HIGH-TEMPERATURE HEAT PUMPS

IEA HPT TCP Annex 58
14th Status Meeting

25 April 2023 | Aarhus

SWISS NATIONAL MARKET
(Synthesis of Annex 58 Task 1 Report)

Dr. Cordin Arpagaus
OST
1. Introduction to HTHP-CH Project and IEA HPT Annex 58 HTHP
2. Market and application potential
3. Funding programs for industrial heat pumps
4. Realized HTHP application examples
5. Overview of the Swiss national HTHP industry
6. R&D projects on HTHPs
Why did we create this HTHP-CH project?

Motivation:
• Establish a larger joint Swiss project with multiple partners (joint forces)
• Integration of HTHPs in Swiss industry
• Participation in Annex 58 on HTHPs

Industrial Swiss Partners

IEA HPT Annex 58 HTHPs
IEA: International Energy Agency
HPT: Heat Pumping Technologies
Structure of the HTHP-CH project
(3 years, Q4/2021 to Q1/2024)

WP1: Defining favorable framework for HTHP integration
WP2: Suitable concepts for HTHP integration
WP3: Solution generation for optimal HTHP integration
WP4: Guideline & tool for HTHP integration in practice
WP5: Project management and dissemination

Case studies
Process information
Cost information
Contacts to planners

Workshops with industry
Endusers
HP manufacturers
Installers
Planners
Associations

Energy data
Cost data

WP1
WP2
WP3
WP4
WP5

National knowledge exchange
Dissemination of guideline & tool
International knowledge exchange

Participation in IEA HPT Annex 58 HTHPs
Task 1 (Technologies), Task 2 (Concepts), Task 3 (Applications),
Task 4 (Definitions and testing of HP specifications), Task 5 (Dissemination)

SWEET DeCarbCH
Decarbonization of Cooling and Heating in Switzerland
www.sweet-decarb.ch
Today, 48% of process heat is produced by fossil fuels (Data source: BFE, 2022)
The distribution of the total heating capacity illustrates the potential for decarbonization of the Swiss industry (Data source: GKS, 2022)
### Potential calculation for HTHPs in Switzerland

<table>
<thead>
<tr>
<th>Category</th>
<th>Value (GWh)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swiss industry energy consumption</td>
<td>42'972</td>
<td>154.7 PJ (as of 2018, SFOE)</td>
</tr>
<tr>
<td>Process heat demand</td>
<td>24'107</td>
<td>56.1% (SFOE, 2019)</td>
</tr>
<tr>
<td>Process heat demand &lt; 150 °C</td>
<td>7'232</td>
<td>30% estimate, Heat Roadmap Europe</td>
</tr>
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<td>30% estimate, Heat Roadmap Europe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>A</th>
<th>B</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion change to HTHPs</td>
<td>10%</td>
<td>50%</td>
<td>Own estimate</td>
</tr>
<tr>
<td>Addressable process heat by HTHPs</td>
<td>723</td>
<td>3'616 GWh</td>
<td>Own estimate</td>
</tr>
<tr>
<td>% of total process heat demand by HTHPs</td>
<td>3%</td>
<td>15%</td>
<td>Own estimate</td>
</tr>
<tr>
<td>Heating capacity of installed HTHPs</td>
<td>145</td>
<td>723 MW</td>
<td>5'000 h/a operation, assumed average</td>
</tr>
<tr>
<td>Electrical need for HTHPs</td>
<td>241</td>
<td>1'205 GWh</td>
<td>COP = 3, own estimate</td>
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<tr>
<td>Energy savings by HTHPs use</td>
<td>482</td>
<td>2'411 GWh</td>
<td>Own estimate</td>
</tr>
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</table>

### Investment volume

<table>
<thead>
<tr>
<th>Category</th>
<th>Min</th>
<th>Max</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>Investment volume min</td>
<td>69</td>
<td>347 Mio. CHF</td>
<td>480 CHF/kW (Wolf et al., 2017)</td>
</tr>
<tr>
<td>Investment volume max</td>
<td>108</td>
<td>542 Mio. CHF</td>
<td>750 CHF/kW (Wolf et al., 2017)</td>
</tr>
<tr>
<td>HTHP units</td>
<td>145</td>
<td>723 Units</td>
<td>1 MW average size, own estimate</td>
</tr>
</tbody>
</table>

High Temperature Heat Pumps | Swiss National Market | 25 April 2023 | Cordin Arpagaus
Technology adoption of heat pumps in Switzerland

Market share of heat pumps in new heating installations

- **Innovators**: 2.5%
- **Early adopters**: 13.5%
- **Early majority**: 34%
- **Late majority**: 34%
- **Laggards**: 16%

Industry 2022 (CH)

Buildings 2022 (CH)

- **65%**
Market Attractiveness depends on Price Ratio between Electricity and Gas

- Decarbonization requires increased use of **renewable electricity**
- **Electricity is more expensive** than fossil fuel in many European countries

For small scale industrial end-users with
2 GWh/a to 20 GWh/a electricity
3 GWh/a to 28 GWh/a gas

Electricity and gas prices for industrial companies in Switzerland

Data source:
Federal Statistical Office (2022)
Case studies of Industrial Heat Pumps in Switzerland


- Presents case studies of successful applications of industrial heat pumps in Switzerland
- Promotes further market penetration of industrial heat pumps
- Highlights typical applications in large-scale
- Establishes a framework for comparison
### Application examples of industrial heat pumps in Switzerland in the food & beverage sector

<table>
<thead>
<tr>
<th>Company, location</th>
<th>Application, process</th>
<th>Heating capacity (kW)</th>
<th>Temperature range (°C)</th>
<th>$\Delta T_{\text{lift}}$ (K)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kably SA, Trubschachen</td>
<td>Hot water for biscuit production</td>
<td>471</td>
<td>20, 65</td>
<td>45</td>
<td>(1), (2)</td>
</tr>
<tr>
<td>Kellermann AG, Ellikon an der Thur</td>
<td>Hot water for greenhouse heating</td>
<td>1000</td>
<td>6, 65</td>
<td>59</td>
<td>(1), (2)</td>
</tr>
<tr>
<td>Hilcona AG, Schaan (LU)</td>
<td>Hot water for fresh convenience foods</td>
<td>507</td>
<td>31, 67</td>
<td>36</td>
<td>(1), (2)</td>
</tr>
<tr>
<td>Nutrex, Busswil bei Büren</td>
<td>Vinegar fermentation and pasteurization</td>
<td>194</td>
<td>30, 70</td>
<td>40</td>
<td>(1), (2)</td>
</tr>
<tr>
<td>Chocolate factory Maestrani, Flawil</td>
<td>Hot water, heating, cooling</td>
<td>276</td>
<td>17, 70</td>
<td>53</td>
<td>(1), (2), (3)</td>
</tr>
<tr>
<td>Feldschlösschen, Rheinfelden</td>
<td>Hot water for beer pasteurization</td>
<td>400</td>
<td>16, 73</td>
<td>57</td>
<td>(4), (5)</td>
</tr>
<tr>
<td>Slaughterhouse, Zurich</td>
<td>Hot water, cleaning water</td>
<td>800</td>
<td>20, 90</td>
<td>70</td>
<td>(1), (2)</td>
</tr>
<tr>
<td>Cheese factory, Gais Appenzell</td>
<td>Hot water for cheese processes, heating</td>
<td>520</td>
<td>18, 92</td>
<td>74</td>
<td>(6), (7)</td>
</tr>
<tr>
<td>GVS Weinkellerei, Schaffhausen</td>
<td>Hot water for cleaning, heating, cooling</td>
<td>63</td>
<td>37, 95</td>
<td>58</td>
<td>(1), (2), (8)</td>
</tr>
<tr>
<td>New Roots AG, Oberdiessbach</td>
<td>Cold air and process water for cheese</td>
<td>n.a.</td>
<td>-8, 105</td>
<td>113</td>
<td>(9)</td>
</tr>
<tr>
<td>Gustav Spiess AG, Berneck</td>
<td>Steam for sausage cooking</td>
<td>550</td>
<td>50, 115</td>
<td>65</td>
<td>Potential (10)</td>
</tr>
<tr>
<td>Cremo SA, Villars sur Glâne</td>
<td>Hot air for drying process of milk products</td>
<td>940</td>
<td>38, 120</td>
<td>82</td>
<td>Potential (10)</td>
</tr>
<tr>
<td>ELSA, Estavayer-le-Lac</td>
<td>Steam for CIP process in milk production</td>
<td>3150</td>
<td>50, 148</td>
<td>98</td>
<td>Potential (10)</td>
</tr>
</tbody>
</table>

**References:**
1. (Arpagaus and Bertsch, 2020a),
2. (Arpagaus and Bertsch, 2020b),
3. (Arpagaus, 2019a),
4. (Möhr and Bertsch, 2022),
5. (EnergieSchweiz, 2022a),
6. (Arpagaus, 2019b),
7. (Arpagaus, 2019c),
8. (EnergieSchweiz, 2021),
9. (EnergieSchweiz, 2022b),
10. (Arpagaus et al., 2023)
Decarbonization of process heat

Financing:
40% of additional costs compared to conventional heating technologies

Link to eligibility criteria

Contact:
Irène Barras, +41 58 465 25 68
irene.barras@bfe.admin.ch
### Financial help for industrial heat pumps in Switzerland

<table>
<thead>
<tr>
<th>Funding program</th>
<th>Pinch Analyses</th>
<th>Heat Pumps for Process Heat</th>
<th>Klimaprämié (Climate bonus)</th>
<th>Pilot and Demonstration (P&amp;D projects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program manager</td>
<td>EnergieSchweiz (SuisseEnergie)</td>
<td>EnergieSchweiz (SuisseEnergie)</td>
<td>Energie Zukunft Schweiz</td>
<td>SFOE</td>
</tr>
<tr>
<td>Financing</td>
<td>SFOE</td>
<td>SFOE</td>
<td>KliK Foundation</td>
<td>SFOE</td>
</tr>
<tr>
<td>Amount</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-analyses: max. 60% of total costs</td>
<td>Max. 40% of additional costs compared to conventional technology (e.g., oil or gas boiler)</td>
<td>0.18 CHF/kWh heat at 2’000 h annual operation</td>
<td>Up to 40% (60%) of non-amortizable supplementary costs</td>
</tr>
<tr>
<td>Funding criteria</td>
<td>Using PinCH-Software</td>
<td>Industrial process heat Payback &gt; 4 years</td>
<td>Replacement of oil/gas boiler with HP</td>
<td>Application potential</td>
</tr>
<tr>
<td></td>
<td>Trained experts</td>
<td>Funding request before construction starts</td>
<td>Order not yet placed</td>
<td>Innovation content</td>
</tr>
<tr>
<td></td>
<td>Publication of findings (summary, final report)</td>
<td>CO₂ savings to be transferred to Energie Zukunft Schweiz</td>
<td>Demonstration: TRL 7 to 9</td>
<td>Pilot: TRL 4 to 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Publication of findings (final report)</td>
</tr>
</tbody>
</table>
Selection heat pump manufacturers in Switzerland (not an exhaustive list)

- Scheco AG
  - [https://www.scheco.ch](https://www.scheco.ch)
- Walter Wettstein AG Kältetechnik
  - [https://www.wwag.ch](https://www.wwag.ch)
- Zero-C
  - [www.zero-c.ch](http://www.zero-c.ch)
- Friotherm AG
  - [https://www.friotherm.com](https://www.friotherm.com)
- MAN Energy Solutions
  - [https://www.man-es.com](https://www.man-es.com)
Realized HTHP application examples in Switzerland

Cheese factory Gais Appenzell
(process water 90 °C)

Slaugtherhouse Zurich
(hot water 90 °C for cleaning)

Sauna NEST EMPA
(hot water up to 120 °C)
Realized HTHP application examples in Switzerland

<table>
<thead>
<tr>
<th>Enduser</th>
<th>GVS Landi, Schaffhausen-Herblingen</th>
<th>Resilux Schweiz AG, Bilten</th>
</tr>
</thead>
</table>
| Application, temperatures, heating capacity | • Cleaning of bottles and wine tanks, heating/hot water  
• 37 °C → 80 to 95 °C (hot water)  
• 63 kW heating capacity | • Production of PET blanks  
• 50 °C → 90 to 95 °C (hot water)  
• 400 kW heating capacity |
| Heat pump type | • Ochsner ISWHS 60ER3 (economizer cycle)  
• Screw compressor  
• ÖKO 1 (R245fa) | • 2x Viking HeatBooster HBS4,  
• Piston compressor  
• R245fa |
<table>
<thead>
<tr>
<th>Enduser</th>
<th>NEST EMPA, Dübendorf</th>
<th>R&amp;D project</th>
</tr>
</thead>
</table>
| **Application, temperatures, heating capacity** | - Wellness area (sauna and hot water)  
- 3 temperature levels  
- Stratified storage tank | - Waste heat of an electrolyzer of a hydrogen production as heat source |
| **Heat pump type** | - Water-to-water HP  
- R744 (CO$_2$)  
- 35% to 100% part-load  
- 19 kW heating capacity  
- COP of 3.6  
- 80 °C → 120 °C (sink)  
- 35 °C → 75 °C (sink)  
- 30 °C → 35 °C (sink)  
- 17 °C → 12 °C (source) | - Water/brine HP  
- R245fa  
- 35% to 100% part-load  
- 54 kW heating capacity  
- COP of 2.3  
- 93 °C → 100 °C (sink)  
- 35 °C → 30 °C (source) |
Walter Wettstein AG

Customized solutions with plant engineering
- Proven years of experience in the planning, installation and maintenance of large heat pumps
- 365 x 24 h support with a total of 55 service technicians
- Extensive spare parts warehouse in Gümligen (>13'000 items)

<table>
<thead>
<tr>
<th>Compressor</th>
<th>Piston /Screw</th>
<th>Piston</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working fluid (Refrigerant)</td>
<td>R717 (NH₃, ammonia)</td>
<td>R717 / R600 (n-butane)</td>
</tr>
<tr>
<td>Heating capacity</td>
<td>0.2 to 20 MW</td>
<td>0.2 to 2 MW</td>
</tr>
<tr>
<td>Source in → out</td>
<td>60 to 10 → 50 to 0 °C</td>
<td>60 to 30 → 50 to 20 °C</td>
</tr>
<tr>
<td>Sink out</td>
<td>Up to 85 °C (implemented)</td>
<td>Up to 118 °C</td>
</tr>
<tr>
<td>Comments</td>
<td>• implemented up to 1.4 MW • up to 70 °C up to 6 MW per plant • up to 4 plants in parallel</td>
<td>in planning</td>
</tr>
</tbody>
</table>
• ZERO-C / Climat Gestion SA: European market
• Specializes on chillers and heat pumps using natural refrigerants
• InnoSuisse project: Compact Low Charge Natural Fluid Turbocompressor for Industrial & Commercial Chillers
• SFOE P&D projects: Heat and cold distribution network using CO\(_2\) as a heat transfer medium (CO\(_2\) network)
• References:
  • Patek Philippe with 16 chillers / heat pumps for a total of 15 MW
  • EMPA with a 570 kW two-stage heat pump with 4 operating modes
  • ZERO-C has also designed its own bench for testing heat pumps up to 2 MW
Friotherm AG – Application range of heat pumps with heat supply temperatures above 100 °C

1- and 2-stage tailor-made HPs
- Centrifugal compressor
- 3 MW to 35 MW
- Various liquid heat sources
- Wide temperature range
- Supplying hot water temperatures up to 120 °C (higher on request)

Customized double-group HP
- 22.5 x 10.8 x 6.8 m (L x W x H)
- up to 35 MW heating capacity

HP producing superheated water at 137 °C
- Low-pressure steam generation
- 25 MW heating capacity
- 55/40 °C heat source
- 130/137 °C heat sink
- R1233zd(E) refrigerant
- COP of around 2.5
- approx. 18 x 15 x 10 m
Return temperature $T_{\text{ret}}$ [°C]

Supplementary table:

<table>
<thead>
<tr>
<th>$T_{\text{source,in}}$ [°C]</th>
<th>$T_{\text{source,out}}$ [°C]</th>
<th>$T_{\text{sink,in}}$ [°C]</th>
<th>$T_{\text{sink,out}}$ [°C]</th>
<th>COP$_{\text{heating}}$ *</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>7</td>
<td>40</td>
<td>110</td>
<td>3.05</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>30</td>
<td>95</td>
<td>3.25</td>
</tr>
<tr>
<td>20</td>
<td>17</td>
<td>50</td>
<td>150</td>
<td>2.85</td>
</tr>
</tbody>
</table>

*) calculated (i.e. predicted) values
Research project – Steam-generating heat pump
Innosuisse (42533.1 IP-EE)

Variable | Target value
---|---
$T_{\text{Sat,steam,Turbo}}$ | 148 °C (4.5 bar)
$T_{\text{Sat,steam,HP}}$ | 111 °C (1.5 bar)
$T_{\text{Sink,in}}$ | 100 °C
$T_{\text{Source,in}}$ | 50 °C
$\dot{Q}_{\text{HP}}$ | 115 kW
$\dot{m}_{\text{steam}}$ | 50 g/s

Research project – Testing HFO/HCFO refrigerants in lab-scale HTHP up to 150 °C (SCCER EIP)

Lab-scale HTHP with 5 to 10 kW heating capacity

HFO: Hydrofluorolefine, HCFO: Hydrochlorfluorolefine

Properties:
- Low GWP
- Zero/near zero ODP
- Short atmospheric life
- Not flammable
- Not toxic

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>ODP</th>
<th>GWP$_{100}$</th>
<th>SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1336mzz(Z)</td>
<td>0</td>
<td>2</td>
<td>A1</td>
</tr>
<tr>
<td>R1233zd(E)</td>
<td>0.00034</td>
<td>1</td>
<td>A1</td>
</tr>
<tr>
<td>R1224yd(Z)</td>
<td>0.00023</td>
<td>0.88</td>
<td>A1</td>
</tr>
<tr>
<td>R245fa</td>
<td>0</td>
<td>858</td>
<td>B1</td>
</tr>
</tbody>
</table>
Research project – Refrigerant mixtures for large temperature glides (SNF Bridge Discovery, 203645)

**One mixture → many options**

Mixture A + B

High flexibility in T-levels and T-glide

Animation from Swiss Bridge Project: High-efficiency high-temperature heat pumps with temperature glide
<table>
<thead>
<tr>
<th>Project</th>
<th>Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCCER EIP – Swiss Competence Center for Research in Energy, Efficiency</td>
<td>ETHZ, EPFL, EAWAG, EMPA, HSLU, OST, FNHW,</td>
</tr>
<tr>
<td>of Industrial Processes (InnoSuisse, Swiss Innovation Agency, 2013-2020,</td>
<td>UNIGE</td>
</tr>
<tr>
<td><a href="http://www.sccer-eip.ch">www.sccer-eip.ch</a></td>
<td></td>
</tr>
<tr>
<td>ARAMIS description (Project No. SI/501782), <a href="http://www.heatpumpingtechnologies.org/annex48">www.heatpumpingtechnologies.org/annex48</a></td>
<td></td>
</tr>
<tr>
<td>Methods for developing integrated industrial heat pump systems considering</td>
<td>EPFL</td>
</tr>
<tr>
<td>existing and novel components, SFOE, 2016-2019), Description, Report,</td>
<td></td>
</tr>
<tr>
<td>Refrigerant Selection Tool</td>
<td></td>
</tr>
<tr>
<td>SGHP – Steam-generating heat pump (InnoSuisse, 2020-2023)</td>
<td>OST, EPFL</td>
</tr>
<tr>
<td>SWEET DeCarbCH – Decarbonization of Cooling and Heating in Switzerland</td>
<td>UNIGE, ETHZ, OST, HSLU, ZHAW, EMPA, Industrial</td>
</tr>
<tr>
<td>(SFOE, 2021-2028), ARAMIS description, (Project No. SI/502260), <a href="http://www.sweet-decarb.ch">www.sweet-decarb.ch</a></td>
<td>partners</td>
</tr>
<tr>
<td>IntSGHP – Integration of steam-generating heat pumps in industrial sites</td>
<td>OST, Industrial partners</td>
</tr>
<tr>
<td>(retrofit) (SFOE, 2021-2023), ARAMIS description, (Project No. SI/502292)</td>
<td></td>
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<tr>
<td>Case studies of industrial and high-temperature heat pumps (Swiss Federal</td>
<td>OST, Industrial partners</td>
</tr>
<tr>
<td>Office of Energy, 2018-2022)</td>
<td></td>
</tr>
<tr>
<td>High-efficiency, high-temperature heat pumps with temperature glide (Bridge</td>
<td>ETHZ, OST, Industrial partners</td>
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<tr>
<td>Discovery, SNF, Swiss National Science Foundation, 2022-2025), SNF</td>
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<tr>
<td>description (Grant number 203645)</td>
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<tr>
<td>DeCarb-PUI – Decarbonization of industrial processes through redesign of</td>
<td>HEIG-VD, HSLU, Industrial partners</td>
</tr>
<tr>
<td>the process-utility interface, SFOE, P+D project, 2021-2024), ARAMIS</td>
<td></td>
</tr>
<tr>
<td>description (Project No. SI/502298)</td>
<td></td>
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<tr>
<td>HTHP-CH – Integration of HTHPs in Swiss Industrial Processes (2021-2025),</td>
<td>OST, HEIG-VD, EPFL, CSD, Industrial partners</td>
</tr>
<tr>
<td>ARAMIS description (Project No. SI/502336), <a href="http://www.heatpumpingtechnologies.org/annex58">www.heatpumpingtechnologies.org/annex58</a></td>
<td></td>
</tr>
</tbody>
</table>
• HTHP-CH project and IEA HPT Annex 58 HTHP are running
• Market potential for HTHPs in Switzerland (estimate optimistic: 723 units 1 MW, 350 to 550 Mio. CHF investment)
• Funding programs for industrial HPs are available (e.g., Pinch Analyses, Process Heat, Klimaprämie, P&D projects)
• A few realized HTHP application examples in Switzerland
• A few Swiss manufacturers active in the HTHP industry (e.g., Walter Wettstein AG, Scheco, Zéro-C, Friotherm AG, MAN Energy Solutions, etc.)
• Some R&D projects on HTHPs are running (e.g., steam-generating heat pumps, refrigerant mixtures, etc.)
Thank you for your attention!

Acknowledgements

**Project: Annex 58 HTHP-CH**
Integration of High-Temperature Heat Pumps (HTHPs) in Swiss Industrial Processes (SI/502336-01)

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[www.sweet-decarb.ch]
References


- Arpagaus, C.: Potentials for High-Temperature Heat Pumps and Market Analysis, Deep Dive HPT Annex 58 on HTHPs, 15 December 2022, online


- Calame-Darbellay, C., CSD Ingénieurs SA, Pompes à chaleur industrielles, Optimisation énergétique et décarbonisation, SYMPOSIUM Optimisation Énergétique 2022, 6 Septembre 2022, HEIG-VD, Yverdon-les-Bains

- Flórez-Orrego, D., Ribeiro Domingos, M. E. G., Maréchal, F., A systematic framework for the multi-time integration of industrial complexes and urban systems, 7th International Conference on Contemporary Problems of Thermal Engineering - CPOTE 2022, Warsaw, Poland, 20-23 September, 2022 (Link to presentation)

- Flórez-Orrego, D., Pina, E., Ribeiro Domingos, M.E.G., Sharma, S., Maréchal, F. High-temperature heat pumps applications for industrial separation and drying processes. 35th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems - ECOS 2022, Copenhagen, Denmark, 3-7 July, 2022 (Link to paper)
