Future Circular Collider

Technical Infrastructure

Heat recovery opportunities in the FCC complex

G. Peon (EN/CV)

FCC week 2023 - London

6/ June / 2023

Outline

- Introduction;
- Waste Heat Recovery (WHR) classification;
- Low grade WHR challenges;
- What to do with the FCC Waste Heat ?
- Primary Cooling of the FCC-ee surface and underground;
- Opportunities for Heat Recovery in the FCC;
- Conclusions.

Introduction

- Waste heat recovery reduces the water consumption, energy bill and CO_2 footprint;
- From CERN Director F. Gianotti FCC week 2022
  - FCC Feasibility Study, high-level objectives:
    - … Elaboration of a sustainable operational model for the colliders and experiments in terms of human and financial resource needs, as well as environmental aspects and energy efficiency …
  - Final remarks:
    - … Scientifically and technically very ambitious: new technologies required in many domains, sustainability and environmental protection are a must → great opportunities for new developments…

Introduction: Heat Recovery and Sustainability

HEAT RECOVERY RELATED

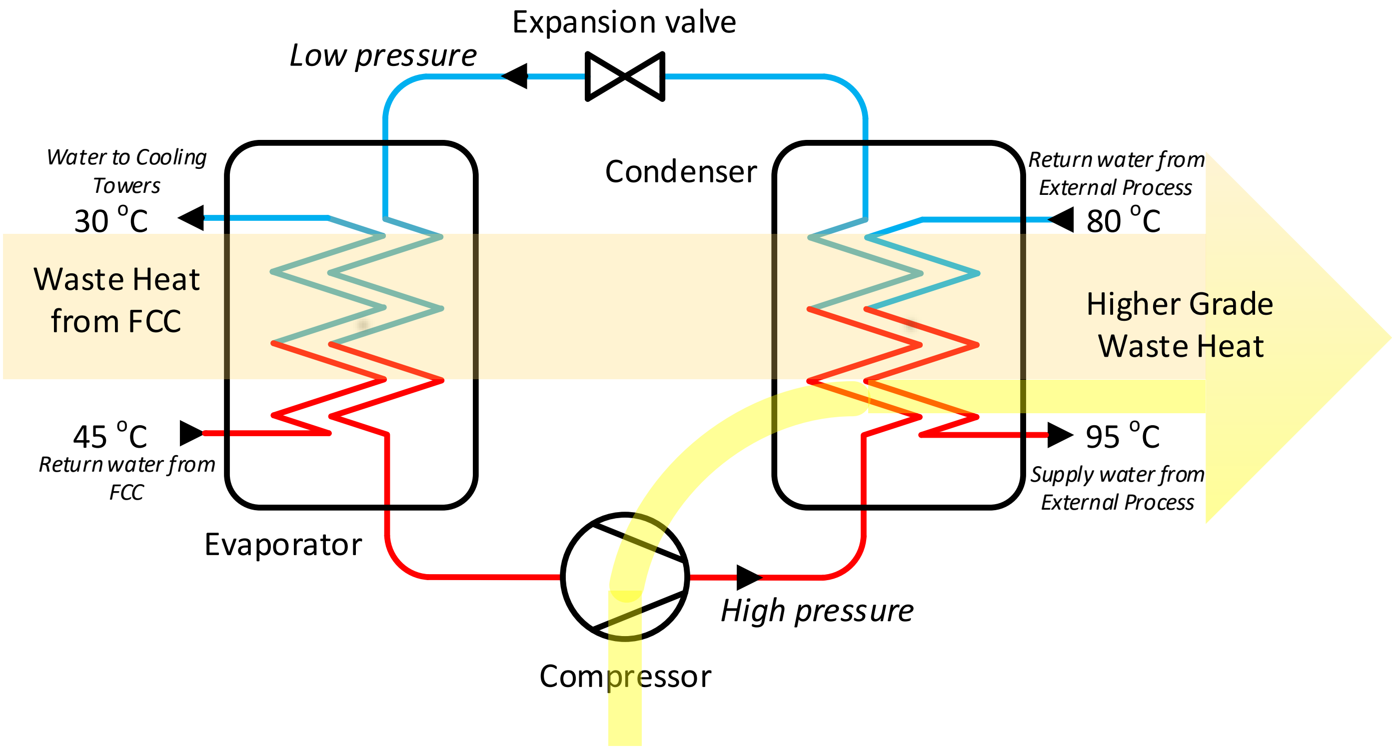
- Sustainability has to do with:
  - Resources;
    - Energy:
      - Its Nature (Electrical Power from Nuclear Plants, from Renewable Sources, Gas, Petrol,…);
      - Its Efficiency;
    - Water:
      - Evaporation;
      - To the drains and eventually to the water sources;
      - From where it is taken;
    - Materials:
      - Its nature;
      - Its origin;
  - Environmental impact (CO_2 footprint, pollutants, waste, effluents,);
  - Benefit for society (in the short and long run, for a person or for the humankind);
  - …

Waste Heat Recovery (WHR) classification

- Heat loss classification:
  - High temperature grade;
    - at temperatures greater than 400 °C;
    - From direct combustion processes;
  - Medium temperature grade;
    - At temperatures from 100 to 400 °C;
    - From the exhaust of combustion units;
  - Low temperature grades;
    - For temperatures less than 100 °C;
    - From cooling in various processes;

FCC

- … but Heat Pumps can transfer heat from a heat source to a heat sink using a "small" amount of energy;
  - Heat pumps are good for low-temperature WHR, as they give the capability to upgrade waste heat to a higher temperature.



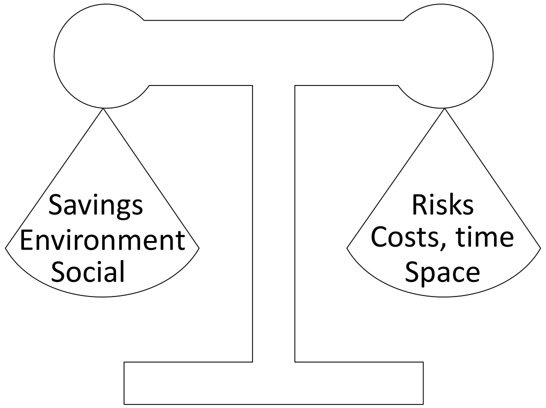
- In the example:

$$COP_{carnot} = \frac{T_H}{T_H - T_C} \qquad COP_{carnot} = 7 \qquad COP_{Real} \text{ from 3 to 4}$$

Waste Heat Recovery (LWHR) Challenges

- “Is it worth the effort ? Savings?"
  - Energy cost savings outweigh the installed cost of the proposed waste heat recovery project plus the operation?
  - Payback period is longer than two or three years ?
  - Quantify environmental and social aspects.
- Reasons why many companies do not consider WHR recovery systems:
  - Lack of information or technology knowledge;
  - Technology risks;
  - No requirement for using the recovered heat;
  - High initial costs;
  - Running and maintenance costs;
  - Lack of financial support or incentives;
  - Available space limitation;
  - Lack of available infrastructure around;
  - Production constraints;
  - Risk of production disruptions;

- Barriers
  - High capital cost per kW generated (low system efficiency);
  - Low quality and not constant heat stream;
  - High-cost material to withstand the heat;
  - Stream with high chemical activity;
  - Transportability (long-distance transport of low-grade heat);



*From: Christodoulides, P., Aresti, L., Panayiotou, G.P. et al. ”Adoption of Waste Heat Recovery Technologies: Reviewing the Relevant Barriers and Recommendations on How to Overcome Them”. Oper. Res. Forum **3**, 3 (2022). https://doi.org/10.1007/s43069-021-00108-6*

What to do with the FCC Waste Heat ?

Heat Recovery World Wide (short summary)

- The industrial sector represents between 32% and 35% of the global energy consumption.
- Process heat accounts for approximately 74% of the global final energy consumption of industry (Epp and Oropeza, 2017; Kumar et al., 2019)
  - In which 30%, 22% and 48% are shared by low (<150 °C), medium (150–400 °C) and high (>400 °C) temperatures respectively (Epp and Oropeza, 2017).
  - The heating energy requirements in the industries are presently met through either burning of fossil fuels or using high-grade energy (electricity).
  - Most of the industrial process heating applications like bleaching, cooking, pasteurization, sterilization, drying, degreasing, washing, etc., require low to moderate hot fluids in the range 60–160 °C (Farjana et al., 2018).

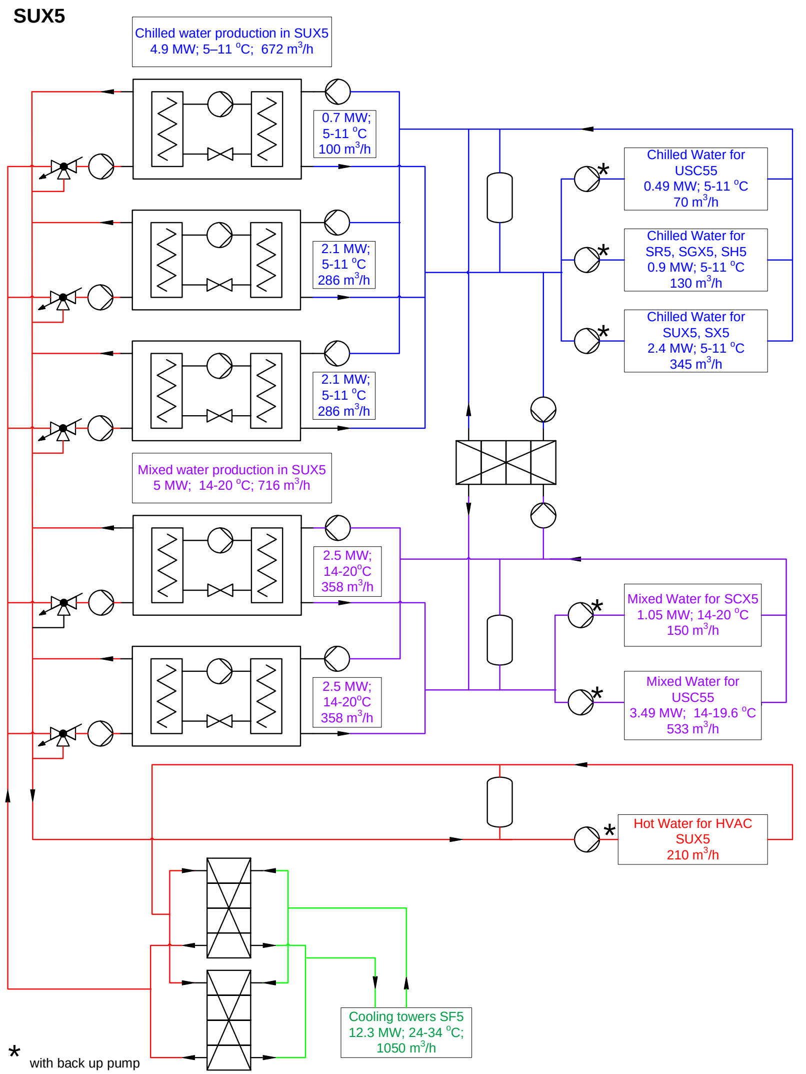
From: https://www.sciencedirect.com/science/article/abs/pii/S0959652622025331

What to do with the FCC Waste Heat ?

- Reuse it in FCC installations for heating;
- Store it in the first place and reuse it where/when needed;
  - *To keep in mind that during winter periods (highest heating demand) the accelerator should be stopped;*
  - Phase Change Materials (PCM);
  - Thermochemical Energy Storage (https://blog.sintef.com/sintefenergy/thermochemical-energy-storage-the-next-generation-thermal-batteries/)
    - Materials store heat through reversible chemical reactions. Upon combination or separation of two substances, heat is absorbed or released. TCES materials can generally store more energy than sensible and latent heat TES compounds.
  - Underground Thermal Storage in particular Borehole Thermal Energy Storage
  - Thermal Storage in the FCC tunnel rock
- Send it away from CERN site to external users for use in:
  - Heating;
  - Processes at the same or higher temperature (Heat Pumps);

What to do with the FCC Waste Heat ? Reuse at CERN

Heat from FCC Recovered in CV installations



- Hot water from Chillers can be cooled either:
  - in heat exchangers connected to the cooling towers or
  - be distributed to our Air Handling units:
- Example, SUX5:
  - [SUX5 Chilled Water Production (cern.ch)]

What to do with the FCC Waste Heat ? Storage

Heat Recovery: Storing in Phase Change Materials

Important Aspects to Consider

- Storage Capacity per unit volume;
- Thermal conductivity;
- Transport;
- Working Temperature;
- Degradation time;
- Price;
- Environmental Issues;

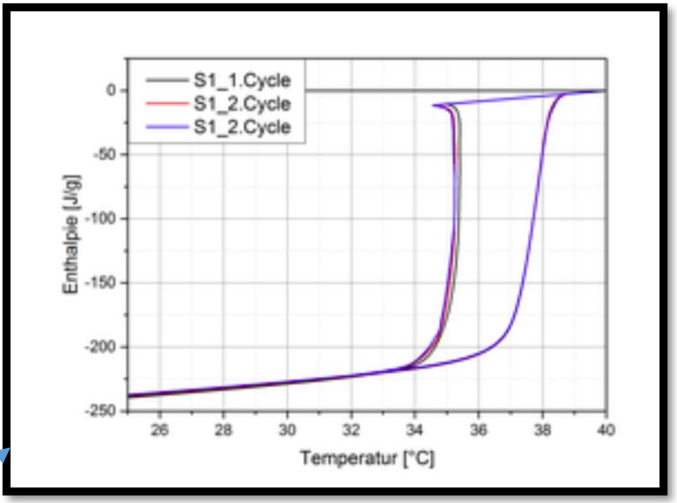
- Most common are:
  - Eutectics: made of mixtures of PCMs as salts in water usually with a phase change temperature below 0°C
  - Salt hydrates: salts able to incorporate water of crystallisation during their freezing process and tend to change phase above 0°C up to 400 MJ/L
  - Organic materials: usually polymers with long chain molecules mainly of carbon and hydrogen. They change phase above 0°C. Examples include waxes, oils, fatty acids and polyglycols.
    - Paraffin waxes with melting temperatures between 20 °C and 70 °C, 250 MJ/L
    - Non paraffin organics: Fatty acids, their melting temperatures ranges between 15 °C and 65 °C

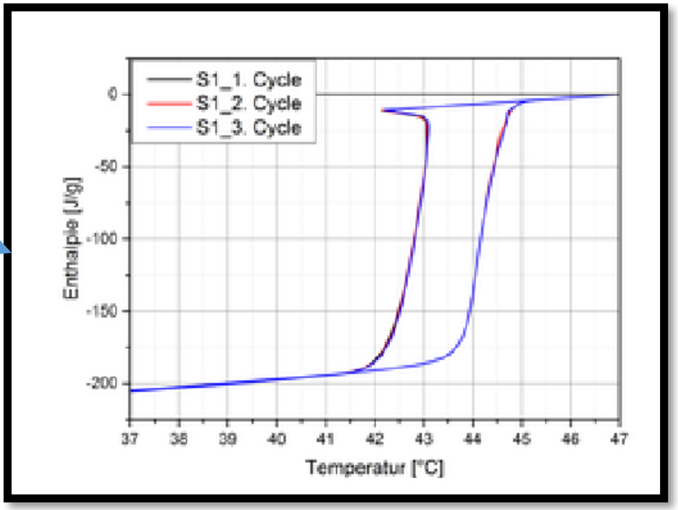
What to do with the FCC Waste Heat ? Storage

Interesting PCMs for LWHR (around 40ºC)

Name	Institution	Last Change	Melting Temperature	Heat of Fusion	Density (liquid)
			[ºC]	[kJ/kg]	[kg/m3]
PEG600	Fraunhofer ISE	Sep 07, 2017	13	137	
gypsum board	Fraunhofer ISE	Oct 18, 2019	18.48	19.4	
Micronal DS 5040 X	Fraunhofer ISE	Apr 09, 2018	19.07	93.6	
Micronal DS 5038 X	Fraunhofer ISE	Apr 09, 2018	21.5	96	
Octadecan Parafol 18-97	Fraunhofer ISE	Jun 13, 2017	27.35	231.3	
n-Octadecane, 99%	Fraunhofer ISE	Sep 07, 2017	27.5	233	
n-Octadecane, 99.5+%	Fraunhofer ISE	Sep 07, 2017	27.66	237	
PEG1000	Fraunhofer ISE	Sep 07, 2017	31	150	
CaBr2·6H2O	ZAE-Bayern	Apr 19, 2017	33.29	135.5	1956
Methyl Stearate (methyl octadecanoate)	Fraunhofer ISE	Sep 07, 2017	36.7	208	
Lauric acid (dodecanoic acid)	ZAE-Bayern	Apr 19, 2017	43.5	178.2	
Lauric acid (Dodecanoic acid)	Fraunhofer ISE	Sep 07, 2017	43.65	180	
RT 70 HC	Fraunhofer ISE	Oct 13, 2015	70.1	256.4	
HDPE natur NT D960/6	University of Lleida	Feb 17, 2022	126.77	221.3	
HDPE natur NT D960/6	Fraunhofer ISE	Oct 13, 2015	128	219	
HDPE natur NT D960/6 (0,5 K/min)	Universität Bayreuth	Feb 17, 2022	128.2	216.7	
NaNO3	Fraunhofer ISE	Oct 02, 2017	307	175	
Potassium nitrate (KNO3)	Fraunhofer ISE	Sep 13, 2016	329.6	92.5	

From: https://thermalmaterials.org/pcm/



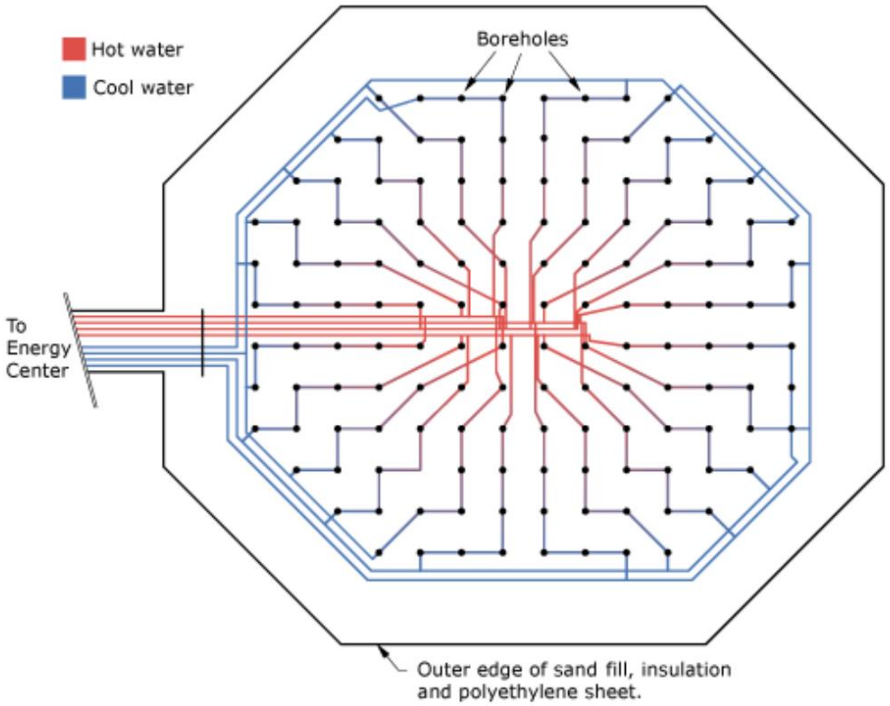


What to do with the FCC Waste Heat ? Storage

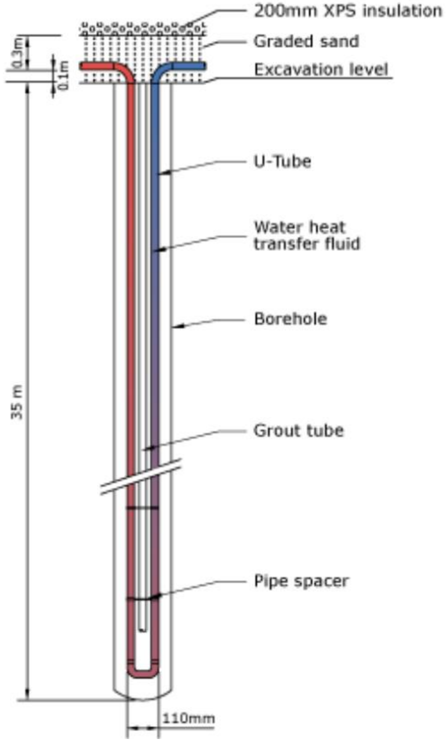
Boreholes for Energy Storage: an example of Alberta, Canada

- A BTES consists of:
  - an array of boreholes resembling standard drilled wells.
  - a plastic pipe with a "U" bend at the bottom is inserted down the borehole.
  - To provide good thermal contact with the surrounding soil, the borehole is filled with a high thermal conductivity grouting material.
- In this example:
  - 24 strings of 6 boreholes in series i. e. 144 boreholes
  - Boreholes
    - 144 – 150mm diameter
    - 35m deep
    - spaced 2.25m on centre.
    - High solids grout – 9% Blast Furnace Cement, 9% Portland cement, 32% fine silica sand, 50% water

Aerial view of Borehole Thermal Energy Storage (BTES)



Sideview of single Borehole Thermal Energy Storage (BTES) tube



From: https://dlsc.ca/index.htm

What to do with the FCC Waste Heat ? Storage

Boreholes as energy storage, Ferney's example

- *The energy network in the Ferney Geneva Innovation ZAC will recover the waste heat generated by one of CERN's particle accelerator to supply the heating needs of neighbouring buildings. The buildings will be able to draw on the heat via heat pumps according to their needs.*
- *As the demand for heating is higher in winter, the heat produced in summer will be stored underground and recovered in winter thanks to geothermal probes installed at a depth of up to 230 metres. Three geothermal probe fields will be installed*

From: https://www.environnement-magazine.fr/territoires/article/2023/02/16/142784/zac-ferneygeneve-celsius-energy-realise-des-champs-sondes-geothermiques

What to do with the FCC Waste Heat ? Storage

Heat storage in the tunnel rock

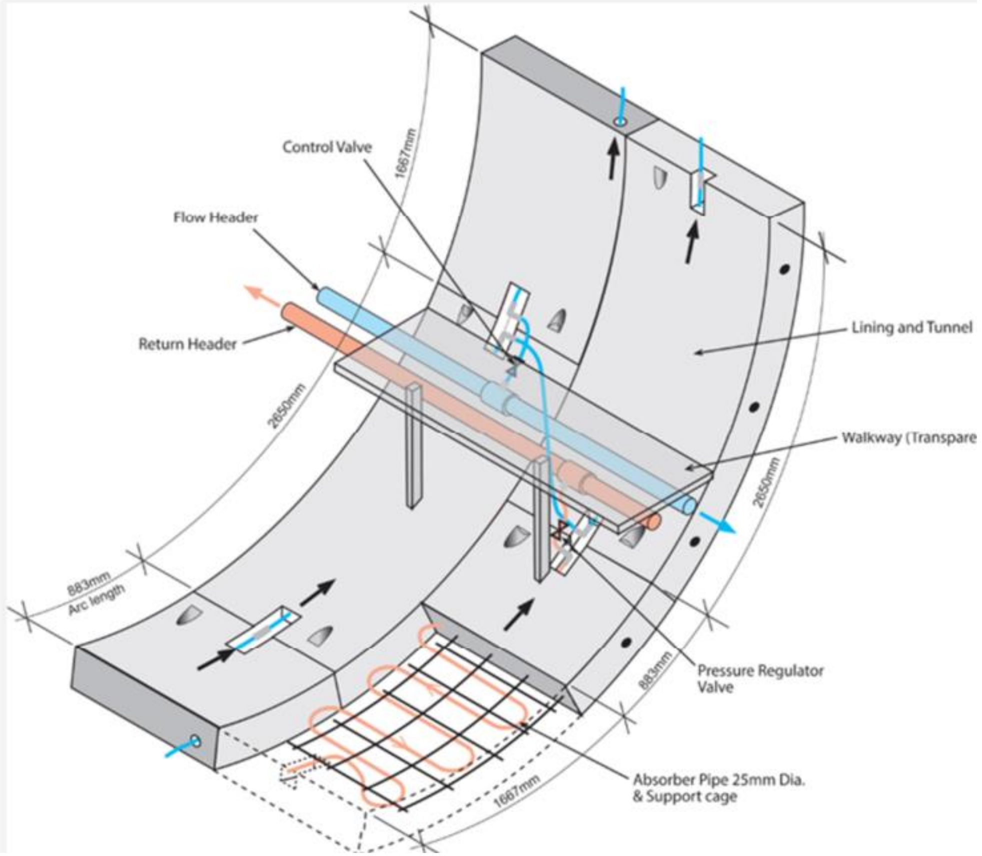
CLIC

Geothermal use of tunnels

Technical Report

Reference: ARUP_202204_CERN

| 05 May 2022



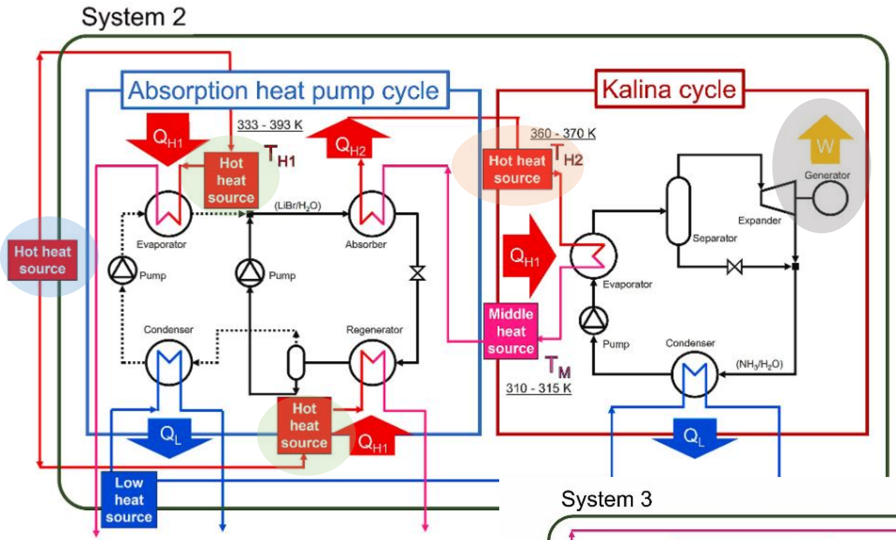
CLIC, Geothermal use of tunnels

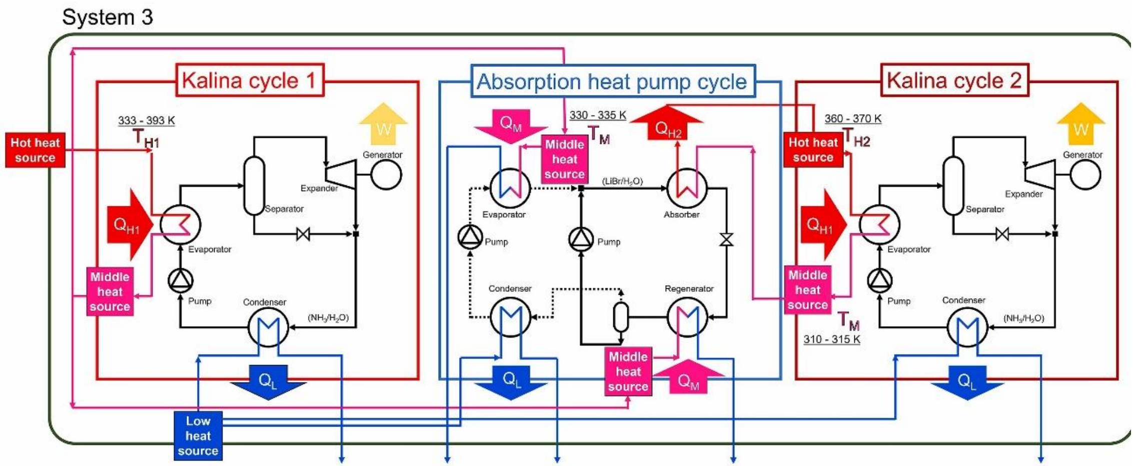
- The temperature of the wall would be about 14°C (The average tunnel axis level is on average 120m from surface, temp. gradient 35°C/km)
- Only heat extraction is not sustainable as the temperature of the tunnel rock decreases constantly at a high rate
- As with boreholes, heat extraction / heat rejection is needed
- Without adding the unknown cost, for a 600m tunnel to be converted to energy geostructure, the estimated cost is £243K.
- For 35 boreholes, it costs £210K.
- The 600m tunnel could have a capacity equivalent to 70 or more boreholes, the latter will cost £420K.
- On this basis, the tunnel is more cost-efficient than the boreholes, but we have under-estimated the tunnel cost. Our comparison is based on our UK experience.

What to do with the FCC Waste Heat ?

Heat Recovery to generate electricity

- Electricity can be generated from Waste Heat but… low efficiency with LWHR





From: R. Akimoto et al. Evaluation of a power generation system that integrates multiple Kalina cycles and absorption heat pumps. In «Case Studies in Thermal Engineering», 2021, Elsevier Vol. 28

What to do with the FCC Waste Heat ?

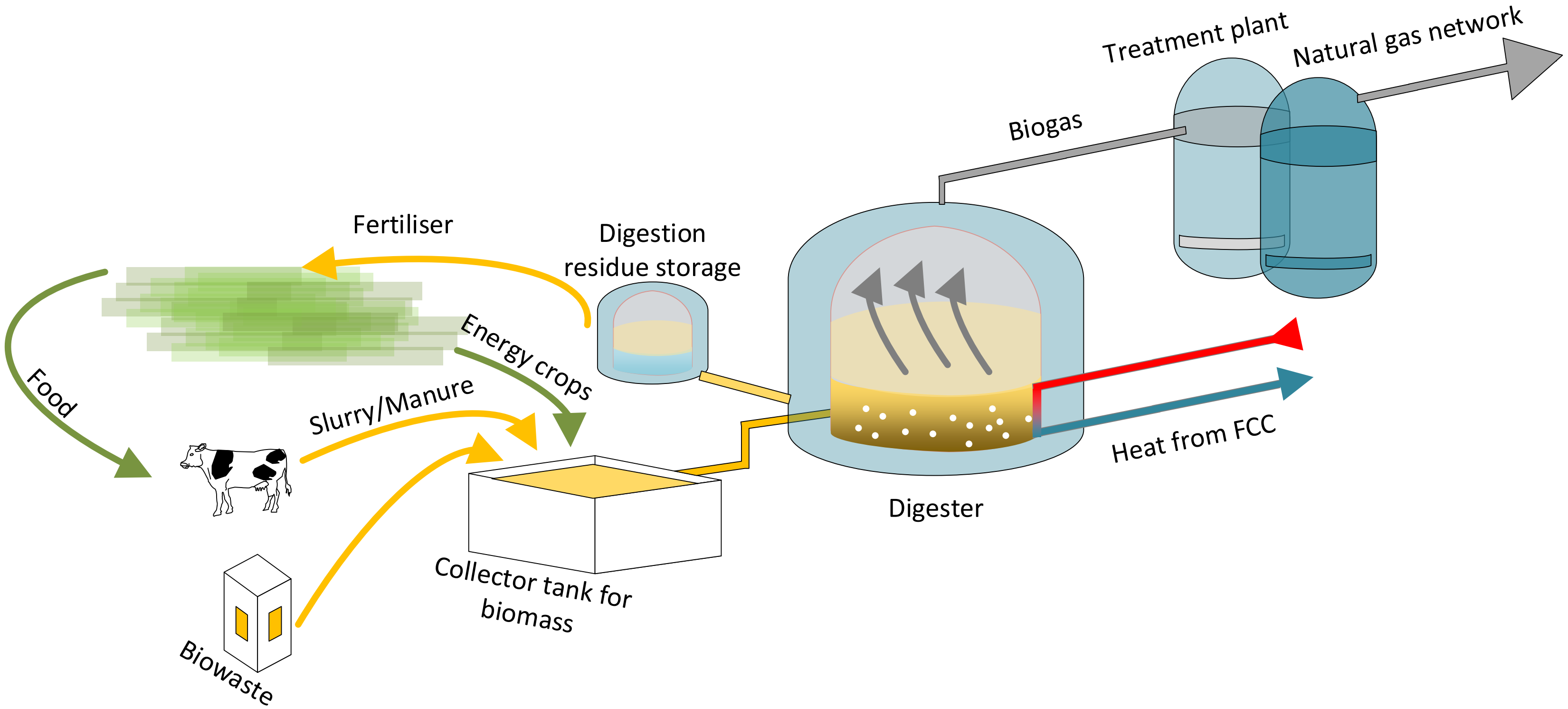
Heat Recovery in the Biogas production

Ref.: Mechanism of waste-heat recovery from slurry by scraped-surface heat exchanger in Applied Energy, Volume 207, 1 December 2017, Pages 146-155

The authors claim that recovering heat from slurry can increase the biogas production up to 8.5%.
But similar gains can be obtained when recovering heat from other processes.

Biogas production:

- The slurry is transferred to a closed tank (digester);
- The anaerobic digestion (AD) process for Biogas production can be
  - Mesophilic (Temperature around 37 °C) or
  - Thermophilic (55 °C) modes
- Recovered Heat from other processes can give the needed energy thus improving the efficiency of the process

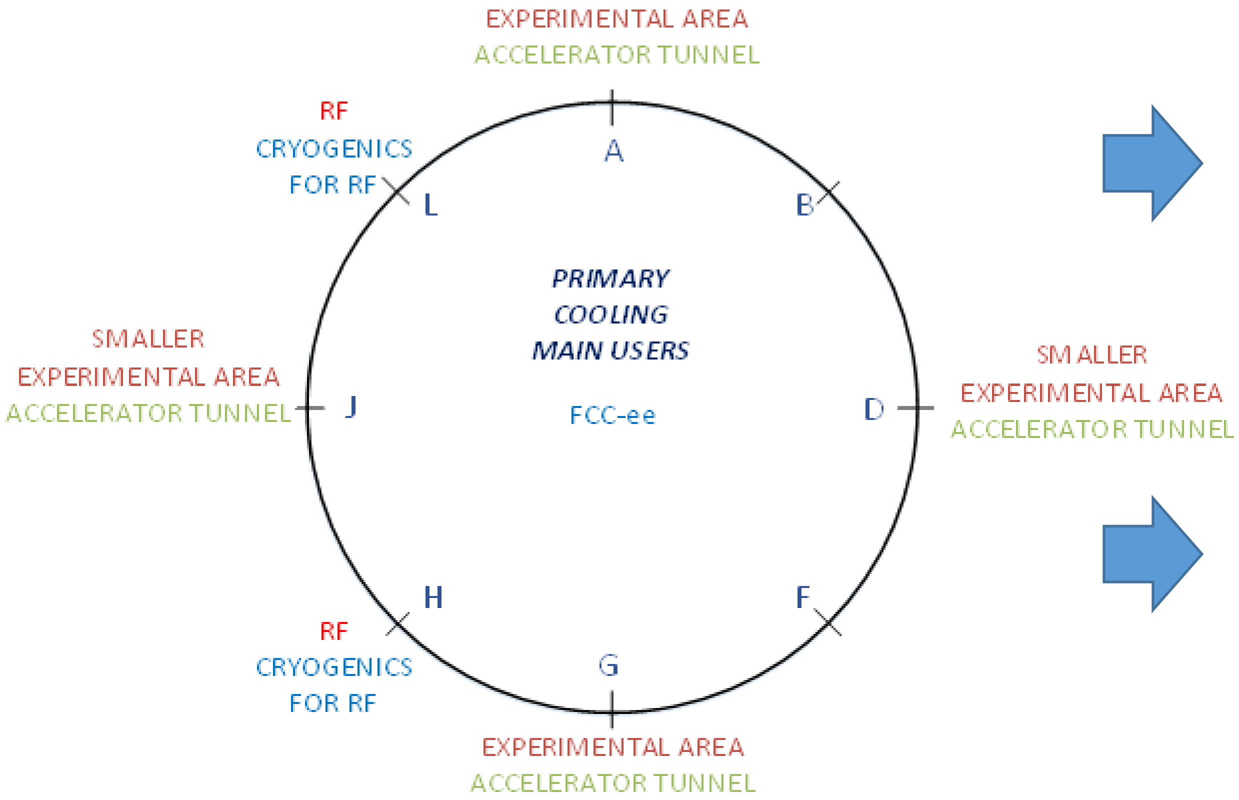


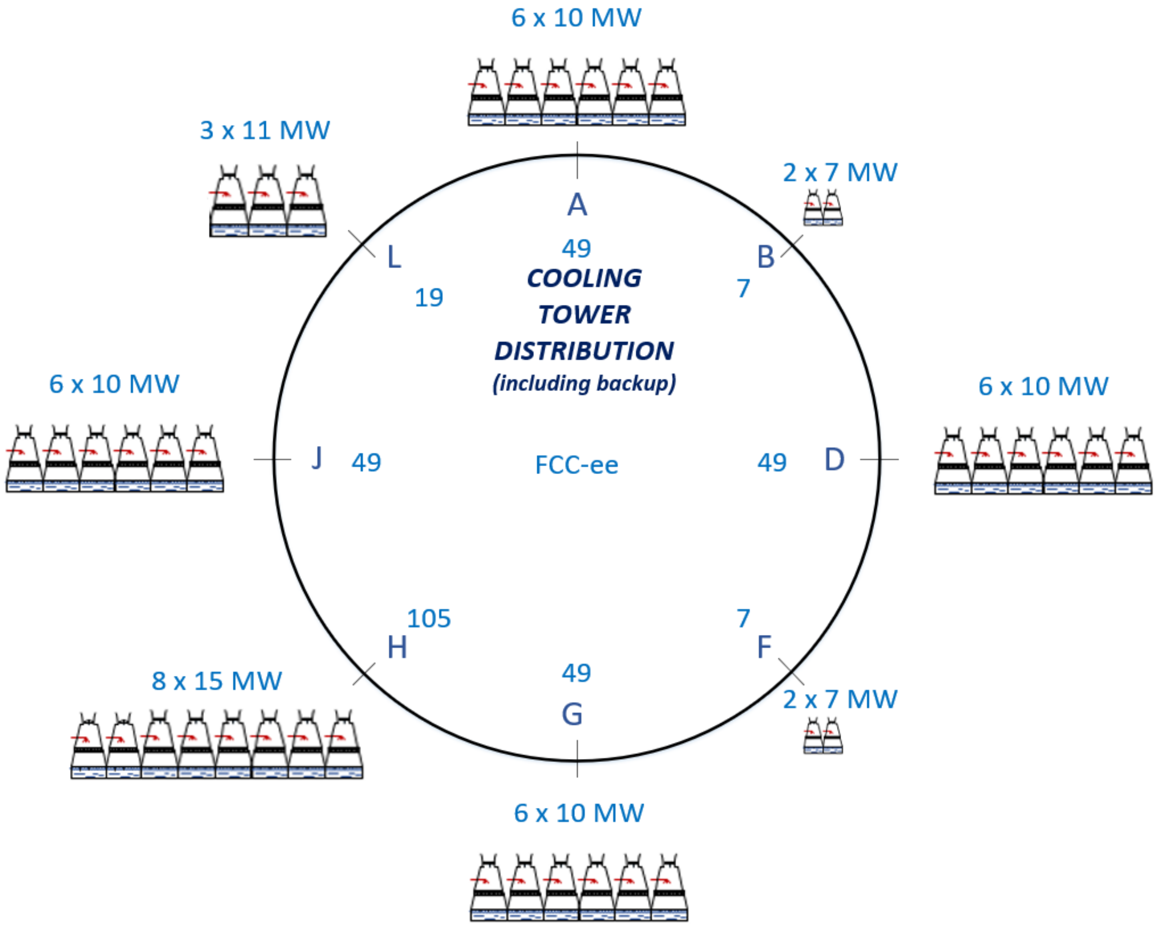
Primary Cooling Water

- The estimative cooling power needed is:

FCC-ee COOLING POWER NEEDS FOR PRIMARY CIRCUITS (MW)							
Point	Cryogenics	Experiment	General Services	Power Converters (RF)	Chilled water	From underground	**TOTAL**
PA		0.5	2		4,6	42.5	**49.6**
PB			2		3,9	1.0	**7.0**
PD		0.5	2		4,6	42.5	**49.6**
PF			2		3,9	1.0	**7.0**
PG		0.5	2		4,6	42.5	**49.6**
PH	40		2	4.5	10.1	48.6	**105.2**
PJ		0.5	2		4,6	42.5	**49.6**
PL	10		2	0.07	4.5	2.5	**19.1**

Primary Water : Cooling Towers (I)





Opportunities for Heat Recovery in the FCC

Disclaimer

- This is not a waste heat recovery and re-use study at concept or design level. It is a first exploration of the consumer-based analysis if waste heat recovery and re-use is worth looking in;
- The heat recovery is considered a durable compensation measure in the ERC approach and therefore remains to be studied in detail;
- Heat recovery and re-use will need to be built in from the beginning in the design of the accelerator and cooling systems to be effective;
- Co-development with the territorial stakeholders has to be engaged to make heat re-use and supply happening. Only if customers are willing to engage in such a project, including financial engagements, it can be done;
- Detailed socio-economic analysis will have to guide the design and implementation from a Benefit/Cost analysis point of view and it has not yet been done at the level of detail permitting a proper conclusion.
- **Acknowledgments to - Leslie Alix (CNRS)- Emanuela Sirtori (CSIL) - Francesco Giffoni (CSIL) as part of the socio-economic study team and to Johannes Gutleberg for his support**

Point A: Opportunities for Heat Recovery

- Located in Ferney Voltaire, in the vicinity of LHC point 8;
- Important synergies with point 8 of the LHC
- It can be connected to the same heat recovery network
- A new ZAC is at present under construction with heating needs;
- Vicinity to the Ecoquartier and to existing commercial sites: E. Leclerc, Espace Candide;
- More generally, there are numerous residential, commercial, educational and public service opportunities in the commune of Ferney-Voltaire
- Potential for connection with GeniLac.

Point B: Opportunities for Heat Recovery

- Located in Choulex (very close to Presinge);
- The HEPIA – Lullier at Jussy (*Haute école du paysage, d'ingénierie et d'architecture de Genève et Centre de formation professionnelle nature et environnement*):
  - 1.2 km away by road,
  - could benefit from the possibility of using waste heat for heating and cooling, energy loop;
  - Heating also for greenhouses;
- The Abbey organic farm,
  - Located 300 m away;
  - Heating of greenhouses;
  - Heating of stables for cows and chickens, riding school;
  - Heating of Presinge tennis club;
- The Foyer de Presinge, which takes in migrants, could also benefit from the supply of heat supply.

Tableau 25: Potentiel de consommation de chaleur du PB.

Commune	Filière	Distance	Consommation d'énergie GWh
Zone commune de Jussy (Nord-Est)			**2.00**
Jussy	Tertiaire	1.5km	1.00
Jussy	Agriculture	1.5km	1.00
Zone commune de Puplinge (Sud)			**5.85**
Puplinge	Tertiaire	1.3km	5.85
Zone commune de Presinge (Est)			**0.78**
Presinge	Tertiaire	1.5km	0.78

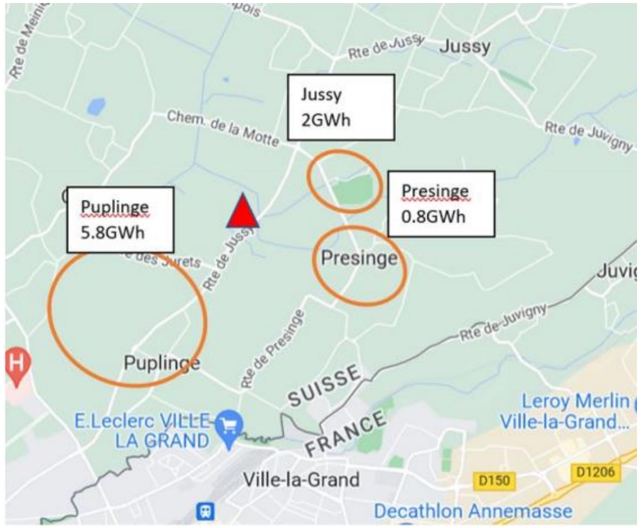


Illustration 124 : Zones à potentiel de consommation de chaleur du PB.

Point D: Opportunities for Heat Recovery

- Located in Nangy;
- "Alpes-Leman" hospital:
  - Less than 300 m away
  - District heating network
  - Heat can also be supplied to all medical services in the vicinity of the hospital and possibly to neighbouring houses.
- There is a district heating network:
  - In the centre of Reignier, 3.5km to the west of the PD, too far away ?
- Two cheese producers to the north of the site on the D1205 at a distance of 350 m to 500 m
  - Potential heat consumers for the production process.

Tableau 26 : Potentiel de consommation de chaleur du PD.

Commune	Filière	Distance	Consommation d'énergie GWh
Zone Hôpital (Est)			**9.00**
Contamine-sur-Arve/Nangy	Tertiaire	400 m	9.00
ZAE des Bègues (Nord)			**4.89**
Fillinges	Industrie alimentaire	700 - 800m	4.89
Zone commune de Nangy (Nord-Ouest)			**0.61**
Nangy	Résidentiel	1 km - 1.8 km	0.61

Illustration 125 : Zones à potentiel de consommation de chaleur du PD.

Point F: Opportunities for Heat Recovery

- Located in Éteaux / La Roche sur Foron
- Proximity to:
  - Three business parks (with approximately 260 companies)
  - Various public facilities in Éteaux and La Roche-sur-Foron, providing the possibility of a heating network,
  - Restaurants and hotels
- Wastewater treatment plant nearby.

Tableau 27 : Potentiel de consommation de chaleur du PF.

Commune	Filière	Distance	Consommation d'énergie GWh
Zone Etaux (Nord-Est)			**7.04**
Etaux/La Roche-sur-Foron	Industrie	1.8 km-2 km	6.77
Etaux	Résidentiel	1.9 km	0.27
Zones d'activités Nord (Nord-Est)			**3.40**
La Roche-sur-Foron	Tertiaire	3.1 km-3.3 km	0.84
La Roche-sur-Foron	Industrie	3.1 km-4 km	2.56
Zone commune La Roche-sur-Foron Nord (Nord-Est)			**5.31**
La Roche-sur-Foron	Tertiaire	3 km-3.3 km	5.31
Zone commune La Roche-sur-Foron Centre (Nord-Est)			**1.20**
La Roche-sur-Foron	Tertiaire	3.2 km-3.5 km	1.20
Zone commune La Roche-sur-Foron Ouest (Nord-Est)			**1.31**
La Roche-sur-Foron	Tertiaire	2.8 km	1.31
Zone commune La Roche-sur-Foron Nord, Centre et Ouest (Nord-Est)			**3.48**
La Roche-sur-Foron	Résidentiel		3.48

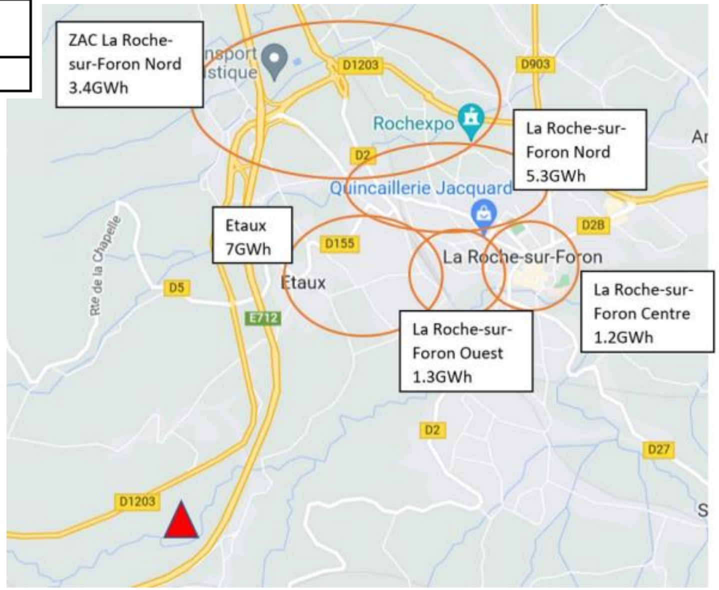


Illustration 126 : Zones à potentiel de consommation de chaleur du PF.

Point G: Opportunities for Heat Recovery

- Located in Charvonnex / Groisy
- Waste heat could heat up:
  - The commercial area of Longchamp, about 1800 m to the north-east;
  - The residential buildings in Charvonnex;
  - A shopping centre, numerous businesses (around 260), catering services.
- Wastewater treatment plant nearby.

Tableau 28 : Potentiel de consommation de chaleur du PG.

Commune	Filière	Distance	Consommation d'énergie GWh
Zone commune de Charvonnex (Sud)			**0.33**
Charvonnex	Résidentiel	1.5 km	0.33
ZA Longchamp (Nord-Est)			**0.39**
Groisy	Tertiaire	1.7 km	0.39
Zone commune de Groisy (Nord)			**2.40**
Groisy	Tertiaire	2.5 km-4 km	0.78
Groisy	Résidentiel	2.5 km-4 km	1.63
Zone Commune de Groisy Ouest (Nord-Ouest)			**1.56**
Groisy	Tertiaire	4 km	1.56
ZA Argonay			**7.13**
Argonay	Tertiaire	4.3 km-7 km	3.43
Argonay	Industrie	4.3 km-7 km	2.44
Argonay	Résidentiel	4.3 km-7 km	1.26

Illustration 127 : Zones à potentiel de consommation de chaleur du PG.

Point H: Opportunities for Heat Recovery

- Located in Marlioz / Cercier;
- Very few potential consumers;
- Tourism: an educational farm and an equestrian center are nearby;
- Agricultural areas;
- Wastewater treatment plant nearby.

Point J: Opportunities for Heat Recovery

- Located in Dingy-en-Vuache et Vulbens
- Opportunity to develop heat networks, particularly towards the commercial and activity zone to the north-east.
- The Vulbens/Valleiry ZAC, with around 30 companies, is set to expand and therefore seems interesting,
- Minzier wastewater treatment plant nearby,

Tableau 29 : Potentiel de consommation de chaleur du PJ.

Commune	Filière	Distance	Consommation d'énergie GWh
ZA de Valleiry (Nord-Est)			**1.05**
Valleiry	Tertiaire	1.5km	1.05
Zone commune de Valleiry (Nord-Est)			**3.63**
Valleiry	Résidentiel	2.5km	3.63
ZI de l'Acquit (Nord-Est)			**0.21**
Valleiry	Tertiaire	3km	0.21
Zone commune de Vulbens (Nord-Ouest)			**1.00**
Vulbens	Tertiaire	2.1km	0.60
Vulbens	Résidentiel	2.1km	0.40

Illustration 128 : Zones à potentiel de consommation de chaleur du PJ.

Point L: Opportunities for Heat Recovery

- Located in Challex
- Possibility of creating a heating network for public facilities, businesses or housing, in particular with the Thoiry ZAC,
- Waste heat from the site could be supplied to the village for heating purposes.
- If necessary, market gardening and fruit growing would particularly benefit from this supply.

Tableau 30 : Potentiel de consommation de chaleur du PL.

Commune	Filière	Distance	Consommation d'énergie GWh
Zone commune de Challex (Sud-Ouest)			**1.34**
Challex	Tertiaire	900 m-1.5 km	0.40
Challex	Résidentiel	900 m-1.5 km	0.95
Zone Centre Commercial de Thoiry (Nord-Est)			**6.70**
Thoiry	Tertiaire	7 km	4.68
Thoiry	Industrie	7 km	2.02

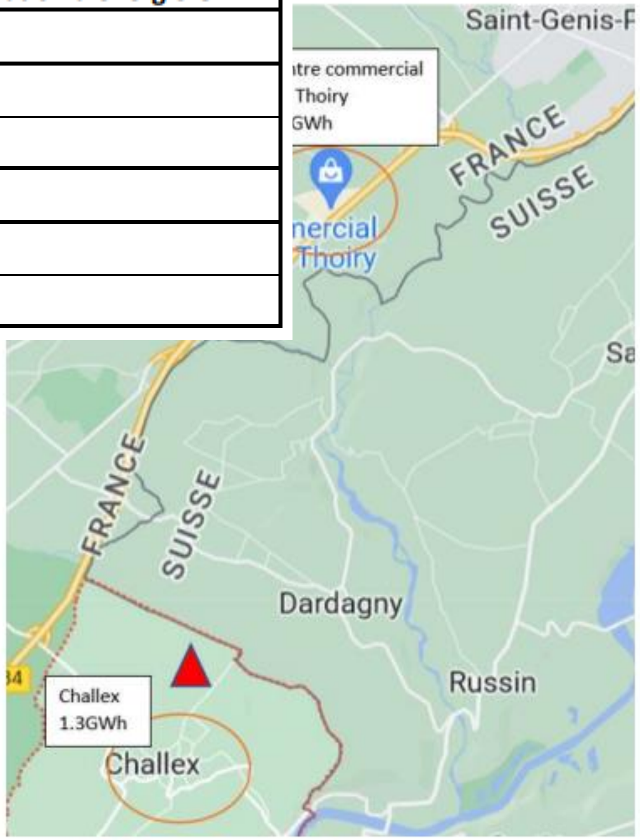


Illustration 129 : Zones à potentiel de consommation de chaleur du PL.

Conclusions

- A considerable number of groups of researches are studying the subject as worldwide a large proportion of the used energy is dissipated to the air or water;
- WHR needs to be interlinked with the existing infrastructures and the future development of the region closed to the FCC surface points: fields such as industry, agricultural facilities (including Biogas production), tertiary, leisure, … can take profit of it : constant communication on the subject with regional stakeholders is of a primary importance.
- Direct use of the WHR for heating (buildings or processes) is the most efficient way to take profit of it;
- Best way to recover heat is when heat source and heat sink are functionally related → simple operation;
- Never forget: reducing energy consumption is always better than recovering it.

Thank you
for your attention.