Modeling and simulation of the valorization of waste heat from hydrogen production in district thermal systems

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Abstract
In recent years, the momentum around green hydrogen is rising. Ambitious plans and roadmaps have been set to enable the massive development of green hydrogen as a mean for decarbonization. For that purpose, a huge focus is being made on currently available water electrolysis technologies which enable to produce green hydrogen as long as they are fed with renewable electricity. Working on the electrolyzer energy losses, efficiency can be maximized through smart thermal systems designed to valorize waste heat for use in district thermal systems. Conceptual studies have been proposed in relation with the waste heat recovery from electrolysis plants, however, there are no extensive reports examining the synergies between hydrogen production hubs and thermal energy valorization in end-use applications at district scale.

To address this gap, this paper aimed to examine how excess heat generated by electrolysis plants can be utilized by thermal energy networks for serving end-use applications such as space heating and domestic hot water heating. The integration potential was evaluated as well as the necessity of heat upgrading technology bricks.

Highlights
- Current electrolyzer efficiencies are limited (over 30% is lost as waste heat) and relevant way to valorize them can be the integration with thermal systems, at district but also at industrial level
- Waste heat potential model with electrolyzer and district thermal system subcomponents was developed and used to determine the behavior and performance of the overall system
- Technical viability of heat waste recovery from electrolyzers and integration with district thermal systems seems realistic according to preliminary studies but more investigations are needed on order to achieve completely manageable configurations for an extended set of electrolysis and district thermal systems

Practical implications
The waste heat production follows the electrical consumption and thus the operation profile of the electrolyser. All connected downstream technologies e.g. district thermal systems need to be capable to cope with these fluctuations.

The temperature of the waste heat is depending on the electrolyser type and the setup of the heat exchanger. In any case it will be on a low temperature level thus less than 80°C.

Heat upgrading technologies are existing on the marked, but the economic value needs to be determined case by case and is depending on market conditions for gas and power, as well as on the load factor and the heat sink characteristics.

The amount of available heat for large scale electrolyzers is very large and it is difficult to identify heat off-takers with a corresponding capacity aligned with the electrolyzers operation conditions and at the current location, for both district heating networks and industrial applications.

Introduction
There is a significant increase in demand for hydrogen in mobility and industrial sectors, which encouraged research and development of water electrolysis, among other hydrogen production technologies. In this current dynamic context, there have been significant advancements in electrochemical efficiency of electrolyzer, little attention has been given to energy losses incurred (over 30% is lost as waste heat) in electrolysis plants. In the case of hydrogen production, efficiency can be maximized through smart energy systems designed to valorize waste heat for use in building heating and low-medium temperature manufacturing operations. More recently and predominantly in Europe, conceptual studies in [1], [2] and [3] have been proposed to model and understand the usage and demonstration of waste heat recovery from electrolysis plants. However, examining the synergies between hydrogen production hubs and thermal energy valorization in end-use applications (utilities, industry, etc.) is still in an early phase and needs more attention from the practitioners and modelers. The specialized literature has exposed several challenges and limitations in modeling, simulating and optimizing district heating and cooling with tools such as TRNSYS, MATLAB/Simulink or EnergyPlus. Managing such large and complex models with these conventional tools can be difficult and time consuming [7], in addition to the unidirectional nature of the equations. To address the abovementioned issues, two modeling software were adopted. On one side the equation-based, object-oriented language Modelica was used to build up district thermal

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system models (with an equation-based and object-oriented language that supports both causal and acausal modeling) featuring both thermo-fluid system models (typically acausal) and realistic controls (typically causal), which are strong arguments for choosing the Modelica language. The native graphical, hierarchical approach, from individual equipment to subsystems and districts [4] allowed us to easily model and simulate these systems.

Available waste heat (cooling water)
- Temperature level
- Mass flow rate

compliance with the return flow temperature

Figure 1: Interaction between modeling software

On the other side, ASPEN Custom Modeler™ and ASPEN Plus Dynamics™ were used to model the electrolyzer behavior (available waste heat (cooling water), temperature level, mass flow rate). The choice of the electrolyzer technology considered for the model fell on the Proton Exchange Membrane (PEM) technology as it is well suited to be powered by renewable energy sources, since it is the most flexible.

Research conducted after the writing of this article is unifying the modeling approaches and fully adopts Modelica for the modeling of both electrolyzer and district thermal systems.

Water electrolysis

Water electrolysis attracts more and more attention as it is a mean to produce hydrogen without any direct need to use fossil fuels (in contrast with steam methane reforming, the most wide-spread hydrogen production process). Water electrolyzers use electrical current to dissociate the water molecule into dioxygen (O₂) and dihydrogen (H₂). If the electricity used to power the electrolyzer comes from a renewable source, the produced hydrogen is carbon neutral (also called “green hydrogen”) and can be considered as a sustainable energy carrier.

Water electrolysis principle

Water electrolysis is an electrochemical reaction based on the dissociation of water molecules (H₂O) to form dioxygen (O₂) and dihydrogen (H₂) under the effect of an electric field. Low-temperature water electrolysis can be classified into two main categories: alkaline and PEM. The electrolysis operation is similar for both technologies but the operating conditions and the ionic transfer involved in each of them differ from one to another [5].

Water electrolysis technologies

Alkaline electrolysis is the most mature electrolysis technology and is widely used in industry. In alkaline electrolysis, the water entering the cathode compartment is dissociated into hydrogen molecules (H₂) and hydroxyl ions (OH⁻). These cross the diaphragm to the anode and deliver O₂ molecules. The electrodes are immersed in a high concentrated aqueous solution of potassium hydroxide (KOH) or sodium hydroxide (NaOH). Both electrodes are separated by a microporous diaphragm, which allows the diffusion of the electrolytic solution and ensures the separation of produced gases [5].

The main components of an alkaline electrolysis (Figure 2) generator can be outlined as follows: the alkaline electrolyzer, gas separators, cooling circuits, circulating pumps, control valves, water and gas tanks. The electrolyte solution is first mixed in the alkaline tank then pumped to the electrolyte tank where it enters into the electrolysis chamber to form the produced gas.

Figure 2: Schematic illustration of alkaline water electrolysis [6]

Thereafter, a two-phase mixture of liquid electrolyte/gases is produced and separated through hydrogen and oxygen separators, where each gas is cooled down, separated from the liquid phase, demisted and purified, and finally discharged from the upper part of the tank. At the H₂ side, the liquid electrolyte is pumped back to the electrolysis stack through the hydraulic circuit [7].

Figure 3: Simplified process flow chart of an alkaline electrolyzer [7]

Polymer electrolyte membrane (PEM) electrolysis differs from alkaline electrolysis by the presence of a solid proton-conducting polymer electrolyte (Nafion), designed to separate H₂ and O₂ products resulting from the electrolysis reaction and to ensure the transport of ionic species. Water is supplied on the anode side of a PEM electrolyzer, where it is oxidized to oxygen (O₂), protons (H⁺) and electrons (e⁻). On the cathode side, the
supplied electrons and the protons that have conducted through the membrane are combined to create gaseous hydrogen (H2) [5].

The main components of a PEM electrolysis generator include: a stack, a control system and a power supply. When the system is started up, power required is supplied to the stack and the electrolysis reaction occurs. Liquid deionized water at environmental conditions is heated up to the working temperature of the electrolyzer and then pumped to the stack via the anode compartment.

Thereafter, both gas produced are separated and demisted. The water levels in the gas separators are regulated to avoid the presence of gas in the water circuits and conversely, the presence of water in the gas circuits electrolyzer [6]. At the cathode, hydrogen produced is cooled down to the environmental temperature. At the anode, oxygen is cooled down to the environmental temperature and then separated from the mixture H2O/O2. Remaining water is transmitted back to the supply water circuit. In PEM configuration, the water tank and oxygen separator form a single component [8].

Table 1: Main differences between the alkaline and PEM electrolysis technologies

| Table 1 : Main differences between the alkaline and PEM electrolysis technologies |
|-----------------------------------|-----------------------------------|
| [Current density (*)]            | Up to 8 A.cm-2                   |
| [Operating temperature]          | 20°C – 80°C                      |
| [Efficiency (**)]                | 65 – 70% LHV                     |
| [Advantages]                     | Solid-state electrolyte          |
| [Drawbacks]                      | Material scarcity (noble metals) |

(*) is referred to as the total amount of current which is flowing through one unit value of a cross-sectional area (vedantu.com)
(**) LHV of hydrogen produced divided by the electrical power

Modeling of the electrolyzer

The electrolyzer model consists of the stack and the auxiliaries necessary for the proper operating of the stack. The PEM stack model is developed under ASPEN Custom Modeler™ and the BoP equipment added using ASPEN Plus Dynamics™. The following three aspects were taken into account when modeling an electrolysis stack:

- The material balance aspect, which allows the calculation of the molar flow rate of chemical species produced and consumed by the electrochemical reactions taking place in the stack,
- The electrochemical aspect of the stack, which enables the voltage in each cell to be predicted as a function of the applied current density (note that a semi-empirical approach was used in this part),
- The thermal aspect, which allows the thermal behaviour of the stack to be described as a function of the operating conditions.
At the Anode we have:
\[
\frac{dn_{H_2,an}}{dt} = \dot{N}_{H_2,0,in,an} - \dot{N}_{H_2,0,out,an} - \dot{N}_{H_2,0,cons}
\]  
(1)
\[
\frac{dn_{H_2,an}}{dt} = \dot{N}_{H_2,in,an} - \dot{N}_{H_2,out,an} + \dot{N}_{H_2,m}
\]  
(2)
\[
\frac{dn_{O_2,an}}{dt} = \dot{N}_{O_2,in,an} - \dot{N}_{O_2,out,an} + \dot{N}_{O_2,prod} - \dot{N}_{O_2,m}
\]  
(3)

At the cathode we have:
\[
\frac{dn_{H_2,ca}}{dt} = \dot{N}_{H_2,in,ca} - \dot{N}_{H_2,out,ca} + \dot{N}_{H_2,0,m}
\]  
(4)
\[
\frac{dn_{H_2,ca}}{dt} = \dot{N}_{H_2,in,ca} - \dot{N}_{H_2,out,ca} + \dot{N}_{H_2,prod} - \dot{N}_{H_2,m}
\]  
(5)
\[
\frac{dn_{O_2,ca}}{dt} = \dot{N}_{O_2,in,ca} - \dot{N}_{O_2,out,ca} + \dot{N}_{O_2,m}
\]  
(6)

The energy balance for finding the correct anode inlet temperature to produce a given amount of hydrogen in transient phase is given by equation (7).
\[
C_{ch} \frac{dT_{in,an}}{dt} = (T_{out,an} - T_{in,an}) \sum c_p n_{i,out}^an - W_{el} + n_{H_2,prod} \Delta H_r
\]  
(7)

The cell voltage defined as the sum of the reversible voltage and the overpotentials (activation, ohmic and diffusion overpotential) generated during the electrochemical reaction is given by equation (8).
\[
U_{cell} = U_{Nernst} + \eta_{act} + \eta_{ohm}
\]  
(8)

In this equation, the diffusion overvoltage is neglected due to the use of NSTF as a catalyst. The Nernst potential \(U_{Nernst}\) is given by equation (9).
\[
U_{Nernst} = 1.229 - 8.46 \times 10^{-4}(T - 298) + \frac{RT}{2F} \ln(p_{H_2}p_{O_2}^{0.5})
\]  
(9)

The activation and ohmic overpotential are given by equations (9) and (10) respectively.
\[
\eta_{act} = \frac{RT_{an}}{\alpha_{an}F} \log \left( \frac{i}{i_{0,an}} \right) + \frac{RT_{ca}}{\alpha_{ca}F} \log \left( \frac{i}{i_{0,ca}} \right)
\]  
(10)

\[
\eta_{ohm} = (R_{ohm} + R_{ele})i = \left( \frac{\delta_m}{\sigma_m} + R_{ele} \right)i
\]  
(11)

\[
\sigma_m = (0.00514\lambda - 0.00326) \exp \left[ \frac{1268}{(303 - 1/7)} \right]
\]  
(12)

The parameters \(R_{ele}, i_{0,an}, i_{0,ca}, \alpha_{an}\) and \(\alpha_{ca}\) representing respectively, the electrical resistance of the cell, the exchange current densities and the charge transfer coefficients are determined by numerical regression at the chosen operating temperature (85°C) using the polarisation curve published by Bassarabov [9].

The screenshot of the simulator can be found on Figure 7 and the stack details in Table 2.

This simulator includes the following features:
- The PEM electrolyser stack model (block STACK)
- An Electricity load profile injection (consisting of the blocks B1, B12, B17 and B18)
- A thermal control loop of the stack in which circulate in closed loop the water which is cooled via a radiator after exchanging heat with the electrolyser stack (consisting of the blocks ACHE, CP200, B6 and HE 600). The role of this loop is to remove the heat produced by the stack during the electrochemical water splitting reaction. This is done by cooling the PEM stack feed water through the HE600 heat exchanger. The "TC" PID controller adjusts the closed loop cooling water flow rate to stabilize the stack temperature at 85°C (which is the selected operating point). The radiator (ACHE) is used to evacuate the rejected heat of cooling water to the ambient air.
- A gas cooling loop whose role is to reduce the temperature of the products in order to condense most of the water in it (consisting of the heat exchangers HE610 and HE620, the splitters B13 and B16, the pump CP400 and the chiller fan AWC200).
- A rectifier cooling loop (consisting of the blocks B1 and AC100). Its role is to evacuate the heat produced by the rectifier during the transformation of the alternative current into direct current for the stack power supply.
- A feed water tank (block WT) and gas separation tanks (blocks ST600 and ST620)
Figure 7: Simulator; dynamic model of the PEM Electrolysis on Aspen Plus Dynamics™

Table 2: PEM electrolyser stack, technical details

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Electrolyser Working point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell number</td>
<td>676</td>
</tr>
<tr>
<td>Current density (A/cm²)</td>
<td>10</td>
</tr>
<tr>
<td>Cell voltage (V)</td>
<td>2.02</td>
</tr>
<tr>
<td>Cell surface (cm²)</td>
<td>1000</td>
</tr>
<tr>
<td>Stack operating temperature (°C)</td>
<td>85</td>
</tr>
<tr>
<td>Anode pressure (bar)</td>
<td>19</td>
</tr>
<tr>
<td>Cathode pressure (bar)</td>
<td>20</td>
</tr>
<tr>
<td>Nominal electric power (MWe)</td>
<td>~14</td>
</tr>
</tbody>
</table>

Waste heat potential from electrolyzer

Depending on the use case, hydrogen production plants by water electrolysis can be operated in steady state or variable load operation (either by direct coupling to renewable energy or by contributing to the grid service). Therefore, six different load cases (see Table 3) have been defined to take into account different operating regimes, ranging from full load to 20% of maximum power consumption in order to observe the dynamic of the available waste heat.

Table 3: Load cases simulated

<table>
<thead>
<tr>
<th>Load case</th>
<th>Description</th>
<th>Characteristic</th>
<th>Electrolyzer power consumption [MWel]</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Stable load 20% electrolyzer power</td>
<td>Constant load; example: constant H2 production</td>
<td>2.8</td>
</tr>
<tr>
<td>#2</td>
<td>Stable load 100% electrolyzer power</td>
<td>Constant load; example: constant H2 production</td>
<td>14</td>
</tr>
<tr>
<td>#3</td>
<td>Wind profile</td>
<td>Extremely volatile; based on realistic wind generation profile</td>
<td>2.8 - 14</td>
</tr>
<tr>
<td>#4</td>
<td>Power profile 1/4h</td>
<td>Volatile with steps of 1/4h, based on intraday power profile</td>
<td>2.8 - 14</td>
</tr>
<tr>
<td>#5</td>
<td>Power profile 1h</td>
<td>Steps of 1h, based on day-ahead power profile</td>
<td>2.8 - 14</td>
</tr>
<tr>
<td>#6</td>
<td>Power profile 1h</td>
<td>Steps of 1h, based on day-ahead power profile</td>
<td>28 - 144</td>
</tr>
</tbody>
</table>

Regardless of the simulated load profile and operating regime, it was found that the outlet temperatures of the cold side of the HE600 exchanger, as the most determining parameter for the heat valorisation are relatively stable and vary between 53 and 59°C for all load cases simulated as shown in Table 4. The same trends were observed for the available recoverable waste heat.

Table 4: Output temperatures of cooling water containing the recoverable waste heat and the average amount of waste heat available

<table>
<thead>
<tr>
<th>Loadpoint</th>
<th>20% / 2.8 MWel</th>
<th>100% / 14 MWel</th>
</tr>
</thead>
<tbody>
<tr>
<td>T outlet HE600 [°C]</td>
<td>54</td>
<td>57</td>
</tr>
<tr>
<td>T inlet HE600 [°C]</td>
<td>26</td>
<td>34</td>
</tr>
<tr>
<td>Flow HE600 cold side [kg/h]</td>
<td>14.185</td>
<td>170.857</td>
</tr>
<tr>
<td>Efficiency</td>
<td>70%</td>
<td>65%</td>
</tr>
<tr>
<td>Available waste heat [MW]</td>
<td>0.46</td>
<td>4.57</td>
</tr>
</tbody>
</table>

District thermal system modeling

In order to valorize excess heat generated by electrolysis plants, we need to be able to evaluate, quantify and analyze the behavior of the district thermal system.

Evaluating the behavior of a district thermal system can be conducted in two ways: ex ante, when the system is not built and ex post when the system is already in place. Thus, different tools and techniques could be used. For our situation an ex-ante evaluation will be conducted by using digital tools or models (the system will be modeled and simulated, and the results obtained will be analyzed in order to optimize the design for example or the business case).

Computer modeling and simulation is an effective means to further improve the utilization of energy systems. They can be seen as a set of numerical models, which represent as close as possible the real behavior of a physical system. The numerical models may address different physics of the system (thermal, electrical, etc.) by using different approaches with divers levels of complexity. Therefore, our analysis focuses on developing numerical models for a district heating system by developing and using modular, reusable, and with limited complexity models.

Simulations are then carried out using a Modelica based commercial tool, in our case Dymola tool with an inhouse numerical model library specific and the open-source library Buildings Library [10].
In order to test the viability of the imagined waste heat production and district thermal systems the whole system behavior was simulated (production – distribution – customer) on an annual basis. This time interval allowed to analyze the interactions between the recovery of waste heat for different temporal evolutions (seasonal, daily, etc.) of the thermal demands. The fluctuation of the variables observed in the study of a heating network does not require a study at a fine mesh as the temperature profile of the electrolyzer is mainly constant, therefore the time step retained is 1 hour over the year.

For the consumption side, a panel of 5 (five) representative thermal profiles was designed to better reflect the fluctuation of consumption at a district scale. The choice of this study scale for small and medium-sized thermal clusters is based on the intention to implement electrolyzers in urban areas with a proximity to existing or future district heating networks. As its has been shown in [11] the size of the district thermal systems has significantly decrease since 2000. Thus, less energy is provided, as network is getting shorter, fewer substations are present and the linear density is lower with a median value of 5 600 MWh/year.

The building loads is represented as a set of elementary approaches intended to evaluate the behavior of the buildings connected to the district heating system. Developed using a Modelica physics-based approach, the models representing the end-user have several typologies, depending of the purpose and the level of detail of the modeling. Thus, high-fidelity models (detailed modeling of the building) or more simplified ones such low-order models (electrical analogy models with low CPU-time/modeling effort) or timeseries (real-life profiles of thermal demand) can be deployed.

In our situation, the modeling is conducted with the use of low-order models already developed in [12] and applied for low-carbon district in France (La Rochelle). This district is populated with building adopting the latest requirements of the Energy+ Carbon- label in France (Net Zero Energy Buildings with carbon constraints). The most part of the 100 buildings composing the district (commercial, residential and education) are new ones. Simulated building thermal demand (Table 5) from this district was used and adapted to model the 5 different types of district (energy demand level, ratio between residential and non-residential buildings).

The distribution side is ensured by a physics-based approach model in order to represent the dynamic equation-based thermo-hydraulic behavior of the piping according to [13], with the heat loss calculation given by:

\[
\frac{\partial (\rho c_v T A)}{\partial t} + \frac{\partial (\rho c_v T + E A)}{\partial x} = \nu A \frac{\partial p}{\partial x} + \frac{1}{2} \rho v^2 |v| f_d S
\]

Finally, on the supply side, an ideal gas boiler is considered to ensure the total needs of the district configurations and constitute the main production plant. References cases will consider a unique main production unit, represented by a gas boiler with a efficiency of 90% at nominal condition.

The second source of supply is integrated for the recovery of waste heat in 2 (two) network configurations.

The first one is a preheating operation of the return temperature (Figure 8 (a)) consisting of a plate heat exchanger placed upstream of the central production system. A bypass is positioned between the centralized system and the recovery station in order to avoid the heat recovery when there is no production or when the return temperature is higher than the recovery temperature, as the objective of the study is to evaluate the recoverable potential of the heat discharged by the electrolyzer.

![Figure 8: Source of supply for the district thermal system](image)

Table 5: District types used for heat network application study

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R (m²)</td>
<td>C (m²)</td>
<td>Mix (m²)</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>270 000</td>
<td>70 000</td>
<td>70 000</td>
</tr>
<tr>
<td>Building area (m²)</td>
<td>43 906</td>
<td>15 237</td>
<td>22 574</td>
</tr>
<tr>
<td>Building density</td>
<td>16%</td>
<td>22%</td>
<td>32%</td>
</tr>
<tr>
<td>Floor area (m²)</td>
<td>158 738</td>
<td>52 275</td>
<td>72 216</td>
</tr>
<tr>
<td>Heating + DHW requirements (MWh)</td>
<td>2384</td>
<td>874</td>
<td>1300</td>
</tr>
<tr>
<td>Energy density (kWh/m²)</td>
<td>35</td>
<td>41</td>
<td>66</td>
</tr>
</tbody>
</table>

* R = Residential; C = Commercial

Excepting timeseries models, all the other models will be able to consider several characteristics of the end-user such as building features: performance (e.g. building envelope coefficients, etc.) and physical characteristics (e.g. GFA, orientation, etc.), and energy systems operational parameters such as thermal energy consumption patterns (e.g. setpoints, occupancy profiles, etc.).
A second case representing a centralized water-to-water heat pump (Figure 8 (b)) is designed to improve the temperature of the waste heat. Euroheat and Power [14] shows that district thermal systems are the predominant final energy demand items for heat process below 100°C, and that the use of waste heat as an energy source for large heat pumps is well implemented in the Scandinavian countries. The use of the heat pump as a stand-alone system was chosen after an early assessment showing that it was capable of providing production as a single system without being assisted by a secondary system.

Water-to-water heat pump central plant is composed of an evaporator heat source (cold side) situated in a closed circuit where the calories from a heat exchanger connected to the fatal heat source are valorized. In case of absence of waste heat or in order to control the cold source’s temperature, a water source at 10-15°C is considered.

In addition to these system variants, two temperature levels are studied. They are represented by two 4GDHC and illustrated in Table 6.

### Table 6: Main specifications of the studied district thermal system use cases

<table>
<thead>
<tr>
<th>Temperature levels</th>
<th>Supply (°C)</th>
<th>Return (°C)</th>
<th>Central plant</th>
<th>Recovery technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>High grade – Reference</td>
<td>70</td>
<td>45</td>
<td>Ideal boiler</td>
<td>-</td>
</tr>
<tr>
<td>Low grade – Reference</td>
<td>55</td>
<td>30</td>
<td>Ideal boiler</td>
<td>-</td>
</tr>
<tr>
<td>High grade – Preheating</td>
<td>70</td>
<td>45</td>
<td>Ideal boiler</td>
<td>Heat exchanger return pipe</td>
</tr>
<tr>
<td>Low grade – Preheating</td>
<td>55</td>
<td>30</td>
<td>Ideal boiler</td>
<td>Heat exchanger return pipe</td>
</tr>
<tr>
<td>High grade – Heat pump</td>
<td>70</td>
<td>45</td>
<td>W/W Heat Pump</td>
<td></td>
</tr>
</tbody>
</table>

For the network with a supply temperature of 55°C, we only consider the case of preheating, assuming that no additional upgrade technology is needed.

### Results

Heating network cases without the use of waste heat, the so-called “reference cases” have been used to define a baseline scenario, for which it will be possible to evaluate the impact of the use of heat recovery. For example, the gas consumption can be used to evaluate the reduction obtained with the preheating and heat-pump configurations. The operation of the model corresponds to a condensing gas boiler in order to define the consumption necessary for its operation. Nevertheless its operation remains simplified so that reference simulation results can be also used as a reference with a centralized electric production.

Thermal losses (see the black frames in the Figure 9) increase with the length of the thermal network, ranging from 19 to 27%. Also the thermal demand at 70°C is marginally higher than at 55°C.

![Figure 9: Thermal demand VS production of reference cases](https://example.com/figure9)

The preheating configuration for a supply temperature of 55°C is still better than the HP-configuration for a network supplied at 70°C with the operation profile, as long as the production is below the threshold n°2 at 4150 MWh. This same preheating configuration has a higher threshold (threshold n°1 in Figure 10) at full load, with a value of 7750 MWh.

![Figure 10: Evolution of waste heat production coverage as a function of thermal production](https://example.com/figure10)

Two advantageous (Figure 10) cases of application can be distinguished: on one hand, for a network at 70°C, the heat pump configuration is better than the preheating one, the best application case corresponds to a medium-high thermal demand. On the other hand, preheating at 55°C supply has a high production coverage ratio for low-medium thermal demand.

The variability of the operational profile has negative impacts on the recovery via preheating. In fact, we observe an increase of 32% in the network production for the cases of network with a 70°C supply temperature for the configurations of large residential & large tertiary. The unstable supply from WH, forces central production to readjust. Intermediate thermal storage would avoid this fluctuation.

For the full-load profile there is a slight difference in heat generation at the two supply temperature levels, nevertheless no additional consumption is to be reported. The highest thermal production represents only 22%. Also recovery via heat exchanger is performant for similar temperature (Figure 11).
Figure 11: Distribution of the production for the full-load profile case studies

A significant reduction in the initial thermal production of the heat network (between 29% and 99%), however on the electrolyser side the evacuation remains relatively low (from 1% to 22% of the waste heat).

Figure 12: Gas cost reduction for the high grade – preheating use cases

A first economic assessment allowed us to quantify the reduction in gas consumption of the central unit up to 45% for the best configuration (see Figure 12). A more in-depth analysis will define the interest for the electrolyzer owner (quantity evacuated vs. investment cost), and for the network operator (savings vs. waste heat’s cost).

Consideration of application on lower temperature networks, however, it does not correspond to the concept of 5GDHC operation which aims to have a relatively low constant temperature (20-30°C) in order to limit losses and facilitate the reinjection of other waste heat energy sources. Nevertheless, it allows a good coverage of the heat production on the heat networks: at 70°C we note a limit of recovery up to 73% for the heat pumps and 46% for the heat exchanger due on one hand to the technology and on the other hand to the recovered temperature which will require an upgrade.

Conclusion

This paper examined by the intermediary of modeling and simulation how excess heat generated by electrolysis plants can be utilized by thermal energy networks for serving end-use applications such as space heating and domestic hot water heating.

According to our simulations, the amount of recovered waste heat in district thermal networks is small and does not exceed 22% for the considered cases. It is strongly depending on the load profile of the electrolyser, the size and consumption profile of the district heating network and the temperature of the available heat.

Extremely large heat networks are necessary to absorb significant amounts of waste heat, especially when it comes to large scale electrolyzers. However, for small district thermal systems and an electrolyser running on full load significant amounts of the heat demand can be provided by the electrolyser (up to 99% in the considered cases), which is translating in the replacement of gas or electrical power for conventional heating. A low temperature district thermal network remains advantageous and the deployment of upgrading systems such as heat pumps can favourably participate to this waste heat absorption.

When planning large-scale electrolyser projects it would be worth to discuss with electrolyser suppliers in order to achieve an overall optimization with respect to heat utilization, especially with the target to achieve waste heat temperatures as high as possible. It is of interest for both sides that the preferred location for electrolyser projects should be in the vicinity of heat off-takers. Moreover, the electrical consumption profile of the electrolyzers has to be aligned with the heat demand profile. In this case, a combination with heat storage might be useful to uncouple heat production and heat demand and to increase the ratio of waste heat that can be valorised.

Further research will be conducted by the team in order to unify the modeling approaches and fully adopt Modelica for the modeling of both electrolyzer and district thermal systems. This work will be supported by the H2 Factory platform developed by R&D of ENGIE which will provide measured data in order to validate the behavior of the electrolyzer and thus derisk the elaboration of new configurations for waste heat valorization.

References


**Notations**

- C<sub>th</sub> Overall thermal capacity
- F Faraday’s Constant, C.mol-1
- H Enthalpy, J.mol-1
- i Current density, A.cm-2
- N Molar flow of the species, mol.s-1
- p Partial pressure of the species, bar
- R Gas constant, J.mol-1.K-1
- T Operating temperature, °C
- U Electric potential, V
- W Power consumed, W