0024
Ni		0,008	0,001	-0,007
Pb		0,004	0,001	-0,003
Cu		0,005	0,001	-0,004
Sn		0,003	0,001	-0,002
Tl		0,001	0,001	0
V		0,006	0,002	-0,004
Zn		0,037	0,006	-0,031
Dioxin (I-TEQ)	$pg\ m_n^{-3}$	0,18	4,23	4,05
PCB	$ng\ m_n^{-3}$	0,348	0,302	-0,046
PAH		217	965	748
CO	$mg\ m_n^{-3}$	22,8	18,2	-4,6
SO_x (as SO_2)		217	258	41
NO_x (as NO_2)		194	180	-14

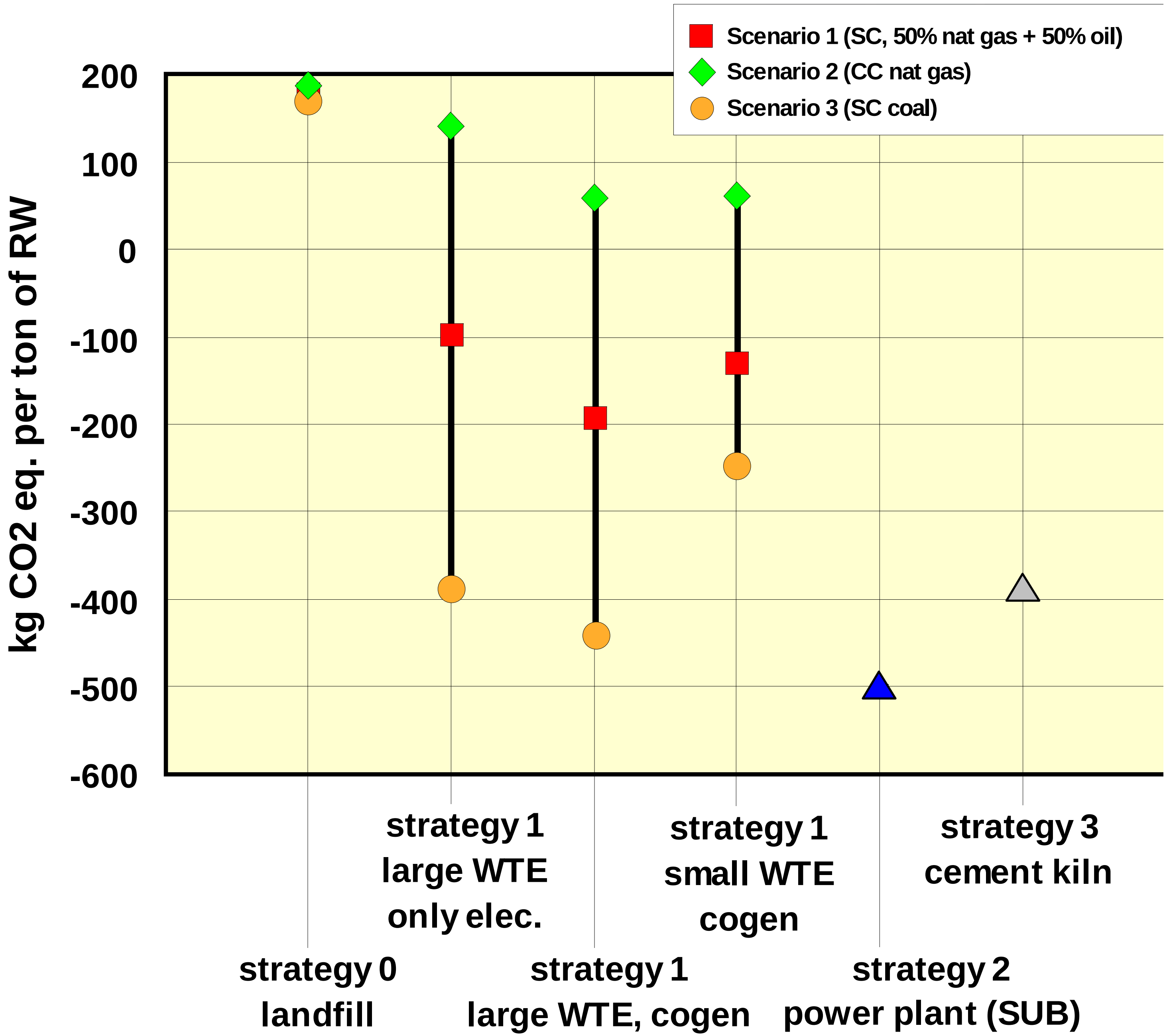
Emissions from cement kiln

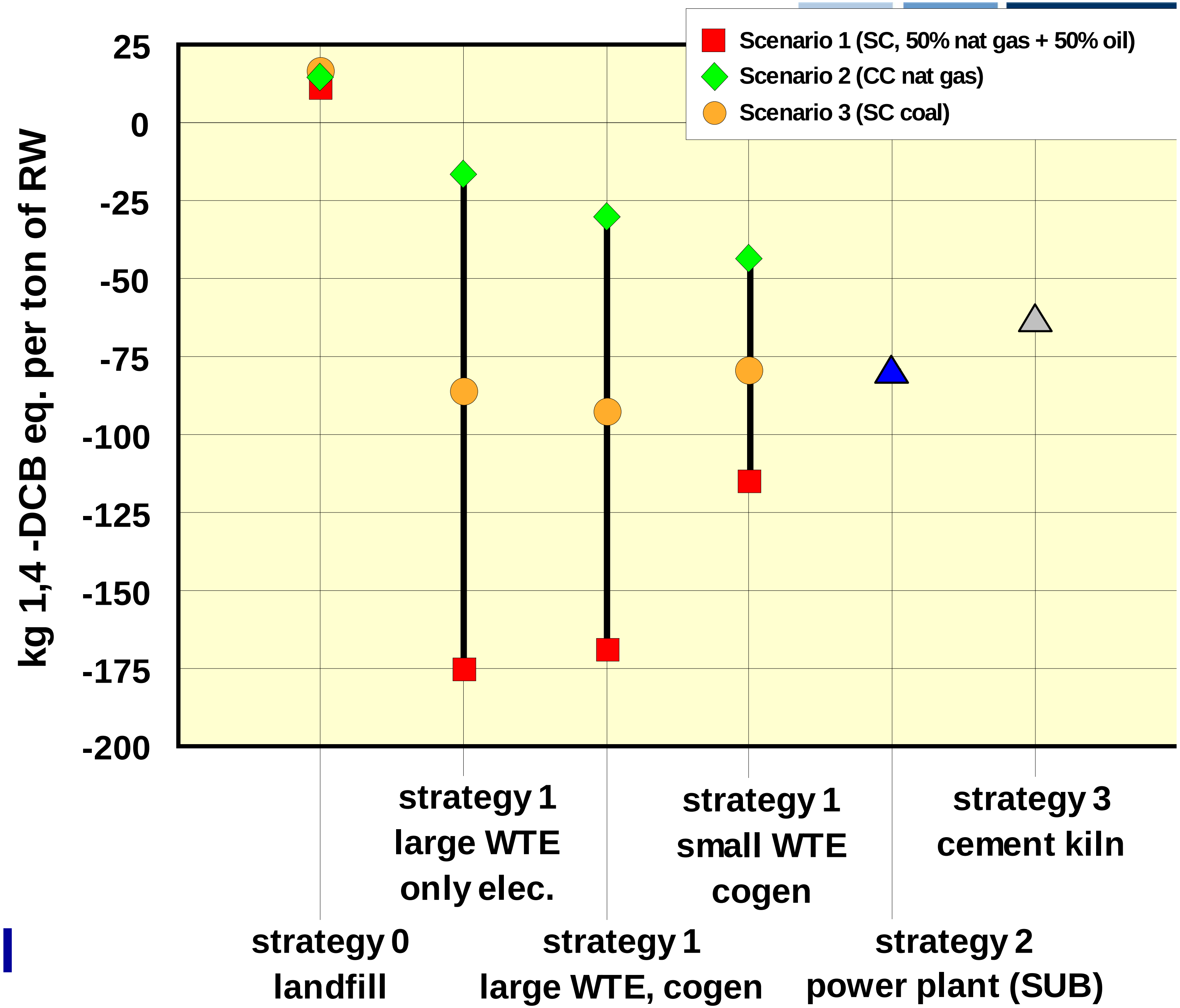
Emission		type of operation: coal-fired	type of operation: co-combustion	difference
NO_x (as NO_2)	$mg\ m_n^{-3}$	1015	786	-229
SO_x (as SO_2)		16,5	12,8	-3,7
Total dust		6	6	0
CO		267	239	-28
TOC		5	5	0
HCl		0,61	0,61	0
NH_3		n.d.	1,33	-
Dioxin (I-TEQ)	$pg\ m_n^{-3}$	11,2	8,2	-3
HF	$\mu g\ m_n^{-3}$	5,38	100	94,62
Cd		0,05	2,43	2,38
Hg		0,83	4,42	3,59
Pb		11,8	9	-2,8
Sb		2,74	32,8	30,06
As		2,91	0,07	-2,84
Co		0,04	3,26	3,22
Cr		1,58	0,07	-1,51
Mn		0,94	4,46	3,52
Ni		0,05	0,73	0,68
Cu		10,7	0,07	-10,63
V		0,83	0,07	-0,76
Zn		131,6	42,7	-88,9
Sn		3,65	10,4	6,75
Tl		0,48	1,2	0,72
PAH	$ng\ m_n^{-3}$	46,2	53,8	7,6

Emissions from bio-drying

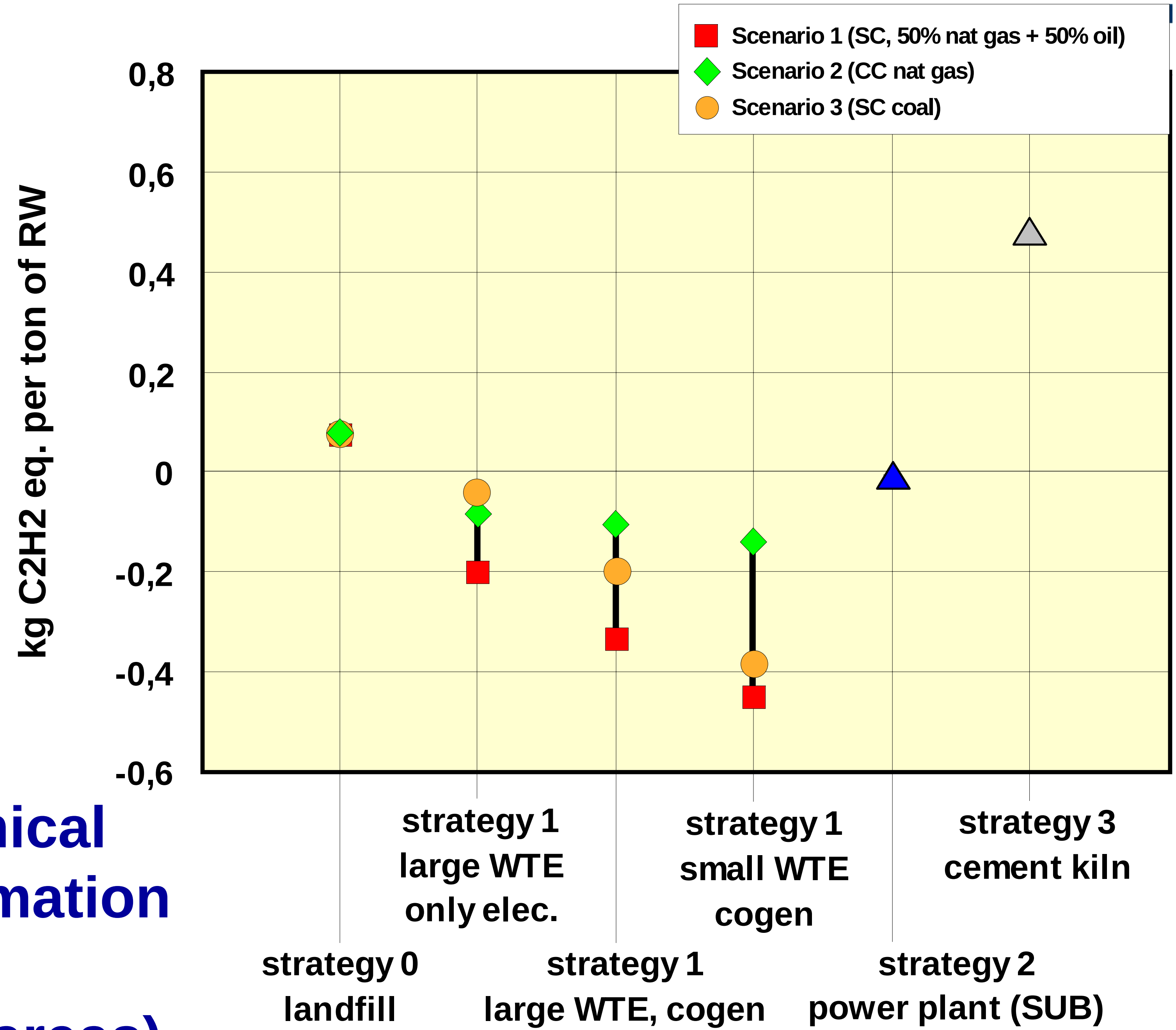
Pollutant		Emission factors	
		strategy 0	strategies 2 and 3
CO_2 (fossil)	kg t_{RUR}^{-1}	0	19,6
CO	g t_{RUR}^{-1}	8,3	13,8
NO_x (as NO_2)	g t_{RUR}^{-1}	0	46,45
SO_x (as SO_2)	g t_{RUR}^{-1}	1,2	0,14
NMVOC	g t_{RUR}^{-1}	50	6,81
NH_3	g t_{RUR}^{-1}	17	6,3
HCl	g t_{RUR}^{-1}	2	2
HF	mg t_{RUR}^{-1}	200	200
H_2SO_4	mg t_{RUR}^{-1}	460	0
Benzene	mg t_{RUR}^{-1}	200	0
Cd	mg t_{RUR}^{-1}	25	25
Hg	mg t_{RUR}^{-1}	125	125
Pb	mg t_{RUR}^{-1}	125	125
Mn	mg t_{RUR}^{-1}	5	5
Ni	mg t_{RUR}^{-1}	25	25
Cu	mg t_{RUR}^{-1}	5	5
Zn	mg t_{RUR}^{-1}	75	75
Dioxin (I-TEQ)	ng t_{RUR}^{-1}	1	5,05
PAH	ng t_{RUR}^{-1}	20	0
Mercaptans	g t_{RUR}^{-1}	0	0,09
H_2S	g t_{RUR}^{-1}	0	0,13
PM_{10}	g t_{RUR}^{-1}	0	1,53
Total dust	g t_{RUR}^{-1}	0	1,53
CO_2 (not fossil)	kg t_{RUR}^{-1}	82,6	82,6

Global Warming Potential



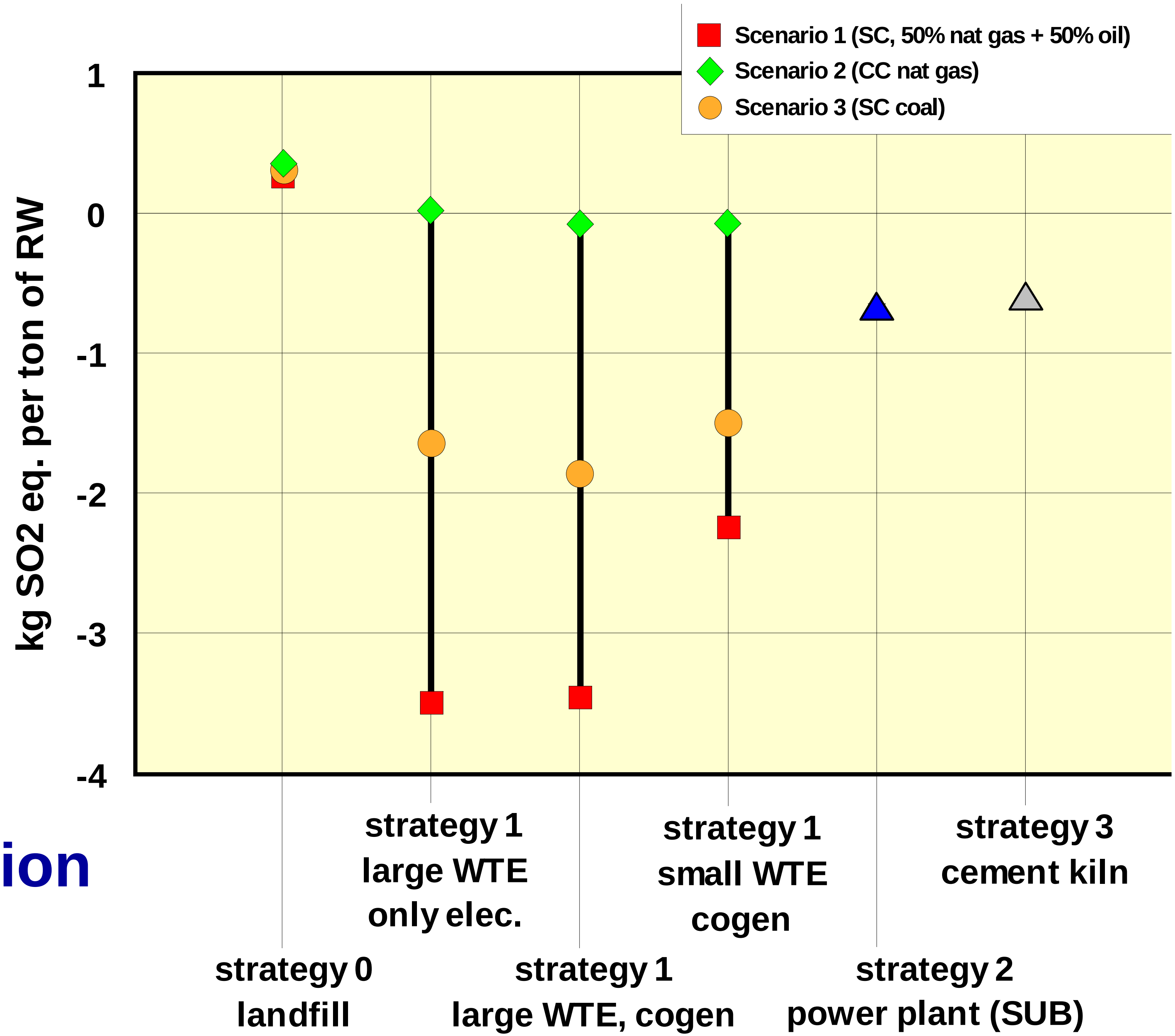


Human Toxicity Potential

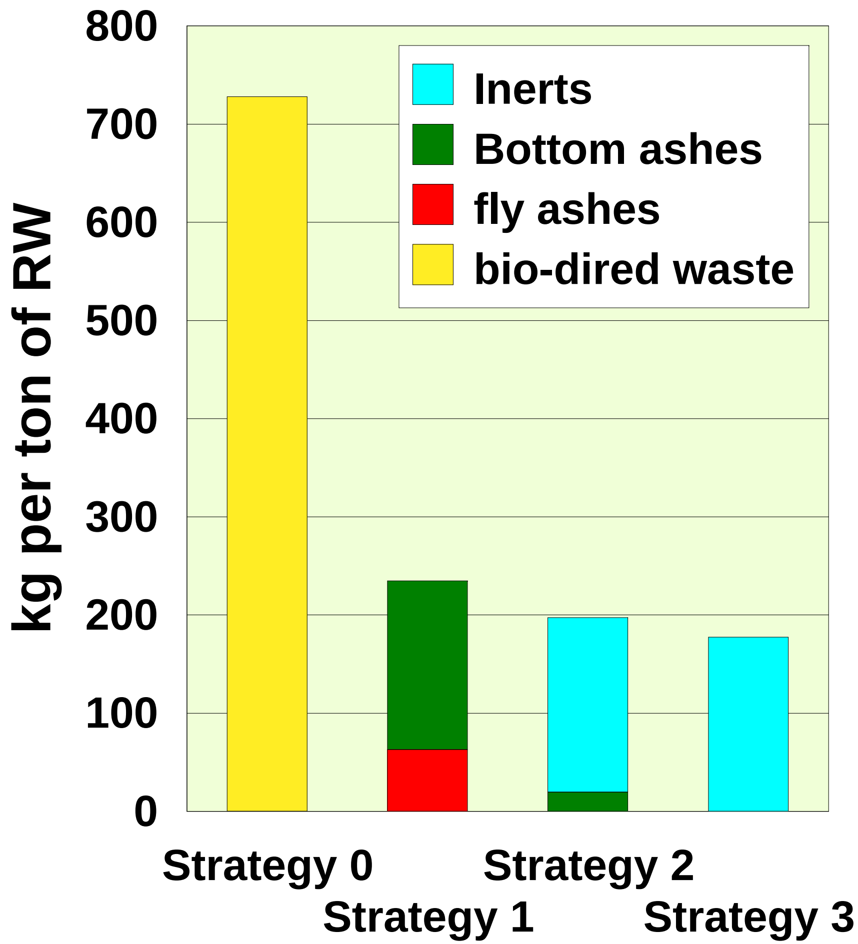


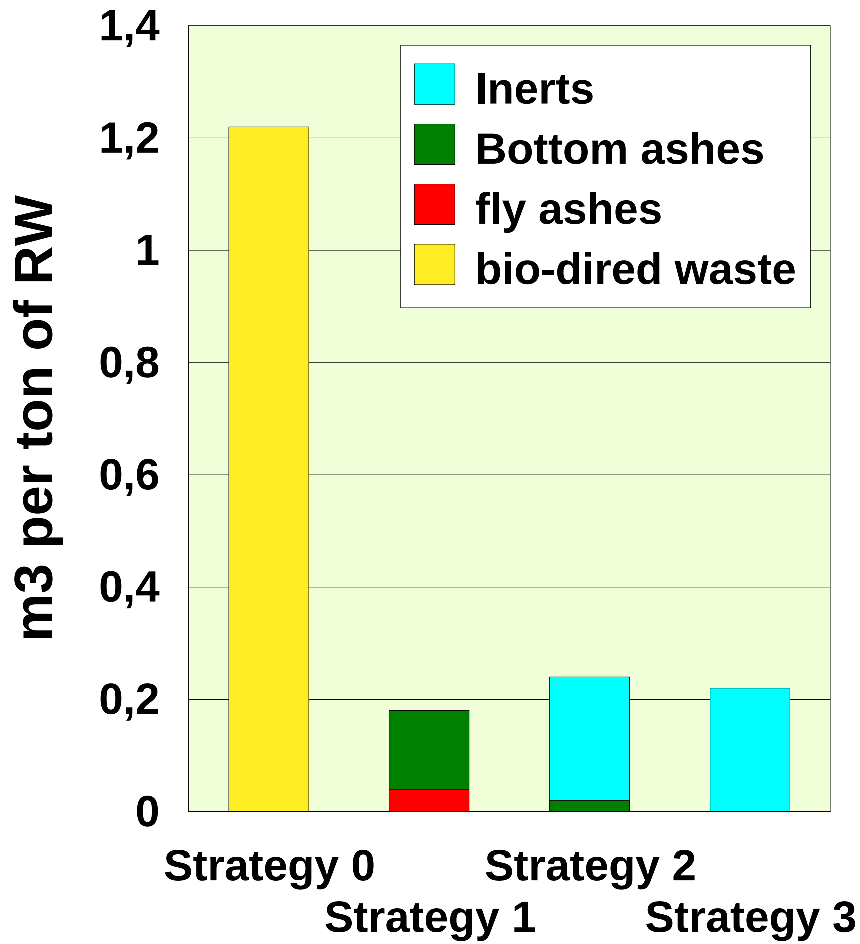
Photochemical Ozone Formation Potential (high-NOx areas)

Acidification Potential



Solid residues to landfill





Potential of co-combustion in power stations (Strategy 2)

Summary of coal-fired power stations in Italy

Plant	Company	Total gross power [MW] 2004	2008
Fusina (VE)	Enel	975	975
Porto Marghera (VE)	Enel	140	140
La Spezia (SP)	Enel	600	600
Brindisi Sud (BR)	Enel	2640	2640
Sulcis (CA)	Enel	240	240
Sulcis letto fluido (CA)	Enel	0	340
Monfalcone (GO)	Endesa	335	335
Fiume Santo (SS)	Endesa	640	640
Vado Ligure (SV)	Interpower	640	640
Brindisi Nord (BR)	Edipower	1280	960
Torrevaldaliga Nord (RM)	Enel	0	1980
TOTAL		**7490**	**7510 (*)**
(*) Does not include the USC plant of Torvaldaliga, which due to its advanced characerisics is unlikely to operate with RDF			

For co-combustion, assume that 5-10% of heat input is provided by RDF

Potential of the options analyzed in this study in the Italian context

	Amount of RW or RDF treated with energy recovery	Corresponding amount of Residual Waste (RW)		Inert residues to landfill
	$t \cdot y^{-1}$	$t \cdot y^{-1}$	% of Italian production	$t \cdot y^{-1}$
Strategy 1, large	11,000,000 (1)	11.000.000	57	2.600.000
Strategy 1, small	7,500,000 (2)	7.500.000	39	1.800.000
Strategy 2 (power plant)	1,600,000 - 3,200,000 (3)	3,050,000 - 6,100,000	15 - 31	600,000 - 1,200,000
Strategy 3 (cement kiln)	350,000 - 700,000 (4)	670,000 - 1,330,000	3.3 - 6.7	120,000 - 240,000

(1) RW of the provinces with a gross MSW production larger than 300,000 t y^{-1}

(2) RW of the provinces with a gross MSW production between 100,000 and 300,000 t y^{-1}

(3) Assuming that all coal-fired subcritical plants run in co-combustion, with 5% to 10% of the heat input provided by RDF. This requires that all such subcritical plants will be equipped with adequate flue gas treatment: at least ElectroStatic Precipitator (ESP) + catalytic deNOx (SCR) + Flue Gas Desulfurization (FGD)

(4) Assuming that 60% of the cement kilns run in co-combustion, with 10% and 20% of the heat input provided by RDF.

Economic analysis

- In order to break even with the economic return of a small WTE plant, an RDF producer can afford to pay for the "disposal" of RDF to a non-dedicated plant where it is co-combusted to generate energy
- At an electricity price of 90 Euro/MWh, in order to break even with the small WTE plant the RDF producer can afford to pay 60-80 Euro per ton of RDF
- In order to break even with the economic return of a large WTE plant, an RDF producer needs to be paid to supply the RDF to a non-dedicated plant where it is co-combusted to generate energy.
- At an electricity price of 90 Euro/MWh, in order to break even with the large WTE plant, the RDF producer needs to sell RDF at 60-70 Euro per ton of RDF

Conclusions - Energy

1. The overall efficiency of eletricity production by the co-combustion of RDF into SUBcritical power stations is about the same of the combustion of RW into a state-of-the-art, LARGE WTE plant
2. The co-combustion of RDF into SUBcritical power stations gives however much more electricity than SMALL WTE plants fed with RW
3. RDF + co-combustion into Ultra-supercritical Steam Cycles (USC) is superior to the use of RW into WTE plants, although less likely due to the sophisticaton of USC plants
4. Primary energy savings generated by the co-combustion of RDF and by the combustion of RW into WTE plants are similar. Large, cogenerative WTE plants achieve the highest savings.

Conclusions - Emissions

1. Co-combustion of RDF tends to give lower GWP than RW into WTE plants
2. RW into WTE plants gives lower Photochemical Ozone Formation
3. More complex situation for Human Toxicity and Acidity. Reference Scenario is crucial to relative ranking
4. The requirements for landfill volumes of RDF co-combustion and RW into WTE plants are comparable, with somewhat lower values for the latter

Conclusions - General

1. Unlike in the comparison:
   {RW in WTE plant} vs {RDF in "dedicated" plants},
   where the former "wins" all across the board,
   in the comparison:
   {RW in WTE plant} vs {RDF in "non-dedicated" plants}
   no technology "wins" across all indicators
2. Large WTE plants fed with RW are most suited to serve large communities, even more when they feed a district heating system in coegeneratio
3. RDF + co-combustion may be a viable opportunities for small communities where a plant that can handle RDF is available
4. It is unlikely that co-combustion alone can be the solution to the treatment of all RW generated in an industrial country

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All of you for your attention !