LCA of Fuel Cell Technology for Urban Transportation System in Europe and Australia

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Abstract

The use of fuel cell technology for urban transportation system in Europe and Australia is demonstrated through the projects CUTE, ECTOS and STEP. This paper gives an overview of these projects and respective characteristics. The department of Life Cycle Engineering of IKP, University of Stuttgart and PE Europe will perform a life cycle analysis of this new technology together with the needed infrastructure. This paper focuses on the LCA of the various forms of hydrogen supply.
Keywords: Fuel Cell, Sustainable transportation, Sustainability, LCA

Purpose of the work

CO_2 emission reduction according to Kyoto Protocol, the enforcement of even stricter European legislation in the reduction of traffic related emissions and the necessity to improve the urban air quality have been imposing the rethinking of energy policy. With this purpose, the CUTE (Clean Urban Transport for Europe) [1], [2], ECTOS (Ecological City Transport System) (both EC funded) [3] and STEP (Sustainable Transport Energy for Perth) [4] projects were established to demonstrate the use of fuel cell technology with hydrogen as fuel as an almost emission-free, low noise and high efficient transport system in public transportation. In a short term the projects aim a resource saving mobility and in a long term, mobility based on non-fossil fuels. In this project frame, this paper focuses on the Life Cycle Assessment (LCA) of the various forms of hydrogen supply: hydrogen production from water via electrolysis and production from natural gas via steam reforming, employed both in Europe and in Australia. Also, the influence of local factors is discussed.

Approach

In order to verify the environmental friendliness of the new system as well as to evaluate the resource saving provided, an analysis over the entire life cycle is assessed. Using the LCA according to the ISO 14040 series [5] the entire systems life cycle (including hydrogen supply infrastructure and fuel cell bus system) is analyzed with respect to ecological aspects. Despite of the favorable environmental profile of the Fuel-Cell bus system in the use phase, in the hydrogen supply phase, the shift of emissions from operation to fuel supply are investigated. Due to the relevance of this phase, this paper will focus on the hydrogen infrastructure with its various options.

The LCA quantifies the emissions and the demand of renewable and non renewable resources related to the bus systems investigated. Moreover, it takes the local boundary conditions into account. For example, the environmental profile of diesel produced in Germany is different from the diesel produced in Spain or Australia due to the different crude oil supply and refinery technologies.

The final results of the LCA provide a picture of the environmental performance of fuel cell technology under a variety of operating conditions and over its complete system life cycle. With the database generated, the most energy efficient and environmentally competitive hydrogen production methods under country specific conditions as well as optimization potentials can be identified.

In this paper, the two main hydrogen production paths (electrolysis and steam reformer) will be analyzed for the German case.

Scientific innovation and relevance

Urban transportation today is based directly or indirectly on fossil-based fuels. In this context, a new technology for public transportation is under investigation in Europe. Compressed natural gas for combustion engines and hydrogen for fuel cells are possible alternative fuels to gasoline and diesel for mobile applications. For fleet applications a hydrogen supply infrastructure can be considered technically feasible and for vehicles, the storage of compressed hydrogen is also possible. The analysis of the different possible supply routes with different boundary conditions allows the selection of the promising technologies for the future.

With the support of the European Commission and the Western Australian Government, the 3 above mentioned projects include 10 European metropolitan areas in 8 European countries and 1 city in Australia, demonstrating together 33 FC buses in daily operation during 2 years. More than 50 Australian and European companies and universities are included and 11 different hydrogen supply infrastructures are set up by leading global infrastructure companies. Together they consist the world's largest fuel cell demonstration fleet for transport applications, providing a unique database for the holistic development of scenarios for fuel cell bus fleets. (Figure 1). Over 21 millions Euro of public funding are involved in these projects.

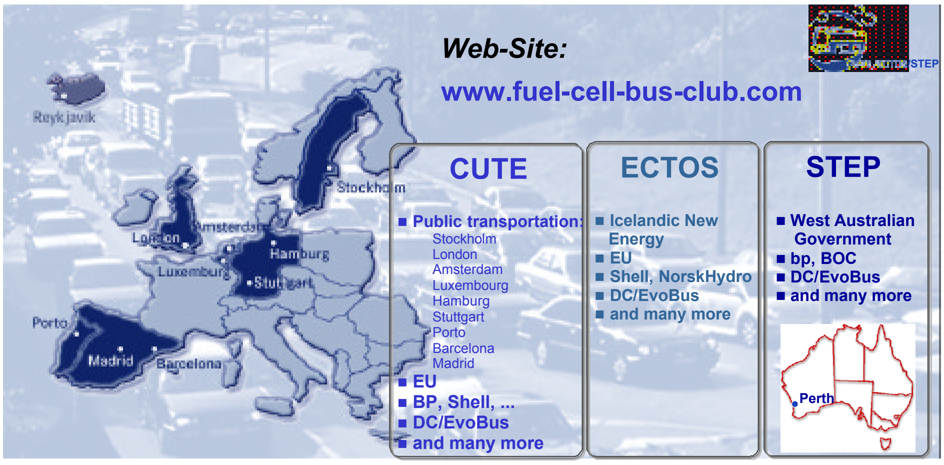

Figure 1 – Project partners of the European and Australian Bus Demonstration Programs

Results

Hydrogen Infrastructure

As part of these projects, different hydrogen infrastructures were installed at all 11 sites. The installations were determined according to the suitable local conditions. Table 1 gives an overview of these infrastructures.

Two main distinctive features can be mentioned: the production of hydrogen using centralized and decentralized facilities according to the chosen hydrogen production path (electrolyser/steam reformer/other chemical processes) and the selection of the energy carrier for hydrogen production (production of electricity from renewable or non renewable resources/natural gas/ crude oil).

Table 1 – Hydrogen Infrastructure at different sites

	Hydrogen Production Path	Technology turn-key supplier	Compressor type	Compressor rated capacity in Nm ^{3}/h	Compressor manufacturer	Storage size in kg hydrogen	Refuelling type	Dispenser supplier	Filling time in min	Interval between 2 buses in min
Amsterdam	electrolysis	Hoek Loos	hydraulic	300	Linde	250	overflow + booster	Linde	15	0
Barcelona	electrolysis	Linde	hydraulic	300	Linde	150	overflow + booster	Linde	10	before 3rd bus: 60 (or slower refuelling of 3rd bus)
Hamburg	electrolysis	Norsk Hydro Electrolysers	diaphragm	62	Hofer	400	overflow	Brochier	< 10	0 [3]
London	external [1]	BOC	cryogenic pump	900	ACD Cryo	3200	vapourisation of pressured LH$_2$	Fueling Technologie Inc.	30	0
Luxembourg	external	Air Liquide	diaphragm	60	Burton Corblin	500	overflow	Air Liquide	10	0
Madrid	steam reformer + external	Air Liquide	diaphragm (two)	50 and 2400	PDC Machines Inc.	360	booster	Air Liquide	9 / 11 / 13 20-25 [3]	0
Porto	external	Linde	hydraulic	300	Linde	174	overflow + booster	Linde	10	before 3rd bus: 60 (or slower refuelling of 3rd bus)
Stockholm	electrolysis	Stuart Energy Systems	1 piston, 1 hydraulic	525	CompAir and Hydro Pac	95	booster	Fueling Technologie Inc.	20-25	0 [4]
Stuttgart	steam reformer	Mahler IGS	hydraulic (two)	100 and 5380	Idro Meccanica	281	overflow + booster	Brochier	< 15	0
Revkjavik	electrolysis	Norsk Hydro Electrolysers	diaphragm	62	Hofer	400	overflow	Brochier	< 10	0
Perth	external	BOC	hydraulic	300	Linde	500	overflow + booster	Linde	10	0

[1] London: details for supply of liquid hydrogen given, as planned to start by the end of 2004; currently gaseous supply
[2] There is a fourth bus in Madrid, operating within the EU-founded project CityCell
[3] Hamburg: up to 120 min when taking in maximum capacity
[4] Stockholm: interval between second and third bus 8 hours due to limited storage size

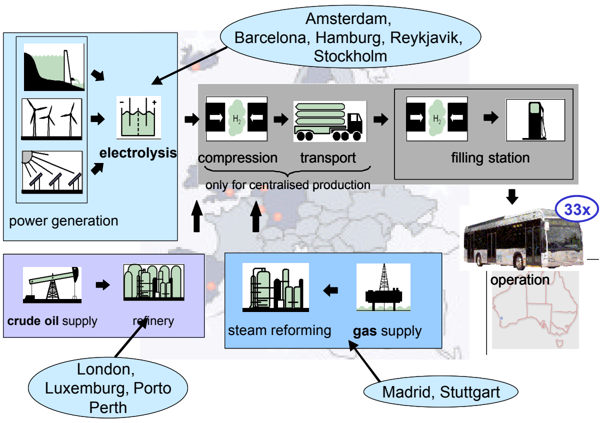

Figure 2 – Infrastructure for hydrogen supply

LCA of the Hydrogen Infrastructure

As mentioned previously, LCA comprises every life cycle step of the system analyzed. At first, the goal and scope of the study is defined. With the in- and outputs of many different substances covering the investigated system, an inventory is formed. Based on these data, the impact assessment can be carried out: emissions are aggregated in impact categories according to their potential impact on the environment. [5]

Goal & Scope

The goal of the study is the LCA of the hydrogen supply via different production paths for the German case. The complete life cycle of the system as well as the system boundary are shown in Figure 3. The operation of the fuel structure is included for the investigated bus system. The most relevant point for the electrolyzer is the source of electricity used. Therefore different electricity supplies are analyzed: German power mix, wind power with generally a windmill located inland and hydropower. The complete system was modeled using the LCA software GaBi 4. [6]

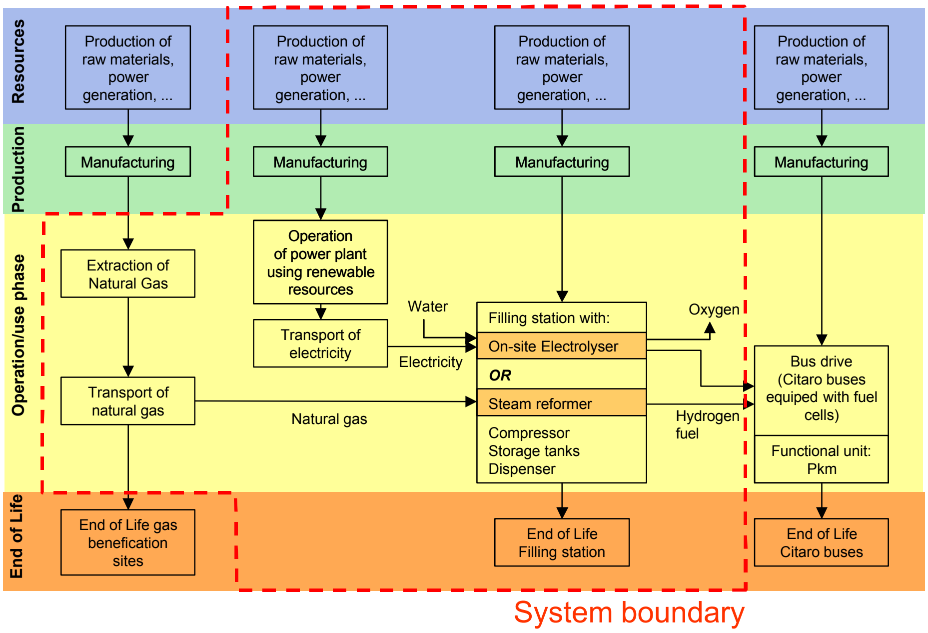

Figure 3 – The life cycle of the FC bus system including system boudaries of the LCA study

LCA Results

Results of the hydrogen production are presented here. [7] is also an important source of reference. The main advantage of renewable electrical power becomes obvious in comparison to non-renewable energy resources for the electrolysis. Grid power cases present the highest energy demand and higher emission values (Figure 4). Steam reforming of natural gas is positioned between electrolysis using grid power and the one using renewable resources. So it can be said that the power source for electrolysis is decisive for the environmental profile of the whole system. In terms of life cycle, the manufacturing phase becomes relevant for renewable resources. However the overall emission figures are significantly lower (Figure 5). The negative values in the End-of-Life (EoL) phase represent the credits given for the recycled materials of the H_2 infrastructure.

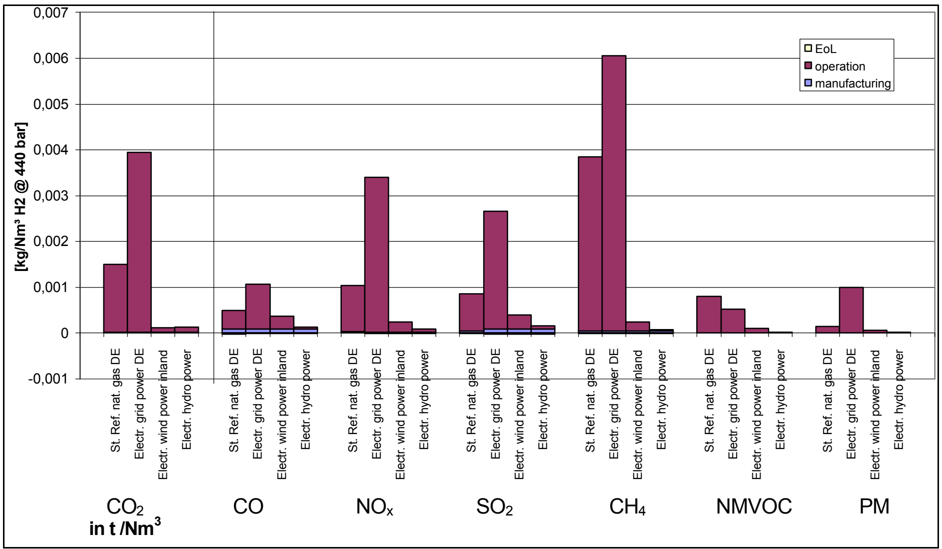

Figure 4 – Emissions to air for producing 1 Nm^3 hydrogen compressed to 440 bar, including the life cycle of the H_2 infrastructure components.

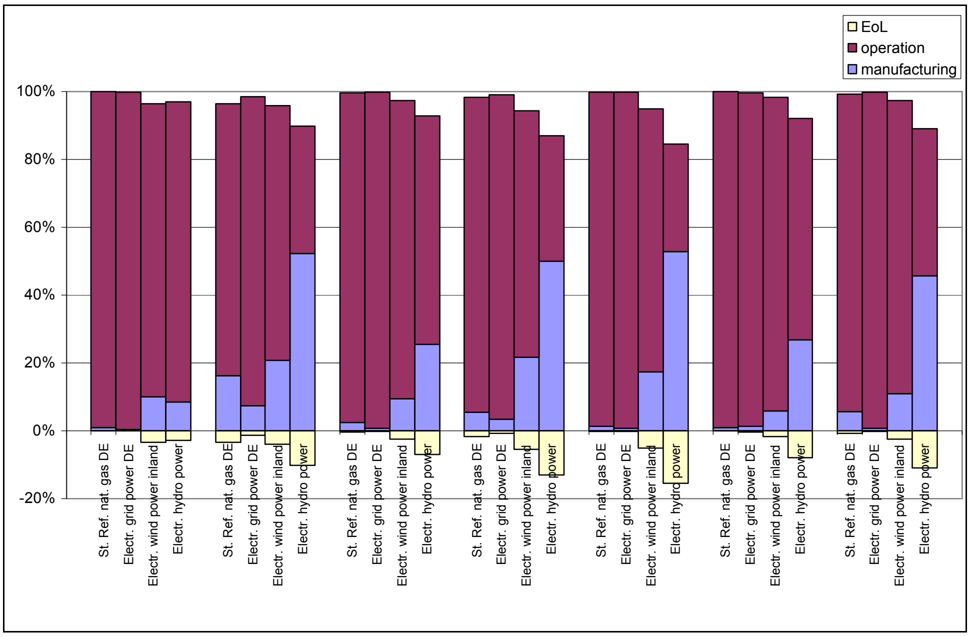

Figure 5 – Relative distribution of emissions to air among the different life cycle stages for producing 1 Nm^3 hydrogen compressed to 440 bar, including the H_2 infrastructure components.

Following the life cycle inventory, the impact assessment is performed. The impact categories considered are presented in Table 2. The impact potential of the H_2 supply paths are shown in Figure 6. Here also, electrolysis using electricity from German grid presents the highest environmental burdens followed by steam reforming using German natural gas mix.

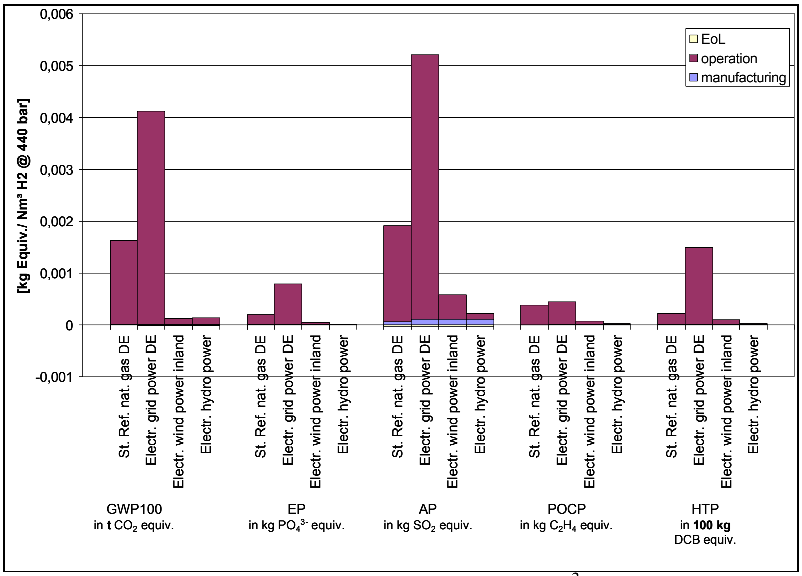

Figure 6 – Impact assessment of the production of 1 Nm^3 H_2 compressed to 440 bar

In this context, other important factors are the country specific energy supply chains. Taking the steam reformer case as an example, Spanish natural gas mix was used instead of the German one. Results can be seen at Figure 7. The EP shows a 30% increase related to higher NO_x emissions from diesel generators and flaring in the natural gas importing countries, mainly Algeria which has a 60% share of the Spanish natural gas mix transported as LNG. The decrease in POCP relevant emissions is related, among other things, to the leakage losses during the pipeline transport of Russian natural gas to Germany (1,5% total loss is assumed).

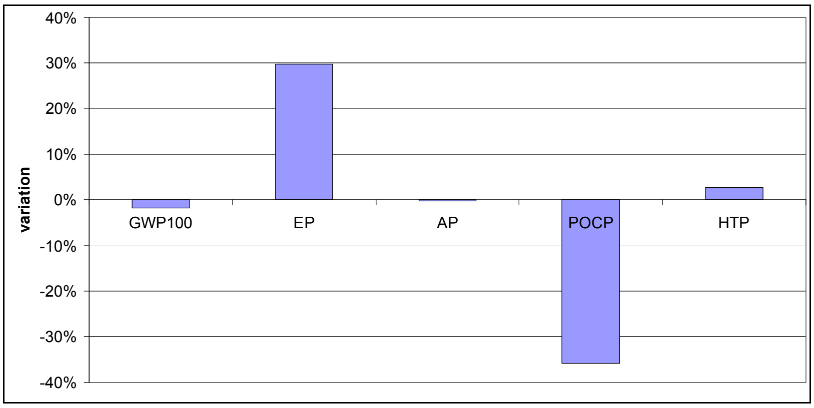

Figure 7 – Variation of the environmental impact for hydrogen produced via steam reforming using Spanish natural gas

Table 2 – Overview of the impact categories

GWP	**G**lobal **W**arming **P**otential [kg CO_2 equiv.], mainly caused by CO_2 and CH_4 emissions.
EP	**E**utrophication **P**otential [kg PO_4^{3-} equiv.], mainly caused by nitrogen emissions in water.
AP	**A**cidification **P**otential [kg SO_2 equiv.], mainly caused by SO_2 and NO_x emissions to air.
POCP	**P**hotochemical **O**zone **C**reation **P**otential [kg Ethene equiv.], mainly caused by hydrocarbon emissions to air.
HTP	**H**uman **T**oxicity **P**otential [kg dichlorobenzene equiv.], mainly caused by emissions from halogen organic compounds

Conclusions

The performance of a LCA can provide important information regarding the environmental performance of fuel cell bus system under varying boundary conditions. Weak-point analysis, optimization potentials and future targets can be defined by locating the main contributors to the environmental load and energy demand of the considered fuels. Based on these results decision support for public authorities, politicians and industry is given. It must be taken into consideration, that country specific conditions have shown to be a critical parameter for the environmental profile of the system in analysis.

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