Innovative system for electricity generation from waste heat recovery

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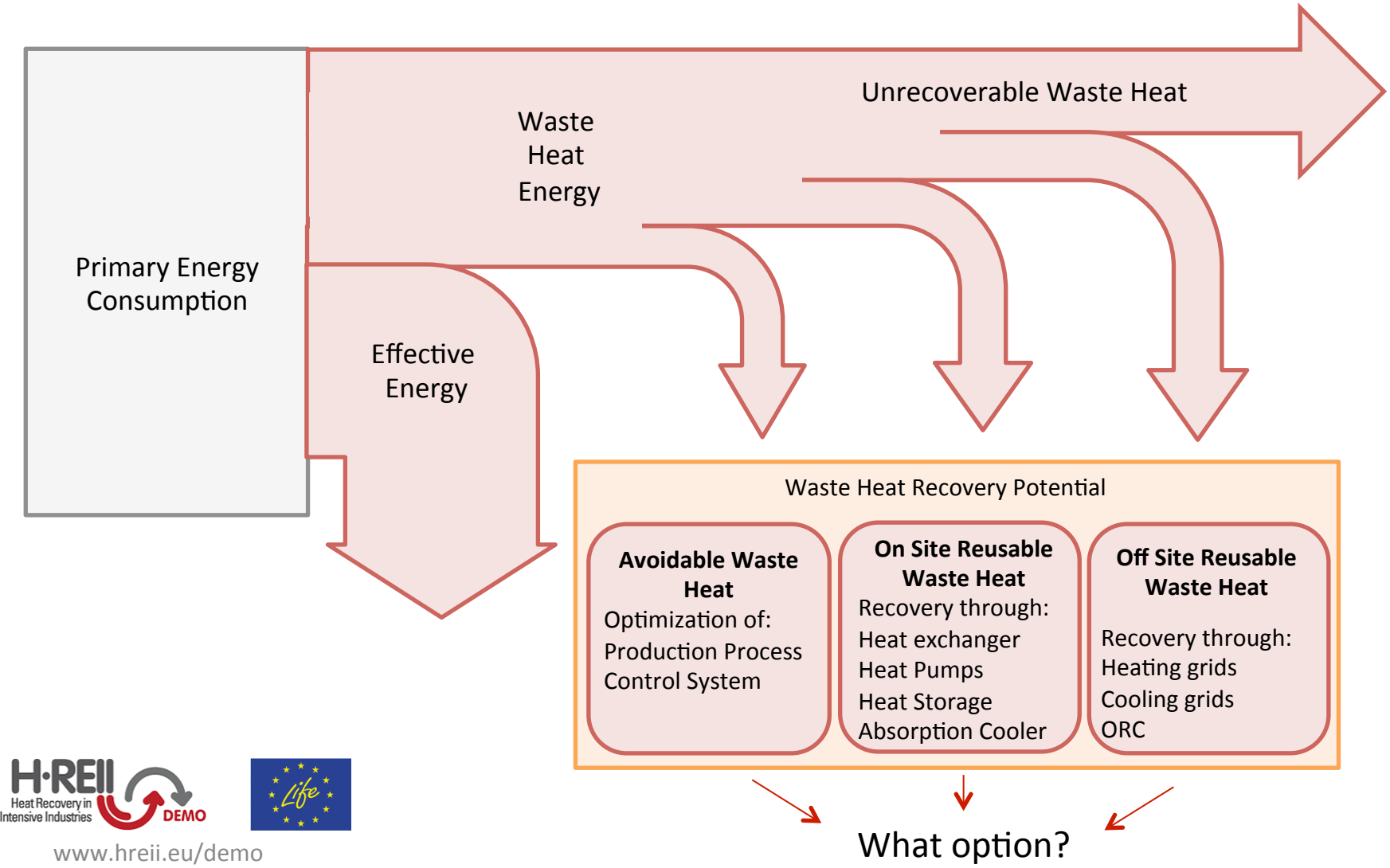
Waste heat in industrial processes



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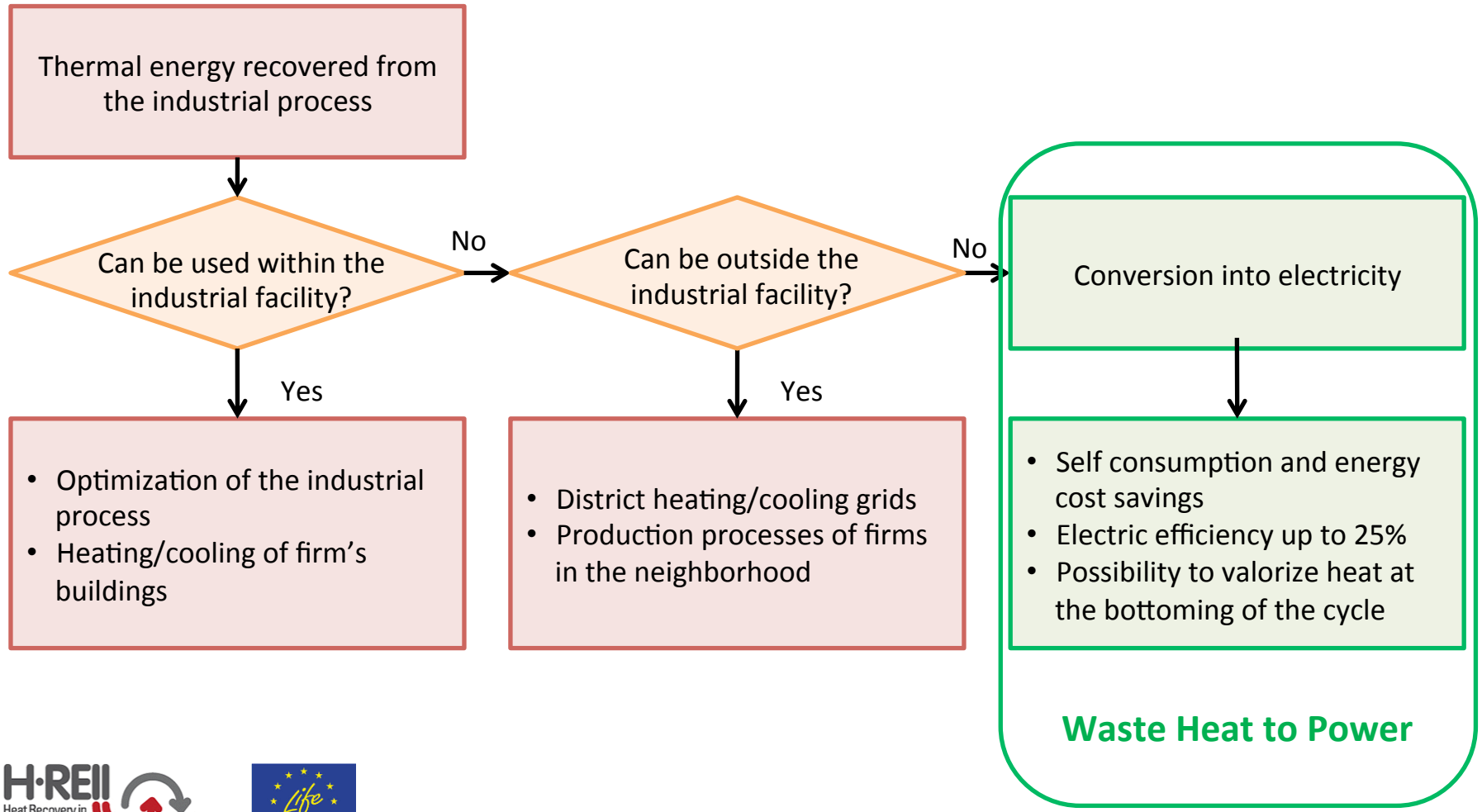
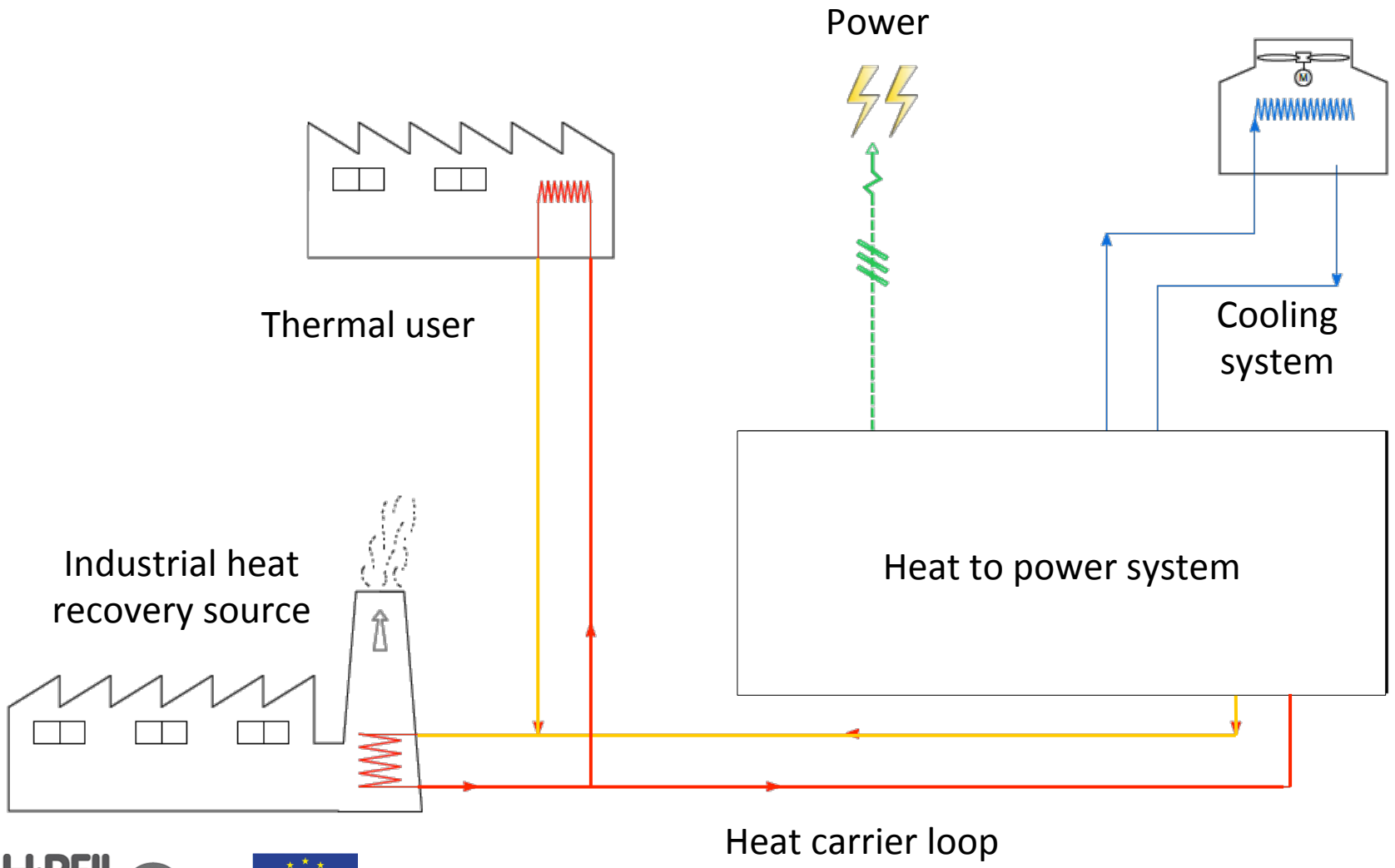
Waste heat users



Waste heat to power



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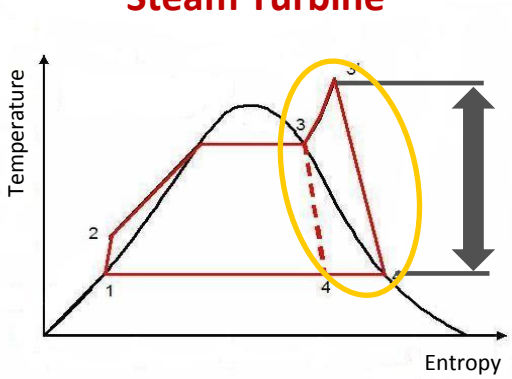
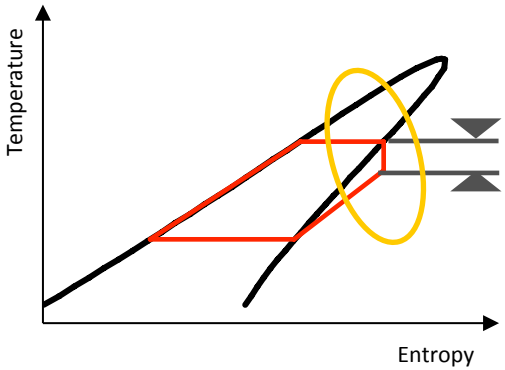
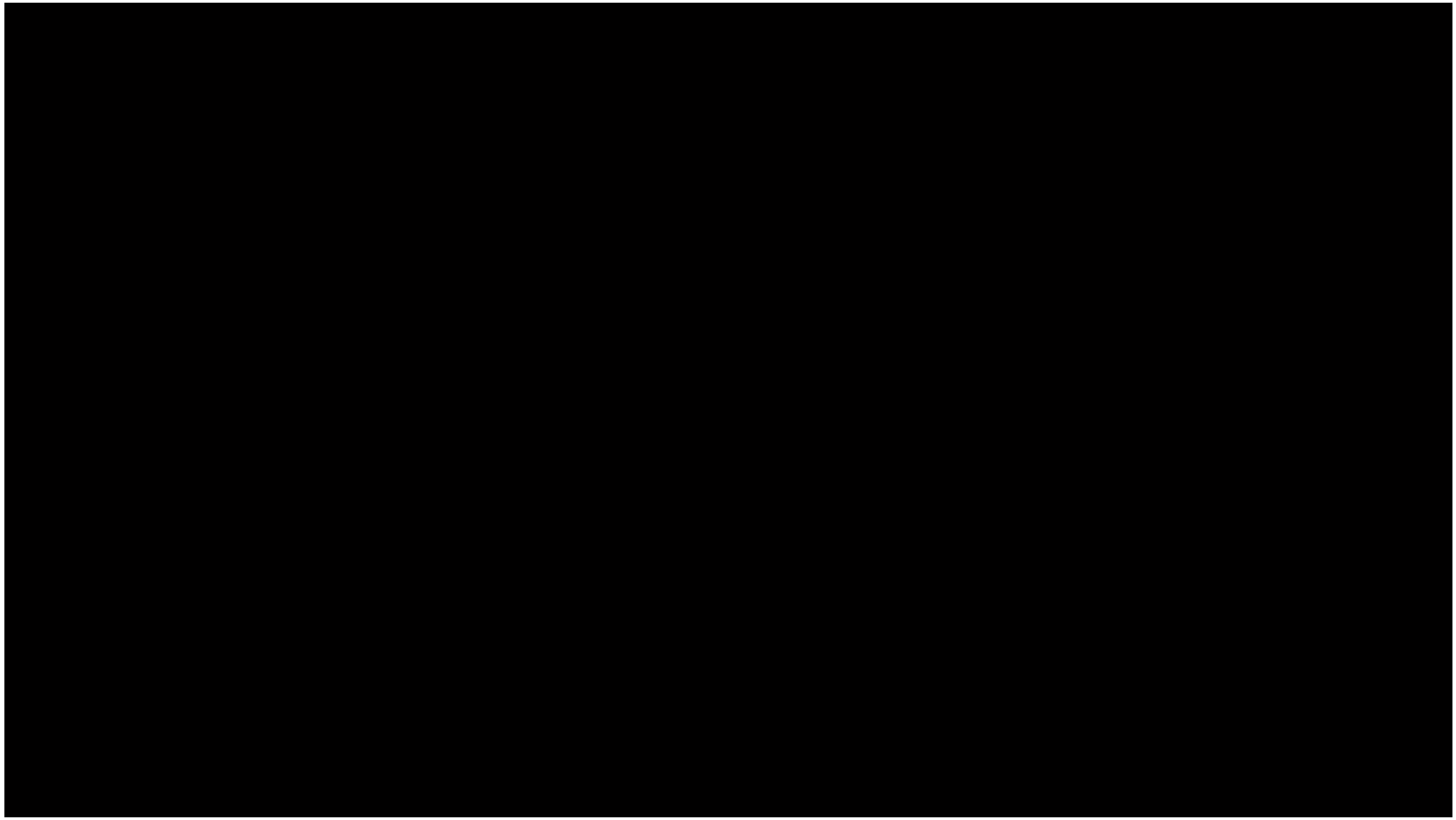
Heat carrier loop

Thermal oil	Hot water	Saturated Steam	Direct exchange
High ORC efficiency (up to 24 % due to high temperature , 300°C)	**Simple technical solution** (low tempe., no phase change)	**Medium ORC efficiency** (~20 % with 27 bar steam)	**Lower investment and O&M**
Reliability (wide spread solution in ORC based heat recovery systems)	**Many application in ORC** (waste to energy, geothermal plants, etc.)		**Many application in ORC** (internal combustion engines, gas turbines, etc.)
Flammable		**Complex system** (e.g. water quality control)	**Technical limits** (heat source cleanliness and temperature below 450°C)
Steelshop operators usually not familiar with thermal oil	**Lower ORC efficiency** (e.g. 16% with 180°C hot water)	**Steam engineer necessary**	

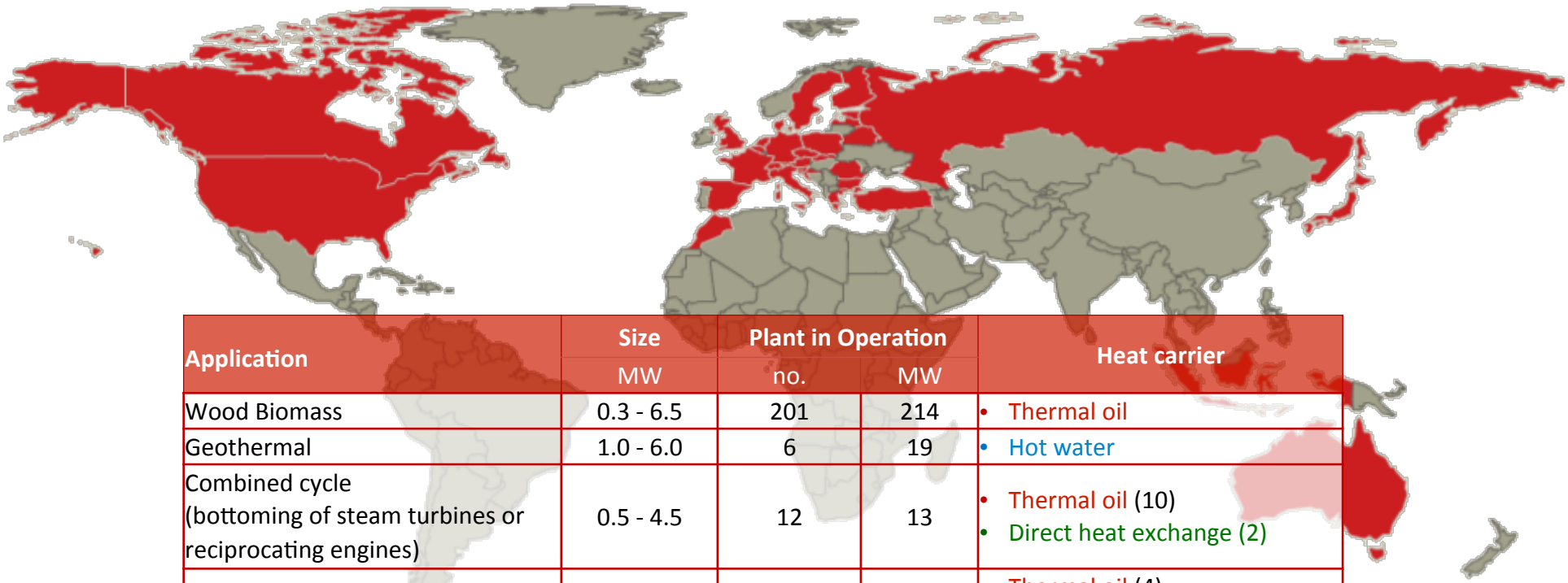
Waste heat to power technologies

	Steam Turbine	Organic Rankine Cycle (ORC)
		
Thermodynamic features	• High enthalpy drop • Superheating needed • Risk of blade erosion	• Small enthalpy drop • No need to superheat • No risk of blade erosion
Operation and maintenance costs	• Water treatment required • High skilled personnel • High pressures and temperatures	• Non oxidizing working fluid • Minimum personnel • Completely automatic
Other features	• Convenient for plants > 10 MWe • Low flexibility • Lower performances at partial load	• High flexibility and good performances at partial load • Well proven in industrial heat recovery

Organic Rankine Cycle



Turboden References



Application	Size	Plant in Operation		Heat carrier
	MW	no.	MW	
Wood Biomass	0.3 - 6.5	201	214	• Thermal oil
Geothermal	1.0 - 6.0	6	19	• Hot water
Combined cycle (bottoming of steam turbines or reciprocating engines)	0.5 - 4.5	12	13	• Thermal oil (10) • Direct heat exchange (2)
Industrial Heat Recovery (Cement, Glass, Steel, etc.)	0.5 - 7.0	7	16	• Thermal oil (4) • Hot water (1) • Saturated Steam (1) • Direct heat exchange (1)
Waste to Energy	0.5 - 6.0	4	10	• Thermal oil (3) • Hot water (1)
Total Turboden Plants		**230**	**272**	

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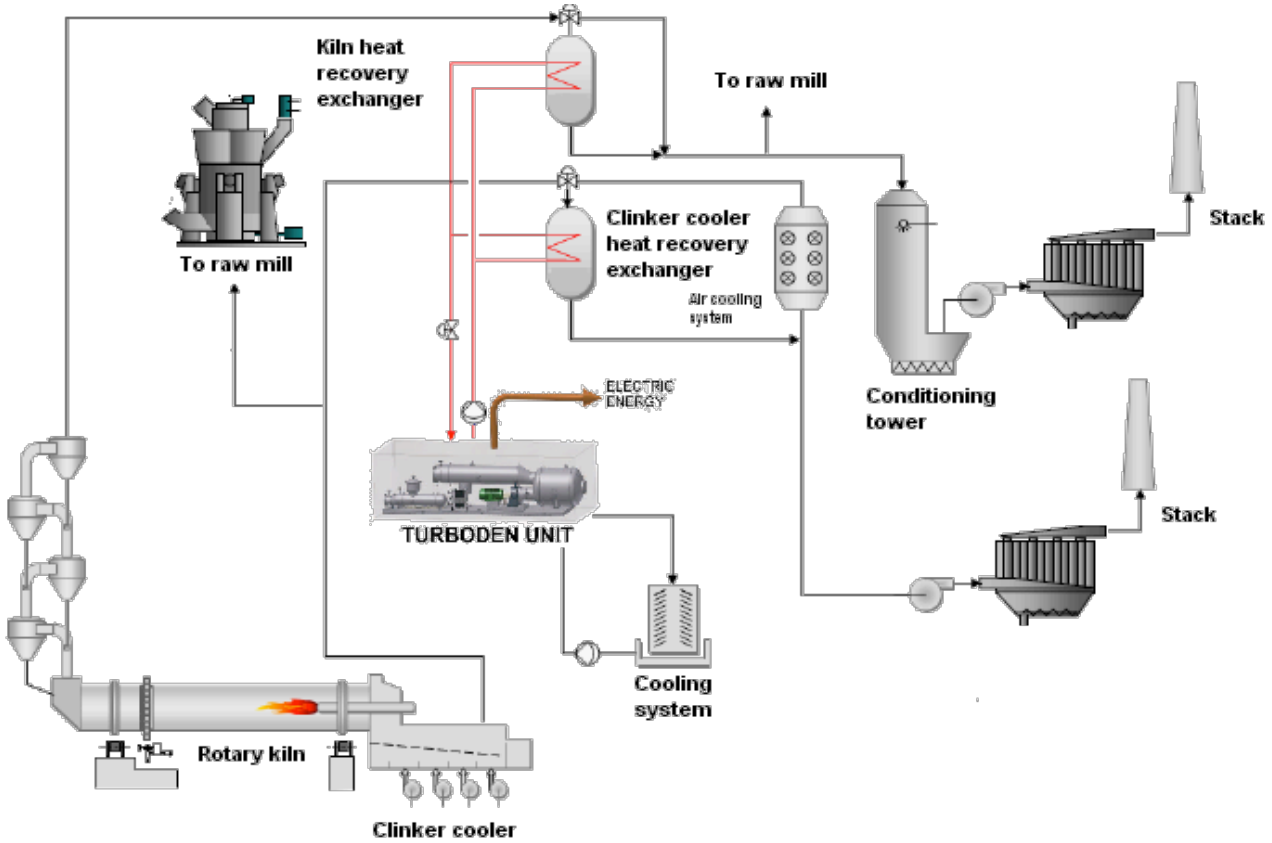
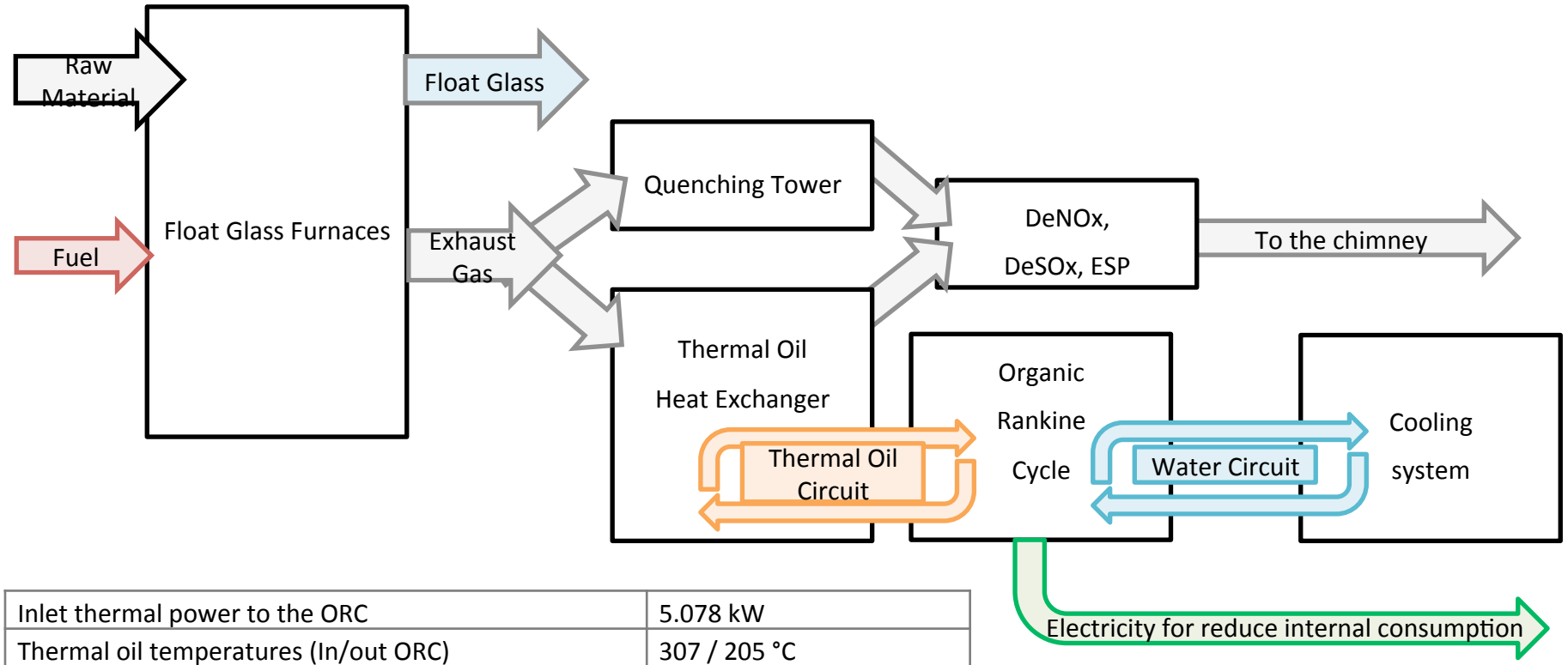
Last Update: April 2014

WHTP with ORC in cement industry



Year of startup	References in cement Plants	ORC Manufacturer	ORC gross power [MW]
1999	Heidelberg Zement, Germany	Ormat	1.5
2010	Italcementi - Ciment du Maroc, Marocco	Turboden	1.5
2012	Holcim Romania	Turboden	4
UC	Jura Cement, Switzerland	ABB	2
2014	Holcim Slovakia	Turboden	5
UC	Heidelberg Cement – Cartpatcement Romania	Turboden	4
UC	Holcim Canada	Turboden	7

WHTP with ORC in glass industry



Inlet thermal power to the ORC	5.078 kW
Thermal oil temperatures (In/out ORC)	307 / 205 °C
Thermal power to the cooling water	3.831 kW
Cooling water/glycol temperatures (in/out ORC)	25 / 35 °C
Gross electric power output	1.253 kW
Net electric power output	1.200 kW

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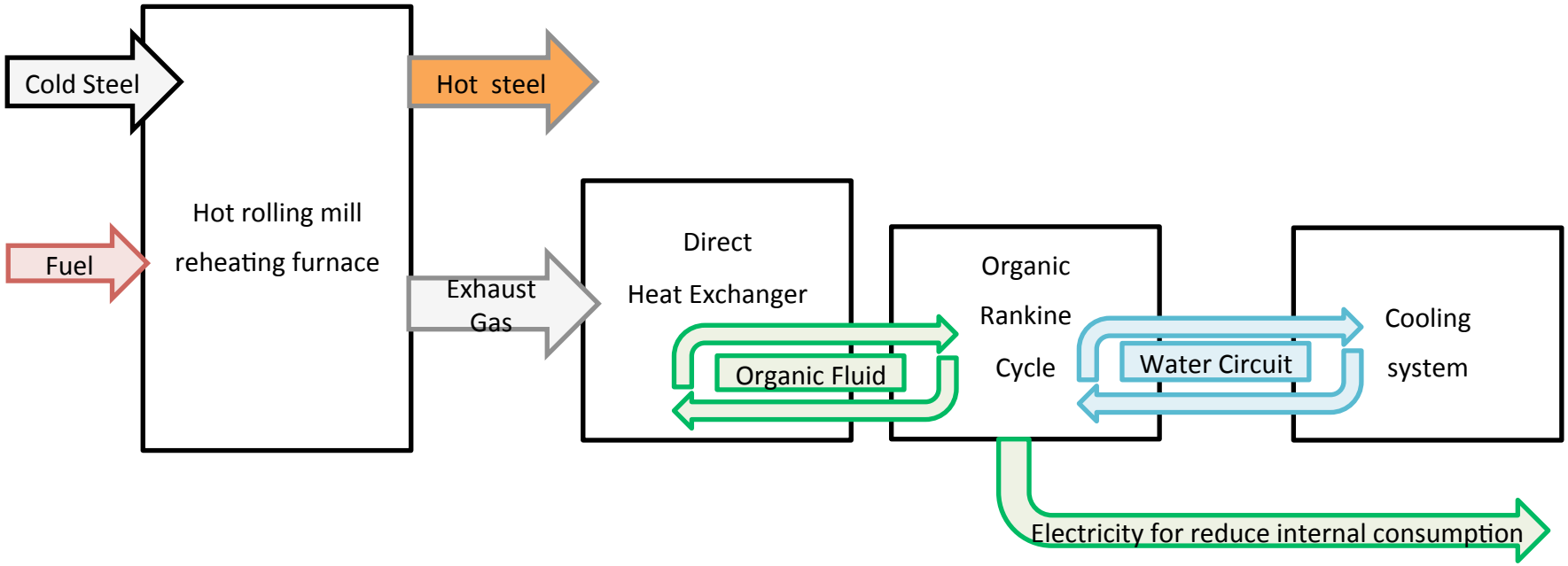
Year of startup	References in glass plants	ORC Manufacturer	ORC gross power [MW]
2011	Vetrerie Sangalli Manfredonia, Italy	Ormat	2
2012	AGC Cuneo, Italy	Turboden	1.3

WHTP with ORC in steel industry



Inlet thermal power to the ORC	2.820 kW
Exhaust gas temperatures (In/out ORC)	400 / 220 °C
Thermal power to the cooling water	2.272 kW
Cooling water/glycol temperatures (in/out ORC)	32 / 47 °C
Gross electric power output	555 kW
Net electric power output	523 kW

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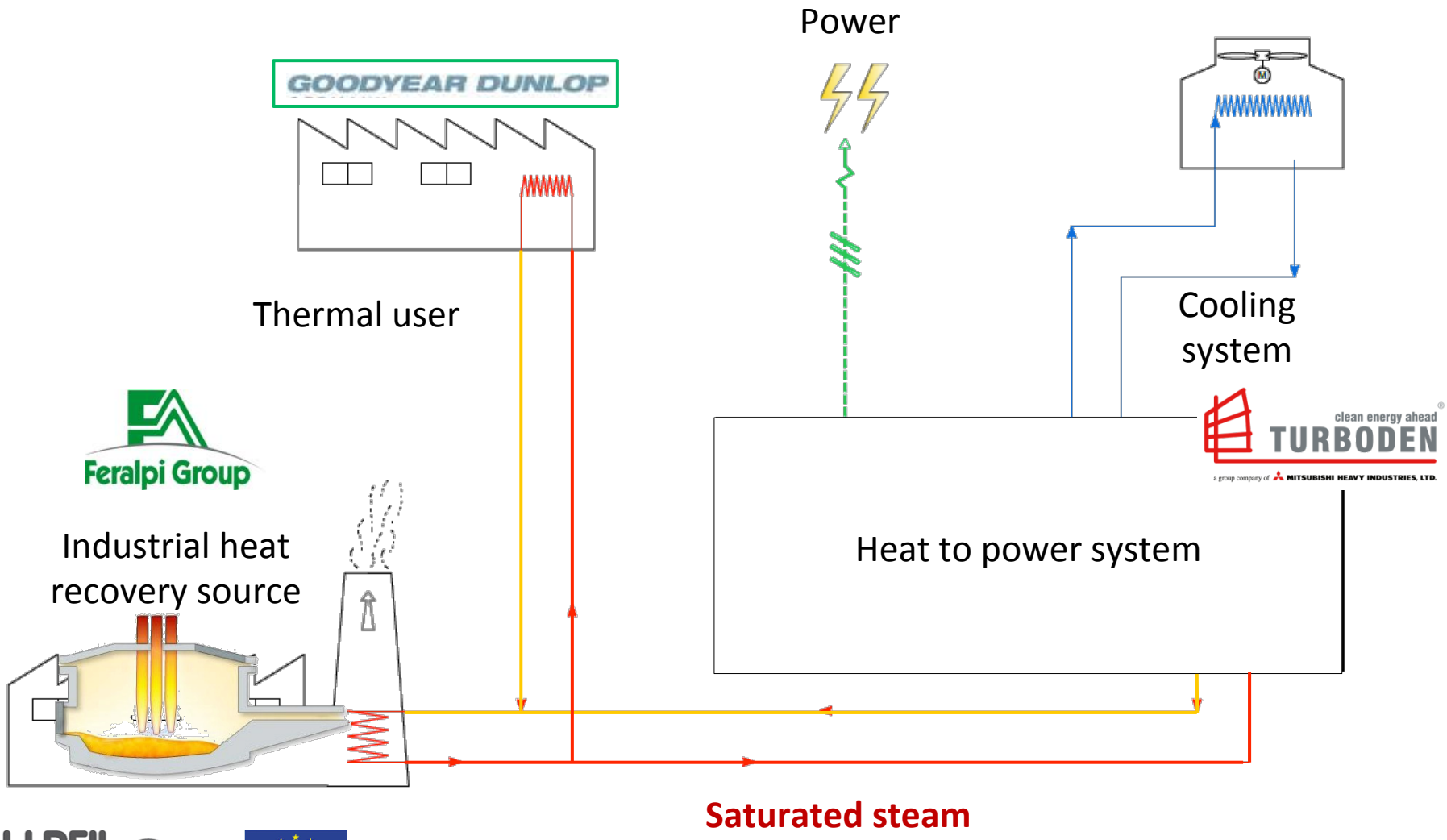
Year of startup	References in hot rolling mills plants	ORC Manufacturer	ORC gross power [MW]
2013	Natsteel (TATA group), Singapore	Turboden	0.6

Innovative WHTP system in steel industry



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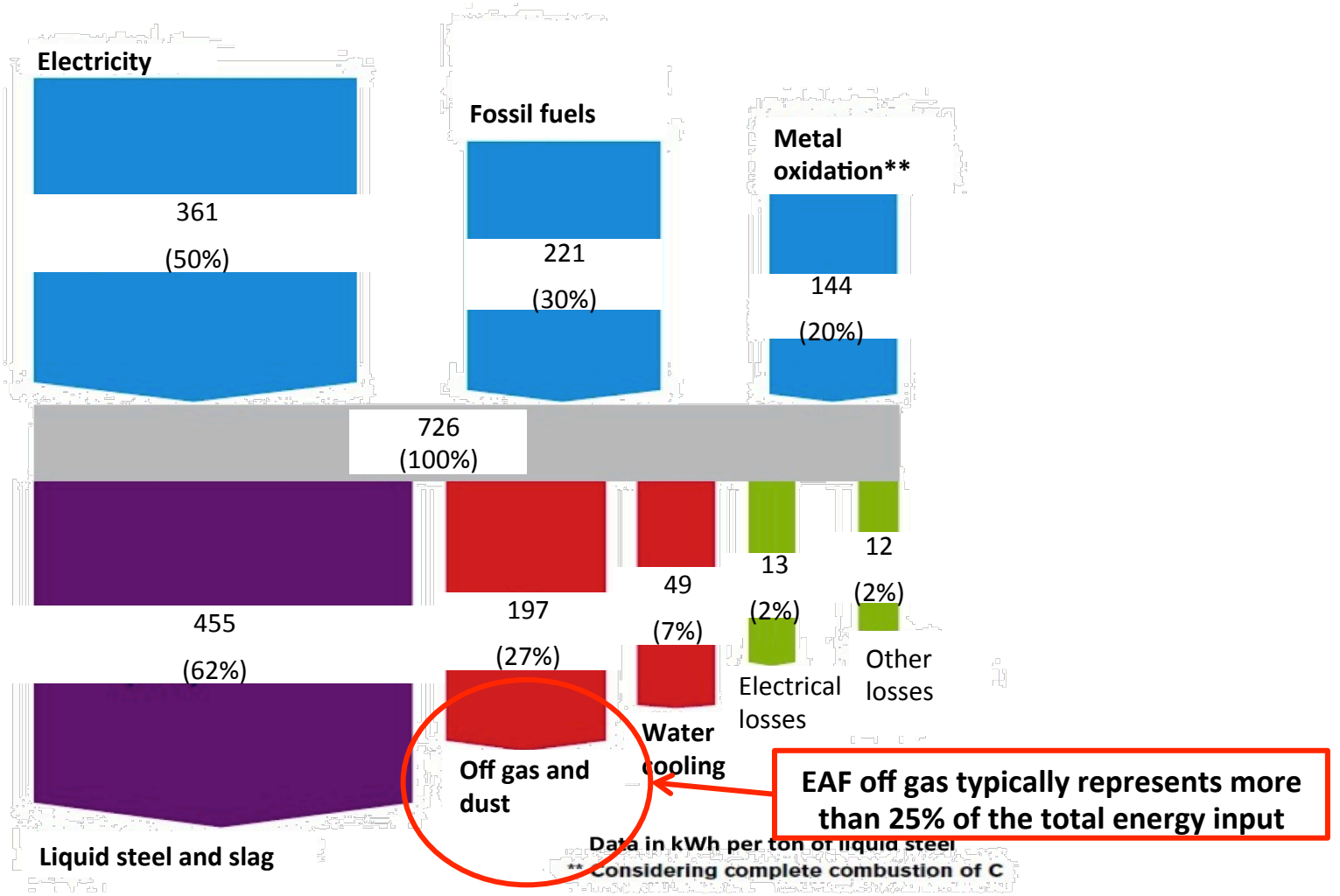
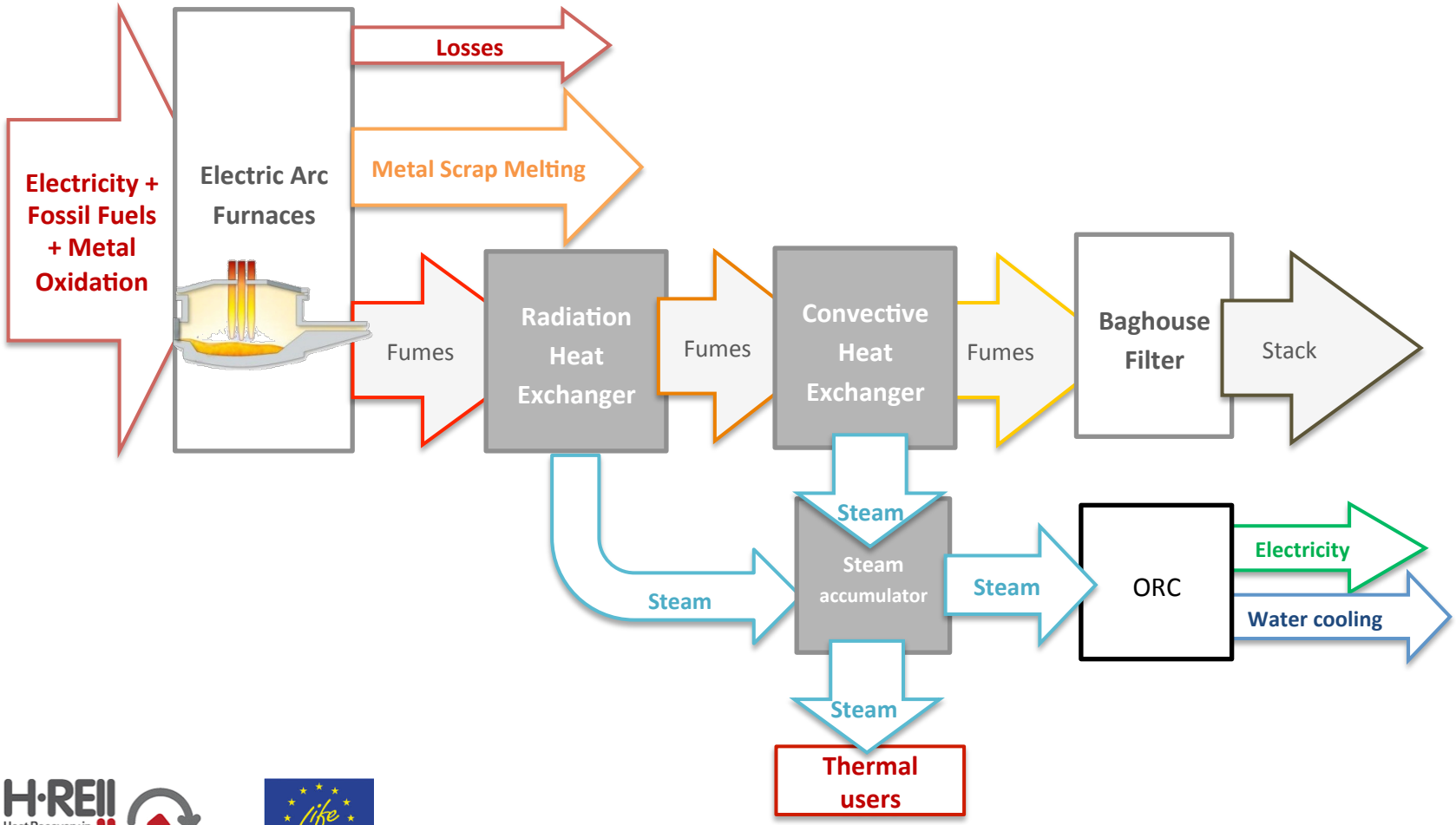
Electric Arc Furnaces Energy Balance



Typical energy balance for top charged scrap based EAF (Tenova)

WHTP from Electric Arc Furnaces



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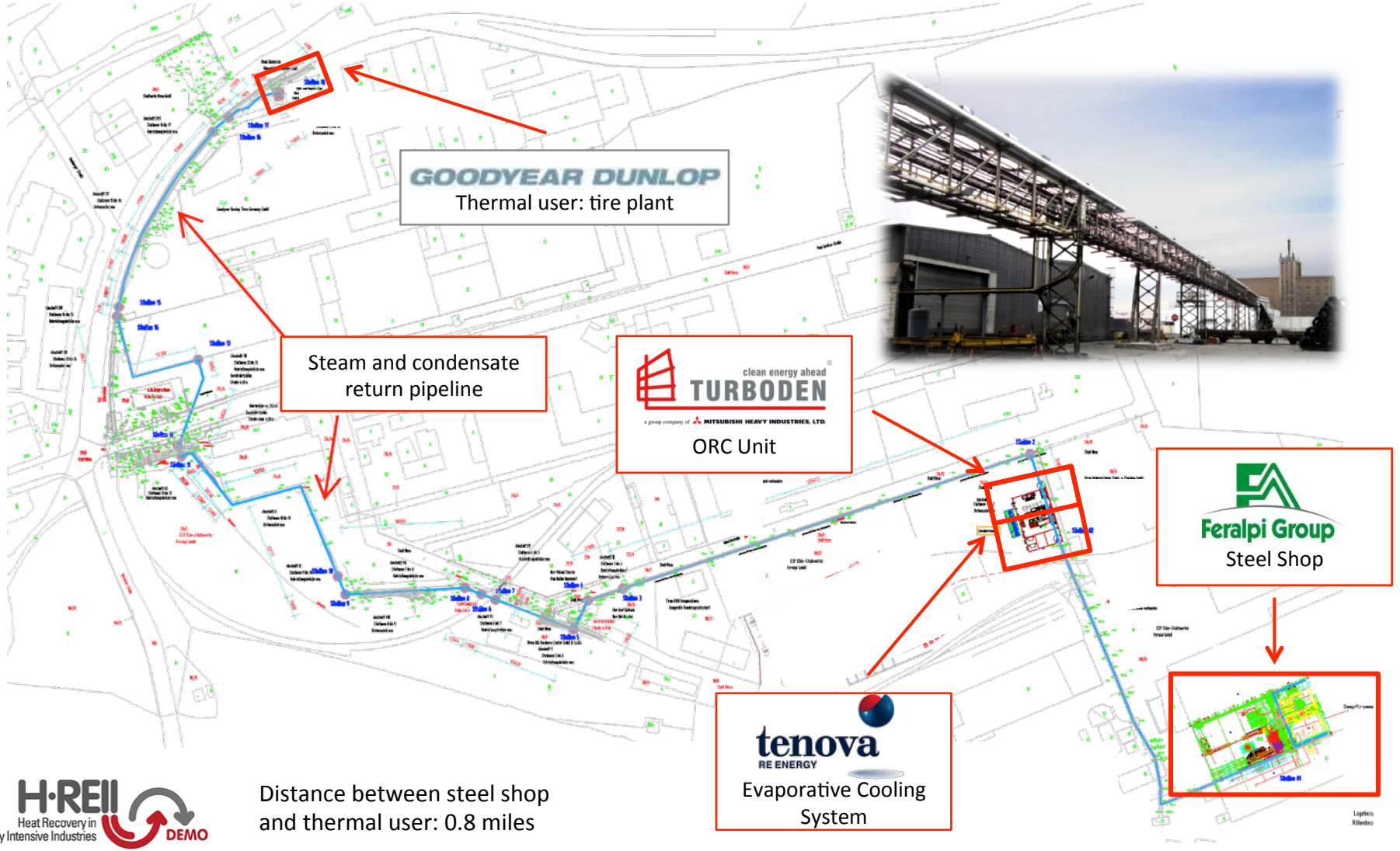
Project Layout



Distance between steel shop and thermal user: 0.8 miles

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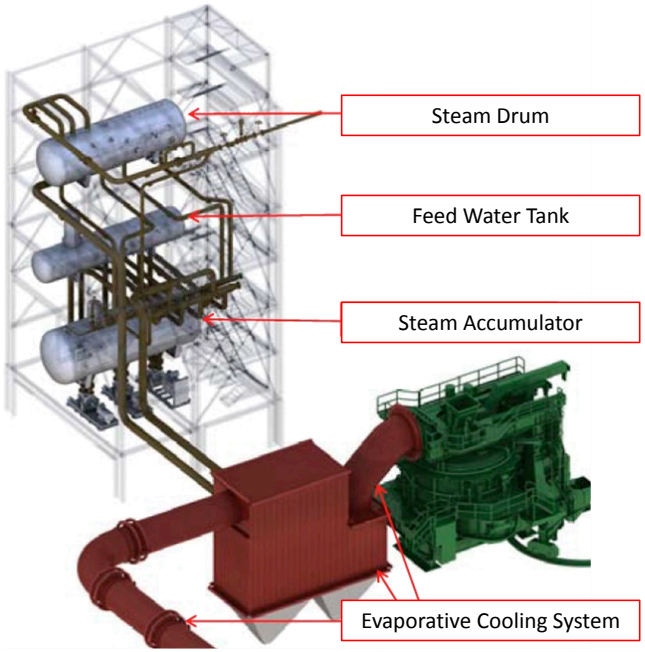
Technical data (1/2)

1. Electric Arc Furnace Data

Heat source	**EAF process off-gas**
Steel production	1M tons/year
Heats per day (average)	32
EAF hourly production	133 tons/hour
Tapping weight	100 tons
Tapping temperature	1600°C
Charge weight	113 tons
Average off-gas temperature (core temperature ex EAF)	1100°
Average off-gas flow rate	100,000 – 140,000 Nm^3/h

2. Evaporative cooling system Data

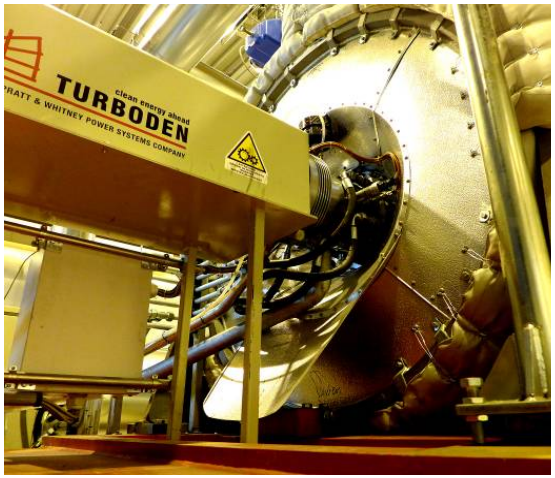
Minimum steam data at steam drum	228°C – 27 bar(a)
Nominal steam data at steam drum	247°C – 38 bar(a)
Maximum design steam data at steam drum	252°C – 42 bar(a)
Feed water pressure at steam drum inlet	45 bar
Water content cooling system (pipes + tank)	approx. 37 m^3
Capacity of steam accumulation of cooling system	1442 kg
Steam drum glide upper limit	19 bar
Capacity of steam accumulator (water content)	76 m^3



Technical data (2/2)

3. ORC equipment

Hot source	Saturated Steam at 27 bar(a)
Inlet thermal power to the ORC	13,517 kW
Steam temperature In to ORC	228÷245°C
Condensate temperature Out from ORC	100°C
Thermal power to the cooling water	10,640 kW
Cooling water temperatures (in/out ORC)	26°C / 44°C
Gross electric power output	2,680 kW
Net electric power output	**2,560 kW**



European Union support

The project obtained contribution from EU to develop a demonstrating plant for an innovative ORC application

- ❑ First heat recovery to power system from EAF
- ❑ Further development of steam based EAF off gas technology proven at GMH adding a Waste Heat Boiler (convective section)
- ❑ First ORC in steel industry fed with saturated steam

CO_2 reduction in electric steelmaking

First glance at economics

Total WHRS investment cost
Influenced by many specific project related factors: size, ambient temperature, exhaust gas temperatures and flows, number of heat source, layout, electric connection, water availability, erection cost, etc.

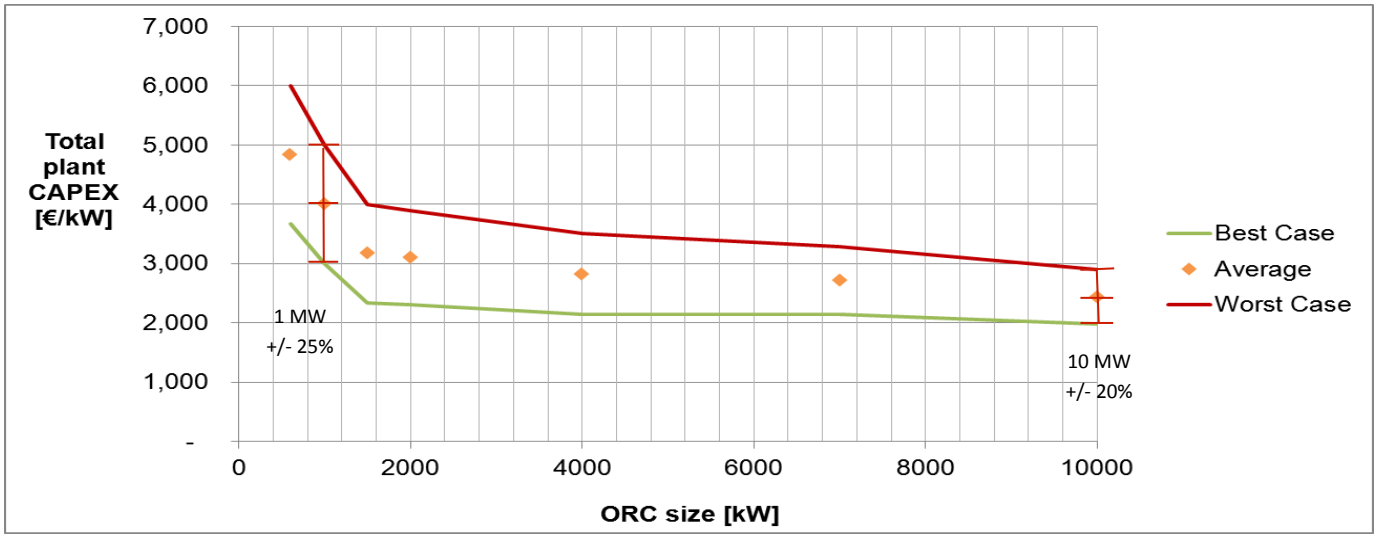
Economical Feasibility is driven mainly by

- *WHRS investment cost*
- *Electricity value* may range between 0.13 €/kWh (e.g. in Italy with White certificates) to less than 0.05 €/kWh
- *Operating hours*: the grater, the better (typical values are 7.500 hours/year)
- *OPEX*: for complete ORC based plant in the range of 5% of CAPEX/year (approximately half of steam based plant)

WHTP investments sizes and returns

CAPEX for the whole heat recovery system varies depending on:

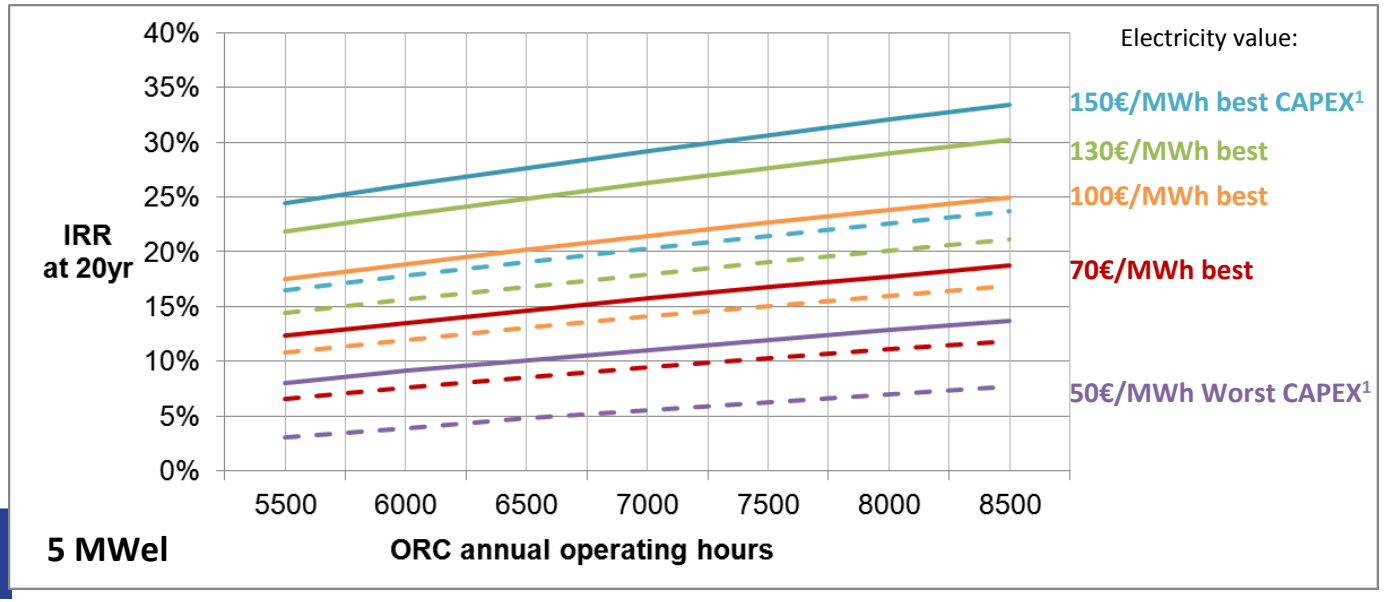
- Source cleanness
- Process stability
- Layout constraints
- Heat carrier
- Cooling system
- Other



Investment IRR varies mainly depending on operating hours and electricity value(1)

——— Best CAPEX

– – – – Worst CAPEX



1) Best CAPEX: 2100 €/kW net, Worst CAPEX: 3400 €/kW net, OPEX: 100 k€/year

WHTP with ORC boosts DH investments

- **Case A - DH only**: heat recovered sold to district heating grid for six month a year (no investment for ORC nor electricity revenues)
- **Case B1 - DH peak, ORC off peak**: heat recovered sold to the DH in wintertime, ORC produce electricity in summertime
- **Case B2 – ORC CHP**: the total energy recovered feed the ORC that works in cogeneration mode (lower electrical efficiency, higher operating hours)
- **Case C – ORC only**: the heat recovered feeds the ORC and no heat is sold to the DHC.

	CASE 1 - DH Only	CASE 2 - DH on winter ORC summer	CASE 3 - ORC CHP	CASE 4 - Only ORC	Unit of measure
Thermal power recovered	15	15	15	15	MW
Operating hours	6,800	6,800	6,800	6,800	h/yr
Potential Energy	102	102	102	102	GWh/yr
District Heating Annual Request	50%	50%	50%	0%	
Energy Available for the ORC	0	51	102	102	GWh/yr
ORC net efficiency	0%	19%	16%	19%	
ORC net electric power	0	2.85	2.4	2.85	MW
Net electricity produced	0	9.7	16.3	19.4	GWh/yr
Electricity revenues	0.00	0.68	1.14	1.36	M€/yr
Thermal energy sold to the DH	51	51	42.9	0	MWh/yr
Thermal energy revenue	1.02	1.02	0.86	0.00	M€/yr
Total Annual Revenues	1.02	1.70	2.00	1.36	M€/yr
Total CAPEX (1)	8.4	10.9	10.9	9.9	M€
Annual OPEX	0.10	0.15	0.15	0.12	M€/yr
Annual Cash Flow	0.92	1.55	1.85	1.24	M€/yr
Discounted Pay Back Time	13.6	9.4	7.5	11.2	year
Net Present Value 18 years	1.6	5.8	9.1	3.5	M€
Internal Rate of Return (18 years)	**8.4%**	**12.5%**	**15.7%**	**10.4%**	**%**
Avoided greenhouse gas emissions	11,477	15,904	17,122	8,915	tCO_2/year

1): Heat recovery system (steam/hot water boiler): 7 M€;, additional investment for DH connection: 1 M€; Additional investment for ORC: 2.4 M€; Balance of plant component: 5% of the total investment

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Benefits and barriers

Benefits:

- Reduction of **internal consumptions** (approx. fumes treatment consumption)
- Reduced **cost per ton** of final product
- **Sustainability** of the process and green image of the company
- Increased **competitiveness**
- **Job saving/creation** for industries intended to delocalize
- Creation of **a new supply chain** with European company as a world leader

Barriers:

- **Uncertain regulation framework**: is nor renewables nor high efficiency CHP
- Industrial owner consider it a **non-core investment**
- **Payback time** depends on electricity value and can be reduced selling thermal energy

Lessons learned

- ORC is **a proven way to recover heat** that cannot be valorized otherwise
- **First WHTP in EAF** open the way to future developments
- **Infrastructural projects** like district heating networks need **cooperation** between industry owners and local authorities
- Energy efficiency investments are **strategic** for European industry

Follow up:

- **Policymakers** should recognize WHTP as an energy efficient industrial initiative
- Innovative **investment** schemes have to be proven to enable initiatives
- **R&D activities** needed to improve actual solution and to develop new ones in other industry (pulp and paper, metallurgy, chemical, etc.)

thanks for your attention

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