Deliverable Report

GrInHy2.0
Green Industrial Hydrogen

Green Industrial Hydrogen via steam electrolysis

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Table of Acronyms

BOF	Basic Oxygen Furnace
GO	Guarantee of Origin
H_2	Hydrogen
HPU	Hydrogen Processing Unit
HTE	High Temperature Electrolyser
RED II	Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources (recast)
SF	Sunfire GmbH
SZFG	Salzgitter Flachstahl GmbH

1 Introduction

In 2013, the steel industry accounted for 6 to 7 percent of total carbon emissions.[1] Hydrogen (H_2) produced from renewable or low-carbon energy sources has the potential to significantly decrease the carbon footprint of the steel industry.

At the iron-and-steel works in Salzgitter, hydrogen is currently used for the annealing of the product. The hydrogen that is used is purchased from suppliers and produced from fossil resources via steam methane reforming, creating a substantial amount of carbon emissions.

The GrInHy2.0 project aims at replacing fossil-based hydrogen with "green" hydrogen. By manufacturing and operating the world's first high temperature electrolyser (HTE) of megawatt class at an integrated iron-and-steel works, using electricity and heat from renewable sources, at least one hundred tons of green hydrogen will be produced. That accounts for 50 percent of today's nominal hydrogen demand of the plant.

To qualify as green, the hydrogen produced under GrInHy2.0 should follow the European "CertifHy" certification standards and requirements. With the goal to validate the CertifHy scheme and point out potential shortcomings, Sunfire GmbH (SF)

- identified and assessed different options to meet the green hydrogen certification standards and requirements under CertifHy, and
- provides the results including recommendations for decision-makers regarding potential improvement areas of the scheme in this Deliverable 4.2.

The findings provide the groundwork for D4.1, in which Salzgitter Flachstahl GmbH (SZFG) provides a plan of action for the supply of renewable electricity to the GrInHy2.0 project.

This deliverable starts with outlining grey, low-carbon and green hydrogen certification standards and requirements under the CertifHy scheme (Chapter 2). To create a baseline for applying CertifHy rules to GrInHy2.0, chapter 3 describes the systems specifications of GrInHy2.0 and the corresponding energy input shares for electricity and heat. Chapter 4 shows different options for providing "green" electricity and "green" heat to the GrInHy2.0 system. Chapter 5 outlines shortcomings of the current CertifHy scheme and provides recommendations for decision-makers.

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[1] IEA (2016): Energy Technology Perspectives

2 CertifHy

2.1 The Guarantees of Origin Trading Scheme

CertifHy introduces an EU-wide Guarantee of Origin (GO) scheme for hydrogen, proving the renewable or low-carbon properties of hydrogen.

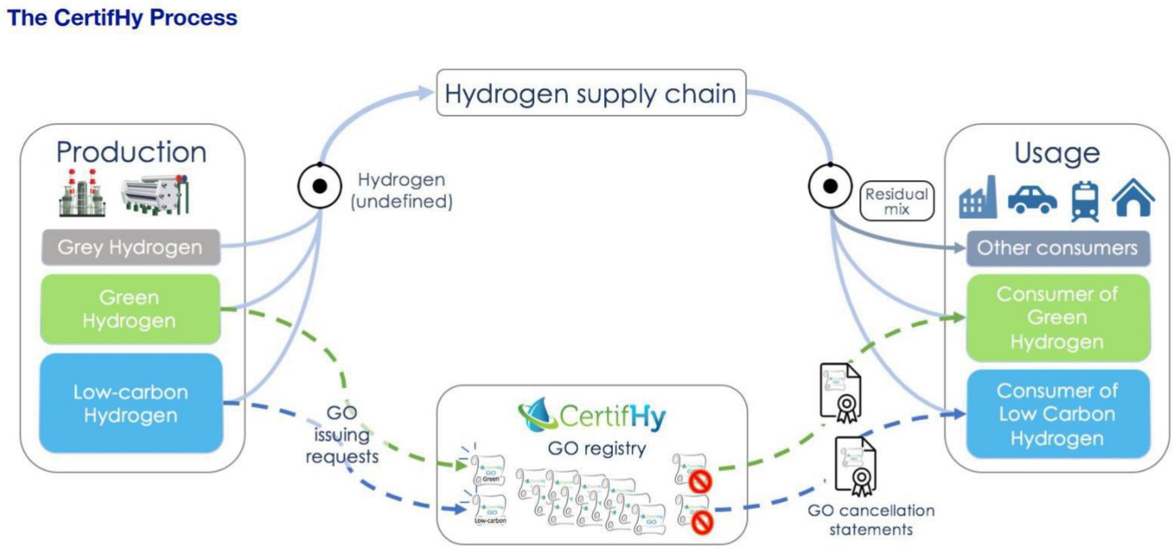

Figure 1: Simplified process description of the CertifHy GO

As shown in Figure 1, CertifHy GO is an electronic document that guarantees and provides information to final consumers on the origin of hydrogen. It is comparable to already existing trading schemes for renewable electricity and biomethane, allowing customers and end-users to purchase the renewable properties, without being physically linked to the energy source.

The process and preparation for the CertifHy project has started in 2014. Until 2016, a common European-wide definition of green hydrogen was developed and an implementation scheme devised. Currently, CertifHy is at pilot stage, with more than 75,000+ GOs already issued and available on the market. The hydrogen within this pilot originates from four production plants demonstrating different hydrogen production pathways located throughout Europe.

2.2 Hydrogen Categories

For a production device to be eligible under the CertifHy scheme, the overall greenhouse gas footprint of the H_2 produced must be lower than 91 gCO_{2eq}/MJ[2]. If this condition is fulfilled, then CertifHy classifies hydrogen into three categories. Each category is determined by the sources of energy used to produce the hydrogen:

- **Green Hydrogen:** Hydrogen made from renewable energy produced from renewable sources as defined in the Renewable Energy Directive recast of 2018 (RED II) with a greenhouse gas intensity below 36.4 $gCO_{2\,eq}/MJ$;

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[2] Based on a benchmark process, which is state-of-the art steam reforming of natural gas in large installations. The value refers to MJ of hydrogen, using the lower calorific value.

- **Low Carbon Hydrogen:** Hydrogen produced from non-renewable, low-carbon energy sources (e.g. nuclear or fossil SMR in combination with CCS) with a greenhouse gas intensity below 36.4 $gCO_{2\ eq}/MJ$; and
- **Grey Hydrogen:** Hydrogen derived from non-renewable energy sources with a greenhouse gas intensity above 36.4 $gCO_{2\ eq}/MJ$ but below 91 $gCO_{2\ eq}/MJ$.

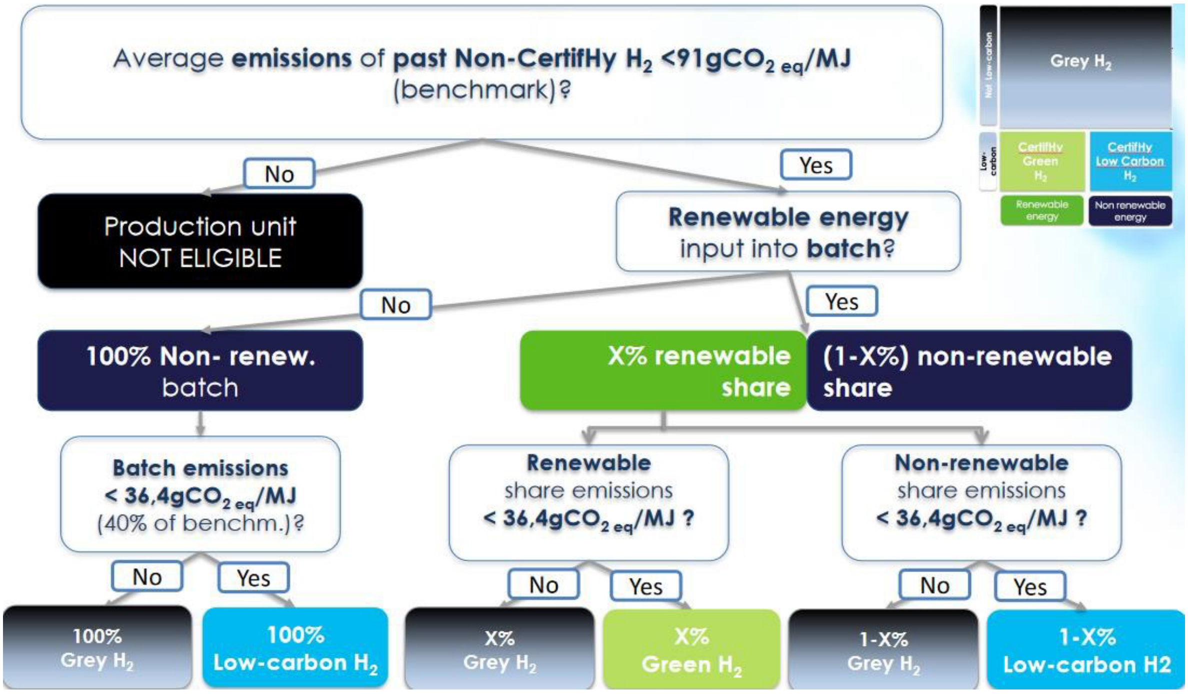

Figure 2: CertifHy Decision Tree

To determine if a certain production batch of hydrogen is eligible for green or low-carbon GO, CertifHy developed a decision-supporting framework (see Figure 2).

In a first step, the greenhouse gas intensity of the whole past hydrogen production gets evaluated. If it exceeds the benchmark intensity of hydrogen produced from natural gas (i.e. 91 $gCO_{2\ eq}/MJ$), the production batch of hydrogen will not be eligible within the CertifHy scheme. If the greenhouse gas intensity is below the benchmark intensity, the quality of hydrogen is further evaluated.

In a second step, the source of the energy provided to produce the hydrogen is evaluated. If the energy originates from different sources, the hydrogen batch will be divided up into the relative shares of the different energy input sources and is then further evaluated. Each energy input source is categorized as either renewable or non-renewable source based on the definition of the Renewable Energy Directive recast of 2018 (RED II).[3]

In a third step, the different shares of energy sources are evaluated concerning their greenhouse gas intensity. If their greenhouse gas intensity is below 36.4 $gCO_{2\ eq}/MJ$, the produced H_2 gets declared as **Green H_2** for the share of energy input from renewable sources and **Low-carbon H_2** for the share of energy input from non-renewable sources. If the

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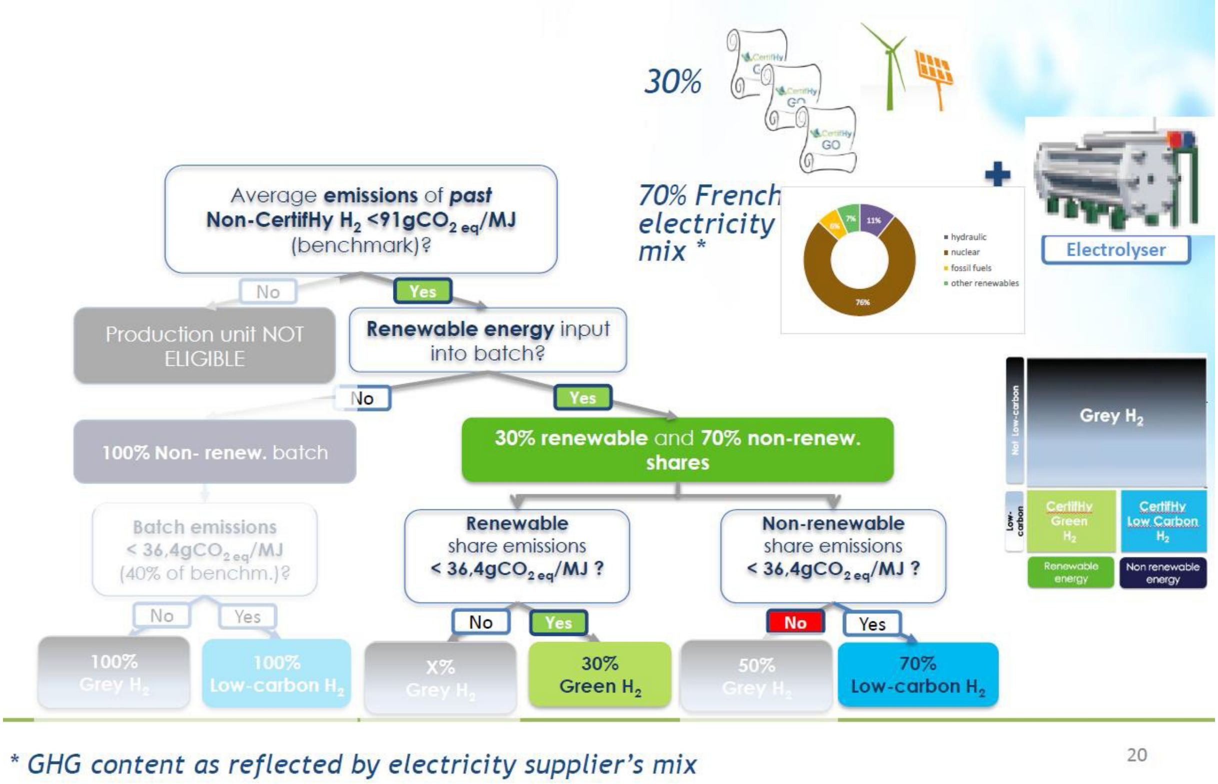
[3] European Commission (2018): Directive 2018/2001 on the Promotion of the Use of Energy from Renewable Sources (recast)

greenhouse gas intensity of any of the energy sources exceeds the limit of 36.4 $gCO_{2\,eq}$/MJ, the respective production batch of H_2 is declared as **Grey H_2.**

2.3 Example


30%

70% French electricity mix *

Electrolyser

Average **emissions** of **past** **Non-CertifHy H_2 <91$gCO_{2\,eq}$/MJ** (benchmark)?

No

Yes

Production unit NOT ELIGIBLE

Renewable energy input into batch?

No

Yes

100% Non- renew. batch

30% renewable and **70% non-renew. shares**

Batch emissions < 36,4$gCO_{2\,eq}$/MJ (40% of benchm.)?

No

Yes

100% Grey H_2

100% Low-carbon H_2

Renewable share emissions **< 36,4$gCO_{2\,eq}$/MJ ?**

No

Yes

X% Grey H_2

30% Green H_2

Non-renewable share emissions **< 36,4$gCO_{2\,eq}$/MJ ?**

No

Yes

50% Grey H_2

70% Low-carbon H_2

* GHG content as reflected by electricity supplier's mix

20

Figure 3: Example of CertifHy scheme

As an example, the CertifHy scheme can be applied to the production of 1,000 tons of H_2 via an electrolyser with input electricity originating 30 percent from renewable sources (purchase of GOs) and 70 percent from non-renewable sources (French electricity mix)[4] (see Figure 3).

As first step, the average emissions of the entire past non-CertifHy hydrogen production is evaluated. As it is below the 91 $gCO_{2\,eq}$/MJ threshold, the production generally qualifies for the CertifHy scheme.

In the second step, the share of renewable and non-renewable energy input, in this case 100 percent electricity, is evaluated. In this example, 30 percent of the used electricity originates from renewable sources while the remaining 70 percent is obtained through using non-renewable sources of energy.

In the third step, the greenhouse gas intensity of each of the two energy shares (30 percent renewable and 70 percent percent non-renewable) is evaluated. Because the greenhouse gas intensity of the electricity from renewable sources is below 36,4 $gCO_{2\,eq}$/MJ, 30 percent of the hydrogen production batch qualifies as Green H_2. Since the greenhouse gas intensity for the

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[4] Without purchase of GOs for renewable electricity, electricity from the power grid is treated as non-renewable energy source, even if a certain percentage may derive from renewable sources.

electricity from the French energy mix (as reflected by electricity supplier's mix) is below 36.4 $gCO_{2\ eq}$/MJ, 70 percent of the H_2 production batch qualifies as Low-carbon H_2.

Hence, CertifHy would issue green hydrogen certificates for 30 percent of the production batch, in this example 300 tons, and low-carbon hydrogen certificates for 70 percent, i.e. 700 tons.

3 Energy Balance of the GrInHy2.0 System

Under CertifHy, the sources of energy used to produce the hydrogen determine the categorization into green, low-carbon or grey hydrogen. This chapter describes the functioning of GrInHy2.0 system and outlines the input energy balance. The balance serves as the baseline for deriving different options to provide green energy to the system, which in turn determines whether the produced hydrogen can be certified as green.

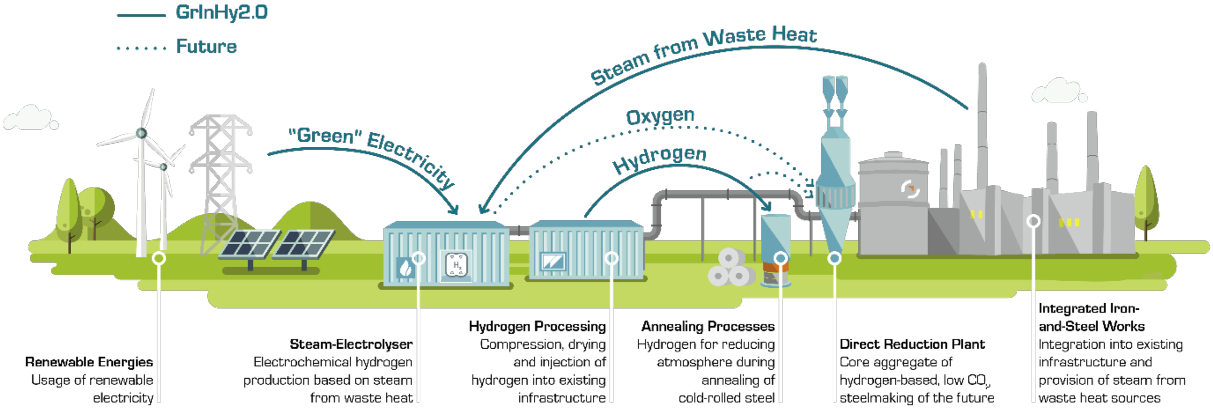

Figure 4: Project concept for the integration of a HTE plant into the iron-and-steel works Salzgitter (Germany).

As shown in Figure 4, an HTE plant will be integrated into the iron-and-steel works of Salzgitter. The plant consists of two main aggregates: The high-temperature electrolyser HyLink from Sunfire ("Sunfire-HyLink" is the proprietary trademark of the product) and a Hydrogen Processing Unit (HPU) designed by Paul Wurth.

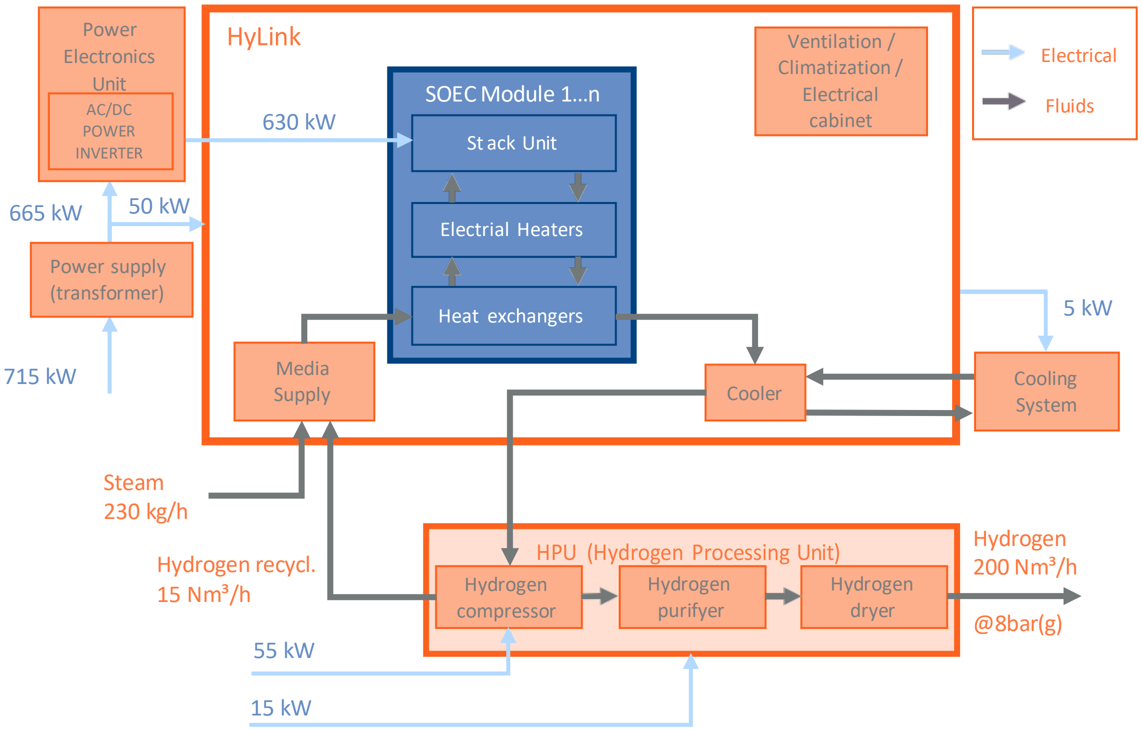

Figure 5: Energy flows in the HTE plant of GrInHy2.0

HyLink consists of multiple SOEC modules, a centralized media supply and a central cooling, integrated in a 40' container as housing, power electronics and electrical cabinets (see Figure 5). The hydrogen produced by HyLink is directed to the Hydrogen Processing Unit. The HPU compresses the hydrogen to approximately 9 bar, dries it and feeds it into the onsite hydrogen pipeline. The HPUs main components are a low-pressure buffer tank, a compressor, a hydrogen dryer and gas analyzers. The injected hydrogen from the HTE plant is used in the downstream processes of steel annealing.

Based on the energy balance shown in Figure 5, the GrInHy2.0 system is supplied with electrical power of approximately 785 kW_{AC} and 174 kW_{th} of heat to produce 18 kg/h of hydrogen at 9 bar.

However, under the CertifHy scheme the boundary condition is defined as follows:

> *"The system boundary shall include all the production stages needed to reach a hydrogen purity of at least 99.9 %vol and a gauge pressure of at least 3 MPa."*[5]

Therefore, a theoretical electricity demand has to be calculated, equalling the "[…] consumption that would be required to reach a pressure of 3 MPa assuming an isentropic efficiency of 60 % and a single compression stage […]".[5] The energy demand for such an isentropic compression from 9 bar to 30 bar equals approximately 13.5 kW_{AC}.

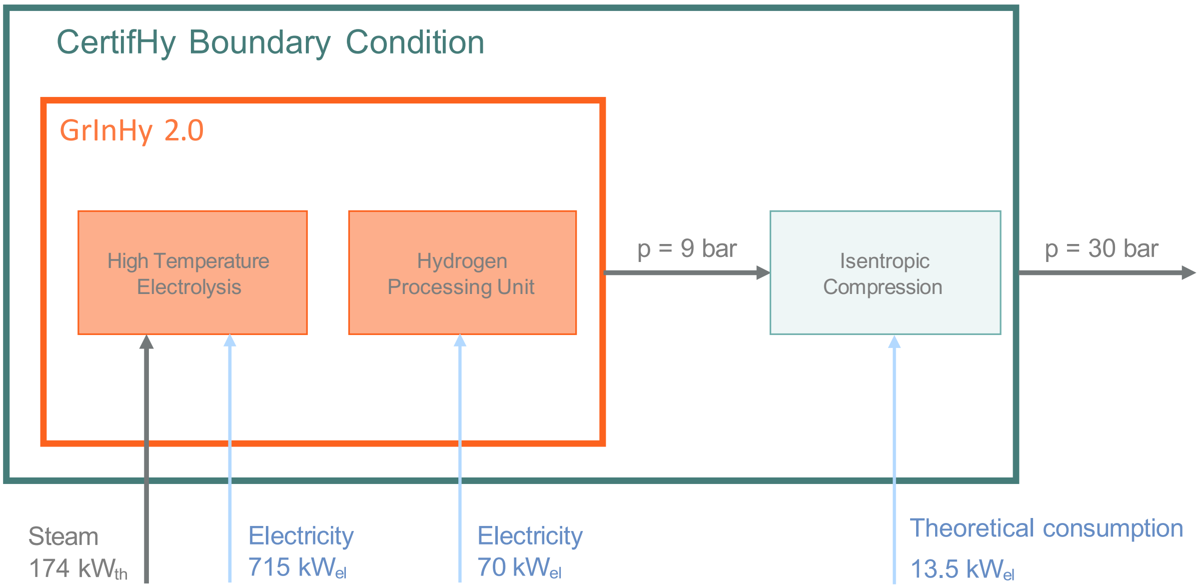

Figure 6: Power demand under the CertifHy boundary conditions

The overall power demand, assuming a theoretical system boundary of 3 MPa, therefore equals 798.5 kW of electricity and 174 kW of heat (see Figure 6). In total, 82.1 percent of the energy is provided via electricity, while 17.9 percent is provided via heat.

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[5] CertifHy (2019): CertifHy Scheme Subsidiary Document, CertifHy-SD Hydrogen Criteria

In the following, the different energy balances of the HyLink, HPU and Isentropic compression are explained:

- **HyLink:** The HTE is supplied with steam from waste heat produced in the iron-and-steel works which equals 174 kW_{AC} of power input (based on enthalpy, flow of 230 kg/h @ 4 bar(a) and 144 °C). The input of renewable electricity sums up to 715 kW_{AC} whereas 5 kW_{AC} are needed for the cooling of the produced hydrogen, 50 kW_{AC} are needed for the power supply of the supporting facilities and 35 kW_{AC} are needed for the AC/DC Power Inverter.
- **Hydrogen Processing Unit:** The hydrogen produced by HyLink is at atmospheric pressure and subsequently directed to the HPU. In order to compress the hydrogen to 9 bar, purify, dry and feed into the onsite hydrogen pipeline, approximately a power input of 70 kW_{AC} is required in total. The compressor accounts for 55 kW_{AC} whereas the other components account for 15 kW_{AC} of the total HPU electricity demand.
- **Theoretical Compression Stage:** According to CertifHy, a theoretical isentropic 1-stage compression with 60 percent efficiency must be accounted for, if the actual system boundary is below 3 MPa. The system boundary for the GrInHy2.0 system lies at 9 bar, as discussed above. Isentropic compression from 9 bar to 30 bar requires an additional 13.5 kW_{AC}.

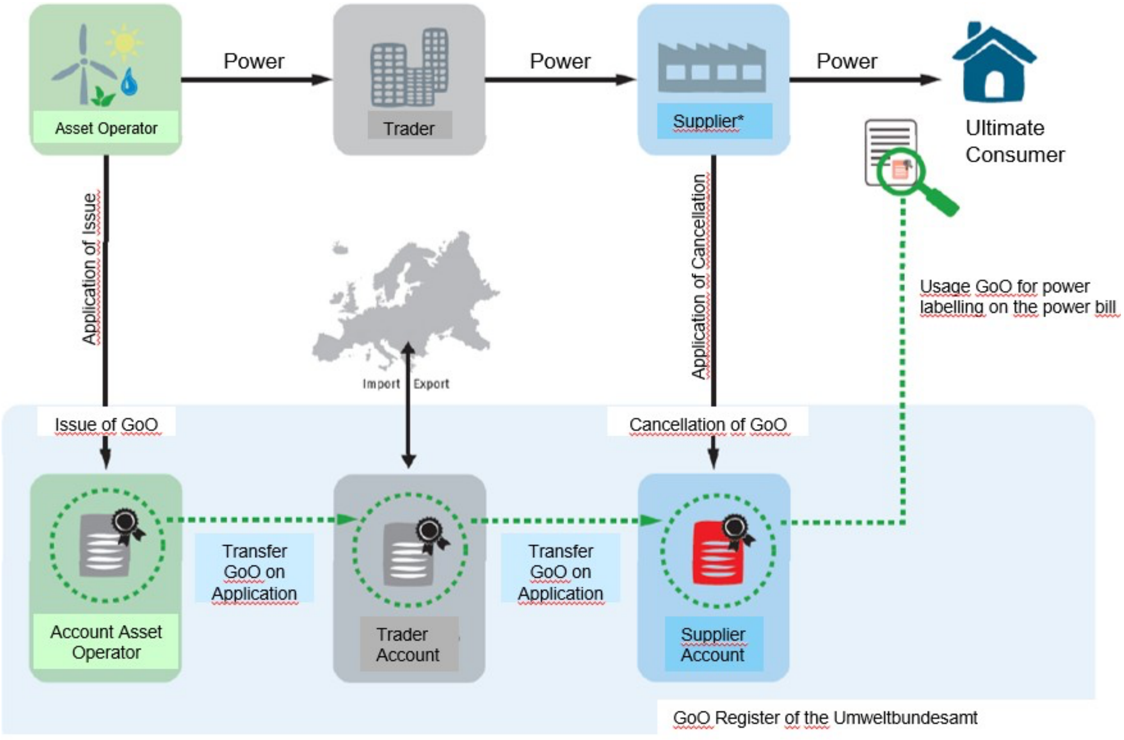
4 Provision of “Green” Hydrogen under CertifHy

To qualify as green hydrogen under CertifHy, the electricity and heat used as input energy for HyLink and the HPU needs to come from 100 percent renewable sources. In the first two sections of this chapter, we briefly describe different options to provide electricity and heat from renewable sources to GrInHy2.0. The last section outlines the most suitable approach for guaranteeing a green hydrogen production of 100 tons as one of the key objectives of this project.

4.1 Options to Provide “Green” Electricity under CertifHy

According to CertifHy, it is required to provide a proof that electricity used in GrInHy2.0 to produce hydrogen is derived 100 percent from renewable sources. CertifHy allows for three options:

- **Option 1 – Guarantees of Origin (with or without grid connection):** The GO trading scheme for renewable electricity enables end-users to buy renewable properties for electricity without being directly linked to a renewable energy source.



* Power Supplier

Figure 7: Guarantee of Origin scheme for electricity produced with renewable energy

A GO is issued by a national authority to a producer of renewable electricity. The producer typically sells GOs to trading companies over the counter. The process is documented in the GO Register. The trading companies then sell the GOs to end-consumers, i.e. GrInHy2.0, and cancel the GOs at the national authority (i.e. GO

Register). The end-consumer gets a cancellation confirmation from the supplier and is able to declare the consumed electricity as renewable (see Figure 7).

- **Option 2 – Power Purchase Agreement (direct or grid connection):** Renewable electricity can be directly purchased from a renewable electricity provider through a long-term power purchase agreement (PPA). The PPA would define all relevant commercial terms for the sale of electricity between the electricity provider and consumer, i.e. GrInHy2.0, and could serve as sufficient proof for the renewable quality of the electricity.
- **Option 3 – On-Site electricity production (direct connection):** In the scope of the project, GrInHy2.0 could also construct or commission its own renewable energy plant, e.g. a wind park, to supply renewable electricity. In this case, the installed capacity would need to be higher than the average electricity demand of GrInHy2.0 to compensate weather-induced electricity volatilities.

A simple grid connection without purchase of GOs or a Power Purchase Agreement is insufficient, even if a certain percentage of the grid mix is derived from renewable sources (see section 2.3 for an example). In Germany, if GrInHy2.0 would take electricity from the grid without opting for Option 1 or 2, it would not be considered under CertifHy because the average emissions in the German power grid in 2017 have been 135 gCO_{2eq}/MJ, higher than the benchmark value of 91 gCO_{2eq}/MJ.[6]

4.2 Options to Provide “Green” Heat under CertifHy

Heat is used as energy input to produce steam. The steam is the input product for the high-temperature steam electrolysis. According to CertifHy, it is required to proof that the heat used to produce hydrogen is derived 100 percent from renewable sources. We see the following options:

- **Option 1 – Electric steam drums (Renewable electricity):** Water at room temperature can be heated and turned into steam by using electric steam drums. To produce green hydrogen, the steam drums would need to be supplied with renewable electricity from the grid or an on-site electricity plant. Applying either option 1, 2 or 3 described in section 4.1 would ensure 100 percent renewable electricity supply.
- **Option 2 – Methane steam boiler (Guarantees of Origin for biomethane):** Similar to the GO trading scheme for renewable electricity, GrInHy2.0 could use methane from the gas grid and purchase GOs for biomethane. In Germany, the relevant quantities to obtain proof of 100 percent renewable gas could be purchased from the *Biogasregister*. The gas will then be used to heat water and produce steam in a methane steam boiler to ensure 100 percent supply with renewable energy.
- **Option 3 – Inevitable, carbon-neutral industrial waste heat:** Waste heat sources in industrial processes are many-fold. This is especially true for the high-temperature processes of an integrated iron-and-steel works. One example is the converter process (see technical infobox below for a detailed description): Therein, both process and

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[6] Umweltbundesamt (2019): CO2-Emissionen pro Kilowattstunde Strom sinken weiter (article)

product related waste heat occurs inevitably, which can be used as carbon-neutral energy to evaporate water while cooling down the off-gas.

So far, CertifHy did not assess carbon-neutral waste heat in one of its pilot projects. Hence, the current scheme does not provide for a clear pathway to categorize waste heat as energy input source.

The GrInHy2.0 consortium advocates to categorize waste heat as carbon-neutral, renewable input energy source, if

- the source of waste heat is inevitable, and
- no additional direct or indirect CO_2 emissions occur.[7]

As both conditions are fulfilled for waste heat from the converter process, this would present a third option to provide “green” heat to the HTE plant.

Technical Infobox – Converter process and waste heat

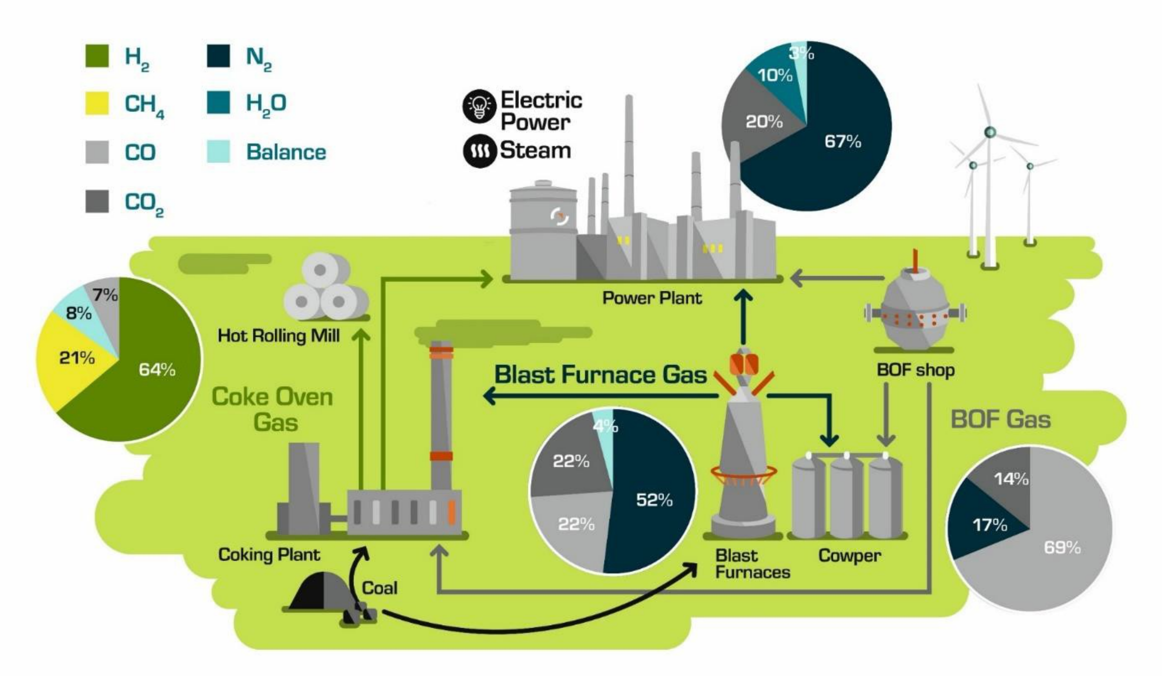

Figure 8: State-of-the-Art carbon-based steelmaking via an integrated iron-and-steel works

Inevitable waste heat not only is **process-related** but in some cases also **product-related**. One example of this combination is the converter process with an oxygen basic furnace of the integrated iron-and-steel works. An integrated iron-and-steel works is characterized by the interactions of its key processes blast furnace, coke oven, basic oxygen furnace (BOF) and power plant which, in turn, operates on process gases that are a side product of the three other key processes, see Figure 8. All these processes represent the state-of-the-art of today’s iron-ore-based steelmaking.

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[7] see Chapter 5 for the complete policy recommendation regarding waste heat treatment

Technical Infobox – Converter process and waste heat (continued)

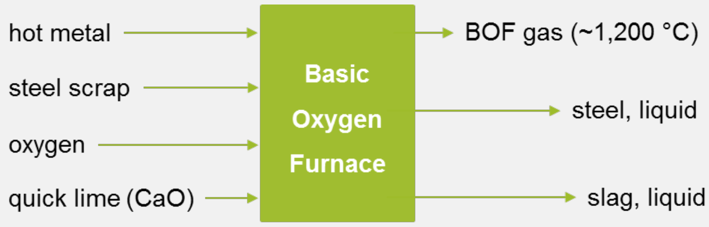


Figure 9: Substantial material and energy flows of the converter process

The role of the BOF is to convert hot metal with its inherent property of 4 to 5 wt% carbon content into steel with usually way less than 2 wt% carbon. Together with undesired impurities (silicon, calcium, phosphorus, manganese, etc.), the carbon is oxidised by blowing pure oxygen into the molten iron. The carbon and impurities are then removed either with the slag or the off-gas (see Figure 9).

Due to the exothermic oxidation (see Annex 1), steel scrap or other iron carrier (iron ore, direct reduced iron, etc.) is added to hold the temperature at approximately 1,600 - 1,700 °C. Usually, scrap rates of approximately 200 kg per ton of liquid steel are reached.

BOF gas treatment

The BOF gas, which is the off-gas of the converter process, has temperatures around 1,200 °C and is caught by the primary ventilation system resulting in a flow rate of approximately 50 to 100 Nm^3 per ton of liquid steel. BOF gas contains about 70 vol% carbon monoxide and has a lower heating value of up to 9 MJ/Nm^3.

As described in the JRC Reference Report (see Annex 1), one way to recover energy from the BOF gas is the buffering of the BOF gas in a gasholder for subsequent use. The suppression or recovering of BOF gas requires proper gas treatment (dedusting and cooling) and strict safety precautions due to its potentially health hazard (carbon monoxide) and risk of explosion.

Since the BOF gas must cool down in order to prevent damage components (sealings, blower, etc.) of the pipeline system, the generation of steam from this waste heat source increases the energy efficiency lowering overall primary energy demand of the system and its CO2 emissions. The role of the BOF is to convert hot metal with its inherent property of 4 – 5 wt% carbon content into steel with usually way less than 2 wt% carbon. Together with undesired impurities (silicon, calcium, phosphorus, manganese, etc.), the carbon is oxidized by blowing pure oxygen into the molten iron. The carbon and impurities are then removed either with the slag or the off-gas (see Figure 8).

Conclusion

One of hot metal's inherent properties is its composition of 4 to 5 wt% of carbon. The exothermic oxidation to reduce the carbon content in the basic oxygen furnace converts the hot metal into liquid steel (< 2 wt% of carbon). During the process, steel scrap is melted to maintain the temperature, liquid slag is formed and BOF gas is generated.

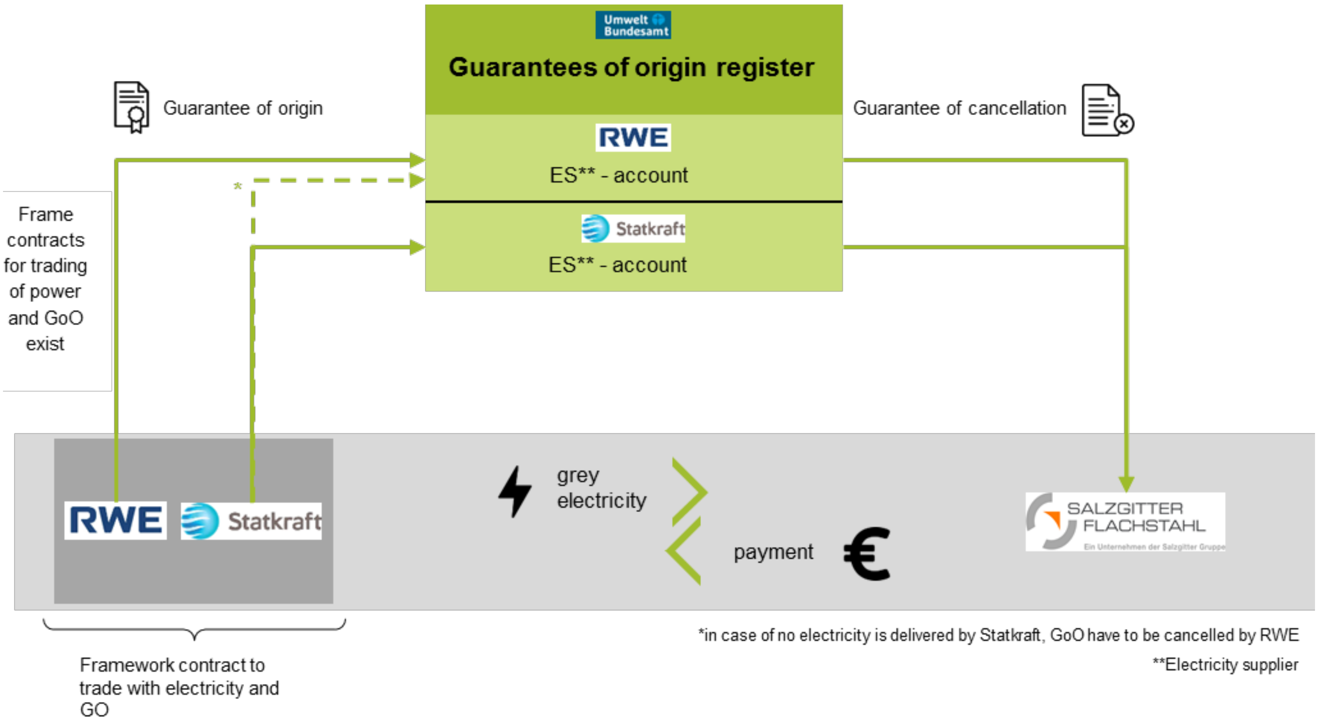
Technical Infobox – Converter process and waste heat (continued)

To recover and to buffer the BOF gas in a gas holder for subsequent use, the gas is cooled down by the endothermic evaporation of water. The heat generated is therefore not based on external fossil sources and unavoidable within the process.

Steam from the cooling process of BOF gas is both based on an inevitable waste heat source and the properties of an intermediate product (hot metal) which, in turn, doesn't increase the carbon intensity of the BOF process.

4.3 Practical Solution in GrInHy2.0

The defined objective of GrInHy2.0 is the production of 100 tons of green hydrogen. To achieve this goal, it is necessary to provide 100 percent renewable electricity and 100 percent renewable heat to the project in order to meet the green hydrogen requirements of CertifHy.



*in case of no electricity is delivered by Statkraft, GoO have to be cancelled by RWE

**Electricity supplier

Figure 10: Power purchase agreement setup for GrInHy2.0

Based on the outlined options under sections 4.1 and 4.2, the GrInHy2.0 consortium will source its input energy as follows:

- **Electricity (82.1 percent of input energy):** SZFG has signed framework contracts for trading power and GOs with RWE and Statkraft. SZFG will purchase power and GOs from one or both suppliers. The supplier will cancel the GOs in the register of the German authority *Umweltbundesamt*. SZFG gets the Cancellation Confirmations and will ensure that the used electricity is produced by using renewable energy (see section 4.1 and Figure 10).

- **Heat (17.9 percent of input energy):** The consortium will use waste heat from the converter process to produce steam (Option 3). As the steam already exists, this solution uses currently unused resources without the need of heating facilities inside the container and enables an economic price for the purchased energy. Furthermore, the described solutions to provide “green” heat under 4.2 with an electric steam drum or a methane steam boiler need additional energy and thus contradict the efficiency purpose of CertifHy to “facilitate the production, procurement, and use of hydrogen fulfilling ambitious environmental criteria”.[8]

However, given the open questions on carbon-neutral waste heat utilization under the current standards of CertifHy, we can only be sure, that the 82.1 percent renewable electricity-based input share of the whole hydrogen production batch will be considered as green by purchasing GOs for electricity. For the remaining 17.9 percent of waste heat, CertifHy does not provide a clear pathway / legal certainty regarding its categorization. This would probably lead to a batch of 17.9 tons either categorized as green or low-carbon hydrogen.

	initially planned	after CertifHy regulatory analysis
Total	**100 t**	**121.8 t**
Electricity share	82.1 t	100 t
Heat share unclear	17.9 t	21.8 t

Figure 11: Hydrogen production quantity under GrInHy2.0

Against this backdrop, we will increase our planned production of 100 tons of hydrogen by 21.8 percent to 121.8 tons by extending the total hours of operation (see Figure 11). Thereby, the 82.1 percent renewable electricity-based input share of the hydrogen batch will rise to 100 tons, whereas the 17.9 percent waste heat share will increase to 21.8 tons. With the production extension, we make sure, that we will achieve the key project objective of producing 100 tons of green hydrogen under all circumstances.

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[8] CertifHy (2019): CertifHy-SD Hydrogen Criteria, p. 4

5 Recommendations for Decision-makers

5.1 Waste Heat

CertifHy provides a robust mechanism for categorizing different hydrogen production pathways into clearly distinguished batches of green, low-carbon and grey hydrogen. Powerful examples are shown in pilot projects concerning the production of green hydrogen from alkaline water electrolysis and proton exchange membrane electrolysis in Belgium (Colruyt Group) and Germany (Uniper).[9]

For high-temperature steam electrolysers that use waste heat as one key energy input source, however, CertifHy does not provide a clear pathway. In fact, to achieve a guaranteed green hydrogen production batch of 100 tons in the GrInHy2.0 project, it is necessary to either produce additional quantities of hydrogen (see section 4.3) or to turn to inefficient alternatives such as using additional electric steam drums or methane steam boilers to produce the required steam (see section 4.2). With waste heat not specified under CertifHy, building up a commercially feasible production of green hydrogen with steam electrolysers will be a difficult mission.

We therefore urge the CertifHy consortium to include an unambiguous definition and categorization of waste heat as energy input source for hydrogen production in their scheme.

We recommend decision-makers to categorize waste heat as renewable, carbon-neutral input energy source, if

- the source of waste heat is unavoidable, and
- no additional direct or indirect CO_2 emissions occur.

If one of the two preconditions is not met, it is not waste heat and the energy used to produce that heat would need to be evaluated according to the CertifHy scheme.

According to our proposed definition, waste heat is inherently emission-free. Hence the share of the hydrogen production batch would be certified as green hydrogen.

To our understanding, this is in line with recent European legislation:

- **RED II** defines waste heat as “unavoidable heat […] generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible.” According to Articles 23.2 and 23.4, waste heat can be counted towards renewable energy targets in the heating and cooling sector.
- Recent documentation of the **ETS Innovation Fund** regarding the GHG emission avoidance calculation methodology, adds: “[…] if the heat is truly “waste heat”, it would be considered free of emissions. On the other hand, if extra fuel needs to be burnt to replace the heat in the existing process, its emissions intensity is the emissions from burning that extra fuel.”

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[9] CertifHy (2020): Pilot Projects, https://www.certifhy.eu/

In the GrInHy2.0 project, we will use waste heat from the converter process. This waste heat is unavoidable, because it is generated from the carbon content of the iron and it would also be part of a purely green hydrogen-based steel production process. As shown under section 4.3 (see Technical Infobox), no additional CO_2 emissions occur in comparison to the already existing process at the plant. Hence, the two waste heat criteria are fulfilled. Consequently, the yet undefined 17.9 percent waste heat-based hydrogen production batch could be certified as green hydrogen under our proposed methodology.

If any other arguments would fundamentally oppose our proposal on treating waste heat as renewable energy source under CertifHy, it must at least be treated as low-carbon energy source. In fact, no additional energy is supplied to the converter process in GrInHy2.0 and thus, no additional emissions occur regarding waste heat. Since zero emissions fall below the 36.4 gCO_{2eq}/MJ threshold applied for hydrogen produced from non-renewable energy input sources, it would then need to be categorized as low-carbon energy source.

Alternatively, policymakers could enable the use of electricity or green methane GOs a proof for the renewable character of waste heat. As stated under section 4.2, electrical steam drums or methane steam boilers are feasible, but economically and ecologically nonsense alternatives to waste heat in order to provide heat / water steam to the high temperature electrolyser in GrInHy2.0. Since GOs are not available for waste heat, but for renewable electricity and biomethane, HTE plant operators should be allowed to do an “as-if-calculation” of the amount of electricity or biomethane required for steam drums or gas boilers and purchase the corresponding quantity of GOs. In this way, we could provide sufficient proof for the renewable content of our waste heat.

5.2 Boundary Conditions of the CertifHy Scheme

Apart from the general discussion on heat, the consortium sees further point for discussion in the boundary conditions of the CertifHy scheme.

Defining the boundary to “[…] include all the production stages needed to reach a hydrogen purity of at least 99.9 %vol and a gauge pressure of at least 3 MPa”[10] is a good way for standardisation in international trading. However, under the current scheme “[…] GOs also need to be cancelled for the additional [theoretical] amount of electricity for compression” to reach said boundary condition, even if the hydrogen (and GOs) are intended for self-usage.

Given the example of a self-consumer such as SZFG, this effectively leads to a “GOs tax” for having a hydrogen application at lower purity and pressure requirements as the CertifHy scheme defines. In effect, SZFG has to purchase electricity GOs for a theoretical compression never intended or applied in the actual process (13.5 kW as explained in Chapter 3).

We therefore recommend decision-makers to exclude hydrogen self-usage from the necessity of fulfilling the CertifHy boundary conditions and instead applying the boundary at the interface form hydrogen production unit to the final application.

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[10] CertifHy (2019): CertifHy Scheme Subsidiary Document, CertifHy-SD Hydrogen Criteria

6 Conclusion

The GrInHy2.0 project aims at replacing 50 percent of the entire fossil-based hydrogen used at the Salzgitter iron-and-steel works with green hydrogen, i.e. approximately 100 tons, using high temperature electrolysers. To qualify as green, however, the hydrogen produced under GrInHy2.0 needs to meet the European "CertifHy" certification standards and requirements.

The categorization of produced hydrogen batches under CertifHy is determined by the energy input source. In GrInHy2.0, 82.1 percent of the energy is provided in the form of electricity, the remaining 17.9 percent as heat. In order to receive green hydrogen certification, both, electricity and heat, must be from renewable energy sources.

For electricity, three options are available to proof the renewable properties: Taking power from the grid and either (1) purchasing GOs or (2) entering into a Power Purchase Agreement with a renewable electricity producer or (3) producing renewable electricity on-site. For providing renewable heat to boil water to water steam, GrInHy2.0 could either (1) use electrical steam drums (renewable electricity), (2) a methane steam boiler (biomethane) or (3) waste heat from the converter process of the iron-and-steel works. The economically and ecologically most feasible way to provide both energy inputs is via signing framework contracts for power and Guarantees of Origin with RWE and Statkraft and using waste heat from the steel plant.

While the electricity sourcing would clearly meet the CertifHy standards and requirements for green hydrogen, waste heat is currently not considered under the CertifHy scheme. To circumvent this legal uncertainty and to achieve a guaranteed green hydrogen production batch of 100 tons in the GrInHy2.0 project, the consortium will produce additional quantities of hydrogen amounting to 21.8 percent. Thereby, the clearly regulated 82.1 percent renewable electricity-based input share of the hydrogen batch will rise to 100 tons. In this way, the project objective will surely be reached.

With waste heat not specified under CertifHy, GrInHy2.0 shows that building up a commercially feasible production of green hydrogen with steam electrolysers will be a difficult mission. We therefore urge decision-makers to include an unambiguous definition and categorization of waste heat as energy input source for hydrogen production in the CertifHy scheme. We recommend decision-makers to categorize waste heat as renewable, carbon-neutral input energy source, if

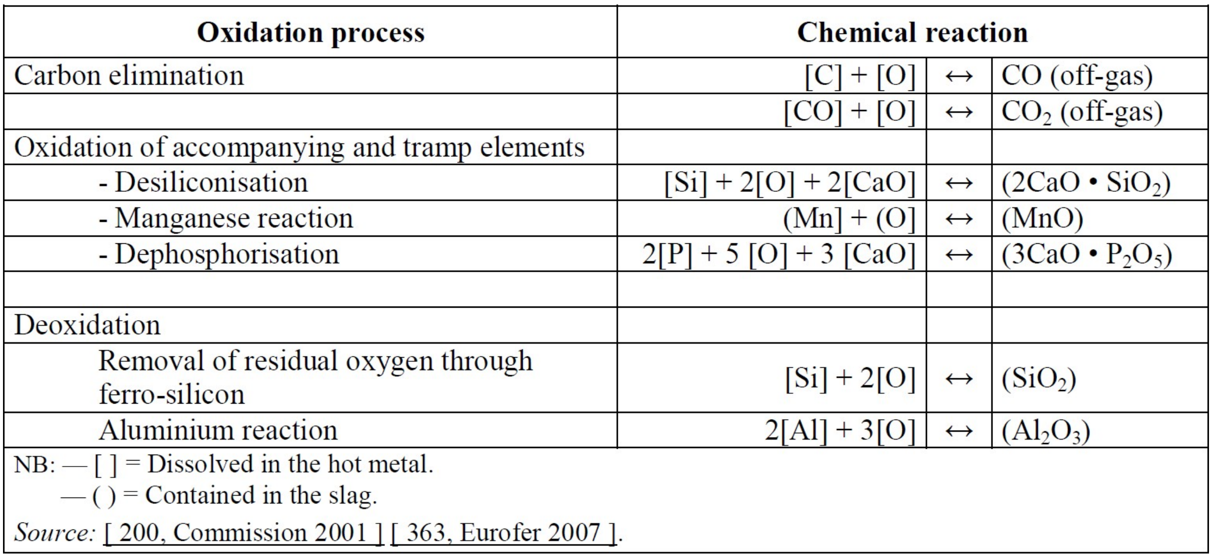
- the source of waste heat is unavoidable, and
- no additional direct or indirect CO_2 emissions occur.

If one of the two preconditions above is not met, it is not waste heat and the energy used to produce that heat would need to be evaluated according to the CertifHy scheme.

Apart from the general discussion on heat, the consortium sees further point for discussion in the boundary conditions of the CertifHy scheme. We recommend decision-makers to exclude hydrogen self-usage from the necessity of fulfilling the CertifHy boundary conditions and instead applying the boundary at the interface from hydrogen production unit to the final application.

An amendment of CertifHy along the proposed lines will strengthen high-temperature electrolysis business cases and contribute to a comprehensive deployment of this green technology in energy-intensive industries, where they are imperative to reach the ambitious European decarbonization goals.

7 Annex



Oxidation process	Chemical reaction		
Carbon elimination	[C] + [O]	↔	CO (off-gas)
	[CO] + [O]	↔	CO_2 (off-gas)
Oxidation of accompanying and tramp elements			
- Desiliconisation	[Si] + 2[O] + 2[CaO]	↔	$(2CaO \cdot SiO_2)$
- Manganese reaction	(Mn] + (O]	↔	(MnO)
- Dephosphorisation	2[P] + 5 [O] + 3 [CaO]	↔	$(3CaO \cdot P_2O_5)$
Deoxidation			
Removal of residual oxygen through ferro-silicon	[Si] + 2[O]	↔	(SiO_2)
Aluminium reaction	2[Al] + 3[O]	↔	(Al_2O_3)

NB: — [ ] = Dissolved in the hot metal.
— ( ) = Contained in the slag.

Source: [200, Commission 2001] [363, Eurofer 2007].

Annex 1: Main chemical reactions taking place during the oxidation process[11]

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[11] JRC (2013): Reference Report Best Available Techniques (BAT) Reference Document for Iron and Steel Production, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC69967/lfna25521enn.pdf