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# LINKING DISTRIBUTED EUROPEAN HYDROGEN PRODUCTION SOURCES

## Executive Summary

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The European Commission is supporting the Coordination Action "HyLights" and the Integrated Project "Roads2HyCom" in the field of Hydrogen and Fuel Cells. The two projects support the Commission in the monitoring and coordination of ongoing activities of the HFP, and provide input to the HFP for the planning and preparation of future research and demonstration activities within an integrated EU strategy.

The two projects are complementary and are working in close coordination. HyLights focuses on the preparation of the large scale demonstration for transport applications, while Roads2HyCom focuses on identifying opportunities for research activities relative to the needs of industrial stakeholders and Hydrogen Communities that could contribute to the early adoption of hydrogen as a universal energy vector.

Further information on the projects and their partners is available on the project web-sites www.roads2hy.com and www.hylights.org

# 1. Introduction

This report is a deliverable of the Roads2HyCom project, a partnership of 29 stakeholder organisations supported by the European Commission Framework Six program. The project is studying technical and socio-economic issues associated with the use of fuel cells and hydrogen in a sustainable energy economy. Within the project, several studies have been made related to the question of primary energy sources to produce hydrogen.

Current sources of hydrogen, whether they are merchant sources from the chemical industry, or pilot projects designed more specifically to produce hydrogen as an energy vector, are generally not linked as a cohesive infrastructure to supply hydrogen as a fuel. As demand for hydrogen as a fuel grows, better integration of the hydrogen production chain may be required to ensure a cost-effective, robust and environmentally efficient supply is maintained.

To capture the broader picture of the technology, this study analyses the interactions of distributed European hydrogen production sources with the existing power generation infrastructures.

As an example, when some of these future hydrogen sources will consist of hydrogen produced by wind-powered electrolysis, the issue of hydrogen production and distribution is then also strongly coupled to the question of electricity production and distribution, because

- Electricity produced by a wind farm can be solely used for hydrogen production, without connection to the grid, but with a connection to a hydrogen distribution network

- But the wind farm could also be connected to the grid, supplying regular electricity and using the hydrogen as a means of balancing power output, or it could use the grid electricity to complement the hydrogen production.

This clearly shows the strong interdependency between the different sectors and sources. This study has looked at three key issues that are pertinent to this interdependency, each covered in its own report as follows:

**Part I – Distribution Issues**
Addressing hydrogen distribution

**Part II – Analysis of Electricity Grid Development Strategies and Constraints**
Focusing on constraints and perspectives for the electricity grid itself

**Part III – Analysis of Hydrogen as a Storage Device for Renewable Energies**
Concentrating on strengths and weaknesses of hydrogen as a storage device for fluctuating energy sources.

## Part I: Distribution Issues

This part addresses techno-economic issues related to the various transport modes of hydrogen. It concentrates on the transport itself and gives insight on cost issues as well as perspectives on developments for the alternatives considered. As such, it is not about infrastructure optimisation, which requires a complete view on the entire chain from production to end-user, with both time and geographical dimensions. It is also important to note that changes (especially relative changes) in the cost of oil, steel and other key raw materials, and of land, will significantly impact any individual decision about distribution infrastructure.

The report addresses the transport of pure hydrogen and gives orders of magnitudes of costs for transportation of hydrogen by pipeline, compressed gas trucks (tube trailers), and cryogenic liquid trucks. Comparisons of these costs on a point-to-point basis show that compressed gas trucks are the preferred form of distribution for low demands and close distances (below 200 km), whereas liquid trucks are more suitable for intermediate demands and medium to long distances, though it should be noted that not all sources of hydrogen have a liquefaction plant.

Pipelines are preferred for high demand at whatever distance. The investment required for a pipeline construction is an economic barrier that is only partially reduced with the introduction of polyethylene (PE) pipes in the distribution networks. For future deployment, R&D efforts need to be directed to the development of less expensive pipelines. These R&D requirements, challenges and perspectives as well as the state-of-the art of current materials are discussed for steel, polymer and composite pipelines. Also, parallel to scenarios developed in the project HyWays, it was taken into account that not always the least-cost route is the most feasible, but that also market demand will have an impact on the choice of the supply route. If, for instance, LH2 for cars is needed at a fuelling station there is no alternative to liquid supply with trucks due to the handful of production sites for LH2, although from the economical perspective tube trailers might be a cheaper option.

Part I also considers other alternatives for hydrogen transport, e.g. the use of the natural gas network to transport hydrogen (at least for a transition period). The main features of the natural gas network are explained including the main issue of low compatibility of the current (and future) pipeline material with hydrogen. As hydrogen causes embrittlement in steel pipelines and permeability in polymer ones, research is needed to explore this interesting transitional approach and to investigate solutions for the gas industry. In the medium term, use of the natural gas pipeline network and hydrogen separators appears to be potentially attractive in some situations, despite the immaturity of the separator technology. Even if costs and efficiencies of the separation of natural gas and hydrogen remain a problem, the addition of low-carbon sourced hydrogen to the gas supply could become an attractive approach to decreasing the $CO_2$ emissions associated with the use of natural gas, either in conventional combustion devices, or in fuel cells for co-generation.

Finally, beyond the techno-economical issues discussed here, the successful deployment of a hydrogen infrastructure will require a strong co-operation between the various stakeholders of the hydrogen energy chain, namely the hydrogen producers, the pipeline manufacturers and/or operators, and the end-users, together with efficient support from governmental policies.

## Part II: Analysis of Electricity Grid Development Strategies and Constraints

This part reviews strategies and restrictions for network infrastructures of the electricity grid. It shows that the development of electric power networks is directly influenced by electricity generation patterns, which are, indirectly, a mirror of consumers' consumption behaviour. The market is currently dominated by centralised sources and requires higher transmission capacities of intersystem connectors. Existing stimulations for further development only consider extra high voltage networks and superconducting technologies. Among these centralised sources a strong position is maintained by coal-fired (and, where policy favours them, nuclear) power plants and large-scale hydro installations. Emission restrictions will require the deployment of Carbon Capture and Sequestration (CCS) technologies for coal. Return to nuclear technologies (however with new solutions of third and fourth generation reactors) and limited use of hydrocarbon fuels is observed.

A new and growing production segment is decentralised distributed generation, including sources fed with fossil fuels (predominantly natural gas) and sources making use of renewable resources (RES). This is why this segment is often referred to as gas/renewable. Distributed sources can either feed into the distribution grid or be consumed directly by consumers. In the case of grid connected devices, intelligent control systems are needed to balance supply and demand and prevent accidental “islanding” of a part of the grid disconnected for maintenance. Solving these challenges is an essential component in the successful uptake of Fuel Cell based co-generation technologies on the domestic to industrial scale (1kW-1MW). These technologies are seen as a potentially important early market for the Fuel Cell, as a dedicated fuel infrastructure is not required, and asset utilisation is high. Therefore policies and standards need to be in place to allow such distributed control to be effective.

Part II also identifies the two most likely large scale renewable electricity producers of the near future: wind and hydro power. Both are a great challenge for the grid as on one hand they need to integrate an unpredictable yet powerful contribution to electricity production. On the other hand, this contribution often accesses the grid at its weakest point: the remote areas where only the thinnest branches of the hierarchical electricity networks reach. Although intermittency of renewables balances over great areas it is not feasible to replace intermittent renewable energy in one place with intermittent renewable energy from another place in Europe as distances are in the magnitude of several hundred kilometers. Instead, conventional balancing and reserve power would be cheaper than reinforcement of large parts of the grid or any kind of storage of wind energy in the affected area. Still, though, renewables could only play out their advantages if the grid allows a certain amount of fluctuation and compensation. As wind and hydro energy are resources that one would wish to harvest when they are available, the grid connection issue here is not just one of control, but of distributing the energy (requiring an effective policy on reinforcing grid capacity and connectivity on strategic lines) or in some situations storing it locally until it is needed (or can be sold at a more attractive price). This latter issue is the topic of the final section.

## Part III: Analysis of Hydrogen as a Storage Device for Renewable Energies

Most renewable energies supply electricity, which is one of the most difficult energy vectors to store. In addition, the introduction of intermittent renewable sources, e.g. wind energy, to attain the policy targets means further challenges for energy production in Europe. A solution could be to store electricity during peak production times and then supply the grid with electricity at periods of high demand low renewable production. This would also help to reduce the impact of demand fluctuations.

Analysis of fluctuations show that long-term variations can hardly be met by storing energy, but small-scale storage can balance the major part of the short-term fluctuations very well. One can distinguish between two storage needs:

- Interim storage, which is needed to reduce short fluctuations or to allow the shift of power supply to peak load hours (midday or early evening).
- Surplus power storage, which is necessary to handle the mismatch between load and power production, thus avoiding an overloading of the grid due to lack of transmission capacity.

It can be shown that surplus power only arises above a penetration level of 25% (wind) or 15% (photovoltaics). Extrapolation indicates that this penetration is rarely exceeded at large-scale. Thus storage of surplus renewable electricity will not be required not before 2020.

Yet storage will be necessary for balancing fluctuations rather than managing the electrical grid as a whole. Available storage systems include pumped hydro, compressed air, flywheels, batteries (including, interestingly, those on board plugged-in electric or hybrid vehicles, which could form a significant resource as numbers rise), and compressed hydrogen production. The study demonstrates that no single storage technology can satisfy every requirement, and that a mix of fast response and long term storage is likely to develop.

The demand for surplus power storage cannot be determined at this moment due to a lack of data for the future development and technical details of new production capacities in power generation and the electricity grid. Also, hydrogen will not be an option for the large offshore installations planned in the North Sea due to the low conversion efficiencies and the costs involved.

In contrast to the other long-term storage options, hydrogen offers the advantage of a high flexibility and the possibility for multiple-use, for instance being delivered as vehicle fuel. On the other hand the overall storage efficiency is low, at least when considering today's technologies. This situation may partly change when development progress is made. The advantages, though, will always be bought at a sacrifice of energy, due to the limited efficiency of the re-conversion to electricity. Though the heat generated might be put to use, the return on the electrical energy initially fed into storage will remain in the order of magnitude of 50%, which is comparable to today's competitor compressed-air storage systems.

However, even given this conclusion, the use of Hydrogen as short term storage still offers the benefit of synergy with its production for other uses, so it is possible to consider in some circumstances a multi-functional plant that both exports Hydrogen and supplies emission-free balancing power for wind, wave and tidal energy schemes, thus improving integration of these sources into the European electricity grid. Such a plant would have a high capital cost, because its elements (Hydrogen production from electricity, Hydrogen re-conversion back to electricity) would be under-utilised by definition, but in some circumstances this could prove to be a favoured solution especially if there were a demand for the (intermittent) waste heat. The issue of surplus energy on a longer timescale will start to occur at a European scale when the share of renewable electricity is further increased well above the 35% envisaged for 2020. Then, though, hydrogen can play an important role due to the possibilities of long-term, low-loss storage and, again, the ability to integrate this function with what could, by that time, be a substantial transport fuel supply need.

Hydrogen offers the advantage of a nearly unlimited size of storage and an instant provision of energy due to a complete decoupling of input and output conversion. As an example, in Part III a wind-hydrogen system is described that enables the user to "schedule" wind power production due to a combination of precise forecasts and hydrogen-based electricity production. This eliminates short-term fluctuations and forecast errors. The resulting predictable production could be used to reduce balancing power or could be sold on the spot-market.