Activity 3

Strategic Corridor Analyses and Plans
HIT-2 Corridors
Activity 3
Strategic Corridor Analyses and Plans

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## Glossary

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<th>Abbreviation</th>
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<tr>
<td>350/700 bar</td>
<td>Pressure levels for hydrogen storage tanks</td>
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<td>AFV</td>
<td>Alternative Fuel Vehicle</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<tr>
<td>CAPEX</td>
<td>Capital Expenditure</td>
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<tr>
<td>CGH₂</td>
<td>Compressed Gaseous Hydrogen</td>
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<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
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<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
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<tr>
<td>EPA</td>
<td>US Environmental Protection Agency</td>
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<td>ETS</td>
<td>Emission Trading System</td>
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<td>EV</td>
<td>Electric Vehicle</td>
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<td>FCEV</td>
<td>Fuel Cell Electric Vehicle</td>
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<td>FCH-JU</td>
<td>Fuel Cells and Hydrogen Joint Undertaking</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<td>H₂</td>
<td>Hydrogen</td>
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<tr>
<td>HFC</td>
<td>Hydrogen Fuel Cell</td>
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<td>HIBIT</td>
<td>Hydrogen Integrated Business Case Impact Tool</td>
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<tr>
<td>HIT</td>
<td>Hydrogen Infrastructure for Transport</td>
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<tr>
<td>HRS</td>
<td>Hydrogen Refuelling Station(s)</td>
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<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
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<tr>
<td>LEV</td>
<td>Low Emission Vehicle</td>
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<tr>
<td>LH₂</td>
<td>Liquid Hydrogen</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<tr>
<td>NG</td>
<td>Natural Gas</td>
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<td>NIP</td>
<td>National Implementation Plan</td>
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<tr>
<td>NOₓ</td>
<td>Nitrogen Oxide</td>
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<td>OEM</td>
<td>Original Equipment Manufacturer</td>
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<td>OPEX</td>
<td>Operational Expenditure</td>
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<td>P2G</td>
<td>Power-to-Gas</td>
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<tr>
<td>PEM</td>
<td>Polymer Electrolyte Membrane</td>
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<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
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<tr>
<td>PM</td>
<td>Particulate Matter</td>
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<tr>
<td>PPP</td>
<td>Public-Private Partnership</td>
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<tr>
<td>RBH</td>
<td>Rural Basic HRS</td>
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<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
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<tr>
<td>SMR</td>
<td>Steam Methane Reforming</td>
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<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
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<tr>
<td>TEN-T</td>
<td>Trans-European Transport Networks</td>
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<td>UBH</td>
<td>Urban Basic HRS</td>
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<td>UFH</td>
<td>Urban Full-Service HRS</td>
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Executive Summary

Summarised Conclusions

1. **Fuel cell mobility requires a basic refuelling infrastructure coverage.** A minimum number of publicly accessible refuelling points should be in place before FCEV roll-out can commence.

2. **Fuel cell mobility requires government support.** Without government support, the total cost of ownership of a fuel cell vehicle is higher than a comparable combustion engine vehicle. Financial support is by far the most important stimulation (‘must have’) while other non-financial incentives have less impact (‘nice to have’).

3. **Early market refuelling station development comes with a financial Valley of Death challenge due to underutilisation issues.** The Valley of Death is the total funding gap between the moment of initial investment until the moment all expenditure has been fully recovered. Initial calculations with the Hydrogen Integrated Business Case Impact Tool (HIBIT) show that all hydrogen refuelling stations and especially small-scale ones in remote rural areas have Valley of Death issues, due to a slow revenue growth and high initial investment levels.

4. **The best HRS development strategy depends on goals, resources and stakeholder commitment.** Two distinct approaches are the ‘national approach’ and the ‘regional approach’. The national approach is a large-scale approach aimed at getting early HRS coverage on a national scale. The regional approach puts regional stakeholders at the helm and allows for more tailor-made solutions than the national approach. The national and regional approaches are not mutually exclusive. They could even be complementary. A national approach could be used to get a very basic HRS coverage in place, followed by a regional approach to fill in the regional ‘blanks’.

5. **A regional approach requires regional arrangements providing tailor-made solutions.** Regional entrepreneurs have limited resources to fund the Valley of Death. Regional arrangements are required to a) coordinate regional refuelling station development – by drawing up regional investment programmes, and b) make funding available and accessible at affordable prices.

6. **Stimulate green entrepreneurship: it leads to innovation.** Entrepreneurs are developing new business concepts, responding to increased environmental awareness and health consciousness. Regional arrangements can support these developments by making funding accessible, but also by establishing expertise networks.

7. **Demand aggregation is a powerful method of creating early markets and support hydrogen infrastructure development.** Demand aggregation includes HRS development in
combination with the identification and recruitment of dedicated early user groups. Group characteristics are: high mileage motorists with a regional scope, such as taxi companies, and environmental awareness such as local/regional governments, but also companies with a (desired) green profile. Demand aggregation will only be successful if motorists are fully compensated for all additional costs of driving a fuel cell vehicle, such as a higher retail price, higher fuel costs and alternative transportation costs in case of occasional journeys to areas with no refuelling station coverage.

8. The eastern part of the HIT-2 Corridor has the most significant missing link issues.
Poland currently has no existing or planned refuelling stations, although it is an essential part of both the North Sea–Baltic and the Baltic–Adriatic TEN-T Transportation Corridors. Connector refuelling stations should be constructed in Poznan, Bialystok, the Polish-Lithuanian border area and Tallinn (Estonia).
In Sweden, the distance between Goteborg and Stockholm is larger than the average fuel cell vehicle driving range. Adding a connector refuelling station enables hydrogen mobility southwards on Swedish and Finnish trunk routes. There is no hydrogen infrastructure northward as yet. Connector refuelling stations will be required there but stations in such areas may face bankability issues as those routes lead to remote, sparsely populated areas.

9. System integration opportunities should be considered when scouting for and selecting refuelling station locations. System integration creates opportunities for lower costs or higher revenues, improving the refuelling station business case. System integration options to be considered are using refuelling stations as a buffer for storage of excess green energy from intermittent energy sources (wind and solar power) to guarantee grid stability, and using Power-to-Gas options.

Hydrogen-fuelled mobility contributes to EU environmental goals

EU countries have agreed on a new 2030 Framework for climate and energy, including EU-wide targets and policy objectives for the period between 2020 and 2030. These targets aim to help the EU achieve a more competitive, secure and sustainable energy system and to meet its long-term 2050 target of 80-95% lower emission levels.

EU long-term climate goals can only be realised with zero tailpipe emission alternatives to today’s combustion engine powered vehicles. Hydrogen offers such a zero tailpipe emission alternative in combination with a driving range of about 500 kilometres. Hydrogen-powered mobility has just started to commence. It faces quite a few challenges as FCEVs require an extensive refuelling infrastructure.

The HIT project aims at stimulating the deployment of a hydrogen refuelling infrastructure serving fuel cell electric vehicles along key TEN-T Corridors. The current HIT-2 Corridor project presents crucial steps to expanding hydrogen infrastructure and interconnectivity along core network routes. It aims at harmonised deployment of hydrogen infrastructure along the TEN-T
core network. The HIT-2 Partners are: Belgium, Finland, the Netherlands, Poland, the city of Riga and Sweden.

*Hydrogen Refuelling Station (HRS) development comes with bankability issues*

In general early HRS face a significant period of underutilisation as the number of fuel cell vehicles is limited during the early market phase. However, the level of underutilisation and, subsequently, its financial impact varies across HRS types. All early HRS face the double disadvantage of high investment costs and low revenue levels – investment costs are expected to fall by 40% in the next 15 years and revenue levels will go up when the fuel cell car market share rises.

Small HRS in remote, rural areas are relatively expensive (higher hydrogen transportation costs or, alternatively, higher costs of on-site hydrogen production) while income growth rates are expected to be relatively low.

Larger HRS in urban areas have a more favourable cost/revenue ratio and have better opportunities to create and capture economies of scale. However, this does not take away from the fact that these HRS types also face business case challenges due to a long period of underutilisation.

Thus, all early HRS have underutilisation issues leading to a significant Valley of Death: the funding gap that grows from when an HRS starts up to when it begins generating revenues. Bankability issues arise as such funding gaps are usually large, their duration is usually long and future revenues are highly uncertain.

*Fuel cell vehicle roll-out comes with production and sales issues*

Fuel cell vehicles are technically quite different from combustion engine vehicles. Fuel cell vehicle manufacturers face the following two production challenges:

- developing integrated technology platforms to fully integrate fuel cell vehicle production into the overall production lines, and
- increasing production in order to profit from economies of scale and to reduce production costs.

Fuel cell vehicle manufacturers such as Toyota have already invested billions in fuel cell technology. The main concerns about the sale of fuel cell vehicles are:

- the higher total cost of ownership of a fuel cell vehicle compared to a combustion engine alternative, and
- limited refuelling station availability leading to customer inconvenience as filling up requires driving extra kilometres.
For these reasons manufacturers are expected to start fuel cell vehicle roll-out in countries with the highest refuelling station coverage and the best incentive policies in place.

**Interconnected vehicle and refuelling station issues require integrated solutions**

Refuelling stations need fuel cell vehicles to generate income, fuel cell vehicles require refuelling stations to fill up. There are many ways to support refuelling station development and fuel cell vehicle roll-out. The hydrogen for transport value chain consists of fuel, fuel stations and vehicles. Their interconnectivity offers opportunities to solve multiple issues with one single integrated solution.

Demand aggregation means that a significant group of potential fuel cell vehicle drivers is identified and stimulated to actually drive a fuel cell vehicle. As these vehicles need to be filled up, early commercial fuel station opportunities arise. Early hydrogen sales contribute to Valley of Death funding gap minimisation. Demand aggregation will also make a market more attractive to car manufacturers as it increases fuel cell vehicle sales opportunities. Thus, demand aggregation stimulates both vehicle and fuel sales.

The most important regulatory incentives are:
- clear greenhouse gas emission regulation with a focus on a gradual and consequent transition to zero tailpipe emission allowances,
- vehicle tax exemptions, bringing the fuel cell vehicle’s total cost of ownership to competitive levels, and
- fuel tax exemptions, bringing the retail price of hydrogen to competitive levels.

The most important non-regulatory incentives are:
- regional/local government being launch customers, to create demand initiatives,
- capital and operational grants for refuelling station development,
- performance-based payments for refuelling stations,
- take-or-pay contracting for refuelling stations as a purchase/income guarantee for station operators, and
- funding assistance by offering soft loans to refuelling station owners by providing guarantees to refuelling station financiers.

**Regional solutions require regional public-private arrangements**

The regional approach puts regional stakeholders foremost and allows for tailor-made solutions. The regional approach puts emphasis on minimising the Valley of Death by actively stimulating and aggregating customer demand. It is a more bottom-up organic model which also allows for HRS initiatives from local entrepreneurs. As local entrepreneurs have limited resources and are not backed by a financially strong parent, funding is usually an issue. Regional public-private arrangements consist of at least the following functions:
- A regional programme including refuelling station development.
- Regional funding, meaning the regional capacity to arrange fuel station funding using various available public and private funding sources such as grants, loans, guarantees and equity coming from existing funds, such as green funds, regional development funds and innovation funds. In cases where no funds exist, such funds can be created. The Norwegian NOx fund is a good example. This fund is replenished with private contributions from shipping and oil companies receiving an NOx tax waiver when they contribute to the NOx fund.

**HIBIT supports regional public-private debates about fuel station bankability**

The Hydrogen Integrated Business-case Impact Tool (HIBIT) is a tool that shows refuelling station bankability, based on revenues and expenditure assumptions. It also shows the bankability effects of various support instruments, including demand aggregation. HIBIT allows for a regional stakeholder debate about bankability issues and the preferred support schemes to improve bankability. Preliminary HIBIT calculations show that:

- expenditure grants stimulate refuelling station availability, but not their performance or use,
- demand aggregation requires more money than expenditure grants, but it is also more effective as it stimulates the sale of hydrogen vehicles and, as a consequence, it stimulates the sale of hydrogen as a fuel, and
- refuelling stations in remote sparsely populated areas face more severe bankability issues due to an unfavourable cost structure and slower growth curves compared to their urban counterparts.

The following two-step approach may offer the best ‘value for money’:

**Step 1:** a national approach to get basic refuelling station coverage, using expenditure grants to make business cases bankable. A national approach is a large-scaled approach aimed at getting early HRS coverage on a national scale. This is more of a top-down approach powered by national governments and large financially strong HRS developers and operators.

**Step 2:** a regional approach to intensify the refuelling station network. This approach is based on local entrepreneurship and demand aggregation. Demand aggregation requires more financial stimulation money than expenditure grants. However, demand aggregation also has more potential stakeholders, such as companies working on their sustainable profile. Governments could use money they would have otherwise spent on grants as seed money to form demand aggregation groups, stimulating private stakeholders to deliver the additional required resources.
**Missing links from a corridor point of view**

The most striking aspect of the HRS infrastructure is the absence of both existing and planned HRS in Poland, while this country is an essential part of both the North Sea–Baltic and Baltic–Adriatic Corridors. The Baltic states, on one end of the North Sea–Baltic Corridor, will have no HRS infrastructure in place in the near future. Also, the northern parts of both Sweden and Finland currently have no existing or planned HRS coverage and also the southern parts of these countries need coverage improvement. Even though the Netherlands and Belgium have HRS development plans, those plans do not cover all economic centres, such as the Amsterdam Schiphol Airport area.

In order to basically cover the North Sea–Baltic Corridor and assuming a coverage of about one HRS per 300 km along the focus corridors, connector HRS should be constructed in:

- Poznan,
- Bialystok,
- Polish-Lithuanian border area, and
- Tallinn (Estonia).

Preferably an HRS should be available in Lithuania as well. To improve HRS coverage in the Scandinavia-Mediterranean Corridor, a minimum of one connector HRS in Linköping (Sweden) or Jönköping (Sweden) should be established connecting Göteborg and Denmark. At least one HRS should be established around Turku in Finland connecting Stockholm and Helsinki.

**System integration opportunities should be considered when scouting for refuelling station locations**

Most countries identify potential HRS locations in areas where the greatest customer benefits can be delivered. Obviously areas of population concentration and national trunk routes end up high on the priority list: they offer the best early revenue potential. However, even though maximum revenue potential from hydrogen sales is rightfully the most important location factor, additional factors should be considered when identifying locations. System integration potential could be such an additional factor. System integration refers to options to synchronise several hydrogen-related uses and applications, allowing for lower HRS costs or alternative income sources. Potential system integration opportunities are:

- Alternative demand aggregation. Hydrogen offers opportunities not just for zero tailpipe emission mobility, but also for zero energy buildings and decentralised energy production. If the energy demand of a region as a whole is taken, new revenue opportunities arise. If a refuelling station is (to be) located in an area, it could also be used as a source for other hydrogen applications such as heating buildings. Such applications bring early refuelling station income opportunities.
• Power-to-gas (P2G). This is the process of converting surplus renewable energy into hydrogen gas by rapid response electrolysis and its subsequent injection into the gas distribution network. Hydrogen can thus be used as an alternative to natural gas or butane. This adds to (imported) fossil fuel independency while creating rural green hydrogen economy opportunities. This option is interesting for countries with an existing natural gas grid, as they have long distance gaseous hydrogen transportation capacity. This is a more efficient option than transportation of electricity through high voltage power lines.
1 Introduction

1.1 Starting Point: The European Climate Goals

The 2030 EU climate and energy framework sets three key targets for the year 2030:

- at least 40% cut in greenhouse gas emissions (from 1990 levels),
- at least 27% share for renewable energy,
- at least 27% improvement in energy efficiency.

The framework contains a binding target to cut emissions in the EU territory by at least 40% below 1990 levels by 2030. This will enable the EU to:

- take cost-effective steps towards its long-term objective of cutting emissions by 80-95% by 2050 in the context of necessary reductions by developed countries as a group,
- make a fair and ambitious contribution to the new international climate agreement, to take effect in 2020.

To achieve the at least 40% target:

- EU emissions trading system (ETS) sectors would have to cut emissions by 43% (compared to 2005) – to this end, the ETS is to be reformed and strengthened,
- non-ETS sectors would need to cut emissions by 30% (compared to 2005) – this needs to be translated into individual binding targets for Member States.

The framework was adopted by EU leaders in October 2014. It builds on the 2020 climate and energy package. [1]

1.2 Reduction of CO₂ Tailpipe Emissions from Vehicles

Road transport contributes about one-fifth of the EU's total emissions of CO₂, the main greenhouse gas. While these emissions fell by 3.3% in 2012, they are still 20.5% higher than in 1990. Transport is the only major sector in the EU where greenhouse gas emissions are still rising.¹ [1]

¹ It has become clear that because of Volkswagen’s rigging of emissions tests for 11 million cars, global pollution levels have been 1 million tonnes per year higher than assumed before. This is apart from the fact that laboratory emissions tests and those conducted in real world scenarios have been showing totally different outcomes for years. [72]
European law requires that the new cars registered in the EU do not emit more than an average of 130 grams of CO\textsubscript{2} per kilometre by 2015. By 2021, phased in from 2020, the fleet average to be achieved by all new cars is 95 grams of CO\textsubscript{2} per kilometre.

In particular, the 2050 EU climate goals require CO\textsubscript{2} emission levels of well below 65 grams per kilometre. Even though ICE technical optimisation allows for further CO\textsubscript{2} reductions, it is recognised that it will be virtually impossible to achieve levels below 65 grams per kilometre, even for hybridised ICE vehicles.

EU long-term climate goals can only be realised with zero tailpipe emission alternatives to today’s combustion engine powered vehicles. Currently, FCEVs and BEVs are the only available zero tailpipe emission vehicles. With the introduction of many mainstream models, BEVs are well on their way to becoming a serious alternative to ICE vehicles, especially for relative short distances.

Hydrogen-powered mobility has just begun. It faces quite a few challenges, as FCEVs require an extensive refuelling infrastructure. Furthermore, with cheaper ICE technology as a main competitor and with oil prices expected to remain depressed in the long term, it will not be easy to promote FCEV motoring. [2]

1.3 The Hydrogen Infrastructure for Transport Project (HIT)

The HIT-1 project aims at stimulating the deployment of hydrogen refuelling infrastructure serving fuel cell electric vehicles along key TEN-T (Trans-European Transport Network) Corridors. This is in accordance with the Alternative Fuels Infrastructure Directive which calls upon each Member State to develop national policy frameworks by 2016 for the deployment of alternative fuel infrastructures.

The current HIT-2 Corridor project presents the next crucial steps for expanding the hydrogen infrastructure and interconnectivity along core network routes. It aims at harmonised deployment of hydrogen infrastructure along the TEN-T core network. The HIT-2 Partners are: Belgium, Finland, the Netherlands, Poland, the city of Riga and Sweden.

The HIT-2 project is composed of the following three main activities:

*Activity 1: National Implementation Studies and Plans*

Within the HIT-2 Corridor, National Implementation Plans (NIPs) for the development of hydrogen infrastructure will be drafted for Finland, Poland and Belgium, and a regional plan for Riga (Latvia). Furthermore, additional studies for new Hydrogen Refuelling Stations (HRS) and more vehicles in Sweden are also part of this activity.
Activity 2: Infrastructure Realisation/HRS Deployment

Three new HRS will be deployed along two TEN-T core network corridors: the Scandinavian–Mediterranean and the North Sea–Baltic. These new HRS fill essential missing links between existing HRS along these two corridors. Germany, Denmark, Sweden, Norway and Finland will be interlinked by two new HRS in Gothenburg and Stockholm. A new HRS in Finland will link Sweden and Finland to the Baltic States. The plans for HRS in Riga will extend the link via Finland towards Poland.

Activity 3: Strategic Corridor Analyses and Plans

This activity will offer important insights and a toolbox for HRS development for policymakers and infrastructure managers at an early stage of European-wide HRS network development, facilitating fact-based and educated planning at EU, national and regional level and will include the following elements:

3A: An HRS network operation business model.
3B: A toolbox of options for strengthening customer demand.
3C: An overview of effective measures and lessons learned for HRS integration in core corridors.

1.4 About this Activity 3 Report

1.4.1 Approach

At the start of Activity 3 it became clear that, in order to maximise its usefulness, the Activity 3 approach should be:

- **bottom up** by approaching HRS network development from an owner/operator point of view and FCEV market development from a customer point of view,
- **integrated** by paying special attention to solutions with an impact on both HRS development and FCEV sales.

Bankability issues turn out to be among the most critical for HRS project development. For this reason the resolution of bankability issues was taken as the central theme for this report.

The approach to the research, specifically designed to identify microeconomic challenges for both HRS and FCEV development, consists of the following parts:

- A small dedicated research team, supported by experts from Linde Gas and the Dutch Hydrogen and Fuel Cell Association.
- About 25 interviews with a focus on (potential) HRS operators, OEMs, central and regional authorities.
- A literature study, with a focus on practical case studies.
- Feedback meetings with the ‘Expert Validation and Acceptance Committee’ (EVAC) – a group of experts and HRS entrepreneurs.
- Meetings with the HIT-2 Partner representatives.
- A quantitative approach to HRS business case development using a tool specifically designed for this purpose: the Hydrogen Integrated Business Case Impact Tool (HIBIT).

### 1.4.2 Content

Chapter 2 introduces hydrogen-powered mobility as a diffusion of innovation, showing how early market investment and slow market growth lead to funding challenges.

Chapter 3 introduces four HRS archetypes based on capacity and location characteristics. Spatial, market and bankability issues as well as their solutions are identified per archetype.

Chapter 4 presents an overview of both the supply and demand sides of the FCEV industry. It focuses on issues to be resolved for a successful roll-out.

Chapter 5 summarises the most important HRS and FCEV development issues and presents a toolbox of options for supporting HRS development and for strengthening customer demand.

Chapter 6 introduces the Hydrogen Integrated Business Case Impact Tool (HIBIT), an integrated HRS FCEV business model. It includes business case calculations of the HRS archetypes.

Chapter 7 presents recommendations for the HIT-2 Corridor development. It includes an analysis of missing links as well as lessons learned that should be considered.

Chapter 8 summarises the most important Activity 3 conclusions.
2 Hydrogen for Transport: Diffusion of Innovation

2.1 Diffusion of Innovation

The development of a market for FCEVs and an HRS network is a major undertaking. It requires new technology and the creation of new markets.

Adoption of technology typically occurs in an S curve. Customers respond differently to new products. The diffusion of innovations theory posits that people have different levels of readiness for adopting innovations and that product characteristics affect its overall adoption.

![Diffusion of Innovations Model](image)

Figure 1: The diffusion of innovations model, according to Professor Everett M. Rogers.

The orange line shows the S curve of market share growth. This growth is the result of phased technology adoption by consumers, shown by the blue line. Major adopter categories are:

- **Innovators.** These are people who want to be the first to try the innovation. They are venturesome, interested in new ideas and willing to take risks.
- **Early Adopters.** These are people who represent opinion leaders. They are already aware of the need to change and very comfortable adopting new ideas.
- **Early Majority.** These people are rarely leaders, but they do adopt new ideas before the average person. They typically need to see evidence that the innovation works.
- **Late Majority.** These people are sceptical of change, and will only adopt an innovation after it has been tried by the majority.
- **Laggards.** These people are bound by tradition and very conservative. They are very sceptical of change and are the hardest group to bring on board.
2.2 Diffusion of Hydrogen for Transport

Even though there is no reason to assume that the diffusion of hydrogen for transport is any different from other new technologies, there are two important characteristics which impact the diffusion.

- Hydrogen for transport is not a single product, but a composite of various related products: hydrogen as a fuel, FCEVs and a refuelling infrastructure. The supply side is not the exclusive domain of one supplier group, but requires a sophisticated balance between fuel, vehicles and a refuelling infrastructure.
- Hydrogen for transport features a high degree of political intervention as this development is the result of increasing environmental awareness, captured in European and national legislation. Low/zero emission mobility has become a major political focus point.

2.2.1 HRS and FCEV Synchronised Development

The development of fuel cell vehicles is propulsive: it is the transition from internal combustion engines to fuel cell vehicles (and other zero tailpipe emission vehicles) that contributes to reaching the environmental goals.

HRS infrastructure development is a pre-condition for a well-functioning hydrogen for transport market. Convenient HRS availability is a necessary prerequisite. Although innovators and early adopters may accept low HRS coverage, other target groups will have higher demands, especially as they will take the current refuelling infrastructure density as a reference.

Figure 2 shows that diffusion of hydrogen as a fuel involves complex technical, functional and behavioural interfaces.
1. FCEV Availability. The availability of affordable FCEVs is a constraint as these vehicles are slow in making their way to market. OEMs are striking a balance between full utilisation of existing technologies (as short-term environmental goals may also be reached using existing internal combustion engine technology) and the introduction of new technologies.

2. FCEV Customer Demand. Diffusion of technology is not just about technology availability, but also about its acceptance and use. Assuming that the majority of vehicle owners are technology neutral, FCEVs will have to compete with a variety of alternatives in terms of reliability, performance and overall user friendliness. Please refer to chapter 4 for a more detailed customer demand analysis.

3. Hydrogen Fuel Availability. Hydrogen production is not something new, but an existing industry with an estimated USD 100 billion annual turnover (2013) [3]. Hydrogen is used, amongst other things, to make ammonia, intermediates for the production of plastics and pharmaceuticals and in the oil-refining process. Most hydrogen is produced from fossil fuels by steam reforming, oxidation of methane or coal gasification whereas today only a small quantity is produced by other routes such as biomass gasification or electrolysis.

4. HRS Operator/Owner Business Case. Hydrogen distribution is a critical factor for success. Currently hydrogen has a specific business-to-business distribution mechanism. Hydrogen as a fuel requires an extensive network of refuelling stations. However, HRS can only be commercially developed if there is sufficient market potential.

A successful deployment of hydrogen as a fuel requires sophisticated synchronised FCEV and HRS development. FCEVs require sufficient HRS, HRS require sufficient FCEVs. With few or no places to fill up, there will essentially be no demand for FCEVs, and if no one owns such vehicles, there is little incentive to invest in an HRS network. Building the infrastructure requires large investments with uncertain returns. Even if private companies did have the funds to build the hydrogen infrastructure, their investment would be worthless if hydrogen cars turn out to be unpopular.

2.2.2 The Need for Government Intervention

Government intervention should be considered normal for innovations related to technologies and infrastructure that benefit the environment since, by their nature, these investments only allow for a partial internalisation of their profits by the innovator and therefore need at least temporary support. Government intervention is twofold:

- Government Intervention to Create Market Certainty. FCEV and HRS developments originate from environmental goals translated to emission-specific legislation for vehicles. Setting more stringent emission standards over time is an essential part of the acceptance of electrification as an inevitable development for future mobility.
- Government Intervention to Support Critical Investment. A desired acceleration of the development of zero emission vehicles may come with market shortcomings. The
abovementioned chicken and egg problem will be solved eventually, but this will take time. Governments can solve market problems by providing financial relief to corporations to stimulate the market for hydrogen vehicles and infrastructure.

Government intervention requires extensive understanding of market economics and private business case development. A successful intervention strategy results in a maximum effect using minimal resources, while maintaining a level playing field.

2.3 Economic Approach

With the after-effects of the recession still being felt, it is becoming increasingly apparent that the road to clean and efficient energy use is one of precarious compromise between technological, social and economic challenges. New technologies, such as the fuel cell, are the key for Europe achieving its environmental goals. Fuel cells come with not just a new technological challenge, but also the economic challenge to build a sustainably profitable fuel cell industry.

The S curve presented in paragraph 2.1 shows the traditional pattern of building up market share. It could also be regarded as the industry’s potential revenue curve. And, as with any new market development, long-term productive investments should direct opportunities along the revenue pipeline. Figure 3 illustrates the trade-off between investment and revenues during the various diffusion phases. The upper diagram shows recurring expenditure and revenue cash flow. The lower diagram shows cumulative cash flow over time.
Figure 3 shows the economic challenge facing the fuel cell: to overcome the funding gap, also referred to as the ‘Valley of Death’. It defines the period of time between a start-up receiving an initial capital contribution and when it begins generating revenues and reaches breakeven. The capital requirement during the Valley of Death period varies over time in both a quantitative (amount of capital needed) and qualitative (type of capital needed) way.

The fuel cell market has entered the pilot/early commercial phase. Investments up until this phase have been funded but still have to be recovered. The current real challenge lies in the further roll-out of both HRS and FCEVs, which involves an investment level well in excess of the total level of past investments. The Valley of Death funding requirement can be divided into the following elements:
The Low-Risk Element (LR). Investors can be confident that their investments will end up being repaid, even in a worst case scenario.

The High-Risk Element (HR). Investors see a potentially high-return business opportunity which also comes with a high level of uncertainty and default risk.

The Non-Profitable Element (NP). This part of the funding requirement is not (sufficiently) backed by expected future revenue streams and therefore cannot be commercially funded.2

The funding gap structure varies over time as overall market uncertainty decreases. Currently the fuel cell market potential is still unclear. Investments are qualified as high-risk or even non-profitable. One can imagine that once fuel cell vehicle technology is completely accepted and absorbed, the industry will become investment grade,3 allowing for more low-risk funding.

Government intervention can be expected to have an impact on the overall ability to overcome the Valley of Death in two ways:

- A consistent, coercive environmental policy favouring zero emission mobility in general and fuel cell vehicles in particular creates more market certainty. More market certainty creates more favourable funding conditions as the funding gap’s low-risk portion increases, while the high-risk and non-profitable portions decrease. This makes it easier for low-risk institutional investors to step in.
- Intervention may include government participation in the most challenging parts of the funding gap: the high-risk and non-profitable portions. Government’s financial participation may pave the way for commercial investors to step in as well. Government participation in these funding portions may not be financially profitable, but as it allows environmental goals to be achieved, it is potentially profitable in a socio-economic way.

2.4 FCEV and HRS Diffusion Enhancement

Government intervention may enhance the diffusion of fuel cell technology, FCEV development and, consequently, HRS roll-out. However, government intervention also comes with a risk of market disturbance and of affecting the level playing field. Governments face a complex challenge to not only establish a trade-off between policy and financial intervention, but also to invest in those parts of the total value chain where the expected effect is the most substantial.

---

2 The fact that some investments cannot be commercially funded is not always caused by the existence of a non-profitable part as such, but by the investment not being profitable (enough) within a certain period of time. Payback time is as important as return on investment – the longer the term the more insecure revenues become.

3 Investment grade refers to ‘A level of credit rating for stocks regarded as carrying a minimal risk to investors’.
Figure 4 shows a simplified version of the hydrogen for transport value chain. The blue arrows illustrate the hydrogen flow: from hydrogen production to hydrogen distribution (HRS) to hydrogen consumption (FCEV).

The blue boxes represent the hydrogen industry, HRS operators and FCEV drivers. The blue arrows indicate the hydrogen flow. The black arrows indicate other products and services that HRS operators and FCEV drivers need for their activities. The red arrows indicate the financial flows: money earned or spent. The syringes show that there are many parts of the overall value chain where support can be given in order to enhance HRS and FCEV diffusion.

In order to be able to distribute hydrogen to FCEV users, HRS owners have to invest in refuelling equipment and a suitable HRS location. Operational expenses include equipment maintenance, utilities (mostly electricity), location (permits, rent) and of course hydrogen procurement or production (if on-site production is applicable). Future hydrogen sales are the backbone of total cost recovery, including financing expenses.
HRS operators generate hydrogen revenues from FCEVs using their refuelling facilities. Obviously this will only happen if FCEVs are (widely) available and affordable. The FCEV total cost of ownership (TCO) consists of both capital and operational expenditure. The vehicle purchase price includes value-added taxes and in some cases special vehicle purchase duties. Operational expenses include road taxes, parking fees, insurance and maintenance costs. Most vehicle users take out a loan to buy their vehicle which makes interest payments a substantial part of the TCO.

The hydrogen for transport industry faces many challenges, competition being one of the main ones, in both the short and the long term.

- As long as (optimised) ICE vehicles and conventional hybrids meet environmental requirements, ICE technology remains tough competition. These technologies are fully proven, costs are fully predictable and the refuelling infrastructure is widely available.
- Alternative technologies such as plug-in hybrid vehicles (PHEVs) and battery electric vehicles (BEVs) are well ahead of FCEV development. They require a more decentralised recharging infrastructure allowing for a more gradual investment approach compared to an HRS network. BEVs are expected to improve driving ranges by increasing battery capacity. However, as this option comes with a higher vehicle weight, it is expected that BEVs will be mostly suitable for shorter distances. Due to the high material costs for BEVs with long range, FCEVs are expected to become cost competitive to such vehicles in the medium term.
- Hydrogen production via electrolysis (wind or solar) offers opportunities for a total zero emission fuel chain. However, zero emission produced hydrogen is currently more expensive and hence not economically attractive. This may change if the role of hydrogen production via electrolysis becomes more significant in the total renewable energy system (see Exhibit 2-A).

Exhibit 2-A: potential hydrogen power generation synergy

Hydrogen production via electrolysis creates potential synergy with variable power generation, which is characteristic of some renewable energy technologies. For example, though the cost of wind power has continued to drop, the inherent variability of wind is an impediment to the effective use of wind power. Hydrogen fuel and electric power generation could be integrated at a wind farm, allowing flexibility to shift production to best-match resource availability with system operational needs and market factors. Also, in times of excess electricity production from wind farms, instead of curtailing electricity production as is common practice, it is possible to use this excess electricity to produce hydrogen through electrolysis. Hence, it enables medium to long-term energy storage and to some extent also possibilities to regulate an energy system based on renewable sources.
There are several ways to stimulate FCEV and HRS diffusion. And there are several parts of the value chain where incentives will have an impact. The incentive effectiveness (in terms of goal fulfilment) depends on the nature of the incentive and the development phase in which the incentive takes effect.

CAPEX grants are very effective in bringing the funding gap down but they do not explicitly stimulate good performance. Furthermore, it is known that grants may stimulate entrepreneurship only up to a certain level. When exceeding the investment’s non-profitable portion, grants may become counter-productive as they may take away commercial incentives. Performance-related support offers financial relief while stimulating healthy performance.

Another challenge is to support those parts of the value chain where minimum resources create maximum environmental effects. In some cases this may be achieved by a 100% subsidy for HRS development. In other cases a vehicle subsidy may result in more significant effects as FCEVs contribute to cleaner air while generating HRS revenues.

This will be discussed further in chapter 5.
3 HRS Archetypes

3.1 Introduction and Objectives

The development of a bankable geographically comprehensive HRS network requires special public and private sector efforts, especially in the early commercial phase where a basic HRS network is required that faces the problem of underutilisation as the number of FCEVs will still be limited. HRS network development requires an approach tailored to the spatial, commercial and financial situation and opportunities of each specific HRS.

The objective of this chapter is to classify HRS development into distinct development categories and subsequently to analyse how public and private support tools can enhance these distinct developments. HRS development is slow because of a lack of sound business cases. This chapter focuses on the business case structure of various HRS types in order to determine which tools improve HRS feasibility and bankability. Chapter 6 demonstrates the effect of support tools on the overall hydrogen value chain.

3.2 HRS Archetypes

As is the case with traditional petrol stations, it is expected that HRS will appear in all sorts of forms: from very small to very large, from unmanned to full service, including shop sales. There are also multiple ways to supply hydrogen: from industrial production to on-site production. All these factors have a significant effect on an HRS business case, especially in the long term (commercial phase) when hydrogen reaches its maximum market penetration.

The impact of incentives on an HRS business case is specific to the HRS type. A small-scale, dedicated HRS in a rural area will find it harder to reach breakeven compared to a large-scale multi-outlet fuel station with an additional shop sales revenue stream. Different HRS types will also have different types of development through the various phases of diffusion.

HRS characteristics and analysis of the impact of tools will be conducted using three HRS archetypes. An HRS archetype serves as a model representing refuelling stations with more or less the same functional and commercial characteristics. The following HRS archetypes will be used:

- Rural Basic HRS. This is a very small HRS serving sparsely populated areas.
- Urban Basic HRS. This is a small to medium-sized unmanned HRS offering several hydrogen positions, allowing for back-to-back fuelling.
- Urban Full-Service HRS. This is a large multi-fuel and multi-service HRS – its business concept can be compared to multi-service petrol stations in urban or motorway areas.

Table 1 specifies some key market and performance indicators for each HRS archetype in their final (commercial) phase.
<table>
<thead>
<tr>
<th>Performance indicator/HRS archetype</th>
<th>Basic Rural</th>
<th>Basic Urban</th>
<th>Full Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRS size (peak capacity)</td>
<td>80</td>
<td>210</td>
<td>420</td>
</tr>
<tr>
<td>HRS commercial capacity at maturity (average hydrogen</td>
<td>56</td>
<td>168</td>
<td>336</td>
</tr>
<tr>
<td>throughput)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of hydrogen dispensers</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Multi-fuel</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Unmanned (um) or full services (fs)</td>
<td>um</td>
<td>um</td>
<td>um</td>
</tr>
<tr>
<td>Additional retail facilities</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Hydrogen supply: delivered (d), on-site production (op)</td>
<td>op</td>
<td>d</td>
<td>d</td>
</tr>
</tbody>
</table>

Table 1: Specification of HRS archetypes (final situation), based on H2 Mobility standards [4] [5].

The abovementioned archetypes will be used to analyse various HRS business cases. They are further explained in paragraphs 3.2.1 to 3.2.3.

### 3.2.1 Archetype 1: Rural Basic HRS

The Rural Basic HRS (RBH) is an HRS serving sparsely populated areas, with both local and through traffic. RBHs play an important role in establishing a comprehensive hydrogen infrastructure coverage. As its capacity is limited, an RBH type may also serve as an initial HRS in urban areas to prevent underutilisation during the pilot and early commercial diffusion phases. The RBH typically has only one dispenser position and requires a considerable waiting time to fuel consecutive FCEVs. The RBH with on-site production from wind, sun or biomass will bring new economy to outlying regions because of the fact that the energy needed does not have to be transported to the region. In other words the money stays within the municipality.

It is important that the energy system around such an RBH is integrated into the energy system of the RBH. System integration and demand aggregation will make the new energy system affordable.

A well-integrated RBH will create a new economy and also new jobs. European structural funds may support such initiatives alongside other clean energy stimulating instruments.

For the outlying regions of Europe such as the north of Finland and Sweden, an integrated RBH will bring the hydrogen economy within reach.
Hydrogen is delivered or will in most cases be generated on-site with a production unit, using water electrolysis, or small-scale steam methane reforming from biomass. On-site power may be generated using renewable energy sources such as solar or wind as an alternative to traditional electricity sources. On-site production eliminates all fuel distribution costs but increases the HRS capital cost compared to HRS using industrial hydrogen supply methods. And on-site production creates new business opportunities as illustrated in Exhibit 3-A.
The Van Peperstraten Group is developing a unique total concept concerning sustainable energy in the Netherlands. Greenpoint is a revolutionary initiative that brings agriculture, technology and innovation together to produce energy from natural resources without producing damaging waste. The roof of newly built farm sheds is ideal for installing solar panels and for collecting rainwater. Also the rinsing water (rainwater and wastewater) that ends up on the surrounding yard is easy to store in cellars under the shed. After purification, the water is used for hydrogen production and crop irrigation, a much cheaper and more environmentally friendly alternative to tap water, as this clean water saves about 15% on pesticides costs. The collected water is also useful to heat or cool the storage facilities using a heat pump. This pump and all the necessary equipment operate on the energy that is generated by the solar panels.

Greenpoint Holland-Zeeland will develop a sustainable alternative BP fuel station. Through electrolysis, the station will produce hydrogen as a fuel for passenger cars, buses, tractors and trucks. In the near future, the facilities will also be used for the storage of solar and wind energy in hydrogen. [6]

RBHs play an important role in establishing full HRS coverage, especially for countries with large, sparsely populated areas such as Finland and Sweden. RBHs are often stand-alone stations on dedicated plots. There is no specific business case argument to integrate RBHs within existing conventional petrol stations, other than the possible advantage of acquiring a plot with the proper land-use permits already in place. Potential synergies with other functions (such as agriculture as illustrated in Exhibit 3-A) may even make locations other than conventional petrol stations a more attractive alternative.
Compared to other HRS types, it is expected that RBHs take considerable time to reach breakeven. Demand aggregation opportunities are limited and there is no market for additional vehicle-related services. However, that does not mean that RBHs cannot become profitable at all. System integration with agriculture offers the potential for cost price reduction. HRS stimulation tools should not only provide financial relief, but also stimulate entrepreneurship leading to long-term sustainable business cases.

### 3.2.2 Archetype 2: Urban Basic HRS

The Urban Basic HRS (UBH) is an HRS serving more densely populated areas. UBHs play an important role in establishing full hydrogen infrastructure coverage. As its capacity is fairly limited, a UBH may serve as an initial HRS in an urban area to prevent underutilisation during the pilot and early commercial diffusion phases. The UBH has at least two dispenser positions allowing for back-to-back refuelling, with up to five minutes waiting time to fuel consecutive FCEVs.

![Figure 6: Impression of an Urban Basic HRS (intended as a ‘look and feel’, not as a blueprint).](image)

UBHs typically follow a cost price strategy. Stations are unmanned and offer no extra facilities such as convenience stores or a car wash. There is no specific functional need to integrate UBHs into traditional petrol stations. However, existing petrol station locations may become economically attractive, especially when ICE vehicles start to make way for zero emission versions causing a decrease in petrol demand and actually creating space for FCEV fuelling.

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4 The minimum level of required HRS facilities differs per country. In the Netherlands and Belgium, for example, low cost unmanned petrol stations are quite common, whereas in Sweden motorists expect a higher service level. This could also be resolved by integrating basic HRS into existing service stations.
UBHs offer the opportunity for phasing capital expenditure, starting with a single dispenser position and expanding when FCEV market penetration increases. However, there may be reasons to commit to forward investments nevertheless:

- Several dispenser positions will improve reliability, especially during the critical pilot and early commercial diffusion phases. HRS reliability is becoming a factor that is at least as important as HRS coverage. Exhibit 3-B shows that a lack of reliability may even become a threat to market diffusion progress.
- It may be commercially attractive to acquire a larger HRS plot and create facilities (such as storage) that are larger than strictly necessary in order to create (cheap) future expansion options. However, this type of forward investment typically falls within the private domain as it does not contribute to HRS reliability or the realisation of a minimum HRS coverage.

**Exhibit 3-B: A Real Life Situation to be Prevented**

‘While they enjoy driving their cars, early lessees of hydrogen fuel-cell vehicles in Southern California are complaining that they cannot reliably fuel them at the handful of stations now supposedly operating in their region. The stations are frequently inoperative, they say, closed for days or weeks at a time. Moreover, when the stations are functioning properly, they sometimes can only fuel one or two cars before an hour-long wait is required – and some stations can only fuel the cars to half-full.

A private Facebook group for drivers of the Hyundai Tucson Fuel Cell SUV overflows with complaints about these issues, and the lack of accountability among the several different parties who oversee pieces of the nascent hydrogen fueling infrastructure.

Hyundai includes unlimited free hydrogen fuel as part of its $499 monthly lease cost (with $3,000 due at signing). But neither Hyundai nor Toyota, which is in the process of launching its hydrogen-powered 2016 Mirai, is responsible for providing the fuel or ensuring a functioning infrastructure. Instead, that task falls to a variety of organizations that own or operate the stations. (…).

*Early lessee Paul Berkman of Corona del Mar, for one, is frustrated. He's paying $500 a month for a vehicle he has not been able to drive for five weeks, because all three hydrogen stations within 20 minutes of his home or workplace have been down for more than a month.*[7]
UBHs may fulfil a key role in pilot projects including demand aggregation. The typical UBH cost price strategy makes UBHs attractive to no-nonsense and cost-conscious ‘heavy users’ such as taxi drivers.

3.2.3 Archetype 3: Urban Full-Service HRS

The Urban Full-Service HRS (UFH) is an HRS serving more densely populated areas as well as motorway traffic. UFH offer a full service with at least multiple fuels and a convenience store. Additional facilities may include a car wash, restaurant(s), hotel/motel and a goods pick-up/delivery point. In the long term, FCEVs are the only zero emission option that secure extra service revenue streams as FCEVs require HRS, whereas BEVs can be charged at a number of different locations.

The UFH archetype has around four hydrogen dispenser positions (in the commercial phase) allowing for continuous back-to-back refuelling.

![Figure 7: Impression of an Urban Full-Service HRS (intended as a ‘look and feel’, not as a blueprint).](image)

From a commercial point of view it makes complete sense to integrate UFHs into existing full-service petrol stations, based on the assumption that that hydrogen will eventually become a major substitute for traditional fuels. It is common knowledge that retail sales generally contribute more to a fuel station operator’s profit than fuel sales.

UFH integration into existing petrol stations is a long-term solution. It requires well designed and fully integrated hydrogen storage, distribution and safety systems, and in some cases also changes in legislation. Obviously this also requires the cooperation of current petrol station owners, operators and suppliers. Currently Shell, OMV and Total are involved in such integration operations in Germany.
UFHs will most likely get their hydrogen supply delivered by truck, either as CGH₂ or LH₂ [8]. However, on-site hydrogen production has also become a serious alternative to truck deliveries. Exhibit 3-C presents a recent UFH development in Hamburg, Germany. Hydrogen is produced on-site through electrolysis, using energy from renewable and controlled sources. HRS offer new business opportunities, alongside the sale of hydrogen as a fuel. Exhibit 3-A and Exhibit 3-C show that entrepreneurship leads to new business models allowing for cost savings and/or additional revenues realised from various synergies.

Exhibit 3-C: New hydrogen filling station contributes to energy transition

‘With the ceremonial opening of its new hydrogen filling station in Hamburg, Schnackenburgalle, the Shell company declares its commitment to the development of a hydrogen infrastructure in Germany and worldwide. (…)’

*Shell is participating in the new H₂ Mobility Initiative – together with Air Liquide, Daimler, Linde, OMV and TOTAL – a massive expansion of the public hydrogen infrastructure, currently with 17 filling stations. The goal is a network of some 400 H₂ stations by the year 2023. Electric vehicles with fuel cells can then refuel in Germany. (…)*

*By storing electrical energy in the form of hydrogen, Shell contributes towards the success of the energy transition in Germany. Currently the storage of energy from unpredictable sources such as wind and solar power is an unsolved challenge (…)*

*With the new and innovative range offered at the Shell station in Schnackenburgalle, motor vehicles of almost all types are supplied the appropriate fuel: petrol, diesel, LPG, natural gas (CNG) or now even hydrogen.’ [9]

As with UBHs, UFHs also play a key role in demand aggregation, supporting the roll-out of HRS by creating an initial demand and preventing excess underutilisation. UFH facilities may contribute to a seduction strategy, offering FCEV drivers special benefits such as a free car wash, free convenience store items, and so on. In this way, UFH operators both stimulate hydrogen mobility and secure future revenue streams from additional services.

Urban HRS play a very important role in demand aggregation. In urban areas it is easier to identify target groups that match the level of HRS coverage in every diffusion phase. In the early commercial phase, with only a few HRS available, urban areas allow for demand aggregation among drivers and operators who use their vehicles almost exclusively for regional journeys, for example municipalities, public transportation companies and some commuters. HRS scaling-up
creates new target groups, those who use their vehicle in the area covered by the scaled-up HRS network.

### 3.3 HRS Capital and Operational Expenditure (CAPEX and OPEX)

#### 3.3.1 Current Expenditure Levels

HRS CAPEX and OPEX estimates vary across countries and locations, and with investment phase and HRS types:

- **Country/Location.** Fuelling station location costs vary significantly, as well as price-setting mechanisms for fuelling stations (public tendering, negotiated contracts).
- **Investment Phase.** The second generation HRS CAPEX (2020) is expected to be about 40% lower compared to the 2015 generation HRS (see paragraph 3.3.2).
- **HRS Type.** Hydrogen processing and storage requirements vary among the different station types. Generally HRS with on-site hydrogen production have a higher CAPEX (as it includes expenditure for on-site hydrogen production) and a higher OPEX (resources for on-site production, such as electricity) than HRS with delivered hydrogen. HRS with delivered hydrogen do not have any on-site production expenditure, but will have to purchase the hydrogen (as a gas or liquid).

Please refer to table 2 for CAPEX and OPEX estimates of the HRS archetypes, based on worldwide HRS research and development.

<table>
<thead>
<tr>
<th>Expenditure component/HRS archetype</th>
<th>Rural Basic</th>
<th>Urban Basic</th>
<th>Full Service</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural Basic</td>
<td>Urban Basic</td>
<td>Full Service</td>
</tr>
<tr>
<td>HRS capital expenditure (EUR million – 2015 level)</td>
<td>0.8</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>HRS asset economic life (years)</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Average hydrogen purchase price (EUR/kg)</td>
<td>n.a.</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>OPEX - fixed amount (EUR/year)</td>
<td>60,000</td>
<td>65,000</td>
<td>80,000</td>
</tr>
<tr>
<td>OPEX – variable amount (percentage of revenues)</td>
<td>12%</td>
<td>5%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 2: Specification HRS CAPEX and OPEX per HRS archetype, based on California Fuel Cell Partnership, Bundesamt für Energie, Electric Vehicle Transportation Center and McKinsey [10] [11] [12] [13].
HRS CAPEX indicated in table 2 include the following items related to HRS development at an existing petrol station site:

- compressors,
- hydrogen storage facilities,
- buffer storage facilities,
- sensors,
- dispenser(s),
- cooler(s),
- engineering,
- piping,
- electrical installations,
- audits performed by notified bodies,
- grounding certification by external body,
- pressure tests by external body,
- permitting, layout drawings, external risk studies,
- installation cost,
- labelling and documentation of all pressure and electrical components,
- dispenser spare parts (nozzle(s), hoses, break-away coupling),
- plant critical spare parts.

Not included are the following additional CAPEX items related to HRS development at new sites:

- fencing,
- roadworks,
- cameras,
- telephone/internet connection,
- lighting,
- civil engineering (piling, foundation),
- electrical/natural gas grid connection for electrolysis/steam reformer,
- site preparation,
- electrolyser (in case of on-site electrolysis),
- steam methane reformer (in case of on-site SMR).

HRS OPEX includes:

- energy costs (significantly higher in case of on-site electrolysis),
- service staff (in case of full service stations),
- location costs (land lease),
- maintenance costs,
- insurance costs.

The Rural Basic HRS archetype’s cost structure is different from the others, as it is the only HRS archetype with on-site hydrogen production. Assumed is an on-site production through electrolysis. The CAPEX and OPEX are relatively high as they include on-site production equipment (electrolyser) and production costs (especially utilities). In case of on-site electrolysis
raw material is limited to the supply of (demineralised) water. The economic life of HRS assets is currently estimated at 15 years.

The other HRS archetypes assume hydrogen delivery by (gaseous tube) trucks, which is compressed, stored and distributed. The hydrogen purchase price varies between countries and is currently on average around EUR 4 per kilogramme (including delivery costs).

The abovementioned expenditure levels have a significant impact on HRS bankability. The Hydrogen Integrated Business Case Impact Tool (described in chapter 6) is a tool that enables HRS business case simulation at various input levels. Simulations are tailor-made to the specific HRS, country and location specifications.

### 3.3.2 Expenditure Development

Expenditure levels are expected to reduce over time. In general, CAPEX is expected to decrease by about 40%-50% in the next 15 years [14]. The main cost reduction factors are:

- growing experience with HRS development [15],
- economies of scale as the number of HRS increases [15],
- innovative technology providing lower cost hydrogen compression, storage and dispensing alternatives [15],
- as more large-scale coal and coke IGCC (integrated gasification combined cycle) plants are built, further improvements and economies of scale can be expected leading to additional hydrogen cost reductions [13].

### 3.4 HRS Revenues

#### 3.4.1 Revenues from Hydrogen Sales

Hydrogen sale is the main HRS revenue source. Figure 8 shows the European cost targets for hydrogen generation: approximately EUR 10 per kilogramme in 2015 and EUR 5 per kilogramme in 2030 (exclusive of taxes and duties).
Figure 8: Hydrogen cost structure (source: McKinsey [13]).

This figure shows that the expected 50% cost reduction in 15 years is mainly caused by an expected shrinking retail margin. The underlying philosophy is that as a result of increasing market diffusion, HRS utilisation rates will go up, creating economies of scale.

However, our business case calculations (presented in chapter 6) show that:

- The pace of the retail margin reduction is very dependent on overall market growth and HRS utilisation growth – lower (realistic) growth curves allow for less spectacular price and margin reductions.
- A gross retail margin of approximately EUR 1 per kg is not enough to ensure long-term bankability. An average retail margin of EUR 2 is expected in a fully mature market situation. This corresponds with a EUR 6 per kg retail price – 40% lower than the current retail price level. Lower retail prices require lower production and transportation costs.

### 3.4.2 Other Revenues

HRS may have various income sources besides the sale of hydrogen. The most significant secondary income source is the station’s convenience store selling items such as confectionery, alcoholic and non-alcoholic beverages, snacks, grocery items and tobacco. As a reference, current full service petrol stations generate a significant part of their income from shop sales. Figure 9 shows the average annual shop sales at petrol stations in the United Kingdom in 2014. Shop sales at Esso petrol stations account for an average of GBP 1 million per shop.
Figure 9: Average annual shop sales at petrol stations in the United Kingdom in 2014, by brand (in 1,000 GBP (source: Statista [16]).

The relevance of shop sales (and other secondary revenue sources) for HRS development is however limited. The transition from ICE vehicles to FCEVs involves a replacement market and does not create extra shop income potential. However, shop sales may be a factor to be included in demand aggregation initiatives in the early market phase. A demand aggregation initiative is a combination of HRS development and the formation of a significant pool of drivers being stimulated to replace their ICE vehicle with an FCEV. If such a demand aggregation group is significant and the underlying HRS is situated at an existing fuel station already including a shop, it is likely that this specific HRS will generate extra shop sales income as the demand aggregation group will almost exclusively visit this specific HRS for refuelling (assumed that the
number of alternative HRS is limited). The extra (marginal) costs are negligible. As the relevance of shop sales for HRS development is dependent on specific local circumstances, shop sale revenues will not be quantified nor integrated in our economic tools. It is however a factor to be included in regional HRS development and demand aggregation negotiations.
4 FCEV Supply and Customer Demand

4.1 Introduction and Objectives

A geographically comprehensive HRS network in itself obviously does not contribute to the EU environmental goals. Replacement of ICE vehicles with FCEVs will lead to desired GHG reduction.\(^5\)

Customer demand stimulation is the backbone of strategies to accelerate hydrogen mobility in the early market phases. This will only work if such strategies are synchronised with industry and customer demand characteristics.

This chapter has the following two objectives:

- Explanation of the FCEV supply chain and customer demand characteristics.
- Identification of supply chain and customer demand related issues to be considered when formulating hydrogen mobility enhancement strategies.

4.2 FCEV Industry Overview

4.2.1 FCEV Characteristics and Contribution to GHG Reduction

FCEVs are electric vehicles comparable to BEVs. The main difference is the way energy is stored. Whereas BEVs use batteries for energy storage, an FCEV stores energy in its hydrogen fuel tank. A fuel cell converts the hydrogen into electrical energy, powering the electric engine. The moderate volumetric characteristics of hydrogen mean that it is compressed to up to 700 bar in a passenger car. Hydrogen has the best kWh/kg ratio of all fuels. The current standard to compress hydrogen to 700 bar in a passenger car means driving ranges are more or less comparable with ICE vehicles [17].

With a zero tailpipe emission level, FCEVs contribute to the EU environmental targets. It is expected that technological optimisation will allow ICE vehicles to meet EU emission standards in the foreseeable future. However, a problem may occur in the longer term. EU 2050 environmental targets allow for exclusive sales of zero tailpipe emission vehicles as of 2035. This is the reason why some EU Member States are preparing zero emission 2035 policies. According to these Member States, short-term EU CO\(_2\) allowances should be further reduced to enhance such policy strategies. See Exhibit 4-A.

\(^5\) The extent to which such replacements contribute to GHG reductions depends on the hydrogen production method.
Exhibit 4-A: Target Emission Facts and Goals

The EU policy responds to many of the identified priorities of the European Commission. Cars are currently regulated up to 2021. By 2021, phased in from 2020, the fleet average to be achieved by all new cars is 95 grams of CO$_2$ per kilometre. This means a fuel consumption of around 4.1 l/100 km of petrol or 3.6 l/100 km of diesel. The 2015 and 2021 targets represent reductions of 18% and 40% respectively compared with the 2007 fleet average of 158.7 g/km. [1].

According to ministers from the Netherlands, Sweden, Ireland and Finland, the EU should set challenging new fuel efficiency targets for new cars in 2025 to reduce motoring costs for consumers and tackle climate change. [18]

Thus, FCEV technology has a significant potential effect on GHG reduction. The challenge is to create a healthy and competitive FCEV industry, selling attractive vehicles to potentially large customer groups in a new zero emission mobility market.

4.2.2 FCEV Availability, Investment and Retail Prices

At present, FCEV availability in European countries is low. Most OEMs are still in the FCEV development phase.

Table 3 shows an overview of available and planned FCEVs. The only commercially available FCEV passenger car in Europe at the moment is the Hyundai ix35.

Toyota’s Mirai is already on sale in California and Japan and is expected to be available in the United Kingdom, Germany and Denmark by the end of 2015. In 2016, Honda is expected to release its first series production FCEV models on the European markets.

Daimler will follow in 2017, having already produced a series of 200 Mercedes F-Cell B-class type passenger cars for fleet demonstration purposes in 2010. The expected production quantities in the coming years are just a few thousand cars per manufacturer per annum. Besides that, only a small part of the FCEV production will reach the EU. For example: Toyota indicates that less than 5% of its annual total of 30,000 FCEV production will be available in the EU, with a focus on the German, British and Danish markets. OEMs tend to give priority to markets with the highest HRS coverage levels.
### Table 3: FCEV introduction years per OEM.

Even though current FCEVs are sold well below cost price, FCEV retail prices are high compared to ICE alternatives. Fuel cell technology development requires large amounts of capital, while the numbers of produced and sold FCEVs are still modest, allowing for limited economies of scale.

As a reference, the currently available Hyundai ix35 sells at a retail price level (after incentives, and including VAT) of around EUR 65k in Germany, GBP 53k in the United Kingdom and DKK 500k in Denmark.

Even though grants and tax exemption options are available, current FCEV price levels are still 20%-30% higher than same model ICE versions. Retail prices are expected to drop when sales volumes increase. It is expected that FCEV retail price levels will be comparable to ICE prices in the near future [13], [17].
4.2.3 OEM FCEV Technological Development Strategies

Most large OEMs are currently developing a variety of drivetrains, including ICE vehicles, BEVs, PHEVs and FCEVs. Interviews with representatives of Hyundai, Daimler and Toyota show that the development and commercial strategies vary among OEMs.

Initial FCEV development was started at individual OEM level. Nowadays most OEMs work closely together to further develop fuel cell technology – such as Toyota and BMW, or Ford, Daimler and Nissan. The scope for collaboration increases, and some Japanese OEMs now even jointly support HRS infrastructure development in Japan [20]. German OEMs have announced the joint development of new technology such as self-driving cars. One of the goals of joint development is the creation of a common technology platform which allows for lower production costs when production numbers go up. This is potentially beneficial to FCEV sales as prices are expected to go down.

*Fuel Cells in Passenger Vehicles*

Toyota’s strategy towards development of zero emission vehicles started with the introduction of the first hybrid model Prius in 1997. Toyota’s current strategy is focused on joint technological platform development which allows for production of all Toyota models in various drivetrain configurations (such as ICE, PHEV, BEV, FCEV), serving multiple markets and segments. This strategy comes with challenges as new configurations such as FCEVs require adjustments to this platform, which was initially developed for ICE applications. This means that current technology platforms are focused on ICE engine placing and reduction of vibration levels, whereas FCEVs require specific attention for hydrogen storage and electric propulsion. Once the joint technology platform is in place, significant cost reductions can be expected. For the time being, Toyota’s first commercial FCEV - the Mirai – is an FCEV-only model based on a flexible platform.

Hyundai has chosen to introduce its first FCEV based on its existing ICE ix35/Tucson model. The FCEV and ICE models are identical, even though their drivetrains are completely different. The next generation FCEV will be a fuel cell only model, as Hyundai aims to create a strong, unique FCEV identity. Hyundai set up a completely new production line for the ix35/Tucson fuel cell, which makes it possible to produce FCEVs in large quantities. The advantage of the Hyundai approach is that this OEM can scale up quickly if new market opportunities arise, mainly driven by HRS availability.

Daimler is expected to be the first non-Asian OEM introducing a commercially available FCEV on the European market. For Daimler, fuel cell technology is proven, as its B-type test fleet has shown to be reliable [21]. This OEM is currently working on the development of a D-type fuel cell model.

All OEMs interviewed stress the fact that FCEV technology is fully reliable. There are no technical or usage drawbacks compared to ICE vehicles or BEVs. Early Hyundai ix35 drivers confirm that
the FCEV is meeting and exceeding their expectations. Hydrogen Moves reports comparable first experiences [21]. Nissan’s FCEV test vehicles have reached over 200,000 km per vehicle [22]. Furthermore, OEMs try to take any possible doubts about quality and second-hand value away by providing full warranties and a guaranteed trade-in value. For this reason Toyota, for example, only offers its Mirai for leasing through affiliated dealers.

**Fuel Cells in Other Vehicle Types**

Even though OEMs have also developed fuel cell technology for heavy goods vehicles, some bottlenecks that were resolved for passenger cars still apply in this category. Fuel cell life is one of the largest issues. It is estimated to be around 5,000 hours, which is enough for a passenger vehicle, but not enough for city buses travelling for around 5,000 hours per year. This would require yearly fuel cell replacement, pushing up the TCO. However, recent successes have been achieved, with buses in California exceeding 20,000 hours of service on one single fuel cell [23].

Polymer electrolyte membrane (PEM, also known as proton exchange membrane) fuel cells with a stated lifetime of up to 40,000 hours exist, although the proven lifetime is around 30,000 hours. In several FCH-JU projects, long(er) life fuel cells for all kinds of heavy duty applications are being developed and tested.

Now that all major technological drawbacks are resolved, fuel cells are completely functional, reliable and long lasting. However, the cost price of the fuel cell components is still an issue [22]. OEMs have developed specific dedicated fuel cell component production lines for passenger cars. Such dedicated component production lines have not yet been created for heavy vehicles and vessels and, accordingly, component quality\(^7\) is not yet optimal.

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\(^6\) 5,000 hours of operation equates to 300,000 to 500,000 kilometres, which is comparable to the average lifespan of an ICE vehicle.

\(^7\) Quality defined as reliable performance between \(-40^\circ\text{C}\) and \(+40^\circ\text{C}\), allowing for required operating voltages for powering vehicle pumps, blowers, etc.
Table 4: Supply chain issues [24] [25].

Table 4, shows that passenger FCEV components are sufficient, while other fuel cell segments still face quality challenges. In all cases, component costs are relatively high and availability is not always optimal.

### 4.2.4 FCEV Standardisation and Production Cycle Impact

Production standardisation through OEM collaboration is a major strategic development. This offers efficiency opportunities for component suppliers, most of them delivering products to multiple OEMs. These expected efficiencies will also contribute to FCEV cost price reductions.

OEM collaboration is not limited to fuel cell technology development, but includes standardisation leading to early product cycle optimisation and a more flexible value chain, adapted to the market situation.

It is expected that when FCEV production volumes have reached current ICE vehicle levels, new FCEV models will be introduced and, accordingly, new production lines will be set up [26].
4.2.5 FCEV Commercial Roll-Out Strategy

Even though every OEM has its own specific FCEV model and geographical strategy (shown in table 3), OEM roll-out strategies have common characteristics.

- Testing: Proof of concept test fleet.
- Prioritising: Geographical roll-out sequence.
- Launching: FCEV retail model.

Proof of Concept Test Fleet

OEMs start commercial FCEV roll-out with the production and sale of a small test fleet. Such a test fleet serves as a proof of the concept: evaluation of technology sustainability and reliability, user friendliness and customer experiences. However, OEMs have different proof of concept approaches. Daimler for example introduced a limited test fleet of 200 Mercedes B-type FCEVs in 2010. Proof of concept experiences are used in the process of further development. OEMs such as Hyundai and Toyota use the first batches of commercially available FCEVs more or less as a test fleet: the FCEV concept is fully proven but early adopters’ experiences are closely monitored. For this reason Toyota chooses to offer its Mirai only through affiliated leasing companies.

Geographical Roll-Out Sequence

OEMs determine a roll-out sequence by evaluating national and regional market conditions. Existing market shares, FCEV grant scheme availability and HRS coverage are major factors. For this reason Toyota announced that the United Kingdom, Germany and Denmark will be first
launch countries in Europe. On a global scale, Toyota prioritised Japan (home market with HRS ambitions) and California (large scale HRS infrastructure investment programme [27]). Hyundai focuses on its home market of South Korea, and Europe. One could qualify such strategies as cherry picking. However, OEMs state that they already have fulfilled their side of the deal by investing large sums of money in FCEV development (see Exhibit 4-B). Now it is time for others to work on a fuelling infrastructure.

Another roll-out element is volume. Toyota estimates that it will be able to allocate only 1,000 Mirai FCEVs per year to Europe in the near future. Hyundai indicates that there are no volume restrictions as special production lines have been constructed in its South Korean production locations. However, it will take some time before these production lines are fully operational as it is generally recognised that a capacity utilisation rate of 85% is the minimum threshold of OEMs to be profitable [28]. In recent years some OEMs have managed to reduce breakeven utilisation rates to 75%.

**FCEV Launching**

As OEMs expect a high volume FCEV market in the long term, table 3 shows that they are choosing to launch fuel cell technology in popular high volume vehicle segments rather than low volume niche markets.

### 4.2.6 FCEV Pricing Strategies

Paragraph 4.2.2 showed that OEMs have invested extensively in FCEV development. These investments will need to be recovered by high volume FCEV sales. This explains why OEM focus on more popular car segments.

Limited HRS coverage is one of the main reasons why OEMs choose to scale-up production gradually. This strategy comes with lower capacity utilisation rates and limited economies of scale in the early introduction years. As a consequence, FCEV cost price levels are expected to remain high in the next couple of years. As a reference, Hyundai’s ix35 FCEV cost price is estimated at USD 150,000 [29]. FCEV cost price levels are expected to become similar to ICE vehicles at a production volume of approximately 100,000 vehicles per year [13] [30].

The Hyundai ix35 and Toyota Mirai sell at retail prices of around EUR 50k–60k. Even though these retail prices are well below cost price levels, FCEVs are still more expensive than comparable ICE alternatives. FCEV retail prices will go down once production levels go up and economy of scale opportunities occur. Meanwhile, OEMs expect public sector assistance bringing FCEV retail prices to competitive levels by the offer of financial incentive mechanisms, such as tax exemptions.
4.3 FCEV Customer Demand

At present, FCEV customer demand is low in Europe. Governments and certain companies are currently the most important launching customers. Hyundai indicates that 40% of its 250 ix35 models have been sold to governments and some 30% to companies. Launching customers belong to a group of users with a special interest in promoting FCEV technology and creating green transportation awareness.

4.3.1 General Customer Demand Characteristics

The main customer demand characteristics are:

- affordability,
- HRS availability and performance,
- FCEV safety,
- FCEV environmental features.

Affordability

Affordability is one of the main automotive market drivers [31]. It comprises a vehicle’s TCO, including retail price, taxation, depreciation, fuel costs and maintenance. Affordability is a main condition for commercial success, which also applies to FCEV sales [32].

As stated before, FCEV retail prices are some 20-30% higher than comparable ICE alternatives. As OEMs are aiming for high volume FCEV markets, retail prices will have to be pushed back down to competitive levels. Even though depreciation is the actual cost driver, retail prices determine loan levels for car purchase, which are limited by customers’ borrowing capacity.

For customers in general and professional large fleet owners in particular depreciation is a major purchase criterion. FCEV depreciation percentages are not yet known, as there is no second-hand FCEV market yet. Second-hand value depends on general market circumstances, but also on expected component replacement costs. Even though fuel cells are expected to last the full FCEV lifespan, the slightest risk of early fuel cell replacement may affect second-hand value. For this reason, Toyota places larger capacity batteries in its FCEVs allowing for partial instead of full discharging and therefore improving battery lifespan. Toyota and Hyundai offer customers second-hand value guarantees as a lump sum or through leasing packages.

Fuel is the second largest TCO component [33]. This makes fuel efficiency and fuel cost a major purchase criterion [31]. Hydrogen retail prices in Europe are around EUR 10/kg, which corresponds to a cost level of about EUR 10 per 100 kilometres. For BEVs, electricity costs are about EUR 2 per 100 kilometres, and a comparable petrol fuelled ICE saloon car costs about EUR 13 per 100 kilometres [34]. FCEV fuel costs are competitive compared to ICE fuel costs, but significantly higher than BEV fuel costs. In Europe, BEV fuel costs are relatively low as electricity
is taxed differently from fuel. Currently, most countries do not impose tax on hydrogen as a fuel. Such tax exemptions contribute to FCEVs’ commercial success by allowing fuel price levels to be competitive compared to alternatives with similar driving ranges.

Maintenance costs of FCEVs are expected to be lower than ICE vehicles as fuel cells do not require maintenance. Brakes and tyre maintenance are expected to be somewhat higher for FCEVs due to the higher torque. The same goes for the FCEV’s air filters which have to be replaced about every 10,000 kilometres given the fuel cell’s air sensitivity.

**HRS Availability and Performance**

European motorists are spoiled with having an extensive fuel station network. Sufficient HRS coverage can thus be regarded as a condition for successful FCEV scaling-up. The H₂Moves Scandinavia project shows that at least two operational HRS are needed within a given area to guarantee customer satisfaction. On top of that, a network of HRS should be available for longer distance driving [21]. Electric mobility research conducted over 20 countries worldwide shows that a reliable charging network is essential for creation of customer demand, regardless of the fact that most people usually drive short distances [35]. Thus, the watchwords are availability, reliability and performance. Where early adaptors are willing to accept HRS limitations, the early majority requires nearby HRS presence, short refuelling times and 24/7 performance.

**FCEV Safety**

If customers perceive an FCEV as unsafe, they will not purchase one. Even though fuel cell technology is completely safe and even safer than petrol fuelled vehicles, customer perception may be different [21]. In general it is recommended to address safety features in promotional campaigns in order to enhance customer acceptance [32] [36].

**FCEV Environmental Features**

Generally, customers prefer clean technology vehicles but are not willing to pay extra. In a Deloitte survey, 53% of respondents indicated a preference for green technology but regarded fuel efficiency and fuel costs as more important [31]. Only a small number of motorists are willing to pay more for a new, cleaner technology.

Many European fleet owners have a CO₂ reduction policy in place. A General Electric survey among 72 fleet owners (representing over 150,000 cars) found that 62% of fleet owners have active CO₂ restrictions in place and 13% of fleet owners use an environmental factor for car allocation [37]. Public fleet owners have become clean vehicle frontrunners, by ‘putting their money where their mouth is’. The city of Stockholm is a very good example of how a green government fleet also stimulates general clean vehicle demand [32]. This is also described in Exhibit 5-A.
When TCO is brought back to competitive levels and HRS coverage is satisfactory, the green FCEV features may create a competitive edge by promoting its zero tailpipe emission and recyclability as a feature. Zero emission hydrogen production (for example through electrolysis using electricity from renewable sources) may enhance these features even further.

### 4.3.2 Low/Zero Emission Vehicle Alternatives

Alternative low/zero tailpipe emission vehicle types are:

- BEVs, fully battery powered,
- PHEVs, optionally battery powered, and
- AFVs (Alternative Fuel Vehicles), equipped for biofuels.

**BEVs and PHEVs**

BEVs are fully zero tailpipe emission, PHEVs offer zero tailpipe emission as an option. The number of electric vehicle (EV) car models is increasing.

![Figure 11: 2012–2014 sales of electric vehicles, source: European Vehicle Market Statistics [38].](image)
Figure 11 shows that EV market diffusion varies across countries, due to differences in taxation and stimulation. The PHEV market share in the EU keeps increasing and reached a level of 1.4% of all new car sales in 2013. And in the case of Toyota, more than one-fifth of all new vehicles sold by the manufacturer in the EU were hybrid-electric [38].

Most BEVs have a limited driving range, with only Tesla’s model S having a theoretical driving range of more than 300 kilometres.

**Biofuelled AFVs**

Biofuels are produced through the so-called short-term carbon cycle, in which (amongst other things) atmospheric carbon is captured in biomass. The biomass is converted into biofuel. This biofuel is used by AFVs, which return the carbon to the atmosphere. The focus on biofuelled cars has mainly taken place in Sweden [32], but since biofuelled cars have not been successfully introduced in other countries, it seems that large OEMs have not continued to develop biofuelled AFVs. The Swedish car market alone is too small to support larger production quantities.

Furthermore, biofuel production capacity in HIT-2 countries is only sufficiently available for passenger car consumption in Sweden, Finland and Poland. In most parts of Europe the biostreams are too small to serve as a significant fuel source.

A small number of OEMs offer multiple biofuelled AFV models: passenger cars, light duty business vehicles, trucks and buses [39].

### 4.3.3 FCEV Competitive Analysis

The number of currently available FCEV models is very limited compared to BEV, PHEV and AFV alternatives. Fully hydrogen light-duty business vehicles are not available at this moment and only a number of hydrogen buses are being produced. As concluded in paragraph 4.2.5, FCEV European market diffusion is expected to be low in the next five years, even for AFV-focussed countries such as Germany, Denmark and the United Kingdom.

<table>
<thead>
<tr>
<th>Fuel cell segment</th>
<th>FCEV</th>
<th>BEV</th>
<th>Biofuel AFV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving range</td>
<td>+</td>
<td>−/−</td>
<td>++</td>
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<tr>
<td>Fuelling infrastructure</td>
<td>−/−</td>
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<tr>
<td>Total cost of ownership*</td>
<td>−/−</td>
<td>−/−</td>
<td>−</td>
</tr>
<tr>
<td>CO₂ tailpipe emission reduction</td>
<td>+/+/+</td>
<td>+/+/+</td>
<td>+</td>
</tr>
</tbody>
</table>

*Table 5: Qualitative FCEV/BEV/AFV comparison. *)Without government incentives.*
Table 5 gives a comparison between the various low/zero tailpipe emission alternatives. FCEVs and BEVs have the largest CO$_2$ impact but are more expensive than biofuel AFVs and have fuelling infrastructure issues. Without government incentives, FCEVs and BEVs have higher retail prices than AFVs.

Table 5 shows that the FCEV and BEV competitive position improves significantly when TCO and fuelling infrastructure issues are resolved. It is expected that FCEVs will serve high mileage groups while BEVs will be preferred for shorter range travelling.

AFVs are a good alternative in countries with good biomass availability, especially the northern and eastern parts of Europe. However, it is doubtful whether OEMs will continue their AFV product lines for a limited number of countries.
5 Hydrogen Infrastructure Challenges and Solutions

5.1 Introduction and Objectives

It is in the interest of both public and private stakeholders to accelerate FCEV market diffusion and HRS availability.

- Public stakeholders have a specific interest in reaching greenhouse gases reduction goals. Zero tailpipe emission FCEVs contribute to this goal.
- Private OEMs have invested large sums of money in FCEV development. They have a specific interest in creating a return on investment.
- Private HRS operators and investors will have to invest large sums of money in HRS development. They have a specific interest in creating sustainably bankable business cases.

The objective of this chapter is to establish a cohesive framework for customer incentives, financial support and technical efficiency.

5.2 Hydrogen Infrastructure Challenges

5.2.1 HRS Challenges

The largest HRS challenges are financial and technical.

1. Financial. HRS operators face a start-up period of HRS underutilisation. Funding is critical as the HRS financial Valley of Death is expected to be significant. HRS revenue potential depends on OEM FCEV roll-out strategies. HRS operators face an initial slow growth period, followed by an uncertain ramp-up. Financial issues mostly affect:
   - small-scale entrepreneurs – this group depends on external funding which is not available or comes with unfavourable terms and costs,
   - rural HRS operators – rural HRS face the double challenge of higher than average costs in combination with a slower expected growth compared to large-scale urban HRS.

2. Technical. Three main technical challenges are technical reliability, cost reduction and system integration.
   - Reliability. The Californian experience shows that HRS technical performance (availability, hydrogen fuel quality) may become an issue when the level of its use increases [7] [40].
   - Cost reduction. The challenge is to create economies of scale as the number of HRS increases.
• System integration. Electricity grid system integration creates extra value as it has the potential to contribute to electricity grid stability. System integration with other low emission fuel generation and the agricultural sector offers cost reduction potentials. Renewable sources can be used to produce both biofuels from waste as well as hydrogen.

5.2.2 FCEV Challenges

FCEV challenges occur in the production and sale fields.

1. Production. FCEVs are technically quite different from ICE vehicles. OEMs are developing technologies that efficiently exploit the potential of hydrogen for use in motor vehicles. As FCEVs require a dedicated technology platform, many components have to be designed. The production challenge is twofold:
   • developing integrated technology platforms in order to fully integrate FCEV production into the overall production lines, and
   • increasing production in order to profit from economies of scale and to reduce production costs.

2. Sales. A production increase is obviously powered by increasing sales. The most important sales issues are:
   • FCEV total cost of ownership. Even though FCEVs are currently sold well below cost price, their TCO is still significantly higher than ICE vehicles, PHEVs and BEVs. It is expected that it will take 10 to 15 years for FCEVs to arrive at a competitive TCO level [13]. However, tax exemptions and other financial incentives may shorten that period.
   • HRS availability. HRS availability consists of HRS coverage and HRS reliability (working HRS stations delivering high quality hydrogen). HRS availability is a main FCEV sales driver. Early adopter groups remain relatively small if being an early adopter comes with the inconvenience of driving extra kilometres to fill up. For that reason OEMs are expected to start FCEV roll-out in countries with the highest HRS coverage and the best FCEV incentive policies in place.

8 HRS provide energy storage potential - an important component of a future electricity grid with a greater percentage of variable generation from renewable sources such as wind and solar.
5.3 From Challenges to Solutions

The challenge for the overall infrastructure for hydrogen transportation is twofold:

- the challenge to establish and ensure maximum market growth for hydrogen mobility, and
- the challenge to ensure bankable HRS investment.

Figure 12 presents the funding challenge and highlights the critical period in hydrogen infrastructure development: the early commercial phase. Furthermore, figure 12 shows a framework for efficiency, incentive and support solution definition. This framework consists of solution categories, solution types, solution objects and solution scope.

Figure 12 is a representation of the hydrogen value chain presented in figure 4, organised by support category. Hydrogen value chain interrelations will be taken into account when formulating solutions.
Solution categories are:

- Regulatory. Regulatory solutions are general public law measures, for example: zero tailpipe emission vehicle taxation, CO₂ emission standards, but also HRS site permits and approval.
- Non-Regulatory. Non-regulatory solutions are more specific private law solutions such as government FCEV procurement and financial project participation.
- Promotional. Private sector solutions to enhance FCEV and hydrogen sales.
- Integration. Integration of HRS with other fuels.

Solution types are:

- Customer Incentives. Stimuli to encourage customers to change their behaviour.
Solution objects are:

- FCEVs. Solutions to increase FCEV customer demand.
- HRS. Solutions to increase HRS availability.

Solution scope consists of:

- Market Growth. Solutions to create and seize market opportunities.
- Investments. Solutions to make HRS business cases bankable.

The following paragraphs list a number of concrete solutions along the lines of the figure 12 framework:

- Paragraph 5.4 describes regulatory solutions.
- Paragraph 5.5 describes non-regulatory solutions.
- Paragraph 5.6 describes promotional solutions.
- Paragraph 5.7 describes technical solutions.
- Paragraph 5.8 shows how to establish regional implementation partnerships and public-private partnerships, given the variety of solutions and the variety of public and private stakeholders.

5.4 Regulatory Solutions

Regulatory solutions come under four categories: legislation, taxation, approvals and other incentives.

1. Legislation. This refers to CO₂ and other greenhouse gas regulation by law. It sets enforceable environmental standards.
2. Taxation. Another element of low/zero tailpipe emission vehicle demand incentives are tax breaks. Purchase, lease, road and fuel tax breaks make these vehicles more attractive to consumers compared to ICE alternatives.
3. Approvals. The HRS approval process includes permits and approvals to build.
4. Other regulatory incentives include special allowances for low/zero tailpipe emission vehicles, such as high occupancy vehicles and toll lane exemptions.

5.4.1 Fuel-related Regulatory Solutions: Importance of Tax Exemptions

The European Union harmonised its fuel taxation system across Member States. However, determination of the taxation levels falls within the competence of individual EU Member States. The current EU Energy Taxation Directive came into force in 2003. It sets a minimum taxation level for energy products. Even though this EU Directive does not consider the environmental importance of low/zero tailpipe emission transportation, it does provide the possibility for exemption for fuels from renewable energy.
Most Member States currently allow tax and duty exemptions for the sale of hydrogen for transportation. Such hydrogen fuel tax exemptions contribute to FCEV market penetration in two ways:

- Tax exemptions bring the FCEV TCO down. TCO competitiveness is ultimately the most important success factor for sustainable FCEV market growth.
- The psychological effect of tax exemptions leading to competitive hydrogen retail prices, compared to other fuels, can be powerful.

Even though an EU proposal to make a distinction between energy taxation linked to CO$_2$ emission and energy taxation based on the product energy content was not accepted – its philosophy could still be used in hydrogen fuel taxation [41]. Future hydrogen retail price reductions may be considered as a reason or opportunity to increase tax levels. Fuel taxation income is an important part of a national budget. There are two reasons to keep a permanent taxation difference between hydrogen and conventional fuels:

- It contributes to FCEV cost competitiveness and sales volumes, hence it contributes to the desire to reduce greenhouse gases.
- It reduces long-term social costs as the result of pollution. Tax and duty exemptions should not be regarded as ‘costs’ but rather as ‘investments’ that pay off in lower long-term costs to society.

5.4.2 FCEV-Related Regulatory Solutions: Emission Targets and Taxation

Chapter 4 concluded there is a need for customised provisions tailored to the specific needs of early adopters. Regulatory incentives stimulate customer demand by discouraging polluting vehicles and encouraging low/zero tailpipe emission alternatives. This can be done through a variety of regulatory incentives.

**Legislation**

EU legislation sets mandatory emission reduction targets for new cars. This legislation is the cornerstone of both the EU strategy to reduce greenhouse gas emission and the hydrogen for transportation industry to create new low/zero tailpipe emission vehicle markets. EU legislation requires that new cars registered in the EU should not emit more than an average of 130 grams of CO$_2$ per kilometre by 2015. By 2021 the fleet average to be achieved by all new cars is 95 grams of CO$_2$ per kilometre [1]. Furthermore, the EU car labelling directive [42] requires a label showing a car’s fuel efficiency and CO$_2$ emissions. However, EU and national legislation do not favour zero tailpipe emission vehicles over ICE vehicles. It is expected that ICE technology optimisation will keep pace with EU environmental standards, at least in the coming decades.

Currently, the state of California is the absolute frontrunner in CO$_2$, NO$_x$ and PM regulation. Its regulatory system is based on US Environmental Protection Agency (EPA) standards, but the
emission standards are more stringent than EPA requirements. The Californian system is based on the following principles:

- The state defines Low Emission Vehicle (LEV) standards. Each standard has several targets depending on vehicle weight and cargo capacity. New LEV standards, with more stringent CO\(_2\), NO\(_x\) and PM allowances are added about every five years. At the moment LEV I, II and III apply. Permissible emission values are well below the EU targets mentioned above.
- OEMs are required to produce a percentage of vehicles certified to the more stringent LEV standard categories, according to schedules based on vehicle fleet emission averages for each manufacturer.

The Californian system works because California is a main automotive market which allows for trend-setting policies. The system also works because the introduction of low tailpipe emission vehicles is not just enforced through legislation, but also stimulated by incentives.

**Taxation**

Vehicle taxation structures and levels vary across European Member States. In most cases, vehicle taxation is a substantial part of a vehicle’s TCO. This also makes taxation a powerful regulatory instrument to stimulate low/zero tailpipe emission sales, especially to private individuals and users of company cars for private purposes. Taxation as a regulatory instrument is less suitable for FCEVs used for business purposes as in those cases taxes are deductible anyway.

OEMs currently sell their FCEVs at price levels comparable to ICE vehicles - well below FCEV cost price levels. EU Member States’ vehicle tax exemptions allow for the introduction of FCEVs at retail prices comparable to ICE vehicles.

**Examples:**

- Denmark allows full tax exemption for FCEVs ensuring a 180% tax and 25% VAT reduction compared to conventional vehicles. This enables competitive FCEV market introductory price levels.
- Sweden allows for an approximately EUR 5,000 VAT reduction for vehicles with CO\(_2\) emission levels below 50 g/10 km. A EUR 0 road tax for vehicles with an energy consumption rate below 37 kWh/100 km (normally EUR 200-400) applies for the first five years from the date of their first registration.
- Norway allows for 0% VAT on FCEV purchase (normally 25%). Furthermore, 0% import duties apply to EVs (normally 50%-100%). These tax exemptions apply until 2018 or until the target of 50,000 electric vehicle sales has been reached.
Retail prices are the result of OEM net FCEV prices and government taxation. OEMs tend to set lower net prices in countries with high taxation levels. Even though tax exemptions may lead to higher net FCEV price levels, they are an essential condition for increasing FCEV sales.

One major concern is the duration of public commitment through tax exemptions. Taxation has a double nature: it is both a clean vehicle incentive mechanism and a major public income source. FCEV market diffusion can only be successful if FCEV price levels stay sustainably competitive with their ICE alternatives. Tax exemption levels can be lowered if FCEV net price levels go down and/or if ICE alternatives are no longer allowed or available.

Another concern is the tax exemption effect on second-hand FCEV value. As a reference, BEV second-hand prices are lower for BEVs bought at subsidised prices than BEVs bought in markets without such support [43]. In other words: grants reduce the FCEV purchase price, but their effect in TCO terms (depreciation rate) may be significantly less. This may lead to market distortion: first time buyers face higher depreciation levels leading to lower second-hand value. When tax exemptions are lifted, new FCEVs may become too expensive compared to a relatively new second-hand vehicle that was originally bought with grant support. OEMs play an important role in ‘protecting’ vehicle second-hand value (discussed further in paragraph 5.6).

**Other Regulatory Incentives**

Tax exemptions can bring FCEV retail prices to a level comparable to their ICE alternatives. Other regulatory (and non-regulatory) incentives can compensate FCEV drivers for current inconveniences such as limited HRS coverage. Other regulatory incentive options, derived from worldwide experience, include:

- free parking for FCEVs,
- mandatory FCEV deployment in public transportation concession tendering procedures,\(^9\)
- permission to use public transportation lanes or high occupancy lanes at all times,
- voluntary vehicle retirement programmes – paying vehicle owners a sum of money if they retire their ICE vehicle early from operation and buy a zero tailpipe emission alternative,
- introduction or extension of environmental zones – allowing only low/zero tailpipe emission vehicles,
- congestion charge exemption for low/zero tailpipe emission vehicles.

\(^9\) Usually, public authorities are required to adhere to technological neutrality in tendering processes. However, exceptions are possible if a specific technology requires a market boost. The City of Stockholm for example executed a specific electric vehicle strategy, described in Exhibit 5-A.
5.4.3 HRS-related Regulatory Solutions: Faster Permitting

For the realisation of HRS, environmental and building permits are required. One of the main objectives is reducing risk to people and the HRS environment to an acceptable level. Permits are usually issued at municipal level.

The European Clean Power Directive, which will have to be integrated into national laws, covers specific HRS requirements, the most important being:

- The hydrogen purity dispensed by HRS shall comply with the technical specifications included in the ISO 14687-2 standard.
- HRS shall employ fuelling algorithms and equipment complying with the ISO/TS 20100 Gaseous Hydrogen Fuelling specification.
- Connectors for motor vehicles for the refuelling of gaseous hydrogen shall comply with the ISO 17268 gaseous hydrogen motor vehicle refuelling connection devices standard.

Permitting costs usually account for 3%-5% of total HRS capital expenditure. However, it is not so much the permitting costs that are an obstacle, but the permitting process duration.

Figure 13: Detailed station progress as of 1 June 2015 per GO-Biz and Energy Commission – California. Source: California Environmental Protection Agency [40].
Figure 13 shows that a majority of HRS in California are still in the permitting stage. Approval periods used to take months or even years. Shortening the permitting timelines contributes to both timely HRS availability and HRS business planning optimisation as permitting time becomes more predictable.

For many permitting agencies HRS are completely new; they need time to become familiar with HRS technology and safety and to translate European Clean Power Directive requirements in local approval processes.

Approval processes can be enhanced in two ways:

- establishing early first contact between HRS developers and permitting agencies,
- establishing national HRS permitting expertise centres, assisting local permitting agencies with knowledge, best practices and identification of potential hurdles.

5.5 Non-Regulatory Solutions

Appendix B gives an overview of frequently used non-regulatory incentives. The following paragraphs discuss the potential of additional incentives to resolve both HRS development and FCEV roll-out issues.

5.5.1 Increasing FCEV Demand: Governments as Launching Customer

Regulatory incentives, especially tax exemptions ensuring competitive FCEV pricing, are very powerful tools to stimulate FCEV demand. However, there is more that public stakeholders can do. Most governments are also fleet owners. And, being guardians of the EU air quality goals, it makes sense to improve the environmental performance of their own vehicle fleet by procuring cleaner vehicles.

Their role as environmental protagonists and the fact that their fleet is substantial and mostly used locally, makes regional and local governments perfect launching FCEV customers. The Stockholm example in Exhibit 5-A shows that it is actually possible to use joint purchasing power to make fleets cleaner and to enhance clean technology market diffusion.
Exhibit 5-A: Best Practice Stockholm: - The city’s vehicles as a driving force

A Clean Vehicles in Stockholm programme has been run by the Environment and Health Administration of Stockholm since 1994 to speed up the transition to clean vehicles and renewable fuels. In 2011, the City Council approved an Electric Vehicles Strategy, in order for Stockholm to become one of the world’s leading clean vehicle cities by 2030.

The joint procurement was initiated by the city of Stockholm and the state-owned utility company Vattenfall to demonstrate Sweden’s purchasing potential to manufacturers of EVs and PHEVs, to contribute to a quieter and cleaner fleet and to enable Swedish organisations to buy or lease EVs or PHEVs under optimal conditions. Swedish procuring entities (municipalities and county councils) and private organisations were invited to participate in the joint procurement process. The joint procurement approach was applied for several reasons:

- to reduce administrative costs for the participating organisations,
- to achieve price reductions (although in this case, prices did not vary much),
- to send a strong demand signal to the market,
- to ensure that smaller municipalities would have access to such vehicles, as bidders may not otherwise be interested in such small calls for tender.

As of 2015, the total clean vehicle fleet in the Stockholm area, which is composed of both publicly and privately owned cars, numbers about 180,000. The clean vehicles programme has been successful in stimulating the introduction of new technologies [44].

The most important lessons learned from the Stockholm joint clean vehicle procurement are [44]:

- Deploy a two-phase procurement process which gives enough preparation time for both buyers and suppliers.
- Consider a first year trial phase, allowing users to include their first time experiences in subsequent delivery specifications.
- Try to involve multiple partners – thus increasing both purchasing power and the public procurement knowledge base. Focus mainly on public buyers in the first rounds.
- Make sure OEM bidders have sufficient knowledge about public procurement procedures to prevent non-compliant offers leading to exclusion.
- Be realistic about the number of vehicles to be purchased.
- Be realistic about the restrictions of new technology vehicles. In case of FCEVs: be realistic about limited HRS availability in the wider region.
5.5.2 Demand Aggregation: ‘Killing Two Birds with One Stone’

The early HRS development dilemma is twofold:

- Early HRS have no or limited revenues because of limited FCEV availability. This may require governments to provide grant support.
- Grant support may stimulate HRS availability, but not HRS use. Capital expenditure grants do not directly promote FCEV mobility.

Demand aggregation is one single solution that tackles both abovementioned dilemmas. Demand aggregation shifts the focus from supporting HRS with grants to supporting FCEV procurement, leading to HRS revenues from actual HRS use. A demand aggregation strategy prevents a situation in which HRS burn money as a result of underutilisation.

Exhibit 5-B: ING Bank orders 51 BMW i3 electric cars

ING has launched the pilot ‘100% Electric Mobility’ with 51 car drivers and the fully electric BMW i3. With this pilot, ING wants to gain experience with 100% electric driving and contribute to reducing CO2 emissions.

Participants in the pilot had to be Amsterdam-based and live within a radius of 45 kilometres from work. The drivers could charge their EV at home using their own home charging point (provided by ING). At the headquarters buildings of ING in Amsterdam 90 charging points were installed. Furthermore, ING supported the EV motorists by providing ICE vehicles if required, for example for longer trips such as a holiday abroad.

The company reports that aside from the 51 drivers there is a waiting list as well. Participants share their electric driving experiences through surveys and other internal media.

ING is one of the first companies to announce a fleet of electric vehicles, others are expected to join in the future. In September 2015, ING Belgium also started leasing several BEVs [45].

Paragraph 5.5.1 shows that joint public vehicle procurement (a form of demand aggregation) can be successful. Public entities are good potential launching customers. However, private early adopters play an important role, as scaling up requires more extensive purchasing power.10

10 Extensive FCEV demand is required to offer HRS developers enough revenue sources and offer OEMs enough FCEV market potential.
A key factor for success in organising demand aggregation is local knowledge of user groups and car fleets that are potentially suitable to make the transition to FCEVs in the current situation with low HRS network coverage. Early private demand aggregation participation can be organised as follows:

- Identification of car fleet owners with a substantial fleet that is mainly used on a local/regional basis – preferably companies with a special interest in promoting themselves as green companies that care about the environment. Exhibit 5-B gives a good example of how a group of ING Bank employees switched to electric driving.
- Identification of individual potential early adopters: local regional drivers within the HRS catchment area. Exhibit 5-C gives a good example of how individual car drivers were identified and enticed to participate in a peak traffic avoidance project.

Exhibit 5-C: Best Practice: How to Recruit Mobility Project Participants

A major mobility demand management measure in the Rotterdam Port area is a peak traffic avoidance programme, encouraging frequent users of the A15 motorway area to avoid this area during rush hour. A dedicated regional traffic management organisation tendered the participant recruitment process. Car drivers were recruited in two ways:

- Information from traffic surveillance cameras was used to identify vehicle drivers frequently using the A15 motorway during rush hour (in accordance with applicable privacy laws). Those users were contacted by direct mail.
- A promotional campaign was started including internet registration options.

Participant rewards included:

- a fixed sum of money (starting at EUR 5) for every time rush hour was avoided,
- providing customised provisions: a smartphone with easy access to alternative transportation information.

In total more than 2,000 participants were involved. A minority dropped out early because of housing or work relocations, or dissatisfaction with the transportation alternatives.

Key demand aggregation success factors are:

- participants have to be fully compensated for the extra costs of (early) participation (the higher TCO of FCEVs compared to ICE vehicles),
participants need to be fully relieved of typical early adopters’ burdens such as possible worries about technical performance or second-hand value,

- early OEM involvement is required to make sure that the required number of FCEVs will be available.

Focusing solely on private passenger cars is not the only way to aggregate demand. For example, early HRS could be designed to serve ‘anchor fleets’ of fuel cell buses, providing predictable early demand for hydrogen at a limited number of well-utilised HRS. To create a bridge to passenger car markets, anchor fleets could be located in cluster cities offering a potential for private FCEV adopters.

### 5.5.3 HRS Financial Support: From Availability to Performance

HRS bankability is one of the biggest concerns during the early commercial phase. Most early HRS face the double disadvantage of high CAPEX levels and low income levels as a result of underutilisation during start-up. The following financial support instruments can be used to offer financial relief:

**Capital Expenditure Grants**

CAPEX grants are the most common form of HRS financial support at this moment. CAPEX grants, usually one-off payments, reduce HRS depreciation costs and external funding needs. CAPEX grants stimulate HRS development, not HRS use, and are therefore the best financial support option for establishing a basic HRS infrastructure in a period of limited FCEV availability.

**Operational Expenditure Grants**

OPEX grants cover fixed operational expenditure in periods of underutilisation. As is the case with CAPEX grants, OPEX grants are focused on bringing HRS operators’ costs down rather than stimulating HRS revenues. This is most effective in periods of limited FCEV availability.

**Performance-based Contracting**

Performance-based contracting is a type of contracting where recurring payments are made in return for an agreed HRS performance level. The grant giver and HRS operator agree on a set of HRS performance criteria such as HRS back-to-back capacity, response times in case of HRS default, customer satisfaction, etc. The certified HRS management system and customer surveys can be used for measuring performance. The HRS operator receives full payment if all performance criteria are met. Payment deductions apply in case of non-compliance. The system may also allow for bonus payments, for example if the HRS is compliant over a longer period or in case of outstanding customer satisfaction. Performance-based contracting stimulates HRS performance rather than just HRS availability and is a good alternative to CAPEX and OPEX...
grants, especially when utilisation rates increase. Scaling up HRS use may lead to technical performance issues. Performance-based payments are a funding source for the HRS operator, while offering the grant giver HRS performance certainty. Performance-based payment mechanisms are common practice in Design-Build-Finance-Maintain PPP projects, where public authorities pay contractors for infrastructure performance rather than just construction. In (road) infrastructure projects the term ‘availability payment’ is used, where ‘availability’ also includes performance criteria [46]. Performance-based contracting requires more extensive contract management as performance has to be evaluated regularly, corresponding payment levels have to be set and possible disputes may occur.

**Take-or-Pay Contracting**

Take-or-pay contracting is a contracting mechanism frequently used in situations that require large investments while there is only a small client base. The seller depends on just a few buyers to generate income to recover expenditure. Such business cases are usually not bankable without provisions that ensure a minimum level of revenues. The HRS operator and its counterpart agree on a realistic HRS sales volume for a period of time (the HRS S curve). If sales fall below the agreed volume, the counterpart will pay a penalty price per kilogramme of hydrogen below the agreed level. The penalty price should at least cover fixed HRS expenditure (debt service and fixed OPEX). The HRS operator gets income certainty, and its counterpart only has to pay if sales stay below the agreed level. The counterpart (which could be a government) participates in the HRS risk. The risk is capped (to the agreed sales volume) and the counterpart will only pay if the risk occurs – which is different from a CAPEX grant where unrecoverable lump sum payments are made. Take-or-pay contracting can be volume based, price based or both. It is an effective and efficient way to support HRS development in a period where FCEV volume growth is critical in the sense that HRS may become financially self-supporting unless FCEV volumes remain low. Take-or-pay contracts are not effective if the forecasted volume is low, in which case a CAPEX grant is a better alternative. Take-or-pay contracts have proved their worth, especially in energy projects with just one buyer [47].

**Demand Aggregation**

As discussed in paragraph 5.5.2, demand aggregation is a very powerful tool to create groups of early FCEV adopters. Their need for fuel generates early HRS commercial market income.

**Soft Loan Funding Assistance**

The abovementioned HRS financial support tools are cash flow tools, leading to additional HRS income or reducing HRS expenditure. This improves HRS bankability in an indirect way. However, it is also possible to improve bankability by direct participation in HRS funding. A soft loan is basically a loan on lenient terms and conditions compared to regular senior debt. Soft loans can improve bankability in two ways:
STRATEGIC CORRIDOR ANALYSES AND PLANS

- their junior position\(^{11}\) offers senior debt investors extra comfort which improves senior debt options and conditions,
- a lower interest rate provides ‘cheap money’, bringing debt service volumes down.

Soft loans are funding capital, meaning that the lender receives interest payments and eventually repayment of the principle amount.

Support Packages

The financial support instruments can also be combined into support packages. For example: a combination of demand aggregation (to create HRS revenues) and take-or-pay contracting, protecting operators from lower hydrogen sales in case too many people resign from the demand aggregation programme.

Also a combination of revenue-based support and investment-based support may be a cost effective solution as it effectively reduces the risks perceived by investors and combines the advantages of both policy instruments \([48]\).

**NOTE:** As financial performance and funding are among the main HRS development issues, a calculation tool (HIBIT) has been developed to demonstrate the impact of the abovementioned HRS financial support tools. Please refer to chapter 6 and Appendix C for more information.

5.6 Promotional Solutions

Hydrogen fuelled mobility promotion falls well within the OEMs’ and HRS developers’ fields of expertise. However, there are some important success factors worth mentioning.

*Fuel Cell Electric Vehicles*

As mentioned before, TCO is a very important factor influencing consumer buying behaviour. Most TCO factors are fairly predictable. However, second-hand value is hard to predict. New technology comes with customer uncertainty about component sustainability. For example: BEV depreciation is relatively high because of expected battery replacement after five to ten years. FCEVs are believed to have a lifetime comparable to ICE vehicles. However, as long as there is no settled second-hand market and no proven statistics, customer perception remains a dominant factor. This is the reason why OEMs choose to offer FCEV leasing or a guaranteed second-hand FCEV value. Such a guaranteed second-hand value is important for three reasons:

\(^{11}\) A junior position means that the loan has a lower repayment priority than other debts in the event of HRS financial default.
- it offers first time FCEV buyers TCO certainty,
- it offers first time FCEV buyers special privileges such as all-in lease contracts including unlimited hydrogen refuelling,\(^\text{12}\)
- it prevents ‘cannibalism’ effects when government grant schemes end and new FCEVs become relatively more expensive than relatively new second-hand FCEVs bought with grant support.

**Hydrogen Refuelling Stations**

Even though it seems that developing HRS is quite a burden, especially at the very early stages, HRS also offer potential for new contemporary business concepts. Increasing environmental and health awareness (refer to Exhibit 5-D).

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**Exhibit 5-D: Example of Changes in Customer Behaviour**

*The Organic Food and Beverages market in Europe is expected to grow on the basis of revenues at a compound annual growth rate of 6.83% over the period 2014-2019 (...)*

*According to the report, a rise in awareness among consumers of the various health benefits of organic over non-organic food and beverages is one of the major drivers in the Organic Food and Beverages market in Europe. This has led to an increase in spending among consumers who are becoming savvy in their choice of food products [49].*

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Big consortia such as H\(_2\) Mobility in Germany are backed up by powerful world players, including Shell, Linde and Daimler, with development and funding power. Local entrepreneurs, however, may have a hard time raising funds. Such innovators could be supported by green funds providing access to capital. This will be discussed further in paragraph 5.8.

**Joint Promotion**

Demand aggregation, as described in paragraph 5.5.2, requires public and private sector, OEM and HRS operator involvement. Demand aggregation projects are good candidates for promotional activities, for example ads placed on vehicles promoting both FCEV and local HRS availability as a tool to increase local customer demand.

\(^{12}\) As in the Californian example.
5.7 Organisational Integration Solutions

*HRS Integration in Existing Petrol Stations*

The organisation of HRS integration in existing petrol stations is determined by:

- fuel station ownership vs. operation,
- the petrol station owner’s commercial strategy.

Petrol station ownership/operations can be roughly divided into three main categories:

a. owned and operated by a local operator,

b. owned by an oil company, operated by a local operator, and

c. owned and operated by an oil company.

Also, franchise formulas are frequently used. A franchise formula includes locations owned by local operators applying oil company owned business concepts. In practice, as oil companies tend to increase the franchise scope (fuels, shop, additional services), franchise formulas resemble the oil company owned/dealer operated organisational structure.

HRS integration in existing petrol stations can be done in different ways, depending on the ownership/operation structure.

**Figure 14: HRS integration approaches.**

**Figure 14** shows four approaches for HRS integration into existing petrol stations.

- Top-Down Approach. A top-down approach means that the oil company is (one of the) HRS initiator(s). HRS are developed at company-owned locations or integrated into franchise contracts. This allows for national programmes such as the H₂ Mobility programme in Germany, a joint venture business model to establish a hydrogen infrastructure in Germany.
• Bottom-Up Approach. Local operators (not being location owners) require owner permission or, even better, full owner cooperation for HRS development at existing petrol station locations. The HRS can be integrated into the overall concession or contracted separately into an HRS concession or land lease construction. Funding could be provided either through the oil company or the local operator.

• Third Party Approach. Third party developers/operators, such as OMV, Air Liquide and Linde, build HRS, which are then operated by either themselves or by petrol station operators. HRS concession and/or land lease constructions apply in case of third party HRS operation.

• Local Owner Approach. Local petrol station owners/operators have the option to initiate and fund HRS integration or to involve third party HRS developers through a concession or land lease agreement.

The significance for HRS support tools lies in the integration type. A local owner approach without oil company backup may be more difficult to fund. Also, smaller-sized third parties may face bankability issues if not backed by a financially strong parent.

Therefore, HRS financial support instruments (discussed in paragraph 5.5.3) are of particular importance for local and regional stakeholder initiatives. Regional support arrangements can contribute to regional HRS development by providing access to affordable funding options.

System Integration Options

System integration refers to integrating multiple hydrogen related applications to cut costs or generate extra income, such as using methane from agricultural waste to produce hydrogen or using HRS hydrogen storage for electricity grid stabilisation. Please refer to paragraph 7.4 to learn more about system integration potential.

5.8 The Key to Implementation: Public-Private Partnerships

The previous paragraphs show a wide variety of solutions to stimulate FCEV mobility and HRS availability. Solutions are more efficient and effective if harmonised and tailored to specific project needs. This requires partnerships at various implementation levels.
Figure 15: Organisational implementation blueprint.

Figure 15 shows an organisational implementation blueprint. It is a cohesive framework of public and private goals and means, focused on green programme and project implementation. Green programmes and projects are not limited to hydrogen infrastructure but may include various green initiatives contributing to policy implementation. This blueprint shows three implementation levels (national, regional and regional/local) and two stakeholder categories (public and private).

**National Level**

GHG reduction goals are set by the national government in a regulatory framework. Also, general fiscal stimulation policies (such as tax exemptions for low/zero tailpipe emission vehicles) are set on a national level. This mix of regulation and stimulation forms the basis for implementation. The European private sector is also working on sustainable development through corporate social responsibility.
Regional Level

Green project implementation starts at the regional level. Regional programme partnerships and deals are the backbone for implementation. A Green Deal is a multi-annual public-private agreement to go green in specific business sectors or regions. HRS development could constitute such a Green Deal.

A Green Deal needs to be specific. Hence, it needs to be translated into a green programme, which includes expertise and network development. In case of HRS, an HRS permitting expertise centre could be such a development. Furthermore, green funding deals are required to ensure programme and project bankability. Regional green funding includes putting financial arrangements in place. Funding has to be made available and tailor-made funding structures have to be arranged, including both public and private sources. This can be done in several ways, depending on regional characteristics. The following options may be considered:

- Dedicated integrated funds or debt funds. Dedicated funds are funds set up to finance green projects. Integrated funds are funds providing multiple funding sources: grants, debt, equity and/or guarantees. Debt funds provide senior or junior debt only.
- Funding arrangement vehicles. In most European countries various sustainability funds already exist, such as energy efficiency funds, NO\textsubscript{x} funds, CO\textsubscript{2} funds, infrastructure funds, innovation funds and regional development funds. Funding arrangement vehicles arrange complete funding packages, combining multiple capital sources. They act mainly as a broker, but can also provide part of the required funding.

Funding arrangement vehicles usually work better than fully integrated funds as they are more flexible (they draw resources from multiple external investors) and more transparent (focus on providing debt - decision-making on grant money stays within the public domain). Funding arrangement vehicles can be founded as separate entities or become part of existing ones, such as regional development corporations.

**Exhibit 5-E: The Norwegian Business Sector NO\textsubscript{x} Fund**

An NO\textsubscript{x} tax was introduced in 2007. An NO\textsubscript{x} fund was established the following year. Industries like the offshore industry, shipping, supply-vessels, fishing, aviation, district heating can participate in the fund. This Participation grants exemption from the NO\textsubscript{x} tax, which is replaced by a lower fund tax. The NO\textsubscript{x} fund is earmarked for the implementation of emission reducing measures [50].

Public funds providing non-regulatory support may participate in both regional programmes and regional funding or, alternatively, participate in regional programmes only while providing financial resources at the regional/local project level. Such public funds can raise capital from
various sources. National and regional government budgets are the most common sources. However, some public funds, such as the Norwegian NOx fund (see Exhibit 5-E) receive income from private sources, transferring funds from more polluting options to cleaner options.

Regional/Local Level

Green project deals are made at this level. HRS development could be a regional green project deal. Such deals include:

- an HRS permitting plan,
- an HRS design and build plan,
- an HRS operating plan,
- an HRS income plan (grants, performance payments, autonomous revenues, demand aggregation revenues, etc.),
- an HRS guarantee plan (for example: take-or-pay contracts and other contractual guarantees),
- an HRS funding plan.

Financial engineering and arrangement services are required for establishing bankable business cases, putting together capital from various sources. Large oil companies have in-company resources to perform such activities. However, small-scale enterprises lack such expertise. In such cases, the abovementioned regional funding arrangement vehicles can be of assistance.
6  Hydrogen Integrated Business Case Impact Tool

6.1  Introduction and Objectives

This report comes with the Hydrogen Integrated Business Case Impact Tool (HIBIT). HIBIT is a comprehensive calculation tool that allows composition of HRS development support schemes based on the support tools discussed in chapter 5 and simulates their impact on the HRS business case.

HIBIT is useful for many stakeholders in various business case phases:

- Central Government. Central government goals and policy have a significant impact on opportunities for HRS development and scaling up of FCEVs. HRS and FCEV market potential also depends on low/zero tailpipe emission transportation regulation and stimulation. HIBIT shows the relationship between market growth and business case bankability.

- Regional Partnerships. Chapter 5 mentioned regional partnerships as a backbone for HRS development. Regional stakeholders will have to decide which support instruments are most effective, efficient and preferred to stimulate both HRS development and FCEV demand. HIBIT assists regional decision makers by showing costs, benefits and business case impact.

- HRS Entrepreneurs. HIBIT is a high level HRS business case tool. (Potential) HRS entrepreneurs can use HIBIT to make preliminary feasibility calculations before consulting partners and investors.

- HRS Investors. Investors can use the tool to prepare HRS funding strategies by simulating various business case scenarios and evaluate their impact on the HRS credit and risk position. HIBIT also shows the potential business case for HRS under various circumstances.

- OEMs. HIBIT makes the demand aggregation strategy concrete: it shows how many FCEVs are required to make an HRS bankable. OEMs can use HIBIT to determine their FCEV roll-out strategy and to evaluate their participation in regional demand aggregation Green Deals.

- Fleet Owners. Fleet owners considering switching to zero tailpipe emission alternatives can use this tool to evaluate how their fleet can contribute to HRS development by participating in demand aggregation initiatives.
The main HIBIT features are:

- Market scenarios can be defined in a few steps (market growth, hydrogen price levels, HRS capacity, capital and operational expenditure, capital costs).
- Multiple support schemes can be designed, combining the HRS support instruments introduced in chapter 5.
- Support schemes can be compared to a reference point (assuming no HRS support) and to each other.
- Demand aggregation can be simulated with the FCEV-HRS interface.
- HIBIT produces general business case bankability indicators as well as total support scheme costs.

HIBIT is a high level business case tool for strategic decision making. It is not designed as a financial model for the development and funding of a specific HRS.

HIBIT allows users to define specific market and support schemes and produces detailed business case financial data per support scenario. This chapter presents the results of market/support scenarios for the HRS archetypes introduced in chapter 3.

**Exhibit 6-A: Archetype HRS calculations available as JUMP-START BUTTONS**

*The pro forma calculations presented in this chapter and detailed in Appendix C are available as JUMP-START BUTTONS in the HIBIT calculation tool that comes with this report. Users can reproduce every HRS/Support Scheme combination discussed by clicking the HRS archetype JUMP-START BUTTON.*

The objectives of this chapter are:

- to demonstrate HIBIT by performing business case calculations on all HRS archetypes presented in chapter 3,
- to quantify the HRS investment challenge,
- to quantify various support schemes,
- to assist regional/local decision makers in their HRS development process.

NOTE: Appendix C contains a detailed description of all HIBIT calculations presented in this chapter.

6.2 **Reference: HRS Development Without External Support**

HIBIT starts with a definition of the HRS specifications and the expected market development. HRS/FCEV market opportunities are not easily quantified as they are driven by environmental
and financial stimulation policies, some of which are still being developed. However, recent experience with HRS development shows that the Rogers S curve presented in chapter 2 also represents the expected revenue pattern of an individual HRS: very slow growth in the early phase, followed by an expected faster growth rate during the commercial phase, followed by a declining growth during the maturity phase.

HIBIT allows users to define a specific HRS sales growth path. Figure 16 shows the S-curved HRS sales growth path assumed for the HRS archetypes presented in chapter 3.

Figure 16: Assumed S-curve growth paths for urban and rural HRS.

Figure 16 makes three market development assumptions:

1. Individual HRS growth is shaped like an S curve. During the early commercial market phases a limited number of HRS cover large areas. Their sales level is low. Sales levels increase in the commercial phase, but so do the number of competing HRS: the service area per HRS will decline. An HRS reaches full market penetration at maturity.
2. Full market penetration is expected in 30 years when the EU 2050 environmental goals will have to be met. The market penetration level is assumed to be 60% when the EU 2030 environmental goals will have to be met.
3. Rural HRS have a slower growth path than urban HRS, and come with greater underutilisation levels compared to urban HRS [51].

HIBIT simulates an HRS business case, using the abovementioned S curve in combination with HRS revenues, investment and cost specifications. HIBIT allows users to enter specific parameter values. The HRS archetype business case calculations were performed using the HRS business case parameters presented in table 1 (page 23), table 2 (page 30) and table 9 (page 109).
6.3 Support Schemes

The HRS business case calculations compare three distinctive support schemes:

- A CAPEX/OPEX grant support scheme. HRS development is supported by upfront CAPEX grants and OPEX grants of up to 100%. This support scheme focuses on HRS expenditure.
- A demand aggregation support scheme. HRS development is supported by creating demand from an aggregated group of early adopters. This support scheme focuses on HRS revenues.
- A mixed tools support scheme. HRS development is supported by a mixture of expenditure and revenue support.

6.3.1 Support Scheme 1: CAPEX/OPEX Grants

This support scheme represents the currently most common form of HRS support: capital expenditure and operational grants of up to 100%. This scheme starts with a CAPEX grant up to the level where the HRS business case is expected to be bankable. If the HRS business case is not bankable at a 100% CAPEX grant, then OPEX support is assumed up to the level where the HRS business case becomes bankable.

This support scheme stimulates HRS availability, but not necessarily HRS use. Support costs are equal to the sum of CAPEX and OPEX grants.

6.3.2 Support Scheme 2: Demand Aggregation

This support scheme is totally focused on the creation of hydrogen demand. HRS do not receive any CAPEX or OPEX support, but they will generate early hydrogen sales revenues from a group of aggregated early adopters. The size of the demand aggregation group is determined by the hydrogen sales volume required for a bankable business case.

This support scheme stimulates both HRS availability and use. Support costs are equal to the difference between the cost of FCEVs and their equivalent ICE vehicles during the support period.

Our FCEV calculations are based on the currently available Hyundai ix35 Fuel Cell. TCO is captured in the total price per kilometre for various types of use (private or business use).

TCO per kilometre of the ICE benchmark vehicle is calculated using the Dutch vehicle MAIS model (Multi Actor Impact Simulation). This simulation model calculates precise TCO per vehicle kilometre based on detailed information from the Dutch vehicle licensing agency and general vehicle usage data. Fiscal differences between vehicle ownership and use are also included in the calculations.
As TCO per kilometre varies across EU countries (mainly due to taxation differences), HIBIT allows for specific TCO per kilometre input matching the situation in a specific country.

6.3.3 Support Scheme 3: Mix of Multiple Support Tools

This support scheme demonstrates how an HRS business case can be made bankable using an optimised mix of multiple support tools. The mix contains the following support tools:

- demand aggregation (but with fewer vehicles than in support scheme 2),
- take-or-pay penalty payments if sales from demand aggregation are lower than agreed,
- performance-based payments to guarantee HRS performance,
- CAPEX and/or OPEX grants,
- provision of soft loans against a favourable interest rate.

6.4 Support Scheme Calculation Results

Table 6 presents a summary of the HIBIT pro forma calculations. Detailed calculations can be found in Appendix C.

This table presents an overview of the HIBIT calculation results. It contains the following key information for each HRS archetype/support scheme combination:

- Estimated total cost to make the HRS business case bankable.
- CO$_2$ and NO$_x$ impact per support scheme. This is the demand aggregation environmental impact. This is calculated by estimating the amount of CO$_2$ and NO$_x$ reduction as a result of demand aggregation group switches from ICE vehicles to FCEVs.
<table>
<thead>
<tr>
<th>HRS archetype</th>
<th>Support scheme 1</th>
<th>Support scheme 2</th>
<th>Support scheme 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRS support scheme</td>
<td>CAPEX/OPEX grant</td>
<td>Demand aggregations</td>
<td>Mix of support tools</td>
</tr>
<tr>
<td>Urban Basic HRS 420 kg/day</td>
<td>Period: 10 years Costs: EUR 2.0 million CO₂ impact: 0 t/y NOₓ impact: 0 kg/y</td>
<td>Period: 10 years Costs: EUR 7.6 million CO₂ impact: 600 t/y NOₓ impact: 725 kg/y</td>
<td>Period: 10 years Costs: EUR 4.9 million CO₂ impact: 300 t/y NOₓ impact: 363 kg/y</td>
</tr>
<tr>
<td>Urban Full-Service HRS 1,000 kg/day</td>
<td>Period: 10 years Costs: EUR 1.5 million CO₂ impact: 0 t/y NOₓ impact: 0 kg/y</td>
<td>Period: 10 years Costs: EUR 6.3 million CO₂ impact: 500 t/y NOₓ impact: 600 kg/y</td>
<td>Period: 10 years Costs: EUR 3.0 million CO₂ impact: 130 t/y NOₓ impact: 160 kg/y</td>
</tr>
<tr>
<td>Rural Basic HRS 80 kg/day</td>
<td>Scenario not applicable.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: HIBIT archetype calculation results summary.
6.5 Support Scheme Conclusions

The following conclusions can be drawn from the HIBIT calculations summarised in table 6 in paragraph 6.4:

- Given the assumed market growth rate in figure 16, all HRS archetypes need external financial support to become bankable.
- Higher assumed growth rates lead to lower amounts of required external support. In other words: acceleration of the transition to zero tailpipe emission transportation (using general incentives and/or legislation) increases early HRS utilisation hence decreases the need for support.
- CAPEX and OPEX grants only guarantee HRS availability, not HRS use. A CAPEX/OPEX grant-based support system facilitates an HRS coverage strategy in a period where FCEVs are not yet widely available. Countries with a high HRS coverage may become prime target countries for FCEV introduction. However, there is a risk of severe underutilisation if FCEV availability is delayed.
- Demand aggregation based support mechanisms require higher support levels. The exact support level is determined by ICE-FCEV cost differences, which vary per country. Demand aggregation support schemes reduce the HRS underutilisation risk as they create early adopters using the HRS facilities. Demand aggregation also has direct environmental impact. As a part of this support programme, drivers substitute their ICE vehicle for an FCEV which leads to emission reductions. However, making business cases bankable with 100% demand aggregation support schemes requires significant numbers of FCEVs which may not be available yet.
- The HIBIT mixed tool support scheme calculations show that it is possible to create bankable HRS business cases using a support scheme that includes multiple support tools. Tailor-made solutions are possible so that HRS development becomes feasible within a framework of available funds and available FCEVs.
- Rural HRS have the following business case disadvantages compared to their urban counterparts:
  - Rural HRS have a relatively unfavourable cost structure as they lack economies of scale.
  - On-site production methods are cost efficient but require an even higher upfront investment.
  - Slower growth means a lower cash generating capacity hence a longer financing period and higher financing costs.
  - The abovementioned issues imply a higher risk profile hence higher expected funding costs.
For these reasons rural HRS archetypes require a higher level of external support for a longer period than their urban counterparts.
6.6 Regional Financial Support Strategy

The best support strategy is determined by hydrogen ambitions, stakeholder commitment, available funds and market phase.

- Hydrogen Ambitions. Technology neutrality is an important factor in low/zero tailpipe emission policy making. However, specific national hydrogen implementation plans are the backbone for HRS development. National implementation plans need further detailing to become regional implementation plans and ultimately regional implementation programmes.
- Stakeholder Commitment. CAPEX/OPEX grant support schemes require public commitment. Demand aggregation support schemes require both public and private commitment in terms of money and willingness to become a frontrunner.
- Available Funds. HRS support costs money: grants, equity, debt, guarantees. As HRS development requires external support, the available funds determine the support range.
- Market Phase. Every market phase has its specific market, costs and investment characteristics determining the level of required external support.

Figure 17 shows the challenges of early HRS development:

- Early HRS investors and operators have the certainty that HRS investment levels are high, as cost reductions are expected only further in the future.
- Early HRS investors and operators have the certainty that HRS revenue levels will be very low during the first few years of operation.
- Early HRS investors and operators have the uncertainty of future HRS revenue levels. An S-curve development is expected but is highly dependent on public sector incentives and environmental policy execution.

![Figure 17: HRS challenges and divided support strategy.](image-url)
Furthermore, figure 17 also shows the main ingredients of an HRS support scheme strategy. It shows the S curve, a 15-year HRS asset life expectancy and an assumed ten-year support period. This support period can be divided into three distinctive phases:

Phase 1 includes the first year of HRS operation. Considering a low level of FCEV availability, hydrogen sales will be limited. A CAPEX/OPEX support scheme is the best and most efficient way to support HRS development in this phase.

Phase 2 is the middle part of the assumed support period when the first significant numbers of FCEV arrive. In this part not only is HRS availability important, but also HRS performance: a reliable HRS that allows FCEV drivers to fill up hassle-free. A mix of the following tools supports these goals:

- partial CAPEX grants to bring the level of required funding and funding costs down,
- performance-based payments: payment for HRS performance instead of HRS availability,
- limited demand aggregation: small demand aggregation groups leading to HRS revenues (from hydrogen sales),
- take-or-pay contracts to offer HRS operators a level of income certainty,
- soft loans providing comfort to senior debt providers.

Phase 3 is the last part of the assumed support period when the market reaches a 25% diffusion rate with FCEVs more widely available and in multiple brands and types. This FCEV availability allows for a demand aggregation support scheme. This support scheme offers a double advantage: FCEV use is promoted (reducing the level of greenhouse gases) and HRS operators’ income increases as the aggregated demand FCEVs need to be filled up.

The period after phase 3 should offer HRS operators and investors enough confidence to invest without any external support, because at that stage:

- there will a proven market with a large growth potential, and
- capital expenditure levels are expected to be up to 40% lower.

### 6.7 Public-Private Financial Arrangements

Regional support arrangements are discussed in paragraph 5.8. The HIBIT HRS archetype/support scheme calculation results can also be used as a basis for a regional public-private financial support arrangement. This strategy follows the three-phase approach presented in paragraph 6.6. Figure 18 illustrates this strategy.
Figure 18: Example of a financial support strategy on a regional level, based on the Urban Basic HRS archetype and pro forma calculations presented in Appendix C.

The three-phase approach entails starting with a CAPEX/OPEX grant support scheme, followed by a period of a mixed tool support approach, followed by a demand aggregation period.

The first phase is the CAPEX/OPEX grant support scheme phase and requires the lowest level of support funds (EUR 2 million in the example above) – but also has the lowest direct environmental impact. Grant funding is a 100% public investment.

The second phase requires a mixture of support tools, including limited demand aggregation initiatives. From a public point of view, demand aggregation is desirable but expensive (EUR 5 million instead of EUR 2 million CAPEX/OPEX grants in the example above). Paragraph □ shows why demand aggregation can be of interest to the private sector. However, it may be too expensive, especially given the inconvenience of the early phases. If we consider the EUR 2 million grant support as a public financial fall-back scenario, this public EUR 2 million could also be spent as ‘seed money’ in a public-private arrangement. This makes a 50% public/50% private PPP possible. Public funds can be used to encourage private initiatives as 50% co-funding is available.

The third phase is the full demand aggregation phase. The financial strategy is similar to the second phase strategy: the EUR 2 million is used as seed money to form larger demand aggregation groups. The market is expected to be more stable (FCEVs and HRS are proved
reliable), but cost differences between ICE vehicles and FCEVs are still there. If public stakeholders invest their EUR 2 million ‘fall-back scenario’ money in a EUR 7 million demand aggregation project, a 25% public/75% private PPP is possible. The 25% public contribution is used as an invitation to private stakeholders to fund their share.

The strategies presented in this chapter focus primarily on a regional implementation level. However, they can also be used for a national implementation level in case a more centralised approach is preferred.
7 HIT-2 Hydrogen Corridor Development

7.1 Introduction and Objectives

The previous chapters show how HRS development and FCEV sales can be stimulated by utilising funding support. Establishing a basic HRS network also takes careful planning, both financial and spatial. The Hydrogen Infrastructure for Transport project aims at stimulating the deployment of HRS infrastructure serving FCEVs along key TEN-T Corridors, indicated in figure 19.

![Figure 19: TEN-T Corridors overview.](image)

This chapter focuses on the HIT-2 Corridor, including the North Sea–Baltic Corridor (indicated in red in figure 19) the northern part of the Scandinavian–Adriatic Corridor (indicated in pink) and the northern part of the Baltic–Adriatic Corridor (indicated in blue).

The North Sea–Baltic Corridor connects ports in the North Sea, such as Rotterdam and Antwerp, with ports in the Baltic, such as Riga. The Scandinavian–Mediterranean Corridor is an important corridor connecting urban and industrial centres from north to south in Europe [52].
The objective of this chapter is to identify missing HRS infrastructure links in the HIT-2 Corridor and to develop an approach to fill the gaps. Recent experience with HRS development in the HIT-2 countries, such as H2Moves Scandinavia [21], but also in other countries such as Germany (CEP) and the United States (California [27]), are used as a reference.

7.2 Existing and Planned HRS in the HIT-2 Focus Corridors

Figure 20 shows an overview of existing HRS in the HIT-2 Corridor.

![Figure 20: Overview of existing HRS locations in the HIT-2 Corridor, situation 2015 [53].](image)

The HIT-2 part of the Scandinavian–Mediterranean Corridor already has some basic HRS coverage, especially with the Helsinki, Arlanda/Stockholm and Goteborg HRS being operational since September/October 2015. However, coverage is still far from the required level for hassle-free hydrogen mobility. For example, the distance between Goteborg and Stockholm is still close to 500 kilometres, a distance beyond the current FCEV driving range. The eastern part of the North Sea–Baltic Corridor as yet has no HRS coverage at all.
Figure 21 shows an overview of planned HRS in the HIT-2 Corridor.

Figure 21: Overview of planned HRS locations in the HIT-2 Corridor, situation 2015 [53].

Most of both existing and planned HRS are situated at the Scandinavian–Mediterranean Corridor. Basic connectivity between Brussels and Sweden, but also between Brussels and the north of Italy is already there.

In Germany, the Clean Energy Partnership programme has taken the lead in the development of about 50 HRS in the next few years. The United Kingdom – especially England – will also have a basic HRS network in place in the near future.

Germany and the United Kingdom, both countries with a substantial automotive industry, are in a leading position. The UK’s eastern and Germany’s western and northern neighbours are catching up. However, in the eastern part of the HIT-2 Corridor, HRS coverage is lagging somewhat.
7.3 Missing Links

Even though there is a degree of HIT-2 basic HRS availability, especially in large urban centres, other HIT-2 Corridor regions lack such basic coverage. This chapter focuses on identifying missing link and developing a strategy to establish basic coverage.

7.3.1 Missing Links: Identification

Figure 22 shows all existing and planned HRS locations on the HIT-2 map. It can be concluded that the HIT-2 Corridor has HRS development challenges as large parts of this corridor lack even basic HRS coverage.

![Overview of existing (green) and planned (orange) HRS locations in the HIT-2 Corridor, situation 2015 [53].](image)

The most striking aspect is the absence of both existing and planned HRS in Poland, even though it is an essential part of both the North Sea–Baltic and Baltic–Adriatic Corridors.
The Baltic states, at one end of the North Sea–Baltic Corridor, have no HRS infrastructure planned in the near future. Also, the northern parts of both Sweden and Finland currently have no existing or planned HRS coverage and also the southern parts of these countries need improved coverage.

Even though the Netherlands and Belgium have HRS development plans, those plans do not cover all economic centres, such as for example the Amsterdam Schiphol Airport area. The only HRS in the Amsterdam area is not publicly accessible as it available for the exclusive use of buses in the CUTE project [54].

7.3.2 Missing Links: Analysis

Figure 22 indicates that from a TEN-T/HIT-2 Corridor point of view HRS availability in the metropolitan areas of Warsaw and Riga is crucial. Filling in those missing links results in a situation where HRS are available in all HIT-2 national capital regions. The missing link analysis is performed along the lines of the Californian HRS designations, explained in Exhibit 7-A.

Connector HRS

Some distances between HRS are still too large, given the FCEV range of approximately 500 kilometres. So, additional HRS infrastructure is required. Following the Californian approach,\textsuperscript{13} connector HRS can fill such gaps.

\textsuperscript{13} For example: In California, along Highway 5 between the metropolitan areas of Los Angeles and San Francisco a soon to open connector HRS has been built, which connects the two cities. The distance from either city to this station is about 300 kilometres, hence within FCEV driving range.
Stations can be broken down into at least four designations: local stations, local freeway stations, connector stations, and destination stations.

Local stations are stations close to a customer’s residence. Local freeway stations are located at the nearest freeway entrance to a customer’s home. A connector station is one located in an area that customers must transit on their way to a destination. A destination station is, as the name implies, located at a customer’s destination [51].

In order to basically cover the North Sea–Baltic Corridor and assuming a coverage of about one HRS per 300 km along the focus corridors, connector HRS should be constructed in:

- Poznan,
- Bialystok,
- Polish-Lithuanian border area, and
- Tallinn (Estonia).
An HRS should preferably be available in Lithuania as well.\textsuperscript{14}

To improve HRS coverage along the Scandinavia-Mediterranean Corridor, a minimum of one connector HRS in Linköping (Sweden) or Jönköping (Sweden) should be established connecting Göteborg and Denmark. At least one HRS should be established around Turku in Finland connecting Stockholm and Helsinki.

\textit{Local and Destination HRS}

HRS networks could evolve further following a cluster approach, based on local/destination HRS development in major cities followed by connector HRS in between.

Finland and Sweden have established initial local and destination HRS. HRS connections to Denmark and Norway will be realised at the end of 2015. This caters for FCEVs travelling on the Brussels-Helsinki Corridor, via Stockholm. However, the routes from the Swedish and Finnish metropolitan areas southwards are trunk routes whereas the routes northward lead to sparsely populated areas. Connector HRS will be required there but as concluded in chapter 6, HRS in such areas may face bankability issues. Cheaper HRS alternatives and system integration are possible solutions. This will be discussed in paragraph 7.4.

To commercialise Poland’s national FCEV market, its main cities such as Gdansk, Poznan, Katowice and Lodz should be connected with the HIT-2 Corridor clusters. This is not only relevant for development of the North Sea–Baltic Corridor, but also the Baltic–Adriatic Corridor.

Most of the HRS in the Netherlands and Belgium are at the planning stage. Only Rhoon/Rotterdam, Helmond and Antwerp are operational. Brussels will be operational in 2016.

\textbf{7.3.3 Missing Links: Strategies}

The number of HRS should be between 8\% and 18\% of the existing number of fuel stations in order to make FCEV sales a success [55]. There is no one best HRS development strategy. A development strategy is the outcome of a) HRS coverage ambitions, b) stakeholder commitment and c) available budgets. However, strategies used in other countries and regions can serve as reference material.

\textsuperscript{14} Lithuania is not a focus country for this study.
Germany

The German HRS network development strategy consists of three consecutive steps:

1. Starting with local and destination HRS development in densely populated metropolitan clusters with FCEV market potential, such as Dusseldorf/Cologne, Berlin, Hamburg and Munich,
2. followed by development of local and connector HRS within the metropolitan clusters,
3. followed by connector HRS connecting metropolitan clusters, along the TEN-T Corridors. In this way, new HRS are developed at new locations between metropolitan clusters. These connector HRS serve as fuelling points for international traffic and create opportunities for hydrogen mobility in more sparsely populated areas as well.

This strategy leads to early HRS redundancy, ensuring HRS operational availability (if one HRS becomes faulty, another one is always nearby).

The German strategy requires a strong centralised organisation and well-resourced committed parties able to endure a substantial period of underutilisation.

California

Within the US, the state of California is working on a state-wide HRS infrastructure to facilitate hydrogen fuelled transportation. California makes a distinction between coverage and capacity [27]. Coverage refers to the selection of HRS locations in areas with the largest potential for early FCEV market adoption. Capacity is needed to ensure sufficient hydrogen supply in those areas. The six HRS 'purposes' as defined by the Air Resources Board can also been seen as an HRS development philosophy [27]:

1. Establish Core Market
   Establish core market HRS in areas with the highest potential for early market adoption of FCEVs. These areas do not yet have any fuelling station coverage, and so the fuelling market must be established there.

2. Expand Core Market Area Coverage
   As soon as some basic core market coverage exists or is planned, the area requires further augmentation of that coverage. Expand core market HRS coverage in areas with the highest potential for early market adoption of FCEVs.

3. Expand Core Market Capacity
   Coverage exists within the market; but the core market may face a challenge with capacity requiring further core market expansion.

4. Future Market
   Markets with early market FCEV adoption potential, but not the highest. Additionally, there may be outside indications that this area could be a significant market that
develops once significant infrastructure exists in the core markets. However, these indications are typically not as strong as for the core markets.

5. Connector
A station in this area could provide fuelling services for FCEV drivers travelling long distances between core and/or future markets. These stations maximise the utility of the FCEV driving range by providing sufficient fuelling opportunity to drivers on routes longer than this driving range.

6. Destination
These stations are sited in areas anticipated to be desirable vacation, recreation or other types of destination locations frequently reached by car. Stations in these locations ensure sufficient fuelling opportunities on the drive to and from the destination location and during the FCEV driver’s stay at the destination location.

High potential HRS areas are identified using government and business data. The HRS Purpose is one of the factors determining the exact HRS locations.

France
France has developed a different strategy, including the development of relatively small 350-bar HRS facilities for small delivery vehicles, buses and trucks. La Poste delivery vehicles are among the group of first users. Symbio FCell has taken the initiative for this approach by using small 350-bar plug-in hybrid fuel cell vehicles [56]. The French approach requires lower investment levels as a 350-bar HRS installation is less expensive than a 700-bar one. Demand aggregation leads to HRS income.

On the other hand, additional investments will be required as the French HRS are not suitable for refuelling future 700-bar FCEVs. Most OEMs are somewhat reluctant to adopt this strategy, as the French two-step approach may come with availability issues, creating FCEV roll-out limits.

The Netherlands/Belgium
Whereas the German strategy is to first establish clusters of HRS within one metropolitan area and then connect these clusters to one another, the Dutch and Belgian approach is to establish individual HRS in several large cities, which can later grow into HRS clusters around these cities. This may be less reliable and less user friendly, as there will be no initial nearby back-up options.

7.4 System Integration Potential as HRS Location Factor
Most countries identify potential HRS locations in areas where the greatest customer benefits can be delivered. Obviously areas of population concentration and national trunk routes end up high on the priority list: they offer the best early revenue potential.
However, even though maximum revenue potential from hydrogen sales is rightfully the most important location factor, additional factors should be considered when identifying locations.

The potential for system integration could be such an additional factor. System integration refers to options to synchronise several hydrogen-related uses and applications, allowing for lower HRS costs or alternative income sources.

One of the most frequently used system integration activities is using HRS hydrogen storage capacity for electricity grid stability purposes. Since energy production from renewable sources and energy consumption are difficult to match, hydrogen can be used as a buffer to store excess green energy from intermittent energy sources (wind and solar power) [57]. In this way, energy supply and demand can be balanced. Excess energy can be stored at relatively low cost as hydrogen, until it is either used at the HRS location itself or fed into the grid. In a study commissioned by NOW, a German research institute, it was found that wind power to hydrogen can be a reasonably feasible economic activity.

7.4.1 Alternative Demand Aggregation

Paragraph 5.5.2 described and chapter 6 calculated how demand aggregation can strengthen HRS business cases. However, there are also alternative demand aggregation options offering additional value.

Alternative demand aggregation drivers are:

- a growing demand for zero energy buildings, and
- a shift from centralised to decentralised energy production.

Urban areas have limited spatial capacity for wind turbines. Solar power is not always a good alternative, given the continuous energy needs in urban areas. Green hydrogen, which can be converted into energy on-site, resolves these issues but comes with transportation issues: transportation by truck of about 200 kg hydrogen per day into urban areas may be problematic and demand is too small for transportation by pipeline.

The challenge is to find multiple users interested in green local energy solutions. If an HRS is situated in the same area, hydrogen demand will increase further by 400 to even 1,000 kg per day. Aggregated demand brings the potential for economies of scale, which all stakeholder will benefit from:

- energy consumers are offered local energy production options at no extra cost, and
- HRS can reduce hydrogen transportation costs.

Pipeline transportation alternatives require long-term business case management, as pipeline construction comes with high capital expenditure levels. Depreciation costs are however limited,
given an expected 50 year pipeline life. Costs can become even lower if a pipeline infrastructure is already in place and available.

7.4.2 Power-to-Gas

The previous paragraph described a possible system integration concept for application typically in urban areas. However, the HIT-2 Corridor also includes sparsely populated remote areas with no or limited demand aggregation potential.

Chapter 6 concluded that given low hydrogen demand in these areas and relatively high HRS expenditure levels, HRS business cases can be problematic. In such cases, system integration can provide options for cutting costs.

The Power-to-Gas (P2G) concept could bring about such cost cuts. P2G is the process of converting surplus renewable energy into hydrogen gas by rapid response electrolysis and then injecting it into the gas distribution network. The underlying philosophy is as follows:

1. Renewable energy is produced in rural areas, offering space for wind and solar installations.
2. The renewable energy is converted into hydrogen to service regional hydrogen demand.
3. Regional demand aggregation (including buses and agricultural vehicles and machinery) strengthens regional hydrogen demand hence maximises rural HRS income.
4. Excess supply is converted into hydrogen gas and injected into the gas distribution network at concentration levels of 5–15% hydrogen by volume. Alternatively, hydrogen combined with carbon dioxide is converted into methane which is injected into the gas distribution network.
5. The blended gas can be used in end-use devices or, alternatively, hydrogen could be separated out using separation and purification technologies and used as a fuel for FCEVs or for electricity production.

Figure 23 illustrates this concept.
Hydrogen can thus be used as an alternative to natural gas or butane. This adds to (imported) fossil fuel independence while creating rural green hydrogen economy opportunities.

This option is interesting for countries with an existing natural gas grid, which provides long distance gaseous hydrogen transportation capacity. This is a more efficient option than transportation of electricity through high voltage power lines. Power-to-Gas options are now being studied and tested in several European countries, with Germany as a frontrunner [57] [59].

### 7.4.3 System Integration Effects on the HRS Business Case

Table 7 shows estimated cost levels of various hydrogen production and distribution options, as well as estimated required retail price levels to recover all costs [13] [14].
Table 7: Overview of costs and sales prices.

Pipeline transportation is by far the cheapest option. However, establishing a new pipeline infrastructure requires both large investments and large volume markets to utilise economies of scale. In the short term, this option will only be feasible if an existing pipeline infrastructure can be used as a starting point. Figure 24 shows that the HIT-2 countries Latvia, Poland, the Netherlands and Belgium offer the best short-term options.
Therefore, hydrogen delivered by truck is currently generally preferred [17]. In more remote rural areas on-site hydrogen production may be the most efficient production option, given relatively high distribution costs of delivery by truck in those areas.
Conclusions

EU 2030 and 2050 emission reduction goals have been set. Low/zero tailpipe emission transportation will have to contribute considerably to GHG reduction. However, development of hydrogen infrastructure for transportation turns out to be a true challenge. This challenge is only manageable if strategies are developed for bridging the gap between macro-level environmental goals (‘what should be done’) and micro-level implementation capacity (‘what can be done’). When developing implementation strategies, the following findings of this study should be considered:

1. **FCEV mobility requires basic HRS coverage.**

   A minimum number of publicly accessible refuelling points should be in place before FCEV roll-out can commence. Such basic coverage should enable national and cross-border mobility between EU Member States and support further commercialisation of FCEVs. As the expected number of produced FCEVs will be limited in the next few years, OEMs give priority to countries with the best HRS coverage in place.

2. **FCEV mobility requires government support.**

   Without government support, the total cost of ownership (TCO) of an FCEV is higher than a comparable ICE vehicle. In general, motorists are not prepared to pay more for greener mobility solutions. Government grants and tax exemptions are required to neutralise such TCO effects. Financial support is by far the most important stimulation (‘must have’) while other non-financial incentives have less impact (‘nice to have’).

3. **Early market HRS development comes with a financial Valley of Death challenge due to underutilisation issues.**

   Early HRS development in combination with limited FCEV market penetration comes with a period of HRS underutilisation. Given the current relatively high HRS expenditure levels, a significant Valley of Death is assumed, both in size and duration. The Valley of Death is the total funding gap between the moment of initial investment until the moment all expenditure has been fully recovered.

   Initial calculations with the Hydrogen Integrated Business Case Impact Tool (HIBIT) show that in particular small-scale HRS in remote rural areas have Valley of Death issues, due to a slower than average expected revenue growth pattern while expenditure levels are relatively high due to limited economies of scale potential.
4. **The best HRS development strategy depends on goals, resources and stakeholder commitment.**

There is no single best HRS development strategy. The best strategy is the one that fits goals, resources and stakeholder commitment. Two distinct approaches are the ‘national approach’ and the ‘regional approach’.

The national approach is a large-scale approach aimed at getting early HRS coverage on a national scale. This is more of a top-down approach powered by the national government and large financially strong HRS developers and operators. Stakeholders will have to assume significant Valley of Death exposure, due to a long period of HRS utilisation. Such a strategy also creates opportunities to reduce the Valley of Death as OEMs will have a preference for markets with a basic refuelling infrastructure in place.

The regional approach puts regional stakeholders at the helm and allows for more tailor-made solutions than the national approach. The regional approach puts the emphasis on minimising the Valley of Death by actively stimulating and aggregating customer demand. The regional approach is, in contrast to the national approach, a more bottom-up organic model which also allows for HRS initiatives from local entrepreneurs.

The national and regional approaches are not mutually exclusive. They could even be complementary. A national approach could be used to get a very basic HRS coverage in place, followed by a regional approach to fill in the regional ‘blanks’.

5. **A regional approach requires regional arrangements providing tailor-made solutions.**

Regional entrepreneurs have limited resources to fund the Valley of Death. Regional arrangements are required to coordinate regional HRS development – by drawing up regional investment programmes and make funding available and accessible at affordable prices.

Arranging finance refers to funding HRS initiatives with a blend of grants, guarantees, equity and debt, using the existing funding infrastructure (regional funds, banks, investors). In case of insufficient funding infrastructure, new dedicated funds for sustainable infrastructure development financing should be considered.

Most early HRS development requires grants. Such grant could be provided from public budgets. Alternatively, public support funds can be put in place. Such funds can for example be filled with resources related to GHG emissions, such as the Norwegian NOx fund.
6. **Stimulate green entrepreneurship: it leads to innovation**

Entrepreneurs are developing new business concepts, responding to increased environmental awareness and health consciousness. Such entrepreneurs have the local knowledge required for launching successful sustainable concepts, turning refuelling into a sustainability experience.

Regional arrangements can support these developments by making funding accessible, but also by establishing expertise networks. These networks can assist such entrepreneurs, for example to get permits or to get in touch with OEMs in case of demand aggregation opportunities.

7. **Demand aggregation is a powerful method of creating early markets and support HRS infrastructure development.**

Demand aggregation includes HRS development in combination with the identification and recruitment of dedicated early user groups. Group characteristics are: high mileage motorists with a regional scope, such as taxi companies, and environmental awareness, such as local/regional governments, but also companies with a (desired) green profile.

Demand aggregation will only be successful if motorists are fully compensated for all additional costs of driving a fuel cell vehicle, such as a higher retail price, higher fuel costs and alternative transportation costs in case of occasional journeys to areas with no HRS coverage.

Demand aggregation comes with two distinct features: a) it creates early HRS income and prevents long periods of HRS underutilisation, and b) it creates opportunities for early GHG reduction as people are encouraged to go zero tailpipe emission in the early commercial phase.

8. **The eastern part of the HIT-2 Corridor has the most significant missing link issues**

Poland currently has no existing or planned HRS although it is an essential part of both the North Sea–Baltic and the Baltic–Adriatic TEN-T Corridors.

In order to basically cover the North Sea–Baltic Corridor and assuming a coverage of about one HRS per 300 km along the focus corridors, connector HRS should be constructed in:

- Poznan,
- Bialystok,
- Polish-Lithuanian border area, and
- Tallinn (Estonia).
In Sweden, the distance between Goteborg and Stockholm is larger than the average FCEV driving range. Adding a connector HRS enables hydrogen mobility southwards on Swedish and Finnish trunk routes. There is no hydrogen infrastructure northward as yet. Connector HRS will be required there but HRS in such areas may face bankability issues as those routes lead to remote, sparsely populated areas.

9. **System integration opportunities should be considered when scouting for and selecting HRS locations.**

System integration creates opportunities for lower costs or higher revenues, improving the HRS business case. System integration options to be considered are:

- Using HRS as a buffer for storage of excess green energy from intermittent energy sources (wind and solar power) to guarantee grid stability.
- Using Power-to-Gas options. This refers to a process of converting surplus renewable energy into hydrogen gas by rapid response electrolysis and its subsequent injection into the gas distribution network so that the energy can be used elsewhere. This is potentially an especially valuable option for rural development in general and rural HRS development in particular. Power-to-Gas allows for sustainable energy production in rural areas and transporting the energy using a pipeline infrastructure. As pipeline construction is very capital intensive and time consuming, for the time being this option is limited to areas which already have natural gas pipelines in place.
Appendices
A References


[5] UK H2 Mobility, “Phase 1 Results,” UK H2 Mobility, 2013.


## B Incentives Overview

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<td>California; Netherlands</td>
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<td>Authorised use of bus lanes</td>
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<td>Reduced parking rate for clean vehicles</td>
<td>Madrid; Finland</td>
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<td>Free use of ferries</td>
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<td>Free public charging</td>
<td>Norway</td>
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<td>Free alternative mode of transport in holiday situation</td>
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<td>Clean taxi preferred vehicle (gains customers earlier)</td>
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<td>Exemption from tunnel use charges</td>
<td>Norway</td>
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<td>Use of high occupancy lanes</td>
<td>California</td>
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<td>Exemption/reduction of toll tariffs</td>
<td>Norway; California</td>
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<td>Alternative Fuel Vehicle (AFV) and Hybrid Electric Vehicle (HEV) Insurance Discount</td>
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<td>Natural gas rate reduction for fuelling</td>
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<td>Preference for AFV owners to get a parking permit</td>
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<td>Special parking places for electric vehicles</td>
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<td>Special traffic lanes electric vehicles</td>
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<td><strong>Other</strong></td>
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<td>Test fleets and test driving</td>
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Table 8: An overview of possible measures that could persuade people to adopt FCEV technology. The abovementioned incentives have been taken from several sources: [27] [34] [32] [35] [60]
C  HIBIT HRS Archetype Calculations

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C.1 General Market Assumptions

Making accurate long-term HIT-2 market predictions in terms of HRS revenues is not easy at the moment:

- Driving an FCEV is more expensive than driving an ICE vehicle – the formation of significant early adopter groups requires forms of financial compensation and stimulation. Such mechanisms are not yet fully in place everywhere.
- The number of available FCEVs will be limited, at least for the next five years. On an international scale (Asian) home markets and the State of California are OEM priority markets; the Californian incentive programmes in particular provide an enormous pull.
- In Europe, OEMs focus on countries with FCEV stimulation policies and an active HRS development support policy. Germany, the United Kingdom and Denmark are such focus countries. It is expected that HIT-2 countries become target areas by 2020 when European FCEVs will be more widely available and Asian OEMs will increase FCEV sales in other countries. Furthermore, OEMs will only have FCEVs available in specific segments. Mr. Frank Meijer (head of Hyundai Motor Europe’s fuel-cell vehicle programme) indicated that it will be a while until hydrogen-powered electric vehicles are a significant part of the car market: 'It is a marathon, not a sprint' [61].
- HIT-2 (and other) countries focus on the number of HRS to be built. However, at this stage the number of HRS is hardly a reliable HRS revenue predictor. HRS utilisation rates are the result of a delicate interaction between (fiscal) FCEV stimulation, and FCEV multiple segment availability.

These are the reasons why the market growth curve in terms of hydrogen sales is a HIBIT input variable. HIBIT allows users to choose an HRS growth curve that fits growth expectations for a specific country, region or individual HRS.

Our pro forma urban HRS archetype business case calculations assume the growth curve shown in figure 25.

Figure 25: Autonomous growth S-curve for urban scenarios used in calculations.
This autonomous growth curve assumes a low level of sales for the first five to ten years of operation, a more or less constant growth in the next five to ten years reaching maturity about 20 years after the initial investment. Our pro forma rural HRS archetype assumes a lower market growth (refer to paragraph C.5).

Table 9 shows other general market assumptions.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Average hydrogen pre-tax retail price</td>
<td>EUR 10 per kg</td>
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<td>HRS retail price reduction</td>
<td>25% in 15 years</td>
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<tr>
<td>Average hydrogen pre-tax purchase price</td>
<td>EUR 4 per kg</td>
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<tr>
<td>HRS asset life</td>
<td>15 years</td>
</tr>
<tr>
<td>HRS CAPEX reduction</td>
<td>40% in 15 years</td>
</tr>
<tr>
<td>Interest rate senior debt</td>
<td>4% nominal, 2% real</td>
</tr>
</tbody>
</table>

Table 9: Market scenario parameters used in calculations for all archetypes.

The EUR 10 per kg hydrogen retail price in 2015 is equal to the European cost targets for hydrogen generation. As discussed in paragraph 3.4.1, a 50% hydrogen retail price reduction is questionable if hydrogen production and transportation costs do not decrease significantly. Furthermore, reduction of the retail margin also depends on the HRS utilisation growth rate. The assumed (conservative) growth curve presented in figure 25 allows for a 25%\(^{15}\) retail price reduction over the next 15 years.

The average pre-tax purchase price of hydrogen (in the case of delivered hydrogen) is based on industry expectations [13]. HRS asset life is assumed to be 15 years [62]. Furthermore, the HRS asset replacement investment (replacement of fully depreciated HRS assets after 15 years) is assumed to be 40% below the initial investment level [14].

Nominal senior debt interest rate is assumed to be 4% (based on a current ten-year swap rate of 1% and a 3% risk/margin mark-up). With an assumed 2% inflation rate, the real senior debt interest rate equals 2%.

\(^{15}\) We assume a 40% hydrogen retail price reduction in a fully mature market compared to the present retail price of EUR 10 per kg (refer to paragraph 3.4.1). The S-curve presented in figure 25 assumes a 60% penetration rate after 15 years. It is assumed that after 15 years 60% of the 40% retail price reduction will have been achieved. This corresponds to a 25% reduction (rounded to the nearest 5%).
C.2 HRS Support Schemes

HIBIT allows for three support schemes. Each scheme consists of a specific support tool configuration. The underlying support tools are discussed in chapter 6.

C.3 Urban Basic HRS

The UBH comes in two versions: a 210 kg and 420 kg station. The calculations and conclusions presented in this chapter relate to the 420 kg version. Table 10 summarises the key data used to run the UBH business case. These data were presented table 1 (page 23), table 2 (page 30) and table 9 (page 109).

<table>
<thead>
<tr>
<th>Parameter</th>
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<tr>
<td>HRS size (peak capacity in kg/day)</td>
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<td>HRS commercial capacity at maturity (average hydrogen throughput in kg/day)</td>
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<tr>
<td>Average hydrogen pre-tax retail price</td>
<td>EUR 10/kg</td>
</tr>
<tr>
<td>HRS retail price reduction</td>
<td>25% in 15 years</td>
</tr>
<tr>
<td>Hydrogen supply: delivered (d), on-site production (op)</td>
<td>d</td>
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<tr>
<td>Average hydrogen purchase price (EUR/kg)</td>
<td>EUR 4 per kg</td>
</tr>
<tr>
<td>HRS capital expenditure (2015 level)</td>
<td>EUR 1.6 million</td>
</tr>
<tr>
<td>HRS CAPEX reduction</td>
<td>40% in 15 years</td>
</tr>
<tr>
<td>HRS asset economic life</td>
<td>15 years</td>
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<tr>
<td>OPEX - fixed amount (EUR/year)</td>
<td>EUR 80k per year</td>
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<tr>
<td>OPEX – variable amount (percentage of revenues)</td>
<td>5% of revenues</td>
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<tr>
<td>Interest rate senior debt</td>
<td>4% nominal, 2% real</td>
</tr>
</tbody>
</table>

Table 10: Urban Basic HRS key scheme data.

C.3.1 Early Market Business Case Challenges

Figure 26 shows the Valley of Death challenge for the Urban Basic HRS archetype. This Valley of Death results from this HRS key data shown in table 10 and the S-curve shown in figure 25.
This graph shows that the discounted payback time (time it takes to recover all expenditure including funding costs) is 28 years.

This Valley of Death is caused by two main factors:

- low market growth, in combination with
- a relatively high investment level.

Figure 26 also shows that the operating cash flow becomes positive in year 10. However, the Valley of Death increases significantly in year 15 when replacement investments are assumed.

Such a Valley of Death is not commercially bankable. It simply takes too long before the assets start to generate a substantial enough income to pay off debt and other funding.
Figure 27: Urban Basic HRS earnings before taxes – reference of no support.

Figure 27 shows that it takes 15 years to reach a level of structural profitability with no external support. In other words, the HRS becomes profitable at the time when assets need to be replaced.

The conclusion is that, given slow expected market growth in early market diffusion stages, HRS investments and operations are not commercially feasible. The main issues are:

- relatively high investment costs,
- very low initial market growth,
- high market growth rate uncertainty,
- bankability issues because of a significant Valley of Death.

C.3.2 Support Scheme 1: CAPEX/OPEX Grants

This support scheme’s general principles are described in paragraph 6.3.1. More specifically, this support scheme’s parameters are:

- a 100% CAPEX grant, and
- a 50% OPEX grant during an assumed ten-year support period.

This resembles current infrastructure grant schemes supporting HRS availability, even though grant percentages vary across countries.

Figure 28 shows the impact of support scheme 1 on the UBH archetype’s Valley of Death.
This support scheme has the following two distinctive business case impacts:

- the total cumulative cash flow curve is about EUR 1.6 million higher than the reference curve as a result of the assumed 100% CAPEX grant, and
- during the first ten years the downward slope of the curve is less steep as a result of the assumed 50% OPEX grant.

The total impact is significant: this support scheme practically eliminates the Valley of Death. Furthermore in this support scheme the HRS becomes structurally profitable eight years earlier than the reference (seven versus fifteen years).

However, this does not necessarily make the UBH financially viable. Lack of commercial activity (as a result of a slow assumed growth during the first ten years of operation) results in a situation where both revenues and cost levels are close to zero (due to the CAPEX and OPEX grants).

Figure 29 illustrates this ten-year period of economic and commercial inactivity due to lack of autonomous hydrogen sales.
CAPEX and OPEX grants stimulate HRS availability but do not guarantee HRS viability. Grants are the dominant income stream for the HRS that lacks encouragement for commercialisation.

This does not mean that this support scheme is never a good option. It depends on the specific implementation strategy. Countries investing in HRS availability are higher on the OEMs’ list for FCEV priority introduction – creating higher growth potential. The financial downside of this strategy is low commercial activity for a significant period.

C.3.3 Support Scheme 2: Demand Aggregation

This support scheme’s principles are described in paragraph 6.3.2. It does not subsidise CAPEX or OPEX, but generates HRS income from demand aggregation.

The demand aggregation level is determined so that the discounted payback time falls from 28 years (reference) to 14 years - one year less than HRS asset life expiration. This means that within the asset life period all expenditure including funding-related expenditure is recovered. The assumed support period is ten years.

The abovementioned financial target requires a hydrogen sales level of 100 kg per day on top of autonomous sales, assuming a 10% dropout rate\(^{16}\) during the ten-year support period.

Figure 30 shows this support scheme’s impact on UBH sales volumes. It also shows the assumption that after the ten-year support period a diminishing number of demand aggregation group members will continue to drive an FCEV and visit the UBH.

---

\(^{16}\) Percentage of demand aggregation participants that cancel their participation before the support period ends.
This requires the formation of a demand aggregation group of early adopters. As concluded in chapter 5, local fleets with a substantial mileage are prime targets.

If the following demand aggregation target group is assumed:

- 10% petrol car, private use, 20,000 km/year - switching to FCEV,
- 10% diesel car, business use, 20,000 km/year- switching to FCEV,
- 15% diesel car, business use, 25,000 km/year- switching to FCEV,
- 20% diesel car, business use, 30,000 km/year - switching to FCEV,
- 45% diesel car, taxi, 65,000 km/year - switching to FCEV,

then the number of required FCEVs is 91 in order to reach 100 kg hydrogen per day additional hydrogen sales.

Figure 31 shows the impact of support scheme 2 on the UBH archetype's Valley of Death.
This support scheme has the following two distinctive business case impacts:

- the initial Valley of Death is significantly smaller and ends well before asset life expires, and
- the funding gap is no longer a Valley of Death as it is expected to qualify for commercial funding options.

Instead of eliminating the Valley of Death (support scheme 1) this support scheme reduces it and makes it commercially fundable. Furthermore in this support scheme the HRS becomes structurally profitable seven years earlier than the reference (eight versus fifteen years).

Another difference with support scheme 1 is that support scheme 2 stimulates HRS economic viability. In support scheme 2, the HRS earns money from selling hydrogen, as opposed to the burning of grants as in support scheme 1.

Figure 32 illustrates this economic viability.
Figure 32 shows that demand aggregation support schemes focus on revenue generation rather than cost recovery. The HRS is not just operational but generates 50% of its maximum sales after ten years.

This does not mean that this support scheme is always a good option. The expected costs of demand aggregation are substantially higher than the costs of providing CAPEX and OPEX grants. Refer to paragraph C.3.5 for a support scheme cost comparison. Furthermore, this support scheme requires substantial FCEV availability, which may not be the case during the early stages of roll-out.

C.3.4 Support Scheme 3: Mix of Multiple Support Tools

This support scheme’s principles are described in paragraph 6.3.3. This support scheme is a mix of the following support tools:

- a 15% CAPEX grant,
- no OPEX grant,
- demand aggregation: 46 vehicles (same composition as described in paragraph C.3.3) leading to 50 kg/day extra sales,
- 10% demand aggregation drop out level,
- take-or-pay contract for 100 kg/day and a penalty price of EUR 2/kg,
- performance-based payment of EUR 100,000 per year,
- EUR 700,000 soft loan support with a 100 basis point (1.00%) interest discount.

This support tool mix leads to a discounted payback time of 14 years (versus 28 years without support) – one year less than HRS asset life expiration. This means that within the asset life period all expenditure including funding-related expenditure is recovered. The assumed support period is ten years.

Figure 33 shows this support scheme’s impact on UBH sales volumes.
As a result of demand aggregation efforts, hydrogen sales are significantly higher than the reference, but not as high as in support scheme 2. Support scheme 3 requires only 46 participating vehicles. That is only 50% of the number of vehicles required in support scheme 2.

Figure 34 shows the impact of support scheme 3 on the UBH archetype’s Valley of Death.

The Valley of Death pattern of support scheme 3 is almost identical to support scheme 2. This scheme also creates a bankable business case.
In this support scheme the HRS becomes structurally profitable 12 years earlier than the reference (3 versus 15 years).

When it comes to HRS economic viability, support scheme 3 lies somewhere between schemes 1 and 2.

Figure 35 shows the blended UBH income resulting from support scheme 3. The HRS earns most of its money by selling hydrogen. The CAPEX grant reduces the funding gap. The other support instruments (take-or-pay mechanism and performance-based payments) are more market driven than the provision of upfront grants.

Furthermore, the EUR 700,000 soft loan strengthens the HRS guarantee capital, making it easier to attract senior debt. As a result of the soft loan, provision solvency in terms of guarantee equity to total assets does not fall below 60% during the first ten years of operation.

C.3.5 Support Schemes Costs, Effects and Funding Comparison

The calculations in paragraphs C.3.2 to C.3.4 show that there are a number of distinct ways to support UBH investment and operation. It is not possible to decide beforehand which support scheme is the best, as it depends on strategic goals, environmental goals, FCEV availability, availability of financial resources and demand aggregation willingness.

Figure 36 shows a combination of the total estimated support costs and CO₂ and NOₓ reductions per support scheme. Costs are determined as follows:

- demand aggregation costs: difference in TCO per kilometre between FCEV and its ICE benchmark during the support period,
- take-or-pay penalties: take-or-pay sales level (kg) minus actual sales level (kg) multiplied by the penalty price per kg,
- performance-based payments: fixed amount per time period,
- capital expenditure grants: lump sum upfront payment,
- operational expenditure grants: annual amount during support scheme period,
- soft loans interest discount: difference between commercial market interest and soft loans interest costs.

Support scheme 1 (CAPEX/OPEX support) requires EUR 2 million support, EUR 1.6 million CAPEX grants and EUR 0.4 million OPEX grants. With the help of these grants the HRS can be built, but there is no guarantee that it will actually be used. As support scheme 1 does not stimulate demand, it has no direct impact on CO\textsubscript{2} and NO\textsubscript{x} reduction.

Support scheme 2 (demand aggregation) requires EUR 7.6 million support. This support money is used to compensate early FCEV adopters for higher FCEV costs compared to their current ICE vehicle. Support scheme 2 creates enough demand to make the UBH commercially viable. The 91-FCEV demand aggregation group contributes to CO\textsubscript{2} reduction (600 tonnes per year) and NO\textsubscript{x} reduction (725 kilogrammes per year).

Support scheme 3 (a mix of multiple support tools) requires EUR 4.9 million support. Demand aggregation requires EUR 3.8 million, the rest of the support consists of reduced interest soft loans (EUR 200k), CAPEX grant (EUR 200k), performance-based payments (EUR 500k) and take-
or-pay penalties (EUR 200k). The 46-FCEV demand aggregation group contributes to CO₂ reduction (300 tonnes per year) and NOₓ reduction (363 kilogrammes per year).

Figure 37 shows funding sources and their application during the support scheme period (ten years). All support scenarios require CAPEX funding and cash flow funding. Support scheme 1 requires a higher level of external funding that the other support schemes as it has a higher level of negative net cash flow (due to lack of sales).

Support scheme 1 shows a funding structure that is based on grant funding. Support scheme 2 shows a more traditional debt-equity funding structure. Support scheme 3 shows a more blended funding structure including grants, equity, soft loans (junior debt) and regular loans (senior debt).

The funding structure is a result of the support strategy. Support strategies without focus on HRS revenue generation cannot be commercially funded – such strategies require grant funding. Support strategies including revenue generation do qualify for commercial funding. As HRS development is still regarded as a high-risk investment, traditional debt-equity structures may not be feasible. Soft loans (with a junior position) are an important funding source as they provide comfort to senior lenders. Alternatively, guarantees have the same function without requiring funding in cash.
C.4 Urban Full-Service HRS

Table 11 summarises the key data used to run the UFH business case. These data were presented in table 1 (page 23), table 2 (page 30) and table 9 (page 109).

<table>
<thead>
<tr>
<th>Parameter</th>
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<tr>
<td>HRS size (peak capacity in kg/day)</td>
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</tr>
<tr>
<td>HRS commercial capacity at maturity (average hydrogen throughput in kg/day)</td>
<td>700 kg/day</td>
</tr>
<tr>
<td>Average hydrogen pre-tax retail price</td>
<td>EUR 10/kg</td>
</tr>
<tr>
<td>HRS retail price reduction</td>
<td>25% in 15 years</td>
</tr>
<tr>
<td>Hydrogen supply: delivered (d), on-site production (op)</td>
<td>d</td>
</tr>
<tr>
<td>Average hydrogen purchase price (EUR/kg)</td>
<td>EUR 4 per kg</td>
</tr>
<tr>
<td>HRS capital expenditure (2015 level)</td>
<td>EUR 2.2 million</td>
</tr>
<tr>
<td>HRS CAPEX reduction</td>
<td>40% in 15 years</td>
</tr>
<tr>
<td>HRS asset economic life</td>
<td>15 years</td>
</tr>
<tr>
<td>OPEX - fixed amount (EUR/year)</td>
<td>EUR 90k per year</td>
</tr>
<tr>
<td>OPEX - variable amount (percentage of revenues)</td>
<td>5% of revenues</td>
</tr>
<tr>
<td>Interest rate senior debt</td>
<td>4% nominal, 2% real</td>
</tr>
</tbody>
</table>

Table 11: Urban Basic HRS key scheme data.

C.4.1 Early Market Business Case Challenges

Figure 38 shows the Valley of Death challenge for the Urban Full-Service HRS archetype. This Valley of Death results from this HRS key data shown in table 11 and the S-curve shown in figure 25.
This graph shows that the discounted payback time (time it takes to recover all expenditure including funding costs) is 21 years.

Figure 38 also shows that the operating cash flow becomes positive in year 8. The Valley of Death increases significantly in year 15 when replacement investments are assumed.

Even though the UFH archetype has more a more favourable cost structure than the UBH archetype, its Valley of Death is not commercially bankable. It simply takes too long before the assets start to generate a substantial enough income to pay off debt and other funding.

Figure 39: Urban Full-Service HRS earnings before taxes – reference of no support.
Figure 39 shows that it takes 11 years to reach a level of structural profitability without any external support.

Even though the Urban Full-Service HRS has a better autonomous performance that the Urban Basic HRS archetype, its business case challenges are comparable. For this reason the following paragraphs will only briefly summarise the UFH support schemes.

C.4.2 Support Scheme 1: CAPEX/OPEX Grants

This support scheme's principles are described in paragraph 6.3.1. More specifically, UFH support scheme 1 consists of only a 70% CAPEX grant.

![Cumulative Free Cash Flow (Valley of Death)](image)

Figure 40: Urban Full-Service HRS Valley of Death, support scheme 1 against a reference of no support.

Figure 40 in shows how this support scenario reduces Valley of Death duration from 21 to 14 years. However, this does not necessarily make the UFH financially viable. Lack of commercial activity (as a result of a slow assumed growth during the first ten years of operation) results in a situation where both revenues and cost levels are close to zero (due to the CAPEX and OPEX grants).
Figure 41: Urban Full-Service HRS support scheme 1 income breakdown.

Figure 41 shows a commercial pattern similar to the UBH archetype discussed in paragraph C.3.2: a significant period of commercial inactivity due to lack of autonomous hydrogen sales. The CAPEX grant reduces depreciation and funding costs enabling the UFH operator to maintain a low cost level during the low-income phase.

C.4.3 Support Scheme 2: Demand Aggregation

This support scheme’s principles are described in paragraph 6.3.2. The demand aggregation level is determined so that the discounted payback time falls from 21 years (reference) to 14 years - one year less than HRS asset life expiration. This financial target requires an 83 kg per day hydrogen sales level on top of autonomous sales, assuming a 10% dropout rate\(^\text{17}\) during the ten-year support period.

\(^\text{17}\) Percentage of demand aggregation participants that cancel their participation before the support period ends.
Figure 42: Urban Full-Service HRS sales volume development: support scheme 2 against a reference of no support.

Figure 42 shows this support scheme’s impact on UFH sales volumes. If the same demand aggregation group composition as described in paragraph C.3.3 is assumed then the number of required FCEVs in order to reach 83 kg hydrogen per day additional hydrogen sales is 76.

Figure 43: Urban Full-Service HRS Valley of Death, support scheme 2 against a reference of no support.

Figure 43 shows the impact of support scheme 2 on the UFH archetype’s Valley of Death. It shows that demand aggregation leads to faster revenue growth and a decreasing Valley of Death volume.
Figure 44 shows how demand aggregation leads to early UFH income.

As is the case with UBH, the UFH business case becomes bankable with a demand aggregation group of 76 vehicles, which is quite substantial in the early days. Total estimated support costs are EUR 6.3 million which is significantly higher than the EUR 1.5 million CAPEX grant of support scheme 1.

C.4.4 Support Scheme 3: Mix of Multiple Support Tools

This support scheme’s principles are described in paragraph 6.3.3. This support scheme is a mix of the following support tools:

- a 15% CAPEX grant,
- no OPEX grant,
- demand aggregation: 20 vehicles (same composition as described in paragraph C.3.3) leading to 22 kg/day extra sales,
- 10% demand aggregation drop out level,
- take-or-pay contract for 100 kg/day and a penalty price of EUR 2/kg,
- performance-based payment of EUR 50,000 per year
- EUR 700,000 soft loan support with a 100 basis point (1.00%) interest discount.

This support tool mix leads to a discounted payback time of 14 years – one year less that HRS asset life expiration. This means that within the asset life period all expenditure including funding-related expenditure is recovered. The assumed support period is ten years.
Figure 45: Urban Full-Service HRS sales volume development: support scheme 3 against a reference of no support.

Figure 45 shows this support scheme’s impact on UFH sales volumes. If the same demand aggregation group composition as described in paragraph C.3.3 is assumed then the number of required FCEVs in order to reach 22 kg hydrogen per day additional hydrogen sales is 20. The demand aggregation impact is significant but modest.

Figure 46: Urban Full-Service HRS Valley of Death, support scheme 3 against a reference of no support.

Figure 46 shows the impact of support scheme 3 on the UFH archetype’s Valley of Death. It shows that this support scenario reduces the Valley of Death volume and duration.
Figure 47 shows how this mixture of various support instruments generates early UFH income.

C.4.5 Support Schemes Costs, Effects and Funding Comparison

The calculations in paragraphs C.4.2 to C.4.4 show that there are many different ways to support UFH investment and operation. It is not possible to decide beforehand which support scheme is the best, as it depends on strategic goals, environmental goals, FCEV availability, availability of financial resources and demand aggregation willingness.

Figure 48 shows a combination of the total estimated support costs and CO₂ and NOₓ reductions per support scheme.
Support scheme 1 (CAPEX/OPEX support) requires EUR 1.5 million CAPEX grant support. With the help of this grant money the HRS can be built, but there is no guarantee that it will actually be used. As support scheme 1 does not stimulate demand, it has no direct impact on CO₂ and NOₓ reduction.

Support scheme 2 (demand aggregation) requires EUR 6.3 million support. This support money is used to compensate early FCEV adopters for higher FCEV costs compared to their current ICE vehicle. Support scheme 2 creates enough demand to make the UFH commercially viable. The 76-FCEV demand aggregation group contributes to CO₂ reduction (500 tonnes per year) and NOₓ reduction (600 kilogrammes per year).

Support scheme 3 (a mix of multiple support tools) requires EUR 3.0 million support. Demand aggregation requires EUR 1.7 million, the rest of the support consists of reduced interest soft loans (EUR 200k), CAPEX grant (EUR 300k), performance-based payments (EUR 500k) and take-or-pay penalties (EUR 300k). The 20-FCEV demand aggregation group contributes to CO₂ reduction (130 tonnes per year) and NOₓ reduction (160 kilogrammes per year).

Figure 49 shows funding sources and their application during the support scheme period (ten years). All support scenarios require CAPEX funding and cash flow funding. Support scheme 1 requires a higher level of external funding than the other support schemes as it has a higher level of negative net cash flows (due to lack of sales).
Support scheme 1 shows a funding structure that is based on grant funding in combination with commercial funding. Support scheme 2 shows a more traditional debt-equity funding structure. Support scheme 3 shows a blended funding structure including grants, equity, soft loans (junior debt) and regular loans (senior debt).

The funding structure is a result of the support strategy. Support strategies without focus on HRS revenue generation cannot be fully commercially funded – such strategies require (partial) grant funding. As HRS development is still regarded as a high-risk investment, traditional debt-equity structures may not be feasible. Soft loans (with a junior position) are an important funding source as they provide comfort to senior lenders. Alternatively, guarantees have the same function without requiring funding in cash.

C.5 Rural Basic HRS

Table 12 summarises the key data used to run the RBH business case. These data were presented in table 1 (page 23), table 2 (page 30) and table 9 (page 109).
### Table 12: Rural Basic HRS key scheme data.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRS size (peak capacity in kg/day)</td>
<td>80 kg/day</td>
</tr>
<tr>
<td>HRS commercial capacity at maturity (average hydrogen throughput in kg/day)</td>
<td>56 kg/day</td>
</tr>
<tr>
<td>Average hydrogen pre-tax retail price</td>
<td>EUR 10/kg</td>
</tr>
<tr>
<td>HRS retail price reduction</td>
<td>25% in 15 years</td>
</tr>
<tr>
<td>Hydrogen supply: delivered (d) /on-site production (op)</td>
<td>op</td>
</tr>
<tr>
<td>Average hydrogen purchase price (EUR/kg)</td>
<td>not applicable</td>
</tr>
<tr>
<td>HRS capital expenditure (2015 level)</td>
<td>EUR 0.8 million</td>
</tr>
<tr>
<td>HRS CAPEX reduction</td>
<td>40% in 15 years</td>
</tr>
<tr>
<td>HRS asset economic life</td>
<td>15 years</td>
</tr>
<tr>
<td>OPEX - fixed amount (EUR/year)</td>
<td>EUR 60k per year</td>
</tr>
<tr>
<td>OPEX – variable amount (percentage of revenues)</td>
<td>12% of revenues</td>
</tr>
<tr>
<td>Interest rate senior debt(^{18})</td>
<td>5% nominal, 3% real</td>
</tr>
</tbody>
</table>

**C.5.1 Early Market Business Case Challenges**

The Rural Basic HRS archetype is a special case. RBHs play an important role in network completion but will most likely not benefit the early FCEV adopters [12]. Therefore, a lower growth rate is assumed.

Figure 50 shows the assumed adjusted RBH growth rate compared to the assumed UBH and UFH growth rates. This growth rate is just a rough indication, region-specific market research will have to result in a more precise forecast.

---

\(^{18}\) As RBHs have a slower expected market growth rate and a significant cost structure, an extra risk premium of 100 basis points (1.00%) is assumed.
Figure 50: Adjusted growth Rural Basic HRS growth rate versus assumed Urban Basic HRS and Urban Full-Service HRS growth rate.

Figure 51 shows the Valley of Death challenge for the RBH archetype. This Valley of Death results from HRS key data shown in table 12 and the RBH S-curve shown in figure 50.

Figure 51: Rural Basic HRS Valley of Death - reference of no support.

This graph shows a non-bankable investment with a continuously growing cash shortage. This situation is caused by two main factors:

- the assumed very low market growth, in combination with
- relatively high investments in on-site production and distribution facilities.
Figure 52 shows that this Rural Basis HRS archetype does not reach a break-even level without external support.

This HRS archetype’s challenge is twofold:

- looking for cost cuts and/or benefits from system integration to reduce expenditure or create additional income, and
- getting external financial support to make the business case bankable.

### C.5.2 Support Scheme 1: CAPEX/OPEX Grants

This support scheme’s principles are described in paragraph 6.3.1. More specifically, this support scheme’s parameters are:

- a 100% CAPEX grant, and
- a 100% OPEX grant during an assumed 15-year period.

Figure 53 shows the impact of support scheme 1 on the RBH archetype’s Valley of Death.
This support scheme reduces the Valley of Death to almost zero. After the assumed 15-year support period each reinvestment results in additional external funding needs. The expected future revenue level provides just enough cash to pay back external funds including interest costs. Furthermore in this support scheme the HRS becomes structurally profitable after 14 years.

However, this does not necessarily make the RBH financially viable. Lack of commercial activity (as a result of a slow assumed growth during the first 15 years of operation) results in a situation where both revenues and cost levels are close to zero (due to the CAPEX and OPEX grants).

Figure 54 illustrates this 15-year period of economic and commercial inactivity due to lack of autonomous hydrogen sales.
C.5.3 Support Scheme 2: Demand Aggregation

This support scheme’s principles are described in paragraph 6.3.2. This support scheme does not subsidise CAPEX or OPEX, but generates HRS income from demand aggregation.

Figure 55 shows the effect of support scheme 2 on the RBH sales volume. Figure 56 shows its effect on the Valley of Death funding gap. Figure 57 shows the RBH income breakdown under support scheme 2.

![HRS H2 Sales Volume Development](image)

Figure 55: Rural Basic HRS sales volume development: support scheme 2 against a reference of no support.

![Cumulative Free Cash Flow (Valley of Death)](image)

Figure 56: Rural Basic HRS Valley of Death, support scheme 2 against a reference of no support.
A demand aggregation group is assumed, which is composed of mostly private vehicle owners. This support scheme requires a demand aggregation fleet of 51 vehicles. The formation of such a large group in sparsely populated areas is questionable if not impossible.

C.5.4 Support Scheme 3: Mix of Multiple Support Tools

This support scheme’s principles are described in paragraph 6.3.3. This support scheme is a mix of the following support tools:

- a 40% CAPEX grant,
- a 25% OPEX grant,
- demand aggregation: 14 vehicles (50% private owners, 50% business and taxis) leading to 10 kg/day extra sales,
- 10% demand aggregation drop out level,
- take-or-pay contract for 46 kg/day and a penalty price of EUR 2/kg,
- performance-based payment of EUR 40,000 per year
- EUR 300,000 soft loan support with a 200 basis point (2.00%) interest discount.

This support tool mix leads to a discounted payback time of 11 years – one year less that HRS asset life expiration. This means that within the asset life period all expenditure including funding-related expenditure is recovered. The assumed support period is 15 years.

Figure 58 shows the impact of this support scheme on RBH sales volumes.
As a result of demand aggregation efforts, hydrogen sales are significantly higher than the reference. Support scheme 3 requires only 14 participating vehicles. That is only 25% of the number of vehicles required in support scheme 2.

Figure 59 shows the impact of support scheme 2 on the RBH archetype’s Valley of Death.

The conclusion from this figure is that support scheme 3 eliminates the reference ‘race to the bottom’ cash flow effects. This support scheme brings the business case to an acceptable level. However, as future investment levels will remain significant, given a sparsely populated market, the RBH is not expected to become investment grade.
Figure 60 shows the blended RBH income resulting from support scheme 3.

Even though the RBH support scheme 3 income structure is very different from the support scheme 1 income structure, the fact remains that most of the income has to be provided by external sources during a long slow start-up period. The RBH stand-alone income generation capacity is limited due to a small market size and slow growth.

C.5.5 Support Schemes Costs, Effects and Funding Comparison

The calculations in paragraphs C.5.2 to C.5.4 show that there are two distinct ways to support RBH investment and operation: a CAPEX/OPEX grant strategy and a strategy using a blend of various financial instruments. The full demand aggregation alternative is not expected to be feasible as it requires a number of vehicles that is probably not available in sparsely populated areas.

Figure 61 shows a combination of the total estimated support costs and CO$_2$ and NO$_x$ reductions per support scheme.
Support scheme 1 (CAPEX/OPEX support) requires EUR 1.7 million support: EUR 0.8 million CAPEX grants and EUR 0.9 million OPEX grants. With the help of these grants the HRS can be built, but there is no guarantee that it will actually be used. As support scheme 1 does not stimulate demand, it has no direct impact on CO$_2$ and NO$_x$ reduction.

Support scheme 2 (demand aggregation) will not be explained here given the conclusion that demand aggregation opportunities are limited in rural areas.

Support scheme 3 (a mix of multiple support tools) requires EUR 2.8 million support. Demand aggregation requires EUR 1.4 million, the rest of the support consists of reduced interest soft loans (EUR 200k), CAPEX grant (EUR 300k), performance-based payments (EUR 600k) and take-or-pay penalties (EUR 300k). The 14-FCEV demand aggregation group contributes to CO$_2$ reduction (63 tonnes per year) and NO$_x$ reduction (51 kilogrammes per year).

Figure 62 shows funding sources and their application.
Figure 62: Rural Basic HRS funding sources and application per support scheme.

This figure shows funding/application during the entire support scheme period, which is 15 years in this case. This means that HRS reinvestment is also included (as HRS asset life is assumed to be 15 years).

Support scheme 1 shows a funding structure that is based on grant funding. As grant funding does not stimulate the HRS revenue generating capacity, the RBH generates very limited cash that can be used to fund HRS reinvestment, so the reinvestment has to be primarily funded with debt.

Support scheme 2 is ignored because of its feasibility issues.

Support scheme 3 allows the RBH operator to generate revenues from the various sources mentioned in paragraph C.5.4. The excess cash earned during the first 15 years is used as a funding source for HRS reinvestment. The initial investment is funded by a mix of CAPEX grants, share capital, soft loans and regular loans.
List of Interviews

A total of 24 interviews have been conducted throughout this study in order to gain experience and important inside information from stakeholders within the international hydrogen for transport sector. Interviews were conducted with several private companies, branch organisations and governments.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Type</th>
<th>Interviewee(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Liquide</td>
<td>Business - hydrogen sales</td>
<td>Jaap Oldenziel</td>
</tr>
<tr>
<td>BETA</td>
<td>Association of petrol station operators</td>
<td>Petra van Stijn</td>
</tr>
<tr>
<td>BETA</td>
<td>Association of petrol station operators</td>
<td>Chris van der Straten</td>
</tr>
<tr>
<td>CNG-net</td>
<td>Business - CNG refuelling station owner</td>
<td>Erik Keemink; Ruud Kos</td>
</tr>
<tr>
<td>Daimler</td>
<td>Business - OEM</td>
<td>Georg Frank; Jörg Wind; Rosario Berretta</td>
</tr>
<tr>
<td>ECN</td>
<td>Research institute</td>
<td>Marcel Weeda</td>
</tr>
<tr>
<td>Element Energy</td>
<td>Business - energy consultancy</td>
<td>Michael Dolman</td>
</tr>
<tr>
<td>FCH JU</td>
<td>Public-Private Partnership - supporting activities in fuel cell and hydrogen energy technology</td>
<td>Bert de Colvenaer</td>
</tr>
<tr>
<td>Formule E Team</td>
<td>Public-Private Partnership - supporting e-mobility</td>
<td>Bert Klerk; Mark van Kerkhof</td>
</tr>
<tr>
<td>H₂Invest</td>
<td>Business - HRS business case</td>
<td>Jan Michalski</td>
</tr>
<tr>
<td>H₂Logic</td>
<td>Business - HRS manufacturer</td>
<td>Michael Sloth</td>
</tr>
<tr>
<td>HIT-2</td>
<td>Hydrogen project</td>
<td>Floris Mulder</td>
</tr>
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<td>HIT-2</td>
<td>Hydrogen project</td>
<td>Cecilia Wallmark</td>
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<tr>
<td>HyER</td>
<td>Knowledge consortium</td>
<td>Marieke Reijalt</td>
</tr>
<tr>
<td>Hyundai</td>
<td>Business - OEM</td>
<td>Frank Meijer</td>
</tr>
<tr>
<td>ING Bank</td>
<td>Business - bank</td>
<td>Dirk Jan van Swaay</td>
</tr>
<tr>
<td>Nationaal Waterstof Platform</td>
<td>Branch association</td>
<td>Ger van Tongeren; Hans van Vliet</td>
</tr>
<tr>
<td>NOW</td>
<td>Research institute</td>
<td>Thorsten Herbert; Oliver Ehret</td>
</tr>
<tr>
<td>Rijkswaterstaat</td>
<td>Government</td>
<td>Floris Mulder</td>
</tr>
<tr>
<td>Rotterdamse Taxi Centrale</td>
<td>Business - Taxi company</td>
<td>Sjaak de Winter; Kris Mohan</td>
</tr>
<tr>
<td>Stockholm Municipality</td>
<td>Government</td>
<td>Eva Sunnerstedt</td>
</tr>
<tr>
<td>Toyota</td>
<td>Business - OEM</td>
<td>Frank Versteeg</td>
</tr>
<tr>
<td>UK Government</td>
<td>Government</td>
<td>Kate Warren</td>
</tr>
<tr>
<td>Van Peperstraten Group</td>
<td>Business – HRS entrepreneur</td>
<td>Tonnie van Peperstraten</td>
</tr>
<tr>
<td>Waterstofnet</td>
<td>HRS developer</td>
<td>Wouter van der Laak; Adwin Martens; Stefan Neis</td>
</tr>
</tbody>
</table>

Table 13: Overview of interviewed persons and organisations
E EVAC Workshop

On 1 September 2015 an Expert Validation and Acceptance Meeting was organised. Members of the Dutch Hydrogen and Fuel Cell Association were invited to this workshop, but also non-members were welcome to join. First results, as well as a first version of the HIBIT tool, were presented.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Type</th>
<th>Attendant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Liquide</td>
<td>Business - hydrogen sales</td>
<td>Jaap Oldenziel</td>
</tr>
<tr>
<td>CNG Net</td>
<td>Business - CNG Refuelling Station owner</td>
<td>Oskar Voorsmit</td>
</tr>
<tr>
<td>Linde Gas</td>
<td>Business - hydrogen sales</td>
<td>Jaco Reijerkerk</td>
</tr>
<tr>
<td>Ministry of Infrastructure and the Environment</td>
<td>Government</td>
<td>Fred Hagendoorn</td>
</tr>
<tr>
<td>Ministry of Infrastructure and the Environment - Rijkswaterstaat</td>
<td>Government</td>
<td>Floris Mulder</td>
</tr>
<tr>
<td>Nationaal Waterstof Platform</td>
<td>Branch association</td>
<td>Hans van Vliet</td>
</tr>
<tr>
<td>NEN</td>
<td>NGO - Dutch normalization institute</td>
<td>Francoise de Jong</td>
</tr>
<tr>
<td>NWBA</td>
<td>Branch association</td>
<td>Ellen van Driel</td>
</tr>
<tr>
<td>RAI</td>
<td>Branch association</td>
<td>Jaap Tuinstra</td>
</tr>
<tr>
<td>Siemens</td>
<td>Business - hydrogen technology</td>
<td>Jaap Bolhuis</td>
</tr>
<tr>
<td>Stichting Initiatief Waterstof Rijden</td>
<td>NGO</td>
<td>Erik van der Steur</td>
</tr>
<tr>
<td>Stichting Initiatief Waterstof Rijden</td>
<td>NGO</td>
<td>Karel van den Berghe</td>
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<td>Taxi MTA</td>
<td>Business - Taxi company</td>
<td>Rick Leen</td>
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<td>Taxi MTA</td>
<td>Business - Taxi company</td>
<td>M. Thoonsen</td>
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<tr>
<td>Techni Control</td>
<td>Business - hydrogen components</td>
<td>Joost van de Laar</td>
</tr>
<tr>
<td>The Green Village</td>
<td>Innovative Energy Solutions</td>
<td>Freerk Bischop</td>
</tr>
<tr>
<td>TU Delft</td>
<td>University</td>
<td>Kas Hemmes</td>
</tr>
</tbody>
</table>

Table 14: Attendants at the EVAC workshop on 1 September 2015.

Figure 63: Jan Piet van der Meer explaining the importance of demand aggregation
F HIT-2 Partners Webinar

On 8 October 2015 a webinar was organised to share intermediate results of the activity 3 study and to present the HIBIT tool to the HIT-2 partners. All HIT-2 countries participated in the webinar. In this appendix the minutes of the webinar are presented.

Webinar for HIT-2 partners – 8 October 2015

This document provides a short overview of topics discussed during the webinar for HIT-2 countries on 8 October 2015.

Goal of the webinar was to present and discuss the HRS FCEV business case simulation tool developed by Infram, to the HIT-2 partners.

Programme:

- Short introduction by Floris Mulder (Rijkswaterstaat – The Netherlands) on the HIT-2 activity 3 assignment goals.
- Introductory presentation by Jan Piet van der Meer on the approach of this study.
- Presentation of the first concept HIBIT by Robert van Hoof.

Introductory presentation by Jan Piet van der Meer

Jan Piet van der Meer introduced the approach that is used for this study. The most important points were:

- A bottom-up approach is used, as HRS network development starts at the local level.
- As part of the approach, a tool is being developed that brings together HRS (business case) and FCEV (demand aggregation). This tool shows the impact of local/national/EU
economic policies and incentives on HRS development. Also the impact on environmental goals is calculated. The tool can be used by policy makers, HRS owners/operators and investors, and its final version will delivered with a manual.

- An important question is how to finance the financial Valley of Death; several methods are mentioned within the presentation, and can be modelled in HIBIT.
- System integration is mentioned as a way to combine HRS with other potential hydrogen customers. This can be an important concept in both urban and isolated areas.
- Making use of specific funds might be an important way to overcome the funding gap. In these funds, local authorities can play an important role. This idea was inspired by the NO$_x$ fund in Norway.

Questions asked by participants:

- What is the feasibility of an NO$_x$ fund at a local level? Are these authorities going to back up this plan?
  - Suggestion: try to speak to three to four cities and explain the idea to check its feasibility.
  - Suggestion: if these funds are focused at the local level, also keep in mind the goals of local governments. This might not just be lowering NO$_x$ emissions, but also improving air quality in general. For that reason, particulate matter (PM10/PM2.5) might also be taken into account.
  - Proposing and implementing these funds are two different things (there are already examples, such as the London congestion charge).
  - We will keep this in mind and get in touch with some local authorities. The stakeholder meeting on 4 November might be a good opportunity to check this as well, as local authorities might participate in this meeting.
- It could be named a ‘local emission fund’ or ‘air quality fund’.
- Suggestion: Try to think of an idea in which this fund is initially financed by local public resources, which can be earned back when the market really takes off (revolving fund).
- It is mentioned that the funding question in itself cannot be solved within this assignment; it is about ideas and possible constructions.
- Take into account that not only hydrogen, but also other alternative (zero emission) fuels might benefit from such funds.
- How did you take Finland into consideration? It seems that there has been no focus on areas other than large urban areas.
  - In order to study differing situations per country/region we make use of archetype HRS. For example: small-scale 56 kg/d in isolated areas vs. medium/large 320 kg/d in urban areas. Both in the report and in the tool we take into account that circumstances differ per country and per region.
Presentation on HIBIT by Robert van Hoof

The most important thing to mention before describing what the tool consists of is that it has been developed bearing in mind large differences between regions concerning the size of an HRS, the possibilities for (government) support at several levels, and the possibilities for demand aggregation. *Therefore, the tool has been created in such a way that most parameters can be adjusted flexibly.* Just as an example: different HRS sizes, hydrogen retail prices, amount of demand aggregation, etc. can be used.

The main parts of the tool are:

- scenario-independent parameters and reference HRS growth curves,
- the option to use three separate scenarios that are compared with the reference scenario,
- for each scenario different support tools can be chosen,
- a demand aggregation tab in which what the demand aggregation composition will look like for specific HRS can be specified,
- a graph showing the HRS growth curve per scenario compared to reference,
- a graph showing income and revenue for HRS, with graphs per scenario for a cost structure breakdown,
- a graph showing total costs for support (in case of demand aggregation this support does not necessarily come from governments),
- a graph showing averted emissions of CO₂ and NOₓ on an annual basis, related to demand aggregation (so not taking into account autonomous growth).

Questions:

- Wouter van der Laak (Waterstofnet) reacts very positively on the model  Very good that it gives an insight into ecological (air quality) effects.
  - His recommendation is to add particulate matter to the graphs.
  - Also the suggestion is made that the social costs of the emissions that can be saved should be looked into (the costs related to current emissions of, for example, 1,000 kg NOₓ/y).
- The source of hydrogen: is it a variable in the tool?  Yes. We are aware that it might be interesting to put this into more detail in the model, but it seems difficult to do so, as it is even more country-specific than other parameters. We tackled this by allowing the hydrogen pre-tax purchase price to be put in the model: this is the cost of hydrogen before it is compressed at the HRS location. If the hydrogen is trucked, it includes production, transportation, etc. If on-site electrolysis is used, the business case figure for producing hydrogen on-site should be part of the pre-tax purchase price in the model, as the revenue calculated in the model is based on the pre-tax purchase and pre-tax selling prices of hydrogen.
- It is suggested that a link with clean energy might be useful.