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Project holder (Institution)	AIT Austrian Institute of Technology
Contact person	Dr. Mag. Christoph Zauner
Postal address	Giefinggasse 2, 1210 Wien
Telephone	0664 8251146
E-mail	Christoph.Zauner@ait.ac.at
Website	https://www.nefi.at/de/projekt/enviotcast

envIoTcast

Environmentally friendly casting

Authors and main project team members:
AIT Austrian Institute of Technology GmbH
Center for Energy
Bastian Fibi, Rene Haslhofer, Florian Grünberger, Nicolas Neubauer, Stephan Kling, Daniela Leibetseder, Philipp Moser, Annemarie Schneeberger, Oxana Schmidt-Mansurova, Margit Özelt, Georg Kränzel, Julian Unterluggauer, Christoph Zauner

AIT Austrian Institute of Technology GmbH
LKR Leichtmetallkompetenzzentrum Ranshofen GmbH
Simon Frank, Lukas Kiessling, Guilia Scampone, Elias Riegler, Rudolf Gradinger, Clemens Simson

HOFMANN Wärmetechnik GmbH
Thomas Mittmannsgruber, Markus Auer

MAXAN Automation
Martin Fischer

Business Upper Austria-OÖ Wirtschaftsagentur GmbH
Stefan Hopfer, Florian Danmayr

1 Table of contents

1 Table of contents 4
2 Introduction 6
3 Project work and results 7
3.1 Green Foundry 4.0 - concept 7
3.2 Energy efficient casting and carbon-neutral heating 10
3.2.1 Energy efficient casting 10
3.2.2 Carbon neutral heating 14
3.3 Energy efficient heating and cooling and waste heat recovery 27
3.4 Demo factory “Green Foundry 4.0” at AIT - LKR Ranshofen 31
3.5 Exploitation, dissemination and business models 46
3.5.1 Stakeholder analysis and industry analysis 46
3.5.2 Marketing plan and business model 49
3.5.3 Dissemination of knowledge 52
4 Conclusions, outlook and recommendations 56
5 Contact details 57

2 Introduction

A large variety of products are manufactured via casting to be employed in many different sectors such as transport and mobility, engineering, building and construction as well as consumer goods. Europe is home to ~6,000 metal casting facilities employing approximately 260,000 people. In 2023, European foundries produced ca. 14 Mt of castings valued at €41 bn[1].

In current foundries, the production of casting parts is performed in a series of consecutive steps, melting, casting, heat treatment and mechanical processing that are, however, largely separated from each other when it comes to energy and CO2 emissions. An overall concept of a Green Foundry is missing, which makes decarbonization of this industrial sector very challenging.

In order to resolve this issue, within the project envIoTcast ("environmentally friendly casting") a modern, sustainable concept of the "Green Foundry 4.0" was developed and demonstrated, which enables complete decarbonization by applying a holistic optimization of the energy flows of the total production process by employing a set of energy efficiency measures, process optimization techniques and the application of carbon-neutral energy carriers.

In particular, the following two key achievements have been developed within the project:

1. Increasing energy efficiency of foundries by up to 30% via reduction of heat losses and substantial waste heat recovery and re-utilisation enabled by an innovative central heating and cooling system.
2. 100% decarbonisation via the replacement of all fossil energy fuels by carbon neutral energy carriers that are based on an adequate mix of green electricity and green gases.

The essential technological and conceptual aspects have been set up and successfully demonstrated in the Green Demo Foundry 4.0 at AIT-LKR Ranshofen, which provides an industry test bed for different technologies and methods required within the complex transition towards full decarbonisation of current and future foundries.

The project contributed to the NEFI Programme goals "technology development" (development and model use of local energy and energy-related transport technologies for the large-scale field testing of intelligent system solutions in live operation), "market development" (strengthening and developing Austria as a lead market for innovative energy and energy-related transport technologies and services) and "acceptance" (Involvement and active participation of users) as well as to the NEFI model region

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[1] CAEF, The European Foundry Industry 2023, 2024, https://eff-eu.org/wp-content/uploads/2024/12/CAEF-Co7_2023-complete.pdf, (accessed on: 14.08.2025)

goals “decarbonization of the industrial energy systems”, “value creation by technology Made in Austria” and “securing production sites and jobs by user involvement”.

The project work was conducted within the framework of six work packages as depicted in Figure **1** starting from 03/2021 and completed by 02/2025.

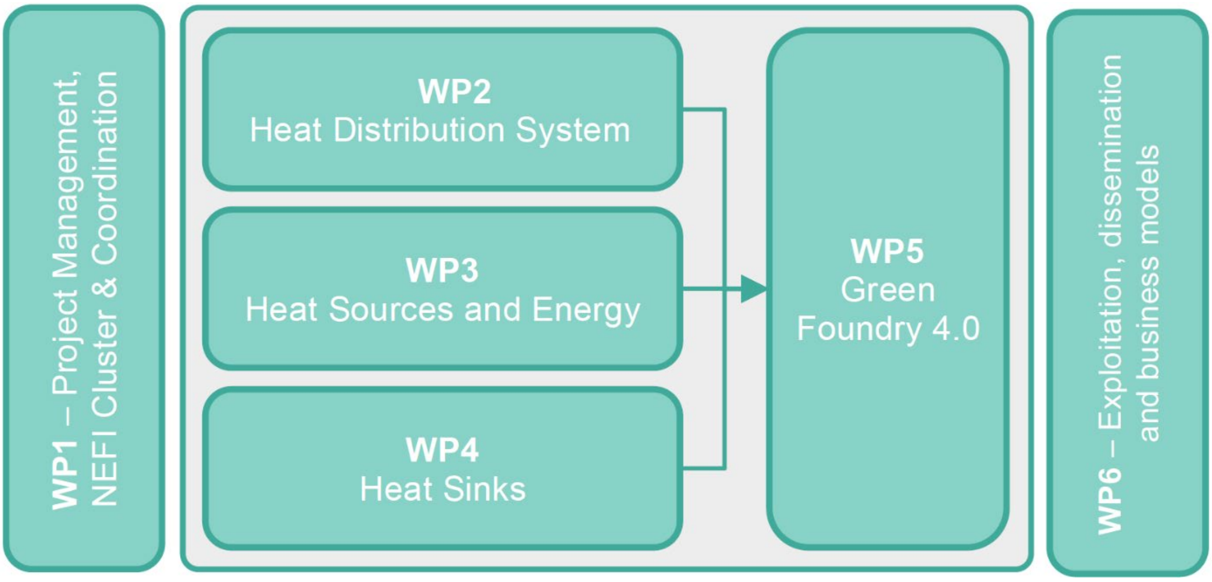

Figure 1: WP Structure of envIoTcast

3 Project work and results

3.1 Green Foundry 4.0 - concept

The main project result is depicted in Figure **2** and shows the schematic layout of a 100% carbon-neutral “Green Foundry 4.0”. With such a design it is possible to produce all sorts of casting parts with zero greenhouse gas emissions. It can be applied to both, greenfield as well as brownfield factories and requires only relatively small changes to existing plants. Technically, the concept can already be implemented in the coming years and thus contribute to national and EU emission targets. The required CAPEX and OPEX that finally lead to corresponding “levelized costs of energy” have to be worked out in detail for each site and depend greatly on the local availability and costs of renewable energy sources. If and only if appropriate mechanisms are installed to render carbon-neutral energy carrier cost-competitive to fossil natural gas, there is a realistic chance of a wide-spread decarbonization of foundries.

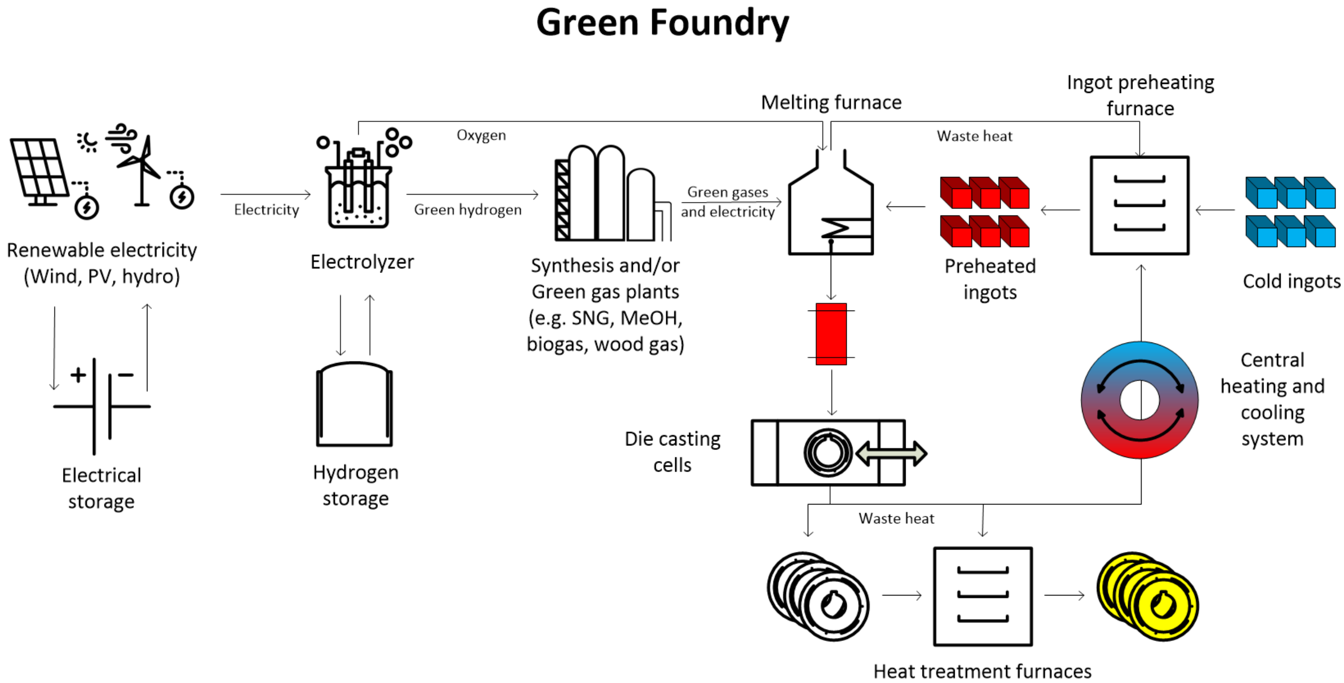

Figure 2: Schematic layout of a 100% carbon-neutral "Green Foundry 4.0".

The layout of the Green Foundry can be subdivided into two sections: “provision of carbon-neutral energy carriers” and “energy efficient factory” (Figure 3). Depending on the local conditions for different possible carbon-neutral energy carriers and various details of the factory facilities, there will be more or less interaction between both subsystems.

In current foundries, electricity is used as the primary energy source for all processes requiring mechanical energy. Also, a considerable part is employed to heat and cool the die casting cells as well as some peripherical processes. In addition, fossil natural gas is employed to melt the aluminum in the melting furnaces, which are the largest energy consumers and CO2 emitters. In the heating season, natural gas is also mostly used for building heating wherever necessary.

Although, energy efficiency is an upcoming topic and many low-hanging fruits are already being implemented in the industry (e.g. LED lightning, tightness of compressed air system, smaller waste heat recovery projects), in most factories there is still enormous potential and need for energy efficiency measures that are able to reduce the energy consumption in the double-digit-percent-range.

Thus, the Green Foundry concept applies energy efficiency measures on a much larger scale via the following measures:

- Application of sufficient and adequate thermal insulation of all “hot” machine/plant parts and pipings.
- Waste heat recovery of the main waste heat sources: melting furnaces and die casting cells at the highest possible temperature levels
- Waste heat re-utilization on a significant scale by pre-heating of aluminum before being melt as well as in the heat treatment furnaces and building heating system.

By applying those 3 key energy efficiency measures, it is possible to increase the energy efficiency of existing foundries by up to 30%.

Two particular innovations that have been developed within this project enable these energy efficiency improvements:

- Application of a set of process innovations that have been summarized into the concept of "HOT-Alu casting" (see below)
- Application of an efficient and modern central heating and cooling system that is capable of collecting, storing and distributing thermal energy between the various heat sources and heat sinks.

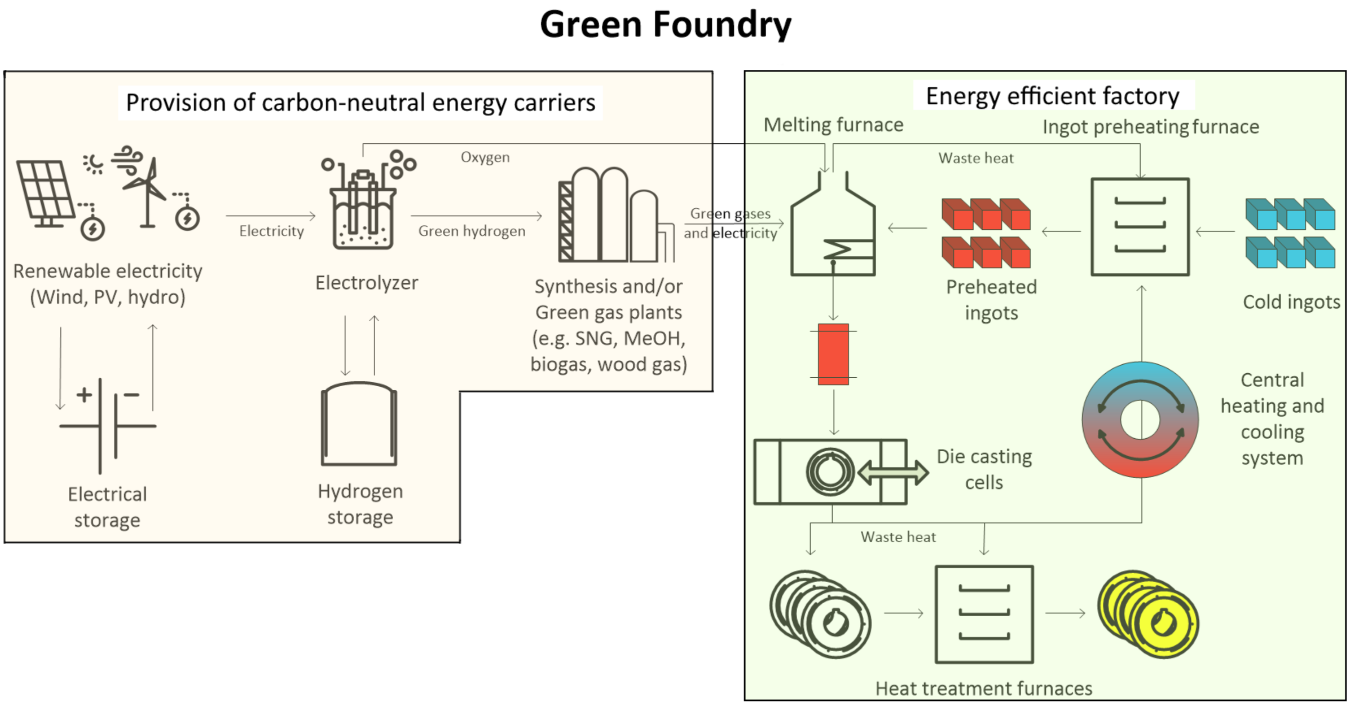

Figure 3: Provision of carbon-neutral energy carriers for an energy efficient factory comprise the two main elements of a Green Foundry.

The concept of "HOT-Alu casting" comprises a set of process improvements and changes that lead to significant improvements of the energy efficiency of the die casting process, the process parameters themselves and finally enable a considerably higher fraction of waste heat re-utilization. The different principles are as follows:

- A set of energy and process improvements (chapter 3.2) allow for much higher temperatures of the waste heat streams of the die casting cells and melting furnaces (up to 300-400 °C)
- Because of the high temperature level of the waste heat streams, the contained energy can be utilized to in suitable processes that have been identified within this project (chapter 3.4).
- In addition to improved energy efficiency, the higher cooling fluid temperatures lead to reduced thermal stress within the casting dies and thus improves their service lifetime

- Due to the improved cooling power of the improved cooling concept shorter casting cycle times are possible, which leads to an increase of production rate

3.2 Energy efficient casting and carbon-neutral heating

3.2.1 Energy efficient casting

Improving energy efficiency should always be the first step in the design of a carbon-neutral factory. This is especially important in view of the fact that most carbon neutral energy carriers will be more expensive than fossil natural gas. Thus, within this project a set of suitable energy efficiency measure was investigated, their potential benefits and drawbacks analyzed and the techno-economically best solutions have been put to a practical test at the “Green foundry demo factory” LKR Ranshofen.

Figure 4 shows the Sankey diagram of the main die casting part (left-hand side Figure 5) that was investigated within the project: a real series production part of an inverter housing employed in an electric vehicle.

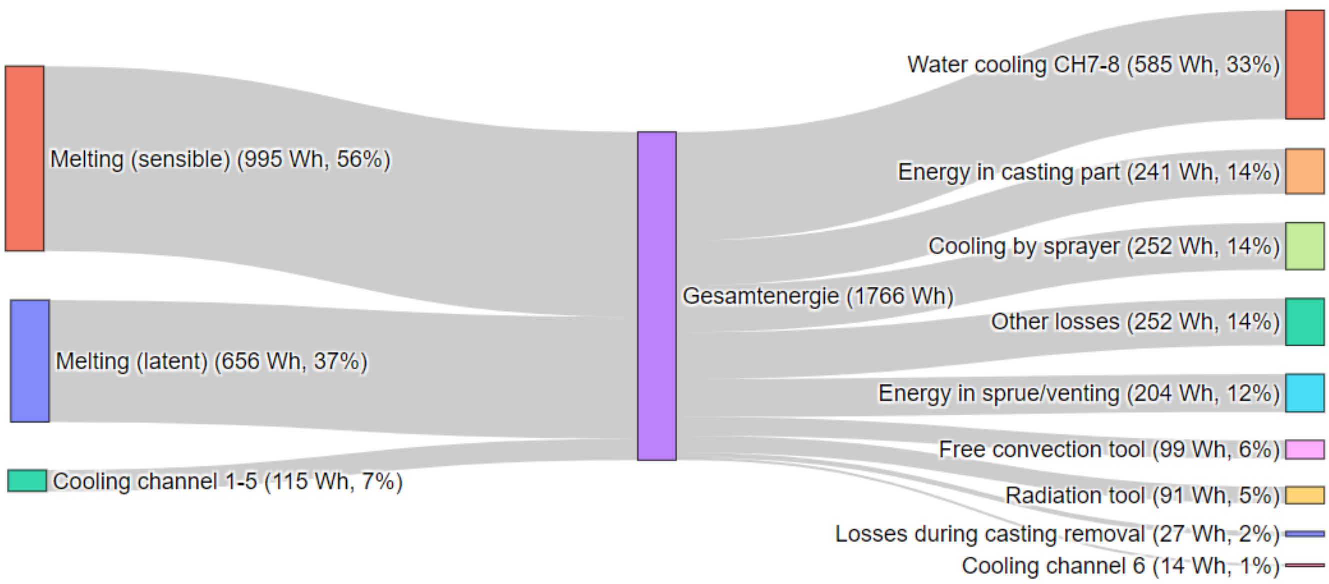

Figure 4: Energy flow diagram of the casting part of the inverter housing that was mainly employed as a representative part in the investigations of this project.

The surface temperature of the casting die was investigated via direct contact measurements as well as a dedicated thermo-camera that was especially adopted to the harsh environment of die casting cells. Without surface insulation, which is still the standard procedure in industry, the temperatures lie in the range of 100 – 200 °C, which lead to the corresponding radiative and convective heat losses to the

environment. Although, the exact fractions depend on the casting die and process, they typically lie in range of the inverter case casting part investigated in this project, i.e. 10-20 % of the total input energy (in our case 6% from convective losses and 5% from radiative losses summing up to around 190 Wh/part).
In addition, considerable losses occur by thermal conduction between the hot casting die and the cooler casting machine, which are in direct contact via a very large area. These losses are part of the “other losses” (145 Wh/part) in the Sankey diagram and cannot exactly be separated from other losses of the whole system easily without sophisticated measurement equipment.

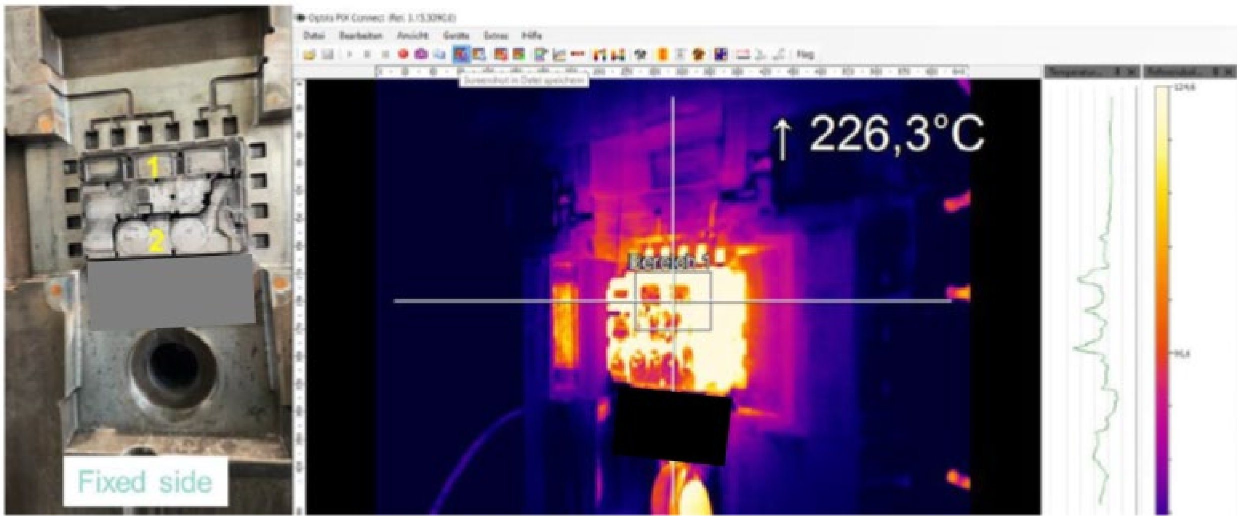

Figure 5: Lhs: The temperatures of the die have been measured at selected position via thermo-couples. Rhs: a dedicated thermo-camera set-up was installed to analyzed the surface heat temperatures in detail.

Many different insulation materials and systems are capable to withstand the temperatures (100 – 200 °C) occurring at the surface of the casting die and also between the casting die and the casting machine. However, in order to be applicable in a real industrial environment, the system has to be economically competitive, robust and easy to maintain. Several insulation solutions have been screened within the project and practical tests have been performed. The best concept is shown on the left-hand-side of Figure 6 and employs special “insulation pillows” that consist of a different possible types of filling material as well as a durable, shapable and flexible cover. The filling material can be any standard mineral or glass wool or also more advanced high-insulating materials (e.g. aerogel-based), which greatly reduce heat losses even when space is limited. The system can be adapted to many different geometries and can also be easily mounted and dismounted via the use of rather simple “velcro type fastening” system. Depending on the exact materials employed and the die details, the heat losses can be reduced significantly with this system with reasonable costs.
Also, investigations have been made to improve the thickness of the rather thin (20-30 mm) standard backward insulation plates. Finally, it was possible to come up with a suitable design and material that could be produced and employed with a thickness of 50 mm (center picture of Figure 6) that roughly halves the heat losses to the die casting machine with rather low investment costs.
The standard insulation that is used in foundries comprises only a very thin (rough 1 cm) of wool-based insulation around the hot heating and cooling tubes that connect the decentralized heating/cooling

systems with the casting die. The tubes can be many meters long in real foundries and still have surface temperature > 50°C, which essentially then lead to considerable heat losses. Thus, we employed adequate insulation with approximately 50 mm of mineral wool and aluminium lamination as it is standard in most industrial tube installation in our project set-up (right-hand side of Figure 6).

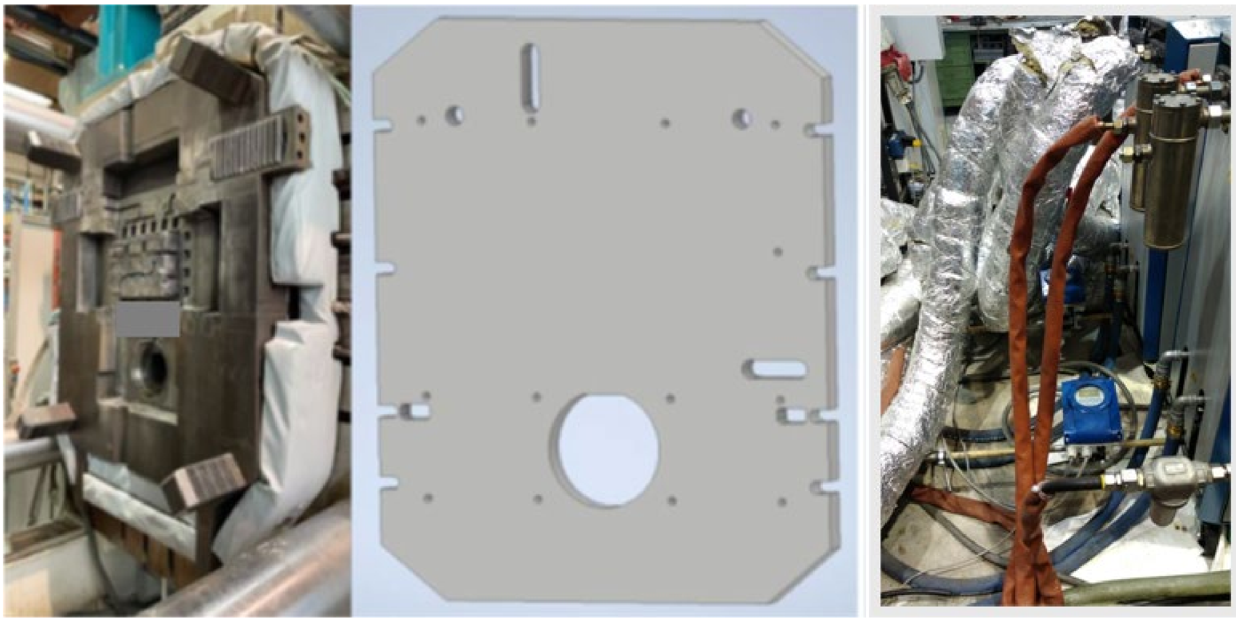

Figure 6: Left-hand side: Casting die of an inverter housing of a real series car with a flexible, cost-effective and maintainable insulation applied. Center: 50 mm thick insulation plate that applied between die and casting machine. Right-hand side: Standard insulation (red tubes) vs. adequate insulation (thick tubes mit aluminum-foil covering mineral wool):

Applying release agent onto the dies will lead to considerable die cooling (for the case of the our reference tool it was around 360 Wh/part; Figure 4) without the possibility of waste heat recovery as it is practically impossible to extract heat from the evaporated fluid in a cost-effective manner. Spraying of cold fluid onto the hot steel surface of the die also poses considerable stress on the material and leads to micro-cracks, which is a main driver of reduced tool lifetime. Thus, spraying should be as minimal as possible.

The reduction of the amount of applied release agent was achieved by re-programming the spraying robot which was in-house at the beginning of the project. Values like start/stop spraying over a defined travelled way and the spraying pressure were changed. The adjustment of the jets made a proper release agent application at a specific location possible. In case of thin swords on sliders and/or small cores, which are often critical areas for the proper casting of the sophisticated parts, proper local spraying is often necessary. This was achieved by focussing several jets on these critical areas instead of covering a larger area where the release agent is less efficient.
To be able to realize this new spraying pattern, a new minimum quantity spraying unit from Wollin GmbH was implemented in the die casting machine at LKR (Figure 7). This unit is a spraying mask with finer nozzles specifically developed and adapted to sophisticated tool geometries. Compared to the standard spraying units that spray the whole tool while going up- and downwards, the benefit of a spraying mask

is a reduced cycle time and a highly reduced application of release agent due to one-position tool spraying. This spraying unit was already successfully tested at LKR and is implemented to the die-casting process.

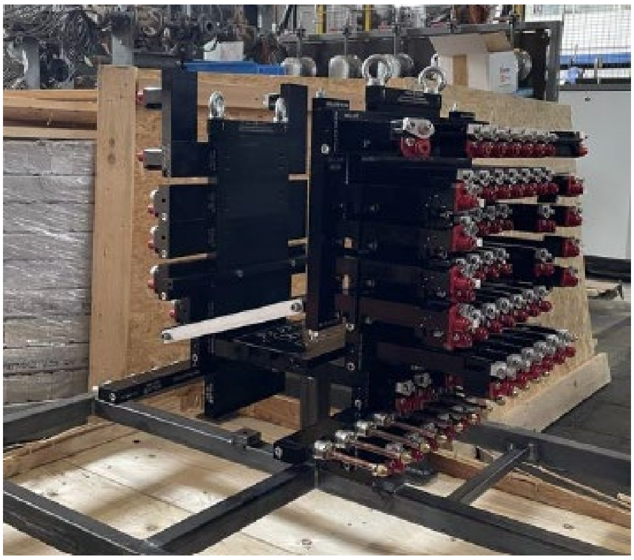

Figure 7: New minimum spraying unit (Wollin) that was applied to reduce heat losses due to spraying and stress on die casting tool.

In order to increase thermal heat recovery from the hot aluminum, a new slider design was developed. Dedicated experimental and casting simulation investigations (top left of Figure 8) of the temperatures of the tool, some inefficiencies where detecting in the design of the gating slider and one side slider (for realizing the lateral geometry). Therefore, two new slider attachments were developed. The derived improved cooling channel concept employs non-linear channels, which require more sophisticated production processes. Thus, a dedicated additive manufactured process was applied in a cooperation with Hermle AG, which finally lead to the successful new channel layout of the sliders and supporting copper inserts (top right and bottom of Figure 8). Due to increased conductive and fluid heat transfer, in our new tool a higher amount of heat recovery can be realized at even higher cooling temperature level, which in turn enables a higher fraction of waste heat re-utilization as the ingots can be preheated to a higher temperature level (cf. heat sinks chapter below for aluminum pre-heating via waste heat).

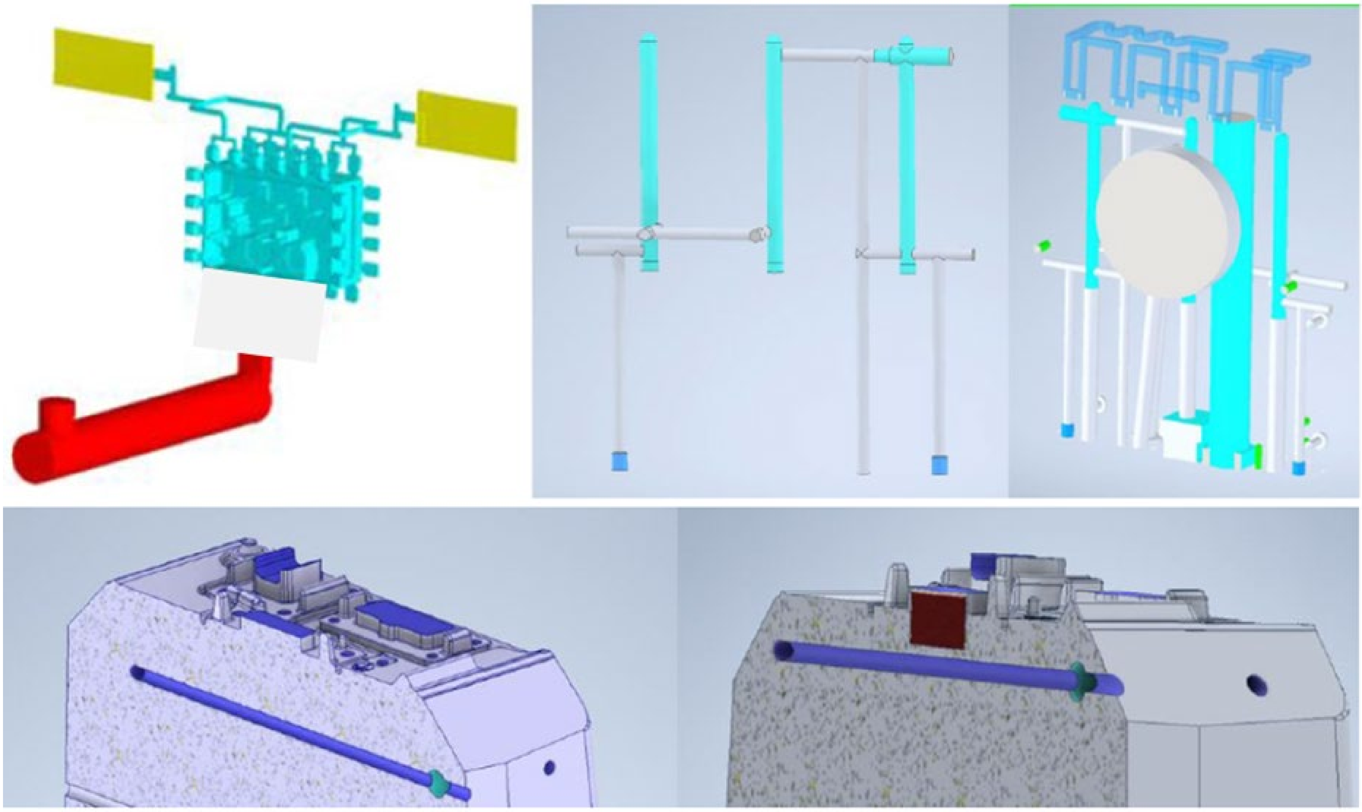

Figure 8. Casting simulation of the tool (top left) were employed to design a better cooling concept employing optimized cooling channels and copper inserts (top right, bottom).

3.2.2 Carbon neutral heating

The first step towards a carbon-neutral foundry is to implement energy efficiency measures by reducing energy consumption and increasing waste heat utilization. By combining the measures developed in the project, an increase of energy efficiency of up to 30% is technically and economically feasible.

The next step to a carbon-neutral factory is to employ carbon-neutral energy carriers instead of fossil ones. This includes the replacement of electricity from fossil power plants and the shift from fossil natural gas to carbon-neutral alternatives. The latter point is technically the most challenging as it involves the largest energy consumers in foundries, namely the furnaces. Foundries typically operate a combination of smaller and larger melting furnaces with a total holding capacity of liquid aluminum of up to around 100 tons and melting capacity of around 10 tons/hour. The typical power consumption of those furnaces is in the range of 1-10 MW depending on size. In addition, heat treatment furnaces are required for certain products, which operate as temperature up to around 500-600 °C.

In order to replace fossil natural gas, two main routes can be followed:

- Heating via carbon-neutral electricity
- Heating via carbon-neutral gases

Smaller melting furnaces and holding furnaces at the die casting cells are routinely heated electrically via induction heating or resistive heating in case of heat treatment furnaces. Also, for larger melting furnaces some manufacturers already offer some products, but still some development is ongoing, which was evident from a basic state-of-the-art research that was done at the beginning of the project and in summarized in Figure 9.

Manufacturer/Supplier	Type	Capacity	Power
Inductotherm	Heavy steel shell Lift swing	0,5 t – 100 t 10 t – 40 t	
Otto Junker	Heavy steel shell Channel	< 10 t 30 t	4,5 MW 5 MW
ITG	Heavy steel shell	1 t	
ABP	Heavy steel shell Channel	8 t – 27 t 8 t – 67 t	35 t/h 70 t/h
EFD	Heavy steel shell		
IAS (SMS-Group)	Heavy steel shell Channel	5 kg – 50 t 1 t – 100 t	10 kW – 20 MW 50 kW – 8 MW
EltaTech	Channel	< 2t	<1,2 MW

Figure 9: Selected induction furnace suppliers with typical technical key performance indicators.

Based on this literature research AIT performed a conceptual study for a typical melting plant when shifting from natural gas to induction including a dedicated calculation of the energy flows (Figure 10). The detailed economical result depends on the exact circumstances of a particular factory and cannot generally be stated, but the following findings hold true on a qualitative basis (an example is shown in Figure 11):

- Existing gas-fired furnaces cannot be revamped by induction technology, which means that a new induction furnace has to be built to replace a gas-fired one.
- Most induction furnaces have a larger footprint (including all necessary electrical peripherical systems), which can be up to around twice as that of gas-fired furnaces.
- Induction furnaces often have the advantage that they operate in a special way that it is not required to “keep the liquid aluminum warm when no aluminium is required”, which is the case for gas-fired furnaces and often consumes a considerable amount of energy.
- Key for the economic feasibility of induction heating are the electricity costs. In a (future) renewable energy system, many energy experts except heavily fluctuating energy prices, which may even be negative for up to several hundreds of hours per year. This bears the potential to heat the aluminum especially in times of cheap/negative electricity prices and may lead to significant economic advantages compared to gas-fired furnaces.

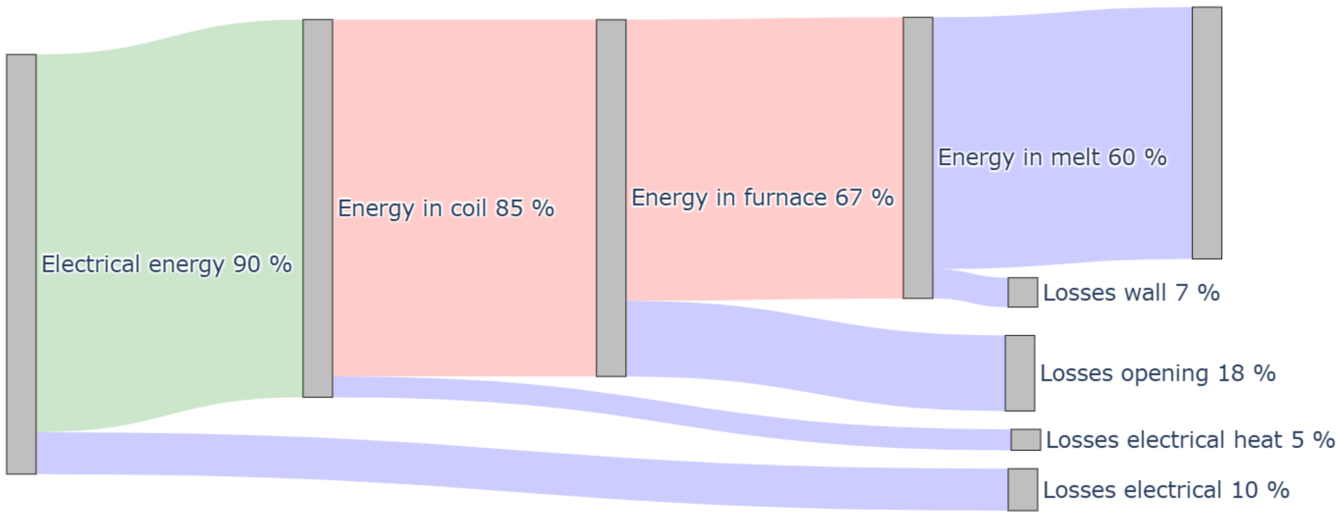

Figure 10: Exemplary Sankey diagram for induction melting furnace.

Figure 11: Exemplary calculation of levelized costs of heating for an induction furnace plant.

Besides induction, there are several new technologies are developed or adapted that use electricity as energy input. Within this project, contact was established with the respective institutes and possible suppliers to evaluate the potential of different technologies. Especially, plasma, show-wave and resistive heating might be applicable if some remaining technical issues can be resolved, in particular sufficient heat transfer, NOx emissions within limits, no detrimental influence on product quality, a sound re-vamping concept and long-term stability.

Besides the possible electrification, another route to achieve carbon-neutral furnaces is the application of carbon-neutral gases. These chemical energy carriers should be combusted similarly to natural gas predominantly in the power intensive large melting furnaces.

Within the project different possible gases have been investigated, which can be reasonably produced in the required quantities by technologies that are mature enough to deliver those quantities also for competitive costs and thus allow the companies to fulfill the national and European CO2-reduction roadmaps.
The following carbon-neutral gases have been investigated for the use in Green Foundries:

- Green hydrogen
- Biogas and biomethane from fermentation
- Biogas from biomass gasification
- Synthetic natural gas (SNG) from green hydrogen and carbon-neutral CO2

Green hydrogen can be produced via electrolysis either locally or in other countries and being imported via future pipelines (cf. European hydrogen backbone, Austrian hydrogen grid). Hydrogen has reasonable physical properties and can be combusted via ambient air. However, in order to achieve a significant reduction in CO2 emissions, the hydrogen must be delivered in almost pure quality (e.g. pipeline or combustion grade) as can be seen from Figure 12, which also casts doubts on possible blending with natural gas.

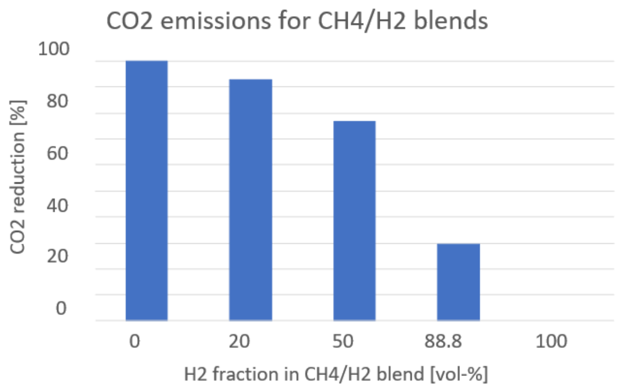

Figure 12: Dependence of decarbonization rate on volume-fraction of hydrogen in a hydrogen/methane mixture revealing the need for high H2 fractions for deep decarbonization.

A state of the art research has been performed, both in scientific literature and conferences as well as via expert interviews from industry. Although a lot of research and development is ongoing, it is still almost impossible to find a company that is capable and willing to build or re-vamp an industrial scale melting furnace to pipeline grade hydrogen.
The main uncertainties arise from three different aspects:

- Heat transfer to the product is changed when combusting hydrogen.
- Thus, it is a non-trivial task to properly size and place the new hydrogen burners instead of the natural gas burners.
- In order to achieve the required NOx values, a non-trivial combustion technique and/or burner and/or furnace design has to be applied

- Combustion of hydrogen leads to a changed flue gas composition (roughly 30% H2O and 70% N2 instead of 15% CO2, 15% H2O and 70 % N2). The increase level of H2O in the flue gas might lead to detrimental effects on product quality due to highly non-trivial chemical reactions that are even different for each and every alloy.

Many burner manufacturers are currently developing hydrogen burner and also employ corresponding simulations and test rigs. However, most of the developments are performed with single-burner set-ups in a very small combustion chamber, which does not reflect the real situation in a big alumium melting furnaces.
Thus, a dedicated diploma thesis (Georg Kränzel) was performed within the project to develop a more advanced model for hydrogen combustion with multiple burners. Different furnace and burner geometries were investigated and especially heat and mass transfer were studied (Figure 13). As a key result, it was possible to develop a thorough understanding and model for the “MILD combustion mode” that allows to fulfill the required NOx values even for multi-burner set-ups.

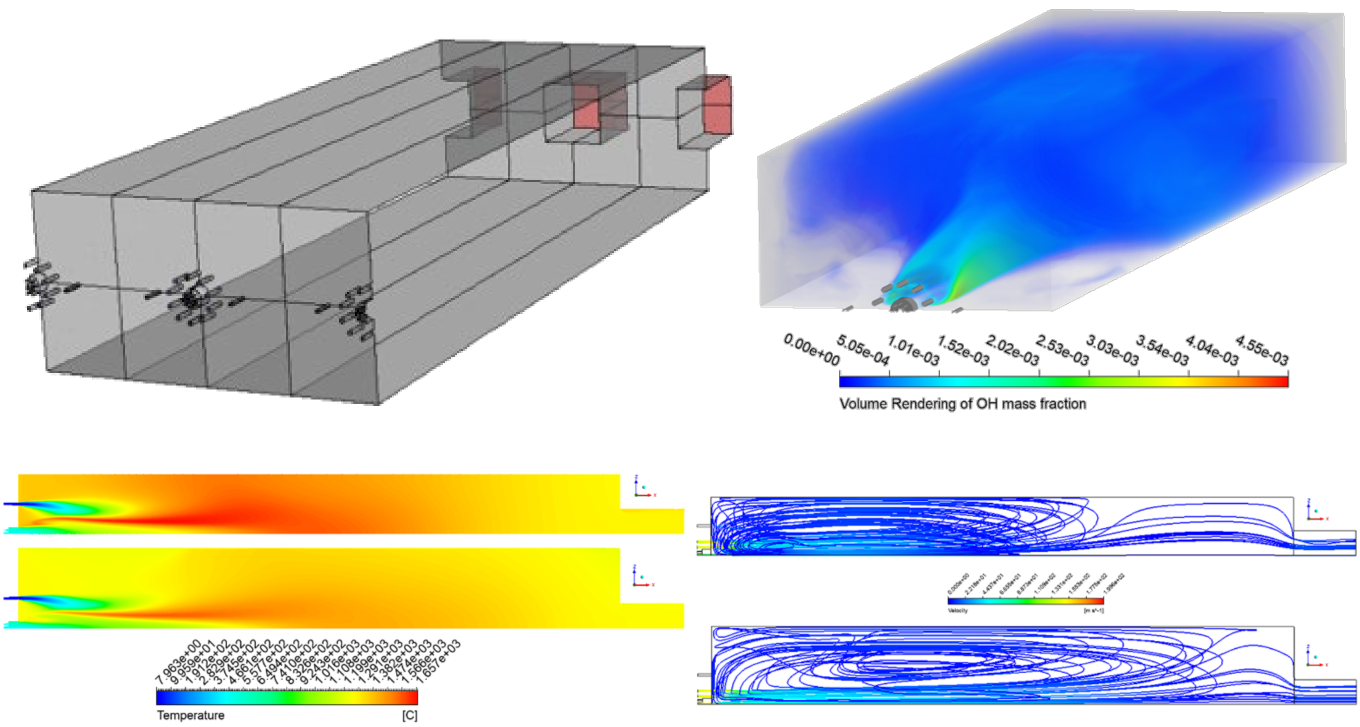

Figure 13: Dedicated CFD simulation models have been developed for multi-burner set-up relevant in large melting furnaces. Employing the model, heat and mass transfer can be analyzed to ensure proper aluminum melting with hydrogen combustion and by employing “MILD combustion mode” it is possible to achieve the demanding NOx emission requirements.

Green hydrogen might be a suitable option. However, for certain alloys and furnaces it might be possible that a non-resolvable detrimental effect on product quality remains. The characterization and understanding of the underlying chemical mechanisms was out of scope of this project, but various researchers in Europe and Austria are studying this issue in detail.

Within this project, we investigated the use of other alternative to natural gas, in particular biogas from fermentation. The technology is rather mature and common in Austria and Europe. However, currently most existing biogas plants focus on the production of electricity (and some heat) and do not produce biomethane in natural gas quality that is fed into the natural gas grid. The main reason for this operation mode was the subsidy situation of the past, which was discussed to be changed during the course of the project ("Erneuerbare Gase Gesetz"). However, the law was finally not passed and therefore it seems very unclear if the target of several TWh of biomethane will actually be built.
From a technological point of view, also the raw biogas (with minor cleaning steps; around 50% CH_4 and 50% CO_2) could pretty easily be combusted within the melting furnaces, however, in that case the biogas plant would have to be built right next to the Green Foundry, which is often not a very likely scenario. Thus, the preferred way is the upgrading of the raw biogas to biomethane and feed that into the grid.
Currently, different efforts are pursued on a European level to allow the European trade of biomethane (via Guarantees of Origin and other certificates). This could lead to a larger European biomethane production industry and thus also to compatible biomethane costs that could then be in the range of 60-100 €/MWh, which is almost at the level of natural gas plus CO_2 fee.

Another possible group of carbon-neutral gases that were investigated in view of their applicability in melting furnaces were gases produced predominantly from solid biomass via gasification. Austria has quite a tradition in that technology and various dedicated academic experts that succeeded in developing the technology up to MW-scale and even demonstrate it for certain operation modes e.g. in Güssing and internationally in Gothenburgh (Sweden, Figure 14).

Figure 14: A 20 MW gasification project was successfully demonstrating the technological viability in Gothenburg (The GoBiGas Project)

Within the project, we investigated different possible gasification technologies (air, steam), different fuels (especially different sort of wood biomass) and also possible and/or necessary cleaning steps relevant in the context of melting furnaces.
On the positive side, the cleaning and upgrading of the product gas does not need to be as high as for e.g. in synthesis applications (e.g Fischer-Tropsch). Also, steam gasification can produce a gas with sufficient heating value comparable to hydrogen. The product composition and the technical parameters (Figure 15) are also suitable for many burners and it is very likely that heat and mass transfer and NOx emission requirements can be achieved.
However, some open issues remain and renders the technology interesting, but not yet completely commercially available:

- Companies need to offer gasifiers including all relevant peripherical systems on a MW-scale with the required performance guaranties at competitive prices (ideally as EPC)
- Adaquate burners have to be integrated into the furnaces and have to be successfully tested
- Solution have to found that the rather fluctuating demand of melting furnaces is either smoothened or that the gasifiers can ramp up and down fast enough and/or the product gas is stored adequately.
- Possible influence on product quality has to be investigated and made sure to be no problem.

Eigenschaften des Produktgases

		Dampfvergasung	Dampfvergasung + CC	Erdgas	H2
CH4	vol.-%	10.1	12.79	100	0
CO	vol.-%	21.8	27.6	0	0
CO2	vol.-%	21.0	0	0	0
H2	vol.-%	41.0	51.9	0	100
N2	vol.-%	3.7	4.68	0	0
C2H6	vol.-%	1.2	1.52	0	0
C3H8	vol.-%	1.2	1.52	0	0
Volumenstrom	Nm³/h	3652.59	2791.37	1246.74	4115.33
Heizwert	MJ/Nm³	12.65	16.01	35.8	10.79
Heizwert	kWh/Nm³	3.51	4.45	9.94	3.00
Heizwert	MJ/kg	14.38	27.06	50.01	119.96
Heizwert	kWh/kg	3.99	7.52	13.89	33.32
Adiabate Flammentemperatur	°C	2227.72	2390.28	2289.43	2452.06
Wobbe Index	MJ/m³	14.19	21.9	44.52	37.86

Figure 15: Composition and selected technical parameters of gas mixtures suitable for melting furnaces from gasification.

As yet another option, AIT investigated the import of Synthetic Natural Gas (SNG) from regions with even more favourable conditions for the production of carbon-neutral electricity and gases. A method developed in the course of the hydrogen import study (Importmöglichkeiten für erneuerbaren Wasserstoff) was extended to include carbon capture from point sources (via amin scrubbers) or from direct air capture and subsequent methanation with green hydrogen (Figure 16).

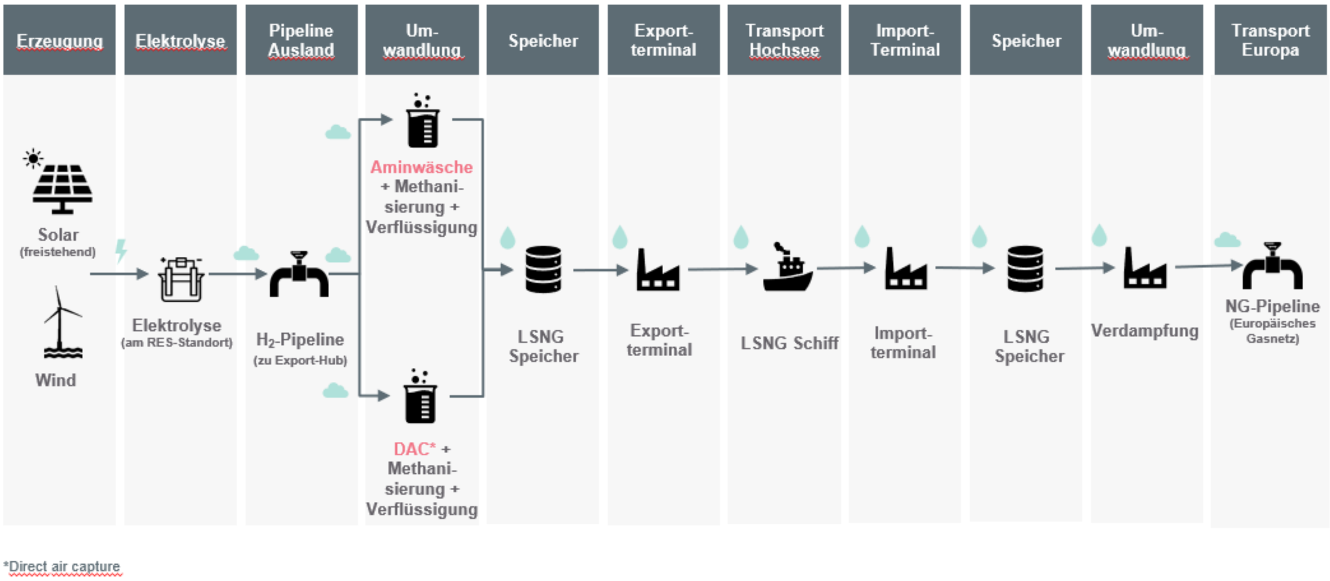

Figure 16: Production and exemplary import of SNG from biogenic CO2 and/or direct air capture. Import from different possible countries was investigated along different routes.

A techno-economic assessment for the import from different countries was performed and is summarized in Figure 17. Especially the import from Tunisia turned out to be interesting from an economical point of view. Compared to hydrogen, the existing infrastructure for transport of gas from the production sites to the end-users (Green Foundries) could stay in place and even nothing would need to be changed at the industrial sites themselves.
However, of course, due to the additional conversion steps and the costs related to carbon capture, the resulting product gas (SNG) is more expensive than green hydrogen. Thus, SNG remains a sort of "fall-back" option if unsurmountable problems associated with the production, transport and combustion of hydrogen occur, but at first hand seems to be economically worse.

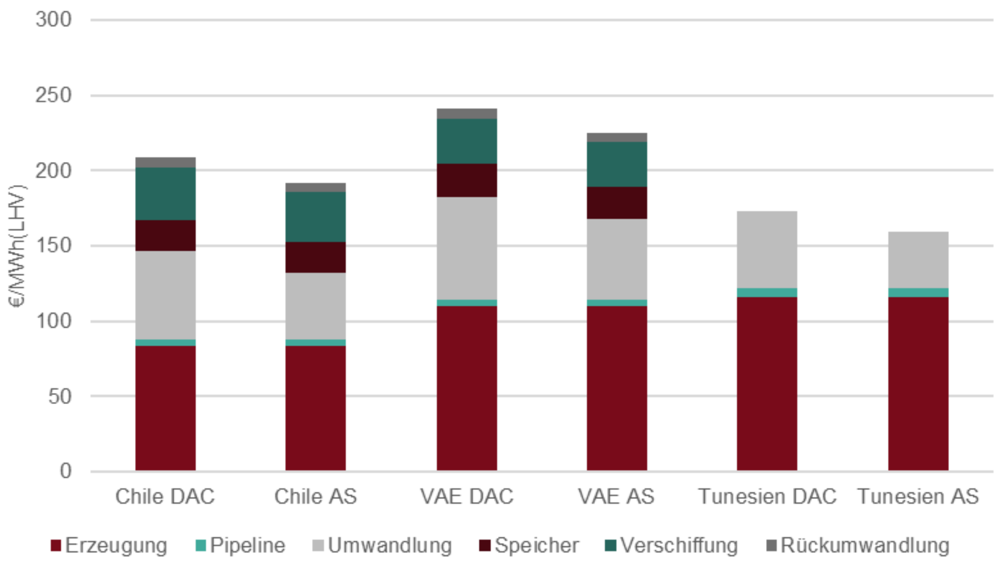

Figure 17: Comparison of SNG costs imported from different countries (DAC…direct air capture; AS…amine scrubber).

For each and every specific site, an optimal decarbonization solution and asset park has to be developed to supply carbon neutral electricity and/or gases at the cheapest possible costs to carbon-neutral furnaces. Thus, AIT developed a versatile simulation framework of a generic "Green Foundry" that is supplied by all possible sorts of renewable energy sources produced either locally or arriving via grid/pipeline. Figure 18 shows the generic model that was developed in Dymola/Modelica, which is capable of simulating an entire year with seconds time resolution.

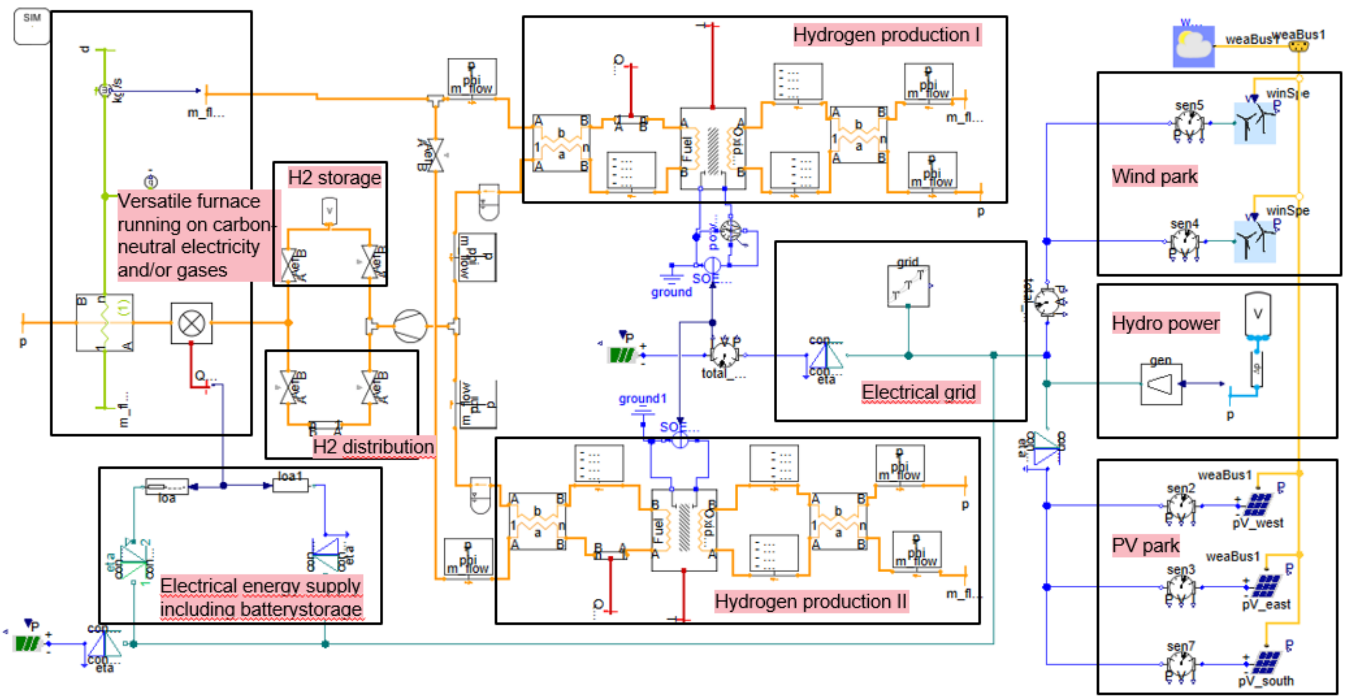

Figure 18: Generic model of a "Green Foundry" including different carbon-neutral energy sources, conversion and storage technologies as well as different types of furnaces running on green electricity or green gases.

This generic model can be employed to assess and compare the different options of a specific site and factory and calculate the optimal solution. Typical results of for such design calculation are shown for the production of green hydrogen from fluctuating renewables in Figure 19.

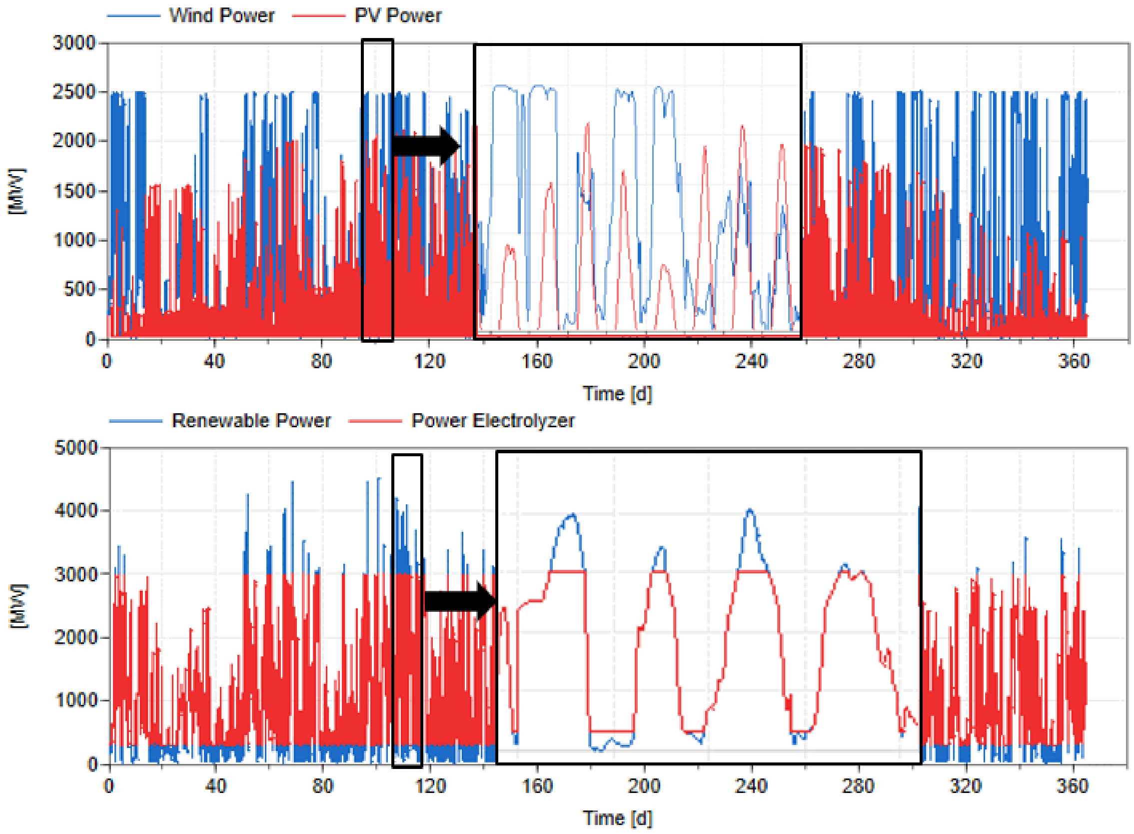

Figure 19: Top: Annual production profile of wind and solar photovoltaics. Bottom: Production of green hydrogen via electrolysis including a proper control strategy for the electrolyzer operating in a highly dynamic manner in the circumstances of fluctuating renewables.

Especially in the case that hydrogen cannot be directly employed as carbon-neutral fuel in the furnaces due to detrimental influences on product quality, which can occur for certain alloys and furnace types, it is necessary to convert the green hydrogen to synthetic natural gas (SNG) by capturing the CO2 from the flue gas of the melting furnace and feed it into a methanation reactor where it is converted to natural gas quality SNG via green hydrogen. Thus, we also developed a methanation plant within our simulation framework, which is shown in Figure 20.

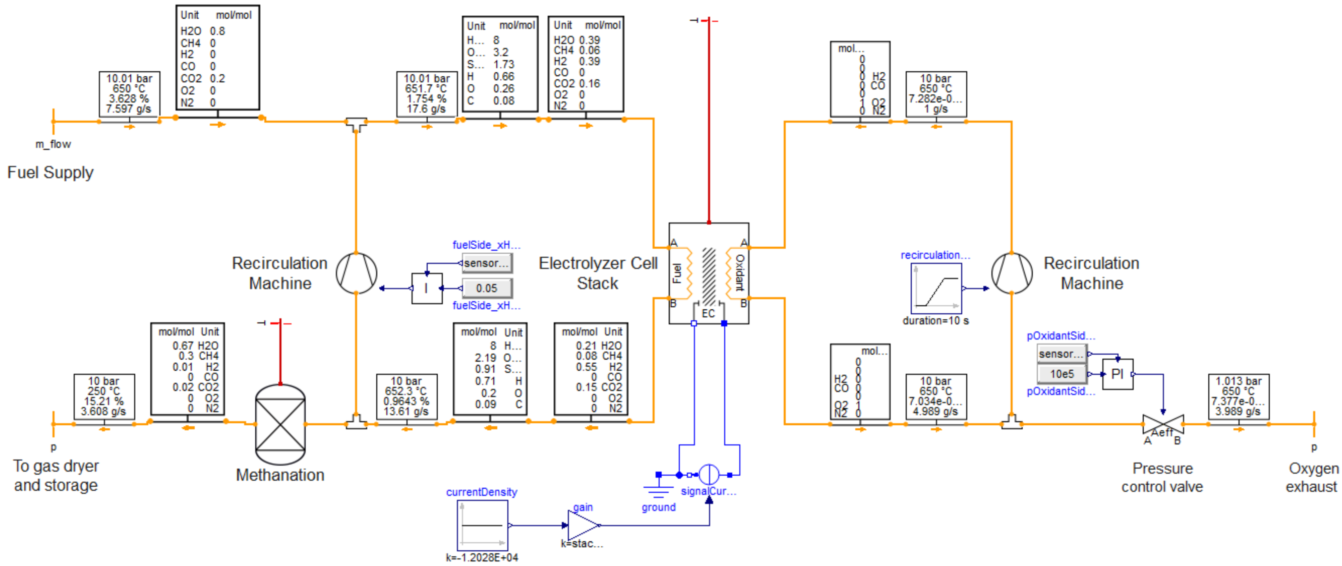

Figure 20: Dymola model of a exemplary methanation plant that converts CO2 and green hydrogen from electrolysis into natural gas quality SNG.

Employing the simulation models, we can calculate and optimize the exact amounts of renewable energy, green hydrogen and SNG that are produced e.g. every months (cf. Figure 21).

Based on the calculation of the technical key performance indicators of the whole plant (especially yield of carbon-neutral energy carriers) and the optimized size of the requried assests (renewables, conversion technologies, storages, furnaces), we can calculate the economic key performance indicators of the corresponding solutions. In particular, we compare the levelized costs of heating/fuel as is shown in the SNG-example of Figure 22.

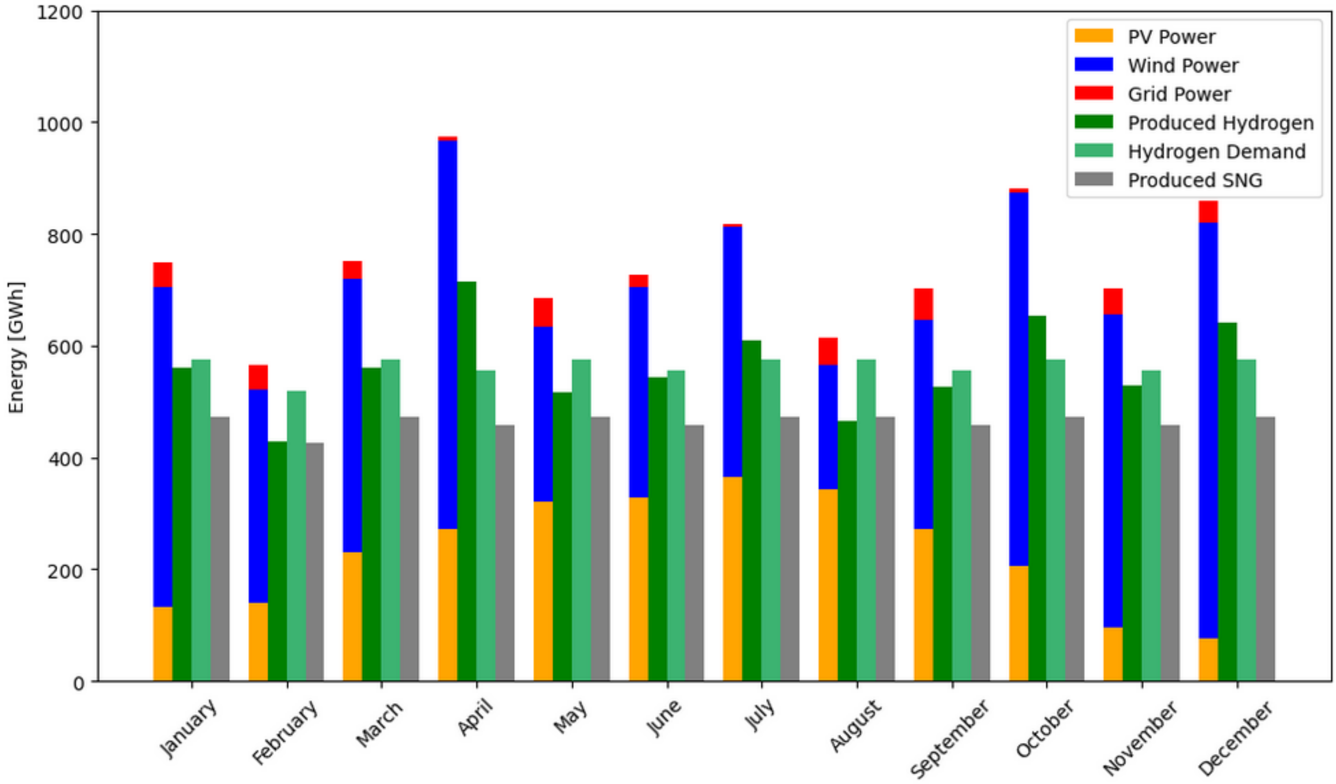

Figure 21: Monthly production of SNG and green hydrogen from renewables to fuel a carbon-neutral furnace.

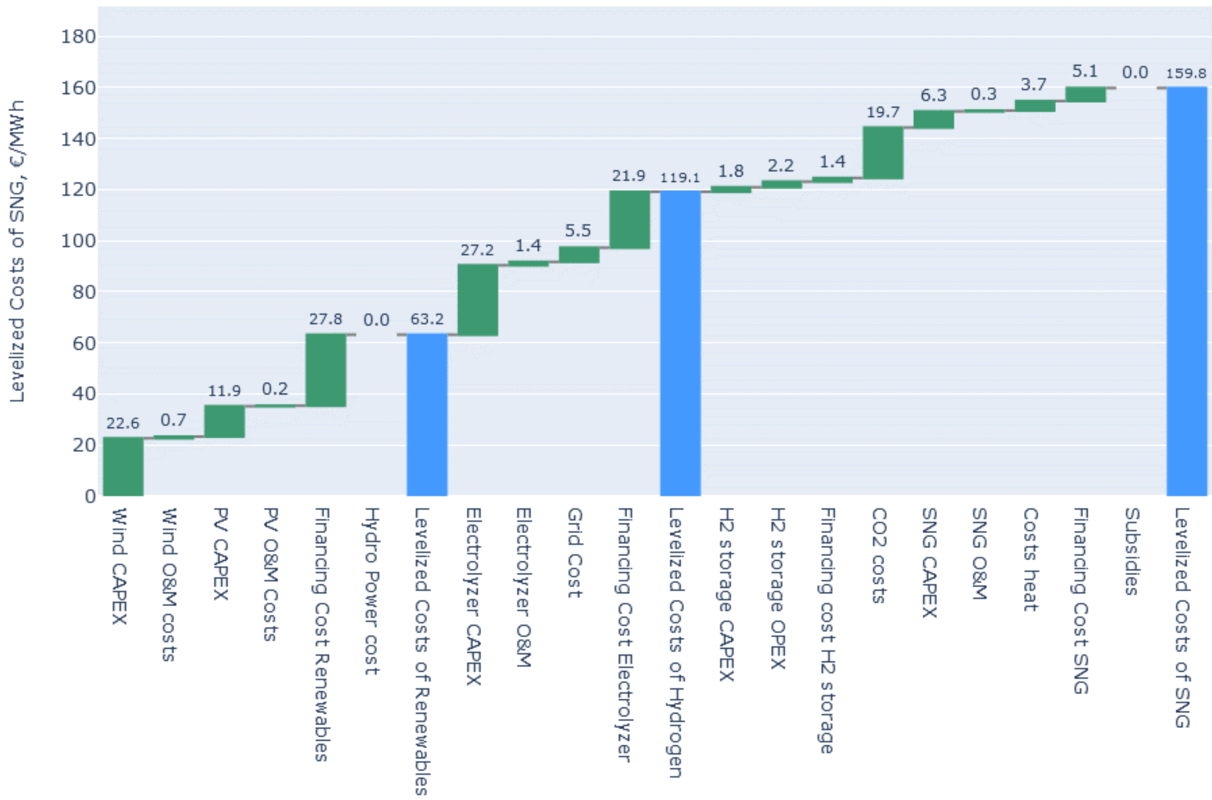

Figure 22: Waterfall diagram of the levelized costs of SNG for a particular fictitious example revealing the corresponding contributions of the different required assets to achieve a carbon-neutral foundry.

A particularly crucial part in the optimal planning of a Green Foundry is the integration of all required assets into the given local geographic conditions of the plant. Renewable energy plants such as wind parks or photovoltaic fields at the relevant scale of Green Foundries demanding energy in the order of 10-100 GWh/year requires many hectares of space. In the case of wind parks often at the top of mountain ridges, which are thus prone to wide visibility. In order to facilitate the optimal planning as well as the early dialogue with all involved and affected stakeholders of such a significant transition project, we developed the “AR industrial simulator”, a dedicated tool based on Augmented Reality that can be used to place all assets of the future Green Foundry including all renewables into a virtual environment and visualize them in an immersed 3d-dimensional AR experience (Figure 23), which can be used by planners as well as stakeholders already in the early planning process to better understand the possibilities and limitations of the various transition pathways.

In order to also be able to employ the tool for technical planning and optimization, a dedicated software code was developed that allows the coupling of the AR experience with the Dymola models. It is possible to place renewable assets within the AR experience and click on “simulate” within the experience, which automatically triggers a simulation on a cloud-hosted Dymola model in the background and returns the relevant techno-economical key performance indicators almost instantly. A dedicated video was produced to showcase the capabilities of the tool (AIT NEFI AR Industry Simulator) and in addition the tool is being hosted in the new Virtual Industry Lab that AIT is building in a new dedicated interactive site in Vienna within the NEFI framework.

Figure 23: A dedicated tool was created by AIT allowing an immersive planning process via Augmented Reality enabling optimal technical solutions as well as facilitating social acceptance via an interactive public stakeholder dialogue. The AR tool is directly coupled with the Dymola models that can simulate the techno-economical key

performance indicators almost live and return the results directly into the 3d AR experience, where they can be analysed to facilitate the optimal planning and sizing of all required assets of a Green Foundry

3.3 Energy efficient heating and cooling and waste heat recovery

In order to further increase energy efficiency and waste heat re-utilization in existing and new foundries, it is necessary to employ a modern, versatile and energy-optimized heating and cooling system that is capable of collecting waste heat from different heat sources and transport it efficiently to various possible heat sinks. Also, the temperature level of the waste heat streams should be as high as possible in order to allow for best possible waste heat re-utilization.

Thus, within this project a new central heating and cooling system concept was developed with the following key aspects:

- Different heat sources (in particular, melting furnaces and die casting cells) can be included via heat exchangers and valves at arbitrary factory locations and feed into…
- …an appropriate set of parallel fluid streams operating at different temperature levels that circulate the fluids through the whole factory via energy efficient pumps (usually centralized).
- Different heat sinks (in particular, pre-heating and heat treatment furnaces, washing processes and building heating systems) are also connected via heat exchangers and valves at different factory locations and can utilize waste heat from the heat sources.
- Thermal storages can be included at suitable positions in the system to balance heat demand and supply.
- A central control system is employed to implement a control strategy that operates at the highest possible temperature level in order to enable maximum waste heat re-utilization and ensures that the process requirements are met.

Figure 24 shows the PID schematics of such a system for the fundamental building block of a single die casting cell with multiple heating and cooling channels operating at different temperature levels, a combined pre-heating and heat treatment furnace (“ALO”), a thermal oil storage, electrical heaters and re-coolers. Additional sources or sinks can be included in an analogous manner in series or in parallel as required by the circumstances of a particular foundry.

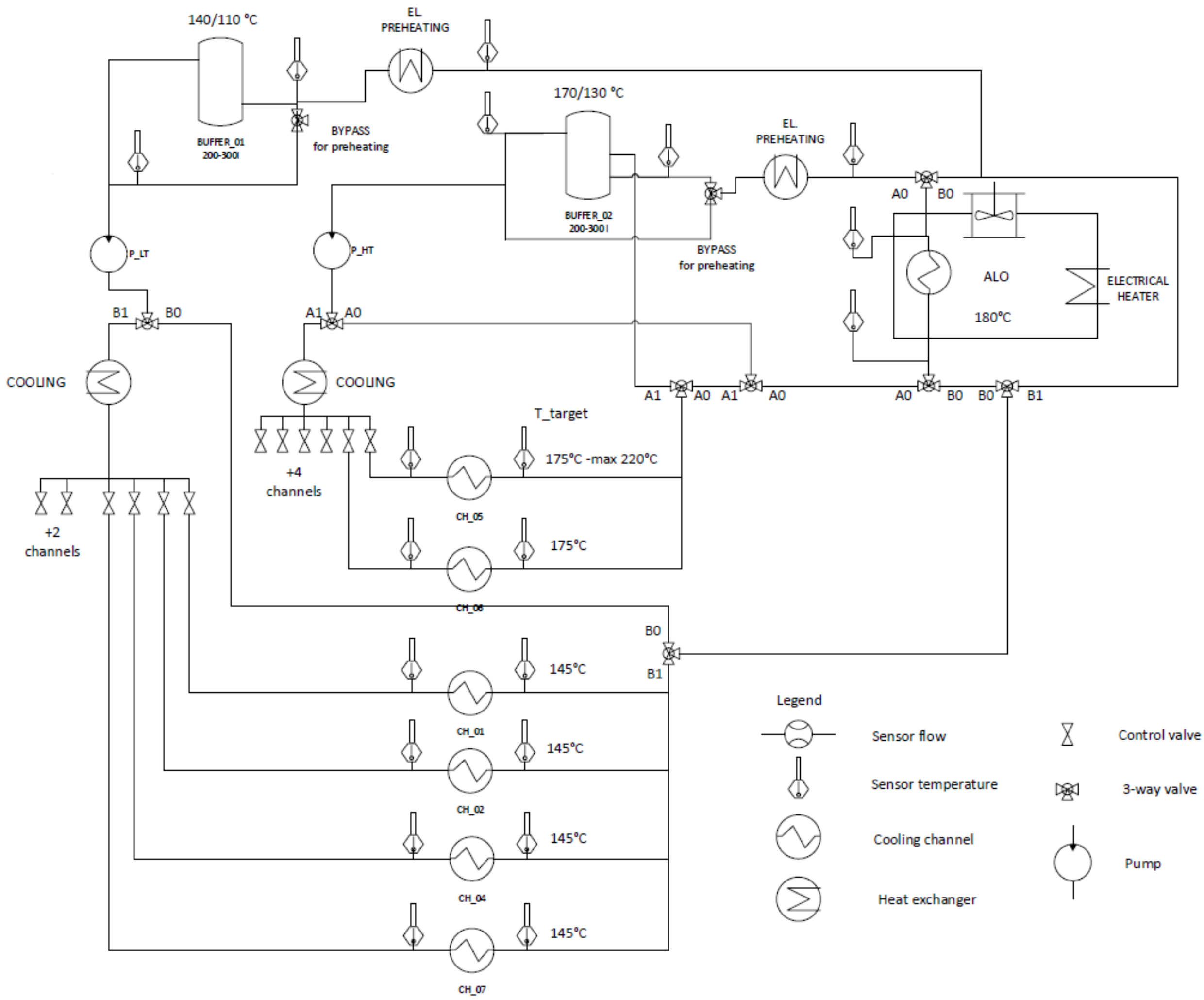

Figure 24: Exemplary PID schematics of the newly developed central heating and cooling system that connects different heat sources and sinks and allows for a high degree of waste heat re-utilization.

As such a new heating and cooling system is a complex equipment, the exact design of sizing and control details requires a dedicated process simulation for which the software environment of Dymola (Dassault Systems, 2023) based on the modelling language Modelica was employed. The TIL Suite library (TLK-Thermo GmbH, 2023) is suitable for transient simulations of thermodynamic systems and its components and was used for the basic components.
Missing equipment in the library have been developed and implemented by AIT in addition. In particular, this was necessary for advanced high temperature latent heat storages as well as the new pre-heating furnaces developed within this project. Figure 25 shows the Dymola model of a pre-heating furnace (top right) and the integration of the latent heat storage (PCM storage) with the furnace (left). The simulation results (bottom right) show that the ingots can be pre-heated in the required time, which leads to a significant reduction in energy demand of the melting furnace compared to the industrial standard where the aluminum is inserted into the melting furnace at ambient temperature.

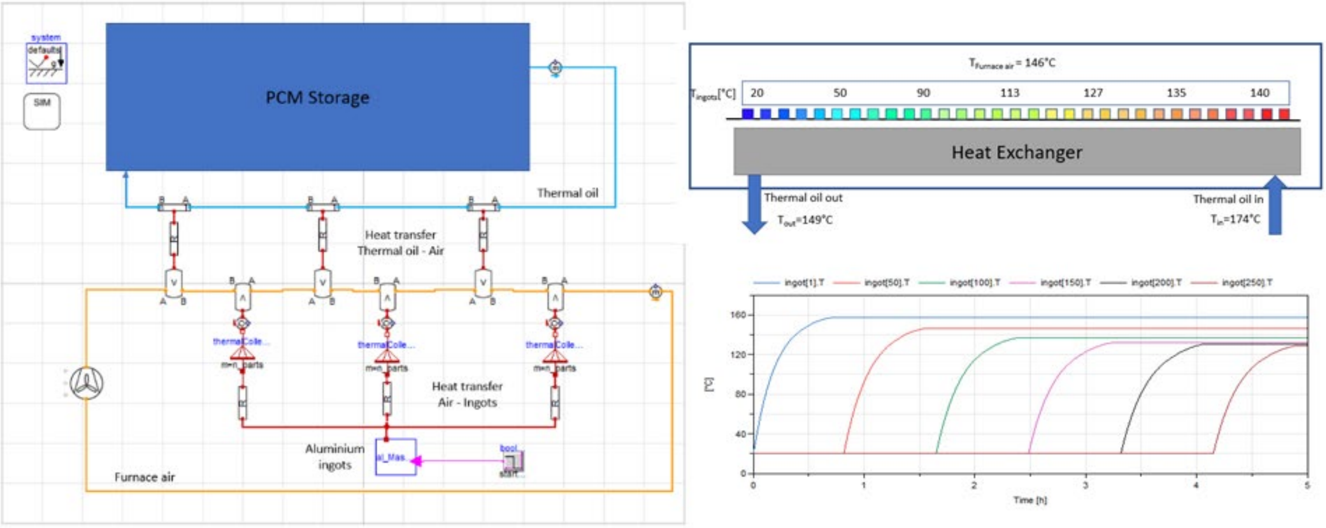

Figure 25: Left: Dymola model of the integration of a high temperature latent heat storage with the aluminum pre-heating furnaces. Top right: Model schematics of the continuous pre-heating furnace. Bottom right: Simulation result of successful ingot pre-heating via waste heat and intermediate latent heat storage.

Figure 26 shows a Dymola model of the main components of the schematics of Figure 24, which was used to design the necessary technical details of the system and its components.

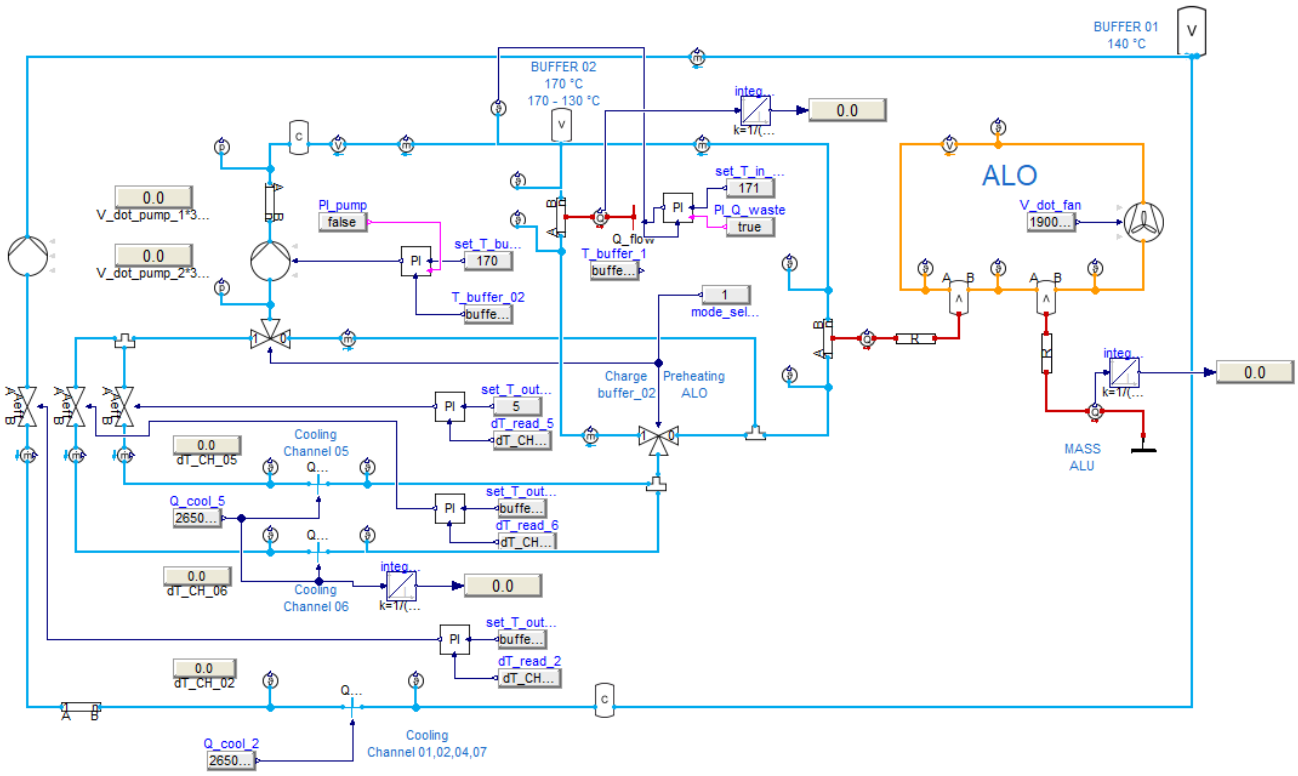

Figure 26: Dymola model of the new heating and cooling system.

Also, this model was used to investigate all the details of the new control concept, which is employing the outlet temperature of the heating and cooling channels of the die casting cell as the main control variable instead of the inlet temperature as is the case in most existing foundries. The advantage of this

new concept is that is allows for higher outlet temperatures (and inlet-outlet spreads) and thus a much higher fraction of waste heat re-utilization.
In detail, this is implemented by means of feed pumps and line regulating valves for the individual cooling channels. The primary pump is used to deliver a constant volume flow and the secondary valves regulate the individual channels more precisely to the required temperatures. The components are actuated in the simulation via PI controllers. Figure 27 shows a section of the Dymola diagram which illustrates the relevant components of the temperature control for the cooling channels.

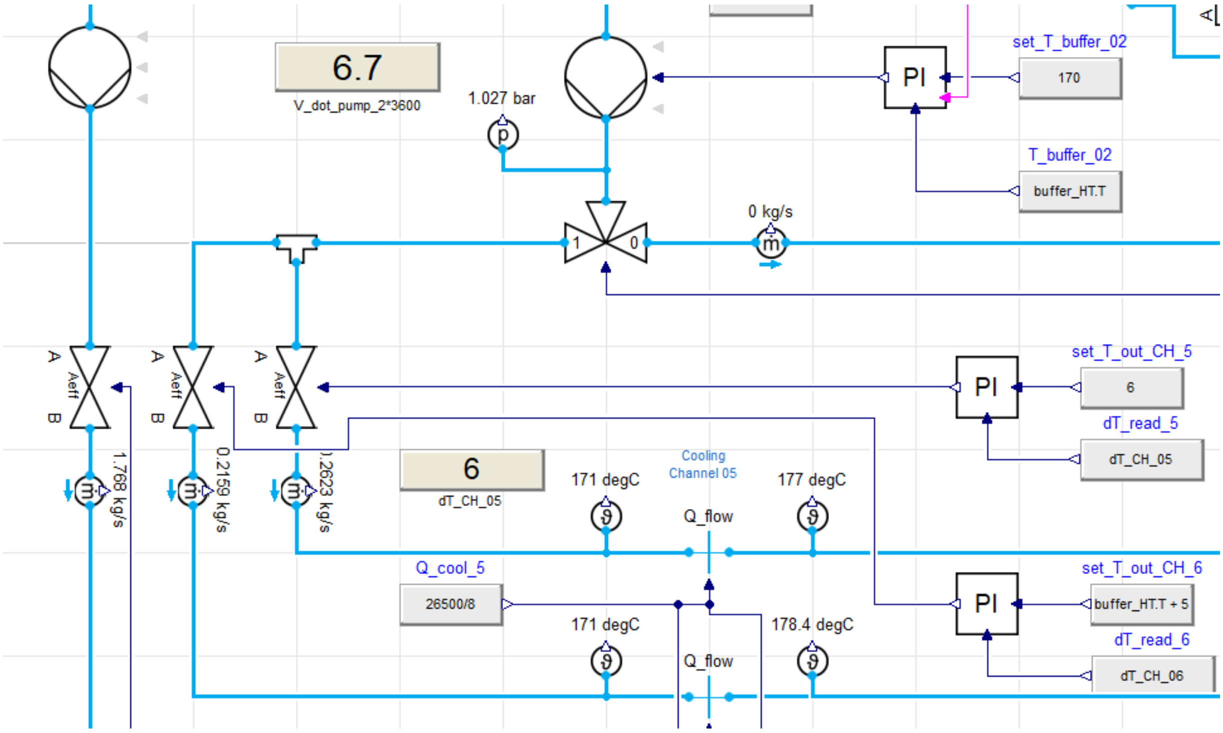

Figure 27: Detailed implementation of the new control concept in Dymola.

Figure 28 shows the final successful simulation of the whole central heating and cooling system including the new control system for the case of preheating of aluminum ingots: waste heat retrieved from the die casting process that was intermediately stored within a sensible thermal oil storage up to 170 °C and finally used to pre-heat the ingot to around 140 °C, which saves around 15 % of the energy necessary to melt the ingots.

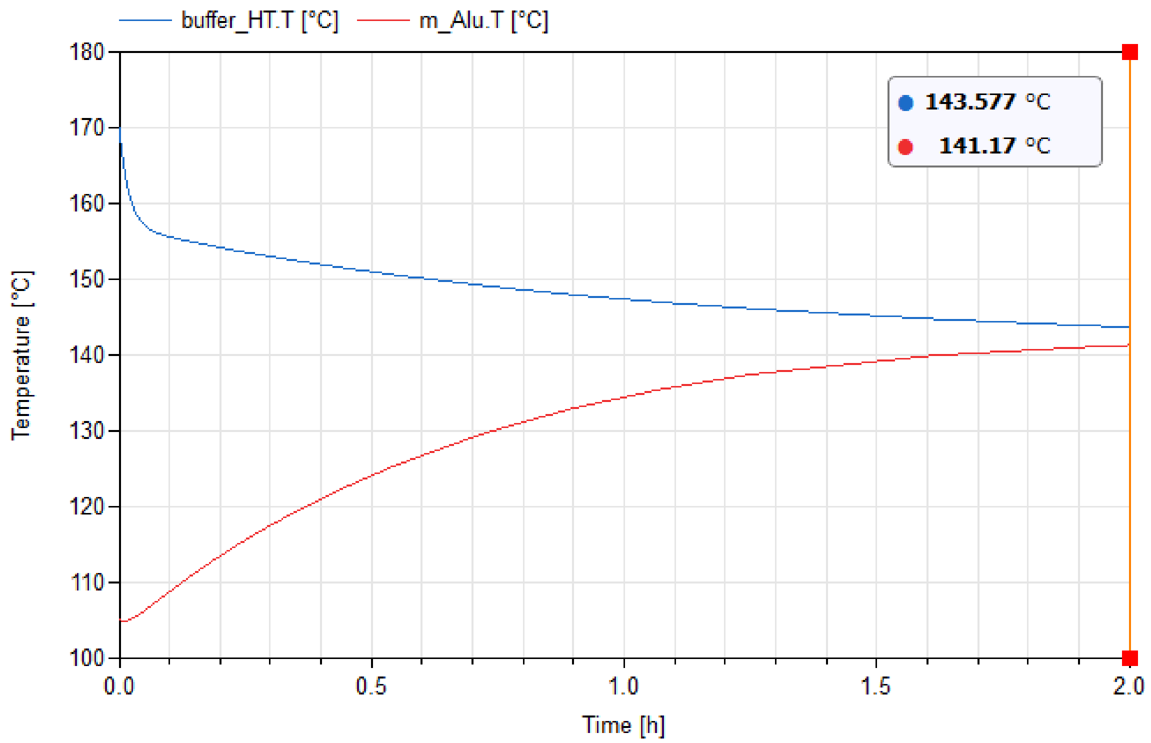

Figure 28: Simulation of the pre-heating of aluminum ingots (m_Alu.T) via waste heat from the die casting process stored within an intermediate sensible thermal oil buffer storage (buffer_HT.T)

3.4 Demo factory "Green Foundry 4.0" at AIT - LKR Ranshofen

After the development of the concept, the main components of a "Green Foundry 4.0" have been demonstrated at the AIT site at Leichtmetallkompetenzzentrum Ranshofen (LKR Ranshofen). The layout of the foundry including all core components was created in 2d and 3d planning software based on a variety of dedicated stakeholder meetings within the consortium as well as external parties to clarify the relevant technical details and connections.

Figure 29 shows the main components of the demo factory and how they are interconnected:

- Aluminum is melted in an electrical furnace close to the die casting machine. A variety of products can be cast with the industrial scale die casting machine (Kaltkammer-Druckgießmaschine DAK1100-112 - AIT Austrian Institute Of Technology) including the energy efficiency improvements described in chapter 3.2.
- A new central heating and cooling system provides the required temperatures and mass flows for the different cooling channels, recovers waste heat from the die casting machine and transfers it to the heat sinks.
- A thermal oil storage is employed to store heat up to a temperature level of 350 °C and balances heat demand and supply.

- Two new industrial furnaces are employed for heat treatment (solutionizing furnace, annealing furnace) and aluminum pre-heating.
- A modern control system is employed for energy and process monitoring as well as process control including a new, innovative type of control strategy.
- A digital twin of the factory employing Augmented Reality is used to improve process and energy visualization and enable optimized operation.

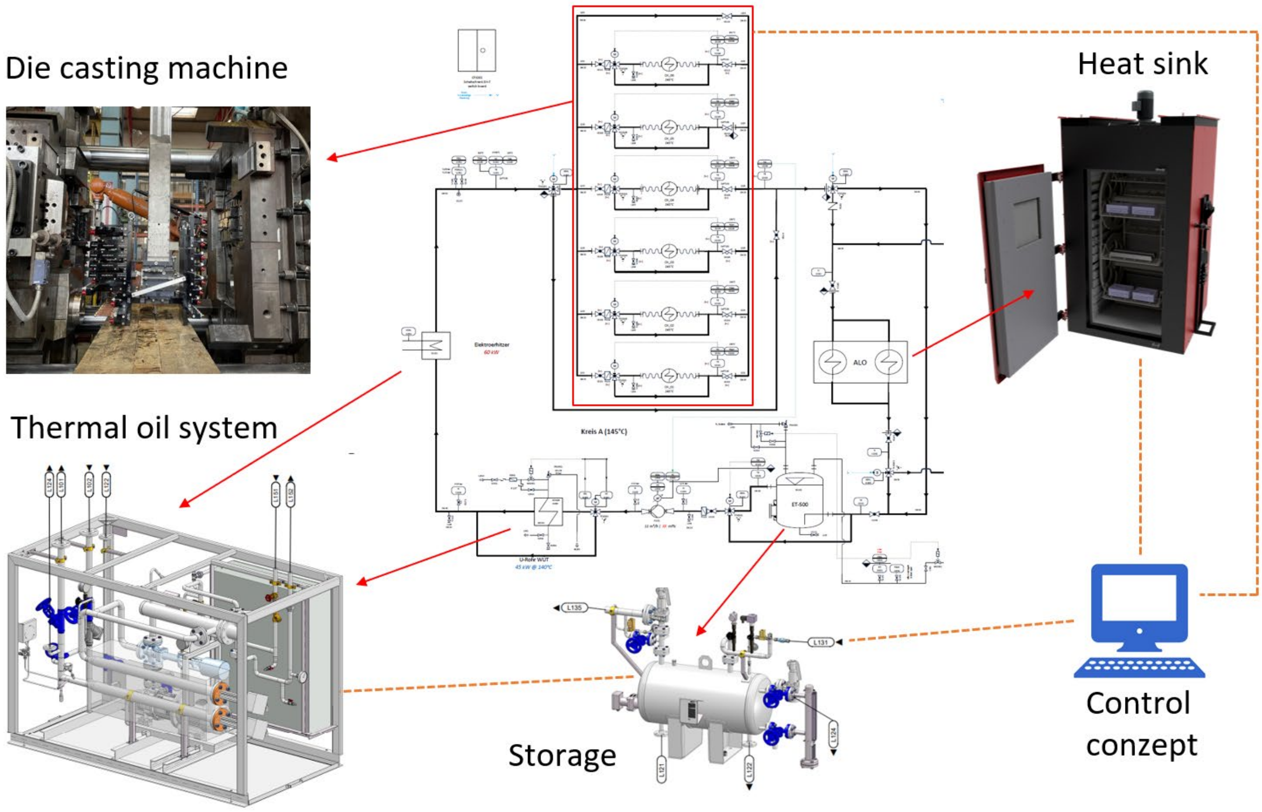

Figure 29: Overview of the main components of the Green Foundry 4.0 demo factory at LKR Ranshofen.

Figure 30 shows the PID schematics of the new central heating and cooling system, which can be used to heat and cool up to six parallel channels of fluid (thermal oil) via a central electric heater, a water/thermal-oil heat exchanger, an energy efficient pump and a special arrangement of valves to achieve the control strategy based on outlet temperature control.

Based on dedicated calculations for the expected and required heating and cooling demand of different operation modes (e.g. pre-heating of casting tool, casting, pre-heating of ingots and/or annealing via waste heat), a sizing of the required components of the heating and cooling system was performed and dedicated manufacturers have been contacted to assess their respective experiences and capabilities.

The most suitable company with a proven record with heating and cooling systems based on thermal oil was the German company heat11, which was finally selected to perform the detail engineering of the central heating and cooling system as shown in Figure 31.

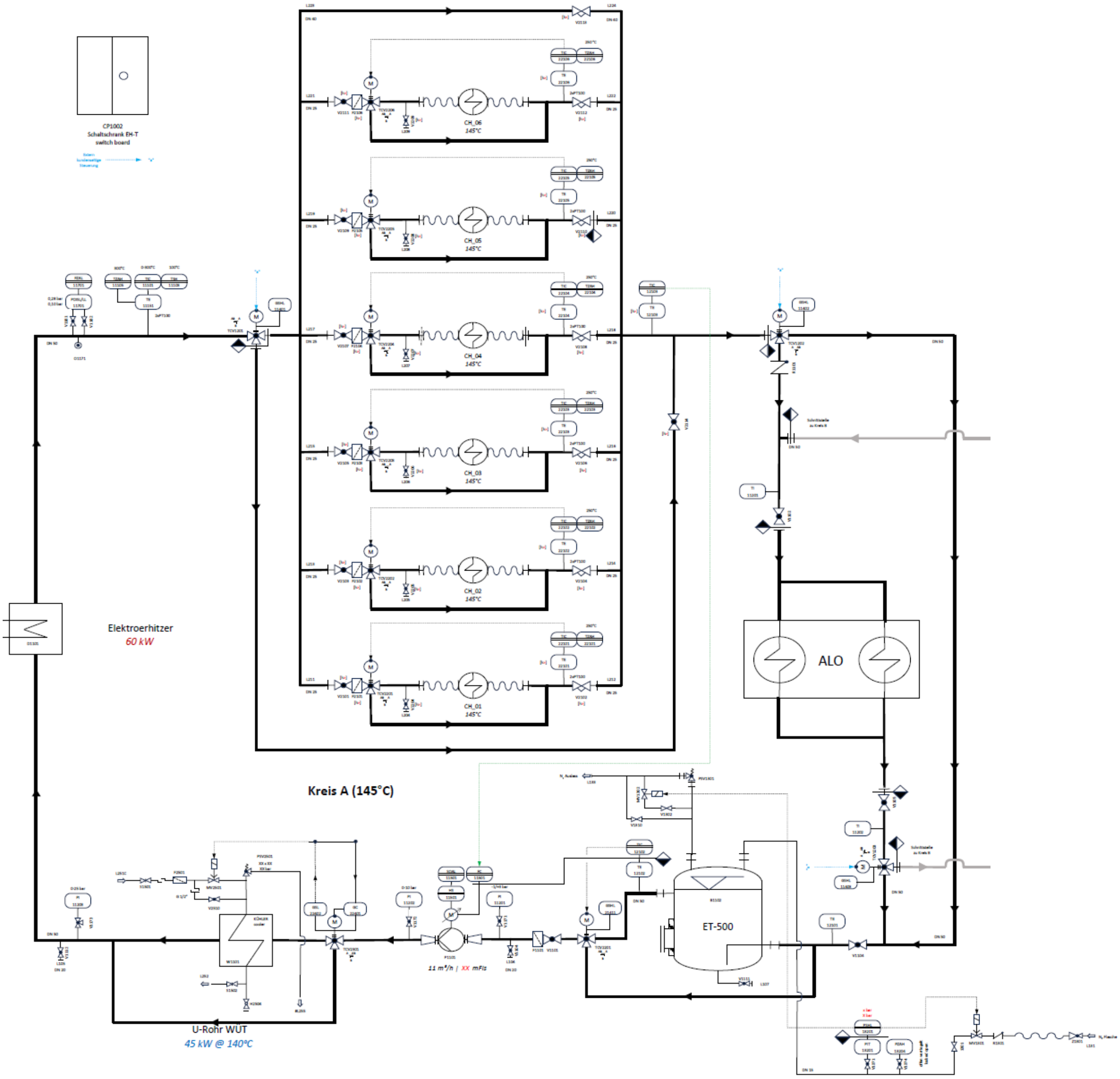

Figure 30: PID schematics of the central heating and cooling system that was finally implemented at the demo factory at the LKR Ranshofen.

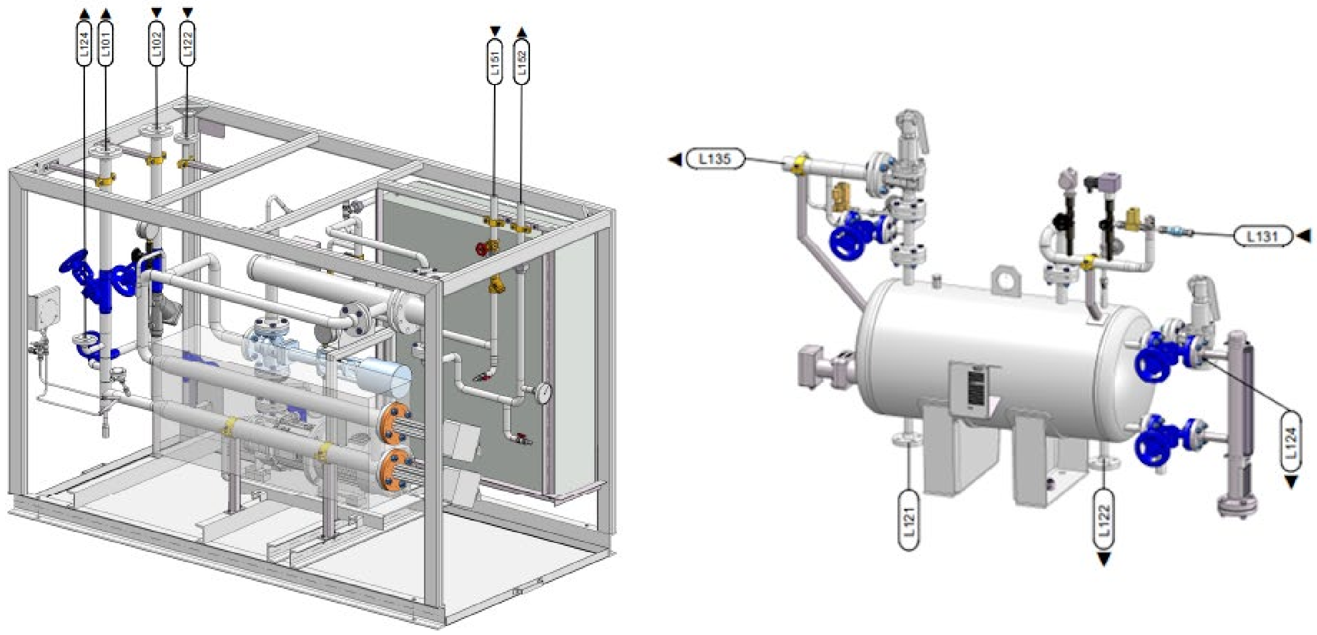

Figure 31: Design of the central heating and cooling system (left: skid with central heater, cooler and pump as well as control system. Right: thermal oil storage including valves).

In order to develop and showcase an industrially viable solution, it was important to respect all necessary industrial standards also of the installation at the Demo Factory at LKR Ranshofen. Thus, a full documentation and TÜV approval procedure was initiated and performed to Austrian and international standards, which ensures applicability of the system in real industrial factories.

The company heat11 finally was contracted to install the new central heating and cooling system according to the design and specifications developed by AIT at the Green Foundry 4.0 demo factory at LKR Ranshofen. Figure 32 shows the installation as delivered, which was in a next step commissioned and successfully delivered the required heating power of 50 kW and cooling power in the range of 100 kW (depending on cooling water mass flow). Also, the thermal storage tank was operating according to the specifications as well as all valves including dedicated control algorithms directly implemented in a separate control system mounted at the skid.

Figure 32: Central heating and cooling system of the Green Foundry 4.0 demo factory at LKR Ranshofen as delivered by heat11 according to the design and specifications of AIT.

The main challenge for waste heat utilization is to find a suitable heat sink. Although very often certain washing processes, warm water for showering and heating of buildings are considered, these sinks are usually much to small compared to the amount of available waste heat in any major industry such as foundries. Building heating often requires a somewhat meaningful amount of energy, however, of course only during the heating period, which is only a few months in full load and a few months in partial load. Under the current economic circumstances of very cheap natural gas, it usually does not pay off to re-use the waste heat within the required amortization times in industry.

Thus, it was necessary to find another suitable possible heat sink in a foundry and actually there can only be a single useful one, which has a heat demand comparable to the available waste heat and that must be related to the produced products themselves. In this case, it is the aluminum that has to be melted, which is by far the most energy intensive process of every foundry. The aluminum scrap and ingots are usually inserted into the melting furnaces at ambient temperature. No proper pre-heating stage occurs outside the furnaces. Sometimes the aluminum ingots lie for a few minutes on the furnace lid for preheating. However, due to very low convective heat transfer coefficients and the short “heating

time", the temperature lift of the aluminum ingots is only a few degrees and thus actually almost no waste heat recovery is occurring at that stage.
Thus, it was necessary to design a completely new pre-heating furnace, where the different waste heat sources of a Green Foundry can be utilized. Figure 33 shows the design of such a furnace that was developed by AIT and Hofmann, which allows to pre-heat aluminum ingot and also to employ the furnace in the annealing step of certain heat treatment programs.

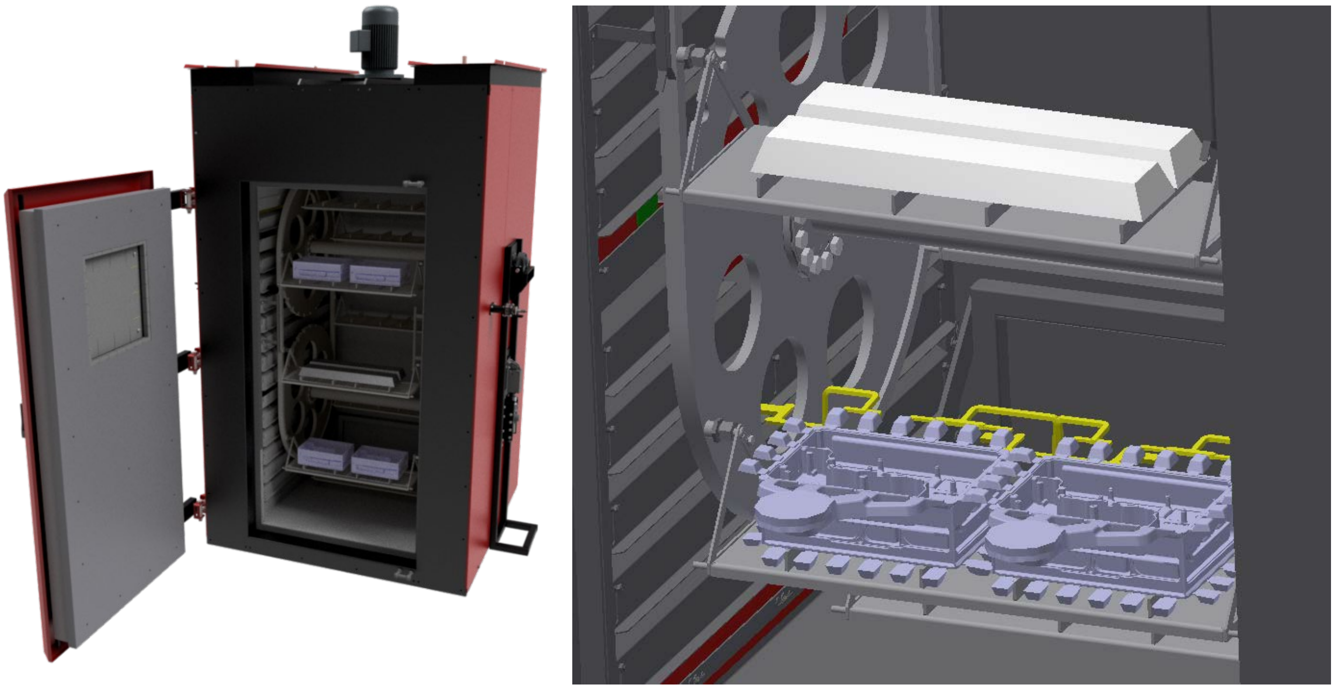

Figure 33: Design of the combined aluminum pre-heating and annealing furnace.

Waste heat can be injected into the furnace in different ways:

- Waste heat from the die casting cell is transferred by the central heating and cooling system to the furnace in the form of hot liquid (ideally thermal oil), which can be injected into the furnaces via a dedicated fluid/air-heat exchanger as shown in Figure 34 (left: design; right: as built by the company Hofmann for the furnace of the demo factory).
- Waste heat from flue gas from the melting furnaces, which is very often exiting the factory at temperatures up to 400 °C (sometimes combustion air pre-heating is applied, but this also requires only a fraction of the available waste heat), can be either injected into the furnace directly or via gas/air or gas/fluid heat exchangers depending on the exact circumstances of the respective foundry.

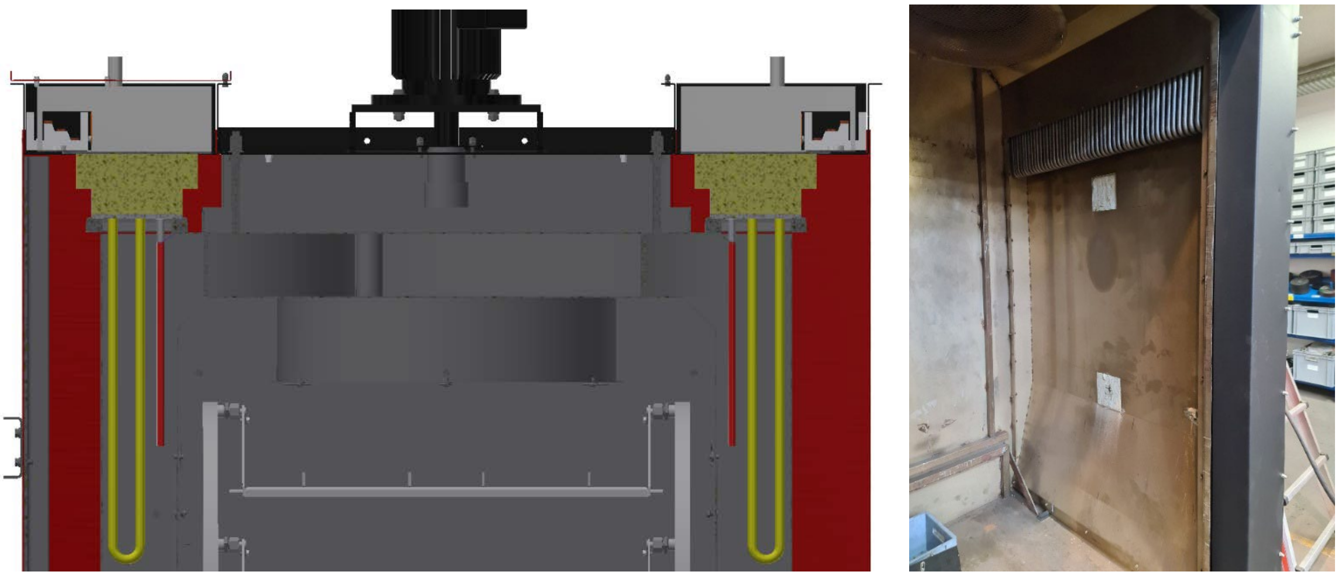

Figure 34: Waste heat from different sources can be injected into the furnace via dedicated fluid/air heat exchangers.

Finally, the exact requirements in terms of heating demand and available waste heat were calculated by AIT within the project for the case of the demo factory. Hofmann performed a proper sizing and detail engineering of the new furnace and finally installed it at the Green Foundry 4.0 demo factory at LKR Ranshofen as shown in Figure 35 (next to the die casting cell and the new central heating and cooling system.

Figure 35: Installation of the combined aluminum pre-heating and annealing furnace the Green Foundry 4.0 demo factory at AIT LKR Ranshofen.

In addition to the combined pre-heating and annealing furnace, a dedicated furnace for the solutionizing process was designed by AIT and Hofmann. Figure 36 and Figure 37 show the complex design of a multi-level rotary plate furnace that can be loaded with a variety of aluminium parts on different levels. By controlling the angular velocity of the rotating product holder, it is possible to adjust the heat treatment time according to the needs of the product and customer. The advantage of this circular design compared to a linear design is a more compact form and also a reduction of heat losses due to the very compact form as well as a reduction of entrances from front and back to only a single combined one.

Figure 36: Design of the solutionizing furnace employing a rotatable mounting system.

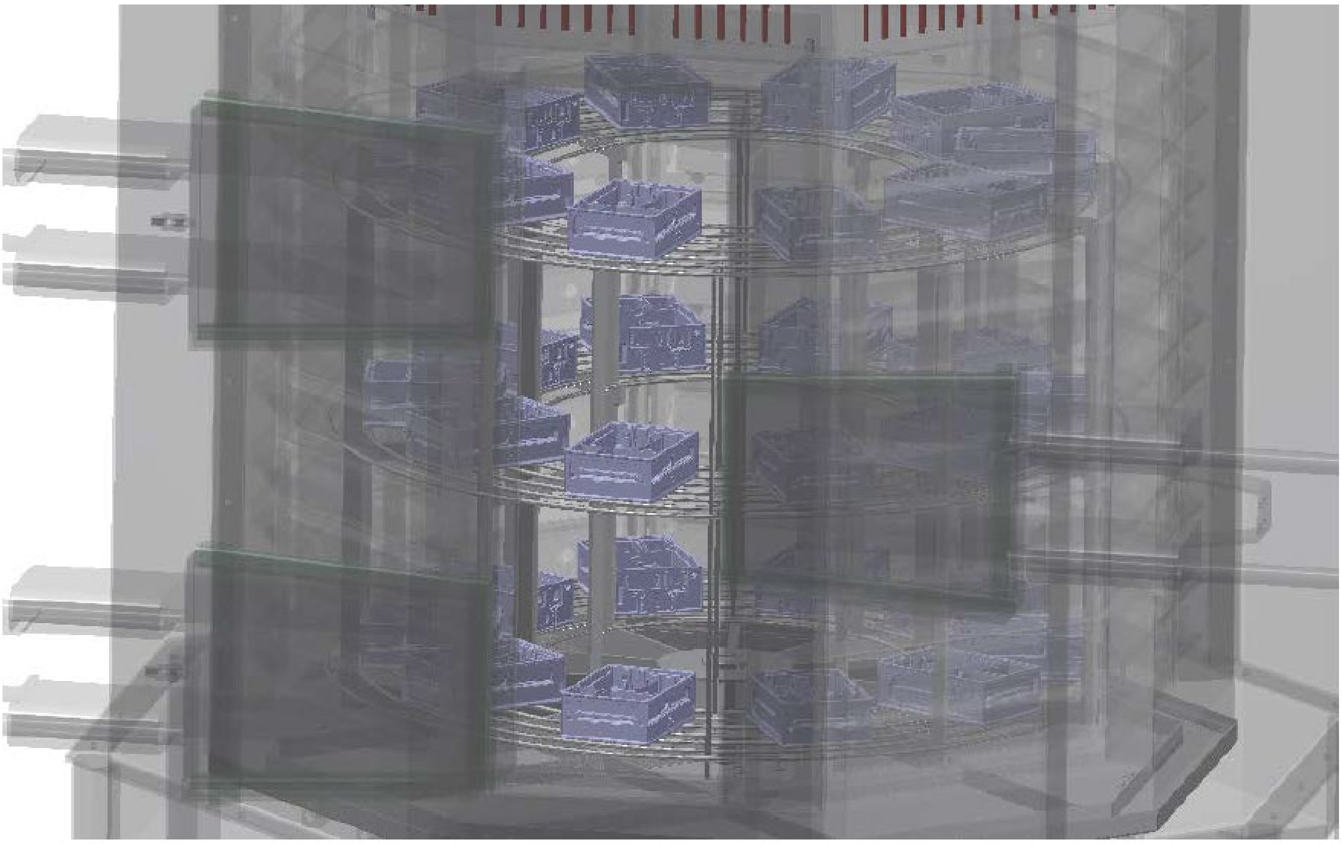

Figure 37: Detailed view of casting parts within the solutionizing furnace.

Similarly to the pre-heating and annealing furnace, also the exact design parameters have been worked out and finally the furnace was installed by Hofmann at the Green Foundry 4.0 demo factory at LKR Ranshofen as shown in Figure 38.

Figure 38: Installation of the solutionizing furnace the Green Foundry 4.0 demo factory at AIT LKR Ranshofen

Both furnaces have been designed and installed according to all relevant international and Austrian standards. They have been successfully commissioned and performed exactly to the required specifications. Trials with different casting parts have been performed at LKR and proved the functionality of the furnaces.

In order to be able to control all different factory components and operate the Green Foundry 4.0 in an energy optimized way, a new dedicated control system was developed by the project partner AIT and Maxan with input from all project partners.

The overall process control system was implemented via an advanced industrial process control system based on B&R hardware and software (APROL) employing modern OPC-UA standard and communication to the Augmented Reality system via Unity. A dedicated user and data interface was created in the automation system that is able to monitor, visualize and control the whole Demo Factory (Figure 39).

In order to maximize the outlet temperature of the die casting cell and thus enable best possible waste heat re-utilization, AIT and Maxan developed a new type of control schematics and algorithm that controls the mass flow of the pump and the individual channels in an appropriate way (Figure 40).

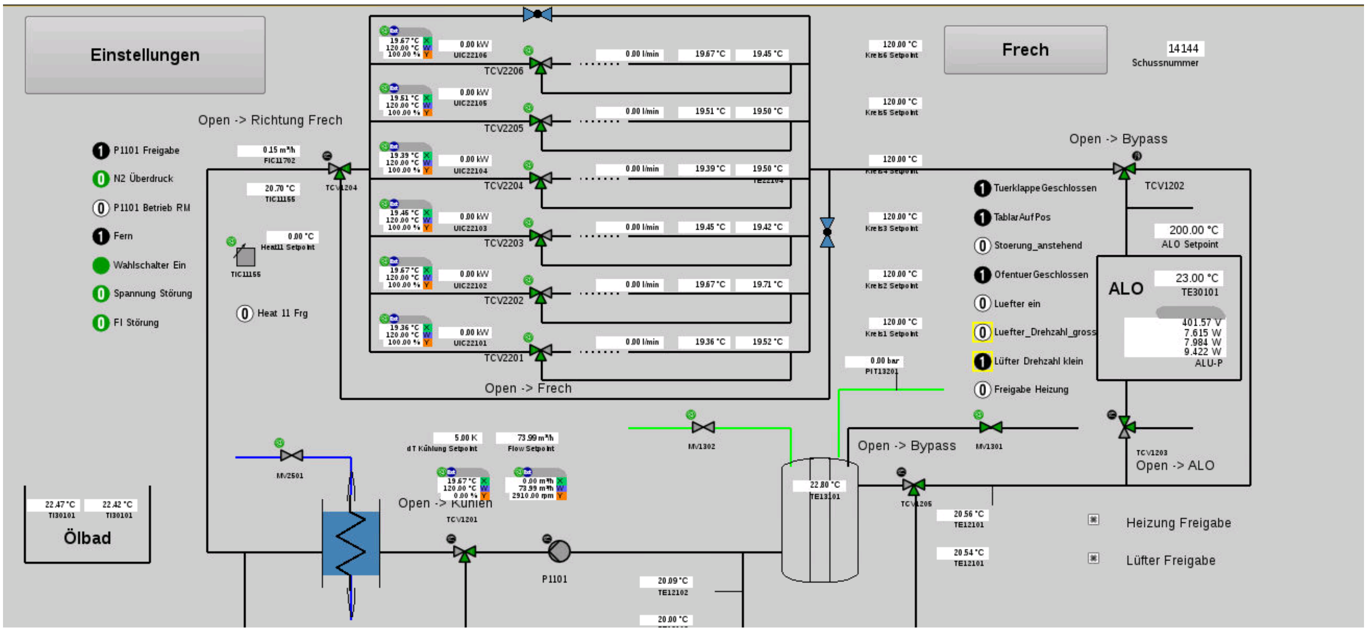

Figure 39: Overview of the B&R process control system of the Demo Factory Ranshofen implemented by Maxan.

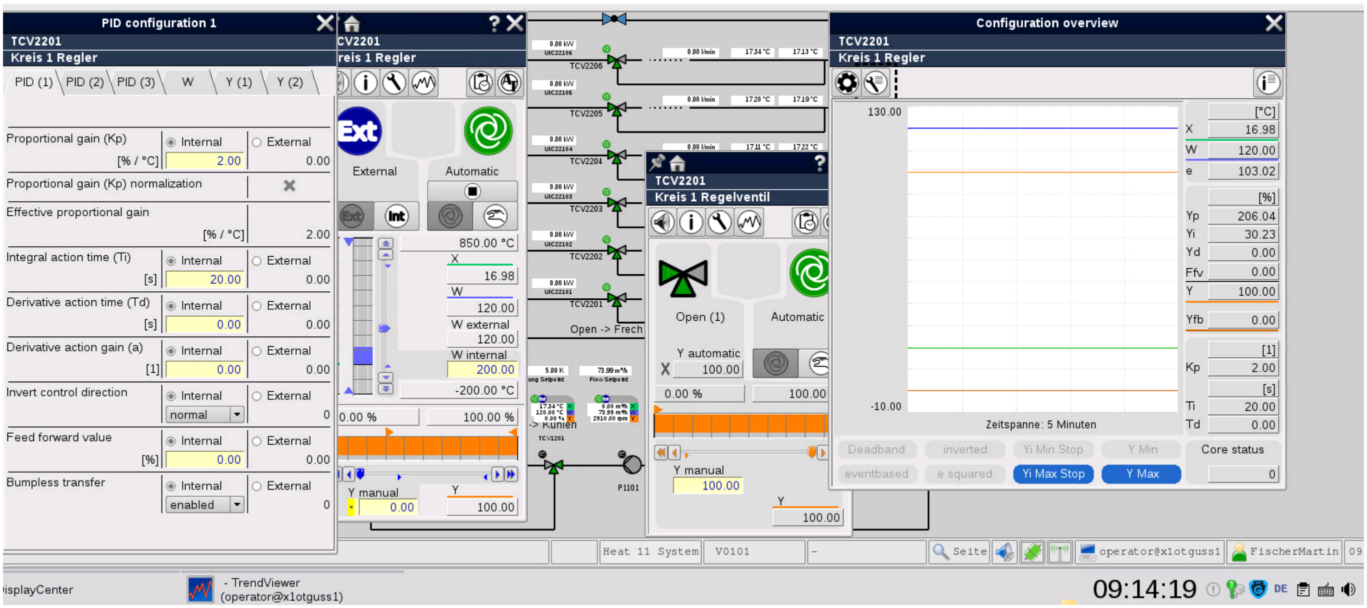

Figure 40: A new control schematics and system was developed that maximizes outlet temperature and thus enable waste heat re-utilization.

The control system was thoroughly tested in different operation modes such as die pre-heatings, die casting with heating and cooling, waste heat recovery from die casting, heat storage and waste heat re-utilization within the new combined pre-heating and annealing furnace. and how exemplary measurement curves of the system that demonstrate the feasibility and proper functionality of the process control system.

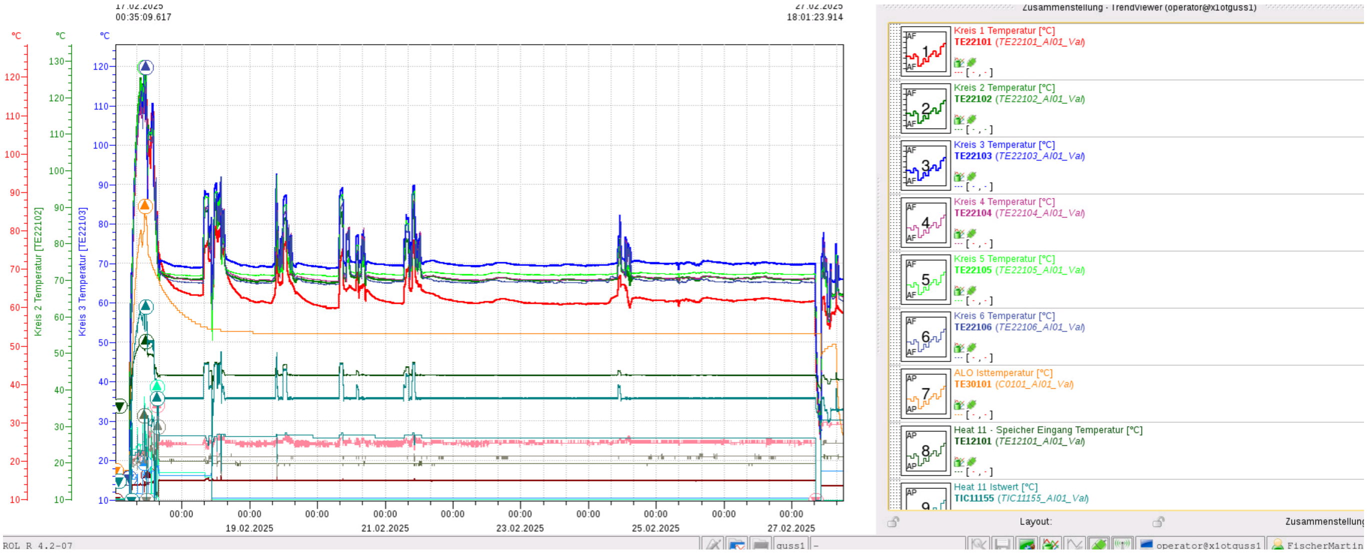

Figure 41: Successful demonstration of the new control strategy capable of controlling the channel temperatures within a few degrees Celsius (almost an order of magnitude superior to many industrial systems).

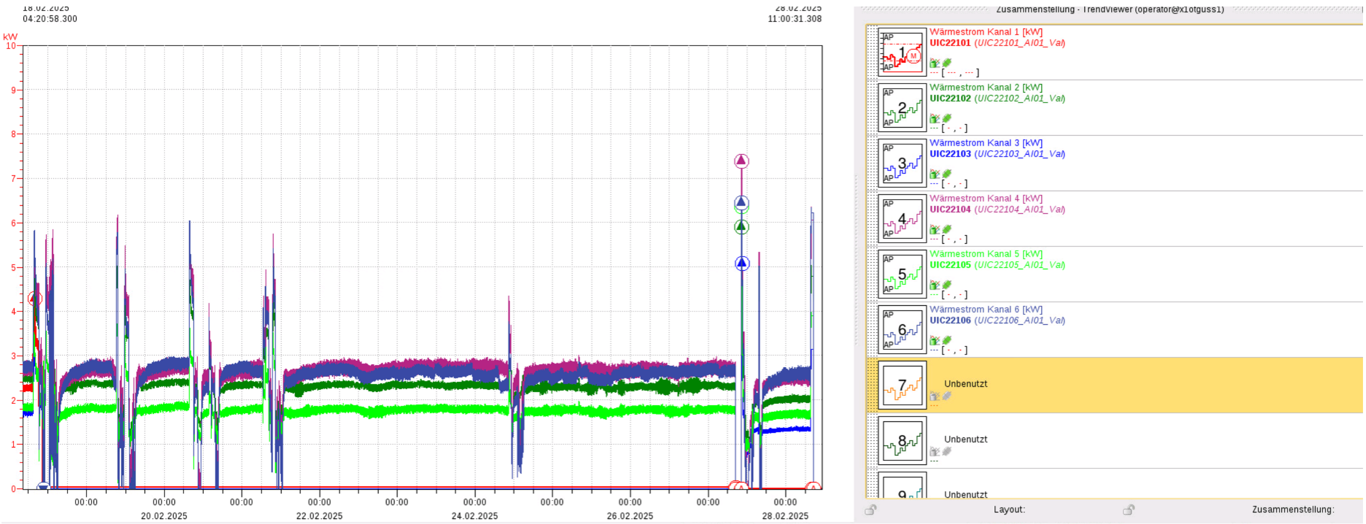

Figure 42: Heat flow curves are calculated live to visualize energy flows and facilitate best possible energy efficient casting.

In order to be able to operate the whole system in a hands-free way and to make use of most modern digital tools, a digital twin of the main factory components was created in Augmented Reality (AR) via Unity software environment and Microsoft Hololens 2 as the augmented reality glasses. A dedicated protocol was developed in Unity that can be used to communicate with the B&R process control system and thus send and retrieve commands to infer the system states or control/set them.

Thus, the relevant energy and process data (e.g. temperature of heating- and cooling system as well as the die casting machine; energy and CO2, product specific data) can directly be visualized in AR and allow the operator of the die casting machine as well as the various foundry managers a live analysis of the machine parameters, process conditions and energy statistics of the casting cells and the whole factory as is shown for the example of the die casting machine in Figure 43 and Figure 44.

Figure 43: AR overlay of the die casting machine with live process and energy data.

Figure 44: Dedicated parameters of the die casting machine can be controlled hands-free via Augmented Reality by using a dedicated communication protocol between Unity and the B&R process control system.

In addition, a demo application was developed to visualize ideas from this project at various trade fairs and serve as a basis for possible future factory training via AR. In this demo, the user has to virtually perform a series of tasks to redesign an ordinary state-of-the-art foundry into a carbon-neutral factory employing the energy efficiency measures and carbon-neutral energy carriers developed within this project. E.g. the operator has to improve the thermal insulation of the machinery, retrieve and store waste heat, integrate a heat pump and re-utilize the waste heat to pre-heat the ingots in a virtual melting furnace (Figure 45 and Figure 46). By using gamification elements, people can learn about the basic ideas of energy flows in a foundry and how to improve energy efficiency in their processes.

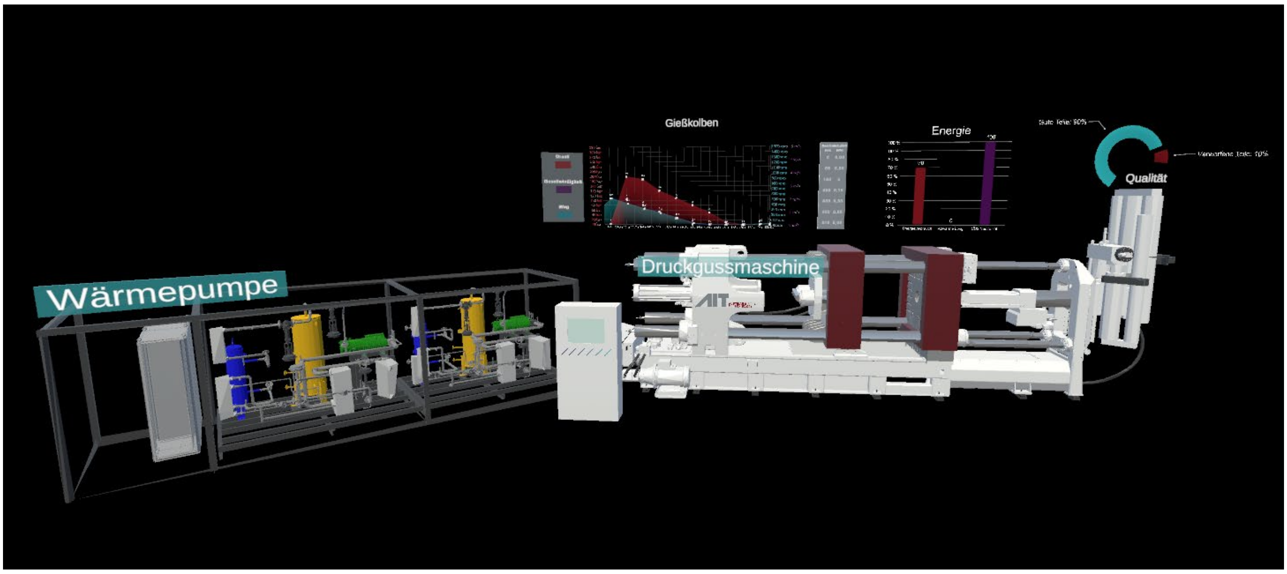

Figure 45: AR digital twin of the die cast machine with a heat pump for waste heat re-utilization.

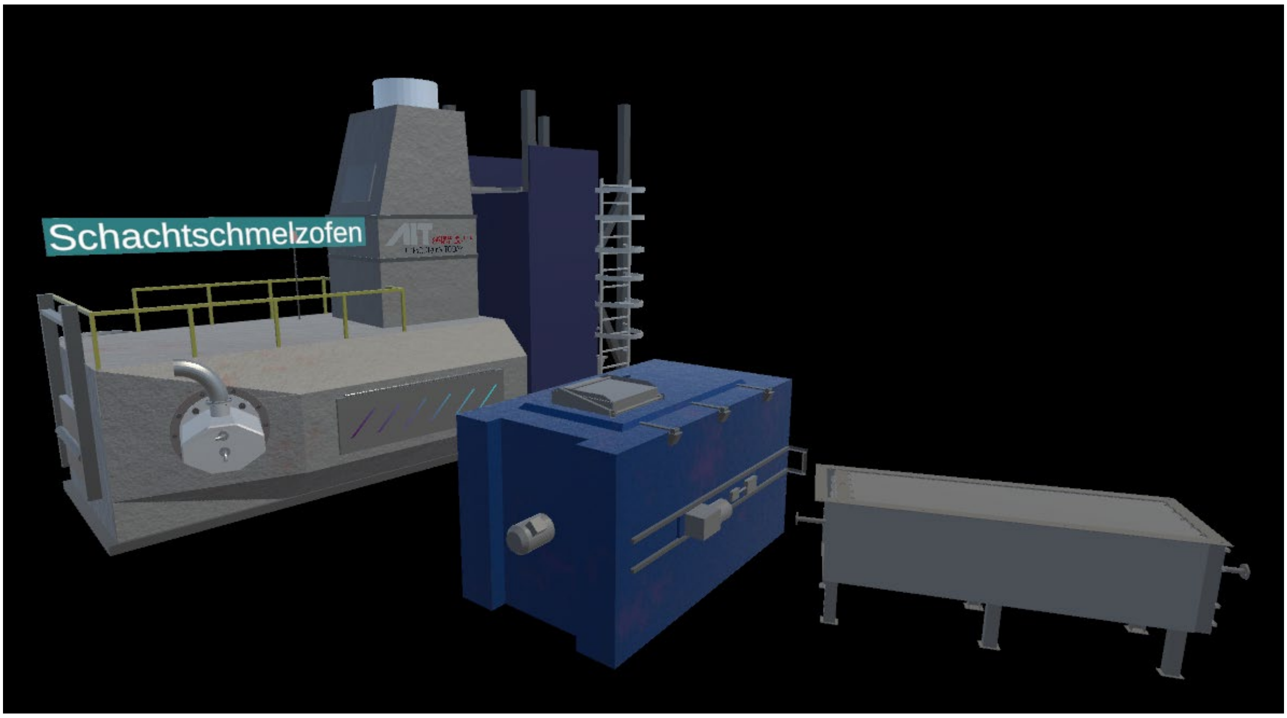

Figure 46: AR view melting furnace, heat treatment and high temperature latent heat storage

The AR experience was tested by casting colleagues at LKR Ranshofen and also shown to potential customers at dissemination events. In addition, a dedicated project video was created to reach a broader audience: NEFI project envIoTcast EN - YouTube.

Figure 47 finally shows an overview of the whole Green Foundry 4.0 demo factory as it was built at the AIT LKR Ranshofen. The factory comprises and successfully demonstrates all key elements of an energy efficient and carbon-neutral foundry:

- Energy efficient casting
- Energy efficient heating and cooling
- Waste heat recovery, storage and redistribution
- Carbon-neutral melting including aluminium pre-heating via waste heat utilization
- Modern central energy and process control system

Figure 47: Overview of the Green Foundry 4.0 at AIT LKR Ranshofen – an energy efficient and completely carbon-neutral factory that comprises and successfully demonstrates the feasibility of carbon-neutral foundries.

3.5 Exploitation, dissemination and business models

3.5.1 Stakeholder analysis and industry analysis

In preparation for the business model development, an industry analysis has been performed covering Austria, the DACH region and the European Union. In this context, extensive internet research has been conducted. In the following, the main results are summarized.

Austria: There are 42 foundries in 2023, employing 7,500 staff and generating a turnover of €2.3 bn. The sector is dominated by small and medium-sized enterprises. The export quota is ~80%. Apart from few finished products, such as e.g. piping systems, fittings, rollers, or ductile iron, most cast products are manufactured for the automotive sector.

36 foundries are organised in the industry association "Proguss Austria"; 19 of them are operated as non-ferrous metal foundry only; 14 as ferrous foundries, 3 foundries produce both non-ferrous and ferrous metal castings. In 2023, 270 kt castings are produced in Austria, 138 kt ferrous castings and 132 kt non-ferrous respectively light metal castings. More information on production quantities is provided in Table 1. In 2023, the members of Proguss Austria generated a turnover of €1.7 bn, with €1.2 bn stemming from metal casting.

Table 1: Production volume 2023 (WKO, Foundries industries, 2023)

Overview Castings Production 2023	
In tonnes	
Grey cast iron	31.899
Ductile cast iron	99.867
Steel castings	6.412
Ferrous Castings	**138.178**
Zinc die castings and total heavy metal castings	8.153
Light Metal Castings	**123.972**
Al die castings	104.762
Al gravity die castings	13.771
Al sand castings	1.148
Magnesium castings	4.291
Metal casting	**132.125**
Total	**270.303**

Trends & market environment: According to data by Proguss Austria, total casting production decreased by ~30 kt from 2019-2023, whereas the productivity per employee slightly increased by 0,4t. Light metal casting is with >40% on the total casting tonnage the most important casting sector. The macroeconomic conditions are challenging. Specific casting prices are continuously increasing and amount to e.g. €9.5/kg (non-ferrous) and €3,8/kg (ferrous) in 2023. The prices for raw materials such as e.g. cupola furnace or steel scrap are steadily increasing since 2016. Austria still relies on gas imports from Russia and is showing high energy costs, which represents a further major challenge for the sector.

Germany: There are ~600 iron, steel, and non-ferrous metal foundries with ~70.000 employees. Among these, 82% of metal casting and 71% of ferrous casting companies are classified as small and medium-sized enterprises (SMEs). Aluminium is the dominant casting material, with the automotive sector being

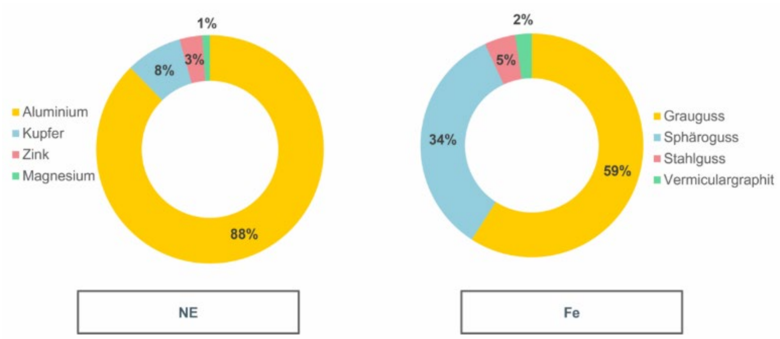

Figure 48: Casting materials (Source: BDG, 2023)

its primary consumer. In iron casting, grey cast iron is the most widely used type, followed by ductile cast iron. Iron castings are also mostly used in the automotive industry, with mechanical engineering as second-largest application sector. In 2023, a turnover of €14 bn has been generated, with €7.8 bn stemming from iron casting.

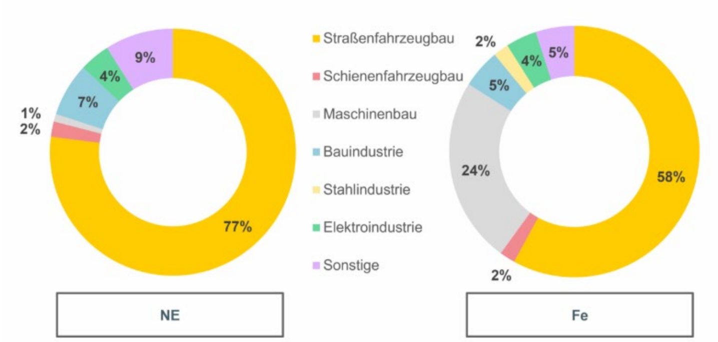

Figure 49: End-users resp. customers of foundries (Source: BDG, 2023)

Trends & market environment: From 2019 to 2023 total casting production decreased in both, ferrous and the non-ferrous cast. Germany also experiences high energy costs, resulting from the Russian sanctions and the merit order principle in the electricity market design, but also from the introduction of a CO_2 tax under the Fuel emissions Trading Act. However, the automotive industry is a major consumer of castings and a key driver for the German foundry market. Especially the growing demand for electric vehicles and other applications requiring lightweight components is driving innovation in specialized casting solutions and high-performance alloys.

<u>Europe</u>: According to CAEF, the European Foundry Association, Europe is home to ~6,000 metal casting facilities employing ca. 260,000 people. ~70% of foundries are operated as small firms (<50 employees). In 2023, European foundries produced ca. 14 Mt of castings valued at €41 bn. Of this output, 73% consisted of iron, steel, and malleable castings. Overall, Europe accounts for 12% of global casting production. German foundries are leading in terms of casting tonnages. Turkey, Italy, France and Poland also show high production volumes (see Figure 50 and Figure 51). The production of castings made of non-ferrous metal alloys is dominated by light metals (share of 86.2%). Germany, Italy and Turkey are leading the production of light & ultralight castings and account for 63% of the production volume.

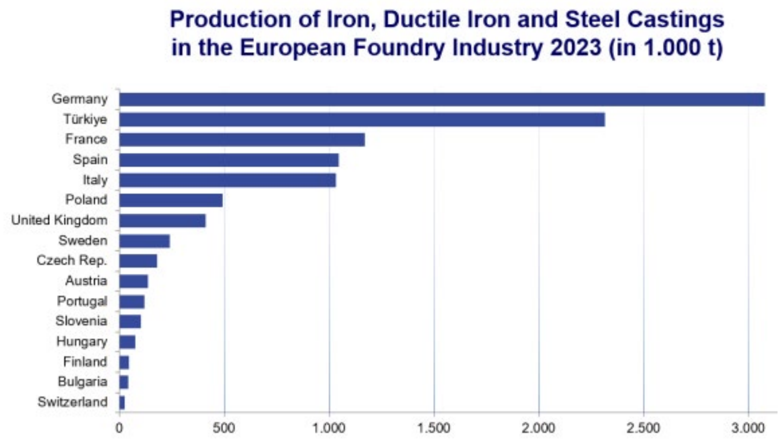

Figure 50: Production of ferrous castings (Source: CAEF, 2023)

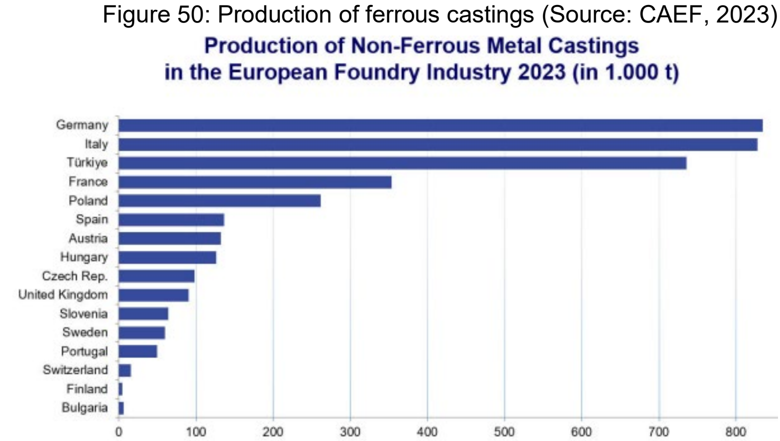

Figure 51: Production of non-ferrous castings (Source: CAEF, 2023)

Macro-economic situation (2023): The situation is challenging and economic growth slowed. Overall, the energy and inflation crises eased compared to previous years in most countries, however the ongoing war in Ukraine and the Israel-Gaza conflict have deepened uncertainty across the European economic landscape. The Russia-Ukraine war continues to strain energy supplies and commodities, causing volatile prices and impacting production costs, especially in countries, which still dependent on Russian gas-imports such as e.g. Austria or Germany.

<u>Major customers of the casting industries</u>: The largest customer sectors for foundries include transport & mobility (esp. automotive, aerospace, shipping), building & construction, engineering (mechanical, electrical, medical), and steel industry.

- **Transport & mobility***:* Cast components are used, amongst others, in engines, drivetrains, chassis/bodies of passenger cars and trucks. The are found in turbines, jet engines and in the fuselages, undercarriages and interior fittings of airplanes and are needed for constructing more energy-efficient cargo and passenger ships of all sizes.
- **Engineering**: Castings are used in a wide range of machines/components. The increasing demand for energy efficiency requires advances in technical developments and light-weight construction. Cast components are required for electrical engineering, such as e.g. power generation equipment (as e.g. transformers, generators, electric motors) or medical engineering (e.g. as integral parts for computerised tomography/scanners, for cast prostheses like knee and hip joints, etc.)
- **Building & construction industry***:* The range of products supplied by foundries to the building & construction industry is wide and includes, amongst others, pressure/drainage pipes, sewer castings and surface boxes, castings for radiators/boilers, sanitary castings as well as malleable fitting.
- **Steel industry:** Steel is supplied to various important sectors including esp. building and transport sectors. Cast rolls, e.g. are absolute high-tech products, required for process stability in steel works around the globe.

Aluminium casting: Aluminium is already the most used non-ferrous metal and seen as strategic material for the green transition. The trend towards lightweight construction in the automotive sector and other application areas leads to increasing demand and material substitution, offering very good prospects for aluminium casting. Figure 52 shows the anticipated global demand for aluminium semi-fabricated components from 2015 to 2030 in Mt; Figure 53 depicts the demand anticipated for various end-user sectors in Europe from 2020 and 2030 with the transport sector showing the highest demand, followed by construction and packaging.

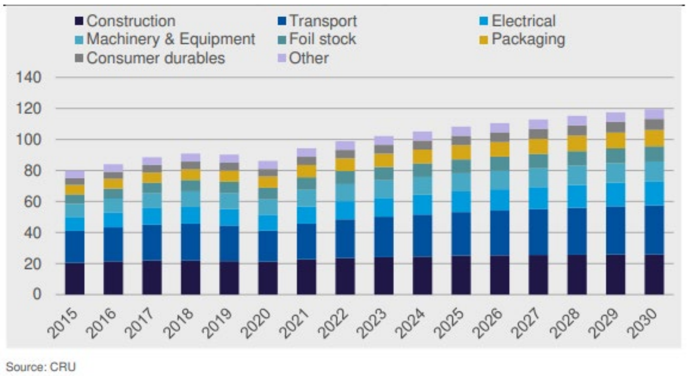

Figure 52: Demand for Aluminium semi-finished products by sector, 2015-2030, in Mt (Source: CRU, 2022)

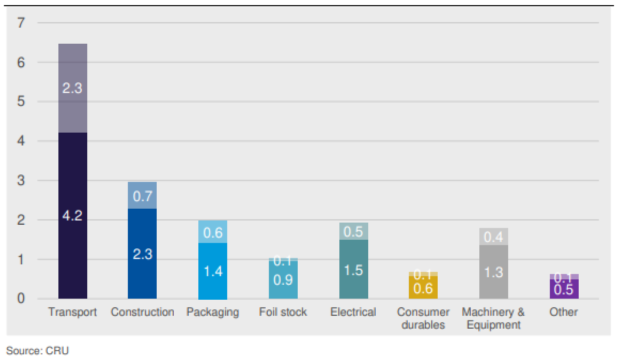

Figure 53: European demand for Aluminium semi-finished products by sector, 2020 vs-2030, in Mt (Source: CRU, 2022)

3.5.2 Marketing plan and business model

Business Modelling Workshop for the Strategic Exploitation of Project Results
As part of the corresponding work package, a Business Model Canvas workshop was conducted by Business Upper Austria – OÖ Wirtschaftsagentur GmbH in close collaboration with all project partners. The aim of this workshop was to systematically identify exploitable results from the research project and to structure them strategically. The focus was on the joint development and analysis of a viable business model that translates the project results – particularly the "Green Foundry Concept" – into marketable approaches.

To prepare for the joint workshop, each project partner first created an individual Business Model Canvas. Key elements such as customer segments, value proposition, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure were analysed and documented. These preparatory steps formed the basis for the subsequent joint discussion and integration of the various perspectives during the workshop.

The Business Model Canvas workshop began with a brief thematic introduction to bring all participants to a common level of understanding. Afterwards, the individually completed canvases of the project partners were supplemented as needed, presented to the group, and discussed collectively. These models then served as the foundation for developing a consolidated, joint Business Model Canvas.

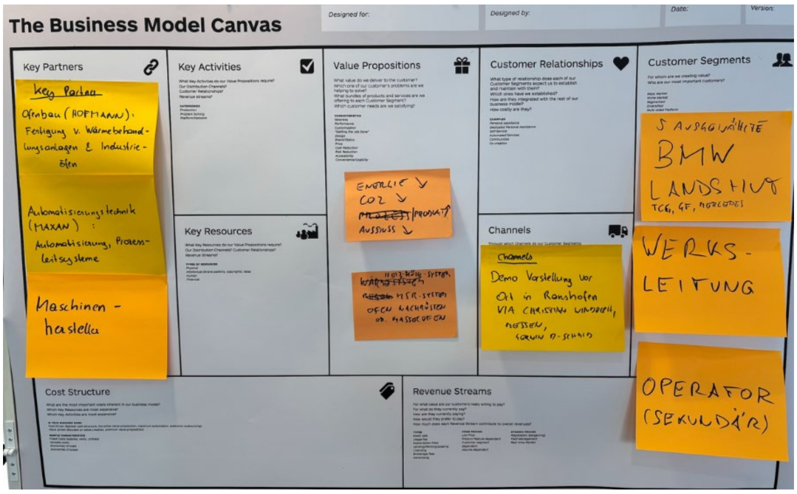

Figure 54: *Consolidated, joint Business Model Canvas*

Based on the consolidated Business Model Canvas, a Value Proposition Canvas was subsequently developed. This tool is used to tailor products and services specifically to the needs of the defined customer segments, thereby complementing the Business Model Canvas with a detailed analysis of customer needs and value propositions.

The focus was particularly on the areas of Customer Segments and Value Propositions. The results of the workshop clearly show that key customer needs – such as reducing energy consumption, lowering CO_2 emissions, and increasing process efficiency – can be addressed through the offerings of the

"Green Foundry" concept. Specifically, these needs are met through increased energy efficiency (e.g., insulation of tools and pipelines / tool optimization), the utilization of waste heat / heat recovery (e.g., use for preheating furnaces, new heat distribution system), and the new Augmented Reality (AR) guidance system.

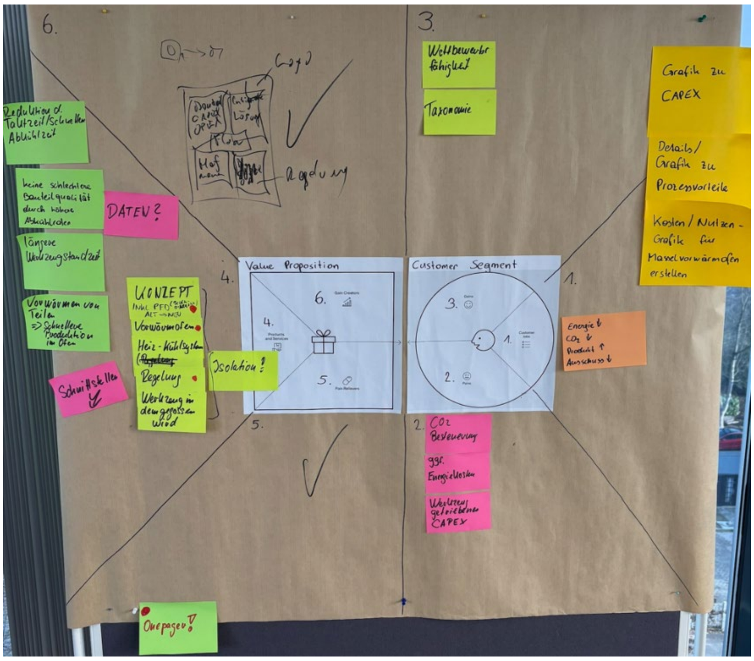

Figure 55: Value Proposition Canvas

Furthermore, the workshop highlighted that the demo event at the demo factory located at the **Leichtmetallkompetenzzentrum Ranshofen (LKR)** makes a significant contribution to the exploitation and visibility of the project results. It provides a hands-on platform for presenting the concept and engaging with potential users and stakeholders.

Demo event at the demo factory at the Leichtmetallkompetenzzentrum Ranshofen (LKR)
The final demo event / dissemination event at the demo factory at LKR served to present the project results to stakeholders, potential users, and funding institutions. The focus was on exploitation perspectives and increasing the visibility of the project.

Within the circle of project partners, it was decided to design the event in Braunau and Ranshofen in a targeted and selective manner. Invitations were therefore extended exclusively to selected representatives of relevant companies, particularly OEMs such as BMW, VW/Audi, and Renault, as well as suppliers like Georg Fischer Casting Solutions, TCG Unitech, Nemak, Borbet, and MWS Aluguss. The event was successfully carried out and provided a valuable opportunity to present the project results and receive direct feedback from the industry.

Figure 56: Demo Event at Leichtmetallkompetenzzentrum Ranshofen

The demo event kicked off in the office facilities of LKR in Braunau. Christoph Zauner, project manager from AIT Austrian Institute of Technology GmbH, first presented the overall project and the newly developed heat distribution system. Following this, Markus Auer from HOFMANN Wärmetechnik gave a detailed presentation of the preheating furnace, explaining its technical features and contribution to energy efficiency. Finally, Clemens Simson, also from AIT Austrian Institute of Technology GmbH, provided a technical impulse on sustainable concepts in die casting, with a particular focus on process and material. After the technical presentations, participants took part in a live tour of the demo factory at the Ranshofen site during ongoing operations. This offered a hands-on insight into the installed technologies and their interaction within the project.
The central component is the developed “Green Foundry Concept”, which integrates several innovative technologies:

- Preheating furnaces for ingots and products,
- A novel heat distribution system,
- An Augmented Reality (AR) guidance system.

These key components were installed in the demo factory and now form the basis for further research and development. The demo factory serves as a practical test environment where various R&D projects and new technologies can be tested and further developed under real-world conditions. This creates valuable starting points for future funding projects and industrial collaborations that build on the foundations established in the project. The demonstration enabled a direct evaluation of the developed solutions under real production conditions and fostered exchange between research and industry.

Following the successful demonstration at the demo factory at LKR in Ranshofen, the next step is to further develop the technologies within the industry project Zero-C-Alu in collaboration with selected industrial partners – particularly Georg Fischer Casting Solutions and TCG Unitech.
The goal is to raise the technological maturity level from the current TRL 4/5 (in the demo factory) to TRL 7.

Potential for commercial exploitation and future collaborations

The project opens a wide range of business opportunities for the participating partner companies:

- Business Upper Austria can promote and disseminate sustainable and "green" solutions within its partner network as well as to other companies.
  In the automotive industry in particular, rising energy costs – alongside high labour costs and increasing bureaucratic burdens – represent a major challenge. The industry is characterized by numerous energy-intensive processes, where the project can make a valuable contribution to cost reduction and decarbonization. Business Upper Austria can actively communicate these solutions and act as a catalyst for further collaborations and innovation projects.
- HOFMANN Wärmetechnik can specifically market the topic of "green furnaces," especially the developed ingot preheating furnace, which makes a significant contribution to energy efficiency and CO_2 reduction.
- MAXAN has developed an innovative AR guidance system that creates a digital solution to make processes more transparent and efficient. This system has the potential to be further developed as a standalone product.
- AIT Austrian Institute of Technology GmbH can use the project results to initiate new R&D projects and offer services in the field of decarbonizing the aluminium industry – both on the energy side through the Energy Center and on the materials and process side through the LKR Leichtmetallkompetenzzentrum Ranshofen.

3.5.3 Dissemination of knowledge

This section describes the implementation and impact of the communication and dissemination activities throughout the entire duration of the project. An effective communication and dissemination strategy was a central component of the project from the very beginning. It was developed at an early stage and continuously evaluated and adapted over time to maximize the reach and impact of the project activities. The goal was to ensure that the key results of the project reached all relevant stakeholder groups. This report provides a detailed overview of the tools developed during the project, the communication channels used, and the dissemination measures carried out.

Factsheet / Flyer: To promote the project at events, conferences, and other public formats, a factsheet and a flyer were specifically developed. These materials enable targeted communication with various stakeholder groups and support the project's external communication and visibility.

Videos: To promote the project and illustrate its core content and technologies, two videos were produced:

- **project video** providing a compact overview of the project's objectives, structure & significance,
- a video on the **AR industry simulator**, demonstrating its functionality and practical benefits.

Both videos serve as engaging communication tools for stakeholders and the interested public and were published on YouTube.

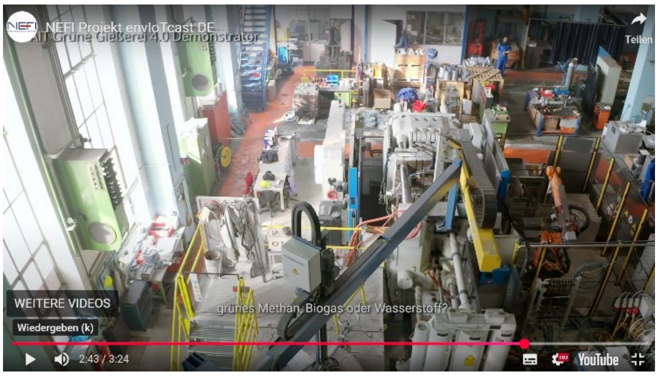

Figure 57: Screenshot from the project video on YouTube

Figure 58: Screenshot from the AR industry simulator video on YouTube

Press and Public Relations: To inform the public and relevant target groups, press releases were created focusing on key project content and milestones. In addition, continuous communication was maintained via the **"News" section of the Automotive Cluster Upper Austria** and the **website of the NEFI initiative**. Project progress was also communicated through **AC-quarterly** – the regularly published magazine of the Automotive Cluster Upper Austria, which reports on current developments and trends in the automotive industry, innovative cooperation projects, and successful partner companies. These channels were used to increase the visibility of the project and to specifically address regional and industry-specific stakeholders.

A total of 3 articles were published in the News section of the Automotive Cluster website.
A total of 5 articles were published through press releases sent to general and specialist media.
A total of 5 articles were published in AC-quarterly.
A total of 54 articles about the project were published in various print and online media. These included articles in the following media: for example science.apa.at, diepresse.com, Die Presse, i-magazin.com Industriemagazin, wallstreet-online.de, ots.at, Oberösterreichische Nachrichten, Kronen Zeitung OÖ, AUSTRIA INNOVATIV, report.at, austriainnovativ.at.

Social Media and Newsletter: To increase the visibility of the project, regular updates and news were shared via the LinkedIn accounts of the **Automotive Cluster Upper Austria**, **A2LT – Austrian Advanced Lightweight Technology**, and **NEFI – New Energy for Industry**. These posts were aimed at specifically addressing professionals and stakeholders from industry, research, and policy, and made a significant contribution to disseminating the project results in the digital space.
A total of 13 posts were published.

In addition, news and project updates were regularly communicated via the newsletters of Business Upper Austria and the Automotive Cluster – with a total of 4 articles**.**

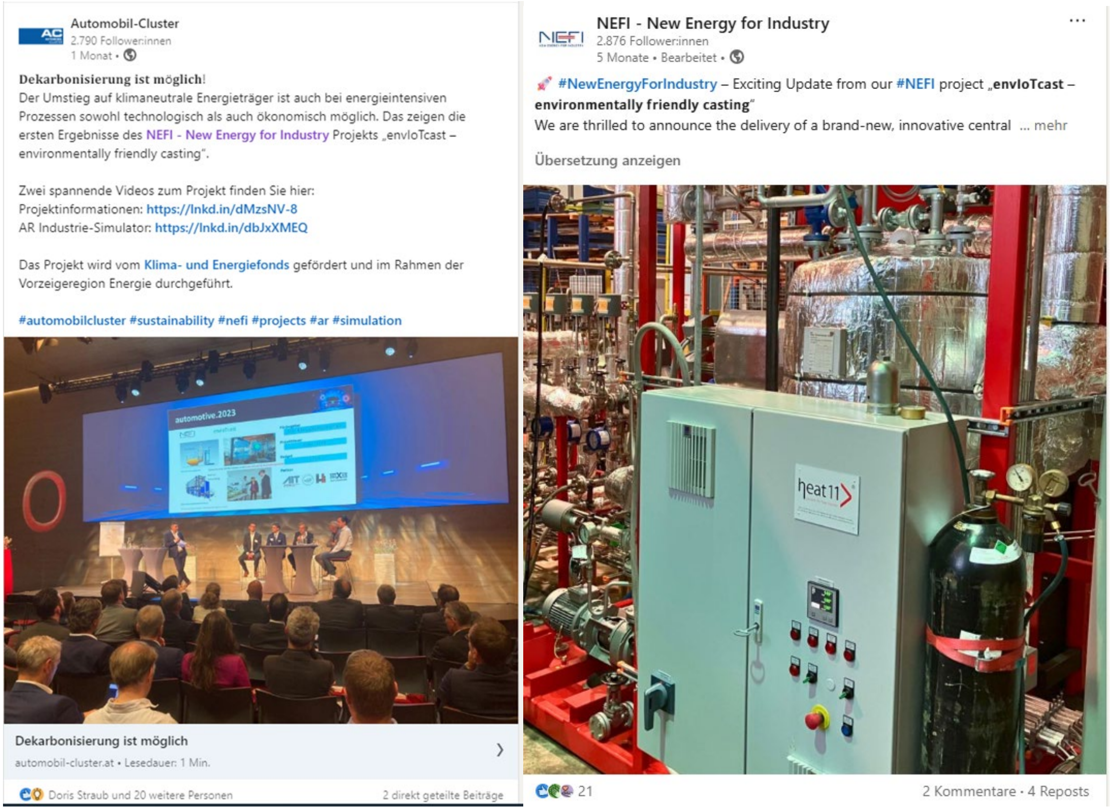

Figure 59: Examples of LinkedIn posts

Events, Networking Meetings and Company Visits: Throughout the project, the envIoTcast partners were actively involved in a wide range of professional events and networking meetings. Their engagement included expert presentations, participation in panel discussions, presence as exhibitors and visitors, as well as the organization and execution of a dedicated demo event in Ranshofen. These activities significantly contributed to the visibility of the project and the dissemination of its results.

A particular highlight was the repeated participation in the automotive.20xx industry event. During a panel discussion, the project was presented to a professional audience and key topics were discussed. Additionally, attendees had the opportunity to test the specially developed AR simulator live on site, which attracted considerable interest. The project partners also showcased the project at an exhibition booth featuring a project poster, informational materials, and selected demonstrators. This comprehensive presence greatly enhanced the project's visibility and facilitated interaction with relevant stakeholders from the automotive and technology sectors.

The final highlight was the demo event at the demo factory in Ranshofen. During this event, the developed key technologies were presented on site and experienced live by the visitors. The hands-on demonstration provided a vivid insight into the project results and fostered exchange with representatives from the industry.

Figure 60: AR simulator demonstration at automotive.2023

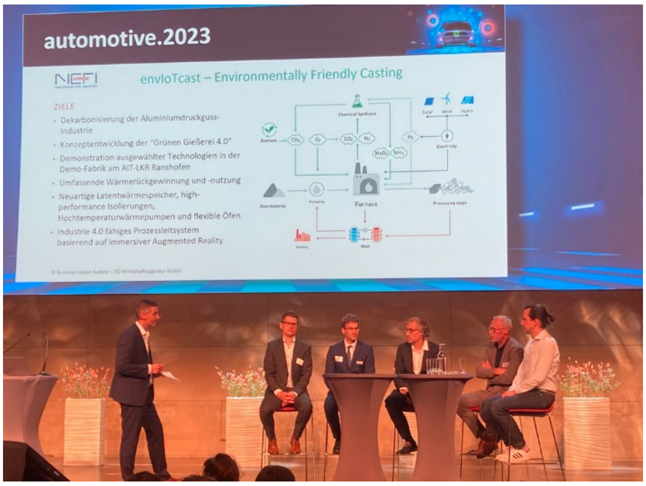

Figure 61: Project presentation as part of the panel discussion at automotive.2023

Name	Date	Location	Activity
ACstyria Leichtbautag 2021	08.06.2021	Spielberg	Participation – outreach to potential companies
Pitstop – Nachhaltigkeit „Sustainable Automotive Hero“	08.07.2021	Online	Project presentation during online event
Promotion AR-Simulator	05.11.2021	Linz	Presentation / testing of AR simulator
OÖ Zukunftsforum 2022	08.03.2022	Linz	Presentation of NEFI & envIoTcast in the “Industry & Production” session
ACstyria Leichtbautag 2022	30.03.2022	Spielberg	Participation – outreach to potential companies
ASMET Automobiltagung	09.06.2022	Linz	Participation – outreach to potential companies
automotive.2022	05.07.2022	Linz	Exhibitor – AR simulator and project information
Internationale Erneuerbare Energiespeicher Konferenz	20. – 22.09.2022	Düsseldorf	Expert presentation
12. Ranshofener Leichtmetalltage 2022	06. – 07.10.2022	Salzburg	Expert presentation, exhibitor with project information
NEFI-Konferenz	13. – 14.10.2022	Linz	Participation – project flyer
ACstyria Leichtbautag 2023	02.03.2023	Spielberg	Participation – outreach to potential companies
NEFI Technology Talk “Auf dem Weg zu einer nachhaltigen Automobilindustrie“	27.04.2023	Kapfenberg	Participation – outreach to potential companies
automotive.2023	25.05.2023	Linz	Panel discussion, exhibitor – AR simulator and project information
Step-Up Best Practice-Konferenz	15.06.2023	Krems	Participation – outreach to potential companies
Forum Aluminium 2023	04. – 06.07.2023	St. Pölten	Expert presentation, exhibitor with project information

AATP Dialogforum	09.11.2023	Wien	Participation – outreach to potential companies
automotive.2024	06.06.2024	Linz	Exhibitor with project information
Step-Up Best Practice-Konferenz	13.06.2024	Krems	Participation – outreach to potential companies
13. Ranshofener Leichtmetalltage 2024	26. – 27.09.2024	Saalfelden	Exhibitor with project information
Steel Circularity Conference 2024	23.10.2024	Linz	Participation – outreach to potential companies
Demo-Event	11.06.2025	Braunau / Ranshofen	Demo event at the demo factory

Table 1: Overview of events

During the project period, around 80 targeted activities were carried out in the form of company visits and B2B meetings. These measures served to facilitate direct exchange with industrial partners, identify application potentials, and strategically disseminate project results in business-relevant contexts.

4 Conclusions, outlook and recommendations

Casting is one of the main production processes in many industries and a variety of materials. Thus, energy efficient and carbon neutral casting is an important part of a carbon neutral industrial sector of the future.
Within the project envIoTcast we developed a set of innovations that improve the energy efficiency of foundries by up to 30%. For the remaining part, we identified different possible production technologies and carbon neutral alternative to natural gas that can be employed to finally achieve a completely “Green Foundry 4.0”.
The key elements of this new carbon neutral production process have been set-up and demonstrated at the Green Foundry Demo Factory at the AIT site of LKR Ranshofen. This comprises a set of process and energy improvements of the die casting process, a new versatile heating and cooling system and a combined aluminum pre-heating and annealing furnace, all controlled by an Augmented Reality enhanced modern process control system.

Thus, we could successfully identify and demonstrate ways towards carbon neutral foundries, which can already be realized on an industrial scale in the very near future from a technical perspective.

Of course, the economic boundary conditions, especially cost-competitive carbon neutral energy carriers and quota to jump-start decarbonization, will be necessary. Fortunately, the costs of most future carbon neutral products will only be slightly higher than for the currently produced fossil-based products.

Austrian companies can contribute to this part of the energy transition in many ways and thus Green Foundries pose yet another chance to strengthen the Austrian industrial competitiveness if the right framework conditions are set-up.

5 Contact details

Dr. Mag. Christoph Zauner
Christoph.Zauner@ait.ac.at

AIT Austrian Institute of Technology
Center for Energy
Sustainable Thermal Energy Systems
Giefinggasse 2, 1210 Wien

https://www.nefi.at/de/projekt/enviotcast