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Life Cycle Assessment of improved high pressure alkaline electrolysis

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Abstract

This paper investigates environmental impacts of high pressure alkaline water electrolysis systems. An advanced system with membranes on polymer basis is compared to a state-of-the-art system with asbestos membranes using a Life Cycle Assessment (LCA) approach. For the advanced system, a new improved membrane technology has been investigated within the EU research project "ELYGRID". Results indicate that most environmental impacts are caused by the electricity supply necessary for operation. During the construction phase cell stacks are the main contributor to environmental impacts. New improved membranes have relatively small contributions to impacts caused by cell construction within the advanced systems. As main outcome the systems comparison illustrates a better ecological performance of the new developed system.

Keywords: Life Cycle Assessment, hydrogen production, alkaline water electrolysis, environmental impacts

1. Introduction

Alkaline water electrolysis is a mature hydrogen production technology. Using renewable energy, it is also stated to be a clean technology. However, the state of this technology did not improve significantly within the last decades. Asbestos has been extensively used as membrane material for many years and is still widely in use in existing electrolysis systems. As for new systems the use of asbestos membranes is not allowed any more, new membranes are necessary for hydrogen generation. Within the "ELYGRID" project improved non-asbestos membrane materials for novel electrolysis systems are investigated.

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This current study aims on presenting an in-depth assessment of environmental impacts induced by these advanced alkaline water electrolysis systems in comparison to state-of-the-art asbestos systems. Environmental assessments of hydrogen production have been subject in many studies. However, a review paper shows that most of these studies had an exclusive focus on Global Warming Potential (GWP) [1]. Little attention has been paid to evaluation of ecological effects of individual alkaline electrolysis constituents. Therefore, modeling of environmental impacts caused by an exchange of membranes was not possible in the past. The “ELYGRID” project provides a great opportunity for a detailed environmental assessment of advanced asbestos-free membrane materials and entire alkaline water electrolysis systems.

2. Method and scope definition

Life Cycle Assessment (LCA) is an adequate method for a holistic evaluation of environmental effects. It is well-established, internationally acknowledged, and defined in the ISO standards 14040 [2] and 14044 [3]. Within LCA environmental impacts along the whole life cycle of products are assessed, comprising processes from mining of raw materials, production and use to recycling and/or disposal.

Most of the data describing the technologies of the electrolysis life cycle are provided by the “ELYGRID” project partners. Additional generic data, for upstream processes like power supply or downstream processes such as waste treatment were taken from GaBi 6.0 and ecoinvent 2.0 databases.

As proposed by the FC Hy-Guide [4] Fig. 1 illustrates the subdivision in construction, operation, and end of life of the considered current and advanced alkaline electrolysis systems. Besides manufacturing of the elctrolyzer components the construction includes the assembly of system and its transport. Steel, copper, and cells are integrated into cell stacks. The cells inside these stacks are constructed in a “sandwich” formation, containing membrane, electrodes, gasket and cell frame.

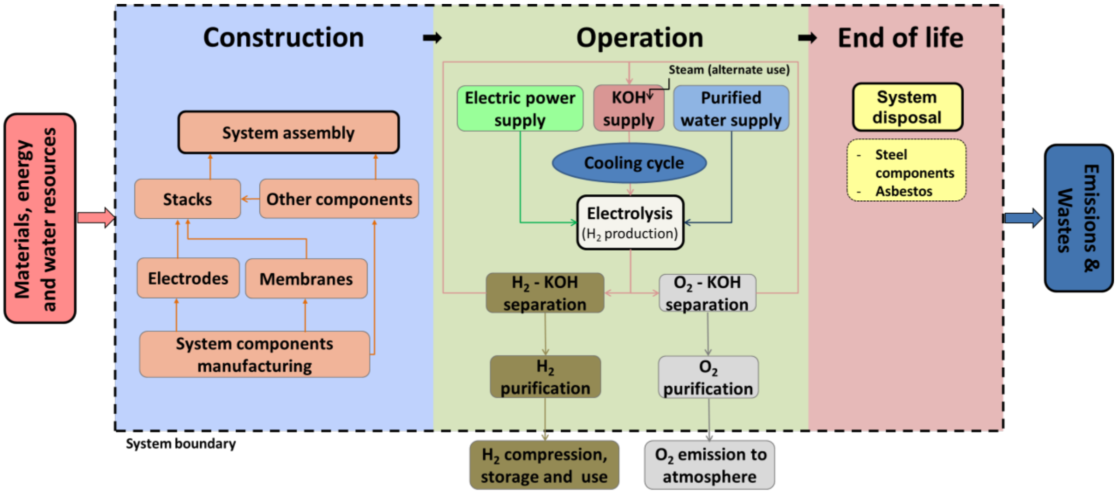


Fig. 1. System boundary and processes of considered alkaline water electrolysis systems

Beside the actual electrolysis process operation includes the necessary electricity and deionzed water supply, the cycles of KOH solution and cooling water. The calculations in this paper are based on electrolysis with Spanish wind power. Spain is chosen because it is the country where the new electrolysis system is tested. A KOH solution with a concentration of 25 % is used and disposed after 10 years. During this operation time the KOH solution can be used without conditioning. Moreover, deionized water is used for system operation. Around 10 l deionized water are required for the production of 1 kg H_2. While oxygen is emitted into the atmosphere, further compression and storage of hydrogen is not included in the system boundaries. A lifetime of 20 years is assumed.

The asbestos parts (mebranes and gaskets) and steel components are considered for disposal. As the disposal modalities of the new improved membranes are not finally clear, this disposal is not considered.

Three systems are distinguished within this LCA. Reference is a state-of-the-art 3,5 MW electrolysis system using conventional asbestos membranes (system I). The second system (II) includes the advanced polymer based membrane instead of the asbestos membrane. This system is assessed to evaluate the effects of changes on cell level solely. In addition, an advanced system, which is planned for commercial operation, including further BOP improvement (infrastructure changes), is analyzed (system III). These changes concern some pumps with enhanced power demand and optimized gas separators and heat exchangers. The system power of 6 MW is planned as commercial size of the advanced system. Essential technical parameters are summarized in Table 1.

Table 1. Technical characteristics of compared electrolysis systems

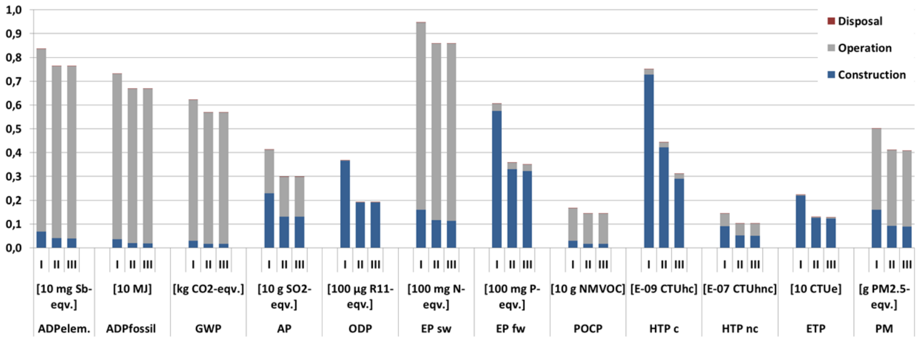
		Current-old System I	Advanced System without changes II	Advanced System with BOP improvement III
Membrane type	-	Asbestos	New improved membrane technology	
System power	MW	3.5	6	
Hydrogen output	kg/hr	68	116	
Number of cells per stack	pcs	139	139	
Number of stacks	pcs	4	4	
Total cell diameter	m	1.6	1.6	
Electricity consumption	$kWh_{el}/kg\ H_2$	57.3	53.9	
Operating pressure	bar	33	33	
Operating temperature	°C	85	85	
Volume of gas separator	l	10,000	10,000	5,000
Power of KOH cycle pump	kW	1.5	1.5	3
Power of di-ion. water pump	kW	10	10	20
Heat exchanger weight	kg	22,000	22,000	3,891

Concerning the construction the main difference of the systems is the membrane material. Moreover, there are additional improvements in the cell, like lower weights, for the advanced system cases. With regard to operation the system power and the resulting amount of hydrogen output are the main differences of the compared electrolysis systems.

As functional unit of all three investigated systems the production of 1 kg H_2 at 33 bar and 40 °C is used. The environmental impacts of the three systems are selected and calculated using ILCD recommendations [5].

3. Results

Results for the selected environmental impacts applied on the three system types and related to the functional unit of 1 kg H_2 are shown in Fig. 2. Beside absolute values of the entire systems, shares on construction, operation, and disposal are illustrated.



ADP elem.	Abiotic Resource Depletion Potential (mineral)
ADP fossil	Abiotic Resource Depletion Potential (fossil)
GWP	Global Warming Potential
AP	Acidification Potential
ODP	Ozone Depletion Potential
EP sw	Eutrophication Potential (saltwater)
EP fw	Eutrophication Potential (fresh water)
POCP	Photochemical Ozone Creation Potential
HTP c	Human Toxicity Potential (carcinogen)
HTP nc	Human Toxicity Potential (non carcinogen)
ETP	Ecotoxity Potential
PM	Particulate Matter

Fig. 2. Environmental impacts of entire electrolysis systems and single life cycle stages per kg H_2 produced

The two considered advanced systems show superior environmental performance in all impact categories in comparison to the system I. Results of advanced systems with or without BOP improvements are for most categories on a similar level. Disposal has a negligible influence on the impacts of the entire systems. In contrast, there is a split between impacts caused by operation or disposal. Some categories are dominated by operation, while others are dominated by construction. This trend is intensified if electricity with higher environmental impacts, e.g. the Spanish electricity mix, is used. Electrodes and cell frames, as cell construction components, embody nickel. Compounds of nitrogen and phosphorous are emitted during nickel production. While EP fw is caused by phosphorous compounds, nitrogen compounds affect EP sw. During nickel production more phosphorous as nitrogen compounds are emitted, provoking notable higher contributions to EP fw than to EP sw.

The results of a detailed analysis of the contribution of operation constituent parts are presented in Fig. 3 for system III as an example.

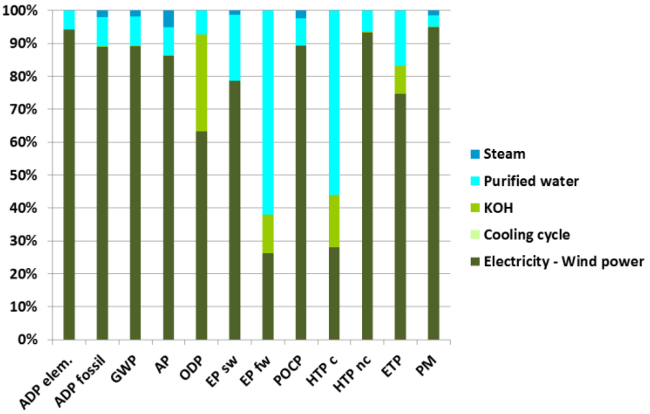
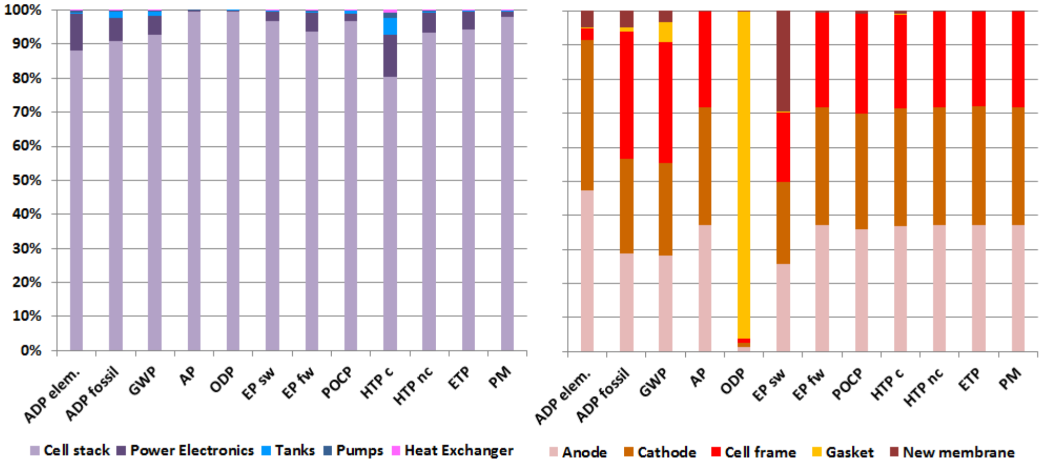


Fig. 3. Contributions of processes to impacts during operation – System III

As Fig. 3 shows, electricity supply clearly dominates environmental impacts in most categories. The most diviating data is given for EP fw, which is largely effected by the upstream processes of deionzed water supply. Purified water supply has the second highest contributions to most of the other categories. This is especially due to its energy-intensive production.

In addition the charts below show results of an in-depth analysis of different construction stages.



a) System construction **b) Cell construction**

Fig. 4. Contributions of processes to impacts during construction – System III

As can be seen from Fig. 4a), environmental impacts of the system construction are primarily caused by cell stack manufacturing. This trend is valid for all categories of the system construction. This also illustrates, why the BOP infrastructure changes are of subordinate importance for the ecological performance of the system. Inside the cell stacks the cells are main contributors of environmental impacts and therefore assessed in detail (Fig. 4b). The contribution of components to environmental impacts of the cell construction is diversified. Electrodes dominate the contributions to most environmental impact categories. This is primarily due to their high nickel contents. The use of nickel also affects the impacts of cell frames. This leads to typical contributions between 20%-30% for most categories. An obvious exception is the impact category ODP. The use of polytetrafluorethylene (PTFE) in the gasket production has a significant impact on ODP. Hence, the gasket contributes to over 95% of the ODP impacts. The new improved membrane technology has relatively small contributions to most impact categories. Only exception is given for EP sw, where the membrane contributes to 30% of the impacts. This is affected by the use of a special amide for the membrane production. In contrast, an analysis of impacts on cell level of the current-old system shows higher impacts by the asbestos membrane. The share of asbestos membranes on environmental impacts on cell level typically ranges from 25%-35 %.

4. Discussion and Conclusions

This study set out with the aim of assessing the environmental impacts of improved alkaline water electrolysis systems compared to systems using asbestos membranes. Systems with new advanced polymer based membrane technology show superior environmental performance. Results of this investigation show slightly dominating contributions of the operation phase on ecological impacts.

Impacts of the operation are to the largest extent caused by the electricity supply. Therefore, the lower specific electricity supply of the new improved membrane technology is the main reason for being advantageous against the current-old system. A major finding for system construction is the dominating contribution of cell stacks to impacts caused during construction. Furthermore, new improved membranes have a relatively small contribution to the environmental performance of the system. These findings enhance the knowledge about ecological aspects of high pressure alkaline water electrolysis systems and their components. Some bordering topics, like integration of specific data from local wind energy plants, hydrogen storage, and different hydrogen applications within the system boundary are not included in our assessment. Further research taking theses aspects into account might explore additional valuable insights.

5. Copyright

Acknowledgements

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Biography

- Education: Engineer in Environmental Technology and Ressource Management at the Ruhr-Universität Bochum, Germany
- Professional career: Scientist of the Institute of Energy and Climate Research - Systems Analysis and Technology Evaluation (STE), Forschungszentrum Juelich, Germany
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Appendix A. An example appendix

Authors including an appendix section should do so after References. They will be ordered A, B, C etc.

A.1. Example of a sub-heading within an appendix

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