Weights and measures methodologies report – Deliverable 4.6.1

Summary

This report, corresponding to the task 6 of the work package 4 of HyTEC project, aims at describing two of the most developed methodologies currently applied to evaluate the cost of hydrogen delivery technologies and analysing the legislation and policy framework related to this topic.

Two models for weights and measure methodologies were analyzed. The Hydrogen Competitiveness Model, focused on measuring the fuel cost per kilometre in order to compare the hydrogen energy systems with competing fossil fuels. This model allows a comparison of the efficiency of energy systems, specifying a general system efficiency that covers all the transformation processes rather than each of them. The model includes in the cost the influence of energy related taxes, as well as the energy costs of fuel throughput, and transformation losses.

The second model analysed is the Hydrogen Deliver Components Model, which employs a different perspective when defining the main parameters related to weight and measures methodologies for hydrogen infrastructures. This cost contribution model is based on inputs provided by the user describing the amount of hydrogen to be delivered and basic capital and operating costs for the component. The model calculates the cost contribution of each component within the delivery infrastructure to the $/kg cost of delivering hydrogen. The influence of legislation in the cost of hydrogen energy system is not considered in the model.

The economic results that can be obtained from these models should be added to the analysis of other price fixation aspects.

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1. Introduction

For hydrogen to become widely used as fuel for private and public transportation, some fundamental problems must still be solved. These problems, present in all stages of hydrogen energy systems, are related to the optimization of efficiency in production, storage, delivery and use stage.

A kilogram of hydrogen has a high specific energy comparable to the energy contained in a gallon of gasoline, about 997 grams of gallon of gasoline equivalents (gge) (Paster et. al, 2011). Producing hydrogen, however, requires another source of energy. This major drawback can be counterbalanced by the high efficiency in the usage stage. In addition, pure hydrogen is a non-polluting fuel, producing only water vapour in the usage stage. Pollutants are allocated in those stages where hydrogen and other elements systems are produced (IUPAP, 2010).

When focusing on hydrogen-powered vehicles, the whole hydrogen energy system can be assembled in many ways. Thus, a reliable assessment of the potential use of hydrogen requires consideration not only of the system itself, but also in an appropriate combination of the system components. Different assembled systems will therefore impact differently in terms of economic and energy cost, energy availability, environmental pollution, safety and efficiency.

From an economical perspective the cost of delivering hydrogen is at present one of the barriers hindering its commercial uptake. Moreover, the relative inefficiency and carbon intensity of existing production and transmission routes weaken public support. Consequently, the analysis of hydrogen delivery alternatives is an issue to be taken into account in order to enhance the benefits of this energy vector.

The Hydrogen Transport in European Cities project (HyTEC) aims at implementing demonstration programmes focused on Fuel Cell (FC) vehicles uses, specifically addressing the challenge of transitioning hydrogen FC vehicles from running exemplars to fully certified vehicles utilised by end-users and moving along the pathway to providing competitive future products.

There are currently very few publically accessible hydrogen refuelling stations in Europe or a standardised weights and measures methodology to accurately determine hydrogen delivery quantities. Besides, the costs associated to the user have not yet been established.

To improve our understanding of technical and commercial viability of hydrogen to be used for transportation, it is important to examine the existing hydrogen delivery technologies. This report, corresponding to the task 6 of the work package 4 of HyTEC project, aims at describing two of the most developed methodologies currently applied to evaluate the cost of hydrogen delivery technologies and analysing the legislation and policy framework related to this topic.

The report is organized as follows. Section 2 describes the infrastructure for distribution and delivery of hydrogen, mentioning the pathways of the project, section 3 lists the most important documents on legislation and standards for hydrogen delivery technologies, section 4 explains the models used to define weight and measure methodologies, section 5 addresses the economic feasibility targets and policy framework, and finally section 6 gives the conclusions and final remarks.

2. Infrastructure for distribution and delivery of hydrogen

2.1. How is hydrogen delivered today (to hydrogen refuelling station)?

Refuelling infrastructures, such as the ones used in this project, are dependent on the hydrogen delivery technology, *i.e.* the processes needed to transport hydrogen from a central or semi-central production facility to the final point of use as well as its loading directly on to a fuel cell vehicle.

Hydrogen is produced from a variety of domestic resources; its production can take place in large, centralized plants or in a distributed manner, on-site, directly at fuelling stations. In the cases were hydrogen is centrally produced, delivery can be done in four possible ways (DOE, 2007):

- **Liquid Hydrogen Trailers**: Liquid hydrogen is transported in cryogenic truck trailers. The liquid hydrogen is off-loaded into liquid storage tanks at the fuelling station. Unlike compressed hydrogen tube trailer delivery, the trailer is not left at the fuelling station (Figure 1a)
- **Hydrogen Tube Trailer**: In this case, the compressed hydrogen is introduced in high-pressure tubes which are dropped-off at the fuelling station and used as on-site storage. Delivery includes picking-up an empty trailer and replacing it with a full trailer (Figure 1b).
- **Compressed Hydrogen Pipeline**: Hydrogen is distributed to fuelling stations through a pipeline network that operates at low pressure (20-60 bars). To avoid large upstream demand spikes, hydrogen is supplied continuously to the fuelling stations and compressed to high-pressure (225 bars) for immediate vehicle fuelling, or compressed to 175 bars for storage in buffer storage tanks (Figure 1 c).
- **Carrier transportation:** In this alternative, still under development, hydrogen is transported in a solid or liquid carrier (Figure 1 d).

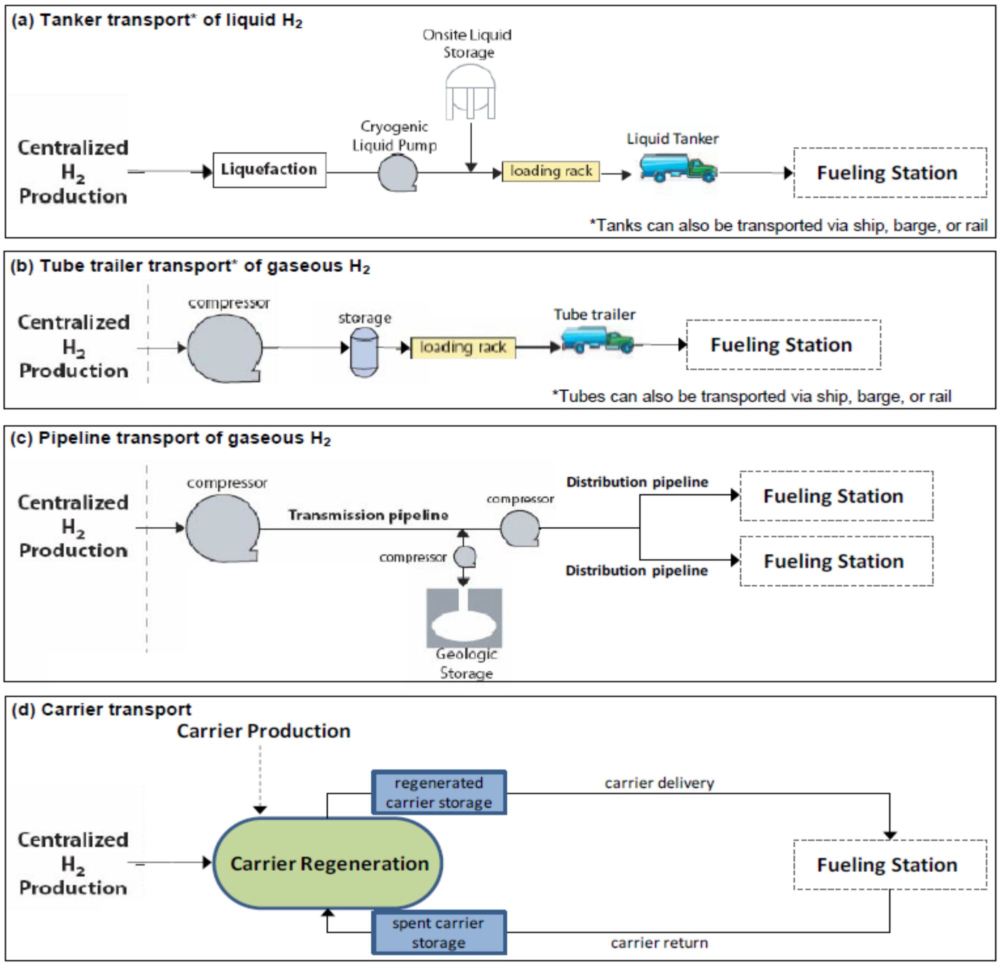

Figure 1 Typical hydrogen delivery options, (DOE, 2009)

2.2. Fuelling Stations

Hydrogen fuelling or refuelling stations are the final component in the hydrogen delivery infrastructure. In conventional (compressed or liquid) delivery scenarios, the fuelling station is likely to be formed by different components; the most important ones are the compressor, dispenser and the storage unit (either in low-pressure vessels or as components of cascade charging system).

Another type of stations is the “integrated fuelling station”; these stations are suitable for gaseous (containing integrated compressor, cascade compression/dispensing, and storage) or liquid hydrogen (containing integrated storage, vaporizer, and cascade compression/dispensing), shown in Figure 2 (DOE, 2009).

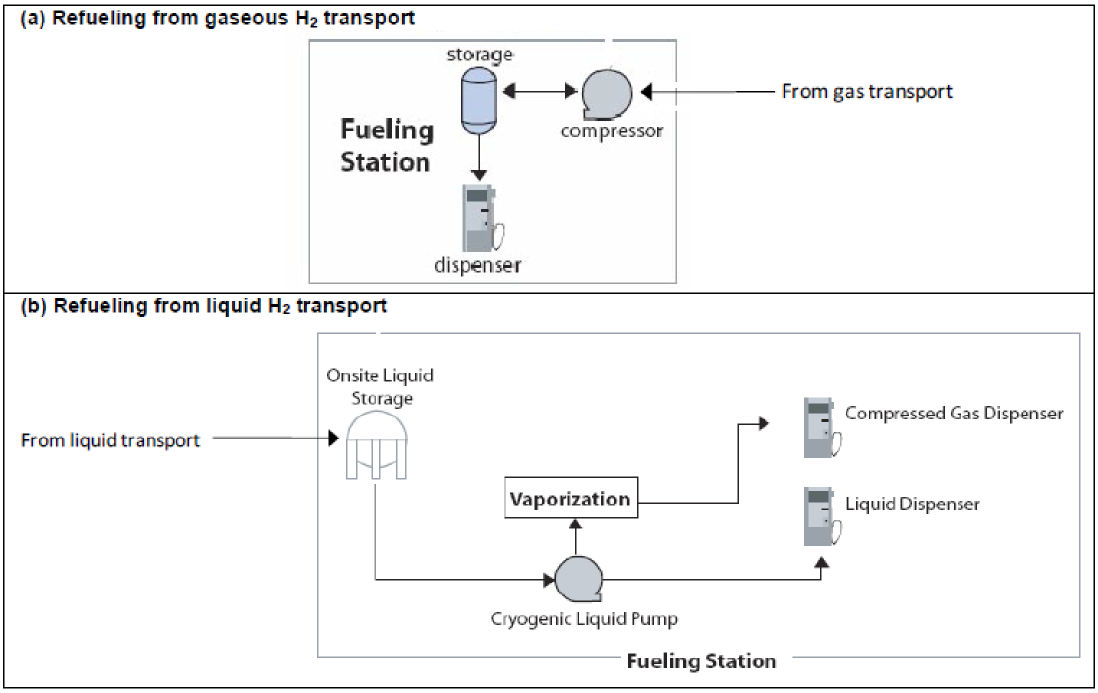

Figure 2 Typical hydrogen fuelling stations, (Source: DOE, 2009)

2.3.Hydrogen dispensing techniques

Also called fuelling operation procedures, is a very important phase of the delivery, where the hydrogen is transferred into the final receiving device (e.g., to an onboard storage tank).

2.3.1 Gaseous dispensing

Gaseous hydrogen is dispensed by means of a nozzle that is connected to the vehicles before pressurization (Figure 3). The filling process is done automatically when the vehicle and nozzle are connected. The hydrogen refuelling is done by fast filling, with a filling time ranging from 12 minutes for large vehicles down to 2-3 minutes for smaller vehicles. The only manual operations are the connection and the disconnection of the nozzle to and from the vehicle.

Figure 3 Filling of gaseous hydrogen, (Source: Hy Approval project, 2008).

Three options are available for transferring the hydrogen into the vehicle tank:

1. Direct compression from a low pressure source without employing gaseous hydrogen buffers.
2. Pressure difference from a gaseous pressure vessel, brought to site (tube trailer or cylinder pack). With hydrogen typically stored at 200 bar.
3. Pressure difference from a high pressure gaseous buffer, previously filled by compressing hydrogen from a source at lower pressure (e.g. tube trailer or on-site production).

Buffer systems consist of pressure vessels at different pressures for cascade filling; dispensing starts from the lowest pressure source and finishes with the highest pressure source in order to optimise efficiency). The buffers store the hydrogen at 400-500 bar for 350 bar refuelling and 850-1000 bar for 700 bar refuelling.

2.3.2 Liquid dispensing

Liquid hydrogen is dispensed by an automotive coupling that is fixed to the vehicles before refuelling (Figure 4). The filling process is done automatically. The normal filling time for an 8 kg storage size is about 5 minutes. Manual operations involve connecting and disconnecting the nozzle to the vehicle.

The stationary liquid storage tank can be arranged as a vertical or horizontal column tank above or beneath ground. Typical tank storage conditions are 20 Bar and approximately 25 K. The liquid hydrogen is supplied directly from the liquid storage to the dispenser by using a transfer pump. The maximum flow capacity of the pump is around 0.05 kg/s. The pump raises the pressure from the tank to a refuelling pressure of approximately 50 bar.

Figure 4 Filling coupling for liquid hydrogen, (Hy Approval project, 2008).

2.4.Possible pathways used in the HyTEC project.

The HyTEC project involves the deployment of fuelling networks and the improvement over the state of the art of the existing fuelling stations in the UK and Denmark. This project will connect existing fuelling stations within a city, initiating a city-wide refuelling network.

For the network in London, Air Products is developing a fleet of hydrogen delivery vehicles capable of delivering high-quality, high-pressure hydrogen to a fuelling facility, thereby minimising the need for further compression at the location. These include a novel liquid hydrogen tanker, which has an on-board vaporiser and compressor capable of delivering hydrogen to the site as liquid or as high pressure gas, and a high pressure composite tube trailer which can dispense high pressure hydrogen into banks of hydrogen cylinders at a filling station.

These vehicles are able to supply high pressure hydrogen to the London’s filling station network, thereby minimising the use of compressors. The challenge is to develop compressed hydrogen transportation to the point where delivery vehicles are filled with either high pressure hydrogen or liquid hydrogen. Compressors can be completely avoided for filling up to 350 bar. For higher pressures (e.g. 700 bar), a small on-site compressor will be required.

Figure 5 illustrates the design of new concepts for the logistics of fuelling network across London. Table 1 describes the characteristics of the existing hydrogen refuelling stations in London.

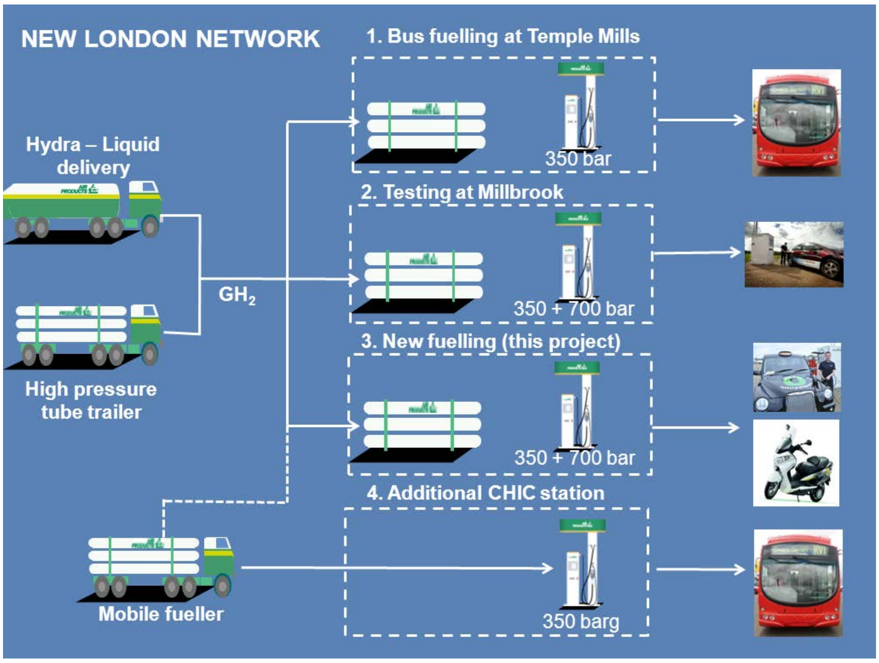

Figure 5 HyTEC delivery pathways for London’s network refuelling stations.

Table 1 Characteristics of London hydrogen refuelling stations related to the HyTEC project.

Location	End user group	Vehicle type	Potential	Capacity	Station type
Lea Interchange, Temple Mills, East London	Transport for London, 8 buses + scope for expansion of the bus fleet	Buses (can also refuel cars and vans) @ 350 bar	Can refuel up to 30 buses without additional capital.	Up to 320 kg/day	Delivered liquid H_2, 350 bar
Sustainable Institute Park Dagenham Docks, East London	Buses, additional fuelling, Olympics fuelling	Buses, cars and vans @ 350 bar	Aim >300kg useable storage	>50kg/day	Delivered gaseous H_2
Millbrook test facility	Passenger cars, vans scooters etc. for testing	All H_2 vehicles, 350 and 700 bar	Modular facility with scope for expansion to 200kg.day	>50kg.day	Delivered gaseous H_2

In the case of Denmark, the focus is on ensuring a fully renewable-based and energy efficient provision of hydrogen for the refuelling stations. In this project, emphasis will be on onsite production, as onsite generators can be powered with renewable electricity thereby avoiding the energy losses incurred in the distribution of hydrogen.

Hydrogen transport activities in Denmark follow a detailed plan on ensuring the deployment of a countrywide network of hydrogen refuelling stations by 2015 which will enable driving on hydrogen all across the country with a maximum distance between two stations of 150 km and of 15 km in the larger cities, including Copenhagen. Furthermore, in Copenhagen a network of fuelling stations will be established comprising 5 stations with a combined capacity of at least 200 kg/day. The first station will be established and operated by Copenhagen Energy early in the project to ensure availability of 700 bar and SAE refuelling for the FC vehiclesTable 2. The remaining stations will be established later in the project to link with expected vehicle deployment activities from major car manufacturers around 2013 and onwards.

Table 2 Copenhagen hydrogen refuelling station- Technical specifications

Specification parameter	Expected performance
Refuelling pressure	700 bar
Instant Refuelling capacity	14 kg (1hou)
Daily refuelling capacity (24 hour)	50 kg
Refuelling time	3 minutes
Refuelling nozzle	TK 17 for 700 bar
Fuel quality & composition	SAE 2719
Control & Refuelling	SAE J2601
Mass flow metering	Yes
Start/Stop	Key card
Hydrogen Supply	Onsite partial Hydrogen production Trucked-in back-up/peak supply
IR communication	SAE J2799
SAE refuelling level	A-level (minus 40 degrees)

3. Legislation and standards for hydrogen delivery technologies

The intention of this section is to give an overview of relevant regulations, standards and codes affecting the different stages of hydrogen delivery, which may be a barrier for market adoption of hydrogen delivery technologies. Some of these regulations, standards and codes are exclusively aimed at hydrogen installations and some are of a much more general nature, but should be taken into account when using the different delivery pathways. Examples of the latter are the Pressure Equipment Directive (PED), Transportable Pressure Equipment Directive (TPED). As an addition to these general directives, the ATEX directives, also known as (ATEX 95 and ATEX 100) and the ATEX User Directive (also known as ATEX 137), regulate the design and manufacturing process of equipment developed for use in explosive atmospheres in order to ensure proper quality standards, while the user directive is focusing on risks to the health and life of workers at a facility where explosive atmospheres may be present (Hy-SAFE, 2007).

The International Organization for Standardization (ISO) codes that should be considered when analyzing hydrogen delivery pathways are:

- The standard ISO 13984:1999, which deals with the design and installation of liquid hydrogen fuelling and dispensing systems. It specifies the characteristics of liquid hydrogen refuelling and dispensing systems on land vehicles of all types in order to reduce the risk of fire and explosion during the refuelling procedure. It aims to provide a reasonable level of protection from loss of life and property.
- The standard ISO 17268:2012, which deals with design, safety and operation verification of refuelling connection devices for a Compressed Hydrogen Surface Vehicle, CHSV. It applies to nozzles and receptacles which (i) prevent hydrogen fuelled vehicles from being refuelled by dispenser stations with working pressures higher than the vehicle, (ii) allow hydrogen vehicles to be refuelled by dispenser stations with working pressures equal to or lower than the vehicle fuel system working pressure, (iii)

prevent hydrogen fuelled vehicles from being refuelled by other compressed gas dispensing stations, and (iv) prevent other gaseous fuelled vehicles from being refuelled by hydrogen dispensing stations.

The Society of Automotive Engineers, SAE, provides a series of standards that applies to hydrogen systems:

- The SAE J2601, Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles, which establishes safety limits and performance requirements for gaseous hydrogen fuel dispensers. The criteria include maximum fuel temperature at the dispenser nozzle, the maximum fuel flow rate, the maximum rate of pressure increase and other performance criteria based on the cooling capability of the station's dispenser.
- The SAE J2600, which defines the connector requirements for fuelling vehicles operating with a nominal working pressure of 350 bar.
- The SAE TIR J2799, which defines the mechanical connector geometry for fuelling vehicles to 700 bar and also provides specifications for the hardware for vehicle-to-station dispenser communication.

These documents apply to light duty vehicle fuelling for vehicles with storage capacity from 1 to 10 kg for 700 bar and 1 to 7.5 kg for 350 bar.

The International Organization of Legal Metrology (OIML, in French) 139 -R- 2007 specifies the metrological and technical general requirements for dispensing technologies, applicable to measuring systems for compressed gaseous fuel for vehicles, in the stages of approval, initial verification and subsequent verifications. It also provides requirements for the approval of constituent elements of the measuring systems (meter, etc.).

Finally, the National Institute of Standards and Technology (NIST) published the Handbook 44 code requirements for the hydrogen dispensing facilities (2007) which apply to hydrogen refuelling equipment used for bulk sales.

4. Quantities delivered and associated costs

In order to compete with alternative transportation and power generation technologies for powering vehicles, the development of hydrogen technologies that needs to be conducted in parallel with defining a methodology for evaluating the associated costs.

The general principle for weights and measures requirements is to provide accurate measurement in commercial transactions that can be considered fair and relied upon by both buyer and seller. Refuelling stations are the last stage of the hydrogen delivery and is where quantities and associated costs need to be established. Thus, in the next section we describe the most relevant aspects of the hydrogen competitiveness model proposed by Hansen (2010) and the H_2 delivery component model proposed by the Department of Energy of the United States (2005).

4.1.The Hydrogen Competitiveness Model

The purpose of the hydrogen competitiveness model is to measure the fuel cost per kilometre to allow a comparison with competing fuels, specifically ‘‘diesoline’’ (defined as a composite conventional fuel formed by an average of diesel and petrol), hydrogen from natural gas, and hydrogen from non-fossil power (Hansen et. al., 2010).

The aim of the analysis is only to quantify conditions for cost-effectiveness of the alternative transport fuel solutions, and not to assess the behaviour of hydrogen vehicle users.

Considering the huge uncertainties surrounding the potential hydrogen and FCEV solutions, the model is deliberately kept as simple as possible and formulated in terms as broad as possible.

One of the properties of future hydrogen production that is known with certainty is that the costs of transport fuels are cumulated along the fuel chain, where each link of the chain adds value to the throughput of energy. Energy consuming processes in this transformation include conversion, conditioning, transport, and storage.

The model specifies a general system efficiency covering all of these transformation processes rather than each of them, with a general figure of €11/GJ to €16/GJ of non-energy part of the costs of transforming natural gas to hydrogen. Energy costs include fuel throughput and transformation loss while non-energy costs include those related to infrastructure and operation costs other than energy.

The competitiveness measure used in the model is the cost of fuel per kilometre, obtained by relating the cost functions of each fuel to the fuel efficiency of the relevant vehicle. A per-kilometre cost function for each of the three alternative fuels, *i.e.* ‘‘diesoline’’, hydrogen from natural gas, and hydrogen from non-fossil power, can be briefly specified as follows:

Per-kilometre cost of diesel and petrol (‘‘diesoline’’) (€/km) = $(a+bP)/EP$ (1)
Per-kilometre cost of natural gas-basedH_2 (€/km)/$(e+(c+dP)\,f)/EH$ (2)
Per-kilometre cost of non-fossil-basedH_2 (€/km)/$(g+hi)/EH$ (3)

Where *“a”* is the feedstock price independent costs per GJ oil-based fuel including taxes (€/GJ), “*b*” is the fuel price dependency on crude oil price (regression coefficient), *“c”* is the oil price independent costs of natural gas (regression coefficient) including taxes (€/GJ), *“d” is* natural gas dependency on oil price (regression coefficient), “*e*” is energy independent costs of NG-based H_2 including taxes (€/GJ), *f* is the NG-based H_2 cost dependency on natural gas (inverse system efficiency), *h* is non-fossil electricity cost (oil price independent) including taxes (€/GJ), *“i”* is non-fossil H_2 cost dependency on electricity cost (inverse system efficiency), *“*P*” is the* crude oil price (Brent, dated) ($/bbl), *“*EH*”* is the quantity of km/GJ H_2 and *“*EP*”* is the quantity of km/GJ ‘‘diesoline’’.

The threshold oil price for competitiveness of natural gas-based hydrogen can be derived from (1) and (2) as:

$$P^* = (a+ak-c-de)/(df-b-bk) \qquad (4)$$

The threshold oil price for competitiveness of non-fossil hydrogen is similarly obtained from (1) and (2) as

$$P^* = (g+hi-a(1+k))/b(1+k) \qquad (5)$$

“Taxes” include energy taxes as well as cost of EU allowances according to the Emission Trading Scheme (ETS) and paralleling CO_2-taxes outside the ETS.

4.2.The H2A Delivery Component Model

The H2A Delivery Component model is one of two models developed by the H2A Delivery Team from the Department of Energy of the United States of America (DOE, 2005). The model focuses on a fixed set of components that will be required to deliver liquid hydrogen or compressed hydrogen gas from a central production plant to a refuelling station and then onto the onboard fuelling tank of a fuel cell vehicle. The tool is based in Microsoft’s Excel spreadsheet program. That needs to be filled by users. Each of the components introduced has a separate tab which contains tables and descriptions to guide users how to enter data.

The components that are modelled in the tool are listed below:

1. Delivery Components
   - Truck – hydrogen gas tube trailer, 2700 psi
   - Truck – hydrogen gas tube trailer, 7000 psi
   - Truck – liquid hydrogen tank
   - Pipeline
   - Liquefier
   - Compressor (single- or multi-stage units)
2. Storage Components
   - Compressed gas tubes
   - Bulk liquid tanks
   - Geologic/underground
3. Delivery/Storage Components
   - Compressed hydrogen gas terminal
   - Liquid hydrogen terminal
4. Refuelling Components
   - Refuelling compressor
   - Refuelling dispenser
   - Refuelling storage
5. Integrated Refuelling
   - Refuelling station – compressed hydrogen gas delivery
   - Refuelling station – liquid hydrogen delivery

The information introduced in the H2A delivery scenario is then included in the Hydrogen Delivery Scenario Analysis Model (HDSAM) that uses an engineering economics approach to cost estimation. For a chosen scenario, a set of "components" (e.g., compressors, tanks, tube trailers, etc.) is specified, sized, and linked into a simulated delivery system or pathway infrastructure. Financial, economic, and technological assumptions are then used to compute cost associated to components and their overall contribution to the delivered cost of hydrogen. Version 2.0 contains default values that represent currently available (2005) technologies and costs and current population and infrastructure characteristics. These parameters can be changed by the user to simulate advancements in technology and changes in other costs or relevant characteristics.

HDSAM draws upon the engineering economics calculations in the H2A Delivery Components Model. In effect, many of the "component" spreadsheets (or tabs) within the Delivery Components Model are embedded in HDSAM, which links them into appropriate combinations to define a delivery pathway, size the individual components consistent with a scenario's demand estimate, and calculate the cost associated with delivering a given quantity of hydrogen via the specified pathway.

5. Economic feasibility targets and policy framework

In the HyTEC project, hydrogen is intended to be delivered to customers at a price below €10/kg on an operation basis including the capital equipment. One of the economic objectives of the project is to demonstrate how is possible to reduce the price of the capital goods, not to overcome the €5/kg on the longer term if sufficient demand on the fuelling network is attained. Alternatively, local hydrogen pricing may be adapted to ensure a competitive level with gasoline in terms of cost per driven km, *e.g.* in Copenhagen this would correspond to a hydrogen price of € 8.4/kg.

For these hydrogen delivery technologies to be widely used in the future, their cost cannot exceed 5 % of the overall cost of FC vehicles, corresponding to €1,000-2,000 per car. In order to reach this target, an investment plan is required to build up the first critical mass of hydrogen supply (EC, 2009) defined in a policy framework.

A European coordinated policy plan enhancing the development of hydrogen energy systems should include energy efficiency as well as regulatory and spending policies as proposed by Bleischwitz & Bader (2010). A short explanation of the objectives of these regulations is described underneath:

- Energy efficiency (EE) regulations are normally designed to decrease the energy intensity of an economy, *i.e.* to minimize ‘‘the amount of energy used per unit GDP’’ (IEA, 1987). Legislation on EE may therefore indirectly favour the development and market introduction of fuel cells. In 2005, the EU also adopted a directive on the ecodesign of energy-using products. This directive applies in principle to any energy-using product and aims to improve EE in the whole life cycle of the product. However, these push factors need to be defined stronger to lead to the deployment of hydrogen and fuel cells markets across Europe.
- Renewable energy policies build on the statement that hydrogen is only as green as its energy source. As long as it is produced via gas reforming or via electrolysis based on

carbon-intensive electricity, it may offer some minor carbon reduction advantages, but will not significantly curb carbon emissions. Policies focused on the penetration of renewable energy sources in the European energy system are therefore a precondition for the sustainable use of hydrogen.

- Emission trading schemes (ETS) are one of the so-called Kyoto mechanisms to implement the reduction of greenhouse gases (GHG). According to economic theory an ETS reduces the costs of reaching a specific emissions target by taking advantage of different marginal abatement costs of the participating actors. Cost savings are particularly big if mitigation costs differ significantly between sources covered by the scheme. Given that hydrogen production can be done via fossil fuels, the specific mechanisms of the EU ETS are of great importance for its future market price. By putting a price on carbon-intensive processes, an ETS could set incentives for low carbon emitting hydrogen production processes such as those derived from renewable or fossil fuel combustion combined with CCS.
- EU regulatory policies can be seen as an essential part of the EU policy framework for hydrogen promotion since some of them may influence the price of hydrogen. Current regulatory policies tend to have a weak but positive impact on hydrogen. In most EU member states hydrogen is exempted from any taxation or taxed at relatively low rates. Thus, taxation currently favours hydrogen over competing technologies, and yet the EU cannot be credited with this situation since hydrogen is neither explicitly mentioned in the directive on minimum taxation nor has the EU strong competence in the field of taxation.
- EU spending policies are a potentially powerful policy instrument for the regional promotion of sustainable technologies and infrastructures since they can channel funds towards them. However, this potential is currently not fully exploited. On the one hand more regional funding has recently been directed towards innovation, a field closely related to hydrogen and fuel cells, being the European Hydrogen Platform and the “Fuel Cells and Hydrogen Joint Undertaking” an example of this. On the other hand, cohesion funding normally does not apply to those regions which are the most innovative and the most advanced in the field of hydrogen and fuel cells.

6. Final Remarks

This report has provided a summary of the technological aspects of the hydrogen delivery alternatives, giving an overview of the selected pathways employed in the HyTEC project. The legal restrictions, standards and codes that should be used when delivering hydrogen have also been described.

Two models for weights and measure methodologies were analyzed. The Hydrogen Competitiveness Model is focused on measuring the fuel cost per kilometre in order to compare the hydrogen energy systems with competing fossil fuels. This model allows a comparison of the efficiency of energy systems, specifying a general system efficiency that covers all the transformation processes rather than each of them, including in the cost, the influence of energy related taxes as well as the energy costs of fuel throughput and transformation losses.

The second model analysed is the Hydrogen Deliver Components Model. This cost contribution model is based on inputs provided by the user describing the amount of hydrogen to be delivered and basic capital and operating costs for the component. The model calculates the cost contribution of each component within the delivery infrastructure to the $/kg cost of delivering hydrogen. When considering technologies under development, different than the ones present in the model, cost definition associated to hydrogen delivery is an issue to deal with. The influence of legislation in the cost of hydrogen energy system is not considered inside the model and should be included separately.

The economic results that can be obtained from these models should be added to the analysis of other price fixation aspects.

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