HYGRID

FLEXIBLE HYBRID SEPARATION SYSTEM FOR H2 RECOVERY FROM NG GRIDS

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Start date of project: 01/05/2016 **Duration: 3 years**

WP9 – Environmental LCA and economic assessment

D.9.1
Goal and scope for the environmental and economic assessment

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PP	Restricted to other programme participants (including the Commission Services)	
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CO	Confidential, only for members of the consortium (including the Commission Services)	
CON	Confidential, only for members of the Consortium	

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(**) indicate the acronym of the partner that prepared the document

Content

1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This document summarises the goal and scope definition for the life cycle assessment (LCA) of the hydrogen recovery system investigated in the HyGrid project. The goal and scope definition is the first step in a LCA study and lays the basis for all subsequent stages. It defines the aim of the study and thereby identifies modelling as well as data availability challenges. Moreover, upon completion of the study, the goal and scope definition helps interested parties in understanding under which framework the study was derived and to what extend its results can be compared to the ones presented in other studies. Typical questions which are addressed in the goal and scope definition are (amongst others):

- What is the aim of the study?
- What is the function of the analysed system?
- What systems exactly are going to be analysed?
- What reference system/ technology will we compare our system against?
- What are the system boundaries of the analysed product?
- What is the data availability for the study?

This report addresses the answers to the above questions within the LCA study for the systems developed within HyGrid.

1.2 Brief description of the state of the art and the innovation

Since the systems under study are currently being developed within the HyGrid project, no LCA results or literature on this specific topic exist. The results of the LCA of the hydrogen recovery systems developed within HyGrid will therefore shed new light on the contributions which these devices can bring in the shift towards more sustainable energy distribution systems.

1.3 Deviation from objectives

The deliverable was initially planned for the end of April. It was decided to present the results of the goal and scope analysis at the M12 meeting and to finalise the deliverable after the meeting in order to be able to include the feedback from the other project partners.

2 INTRODUCTION

2.1 Context and background

The increasing awareness of the importance of sustainability has sparked the innovation of methods to better understand, measure and reduce the potential environmental impacts associated with products and services. The leading tool for achieving this is life cycle assessment (LCA), a method standardized by the International Organization for Standardization (ISO) 14040-44 standards (ISO 14040; 2006; ISO 14044; 2006).

LCA is an internationally recognized approach which evaluates the potential environmental and human health impact associated with products and services throughout their life cycle, from raw material extraction and including transportation, production, use, and end-of-life treatment (**Figure 1**).

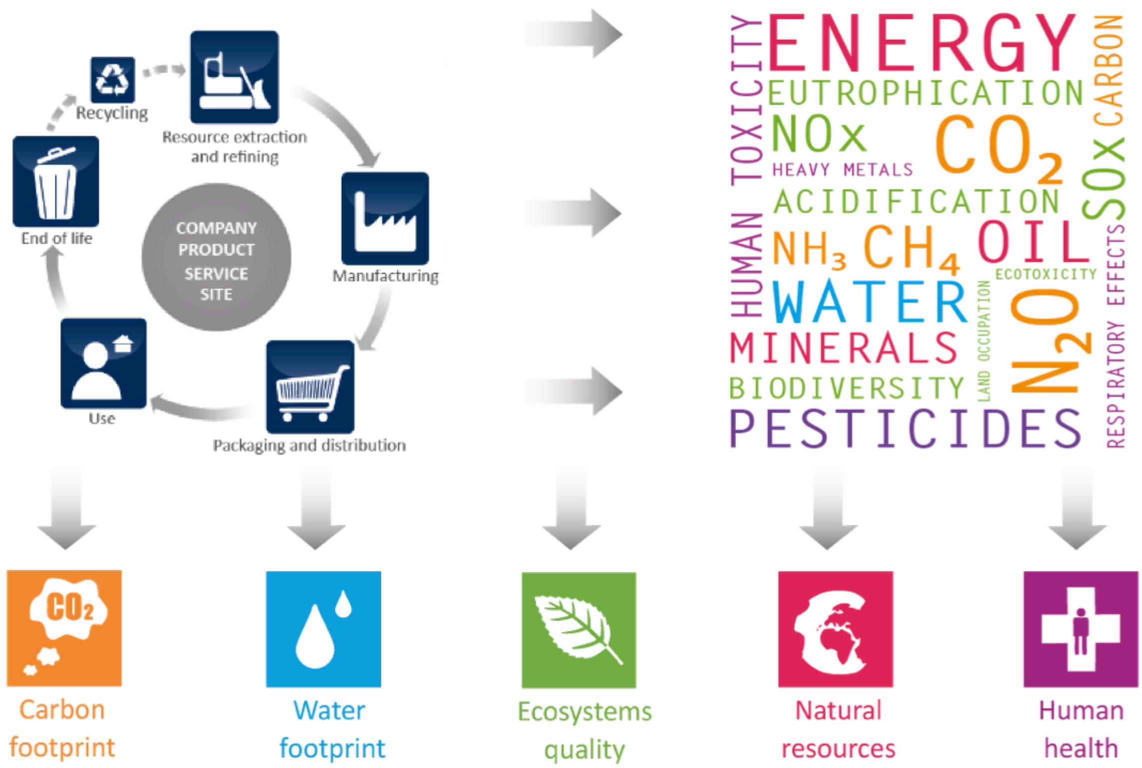

Figure 1: LCA concept.

Among other uses, LCA is used to identify opportunities to improve the environmental performance of products at various stages along their life cycle, inform decision-makers, and support marketing and communication. Following the same philosophy, life cycle costing

(LCC) studies allow to estimate the associated costs which occur during production, use and the end-of-life of a product, service or technology and thereby help to understand what the real economic burden will be as opposed to the simple selling price.

The aim of the HyGrid project is to develop innovative hydrogen recovery systems based on the combined use of membranes, electrochemical hydrogen separation (EHS) and temperature swing adsorption (TSA). The idea is to use such systems to recover hydrogen from the mixture of gases flowing through the natural gas grid. This would allow for using the existing natural gas grid as a transport system for hydrogen avoiding having to build a dedicated hydrogen distribution grid and the related costs.

The aim of WP9 is to perform an environmental LCA and economic assessment of the hydrogen recovery systems developed within HyGrid. Further, since the LCA will accompany the research, the idea is to use the LCA work to steer the development of the systems towards more sustainable solutions. Finally, a comparison will be made between the life cycle performance of the systems developed within HyGrid and the conventional technology currently able to deliver the same service.

This document reports on the development of the goal and scope of the LCA work within HyGrid. As will be described in more detail below, this is the first step in such studies and it is key for the rest of the analysis since it defines its foundation and main framework.

2.2 Life cycle assessment approach

An LCA is comprised of four phases, as shown in **Figure 2**:

a) **Goal and scope definition:** defining the purposes of the study, determining the boundaries of the system life cycle in question and identifying important assumptions that will be made;

b) **Inventory analysis:** compiling a complete record of the important material and energy flows throughout the life cycle, in addition to releases of pollutants and other environmental aspects being studied;

c) **Impact assessment:** using the inventory compiled in the prior stage to create a clear and concise picture of environmental impacts among a limited set of understandable impact categories; and

d) **Interpretation:** identifying the meaning of the results of the inventory and impact assessment relative to the goals of the study.

LCA is best practiced as an iterative process, where the findings at each stage influence changes and improvements in the others to arrive at a study design that is of adequate quality to meet the defined goals. The principles, framework, requirements and guidelines to perform an LCA are described by the international standards ISO 14040 series (ISO 14040:, 2006; ISO 14044:, 2006).

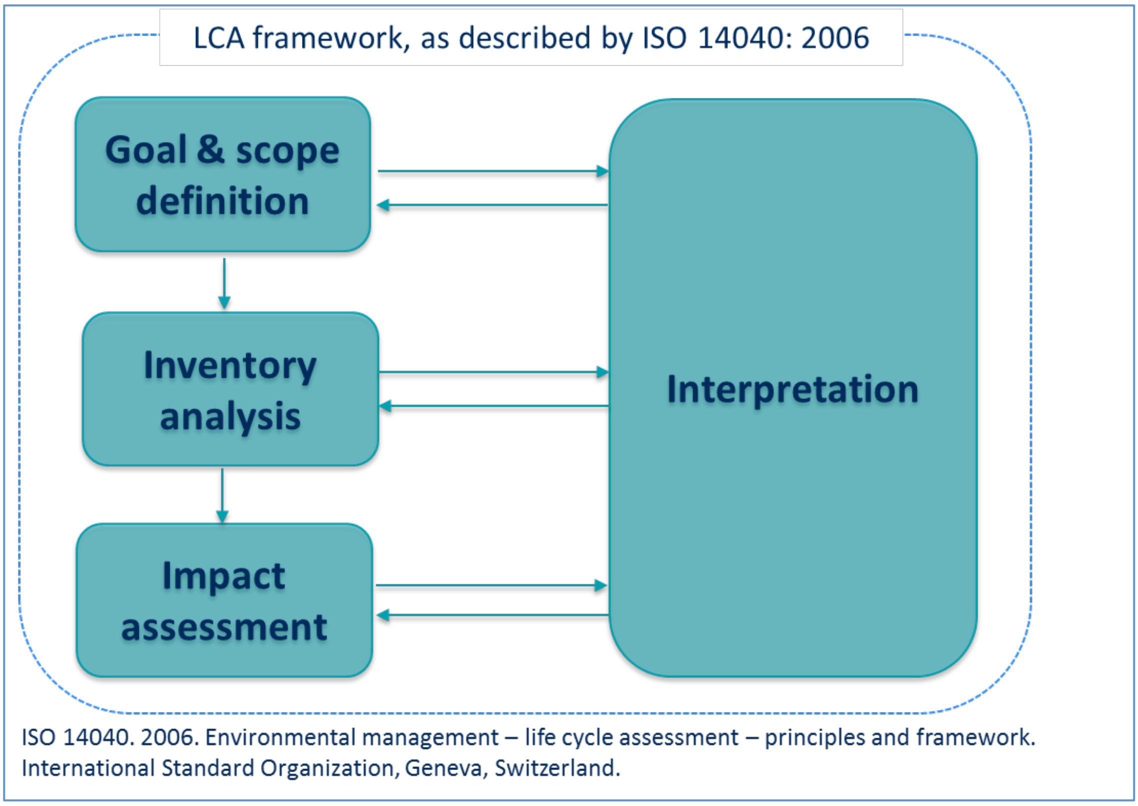

Figure 2. Life cycle assessment methodology.

This deliverable 9.1 focuses on the first step of an LCA: the goal and scope definition.

3 GOAL AND SCOPE DEFINITION

The goal and scope definition is the first step in a LCA study and lays the basis for all subsequent stages. It defines the aim of the study and thereby identifies modelling as well as data availability challenges. Moreover, upon completion of the study, the goal and scope definition helps interested parties in understanding under which framework the study was derived and to what extend its results can be compared to the ones presented in other studies. Typical questions which are addressed in the goal and scope definition are (amongst others):

- What is the aim of the study?
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This report addresses the answers to the above questions within the LCA study for the systems developed within HyGrid. The key results of the goal and scope development phase obtained during the first year of project activity were presented at the M12 meeting and adapted based on the feedback obtained by project partners.

3.1 Reasons for carrying out the study

The aim of WP9 is to perform an environmental LCA and economic assessment of the hydrogen recovery systems developed within HyGrid. This will allow to understand what environmental impacts could be caused by the investigated systems and what economic burden will result from their production, use and end-of-life. In order to further asses the advantages and challenges connected to the development of HyGrid's hydrogen recovery systems, the results of the environmental and economic life cycle analysis will be compared against those of the current available technology typically used for the recovery of hydrogen from a gas mixture mainly comprising natural gas. Finally, by doing an accompanying study which develops together with the findings of the other WPs, the idea is to steer the project towards the realisation of more environmentally friendly hydrogen recovery systems by highlighting along the way critical environmental issues which may be optimised.

3.2 Intended audience

The results of this LCA will be publicly available and the reporting will accordingly target experts, stakeholders and interested parties who want to better understand the life cycle impacts and costs of the hydrogen recovery systems developed within Hygrid.

3.3 Function, functional unit and reference flows

The functional unit quantifies the performance of a product system and is used as a reference unit for which the life cycle assessment study is performed and the results are presented. It is therefore critical that this parameter is clearly defined and measurable.

The purpose (or function) of the systems developed within HyGrid is the recovery of pure hydrogen from a mixture of gases mainly comprising natural gas and available from the natural gas grid. Moreover, since one potential application of these recovery systems is to use the hydrogen in automotive systems, the recovered hydrogen should be of sufficient purity to be used in fuel cell systems for road vehicles. The functional unit for the analysis will therefore be:

The recovery from an average European natural gas grid of 1 kg of hydrogen with a purity of at least 99.97%.

The value of 99.97% was chosen as this represents the minimum in terms of H_2 mole fraction for Type I Grade D in ISO/TS 14687-2-2012 hydrogen fuel specifications for PEM fuel cell applications for road vehicles. Fulfilling this target means to also fulfil the target for:

- Stationary applications (Type I grade A - 98% minimum H_2 molar fraction)
- Hydrogen fuelled ICE (Type I grade E category 3 – 99.9% minimum H_2 molar fraction)

The functional unit only describes the measure used for analysing the system. Its productivity as well as other characteristics will be addressed below.

3.4 System general description

The hydrogen recovery systems developed within HyGrid comprise three successive recovery steps. As schematically shown in Figure 3, the natural gas mixture is first sent through a membrane system, then through electrochemical hydrogen separation (EHS) and finally through a temperature swing adsorption (TSA) unit.

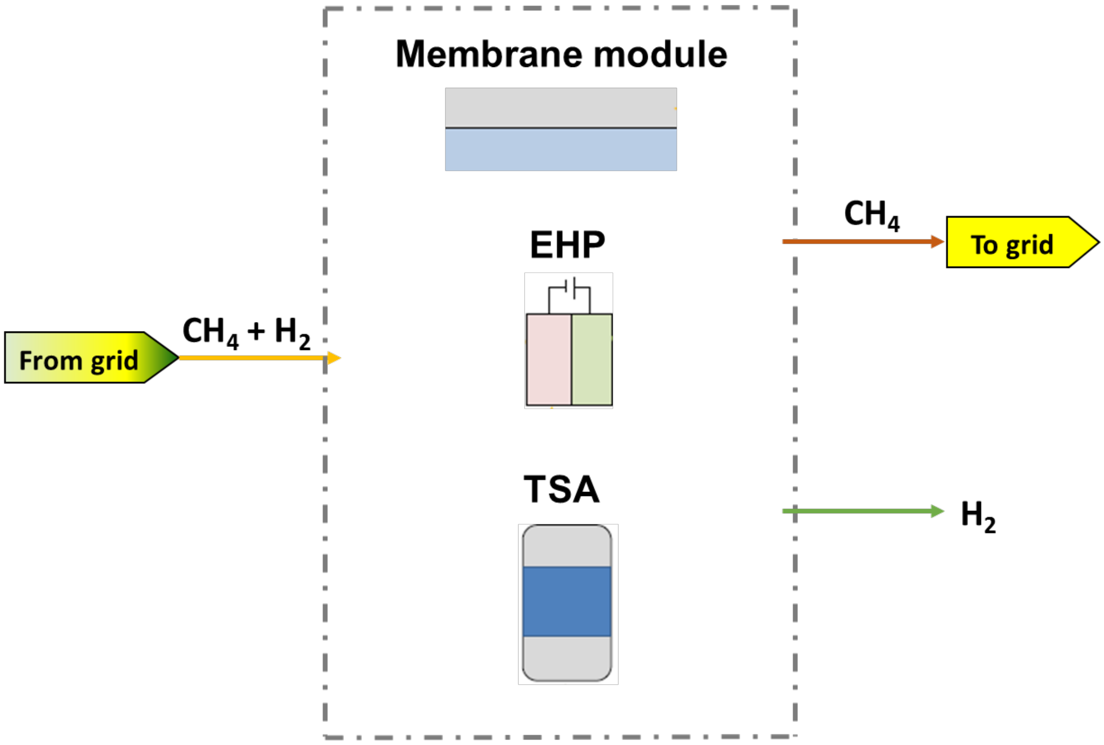

Figure 3: Hydrogen recovery system within HyGrid.

Various membrane systems are currently being investigated. Particularly, Palladium-based and Carbon Sieve Membranes (CSMs) will be considered. Moreover, the impact on the system's performance of metallic and ceramic supports for the membranes will also be analysed. The life cycle analysis will, as far as data availability will allow, address the various subsystems (membranes, EHS and TSA) as well as the different membrane types and supports in order to try an identify the most sustainable solutions. **Fehler! Verweisquelle konnte nicht gefunden werden.** summarises the key target parameters for the recovery systems addressed within HyGrid (DoW, 2015).

Table 1: Target parameters for HyGrid's hydrogen recovery systems.

	P [bar]	T [°C]	H_2 production [kg/day]	H_2 cost [€/kg_{H2}]	Power consumption [kWh/kg_{H2}]	Payback time [years]	Lifetime [years]
HyGrid System	0.03-80	T<400	>25	<1.5	<5	<6	>15

In terms of reference technology, at the M6 meeting in Bilbao it was agreed that the most relevant technology which could deliver a hydrogen recovery service similar to the one provided by HyGrid's systems is pressure swing adsorption (PSA). It was therefore decided that PSA will be used as reference technology against which the environmental and cost performance of the recovery systems developed within HyGrid will be compared.

3.5 System boundaries

The system boundaries define what processes will be considered in the analysis. The aim of the environmental and economic assessment in HyGrid is to identify the relevant mechanisms in the life cycle of the hydrogen recovery systems which might impact the environment and to understand its key cost aspects. As such, as far as data availability will allow, the target is to try and include all potential main impact and cost contributors. As schematically shown in **Figure 4** for the environmental assessment, this means that all emissions caused and resources consumed by processes such as the production of the raw materials and energy vectors required for the manufacturing, use and end-of-life will be included in the analysis. This includes the impacts deriving from the extraction of the raw materials, production or dismantling infrastructure, all transport services which might be required as well as waste disposal systems or the generation of the needed electricity or fuels. For the cost analysis, the same approach will be used, only focusing on the cost information for each item considered.

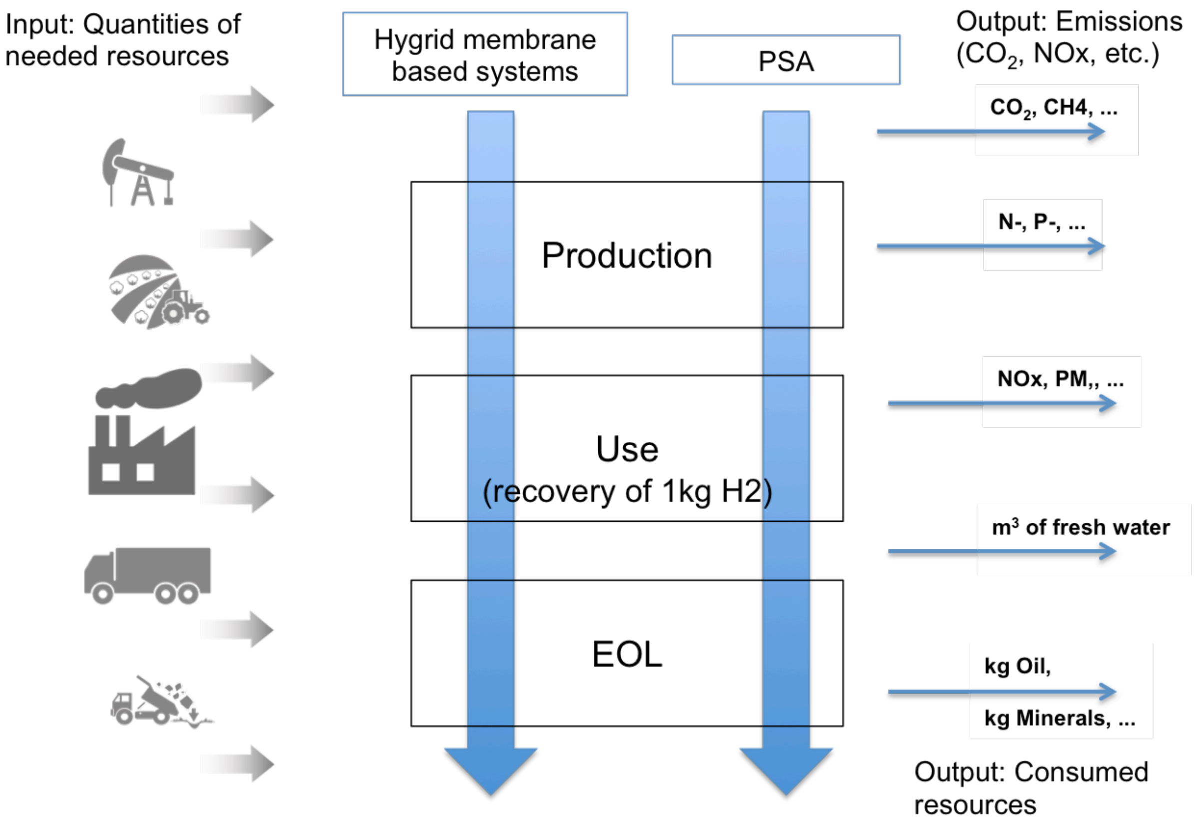

Figure 4: System boundaries in the LCA of the hydrogen recovery systems.

Following the definition of the functional unit the results will be scaled to the life cycle environmental and cost impacts for the recovery of 1 kg of hydrogen. As already mentioned above, for the recovery systems developed within HyGrid, the analysis will address the various sub-systems (membranes, EHS and TSA) as well as the various membrane types and supports. This will highlight the hot spots of the systems (meaning the sub-processes responsible for the largest environmental impacts and cost contributions) and thereby help to identify potential for optimisation.

While the key analysis will address the life cycle related to the recovery of 1 kg of hydrogen, in a second step, the focus will also be shifted to the use of the recovered hydrogen in a fuel cell automotive application including the life cycle impacts coming from, amongst other things, the fuel cell vehicle and road infrastructure and the specific hydrogen consumption used per km for current fuel cell vehicles (**Figure 5**). Including this specific application of the recovered hydrogen in the analysis will help to understand the relative contribution of the recovery of the hydrogen as opposed to the other processes involved in its use (e.g. the life cycle of the vehicle and road infrastructure as opposed to the production of the hydrogen distributed through the natural gas grid). Since about 95% of the hydrogen produced today is obtained from steam reforming of natural gas[1], this hydrogen production chain will be considered in this part of the analysis.

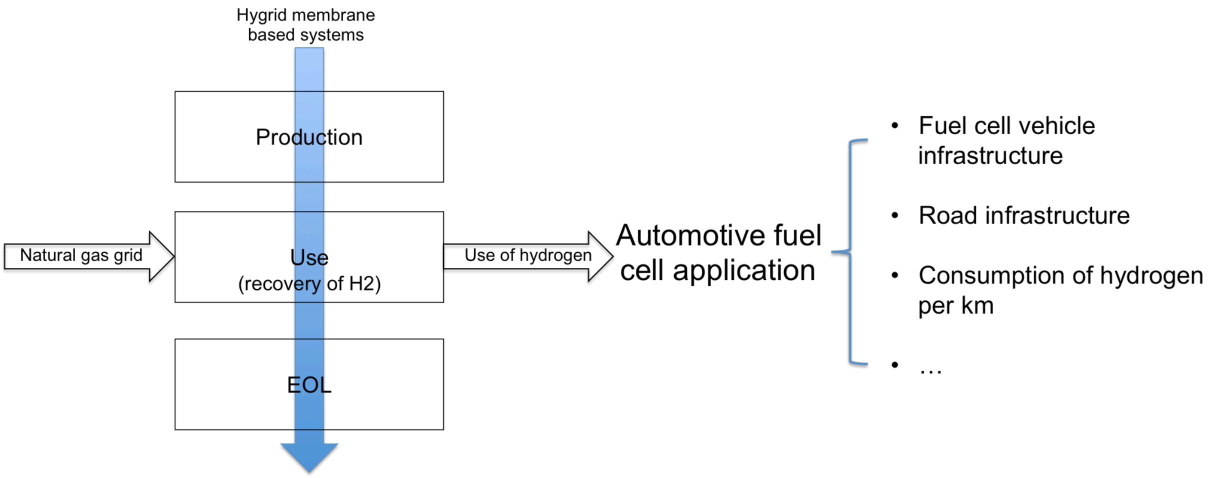

Figure 5: Impact analysis for HyGrid's hydrogen recovery systems including the use of the hydrogen in a fuel cell vehicle.

3.6 Data availability

Since HyGrid's consortium includes experts in all sub-systems of the hydrogen recovery systems, the idea is to use as far as possible project-specific primary data from project partners, at least regarding the quantities of required input materials, energy and direct emissions occurring for the production and use phase. For the disposal phase, where higher uncertainties about the fate of components during disposal or recycling processes available in the future occur, it might be necessary to rely on literature data and experts' feedback. Further, data on the environmental impacts of background processes such as general transport services, the production of the manufacturing infrastructure, the production of the required raw materials or the generation of the necessary fuels will be taken from the environmental database ecoinvent. The various data sources used in the project are shown in **Figure 6**.

[1] https://energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

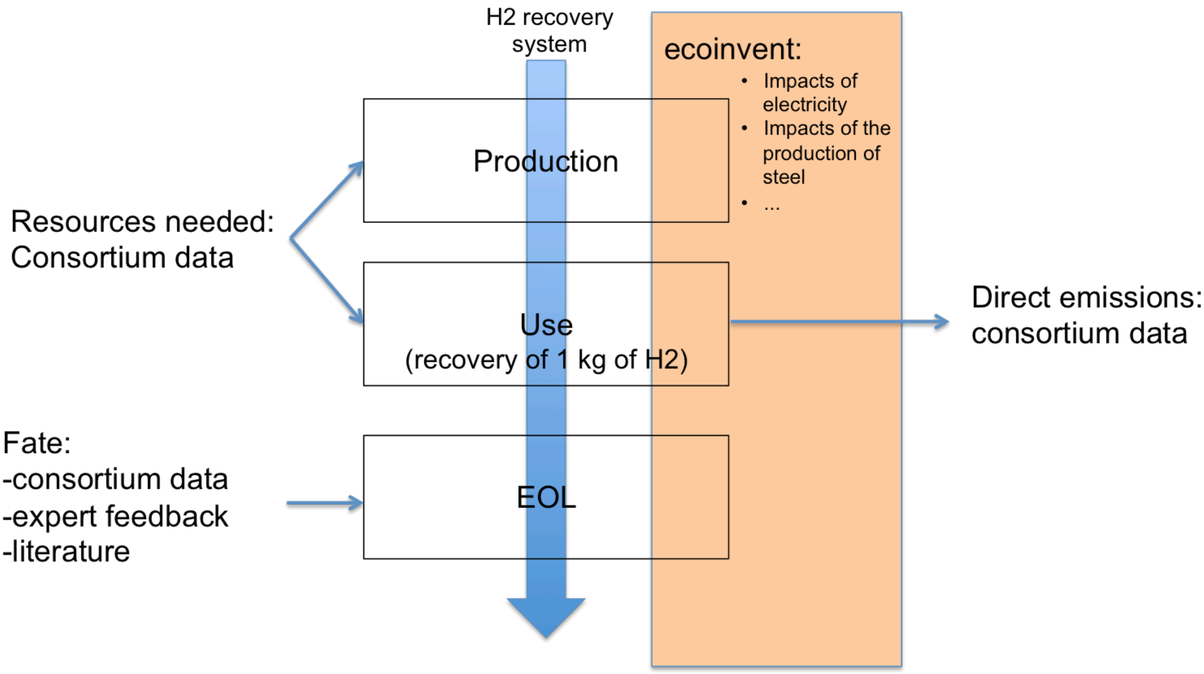

Figure 6: Key data sources used for the LCA.

3.7 Impact assessment

The life cycle impact assessment (LCIA) is the step in which the data on the quantities of emissions produced and resources consumed by the life cycle of a system is transformed into information on the damages caused to the environment. The impacts are calculated using characterization factors recommended in internationally-recognized impact assessment methods.

In the LCA of the hydrogen recovery systems developed within HyGrid, the IMPACT 2002+ (Humbert, De Schryver, Bengoa, Margni, & Jolliet, 2014) LCIA method is used for this task. The IMPACT 2002+ framework links the emissions caused and resources consumed by the life cycle of a system to five so-called endpoint (damage-oriented) categories (human health, ecosystem quality, climate change, resources, and water withdrawal). It was originally developed at the Swiss Federal Institute of Technology of Lausanne (EPFL), Switzerland. Subsequently, Quantis made some updates to the original IMPACT 2002+ methodology version 2.1[2]. This adapted version is referred to as "IMPACT 2002+ version Q2.27 (adapted by

[2] The main difference between IMPACT 2002+ v2.1 and IMPACT 2002+ vQ2.2 (adapted by Quantis) are (i) climate change characterization factors are adapted with global warming potentials for a 100 year time horizon, (ii)

Quantis)". The life cycle assessment focuses on the five IMPACT 2002+ end-point indicators (described in Table 2 below) over the entire life cycle of the processes.

Table 2: Description of IMPACT 2002+ endpoint indicators.

Indicator		Definition
	Greenhouse gas emissions	This indicator measures the potential impact on climate change from greenhouse gas emissions associated with a product, process or organization. It takes into account the midpoint category "global warming". The impact metric is expressed in kg CO2-eq.
	Resources depletion	This indicator measures the potential impact on resource depletion from resource use (e.g. fossil fuels and minerals) associated with a product, process or organization. It takes into account non-renewable energy and mineral extraction. These factors are simply the sum of the endpoint categories non-renewable energy consumption and mineral extraction. The impact metric is expressed in MJ ("measures the amount of energy extracted plus the amount needed to extract the resource itself").
	Water withdrawal	This indicator measures the amount of water withdrawal associated with a product, process or organization. It takes into account water (whether it is evaporated, consumed or released again downstream) excluding turbined water (i.e., water flowing through hydropower generation). It considers drinking water, irrigation water and water for and in industrialized processes (including cooling water), fresh water and sea water. This indicator is actually based and expressed on volumes (m3) of water withdrawal.
	Human health	This indicator measures the potential impact on human health caused by emissions associated with a product, process or organization. It takes into account human toxicity (carcinogenic and non-carcinogenic), respiratory inorganics, ionizing radiation, ozone layer depletion and respiratory organics. It characterizes disease severity, accounting for both mortality (years of life lost due to premature death) and morbidity (rate of incidence of a disease). The impact metric is expressed in DALY ("disability-adjusted life years").
	Ecosystem quality	This indicator measures the potential impact on ecosystems (biodiversity, species and their inhabitant) caused by emissions or resource use associated with a product, process or organization. It takes into account aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification & nutrification, aquatic eutrophication, aquatic acidification, water turbined and land occupation. It characterizes the fraction of species disappeared on one m2 surface during one year. The impact metric is expressed in PDF.m².y ("potentially disappeared fraction of species over one m2 and during one year").

water withdrawal, water consumption and water turbined are added as the midpoint categories, (iii) aquatic acidification, aquatic eutrophication and water turbined are brought to the damage category ecosystem quality, and (iv) normalization factors are updated.

4 REFERENCES

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