Abstract

This study presents the environmental impacts of hydrogen and petrol production and use as energy for vehicles. The assessments using the Eco-indicator 99 (E) v 2.03 as indicator and Simapro v.06 Life Cycle Assessment software on both fuel were assigned and compared on: carcinogens, respiratory organics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuel,. The result shows the hydrogen is the preference from environmental perspective except for the acidification/eutrophication impact.

Key words: *environmental impacts, hydrogen, petrol, eco-indicator 99(E) v2.03, Simapro v.06*

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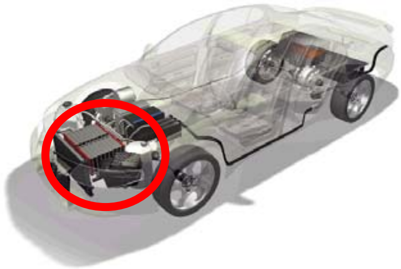
1.1 Background



Recent developments have been paving way for innovative ideas in the type of energy used in cars. Sources of energy for propelling cars come in diverse forms. More so, there have been great concerns about the usage of these fuel types that have great impact on the environment. Most cars are run on fossil fuel, but this has an adverse effect on the environment (Wikipedia, 2006)

This project work came about due to the dying quest of participants to help to find alternative solution to the use of fossil fuel powered engine in cars. The best option that comes to mind is the use of fuel cell engines. A fuel cell is an electrochemical energy conversion device similar to a battery, but differing from the latter in that it is designed for continuous replenishment of the reactants consumed; i.e. it produces electricity from an external supply of fuel and oxygen as opposed to the limited internal energy storage capacity of a battery. Additionally, the electrodes within a battery react and change as a battery is charged or discharged, whereas a fuel cell's electrodes are catalytic and relatively stable. Typical reactants used in a fuel cell are hydrogen on the anode side and oxygen on the cathode side-a hydrogen cell.

- Petrol

Oil wells are running dry; in the future we will see no more cheap high quality crude oil and the oil supply are increasingly reliance on politically unstable regions. From the environment point of view; the emissions produced by a petrol vehicle fall into two basic categories:

Tailpipe emissions:

This is what most people think about vehicle’s air pollution; the products of burning fuel in the vehicle's engine, emitted from the vehicle's exhaust system. The major pollutants emitted include:

1. Hydrocarbon: this class is made up of unburned or partially burned fuel, and is a major contributor to urban, smog, as well as being toxic.
2. Nitrogen oxides (NOx): These are generated when nitrogen in the air reacts with oxygen under the high temperature and pressure conditions inside the engine. NOx emissions contribute to both smog and acid rain.
3. Carbon monoxide (CO): a product of incomplete combustion, carbon monoxide reduces the blood's ability to carry oxygen and is dangerous to people with heart disease.
4. Carbon dioxide (CO_2): as a product of the complete combustion of hydrocarbons, this substance is plentiful in the atmosphere and has no immediate harmful effects to humans and essential to plant life. Emissions of carbon dioxide are considered a pollutant because it is a significant greenhouse gas and increasing its levels in the atmosphere is thought by many to be a contributor to global warming. (Wikipedia, 2006)

Evaporative emissions:

These are produced from the evaporation of fuel, and are a large contributor to urban smog, since these heavier molecules stay closer to ground level. Fuel tends to evaporate in these ways:

1. Gas tank venting: the heating of the vehicle as the temperature rises from the night-time temperature to the hottest temperatures of the day mean that petrol in the tank evaporates, increasing the pressure inside the tank above atmospheric pressure. This pressure must be relieved, and before emissions control it was simply vented into the atmosphere.
2. Running losses: the escape of petrol vapors from the hot engine.
3. Refueling losses: these can cause a lot of hydrocarbon vapor emission. The empty space inside a vehicle's tank is filled with hydrocarbon gases, and as the tank is filled, these gases are forced out into the atmosphere. In addition, there is loss from further evaporation and fuel spillage. (Wikipedia, 2006)

- Hydrogen

Compare with oil, hydrogen is an equal opportunity energy carrier. It solves foreign oil dependence and it is everywhere-"right in our backyard" with highest energy content per unit mass of all fuels.

From environment point, it is friendlier both during the generation and combustion.

Hydrogen can be made using energies of from wind, solar, geothermal, hydropower and biomass. And most important, the only emission when using on electric car is only water.

In this study, natural gas is used as raw material and the hydrogen is generated via stream reforming of natural gas which contains 94,5 % CH_4 (Spath, 2001).

1.2 The reason for carrying out the study and choosing LCA as the method

The number of vehicles running on the road is growing in a high speed in nowadays. What accompanying is the huge energy consumption and that in turns is the main factor for environmental impact, for example, the hot topic—climate change. A lot of environmentalisms have made ceaseless effort to save our planet to improve the living condition for human beings, to create sustainable ways for daily life. For the essential transportation tool—vehicles, if we have an environmental friendly way to solve the energy and emission problem it will defiantly contribute a lot. But how can we know which one is more friendly? How to make the comparison reasonable? The answer is LCA—it can help us to analysis the whole life cycle of these two alternative energies based on the scientific and reliable data.

1.3 Goal

The ultimate goal of this project is to compare the environmental impacts of hydrogen and petrol production and use as energy for vehicles by using the method of Life Cycle Assessment.

1.4 Methodology

SimaPro 6.0 software program is used to create the model of Life Cycle Assessment for both the alternative energies. The Eco-indicator 99(E) V2.03 is chosen in this study which taking into consideration eleven types of environmental impacts on carcinogens, respiratory organics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuel . The unit used :for carcinogens, respiratory organics, climate change, radiation, ozone layer is DALY (Disability Adjusted Life Years); for ecotoxicity, acidification/eutrophication, land use is PDF (Potentially Disappeared Fraction of

Plant Species); for minerals and fossil fuel is MJ (Mega Joule, surplus energy requirement to compensate lower future ore grade)

For Eco-indicator 99 method, "E" refers to the weighting set belonging to the egalitarian perspective. Egalitarian is the preference due to the long term perspective of the assessment and the valuation of all substance and impact categories are equal. The substances included are applied if the effects occur.

1.5 System Boundary

In this study, only the main differences during the production and combustion are taken into account. See the flow chat at figure 1.

- Crude oil extraction

  Crude oil extraction is the cradle for petrol production that is the first step that we take into consideration.

- Natural gas extraction

  Hydrogen is generated through stream reforming of natural gas. The natural gas extraction and its transportation are taken into account together with the energy use and emission during these two upstreams.

- Production (energy use and emission)

  The system included in the energy use and emissions during the production process of hydrogen (from natural gas as raw material) and Petrol (from crude oil).

- Distribution

  The energy use and emission from the transportation and distribution of hydrogen and petrol are considered in this system.

- Emission (combustion car engine)

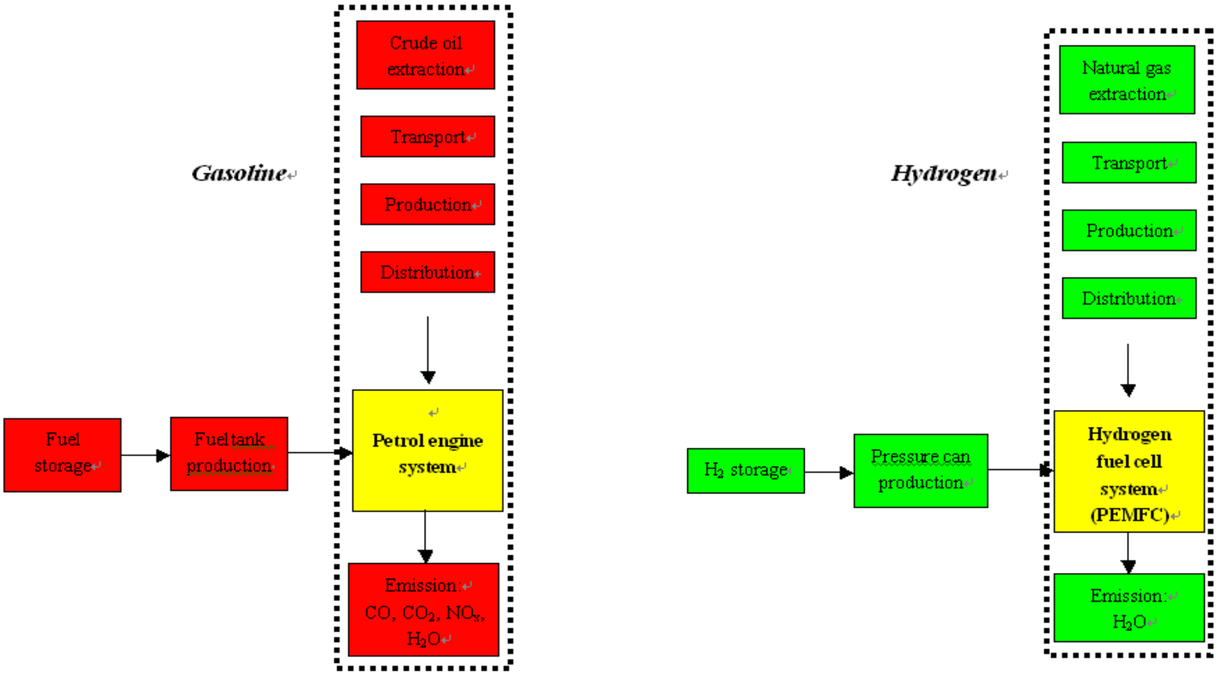


Fig 1. System boundary

1.6 Functional Unit

In automobile design, 100 km is the well commonly accepted as the unit to measure the fuel economy. Following this, the whole assessment of this study for both alternatives is based on the amount of fuel required to run a car for 100 kilometers. 1kg of hydrogen (Yi, 2005) and 10 liter of petrol (assumption based to the design experience) as detail unit are assumed to run a normal car for 100 km.

1.7 Assumptions and Limitation

The assumptions were however carefully made based on the reliable data to make the assessment possible and comparable.

1.8 Impact Categories

The main impact categories are: carcinogens climate change, respiratory organic, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals, fossil fuel.

1.9 Intended audience

Since driven by the increasing and the scarcity of oil supply, the invention of renewable energy has become major role in sustaining the intergenerational society. Even though the skeptical voice that this is too late due to the interest of major energy company's share holder to gain profit form the fossil fuel, the crisis has lead to invent other sources. Hydrogen as one of the option due to the zero emission (water vapor only) should be assessed. The Life Cycle Assessment of those two energy sources for running car will give holistic perspective for the energy policy maker, the car manufacturer, the energy company and one of the most important actor, the energy consumer.

2. Life cycle inventory analysis

2.1 Data collection and calculation--Hydrogen production and use

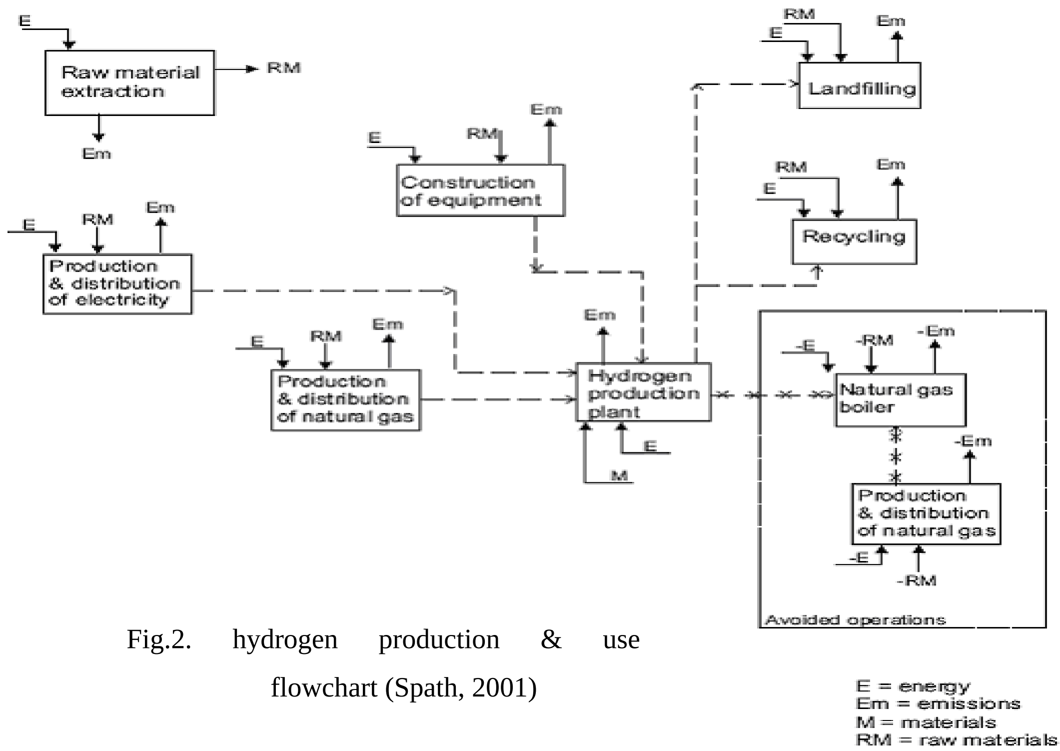


Fig.2. hydrogen production & use flowchart (Spath, 2001)

Hydrogen production and use is presented above. E, EM, M, RM stand for Energy, Emissions, Materials and Raw Materials respectively. The data is taken from the Life Cycle Analysis of producing hydrogen conducted by National Renewable Energy Laboratory (NREL), US Department of Energy Laboratory (Spath, 2001).

In this study, natural gas with the energy value 46,8 MJ in the ground is base material to produce hydrogen. The amount of natural gas required to produce 1k g hydrogen (with the respect to fulfill the functional unit) is 3642,3 grams (see table 1). The amount required for feeding is 2908 grams only in the h ydrogen production and use and 318 grams go as fuel in

Table 1. resource consumption for hydrogen production (Spath, 2001)

Resource	total (g/kg H_2)
Coal (in ground)	159.2
Iron (Fe, ore)	10.3
Iron scrap	11.2
Limestone ($CaCO_3$, in ground)	16.0
Natural gas (in ground)	3,642.3
Oil (in ground)	16.4

hydrogen generation. The 340 grams left is excluded from the total amount due to the assumption that natural gas contains only methane (in fact, it contains only 94,5 % with conversion rate from kg to m^3 is 1,528) (see the conversion in table 2). .

From the table 2, the input parameter for natural gas form the raw NREL data is converted to the functional unit.

Table 2. Conversion of required natural gas

	NREL data (Spath, 2001)	Equalization to 1 m^3 H_2	Equalization to functional unit
Hydrogen production	1,5 million m^3/day	1 m^3 H_2	1 kg H_2
Natural gas consumed	392 Mg/day (feed) 43 Mg/day (fuel)	261,3 grams 28,6 grams	2908 grams 318 grams

Other materials required are shown at table 1. The amount of iron and limestone cover only the requirement of construction and decommissioning, while coal covers also electricity production. The electricity required for the production is 153,311 MJ/day (Spath, 2001).

Table 3. Air emission from the production & use of hydrogen

Air Emission	System total (g/kg of H_2)
Benzene (C_6H_6)	1.4
Carbon Dioxide (CO_2)	10,620.6
Carbon monoxide (CO)	5.7
Methane (CH_4)	59.8
Nitrogen oxides (NO_X as NO_2)	12.3
Nitrous oxide (N_2O)	0.04
Non-methane hydrocarbons (NMHCs)	16.8
Particulates	2.0
Sulfur oxides (SO_X as SO_2)	9.5

The use of hydrogen does not include the storage tank to avoid the double counting from the Life Cycle Analysis of the car itself and emits its emission which has zero contribution to the environmental impact due the water vapor emission only

The air emission emitted from the production and use of hydrogen is shown at table 3. The main emission is the carbon dioxide which may contribute to green gas house effect. Other emission is the 201,6 grams coal ash/ 1 kg hydrogen from the energy generation to produce hydrogen.

The transportation to deliver the produced hydrogen from the plant to the fuelling station is assumed 200 km with 40 tons lorry and to deliver the natural gas with through pipeline is 18 km. Based on this, the unit to transport 1 kg of produced hydrogen is 0,2 tkm and 0,15 tkm.

The pipeline to transport the natural gas is the pipeline transport gas Norway with original German title: Transport Erdgas-Pipeline N (ETH-ESU 96 database, as included in SimaPro6). In this project steel pipelines with a diameter of 950 mm and a wall thickness of 10 mm are assumed. Around 240 ton steel per km pipeline is thus needed. Life time is assumed to be 50 years. Crude oil as the input for hydrogen generation or production (see table 1), crude oil is taken as the already transported one (Crude oil with original German title: Rohoel ab Ferntransport, transported, ETH-ESU 96 database as included in Simapro6). The transportation for crude oil is not required anymore to avoid double counting.

The end product of this hydrogen generation is not the pressurized one with the assumption that pressurizing should be conducted in the LCA of the fuelling station or the LCA of the car manufacturer to produce the hydrogen tank. Thus the pressurizing is excluded from the study.

2. 2 Data collection and calculation—Petrol production and use

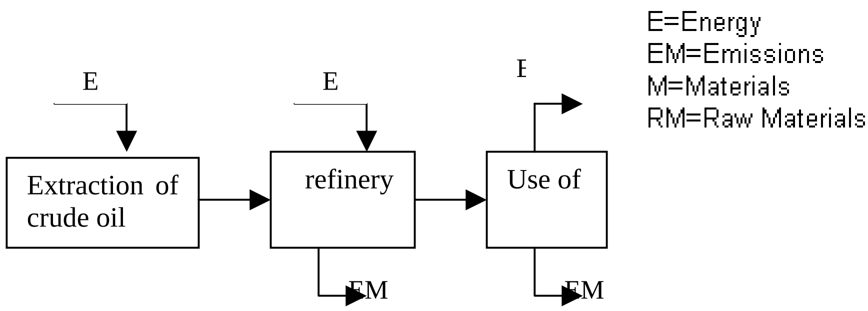


Fig. 3 production & use of petrol

The required data to conduct the impact analysis for petrol production and use was taken from the Simapro database, except for the emission. As the unleaded petrol is the widely common used in Europe, the Unleaded Refinery Europe S is chosen. The emission of the use/ combustion is based on EURO 4 passenger car petrol (wikipedia, 2006) and for carbon dioxide emission, the emission data is taken from the www.vcaccarfueldata.org.uk (see table 4)

Table 4. Petrol combusted emission

Emissions Categories	Unit	Emissions of combustion	Source
Nitrogen oxide	g/0.1 kg	0.08	EURO 4
Carbon dioxide	g/0.1 kg	140	www.vcaccarfueldata.org.uk
Carbon monoxide	g/0.1 kg	1	EURO 4

In order to compare with transportation of produced hydrogen, the transportation of produced petrol is done by the 40 tons lorry and with the distance 200 km. which is exactly the same with hydrogen.

The enormous amount of carbon dioxide is suspected as the major contribution for climate change impact. In the life cycle interpretation, this will be compared with the carbon dioxide emission from the production of hydrogen.

3. Life cycle interpretation

3.1 Assessment 1: Hydrogen production & use

The environmental impacts resulted by the production and use of 1 kg hydrogen is shown below in fig.3. Only processes with contribution more than 0,12% are indicated.

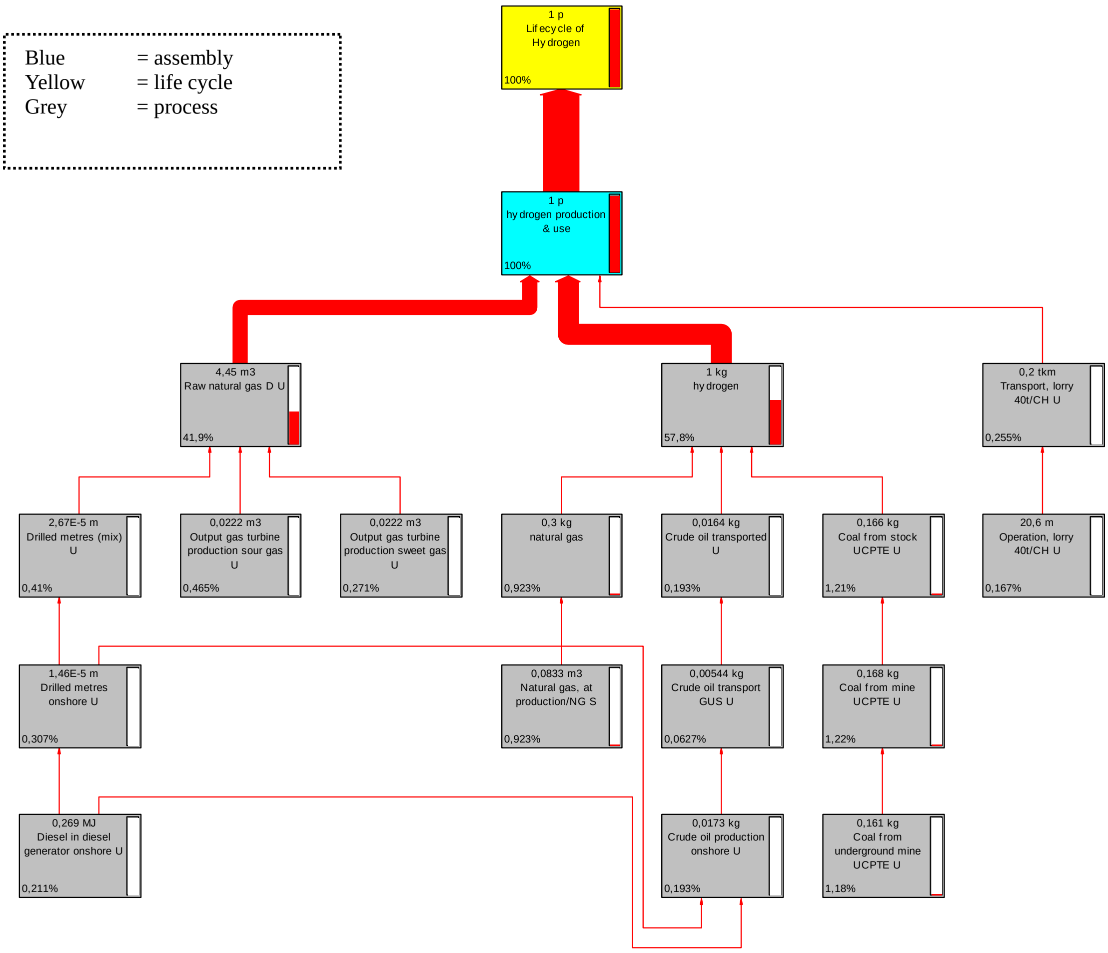


Fig 4. Process contribution to environmental impacts (single score) of 1 kg hydrogen production & use

The production of raw natural gas as the base material to produce hydrogen contributes 41,9% where as the hydrogen production itself contributes 57,8% of the total environmental impact. The transportation of the hydrogen produced to the fuelling station is considered very low even the assumption of the distance is far (200 km).

$$H2 + O2 \rightarrow \quad H2O + electricity$$

As mentioned in the inventory analysis, the input of the natural gas appeared twice in the model as the feedstock to produce hydrogen trough the streaming process and the fuel.
The flashlight point in this life cycle impact is the use of hydrogen that contributes zero to

the impact due to the product of combusted hydrogen is only water and the electricity.

3.2 Assessment 2: petrol production & use

For the environmental impacts of its 10 liter production and use are shown in fig. 4 with the processes contributes more than 0.17% are indicated

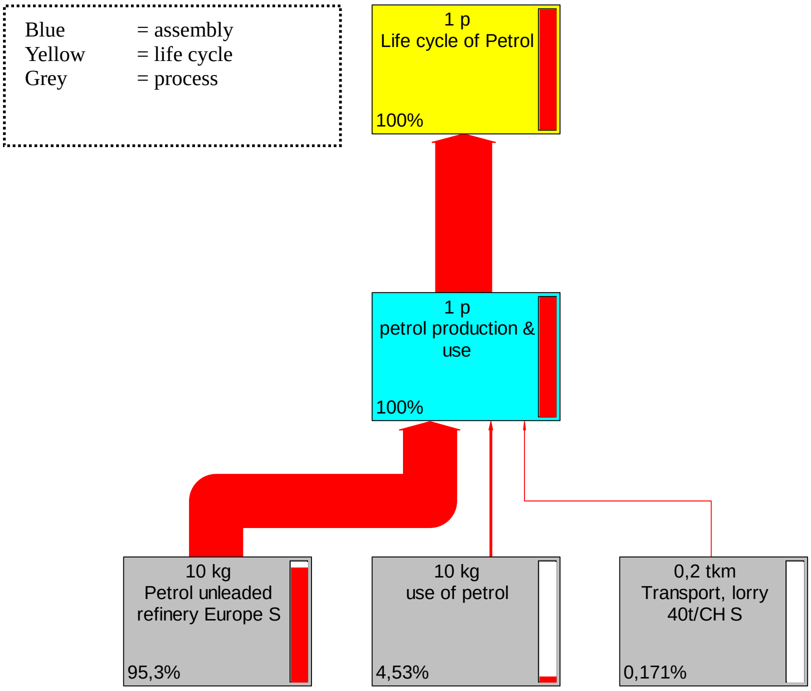


Fig 5. Process contribution to environmental impacts (single score) 10 kg petrol of production & use

The previous assumption for the environmental impacts for petrol was the use of it that contributes the most, but from the network analysis in fig. 4, the production acts as the major contributor (95,3%). The emission such as NOx and CO as the result of incomplete combustion and the CO_2 from fossil fuel combustion that contributes to the global warming are assumed to contribute less (4,53%) . Hydrocarbon particulate, CO and NOx that contribute to human and eco toxicity do not contribute as much as predicted previously.

The unleaded petrol was chosen to be compared with hydrogen as the respect to zero contribution of hydrogen emission to the impacts and European Union legislation S.I. No. 374/1986 for lead content of petrol.

3.3 comparative environmental impacts

3.3.1. Characterization

Eco-indicator 99 (E) v2.03 which is used in the analysis, characterized the impact to 11 impact categories: carcinogens, respiratory organic, respiratory inorganic, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuel.

Table 5. Characterization result

Impact category	Hydrogen production & use	Petrol production & use	unit
carcinogens	8,51E-8	3,57E-7	DALY
respiratory organic	2,55E-8	1,16E-7	DALY
respiratory inorganic	5,72E-6	7,31E-6	DALY
climate change	2,58E-6	4,82E-6	DALY
radiation	5,54E-10	2,32E-8	DALY
ozone layer	2,27E-10	5,56E-8	DALY
ecotoxicity	0,0528	2,36	FAF*m2yr
acidification/eutrophication	0,321	0,254	FAF*m2yr
land use	0,00473	0,00396	FAF*m2yr
minerals	0,00473	0,0287	MJ
fossil fuel	28,4	41,8	MJ

The result of the comparison shows that hydrogen production and use is considered as having lower environmental impacts. All impact categories except acidification/eutrophication justify the comparison result. The reason behind the higher impact on acidification/eutrophication for hydrogen is due the presence of NO_2, NO_x and the SO_2 in higher amount within the process. Those substances are the agent to form acidic material and excess of nitrogen that cause acidification and eutrophication. As shown below at table 6, the amount of extremely high NO_2 in and the slightly higher SO_2 in hydrogen process compensate the less amount of NO_x in acidification/eutrophication impact

Table 6. Substance contributes to acidification/eutrophication

substance	Hydrogen production & use	petrol production & use
NO_2	12,3 grams	1,16E-6 grams
NO_x	0,04 grams	0,8 grams
SO_2	9,5 grams	1,5 grams

The suspected carbon dioxide from the hydrogen production is still even less (almost a half) in the contribution of climate change impact. This is due to the use of the petrol that contributes much more in producing carbon dioxide.

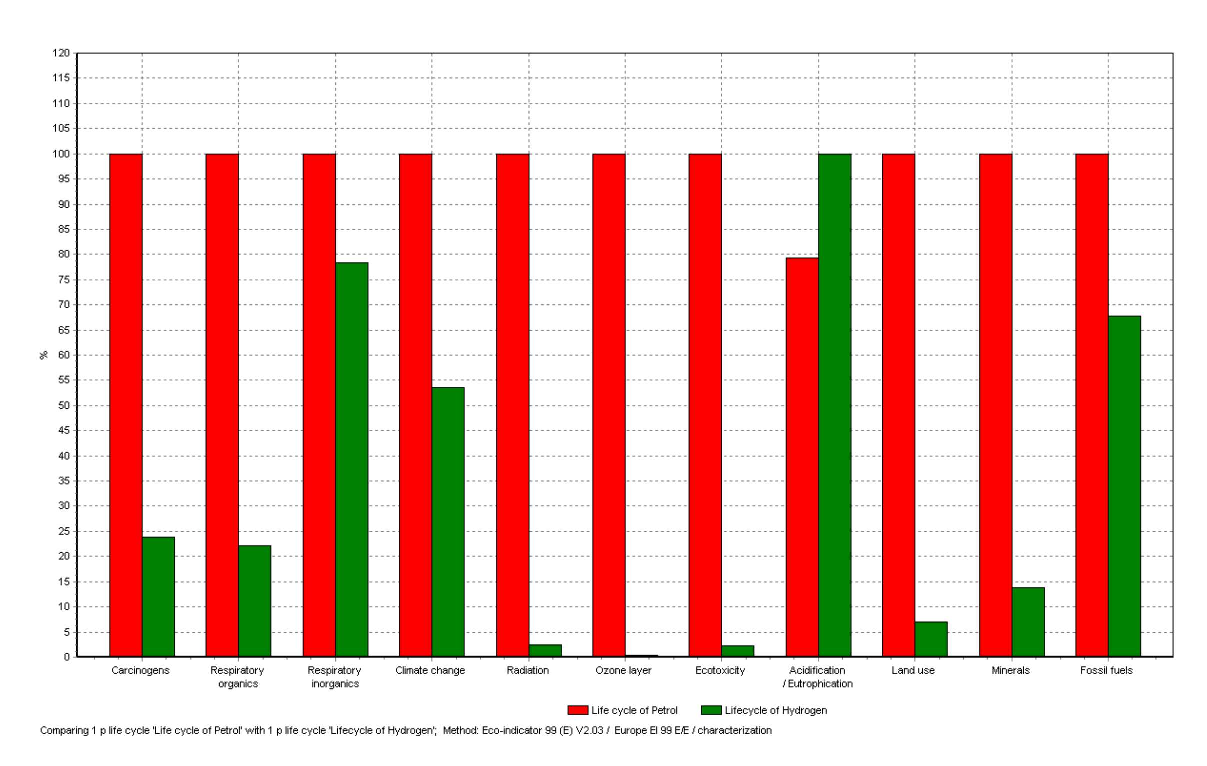


Fig 6. The characterization result in bar chart

3.3.2 Single score

The processes stage in fig. 4 and fig. 5 which contributed to the single score result, compiled all 11 impacts categories from characterization into single score for both processes. Each value from each category was calculated into a score and added to form the single score.

The single score result points out that fossil fuel use contributes the most for the environmental impact for both processes (81% for hydrogen and 82% for petrol). And, the final total score indicates obviously that the hydrogen production & use contribute less than the petrol production & use to the environmental impact (1,15 versus 1,71)

Table 7. Single score result

	Hydrogen production & use	production & use
Total single score	1,15	1,71

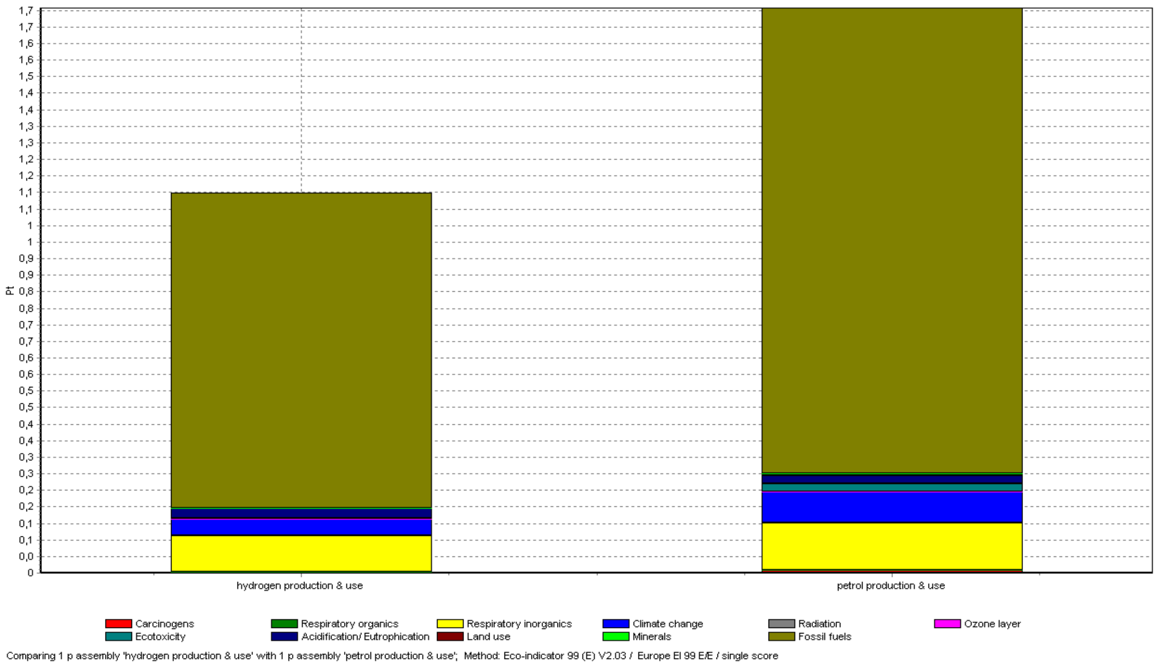


Fig. 7. Single score in bar chart

4. Conclusion and recommendation

From the assessment of these two alternatives, the contribution of hydrogen production and use to the 10 environmental impacts: carcinogens, respiratory organics, climate change, radiation, ozone layer, ecotoxicity, land use, minerals and fossil fuel are proven as less to the petrol production and use. The exception applies only in acidification/eutrophication due to the presence of NO_2, NO_x and the SO_2 in higher amount in hydrogen production.

As known broadly, hydrogen is much cleaner in the emission perspective. This LCA study gives additional important information regarding the production of it that also contributes to environmental impacts. The eutrophication/acidification impact mentioned above is the highlight impact that should be considered.

The technical barrier to expand the use of hydrogen for transportation will be the safety due to the high pressure requirement to reduce the volume. The acidification that is caused by the use of coal and fossil fuel as energy source should be reduced by not employing such those nitrogenic and sulfuric fuel. Improvement of this input will reduce acidification impact significantly.

Since hydrogen as the product is not the pressurized one, further LCA for fuelling station or car manufacturer that includes the pressurizing process should be conducted to give more practical information.

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