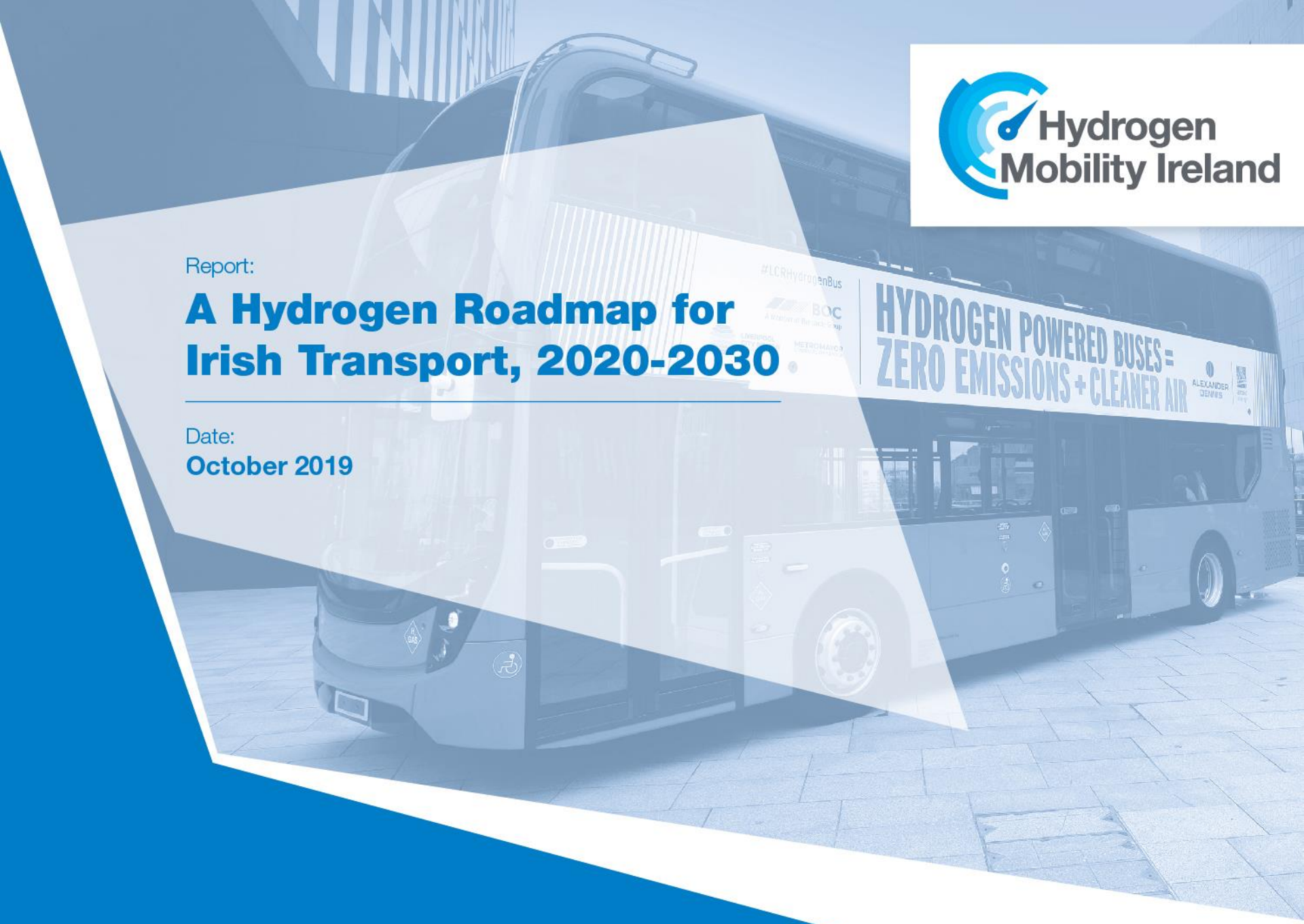
Hydrogen Mobility Ireland

Report:

A Hydrogen Roadmap for Irish Transport, 2020-2030

Date:

October 2019



Executive Summary: Project Aims and Structure

Project Background

Hydrogen Mobility Ireland was formed in February 2019 by a diverse group of industrial stakeholders with input from both policy and academic stakeholders for the purposes of developing and then overseeing the implementation of a strategy to introduce the use of hydrogen for mobility in Ireland. The group commissioned the consultancy firm, Element Energy as principal advisors. The objectives of the project were:

1. Develop a strategy to introduce hydrogen vehicles and related infrastructure (hydrogen production and refuelling sites) into Ireland between 2019 and 2030
2. Set out the business case for industry actors to invest in a profitable hydrogen mobility market in Ireland
3. Understand the policies required for the hydrogen mobility market to grow in Ireland

Executive Summary: Report Aims and Key Findings

Report Aims

This report aims to give the reader a clear vision of what hydrogen mobility can achieve in Ireland over the next ten years and to demonstrate that this vision is clearly achievable at levels of commitment that industry and government can support

Report General Findings

- The hydrogen mobility sector is gaining momentum which means **the cost of hydrogen vehicles and infrastructure is falling quickly** and the number and type of vehicles available is increasing
- Progress made in other countries will bring down the cost of the hydrogen mobility option for Ireland. This **allows Ireland to skip small scale demonstration projects and jump straight to projects at a scale** that can be profitable for investors
- The rollout of hydrogen infrastructure and the growth of fleets takes time. This means **to benefit from the decarbonisation potential of hydrogen in the 2030s action is required now**
- Cost projections for hydrogen supply and also vehicles suggest that the **total cost of ownership of hydrogen vehicles will match that of conventional vehicles** in many vehicle segments by the mid to late 2020s (assuming FCEV receive the same policy incentives as BEV)
- For hydrogen stations to be economically viable, **hydrogen needs to be delivered at scale**. The implication of this is that in the early rollout **a smaller number of larger stations is preferable**
- To ensure these stations and production sites are well utilised **projects should look to include captive fleets who can guarantee demand** and, **especially fleets of heavy duty vehicles** which use much larger quantities of hydrogen per day

Executive Summary: Key Findings for Policy Makers ①

Key Findings

- **Hydrogen refuelling infrastructure can be delivered by industry with limited government support:** There is a business case for industry to invest in hydrogen mobility if government provides grant funding to very earliest projects to de-risk the investment and ensures that hydrogen plays a positive role in Ireland's implementation of the Renewable Energy Directive II (which is implemented via the Biofuels Obligation Scheme).
- **Support required is in-line with BEVs:** FCEVs can be introduced with the same level of support given to BEVs.
- **Hydrogen mobility delivers additional benefits:** The learnings from hydrogen mobility allows the easier adoption of hydrogen for industry and heat decarbonisation.
- **Action is needed now:** For Ireland to benefit from having hydrogen as a major decarbonisation option in 2030, actions to support the hydrogen industry in Ireland are needed in the short term.
- **Hydrogen is a complementary fuel to electricity for zero carbon transport:** Hydrogen complements electricity as a zero-carbon transport fuel by offering greater range and faster refueling, making it an ideal solution for vehicles where plug-in vehicles don't meet the users needs. The availability of both vehicle options offers a more cost-effective pathway to deep decarbonisation of transport than using just one vector[1].

1: FCHJU, 2019, Hydrogen Roadmap Europe, https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

Executive Summary: Key Findings for Policy Makers ②

Key Findings

- **Hydrogen is a very low carbon fuel:** Three pathways for hydrogen production are considered, including a complete elimination of carbon emissions via production exclusively from renewable sources. The cost of the decarbonisation achieved through the project is on average 75-100 €/tonne of CO_2 abated
- **Benefits for the economy:** Hydrogen is a clean fuel that can be produced domestically, helping to reduce the cost of decarbonising transport, industry and heat while supporting the economy by localising the production of energy for transportation.
- **Deeper decarbonization of the power system:** Hydrogen can support deployment of intermittent renewables by acting as an energy store over many days, as well as by introducing flexibility into the transport demand, from BEV, on the grid and thus reducing the need for costly reinforcements

Executive Summary: Key Findings for Hydrogen Industry Investors ①

Key Findings

- **An initial deployment phase (Phase 1) is suggested involving a deployment of 3 refuelling stations & 2 production sites to support a fleet of 30 buses, 50 cars and 10 vans.** This would serve as a catalyst for the deployment of hydrogen in Ireland and would require significant state support.
- **This would have a cost of €34m** and would require two main state interventions:
  - **A capital grant** to help match fund the program of €14m
  - **Inclusion of green hydrogen in the Biofuels Obligation Scheme**

Following a successful Phase 1 project, an expansion phase (Phase 2), running to 2030, has been mapped. This envisages:

- **Basic hydrogen refuelling national coverage for commercial fleets and commuters** ensuring over half of the population has immediate access to hydrogen fuel
- This will require a total of **76 stations** across the island of Ireland
- Three production scenarios, of which the most realistic involves the deployment of **27 electrolysers co-located with renewable generators and the purchase of hydrogen from an industrial reformer** at the Whitegate Refinery. This mix delivers the same well to wheel emission saving as BEV charged from the grid every year from 2022 to 2030
- A deployment of hydrogen vehicles in a range of vehicle segments including **bus (9% of the fleet), car (2% of the fleet), truck (2% of the fleet) and train (1% of the fleet)**

Rollout of Hydrogen Stations in Ireland

Phase 1 Phase 2.1 Phase 2.2 Phase 2.3 Phase 3

Hydrogen Mobility Ireland

Executive Summary: Key Findings for Hydrogen Industry Investors ②

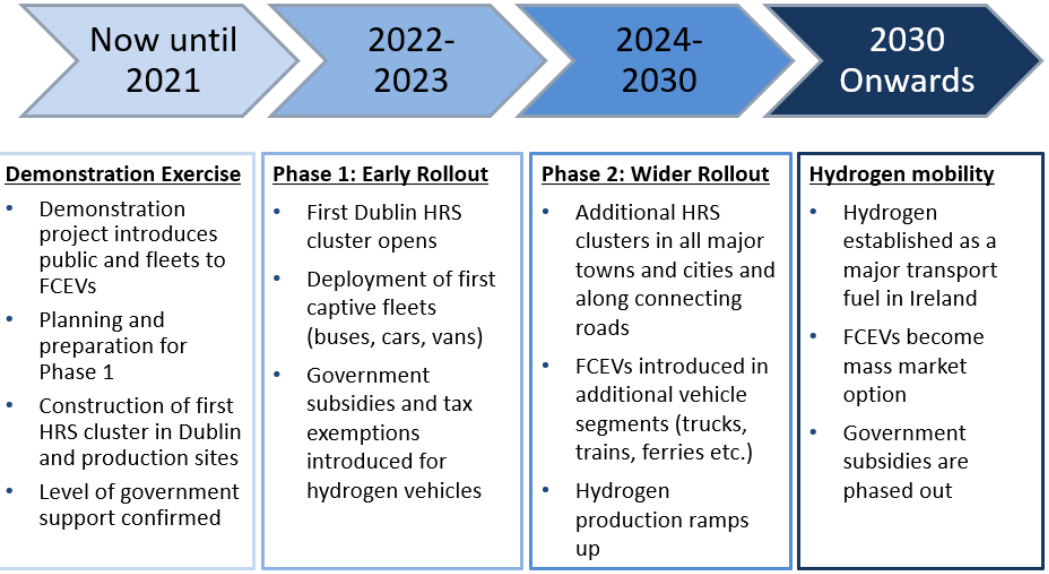
Key Findings

- **An investment of €350 million is required for all aspects of the hydrogen production chain to fulfil the strategy by 2030**. This covers all costs of production equipment, compression, distribution trailers and hydrogen fuelling stations.
- **An acceptable investment per company can create the hydrogen mobility industry:** This investment can be financed by industry whilst delivering an affordable hydrogen price (<<€10/kg) to customers and an attractive rate of return for investors.
- **The investment case requires two main Government interventions:**
  - **BOS credits are needed to support green hydrogen production:** Before 2030, the case is dependent on hydrogen having access to the Biofuels Obligation Scheme to allow hydrogen to be sold at an acceptable price to customers whilst still making returns on the infrastructure investments. The way this policy is implemented will dictate whether industrial players choose a low carbon or zero carbon path for their hydrogen production.
  - **Extension of BEV purchase grants and preferential tax rates to FCEV**: By the time BEV purchase incentives have been phased out, BEVs will have received over a decade of government support. Offering the same policy support to FCEV over a similar timeframe is required for FCEVs to be cost competitive for consumers
- **The modelling assumptions and business case are achievable in the real-world:** Our assumptions, especially around the future price of electricity from renewables, are relatively conservative, suggesting the modelled hydrogen price and project IRR are achievable

Executive Summary: Key Findings for Hydrogen Industry Investors ③

Key Findings

- **Finding sufficient vehicle users is key to a successful infrastructure business case:** Good utilisation of assets is key to a successful business case, suggesting infrastructure providers should take an active role in encouraging vehicle users to choose hydrogen fuel cell vehicles and thereby ensure good use of the hydrogen infrastructure
- **Positioned for expansion:** This 2020 to 2030 strategy will position Ireland to expand the use of hydrogen as a major part of the decarbonization of the national energy system from 2030. Looking forwards from 2030, the consortium data suggests the hydrogen vehicle and refueling network can be self-sustaining and profitable without subsidy. This means that the activity in the 2020s positions hydrogen to become the dominant zero carbon fuel for a wide range of vehicle types from trains to trucks, buses and long range cars.



Overview of Hydrogen Mobility Ireland Strategy

Hydrogen Mobility Ireland

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Hydrogen Mobility Ireland is a co-ordinated group of industrial companies and policy stakeholders developing a strategy to deploy hydrogen-powered transport in Ireland

The group's mission: Create a strategy for the mass market introduction of zero-emission Fuel Cell Electric Vehicles (FCEVs) and make a significant contribution to reducing Ireland's CO_2 emissions.

Long-term benefits to Ireland from hydrogen:

- **Decarbonisation of transport –** FCEVs provide a decarbonisation option for a wide range of vehicle types and use cases
- **Energy security** – hydrogen offers a domestically produced transport fuel that can displace fossil fuel imports
- **Increased renewables** – hydrogen can be produced from electricity and stored, helping to manage intermittent electricity generation from renewables
- **Decarbonisation of heat** – blending and eventually replacing natural gas with hydrogen could provide a low-carbon use for existing gas grid infrastructure and an attractive option for 'hard-to-decarbonise' sectors such as domestic and industrial heat

The approach: Develop a long-term strategy for hydrogen deployment and in parallel create a first project building hydrogen production capacity and hydrogen refuelling facilities to support the first FCEVs in Ireland.

Specific Goals:

- Create the conditions to facilitate the production of low carbon hydrogen for use in transport
- Facilitate the rolling out of hydrogen refuelling infrastructure on a national basis
- Enable the introduction of FCEV transport across various vehicle categories

Hydrogen Mobility Ireland

Hydrogen Mobility Ireland is a Republic of Ireland-focused initiative with an all-island dimension, working with members and stakeholders from Northern Ireland to avoid barriers to all-island hydrogen transport

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An Roinn Iompair Turasóireachta agus Spóirt Department of Transport, Tourism and Sport

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Introduction to Hydrogen

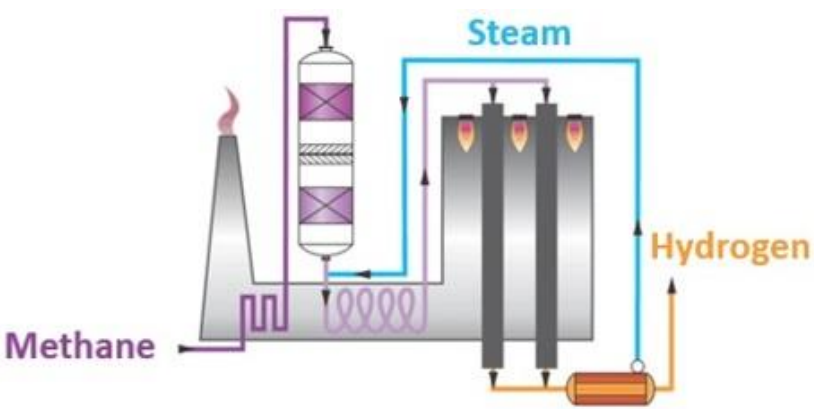
Hydrogen (H_2), the most abundant element on earth is typically found in compounds such as methane (CH_4) and water (H_2O), from which it can be extracted

Hydrogen is of interest as a transport fuel because **hydrogen vehicles are zero tailpipe emissions** and **hydrogen can be produced with low or zero CO_2 emissions**.

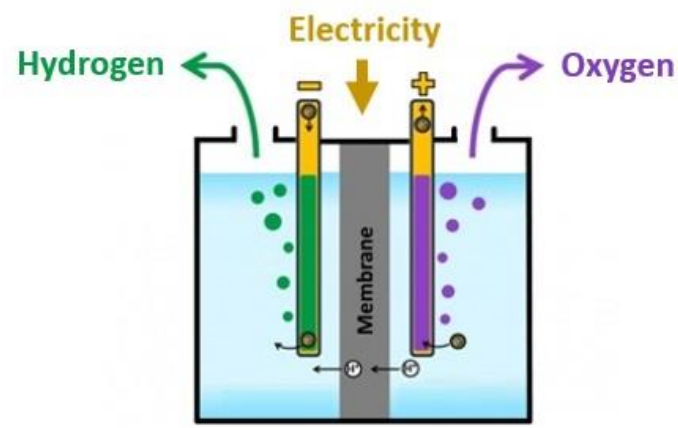
Hydrogen has much better energy density than batteries (the other zero emission option) **giving hydrogen vehicles longer range, making hydrogen particularly attractive for long-range and heavy-duty vehicles**. The challenge of hydrogen vehicles is that the current low volumes of production mean that they are expensive and not widely available.

Hydrogen Production (main methods today)

Reformation: Methane (CH_4) and Steam (H_2O) are combined at high temperature and pressure to produce hydrogen (H_2) and carbon monoxide (CO)



Electrolysis: An electric current passed through water (H_2O) in an electrolyser separates the hydrogen (H_2) and Oxygen (O_2).

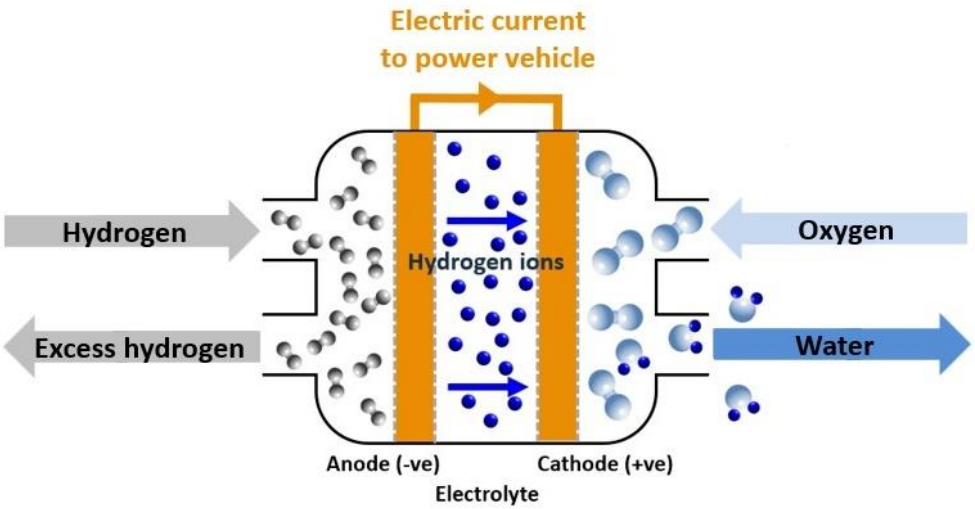


How is hydrogen used to power a vehicle

Hydrogen fuel cells:

- In an internal combustion engine, fuel is burnt at high temperatures, producing carbon emissions and pollutants such as nitrogen oxides (NOx).
- **Hydrogen is generally used in a fuel cell –** Hydrogen reacts chemically with atmospheric oxygen at a much lower temperature, producing an electric current that powers the vehicle.
- **No harmful exhaust –** Fuel cells emit only Water vapour and heat – no CO_2 or NOx pollutants.
- **Hydrogen Refuelling** – Hydrogen vehicles are as quick and convenient to refuel as conventional cars
- **Hydrogen safety** – Hydrogen tanks are tested under extreme collisions to ensure safety

Hydrogen Fuel Cell



Hydrogen Vehicle Refueling

What is the role of fuel cell electric vehicles (FCEVs) in transport?

Benefits of hydrogen for mobility

When used in a fuel cell vehicle, hydrogen ensures:

- Fast refueling (<3 minutes for a car)
- Long range (the Hyundai Nexo has a range of over 650 km)
- Leads to no compromise for the owner of the vehicle
- No air pollutant emissions
- A pathway to complete decarbonization of road transport
- Integration of intermittent renewables for transport

Hydrogen will find the easiest early application for:

- **Long-range/rapid refuelling customers:** where long range between fuelling is required (e.g. taxis)
- **Heavy-duty users:** Able to meet operational needs of trucks, buses etc
- **Rapid response vehicles:** Users that require vehicles to be available at short notice (e.g. police)

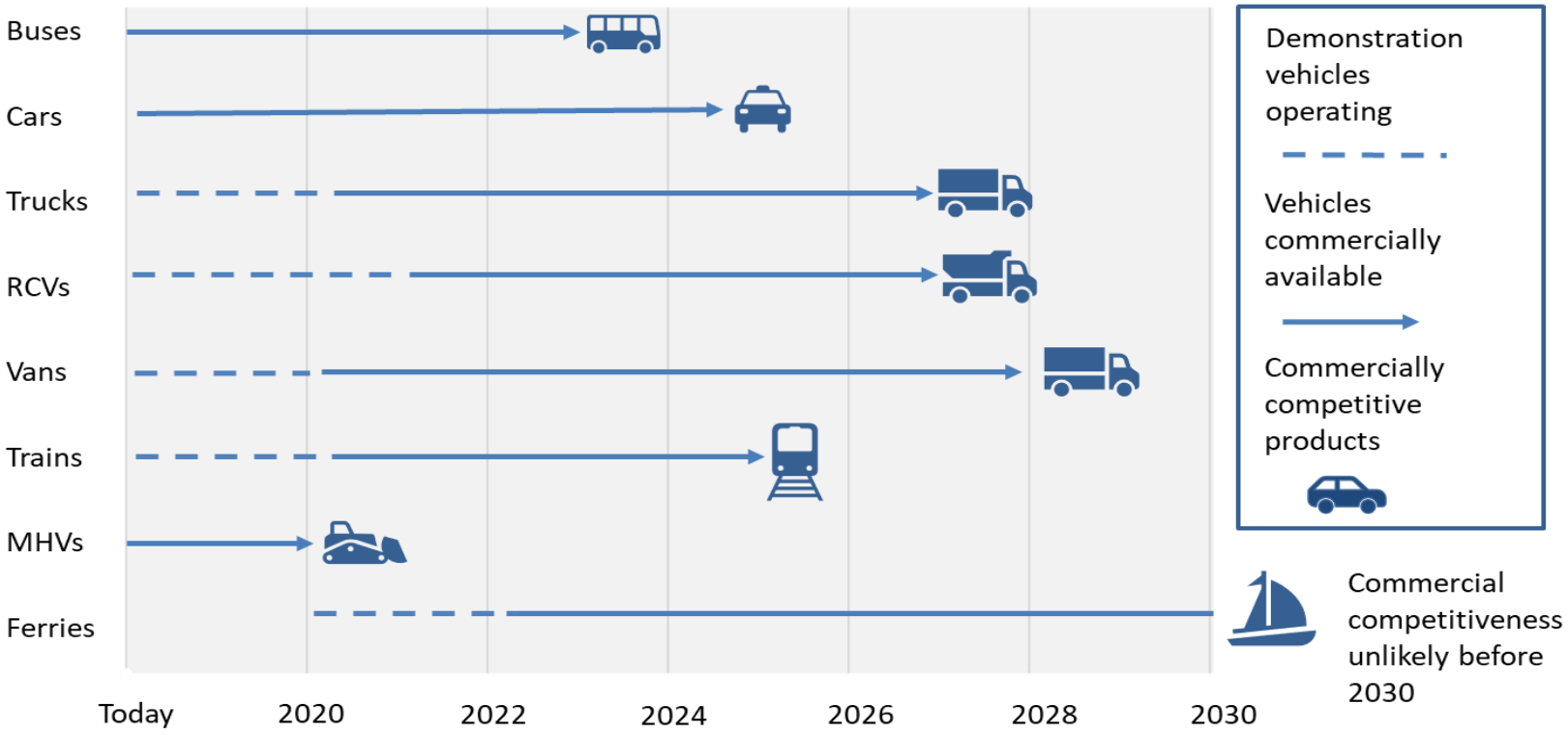
The total decarbonisation of transport using electricity and hydrogen results in lower overall costs than a strategy that relies on one energy carrier alone[1]. This is because the two energy carriers are complimentary, each suited to different vehicle segments/usage profiles

1: FCHJU, 2019, Hydrogen Roadmap Europe, https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

Hydrogen vehicles are already being deployed around the world in all vehicle segments

Many of the successful early use cases for hydrogen vehicles have been with heavy duty vehicles from taxis to trucks, buses and refuse collection vehicles, due to their range and refuelling advantages over battery vehicles

Timing of vehicle introduction (indicative)



Note: Commercially competitive products refers to hydrogen transport modes which are competitive with other forms of low/zero emission transport. They may still have a small total cost of ownership premium compared to conventional drive trains.

RCVs: Refuse Collection Vehicles

MHVs: Material Handling Vehicles

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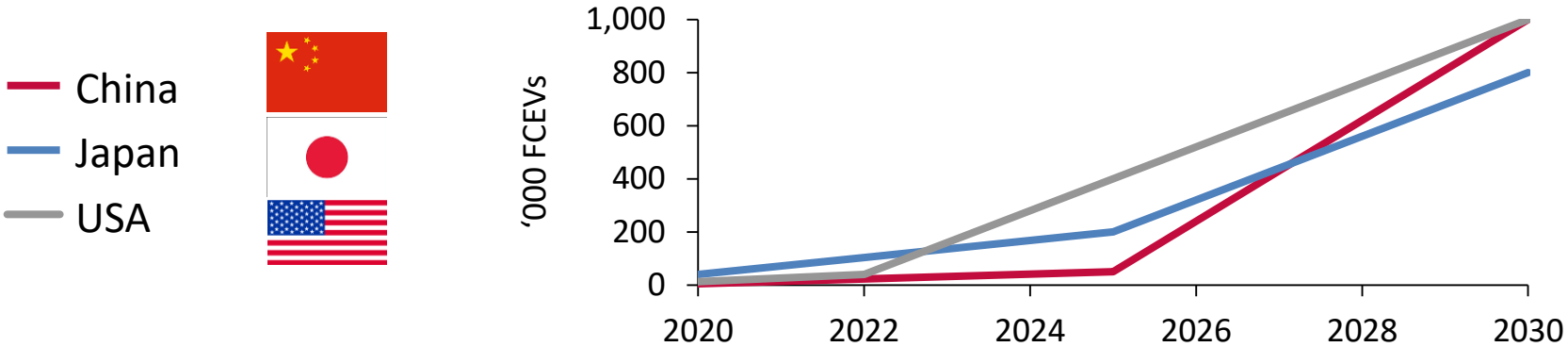
The demand for FCEV in China, Japan and USA alone should drive down the cost of FCEV to a comparative level to conventional vehicles

Japanese, Chinese and American targets for FCEVs on the road



China

- **Target for 1m FCEVs & 1,000 HRS** by 2030
- **Extensive investment in fuel cell technology:** In 2018 China invested $12.4 billion in FC systems and companies
- **Ten Cities Thousand Vehicles Plan:** China hopes to replicate its success in BEVs with FCEV

Japan

- **Target for 800,000 FCEVs & 320 HRS** by 2030
- **2,800 FCEVs in use:** Japan has the second highest deployment of FCEVs
- **Toyota plans to ramp up production** of FCEVs from 30,000 per year in the early 2020s to 300,000 per year by 2030

USA

- **Target for 1m FCEVs** by 2030
- **6558 FCEV in use**: Led by California USA has the highest uptake of FCEV in the world (~ 5,000 of these are Toyota Mirai)
- This fleet is supported by only ~**45 HRS**

A range of policy mechanisms are being used across Europe to support the deployment of hydrogen vehicles

Germany

Existing Deployment

- 70 hydrogen refuelling stations (HRSs), with 30 more due to open in 2019 and 300 planned. C.450 vehicles including cars, buses and LDVs in 2018

Policies supporting zero-emission vehicles

- Company car tax reduced from 1% of list price to 0.5% for electric vehicles

From 2023 the following incentives are proposed

- **€4,000** plug-in new vehicle grant
- **€8,000** plug-in new taxi grant
- **€500** plug-in second hand vehicle grant

Government funding

- **National Innovation Programme Hydrogen and Fuel Cell Technology (NIP):** €250m to support hydrogen and fuel cell technology from 2016-2019. Part of this aimed at part funding publicly available HRSs and on-site electrolysers.

UK

Existing Deployment

- 17 HRSs with 6 more in planning - 123 vehicles

Policies supporting hydrogen vehicles

- **Fuel Duty:** Hydrogen vehicles exempt
- **Vehicle Excise Duty:** Zero-emission vehicles below £40,000 purchase price exempt, otherwise £310 for first 5 years
- **Purchase grant:** £3,500

Government funding

- **£20m hydrogen supply programme:** funds pilot projects for hydrogen production at scale
- **£23m Hydrogen for Transport Programme:** funding for FCEVs and refuelling infrastructure
- **Hydrogen for Transport Advancement Programme:** funded the development of the first 12 hydrogen refuelling stations
- **Fuel Cell Electric Vehicle Fleet Support Scheme:** £2m funding for early FCEV fleets

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Hydrogen production is already underway on the island of Ireland with more production options in the planning process

The Island of Ireland has several hydrogen projects in development that will significantly increase the amount of hydrogen produced in Ireland over the next 5 years

Existing | In planning | Proposed

Existing and planned hydrogen projects

- Gencomm (160kg/day) – Planned 500kW electrolyser coupled with a wind farm to utilise curtailed electricity
- Belfast HRS – OLEV funded project in planning to support 3 FCEV buses with hydrogen from Gencomm project
- Indaver waste-to-energy plant (3,000kg/day) – existing facility at Meath producing electricity from waste. Exploring 9MW on-site electrolysers to avoid curtailment
- BOC Electrolyser (200kg/day) – Dublin plant producing hydrogen for aerospace, pharmaceuticals, electronics and biomedical industries
- *Whitegate Refinery (hundreds tonnes/day) – Existing refinery producing hydrogen for internal use. Currently exploring the option to increase production to meet internal demand with the option to sell to the mobility market if demand is clear (this option will need to include CCS in the future to remain a viable option in Ireland's increasing decarbonised economy)*

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Introduction to the case for hydrogen mobility

This section sets out the evidence needed to develop a hydrogen mobility strategy. Evidence is presented relating to cost and availability for the three key pieces of a hydrogen mobility strategy

1. Hydrogen Vehicles. Evidence is presented on the availability of hydrogen vehicles suitable for the Irish market from a range of vehicle OEMs in all vehicle segments where hydrogen could play a role by 2030. The total cost of ownership has been calculated for hydrogen and alternative fuels for all vehicle types to show when hydrogen vehicles will become cost competitive and to highlight the need for policy support
2. Hydrogen Production. Evidence on the availability, cost and emissions of a wide range of hydrogen production options has been complied and a down selection to a preferred range of production options is presented
3. Hydrogen Station. Evidence on the cost of different hydrogen station sizes is presented and an optimal station size is put forward. Evidence on the Irish population distribution and road network utilisation is presented to highlight regions best suited to hydrogen station deployment

The evidence presented in this section comes from the latest literature and Element Energy's internal modelling and experience of supporting the delivery of hydrogen projects across Europe. This section presents the evidence in graphical format to help the reader understand the key conclusions

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Introduction to the case for hydrogen vehicles

This section sets out the evidence base used to create the hydrogen vehicle uptake projections in the next section. The evidence needed to model the vehicle uptake projections includes:

- The availability of hydrogen vehicle models. Vehicle OEMs in many vehicle segments have been interviewed to understand the expected availability of hydrogen vehicle models in Ireland. The interviews demonstrated that hydrogen vehicles are now available from major vehicle OEMs in many vehicle segments. A growing interest in the technology is expected to deliver commercially available hydrogen vehicles in most segments by the early 2020s
- Hydrogen vehicle price. The growing demand for hydrogen vehicles will be strongly influenced by the falling purchase price driven by production scale. The total cost of ownership for hydrogen vehicles and competing technologies has been modelled to understand this factor
- Hydrogen refuelling availability. Consumers will not purchase hydrogen vehicles until sufficient refuelling infrastructure is available. The results of the hydrogen station strategy is therefore fed into the vehicle uptake strategy to ensure hydrogen vehicle sales only occur in regions with refuelling infrastructure available

There are opportunities for hydrogen in many different transport sectors

Private Cars	In the short term will struggle to match cost down curve of BEV and national refueling network required is a major barrier
Car Fleets	Opportunity in fleets where down time is costly or operationally unacceptable e.g. police, taxi, shared fleets
Vans / LCV	Opportunity in high mileage, highly utilized fleets
HGV/RCV	Currently the best ZE option for very demanding operational profiles such as long-haul HGVs and suburban refuse collection
Buses/Coaches	Opportunity especially in larger vehicles on longer routes - projected to become the most cost effective ZE technology in the future
Trains	Opportunity on train lines where overhead electrification is not cost effective
Maritime	Increasing interest for use in port and for ferry routes

There are a wide range of H_2 car and van models coming onto the market in the near future to support a growing H_2 mobility sector

2019	2020	2021	2022	2023	2024	2025

Cars

Deployment begins for 1st gen Toyota Mirai and Hyundai ix35

2nd gen Toyota Mirai begins production of ~30,000 stacks per year

Planned deployment of 3rd generation mass production Mirai

Hyundai Nexo starts European deployment

A range of other cars are being deployed worldwide, likely to come to Ireland with the right support regime. Audi, BMW, Honda Daimler, PSA and many Chinese brands all have hydrogen plans in the early 2020s

Vans

125 Symbio/Renault Kangoo's are operating across Europe

Numerous Chinese initiatives to develop FC vans (e.g. SAIC), likely available in Europe in early 2020s

787 Symbio/Renault Kangoo's planned for EU deployment

StreetScooter to produce over 400 Work L vans for DHL and Innogy in Germany

Demo projects / development

Early commercial

Mass market introduction

There are a wide range of H_2 train and bus models coming onto the market in the near future to support a growing H_2 mobility sector

2019	2020	2021	2022	2023	2024	2025

Demo projects / development | **Early commercial** | **Mass Market Introduction**

2 Coradia iLint trains are carrying passengers in north Germany

Alstom's first Breeze HFC trains manufactured in the UK

c. 50 Breeze trains to be operating in the UK

Trains

Siemen's Mireo Plus H prototype to be completed

Freight and other train types to be prototyped

Buses

Wrightbus and Alexander Dennis actively developing FC buses for export markets

100s of additional buses deployed across Europe due to H2 Bus Europe and other initiatives

JIVE Project deploys 300 FC buses across 22 European cities

JIVE 2 will deploy 152 extra FC buses in 14 European cities.

There are a wide range of H_2 truck models coming onto the market in the near future to support a growing H_2 mobility sector

2019	2020	2021	2022	2023	2024	2025
Demo projects / development		Early commercial		Mass Market Introduction		

Trucks

Scania deploy 4 fuel cell trucks for ASKO in Sweden. FCH JU project for 15 trucks (with new European OEMs) deployed

1600 Trucks project fully deployed in Switzerland

Hyundai 1600 Trucks project in begins deployment in Switzerland

Nikola/Iveco Tre enters European production

Scania refuse truck deployed in Sweden

Introduction to hydrogen vehicle costs and total cost of ownership ①

The best way to conduct a comparative economic analysis of vehicle technologies is by using the Total Cost of Ownership (TCO), which captures all costs faced by a vehicle user during vehicle purchase and ownership. The purchase cost of vehicles is still a useful comparative matric as it tends to have a higher impact on consumers perception of costs than some ongoing costs. This work compared different powertrains technologies for different vehicle types using these two economic metrics. The vehicle types considered included: Private car, Taxi car, Vans, Trucks, Single decker bus, Double decker bus & Trains. In this report the results for private cars are presented to demonstrate the type of work completed

This section is presented in two sections:

1. The assumptions used in the TCO analysis including: policy assumptions and fuel price assumptions
2. The economic analysis which presents the purchase cost followed by the TCO for vehicles purchased in 2022, 2025 and 2030

One of the most important assumptions for the TCO analysis are the assumptions around taxation policy. There is currently no tax policy for hydrogen vehicles in Ireland. It has been assumed that hydrogen vehicle are subject to the same grants and taxation as other low emission vehicles in Ireland. As other low emission technologies are now more mature it is expected that supporting grant and tax policy will begin to be withdrawn for these vehicles from the early 2020s. To reflect the earlier stage of development of hydrogen vehicles the withdrawal of support is delayed for hydrogen vehicles

Introduction to hydrogen vehicle costs and total cost of ownership ②

The TCO method (summarised in the boxes below) used calculates the TCO as an annual value (€/year) that a first vehicle owner pays each year they own the vehicle. This metric allows comparison between different vehicle powertrains. The TCO is presented as a line graph over time. Each point on the line represents the annual TCO for a buyer who purchases their vehicle in that year

Inputs

One off, capital costs such as:

- Purchase cost
- Purchase tax

Annual operational costs such as:

- Fuel
- Maintenance
- Motor tax

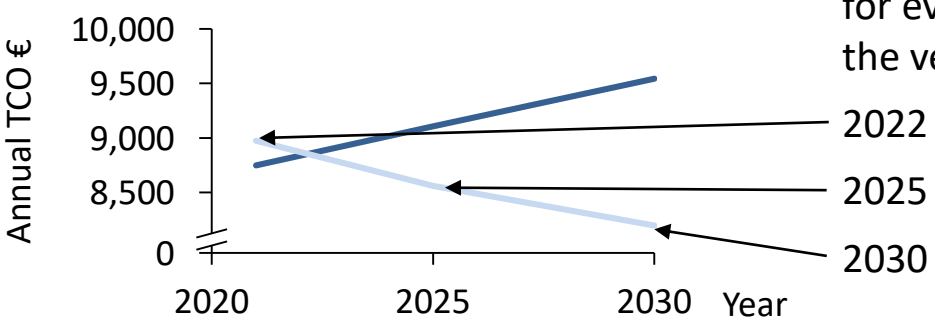
Calculation

For a given expected first owner lifetime (e.g. first car owners are expected to keep the car 4 years) the cost paid for the depreciation of the vehicle and the total operational cost paid over the first owner lifetime are added to give a total TCO cost

Output

The total TCO value is divided by the number of years the vehicle is owned to give an annual TCO that is compared across different vehicle powertrain types

Example TCO Output



Annual TCO paid by the vehicle owner for every year they own the vehicle if the vehicle is purchased in

2022

2025

2030

Example Vehicle 1

Example Vehicle 2

Hydrogen Mobility Ireland

TCO Assumptions: hydrogen price

This range reflects Element Energy's experience in other countries, the hydrogen price resulting from analysis elsewhere in this report and the price required for hydrogen parity with diesel

Using this range of hydrogen prices allows the analysis in this section to focus on the variables affecting the TCO, while also illustrating the potential impact of hydrogen price, under different hydrogen production pathways. In later sections the analysis narrows down the production pathway to specific production options allowing TCO analysis at specific hydrogen prices to be conducted

€5-10/kgH2 represents a reasonable expected range of hydrogen prices that will need to be achieved for successful hydrogen mobility rollout, based on:

<u>The range of hydrogen prices resulting from analysis in this report:</u>
Production Costs: Hydrogen production costs range from 3 – 5.8 €/kg in 2021 for the suitable production options identified. The production price is expected to fall to between 2.8 – 4.5 €/kg by 2030.
HRS Costs: A medium sized HRS (400kg/day) with utilisation rates between 50-95% can deliver hydrogen with operating costs in the range of 2.1 - 3.8 €/kg.
Total: This produces a range of hydrogen prices from €4.90-9.60/kgH2 between 2021 and 2030

<u>The range of hydrogen prices required to achieve parity with diesel:</u>
An alternative range of prices is based on the price hydrogen will need to achieve to equal the price of diesel as a fuel. This varies depending on the efficiency of vehicles and is calculated from:

- The price of diesel (ex VAT, including excise duty) - €1.06/L
- Diesel vehicle efficiency – car (Toyota Avensis - 6L/100km), double decker bus (40L/100km)
- Hydrogen vehicle efficiency – car (0.75kg/100km), double decker bus (8kg/100km)

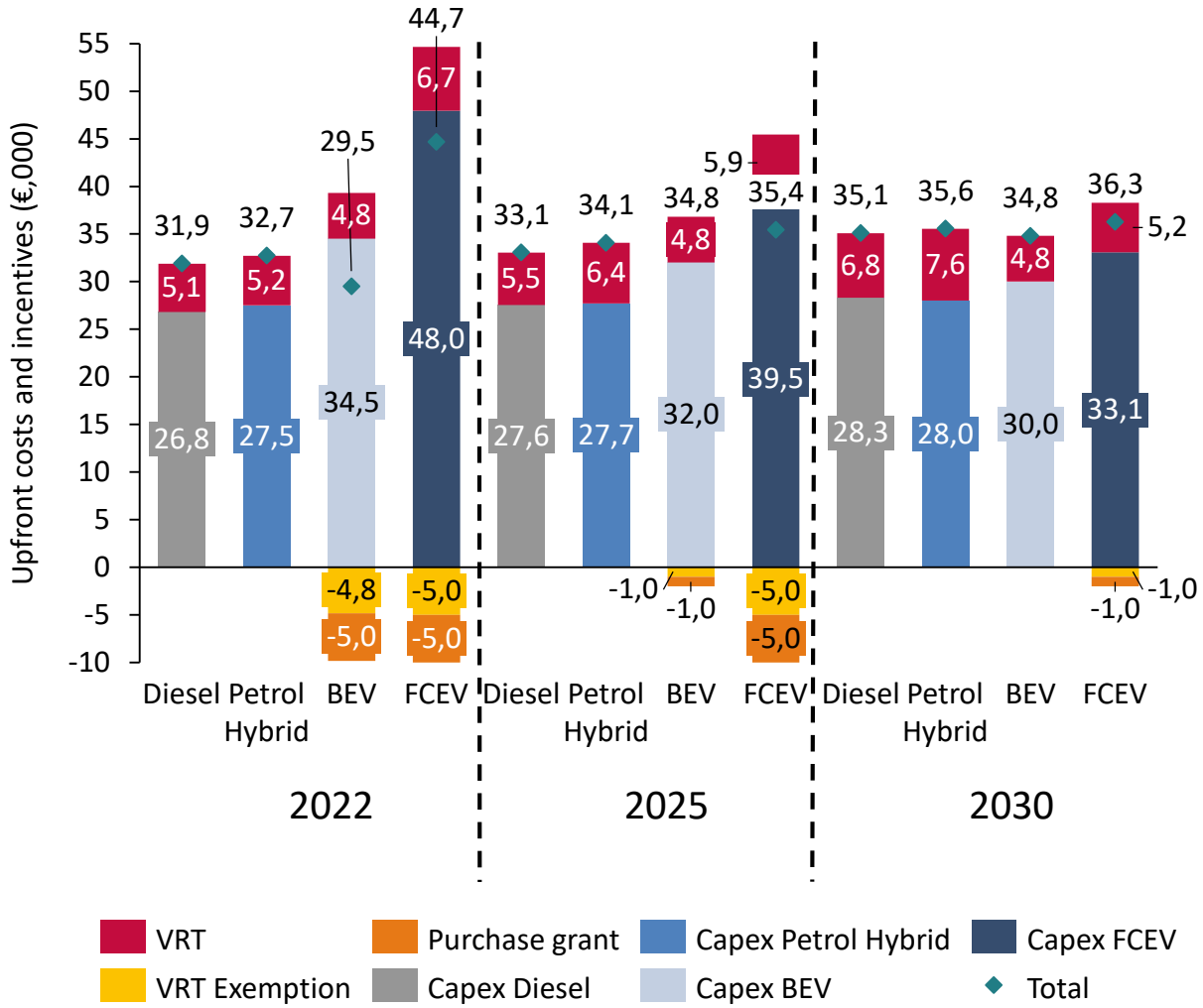
This results in a hydrogen price range from €5.30/kgH2 (bus) to €8.48 (car).

Car purchase price and TCO analysis

The following section presents the economic analysis for private cars, demonstrating the type of analysis completed for all vehicle types

Private Car: Purchase costs for fuel cell cars quickly comes down to a level that the average consumer would consider

Vehicle purchase costs for all passenger car drivetrains including taxes and incentives



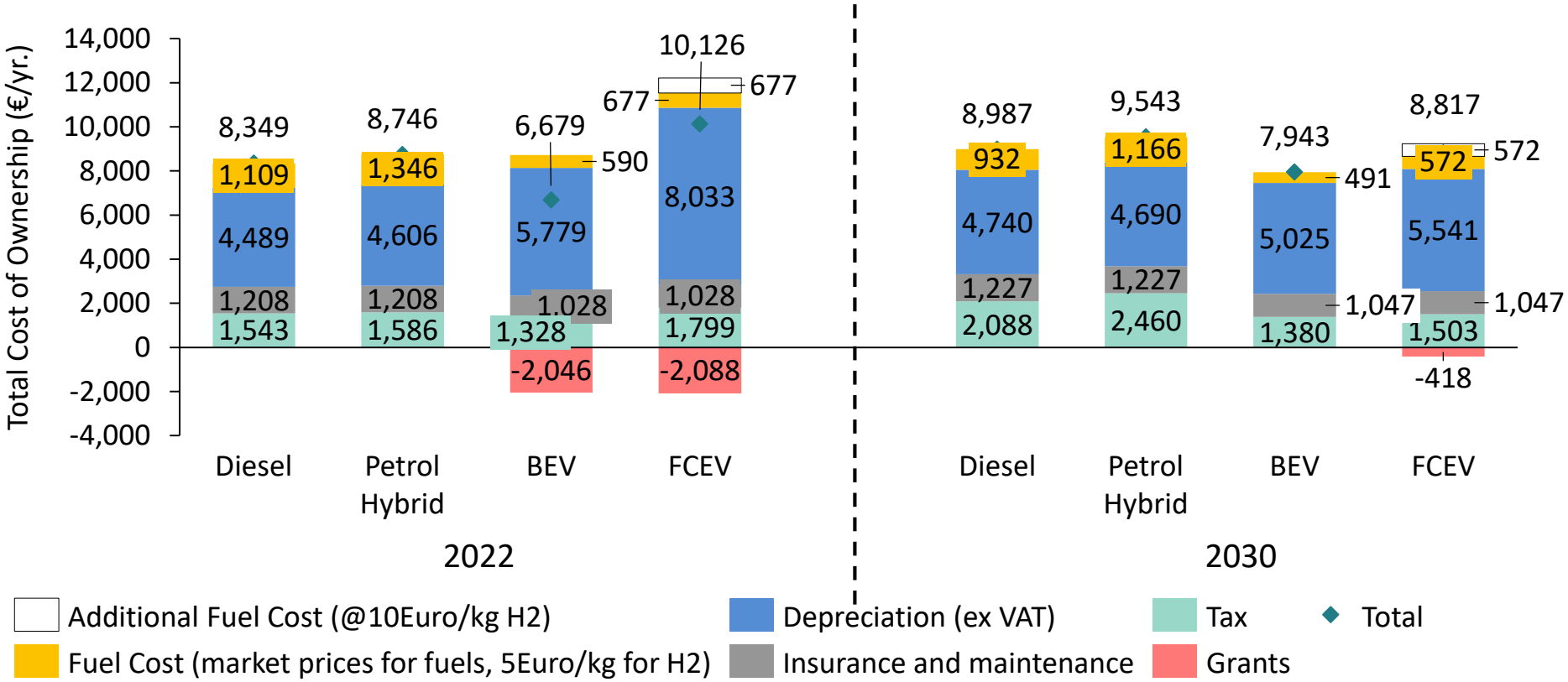
Assumes current VRT system

- The VRT exemption and purchase grant have been extended for FCEV following the pattern of support provided to BEV (assuming BEV subsidies will be withdrawn slowly over the next couple of years)
- Fuel cell car costs follow the US DOE fuel cell cost down curves assuming a D segment car (medium/large saloon) and fuel cell sales inline with the stated fuel cell sales targets in key markets (USA, China, South Korea and Japan)
- By 2030, the FCEV is expected to become very cost competitive, once the policy support is included, with the BEV option only slightly cheaper

Private Car: TCO is dominated by depreciation which means bringing down purchase costs is vital to the success of new technologies

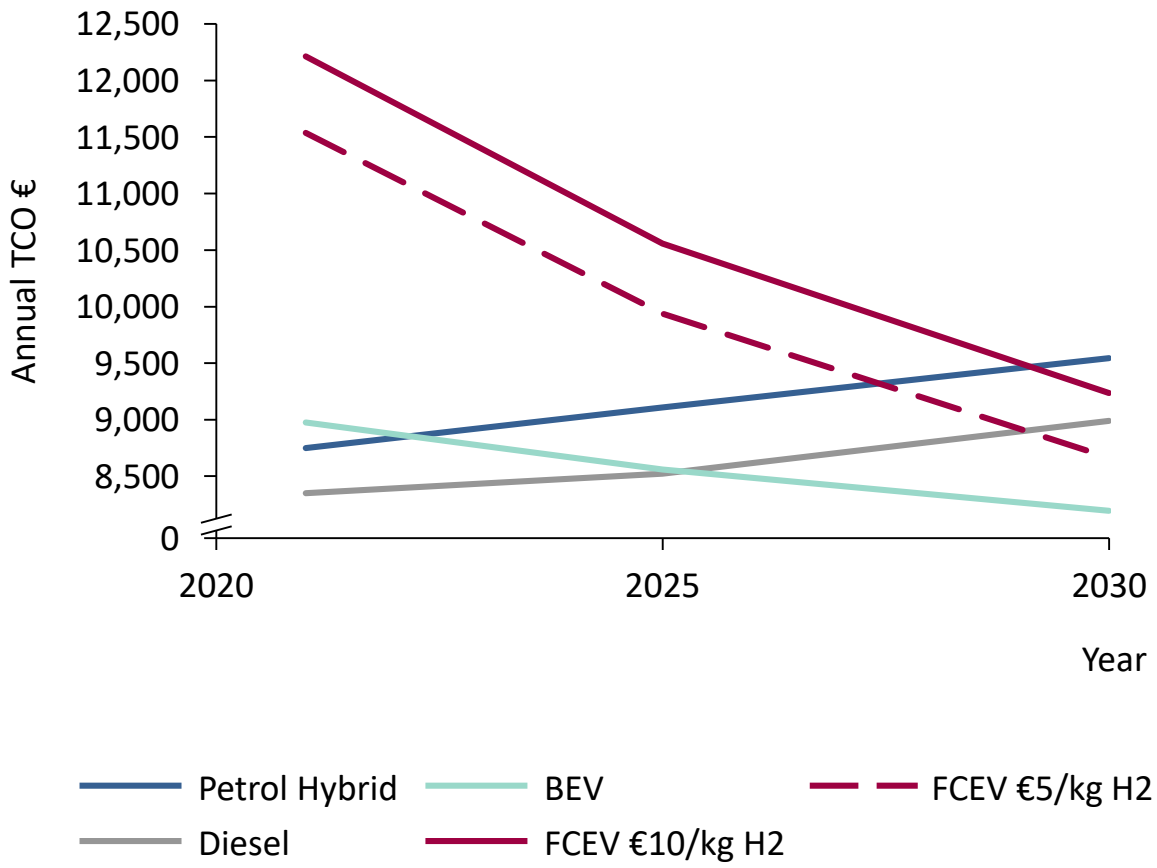
Vehicle TCO for car first owners in 2022 and 2030 assuming a 4 year ownership period

For private car users, vehicle depreciation is the highest cost for new vehicle owners. This is higher for zero emission vehicles due to their higher purchase costs. This is offset by policy support making zero emission vehicles cost competitive in 2022 and 2030



Private Car: Without policy support fuel cell cars will be cost competitive, on a TCO basis, with conventional vehicles by 2030

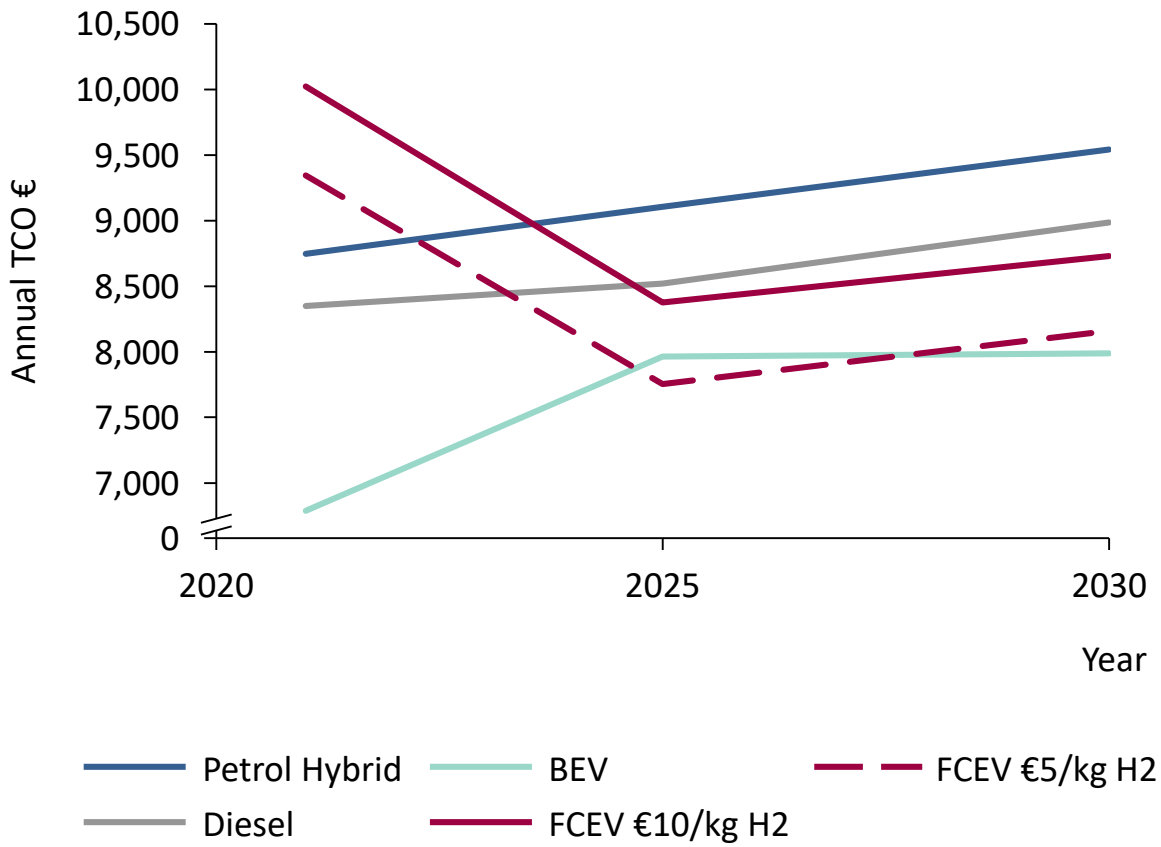
Total annual TCO for all passenger car drivetrains including taxes but **excluding incentives**



- Using the latest US DOE hydrogen vehicle volume projections, which are less ambitious than those proposed by Toyota, would still lead to FCEVs being in a cost competitive range (on a TCO basis) with conventional petrol vehicles by 2030, without Irish Government policy support
- This suggests uptake of hydrogen vehicles in the late 2020s could be constrained by production volumes, as battery electric vehicles are today, and that countries should aim to plan refueling infrastructure and educate consumers ahead of this date to allow strong growth

Private Car: With policy support fuel cell cars will be cost competitive, on a TCO basis, with conventional vehicles in the early 2020s

Total annual TCO for all passenger car drivetrains including taxes and **incentives**



- If current BEV incentives are extended to FCEV then FCEV will be very cost competitive in the 2020s (assumes RED certificate price of €1.51)
- As has been demonstrated with BEV, new technologies need to be cheaper than the alternatives to encourage consumers to risk buying a new technology
- Once cheaper FCEV uptake will be limited by consumer understanding, refueling infrastructure availability and OEM model availability
- Early steps should be taken now to overcome these barriers to ensure that hydrogen vehicles are available to policy makers as a decarbonisation technology in the 2030s

The most advanced and therefore cost competitive hydrogen vehicles are in the bus and car segments

Vehicles identified for the early roll out strategy:

Hydrogen fuel cell buses and cars have been in development longer than hydrogen powertrains in other vehicle segments. We are now seeing the arrival of second-generation hydrogen buses and cars which offer major cost reductions on the first generation. The fuel cell private/taxi car, double decker bus and van were identified as suitable vehicle types for the early deployment phase of hydrogen mobility Ireland.

- **Private Car/Taxi:** Fuel cell cars can deliver annual TCO savings to private car and taxi car users. With policy support measures in place, hydrogen fueled private cars and taxi cars offer lower annual TCO's than diesel and petrol hybrid cars from 2025 onwards. With purchase grants and incentives to avail of, hydrogen emerges as a zero-emission solution for operators with very daily mileages and long operational hours
- **Double Decker Bus:** Rapid purchase cost reductions in the lead up to 2025 see fuel cell double decker buses emerge as a cheaper solution than the battery electric equivalent. With lower annual TCO's achievable, fuel cell double decker buses become the front runner for zero emission transport.
- **Van:** Fuel cell vans also offer annual TCO savings relative to diesel fueled vans from 2025 onwards. With purchase grants and incentives to avail of, hydrogen emerges as a zero-emission solution for operators with high daily mileages and long operational hours

These vehicles bring the added advantage that suppliers exist who are willing to bring the vehicles to the Irish market.

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Introduction to the case for hydrogen production

This section sets the findings from a review of evidence of hydrogen production methods. The evidence analysed includes:

- **Hydrogen production options:** The range of options for producing hydrogen in Ireland under three broad categories; electrolyser connected to a renewable generator, grid connected electrolyser and natural gas reformation.
- **Timeline for production site delivery:** Different production options require different planning, consenting and construction timelines. This means that the various production options will become available at different stages throughout the rollout.
- **Hydrogen production costs:** The cost that hydrogen producers can sell hydrogen to refuelling stations depends on fuel costs, equipment CAPEX and OPEX, distribution costs etc. These have been modelled to understand the hydrogen production price
- **Hydrogen production emissions:** The goal of introducing hydrogen vehicles is to reduce emissions from the transport sector. An analysis of production and distribution emissions has been completed for each production option so that the higher cost of low carbon production options can be weighed against the greater emission savings

The project started by considering a long list of hydrogen production pathways to be explored

Electrolyser: Co-located with renewable power generator

1. Curtailment Driven:
A small electrolyser sized and used to maximise use of curtailed electricity

2. Market Price Electricity:
A medium electrolyser with an electricity price estimated based on market price

3. Generators Investment Return Electricity Price:
A medium electrolyser with an electricity price estimated based on the power generators investment return requirements

Electrolyser: Grid connected near HRS

4. On-site Base Tariff Electricity Price:
Small on-site electrolyser. Electricity price taken from SEAI publication

5. On-site Time of Use Tariff Electricity Price:
Small on-site electrolyser. Electricity price supplied by Bord Gais

6. Offsite Time of Use Tariff Electricity Price:
Medium electrolyser supplying multiple HRS. Electricity price supplied by Bord Gais

Gas Reformer

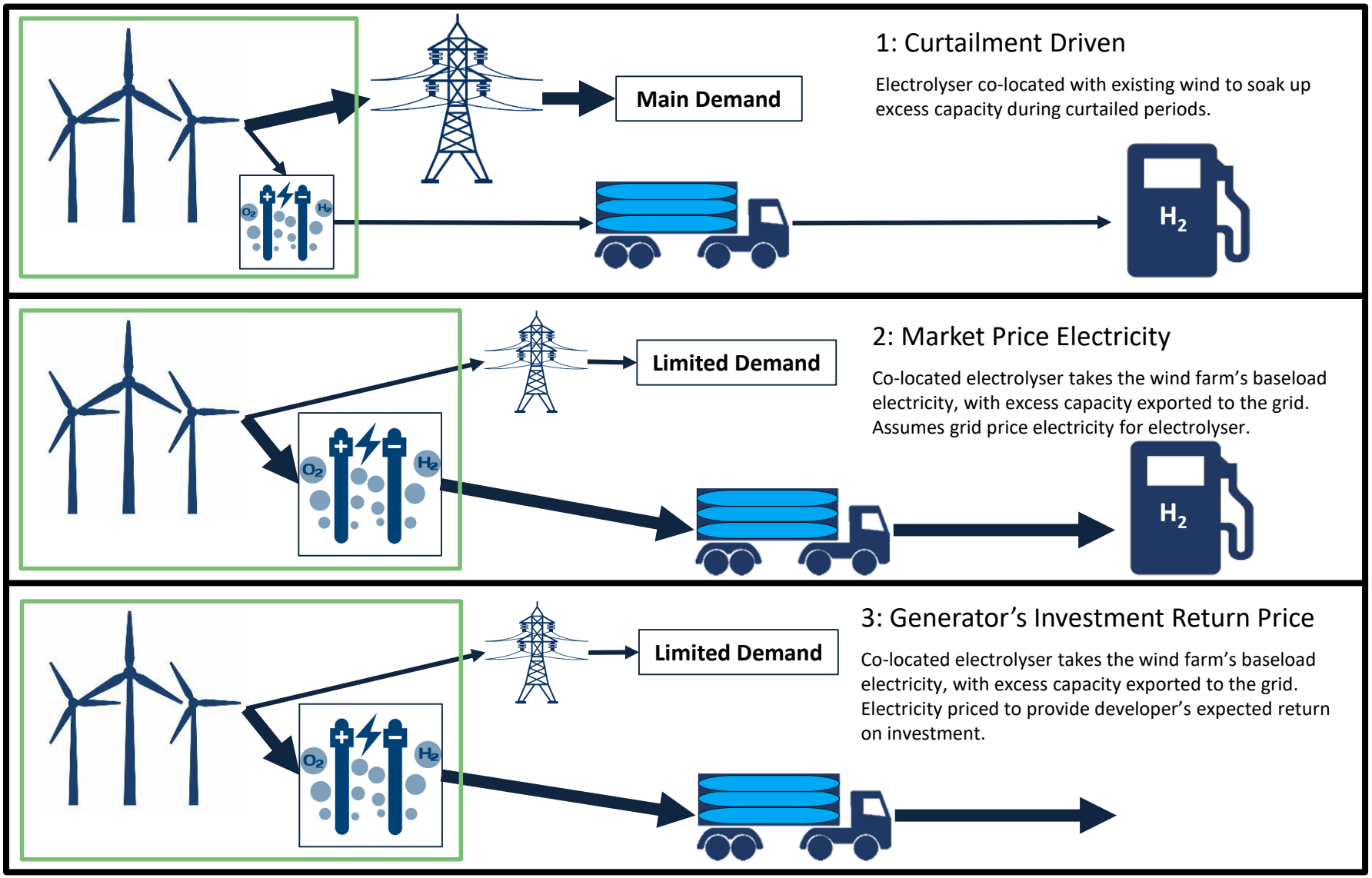
7. Small Reformer:
On-site reformer connected to the low pressure gas grid. Gas price taken from SEAI publication (function of gas demand)

8. Large Reformer:
Centralised reformer connected to the high pressure gas grid. Gas price from Working Group members

9. Large Reformer with CCS:
Centralised reformer connected to the high pressure gas grid. Gas price from Working Group members

10. Hydrogen Imports

Production Options: Electrolyser co-located with renewable power



Detailed Description: Electrolysers co-located with renewable generators

Renewable Sources: Wind farms, solar farms, waste to energy plants

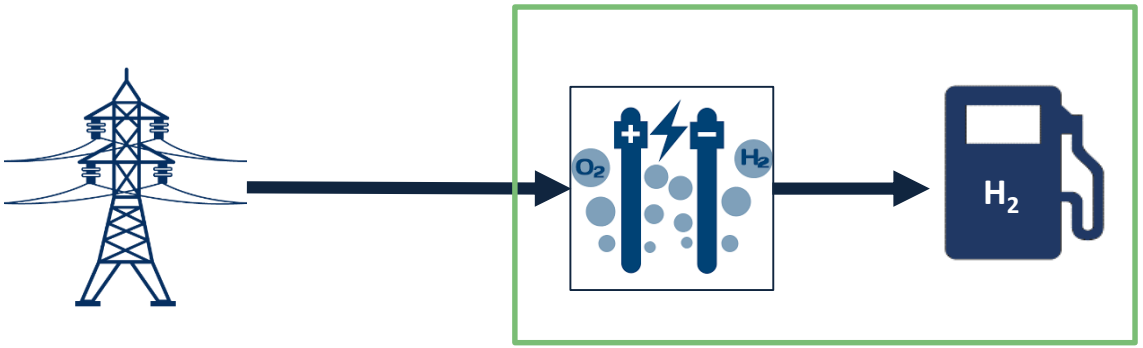
Distribution: In all cases the hydrogen needs to be distributed by road to the HRS adding cost and limiting which renewable generation locations will be suitable

1. **Curtailment Driven:** A small 0.5-1MW behind the meter electrolyser designed to make use curtailed electricity. Advantage: Can be added to current renewable generators as the electricity used is above what would normally be sold to the grid. This will lead to ultra-low electricity prices. Disadvantage: The small size makes distribution less cost effective and the low utilisation means that the project CAPEX cost per kg of H_2 is very high
2. **Market Price Electricity**: A larger 1-10MW behind the meter electrolyser. The electricity price is assumed to match the market price the renewable generator would have sold the electricity for. Advantage: The electricity price is cheaper because distribution charges and taxes do not need to be paid. Disadvantage: The usual arrangement for wind farms is that the electricity is purchased by energy suppliers under long term contracts. This means the electricity may not be available for sale to an electrolyser suggesting this scenario may be limited to new projects
3. **Generators Investment Return Electricity Price**: A larger 1-10MW behind the meter electrolyser. The electricity price is estimated based on the required return on the investment for the renewable generator. Advantage: The electricity price is potentially lower than the market price option. Disadvantage: The value will vary significantly between wind farm sites

Production Options: Grid connected electrolyser located near to HRS

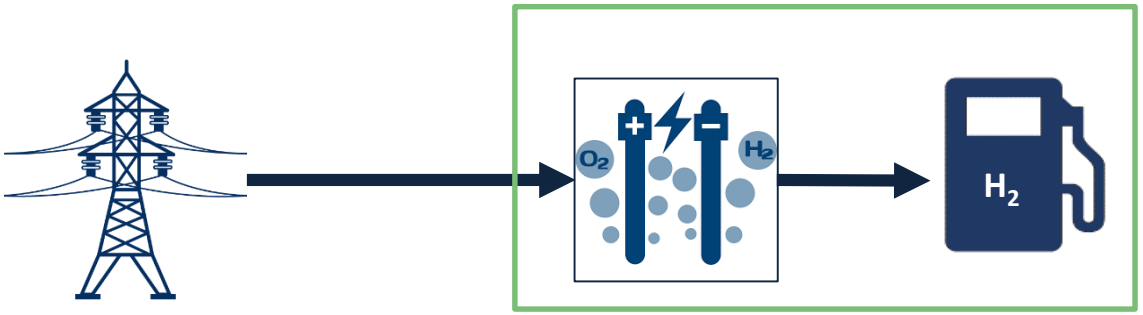
4: On-site Base Tariff

Small electrolyser on-site at HRS takes market price electricity from the grid



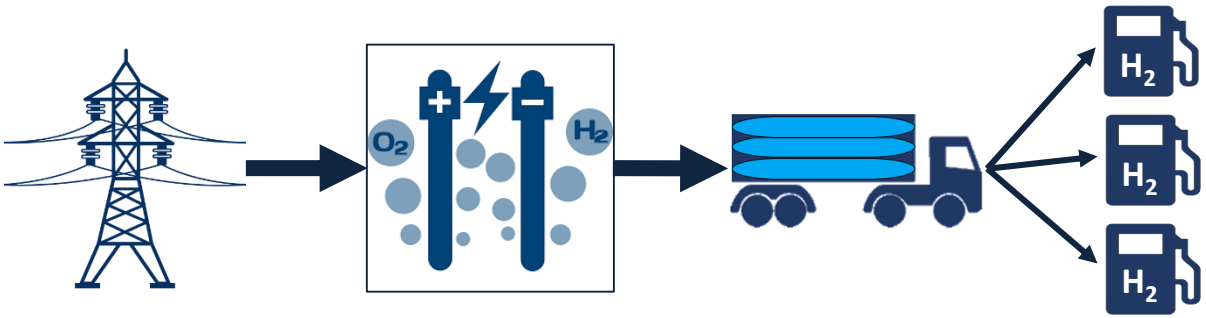
5: On-site Time-of-Use Tariff

Small electrolyser on-site at HRS makes use of TOU tariffs and other grid service mechanisms to make additional revenue and reduce cost of hydrogen.



6: Off-site Time-of-Use Tariff

Large electrolyser located away from HRS taking advantage of lower electricity prices and grid service opportunities to reduce the cost of hydrogen. Supplies multiple HRSs in an area.



Detailed Description: Grid connected electrolysers located close to hydrogen demand

Electricity Source: Grid mix electricity although green energy tariffs could be used
Distribution: Limited or no distribution required

4. **On-site Base Tariff Electricity:** A small 1MW electrolyser co-located with the HRS using a fixed price electricity tariff. **Taken as a base case for comparison**

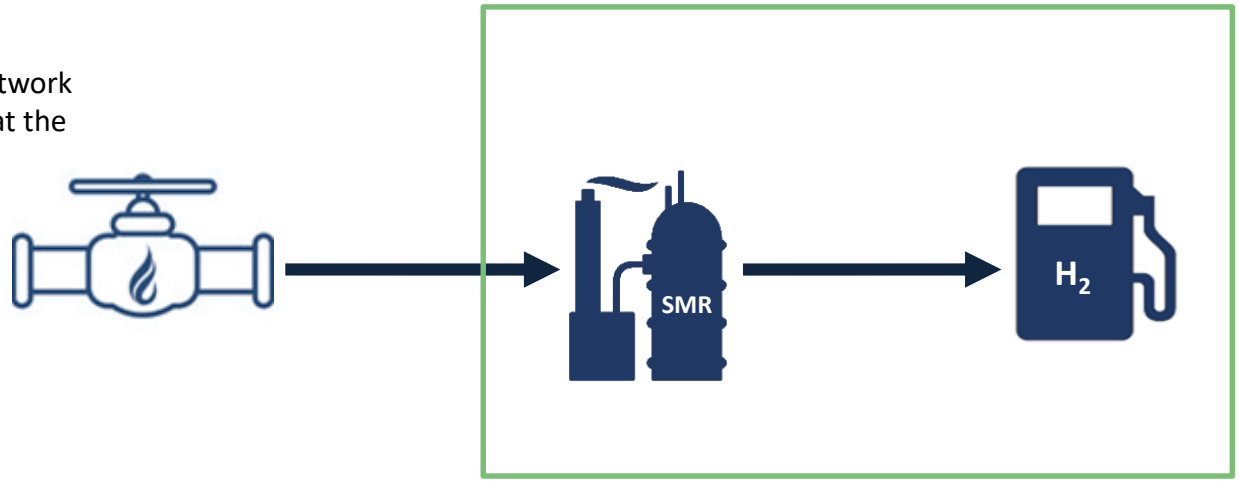
5. **On-site Time of Use Tariff Electricity:** A small 1MW electrolyser co-located with the HRS using a time of use electricity tariff. Advantage: The time of use tariff offers the best electricity price for the size of the electrolyser. No hydrogen distribution is required. Disadvantage: A small electricity user pays a much higher price for electricity per kWh. Grid distribution charges will be significant.

6. **Off-site Time of Use Tariff Electricity**: A large 10MW electrolyser located near a cluster of HRS using a time of use electricity tariff, including balancing payments. Advantage: The larger electrolyser can offer more services to the grid and can gain a lower electricity tariff than a small electrolyser. Disadvantage: The hydrogen needs to be distributed to the HRS

Production Options: Gas Reformation

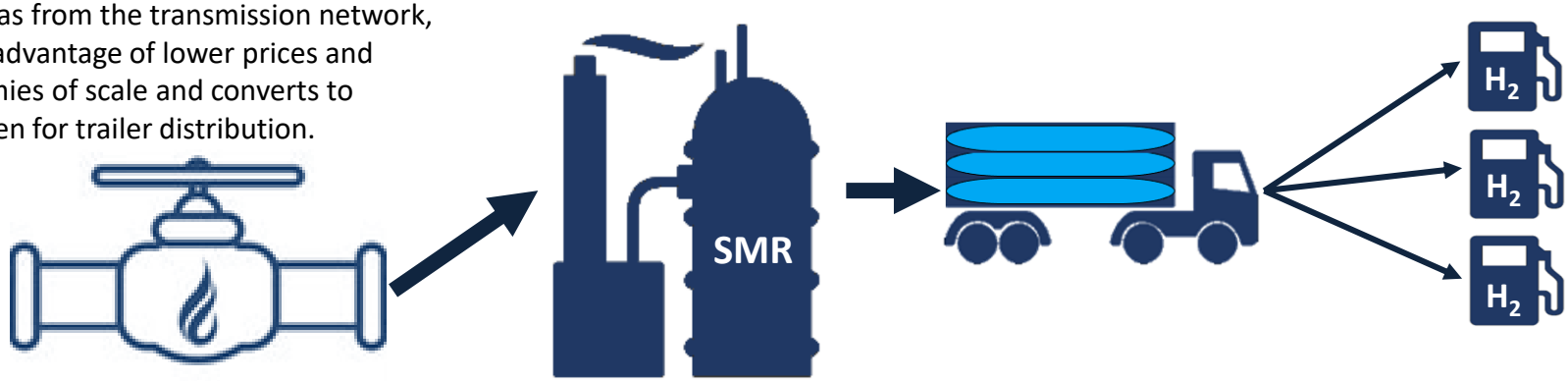
7: Small On-site Reformer

Takes gas from the distribution network and converts to hydrogen on site at the HRS.



8/9 Large Off-site Reformer

Takes gas from the transmission network, taking advantage of lower prices and economies of scale and converts to hydrogen for trailer distribution.



Detailed Description: Gas reforming

- **Gas Source:** Grid gas although bio-gas could be used through a certificates program
- **Distribution:** No distribution for the small reformer. Long distance distribution for the large reformer

7. **On-site Small Reformer:** A small 500kg/day reformer located close the HRS fed with gas directly from the low-pressure gas grid. Advantage: Gas is much cheaper than electricity resulting in cheap hydrogen. Disadvantage: The well to wheel emissions of the hydrogen is much higher than for electrolytic hydrogen from renewables. Small scale production is a) less economic and b) less reliable/proven than large scale production.
8. **Off-site Large Reformer:** A large industrial 200 tonnes/day reformer fed directly from the high-pressure gas grid. Advantage: The reformer receives a low gas price as it is a large user. The scale is large enough that CCS could become a viable option for mitigating the CO_2 emissions. Disadvantage: The hydrogen has to be distributed to the HRS. Significant hydrogen demand is required before the investment is worthwhile
9. **Large Reformer with CCS:** An industrial reformer built or retrofitted with CCS capability. Advantage: Allows low-cost hydrogen production from natural gas to become a low-carbon option. **Disadvantage:** Adds to costs and is unlikely to be deployed in the near future.
10. **Hydrogen Imports:** A global market for hydrogen may develop in the future but is unlikely to occur in the 2030 timeframe of this project. It is also unclear whether this would be an attractive option for Ireland, as liquefication and international shipping add to costs and there are benefits from domestic fuel production that go beyond costs. For these reasons this option is not included in further analysis.

A down selection of the production options was conducted to identify the most suitable production options for use in the strategy

For the down selection the options were evaluated on three main criteria:

- Availability
- Production emissions
- Production costs

Analysing the production options based on these criteria, the lowest cost and emission production options were identified for the early stage deployment through to 2030 while accounting for the project development, planning and construction timelines.

Production Option	Availability (Yrs)	Production Emissions kgCO2/kgH2		Production Costs €/kg	
		2022	2030	2022	2030
1. Curtailment Driven	2.5	0.9	0.6	13.3	-
2. Market Price Electricity	**2.5**	**0.9**	**0.6**	**7.0**	**5.1**
3. Generators Investment Return Electricity price	**4 – 6**	**0.9**	**0.6**	**6.9**	**4.6**
4. On-site base tariff electricity price – small scale	2.5	24.9	7.6	11.1	-
5. On-site time of use tariff – small scale	2.5	24.9	7.6	10.6	7.7
6. Offsite time of use tariff – medium scale	2.5	23.1	7.0	10.7	8.2
7. Small Reformer	**2.5**	**13.0**	**12.6**	**5.3**	**4.8**
8. Large Reformer	**3 - 5**	**11.3**	**10.8**	**3.4**	**3.0**
9. Large Reformer with CCS	**Late 2020's**	**3.2**	**2.7**	**-**	**3.6**

Options included in further analysis

Options not included in further analysis

Hydrogen Mobility Ireland

A range of production options based on electrolysis and reformation were selected for use in the strategy based on price and emissions

The production options identified for further analysis:

2. Market Price Electricity

Purchasing market price electricity directly from a renewable generator emerged as the most viable low emission production option for the early stage deployment with the option becoming available earlier than option 3.

3. Generators Investment Return Electricity price:

This option was identified as the lowest emission production source for the mid to late 2020's with competitive production costs.

7. Small Reformer:

From the down selection of production options, the small scale reformer for hydrogen production presented itself as a viable production source that could be deployed in the short term. With cheap production costs and relatively low emissions in comparison to the production options utilising electricity from the grid.

8. Large Reformer, 9. Large Reformer with CCS:

The large reformer without CCS provides an opportunity to avail of cheap hydrogen production prices in the mid 2020's. The large reformer with CCS option is expected to have longer development timescales, but offers a low cost low emission production source for the late 2020's assuming a commitment is made to further develop CCS

Other productions options have been excluded from further consideration because they are uncompetitive on price

The production options excluded for further analysis:

1. Curtailment Driven

From analysing the low emission production option which utilises curtailed electricity only, uncompetitive production costs were behind the reasoning for omitting this option from future analysis.

4, 5, 6 Grid Electricity Options

The small and medium scale electrolysers using base tariff and time of use tariff electricity were excluded from further analysis due to high production costs and emissions. While these options ranked well in term of availability and could be delivered in the early 2020's, the market price electricity and small reformer production options offered cheaper production costs and lower emissions.

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Evidence base for the hydrogen station rollout strategy

This section sets out the evidence used to determine the required specifications for refuelling stations and the expected number and location of hydrogen refuelling stations required for a whole island network. This evidence covers 2 key areas:

The factors affecting the HRS business case:

- **The impact of HRS size and utilization:** Whether the strategy in Ireland deploys a large number of small stations or a smaller number of large stations is dictated by the relative profitability of the different options.
- **Serving captive fleets:** Initial HRSs will need to be supported by fleets to ensure a high level of utilization.

The factors affecting the location of HRSs:

- **Population distribution**. Proximity to large population centres is a key factor for identifying early HRS locations and ensuring that they are accessible to as many users as possible to support the early phases. Spreading to smaller population centers as the industry grows will then allow the national network to develop.
- **Road network usage**. As the rollout progresses it will become important to facilitate cross-country travel for hydrogen vehicle users. HRSs will therefore need to be placed at strategic locations on the national road network – locations that are both close to population centres and major roads are ideal as they can support more use cases.

In this analysis a number of different station sizes are considered to cover the range of station sizes seen in use today

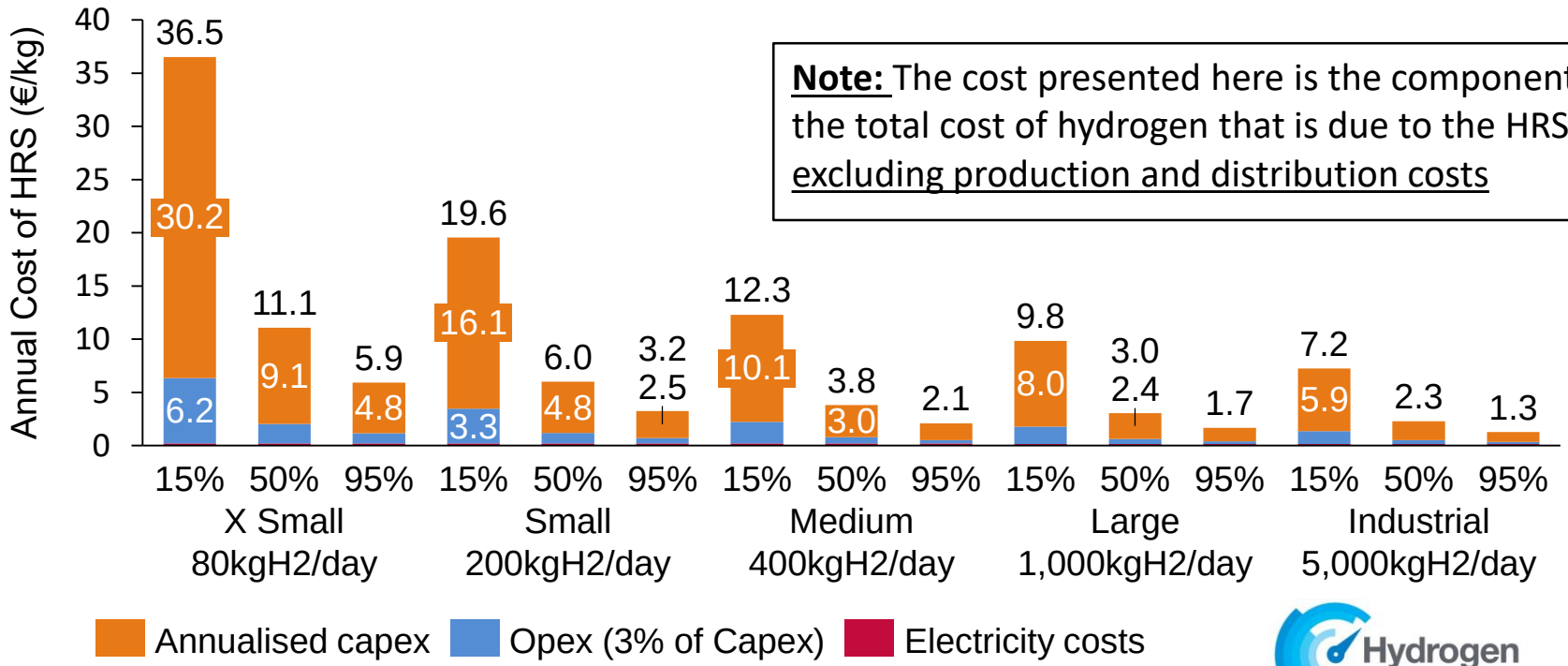
At the outset of the project station specifications were agreed by the group (summarised in the table). Station sizes range from Extra Small (representing some of the very early stations) to Industrial (representing a train refuelling station). The station capacity is sized to include all of the contingencies required to deliver this level of average capacity reliably everyday. Once the stations are supporting a large fleet, we would expect them to dispense hydrogen at this capacity on an average day but that some days the demand for hydrogen would fluctuate above and below this level

Metric	Unit	Extra Small	Small	Medium	Large	Industrial
HRS capacity	Kg/day	80	200	400	1,000	5,000
Number of refuelling positions		1	1	2	4	4
Refueling per hour per position		2.5	6	6	10	3
Max refuels per hour/day		2.5/20	6/40	12/80	40/180	N/A
Passenger cars served per station		100	400	800	1,600	N/A
Delivery Pressure	Bar	350	350	350	350	350
Dispensing pressure	Bar	700	700	350/700	350/700	350
Speed of 700 bar fill	mins	<5	<5	<5	<5	N/A
Speed of 350 bar fill	mins	N/A	N/A	10	10	20
Hardware redundancy factor		Single train	Single train	N+1	N+1	N+1
Hydrogen purity	%	99.999	99.999	99.999	99.999	99.999
Target station reliability/availability	%	98	>99	>99	>99	>99
Access		Public	Public	Public	Public	Private

Factors affecting the HRS business case

Larger hydrogen refueling stations with high utilization produce significantly lower costs per kilogram of hydrogen.

- The graph below shows the cost added to the price of hydrogen for the services provided by the station. This is shown for the different station sizes and utilisation rates but does not include profits for the station owner (key technical and business assumptions can be found in the annex)
- The trends clearly show the benefits of moving towards larger stations as station capex does not scale with hydrogen output – spreading the costs of a larger station over its far higher hydrogen output significantly reduces the costs that must be recovered from each kilogram sold.
- The importance of good station utilisation is also clear as this brings down the price for consumers



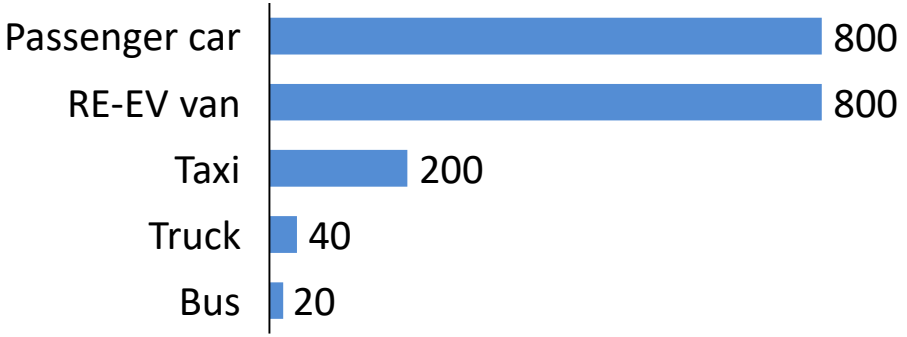
Note: The cost presented here is the component of the total cost of hydrogen that is due to the HRS, excluding production and distribution costs

Our analysis demonstrates that HRSs in Ireland should have a minimum 400kgH2/day capacity to allow them to sell hydrogen at a competitive price

Captive fleets of heavy-duty vehicles can help to justify large capacity refueling stations, achieve high levels of utilization and drive down the price of hydrogen for all users

Vehicles required to meet the capacity of a 400kg/day refuelling station

Passenger cars typically use just 0.5kg/day, so 800 would be required to meet a capacity of a 400kg/day. Alternatively, just 200 taxis, 40 trucks or 20 buses would also use all the capacity of a station of this size.



Opportunities for 'return to base' fleets

Buses: Dublin Bus operates 1,000 buses from 7 depots across the city - 20 buses would represent a small proportion of the fleet. Diesel refueling currently takes place in-depot; providing hydrogen refueling in-depot would mean a lack of existing hydrogen refueling elsewhere would not impact operations.

Trucks: There are several large distribution centers in Ireland, particularly around Dublin, which could provide similar opportunities for trucks. Refuse collection vehicles (RCVs) operate regular routes, are refueled in-depot and consume similar volumes of hydrogen to trucks, making them another potential captive fleet. Hydrogen fueled trucks and RCVs are in development but are behind buses.

Hydrogen Mobility Ireland will deploy high capacity refueling stations and ensure that demand is in place from heavy duty vehicle fleets

The evidence presented so far in this section demonstrates that this is necessary to develop a sustainable hydrogen mobility industry in Ireland. Below are the other specifications that have gone into our analysis:

- **Refuelling capacity:** 400kg/day minimum is required to ensure stations can become profitable
- **Delivery pressure:** 350Bar – high pressure delivery reduces distribution costs
- **Dispensing pressure:** 350 and 700Bar to ensure that all stations built are able to refuel all vehicle types.
- **Redundancy:** N+1 for all early stations. As clusters become established and multiple refuelling options are available in an area, redundancy can be reduced to lower costs.
- **Target station reliability/availability:** >99% is achievable with effective clusters and station redundancy. This will be particularly important to establish early on to avoid negative public perceptions

- **Public access:** Early stations will need to be accessible by both heavy user fleets and private vehicle owners, but as the industry develops this will be less important

Hydrogen Mobility Ireland

Identifying locations for HRSs

Having highlighted the specifications for individual HRSs, the next section introduces the evidence for identifying where they should be located. This covers two areas:

- **Population distribution in Ireland:** Early in the rollout HRS clusters and refuelling infrastructure need to be accessible to as many users as possible to increase utilisation. This will mean targeting the major urban areas first before connecting the clusters and then providing access to towns with smaller populations as the industry matures.
- **Road networks:** Once urban clusters have been established, refuelling will be required at strategic locations on the road network to increase utility for early users and facilitate more types of journey.

- This evidence will be used to map out the location of the station rollout throughout the phases of hydrogen infrastructure introduction in Ireland. The full mapped results are given in the chapter "A Hydrogen Mobility Strategy for Ireland" which follows this chapter

Ireland's population is centered in a few large cities and the core road network is made up of 4 key roads

Population is concentrated in a few cities

Republic of Ireland - Dublin is the dominant population centre with several small towns within commuting distance. Cork, Galway and Limerick are the other major population centres in the west of the country.

Northern Ireland - the population is clustered in and around Belfast and along the A1 towards Dublin. Three of the 10 largest towns are also near ports – Londonderry, Newry (Warrenpoint Port) and Belfast.

Left: Population of 25 largest towns.

Below: TEN-T road network. Yellow roads – core, green roads – comprehensive

<u>TEN-T Road Network</u>

EU regulations require 'core' roads to be motorway or expressway by 2030 and provide availability of alternative clean transport fuels.

The 'comprehensive' road network (green) will need to be upgraded to 'conventional strategic' roads by 2050.

These regulations suggest that the roads connecting Dublin with Belfast, Cork and Limerick should be prioritised for facilitating hydrogen refuelling.

High traffic densities are found around Dublin and Cork. Stations along these roads will provide convenient refuelling access to large numbers of vehicles

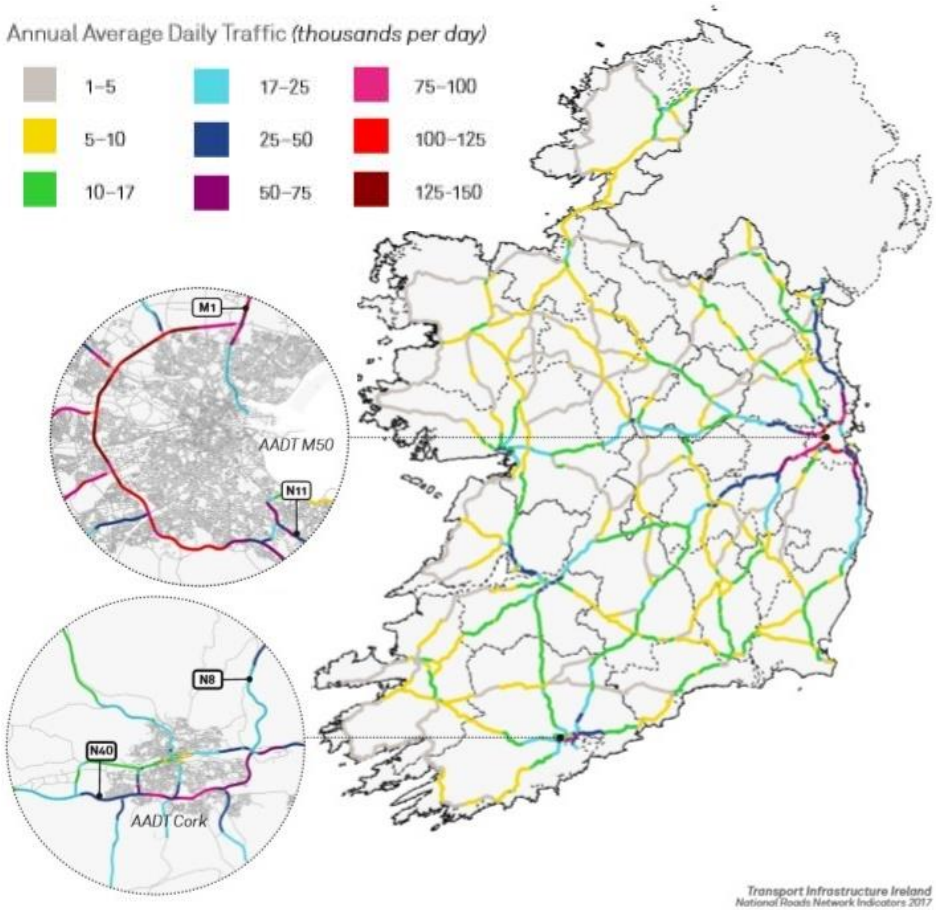
In the Republic of Ireland the major roads join Dublin with Belfast and the South West

Transport Infrastructure Ireland

- The busiest roads in ROI are around Dublin, spreading out to the South West and North.
- The road to Belfast is consistently busy, suggesting heavy traffic flow between the cities.
- The traffic density on roads to the South West drops off rapidly suggesting most traffic is connecting Dublin with regional towns rather than cross-country connections to Cork Limerick and Galway.

Implications for hydrogen rollout strategy

The combination of high population density, high daily road usage and connectivity to Northern Ireland suggest Dublin would be the best location for early refueling infrastructure. This would be followed by Cork, Limerick and Galway.



HRS mapping methodology

From the evidence base we have created a HRS rollout strategy and identified the number and likely locations for refuelling stations required to support hydrogen vehicle uptake in Ireland.

1. Map and rank population centres to prioritise locations for HRS clusters: The largest population centres are spread out across the island. Starting with Dublin and Belfast, followed by Cork, Galway and Limerick creates more opportunities for heavy duty fleets based in those cities to support the early clusters. Later smaller commuter towns are added as hydrogen vehicles become available to the mass market.

2. Identify the number of HRSs required on major roads to connect HRS clusters: Strategically locating HRSs on the road network to connect the HRS clusters as they develop facilitates longer distance journeys and more heavy duty use cases. Access to hydrogen refuelling can be further expanded by serving smaller towns along the routes.

3. Combine cluster locations and road network mapping to calculate the total HRS network required for basic national coverage. Initial basic all-island coverage can be provided with ~80 HRSs.

Conclusions from the evidence base dictate the HRS rollout strategy for Ireland

The next section lays out Hydrogen Mobility Ireland's strategy for the rollout across vehicles, production and refuelling. Based on the evidence presented in this section, the HRS strategy will:

- **Target 400kgH2/day refuelling stations as a minimum.** Below this level HRSs cannot sell hydrogen cheaply enough to make hydrogen attractive for early users.
- **Identify captive fleets to ensure early utilisation.** Early investors in HRSs need high utilisation as quickly as possible to achieve a return on investment and this can be provided with the high demand from fewer larger vehicles. The location of early HRSs will to some extent be decided by the fleets willing to become early adopters.
- **Initially focus on the main population centres before spreading to smaller towns.** This will help to ensure that as many people as possible have access to refuelling infrastructure and also establish opportunities for cross-country travel early on.
- **Provide refuelling for the core road network first.** This is in line with EU regulations and can help connect the early clusters established in population centres and create an initial national network.
- **Build early HRSs in clusters.** Early users will need reassurances that refuelling will be available when they need it. Increasing the redundancy of individual stations provides some assurance, locating multiple HRSs in a limited number of areas can also help to build this confidence.
- **Identify strategic HRS locations.** HRSs that can serve multiple user types will be prioritised, for example through proximity to; major roads, population centres, transport hubs and major logistic depots

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Introduction to the hydrogen mobility strategy for the Republic of Ireland

A key outcome of this project is to deliver a strategy for the introduction of hydrogen vehicles and supporting refueling infrastructure. The strategy will support members in their decision making. The strategy is a first step in fostering investment in the hydrogen sector by aligning industry efforts across the supply chain

This section of the report introduces a phased strategy running from 2019 to 2030. The strategy will transition hydrogen mobility in Ireland from the situation today, where hydrogen vehicle deployment has not started and understanding around the sector is low, to a self sustaining industry in 2030, where policy support is no longer required and the sector is well placed to grow in the 2030s making a significant impact to emission reduction efforts

The strategy is divided into three phases, detailed on the next slide:

- Phase 0: Demonstration Phase
- Phase 1: Early Rollout Phase
- Phase 2: Wider Rollout Phase

The strategy has been broken down into phases with distinct business cases and policy support mechanisms requirements

Now until 2021 → 2022-2023 → 2024-2030 → 2030 Onwards

Demonstration Exercise

- Demonstration project introduces public and fleets to FCEVs
- Planning and preparation for Phase 1
- Construction of first HRS cluster in Dublin and production sites
- Level of government support confirmed

Phase 1: Early Rollout

- First Dublin HRS cluster opens
- Deployment of first captive fleets (buses, cars, vans)
- Government subsidies and tax exemptions introduced for hydrogen vehicles

Phase 2: Wider Rollout

- Additional HRS clusters in all major towns and cities and along connecting roads
- FCEVs introduced in additional vehicle segments (trucks, trains, ferries etc.)
- Hydrogen production ramps up

Hydrogen mobility

- Hydrogen established as a major transport fuel in Ireland
- FCEVs become mass market option
- Government subsidies are phased out

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Phase 1 Early Rollout Phase (2022-2023): Overview

Phase 1: 2022-2023

A proposed Phase 1 deployment project has been put together to demonstrate the scale and form this project could take. The actual project delivered will be shaped by the fleet operators willing to purchase hydrogen vehicles and so the real project will not be an exact match to the one set out here. The proposed Phase 1 project will deliver a cluster of hydrogen stations in the greater Dublin area supported by a mixed fleet of buses, cars and vans. The hydrogen will be supplied by electrolysis of water at a power generation site (e.g. wind farm, waste to energy site) and trucked to the stations

Vehicles:

30 Buses

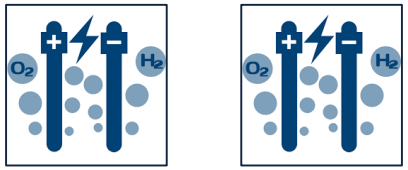
50 Cars

10 Vans

Production & dispensing:

3 Refueling Stations

2 Hydrogen Production Sites



Hydrogen Mobility Ireland

The vehicles proposed, the size and number of production and refuelling sites is all guided by the evidence presented in the last chapter

Phase 1 is designed to deliver hydrogen infrastructure and vehicles to Ireland at a scale that makes the project economically viable. The strategy:

30 Buses, 50 Cars, 10 Vans. Hydrogen buses and cars have been particularly selected as these vehicles are the most cost competitive as the technology is the most developed. As demonstrated in the evidence base in the previous section the profitability of HRS and production sites relies on good utilisation which can be best provided by heavy duty vehicles as each vehicle consumes a significant amount of hydrogen. Buses have been selected because the technology is well developed, and government procured bus fleets have quotas of zero emission vehicles to purchase under the Clean Vehicle Directive. However, RCV could also be considered if good progress is made in the development of these vehicles in the next 2 years

2 Hydrogen Production Sites. To ensure security of supply 2 production sites are proposed. The companies in the group interested in producing hydrogen are only interested in electrolysers. These are best positioned co-located with energy producers. This avoids grid charges making the hydrogen more affordable and allows companies to use the electrolyser as an electricity load during curtailment

A cluster of 3 medium sized HRS in the greater Dublin area. Experience in other countries has shown that customers need a cluster of reliable stations to feel confident in station availability. Three N+1 redundant stations will offer customers this confidence. Dublin has been selected for the station location due to the greater availability of vehicle customers. The evidence base presented in the previous section demonstrated that hydrogen stations smaller than a medium size (400kg/day) are not able to deliver hydrogen at a competitive price making medium sized stations the best option

Starting in the greater Dublin area provides a range of opportunities for fleets to support the hydrogen rollout during the early stages

Supermarket logistics

There are several large logistics centres around Dublin that could provide opportunities for individual captive truck fleets.

Other logistics

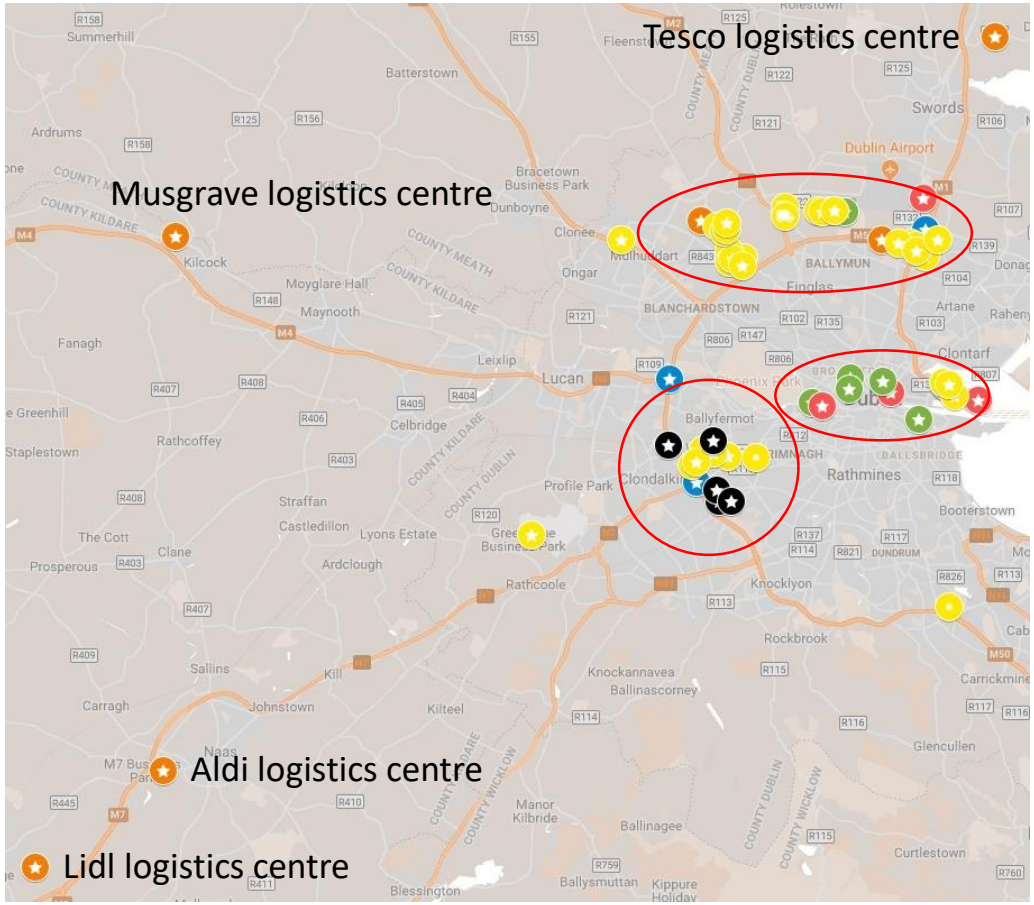
Within Dublin logistics and distribution depots are clustered in the north and west of the city as well as the port. This could provide opportunities for several companies to share refueling facilities

Buses

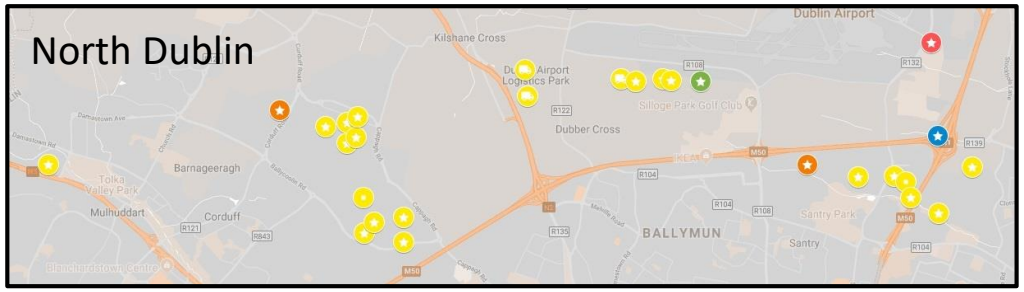
Dublin's bus depots are in the centre or near the airport, locations that could also be convenient for other users such as taxis.

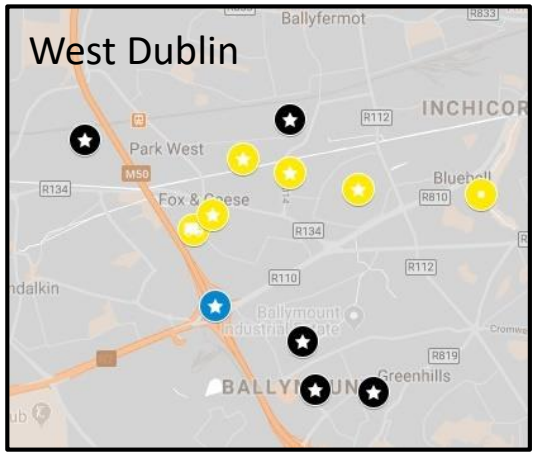
Taxis

Some taxis regularly run between the city centre and the airport - refueling in these locations could facilitate early uptake



We have explored three options for siting an HRS cluster in Dublin. The final locations selected will be driven by the location of interested fleets





Phase 1 – HRS Cluster in Dublin

Initially, clusters will be required to provide refueling options for fleets that adopt hydrogen early. This will likely mean selecting one of the three Dublin areas highlighted here to ensure there is sufficient density of refueling options.

Selection of the cluster location will depend on the participating fleets:

North Dublin: Convenient for Dublin buses based at the Harristown depot, as well as taxis serving the airport and the local distribution companies clustered in the area. Good connections to Belfast
Central Dublin: Most of Dublin Bus's depots are here, as are a cluster of logistics companies at the port. Convenient for taxis serving the centre
West Dublin: Several distribution companies and proximity to national roads connecting to cities in the west. Strong presence of refuse collection companies that could be an early HDV user

Transport terminals
Bus depots
Supermarket logistics
Other logistics
Major junction
Refuse collection

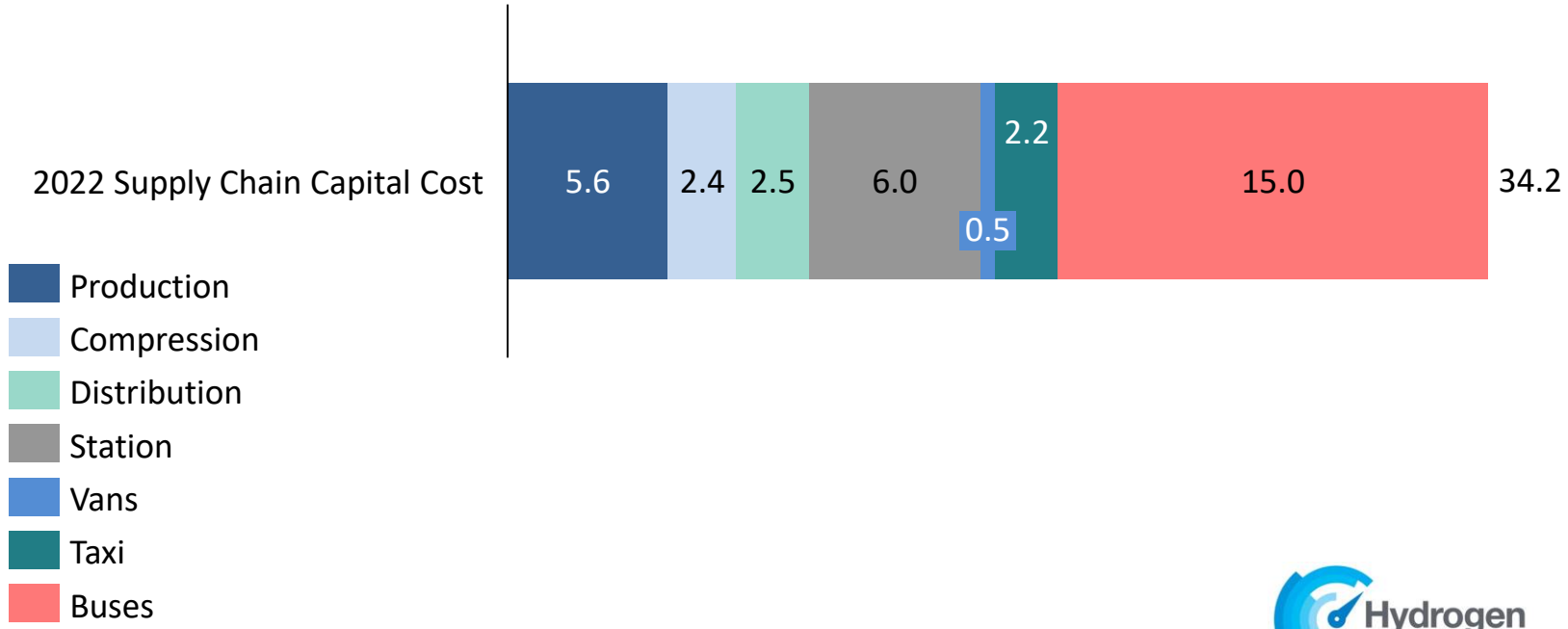
Hydrogen Mobility Ireland

The Phase 1 project requires €34million of investment. This can be provided by vehicle consumers, industry and government funding

Phase 1 investment costs:

- In Phase 1 €34million of investment is required. Although, a significant proportion of the vehicle investment would have been made anyway by consumers (bus, car and van fleet operators) if they were buying a conventional petrol and diesel vehicle
- The full breakdown of how this investment could be shared across investors is presented in the project business case (see next chapter)

Breakdown of All Capital Costs (€)



A relatively small investment in the Phase 1 project can help to develop hydrogen as a real decarbonisation option for Ireland in the future

The Phase 1 project requires a relatively small investment from vehicle consumers, industry and government to realise the potential of hydrogen mobility for Ireland.

By completing this project hydrogen production and refuelling capacity will be built to support the Phase 1 vehicles but also hydrogen vehicles purchased in the next couple of years after Phase 1 has been completed.

The investment in this infrastructure will support Irelands transition from the Phase 1 commercial demonstration project to the wider rollout of hydrogen mobility in Ireland helping Ireland realise hydrogen as a technology option for deep decarbonisation in the 2030s

Delivering Phase 1 requires industry has confidence that hydrogen mobility will grow beyond the Phase 1 project.

This will involve policy makers showing a commitment to deep decarbonisation and a clear sign that hydrogen is seen as a key technology options in decarbonisation efforts.

Confidence can also be built by interacting with fleet operators to get them on-board with hydrogen mobility to help ensure there are willing customers for hydrogen infrastructure in the future

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Phase 2: Wider Rollout Phase (2024-2030)

Phase 2 is designed to show a realistic rollout of hydrogen that will deliver a hydrogen industry in 2030 that is:

1. Self supporting, requiring no hydrogen specific policy support
2. Ready to rollout hydrogen vehicles on a large scale, significantly contributing to decarbonisation in the 2030s, having demonstrated hydrogen vehicles in all vehicle segments cars, vans, buses, coaches, trucks, RCVs, trains & marine
3. Experienced in producing hydrogen from renewable sources and has a detailed understanding of how hydrogen can be integrated into the energy system to support deep decarbonisation
4. Able to refuel hydrogen vehicles across the island of Ireland providing a basic national coverage of HRS, for the key fleets adopting hydrogen vehicles in the 2020s, allowing hydrogen vehicles to travel anywhere in Ireland without infrastructure limitations

Hydrogen vehicle sales in Phase 2

Two scenarios a high and a low hydrogen vehicle uptake scenario are presented. The scenarios are designed to be realistic and achievable reflecting the lessons learned from BEV uptake in Ireland to date. However, it is expected that political ambition to decarbonise will increase over the next decade and that hydrogen vehicles uptake above these scenarios is achievable.

The hydrogen vehicle uptake projections are based on three indicators:

1. Hydrogen vehicle availability. Discussions with vehicle OEMs has given a clear guide on when hydrogen vehicles in different segments are expected to be available in Ireland
2. Hydrogen refuelling station rollout. Only consumers within a realistic radius of refuelling stations are given hydrogen vehicles within their vehicle choice set
3. Hydrogen vehicle TCO. The comparative vehicle TCO is used in Element Energy choice models to understand the proportion of consumers who would consider purchasing a hydrogen vehicle at different price points

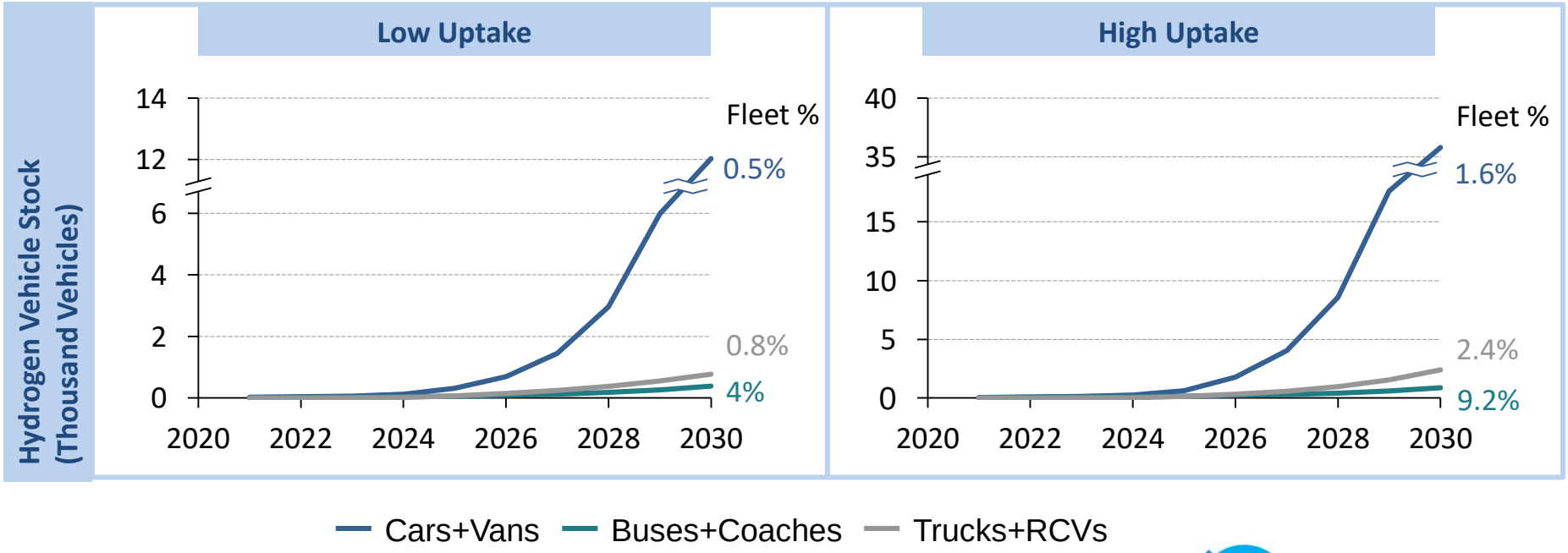
Annual hydrogen vehicle sales represent a realistic uptake of hydrogen vehicles if Ireland is to meet its 2050 decarbonisation targets

- The sale of hydrogen cars and vans represent realistic and conservative uptake projections which could be exceeded in reality as the decarbonisation agenda gains importance throughout the 2020s
- Hydrogen buses, coaches and RCVs will be very cost competitive by 2030. It is, therefore, assumed government will chose to purchase exclusively zero emission options by this time
- There are very few options for full decarbonisation of trucks. Hydrogen is a promising option and numerous OEMs are developing FC trucks.

Vehicle	Sales in 2025		Sales in 2030	
	Low	High	Low	High
Car	150	250	5,000	15,000
Van	35	60	1,000	3,500
Bus	20	50	60	140
Coach	5	10	60	140
RCV	10	20	35	100
Truck	50	100	200	750
Train Carriage	0	0	0	40
Ferry	0	2	2	5

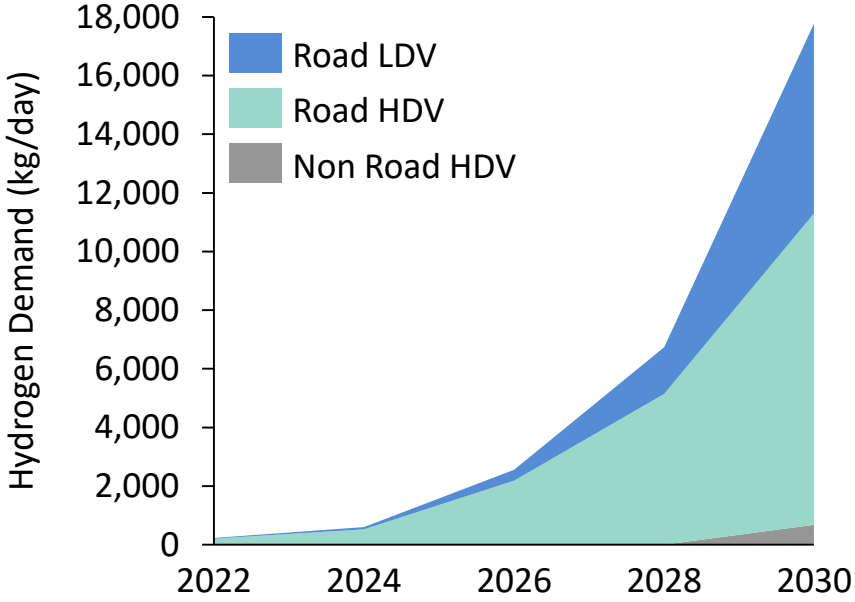
By 2030 vehicles in our conservative high uptake scenario could represent ~2% of the car, van & truck fleet and 9% of the bus fleet, creating the potential for fast growth in the early 2030s

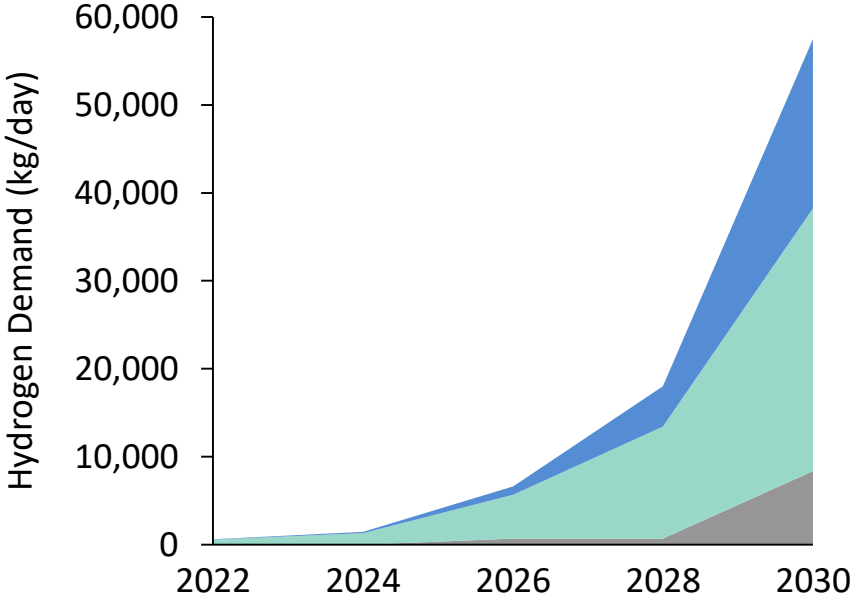
- The total number of hydrogen vehicles within the Irish vehicle fleet is relatively low by 2030 reflecting the slow turnover of the fleet and the significant time and effort required to deliver a new fuel
- The efforts made to support hydrogen in the 2020s will allow hydrogen to make a significant difference to the vehicle fleet emissions in the 2030s
- Delaying the introduction of hydrogen to the mid/late 2020s will delay the benefits until the mid/late 2030s



The hydrogen demand from the vehicle uptake scenarios would require a network of tens of stations and production sites to be built by 2030

- The two hydrogen vehicle uptake scenarios result in a demand of between 18,000kg/day and 60,000kg/day of hydrogen in 2030
- A medium sized refuelling station can dispense 400kg/day and a large station 1,000kg/day. A network of at least 60 stations would be required to support the high vehicle uptake scenario
- A medium sized electrolyser could produce 400kg/day and a large electrolyser could produce 4,000kg/day. A network of at least 30 production sites would be required to support the high vehicle uptake scenario





Hydrogen production in Phase 2

Phase 2 requires the production of significant volumes of hydrogen. As set out in the case for hydrogen in the previous chapter this can be produced using a number of different pathways. The most relevant pathways for Ireland are:

- Pathway 2: An electrolyser co-located with an existing electricity generator and purchasing electricity at the market price. This option can be built relatively quickly and offers a pathway to producing low production emission hydrogen
- Pathway 3: An electrolyser located at a new electricity generation site. This option would require a longer time to build but offers a pathway to the cheapest low production emission hydrogen
- Pathway 7, 8, 9: Reforming of natural gas either at a small scale co-located with an HRS or at large scale providing for multiple HRS

There are a number of potential production options in Ireland that meet these pathways. The potential mix of these production options is explored in the next slide

- Wind farms coming to the end of their REFIT tariffs could offer market price electricity to electrolysers under Pathway 2
- Waste to Energy plants which suffer from high levels of curtailment could offer market price electricity to electrolysers under Pathway 2
- Large new wind farms, in planning, in areas with high levels of grid constraint could be built with an electrolyser to produce hydrogen under Pathway 3
- A very large SMR is planned to be built at the Whitegate Oil Refinery. Excess production from this site could be sold into the mobility market under Pathway 8

A wide range of production mixes are possible. Government can steer the production mix by designing the BOS to encourage green production

Scenario 1: Follow BEV Emissions

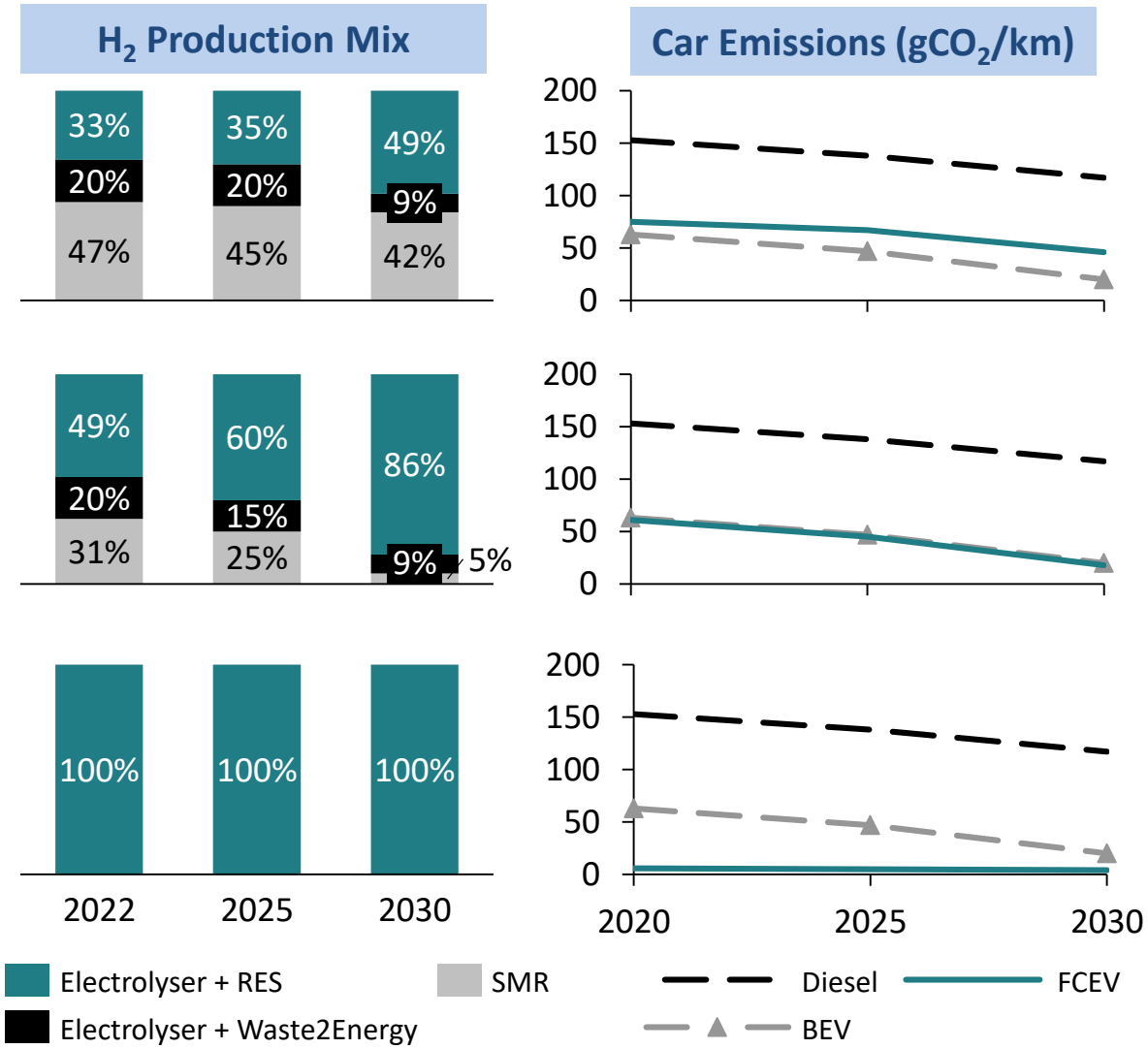
In recognition that BEV were supported before the decarbonisation of the grid, with the expectation that emissions would come down, this pathway follows the BEV pathway 5 years behind

Scenario 2: Match BEV Emissions

From the first introduction of hydrogen the Well to Wheel emissions match those of a battery electric vehicle using grid electricity

Scenario 3: Going Green

Enough wind/solar capacity is available, and hydrogen is produced purely from electrolysers co-located with renewable generators



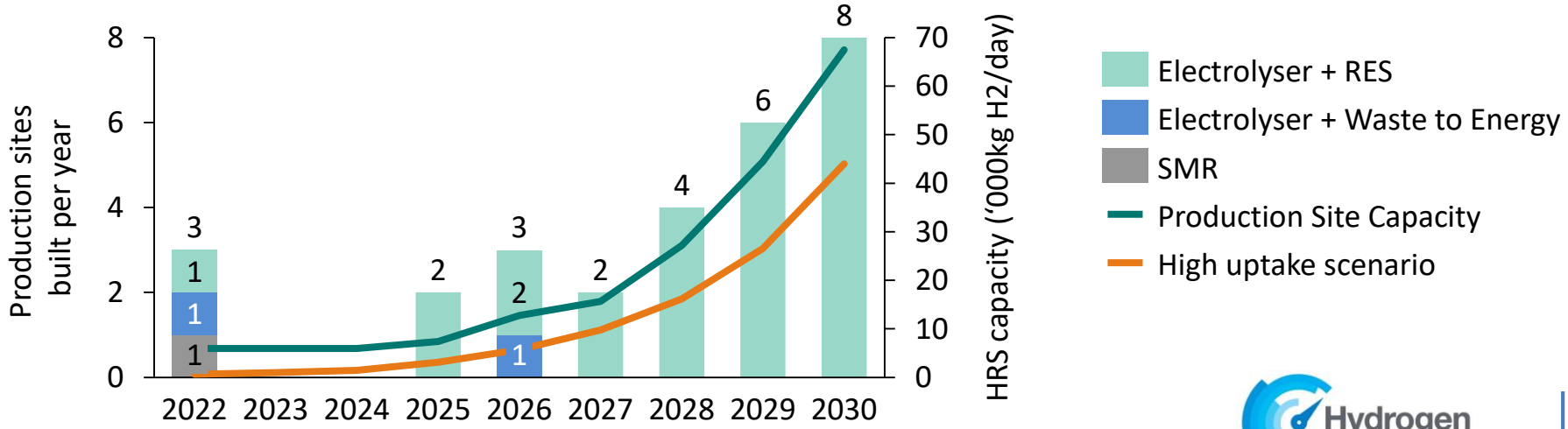
BOS: Biofuels Obligation Scheme

Hydrogen Mobility Ireland

The production mix delivered will depend on the BOS structure, which has not been agreed. The group is therefore not in a position to select a specific mix

- The mix of production sites built will be dependent on how policy makers decide to support hydrogen production. For example, a high BOS price for low emission hydrogen production will drive hydrogen suppliers towards the Match BEV or Going Green scenario mix
- With the BOS structure current unknown the group is unable to come to a definitive position on the most likely production mix
- Hydrogen production capacity needs to be built ahead of vehicle demand to ensure that vehicle uptake is not hampered by the availability of hydrogen (modelling assumes 1 year lead time)
- The graph shows the building rate for hydrogen production capacity under the Match BEV scenario, assuming capacity is built to allow the high vehicle uptake scenario to be realised
- The electrolyser + Waste to Energy is assumed to be 2MW in 2022 expanding to 9MW in 2026
- Electrolysers + RES are assumed to be 2MW: 2022-2025, 4MW: 2026-2027 and 8MW: 2028-2030

Example production site rollout under the Match BEV Scenario



Hydrogen stations in Phase 2

In conjuncture with the rollout of hydrogen production sites, hydrogen stations need to be rolled out to provide hydrogen to vehicle users. The rollout of hydrogen stations in Phase 2 has been split into three sub-phases. Each one expanding the rollout of stations to provide hydrogen access to a wider range of vehicle users. The sub-phases are summarised below

Phase 2.1 – Key cities and roads: HRS clusters added in Lisburn, Cork and Galway and refuelling along the major roads linking them. This starts to facilitate inter-city travel for early FCEV car users such as taxis and expands the number of cities that can deploy FCEV buses.

Phase 2.2 – Basic coverage for commercial fleets: Clusters in regional cities and ports are added, with the roads connecting them. This is the first point at which trucks and vans that operate nationally and internationally can switch to hydrogen. Facilitates national travel for early adopters of private FCEVs

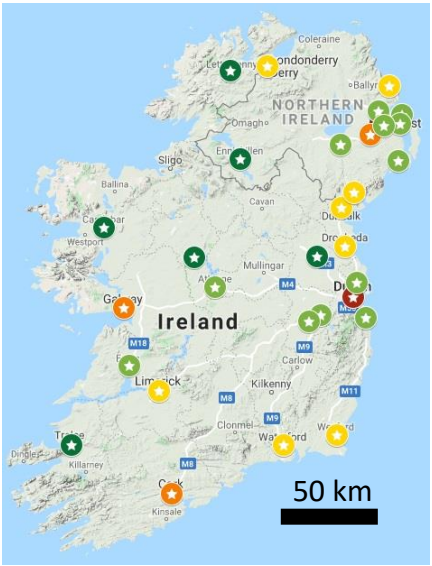
Phase 2.3 – Basic coverage for commuters: Largest regional towns receive HRS clusters and refuelling stations are added to roads connecting regional cities. This provides infrastructure for commuters around Belfast and Dublin to purchase FCEVs when these vehicles are expected to be available as a mass market option

Phase 3 – Basic national coverage: All regions are added to the HRS network. The timeframe for Phase 3 is dependent on hydrogen vehicle uptake. The timing is, therefore, to be confirmed once initial rollout has begun

Focusing on large population centers first allows basic national coverage to be provided quickly. Once hydrogen is an established fuel, HRSs in areas with lower population density provide full national coverage

Road network coverage - Assumptions

- 1 HRS Located every 50km on the roads connecting the main population centres produces coverage similar to the 22 existing motorway services in the Republic of Ireland.
- 9 HRSs would be required in phase 2.1 to facilitate the cross-country journeys linking the four largest cities.
- Fewer HRSs would be required in later phases to fill in the shorter distances between smaller towns – 7 in Phase 2.2 and 5 in Phase 2.3.



Urban clusters - Assumptions

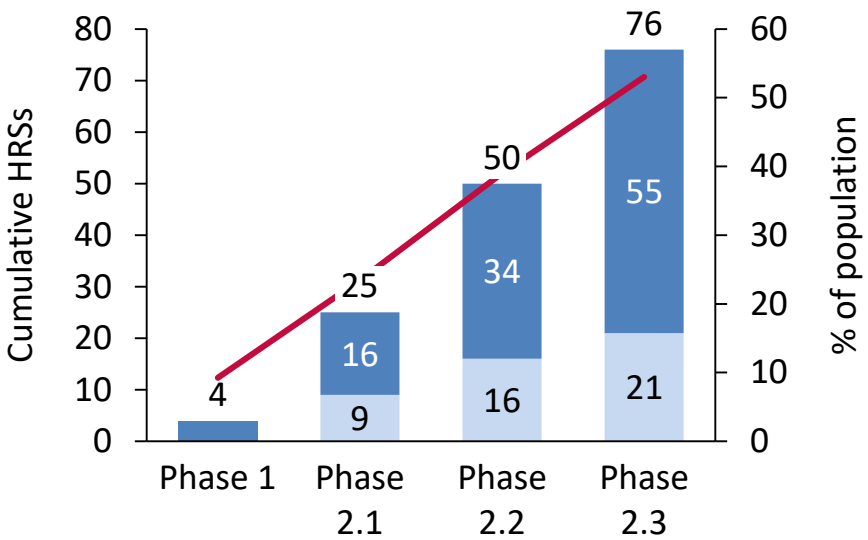
- Towns in Phase 2.1 have 3 HRSs and those in Phase 2.2 have 2 HRSs. In Phase 2.3 towns within 20km of existing HRS clusters receive 1 HRS.
- Motorway HRSs within 10 km of a town count towards that town's cluster
- The largest cities have more HRSs by Phase 2.3: Dublin – 10 & Belfast - 7

Phase 1 Phase 2.2 Phase 3

Phase 2.1 Phase 2.3

Hydrogen Mobility Ireland

76 HRSs are required by 2030 to support early adopters of hydrogen vehicles in the LDV and HDV segments



Basic national coverage for large fleets and the major commuter belts

- In the Phase 1 timeframe 3 stations are planned for Dublin and 1 station in Belfast
- By the end of Phase 2.3, 53% of the island's population lives in a town with at least 1 HRS.
- Assumes that in Belfast and Dublin only a proportion of the population is served by the city's HRS cluster – 30% in Phase 1 rising to 80% in Phase 2.3.
- **76 HRS locations** are required to provide this level of coverage – 34 in urban clusters in the Republic, 21 in urban clusters in Northern Ireland and 21 on the road network across the island

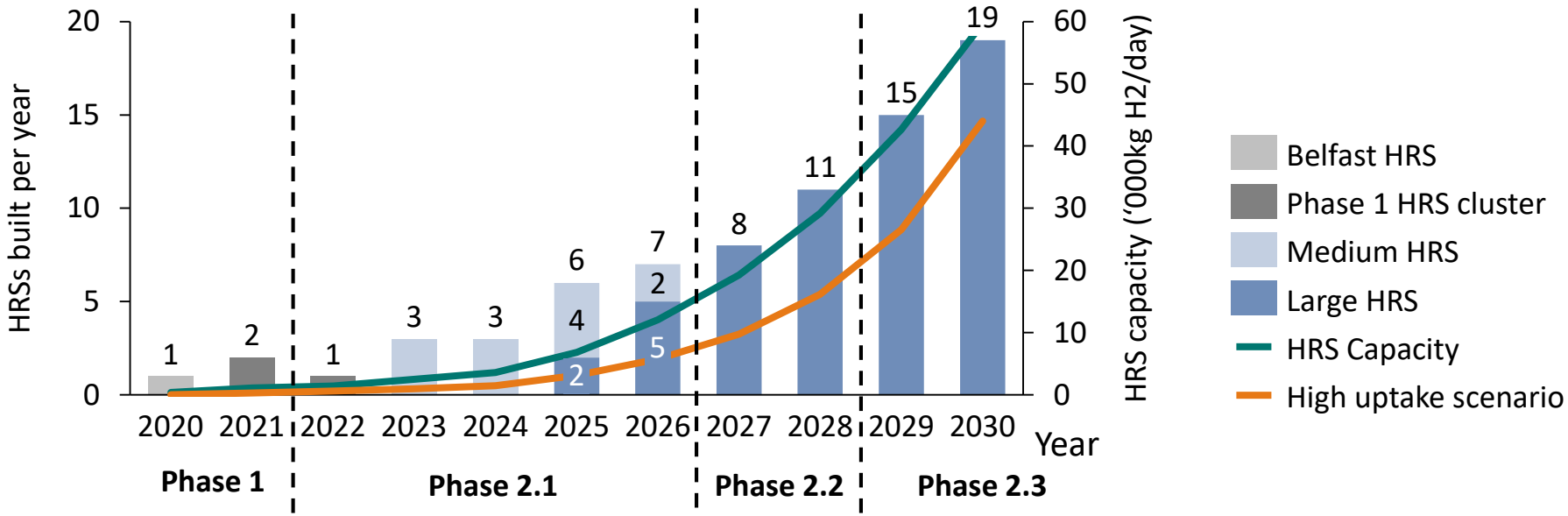
Comparison to other refuelling infrastructure

- C. 170 conventional refuelling stations in Dublin alone.
- GNI plans to deliver 27 public access CNG stations across the island, as part of a total network of 70.
- C. 1,200 BEV chargers on the island, mostly 22kW with 50 new fast charging hubs announced (50&150kW)

Urban HRS — % of people with HRS access — Road network HRS

The number of hydrogen stations ramps up quickly after 2025 with a shift from medium (400kg/day) to large stations (1,000kg/day)

The current HRS rollout strategy targets 76 stations. For these stations to meet high uptake demand at the end of this period, many of those built from the end of Phase 2.1 onwards will need to be large stations



For a total of 76 HRSs to provide the demand expected from vehicles in the high scenario, the first 16 can be medium sized, while the remaining 60 will need to be large. Without building for the high scenario, a lack of infrastructure could become a barrier. It is assumed stations build rate leads hydrogen demand by 1 year to ensure hydrogen uptake is not limited by station availability

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Demonstration Exercise (2019-2021)

In the time period from 2019 to 2021 industry actors interested in hydrogen will need to work on two areas:

1. The duration of this phase is defined by the time required to complete the planning and preparation for the rollout of hydrogen vehicles and stations in Phase 1. This timeline is predominantly defined by the time required to gain planning consent for the hydrogen production and station sites
2. This time can be productively used to demonstrate hydrogen vehicles in Ireland improving consumer awareness and educating fleets about how hydrogen vehicles can decarbonise their fleet and meet their operational demands. Demonstrations should aim to include cars from Toyota and Hyundai, vans from LDV and buses from Wrightbus, ADL and CaetanoBus

The demonstration of hydrogen vehicles will require financial and infrastructure support

1. Finance. SEAI has funding available to support the demonstration of new vehicle technologies in Ireland
2. Hydrogen Production Infrastructure. BOC operate a grid connected electrolyser in Dublin with spare capacity and the GENCOMM project will deliver a wind connected electrolyser in Northern Ireland in 2020 that could also supply to demonstration projects
3. Hydrogen Refuelling Infrastructure. BOC offer mobile refuelling platforms that could be used to supply fuel to the demonstration vehicles

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Introduction to the hydrogen business case

This section sets out the business case for private companies to invest in hydrogen production sites, stations and vehicles. The business cases presented in this section have been constructed with the support of the industry members of Hydrogen Mobility Ireland to ensure that the data represents the latest cost projections. The business case results highlight the need for policy support to ensure an effective business case can be realised. The financial support requirements set out in this section therefore lead directly into the policy requests (presented in the following chapter). By ensuring the policy requests meet level required for an effective business case and by working with industry members to develop the business case assumption an effective strategy is developed that industry can invest in and deliver.

<u>Business Case Method</u>

The business case analysis uses the following procedure:

1. The business case starts with the vehicle TCO to understand the sale price of hydrogen required to provide fleet operators with a TCO that means they are happy to take on the vehicles
2. The analysis then models the cashflow for the hydrogen station and production sites to understand what capital grants are required for the supply chain to offer the hydrogen at the target price

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Phase 1: Project Recap

Phase 1: 2022-2023

The Phase 1 project will deliver a cluster of hydrogen stations in the greater Dublin area supported by a mixed fleet of buses, cars and vans. The hydrogen will be supplied by electrolysis of water at a power generation site (e.g. wind farm, waste to energy site) and trucked to the stations in Dublin

Vehicles:

30 Buses

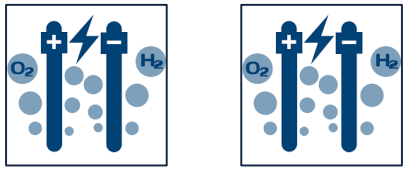
50 Cars

10 Vans

Production & dispensing:

3 Refueling Stations

2 Hydrogen Production Sites



Key business case assumptions: vehicles

All hydrogen vehicles are assumed to receive purchase grants in Phase 1. The expected grant levels are as follows

City Buses:

All of Dublin's public service offering buses are purchased by the NTA. The additional cost of purchasing hydrogen buses, rather than diesel hybrid buses, will be covered by an application for innovation funding from The Climate Action Fund or a similar fund. We have assumed funding support of €144,000 per bus. This covers the capital cost difference between diesel hybrid and hydrogen buses and covers the additional maintenance costs by purchasing a powertrain maintenance package for the hydrogen buses

Taxi / Service Cars (police etc.):

- Taxi receive €15,800 in SEAI grant (€3,800), Vehicle Registration Tax (VRT) exemption (€5,000) and eSPSV19 (€ 7,000)
- Service cars receive €8,800 in SEAI grant (€3,800), Vehicle Registration Tax (VRT) exemption (€5,000)
- Capital Funding for the first demonstration project will be used to make these up to €24,000

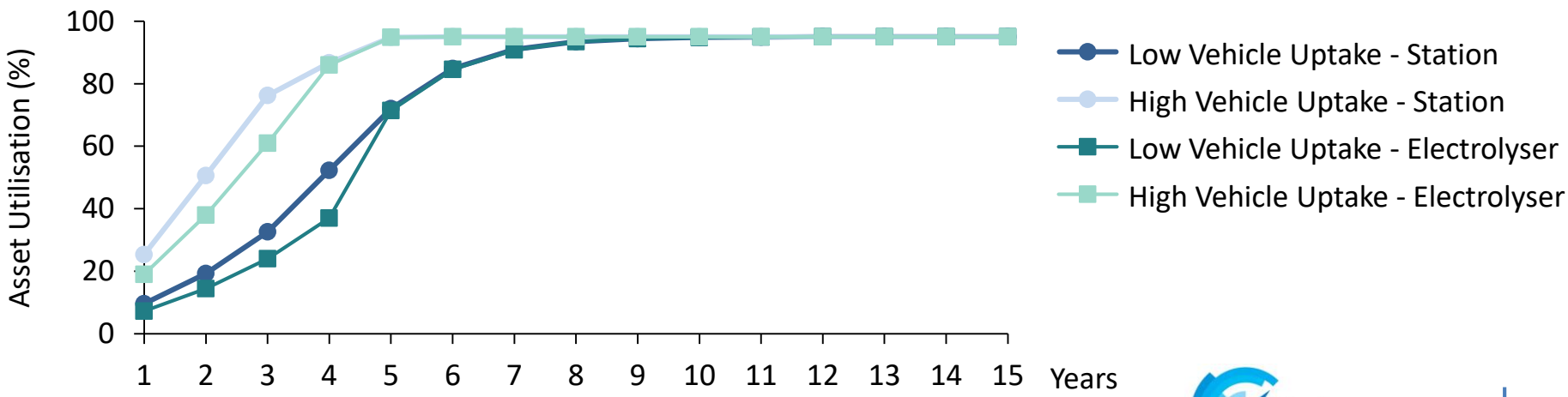
Vans:

- Vans receive €8,800 in SEAI grant (€3,800) and Vehicle Registration Tax (VRT) exemption (€5,000)
- Capital Funding for the first demonstration project will be used to make these up to €17,000

Key business case assumptions: infrastructure

Scenario	Number	Capacity (kg/day)	Station CAPEX (€m)	Fixed OPEX (% of CAPEX)	Interest on Dept (%)	Required IRR (%)
Production Site	2	800	2.8	3	5	8
Refuelling Station	3	400	2	3	5	8

The vehicles introduced in Phase 1 will demand 350kg/day of hydrogen a day. This equates to 30% utilisation of the stations and 22% utilisation of the production sites. To deliver a working business case it is assumed that hydrogen vehicle demand grows beyond Phase 1 to further drive up the utilisation of the assets installed. Asset utilisation is assumed to be high (95%) because the capacity is sized to include all of the contingencies required to deliver this level of average capacity reliably everyday. The building of the infrastructure is assumed to be supported by 50% capital grants in Phase 1



The business case analysis shows that hydrogen in 2022 can be supplied to the consumer at €8.75/kg if a 50% capital grant is given for all hardware purchases in the supply chain

Complete Supply Chain Costs:

- In Phase 1 hydrogen can be supplied to the consumer at €8.75/kg if a 50% capital grant is available for hardware purchases for the station, compression, distribution and production equipment (this also assumes hydrogen demand grows beyond Phase 1 along the high vehicle uptake scenario)
- This is close enough to the hydrogen price required for taxis (€8.30-11.50/kg) that a successful business case for stakeholders along the supply chain should be realisable. However, capital grants alone are not enough to bring down the price to a competitive level for buses and vans (see next slide)

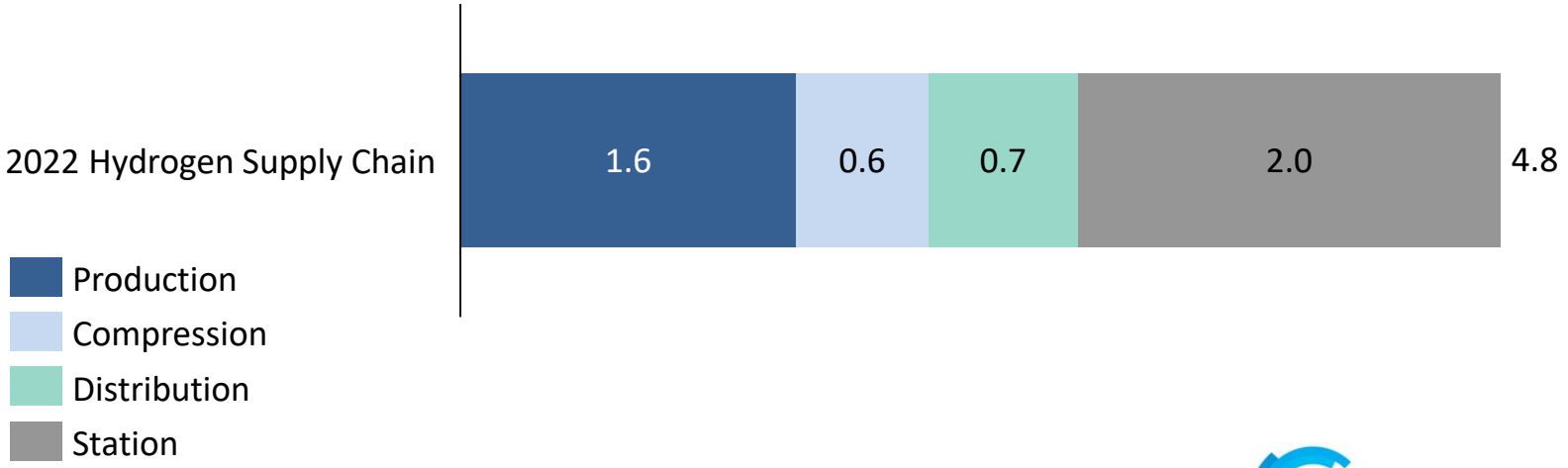
Breakdown of Hydrogen Supply Costs in 2022 (€)

A BOS credit worth €3.95/kg is needed to provide bus operators with cost competitive hydrogen

Complete Supply Chain Costs:

- A Biofuels Obligation Scheme credit worth €3.95/kg is required in 2022 to bring the hydrogen price down to €4.80/kg, making hydrogen buses cost competitive with diesel hybrid
- At this price hydrogen would also offer a significant saving to van users who need a price of €5.90/kg to break even
- A €3.95/kg credit for renewable hydrogen can be achieved by hydrogen receiving multiple counting of the standard credit price or by receiving an advanced biofuel credit price (see policy section)

Breakdown of Hydrogen Supply Costs in 2022 with BOS grant (€)

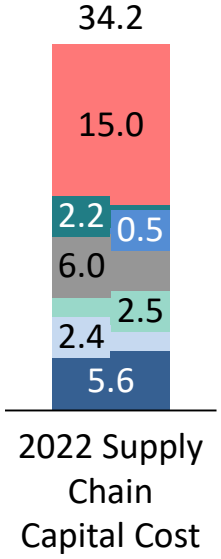


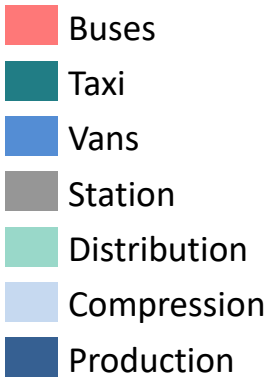
The Phase 1 project requires €34million of investment across vehicle consumers, industry and government support

Phase 1 investment costs:

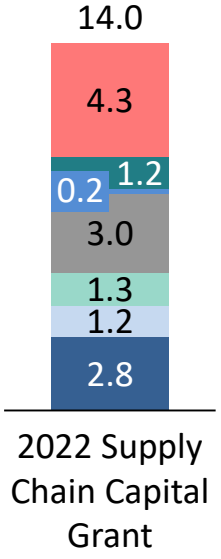
- In Phase 1 €34million of investment is required. Although, a significant proportion of this investment would have been made anyway by consumers buying conventional vehicles
- Industry is required to invest €8.3million in hydrogen production and refuelling infrastructure
- €14million of capital grants is required to deliver the project, this will be sought from Irish and European funding schemes such as the Climate Action Fund

Breakdown of All Capital Costs (€)





Breakdown of Phase 1 Capital Grants (€)



A successful Phase 1 requires: confidence in the growth of hydrogen mobility, vehicle subsidies, infrastructure capital grants and a BOS credit

Conclusions:

- A strawman for the economics of the Phase 1 project illustrate what this deployment project could look like with the expectation that as a real project is developed, many aspects of the plan will change
- The industry members can use this analysis as a first step to shape their internal analysis on their own ability to invest in a Phase 1 project
- The analysis clearly shows that there are three main requirements for a successful Phase 1 project. These are:
    1. Infrastructure providers must be confident that the industry will continue to grow beyond Phase 1. This will require that the group actively engages with potential Phase 2 vehicle users during the planning of Phase 1
    2. Vehicle subsidies and capital grants worth €14million are available to support the project
    3. BOS credits worth €3.95/kg are available from the deployment of the first green hydrogen production projects
- With these elements in place the final step is to ensure customers (particularly bus operators) are happy to participate

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The business case for Phase 2 shows how the industry can progress beyond the capital grant support of Phase 1 into an industry led rollout

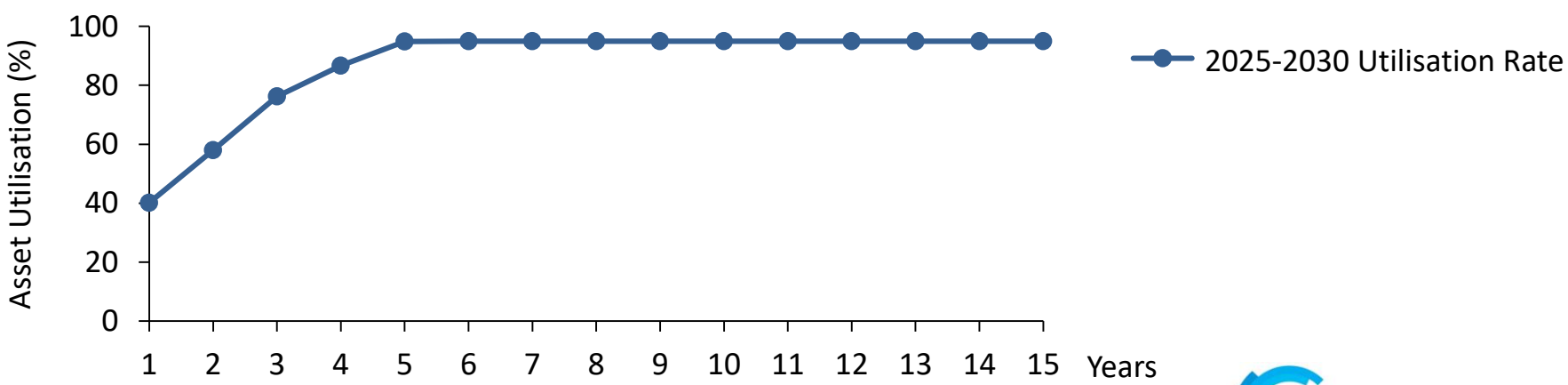
Phase 2 Business Case:

- The Phase 2 business case follows the same method as the Phase 1 business case
- However, in Phase 2 significantly less policy support is available
- In Phase 2 hydrogen buses do not receive any funding support. The hydrogen buses are still competitive because the cost of the buses will come down and hydrogen buses are competing with battery electric buses, rather than diesel hybrid, in this time period for selection within the zero emission bus procurement strategy
- In Phase 2 hydrogen cars, taxis and vans still receive capital funding support, although this tails off towards 2030
    - Car: VRT is -€5,000 in 2025 and €-1,000 in 2030. SEAI grant is -€5,000 in 2025 and -€1,000 in 2030
    - Taxi: VRT is -€5,000 in 2025 and €-1,000 in 2030. SEAI grant is -€3,800 in 2025 and -€1,000 in 2030. Taxi grant is -€3,500 in 2025 and -€1,750
    - Van: VRT is -€5,000 in 2025 and -€3,000 in 2030. SEAI grant is -€3,800 in 2025 and -€1,000 in 2030
- In Phase 2 infrastructure providers receive no capital funding support. The production of green hydrogen is supported through the BOS

Key business case assumptions: infrastructure

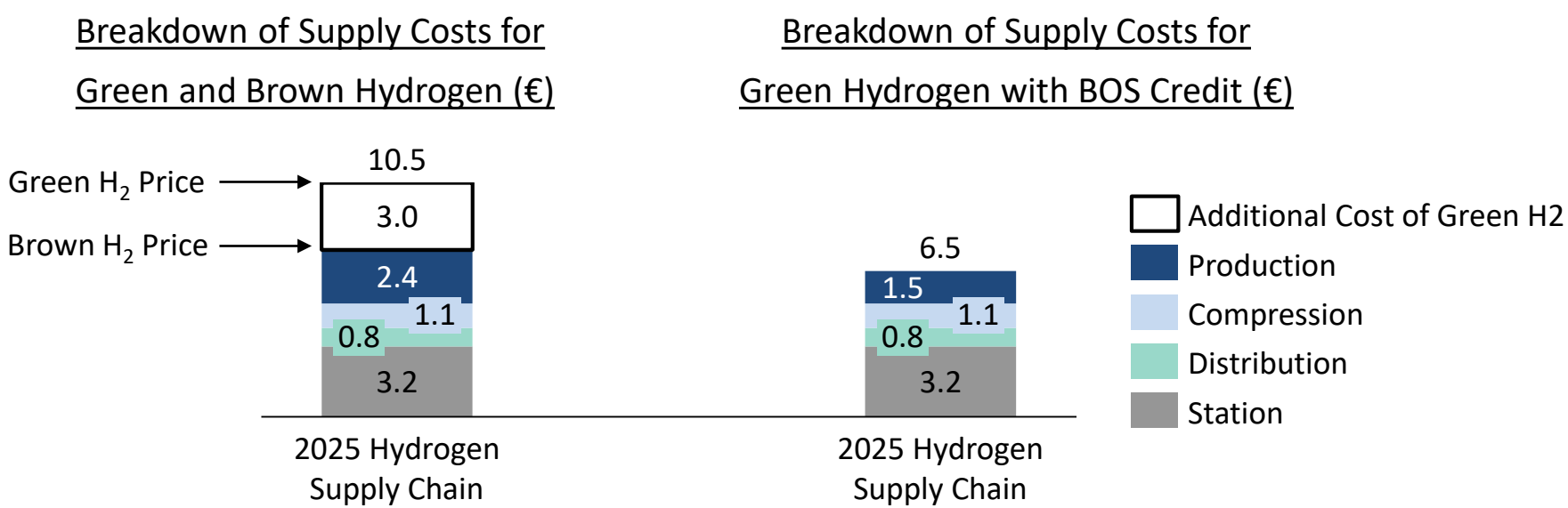
Scenario	Station Capacity (kg/day)	Station CAPEX (€m)	Fixed OPEX (% of CAPEX)	Interest on Dept (%)	Required IRR (%)
Production Site 2025	800	1.9	3	5	12
Production Site 2030	3,200	5.3	3	5	8
Refuelling Station 2025	400	2	3	5	12
Refuelling Station 2030	1,000	3	3	5	8

In Phase 2 it is assumed infrastructure is built to support new hydrogen demand with all projects identifying a captive hydrogen fleet to act as a base load for hydrogen demand. Asset utilisation is assumed to be high (95%) because the capacity is sized to include all of the contingencies required to deliver this level of average capacity reliably everyday



The business case analysis shows that brown hydrogen can be supplied to the consumer at €7.50/kg and green hydrogen at €6.50, if a €3.95/kg BOS credit is available, in 2025

- In 2025 brown hydrogen can be supplied to the consumer at €7.50/kg. With a €3.95/kg BOS credit green hydrogen can be supplied at €6.50/kg
- These prices reflect a best estimate, however, the prices could be lower than this if the price of electricity from wind comes down faster than expected or the scale of the hydrogen industry leads to greater cost reductions in the CAPEX of hardware
- This is below the hydrogen price required for buses (€7.40/kg), cars (€9.70/kg) and vans (8.00/kg) in 2025 meaning that a successful business case for stakeholders along the supply chain should be realisable

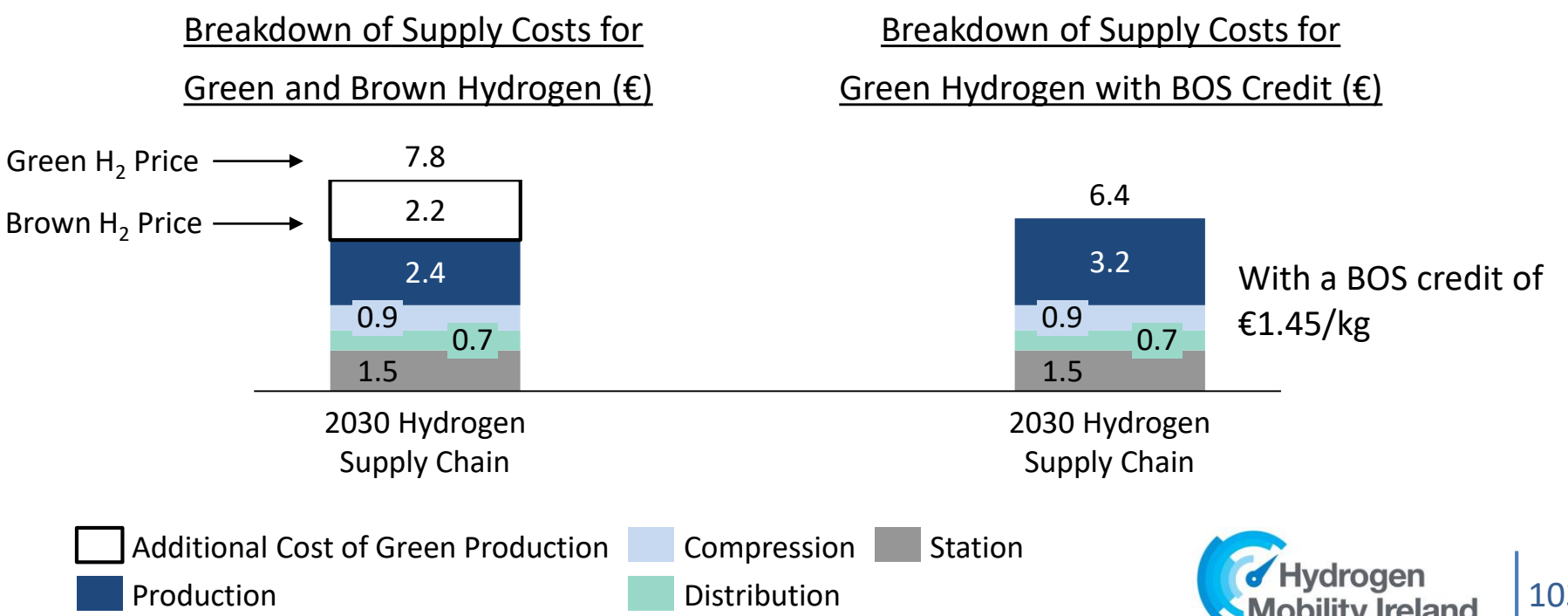


Brown Hydrogen: Hydrogen produced from fossil fuels

Green Hydrogen: Hydrogen produced from renewables

Brown hydrogen can be supplied to the consumer at €5.50/kg and green hydrogen at €6.35, if a €1.45/kg BOS credit is available, in 2030

- In 2030 brown hydrogen can be supplied to the consumer at €5.50/kg and green hydrogen for €7.80/kg
- To deliver green hydrogen to the bus market at a competitive price (€6.35/kg) a BOS credit of €1.45/kg is still required in 2030. However, if sufficient light duty hydrogen vehicles are on the road and able to buy hydrogen at a higher price, fuel providers may be able to provide hydrogen to bus operators at a lower price without policy support
- This is below the hydrogen price required for buses (€6.35/kg), cars (€14/kg) and vans (€8.10/kg) meaning that a successful business case for stakeholders along the supply chain should be realisable



There is a clear business case for hydrogen infrastructure to be provided by industry in Phase 2, once the capital grants in Phase 1 are removed

Conclusions:

- The significant reduction in the purchase price of FCEV by 2025 means that vehicles can pay a higher price for hydrogen and still be offered a competitive TCO
- At these higher prices hydrogen infrastructure can be built and operated by industry without the need for government capital support, as shown in this section
- Policy support through the BOS will be required to encourage the delivery of green production sites such as an electrolyser co-located with a wind farm. Instead of the cheaper option of a natural gas reformer
- By 2030 if industry accepts an IRR for infrastructure projects of 8% then brown hydrogen can be offered to consumers at €5.50/kg and green hydrogen can be offered at €6.40/kg (€7.80/kg without the BOS credit)
- At these prices both light and heavy duty vehicles can be offered a competitive TCO case to consider adopting hydrogen vehicles
- Delivering this strategy to 2030 will place Ireland in a good position to use hydrogen to help meet decarbonisation targets in the 2030s. The growth of hydrogen vehicles in the 2030s will also help infrastructure providers by ensuring demand for hydrogen is high and their infrastructure remains well utilised throughout its life

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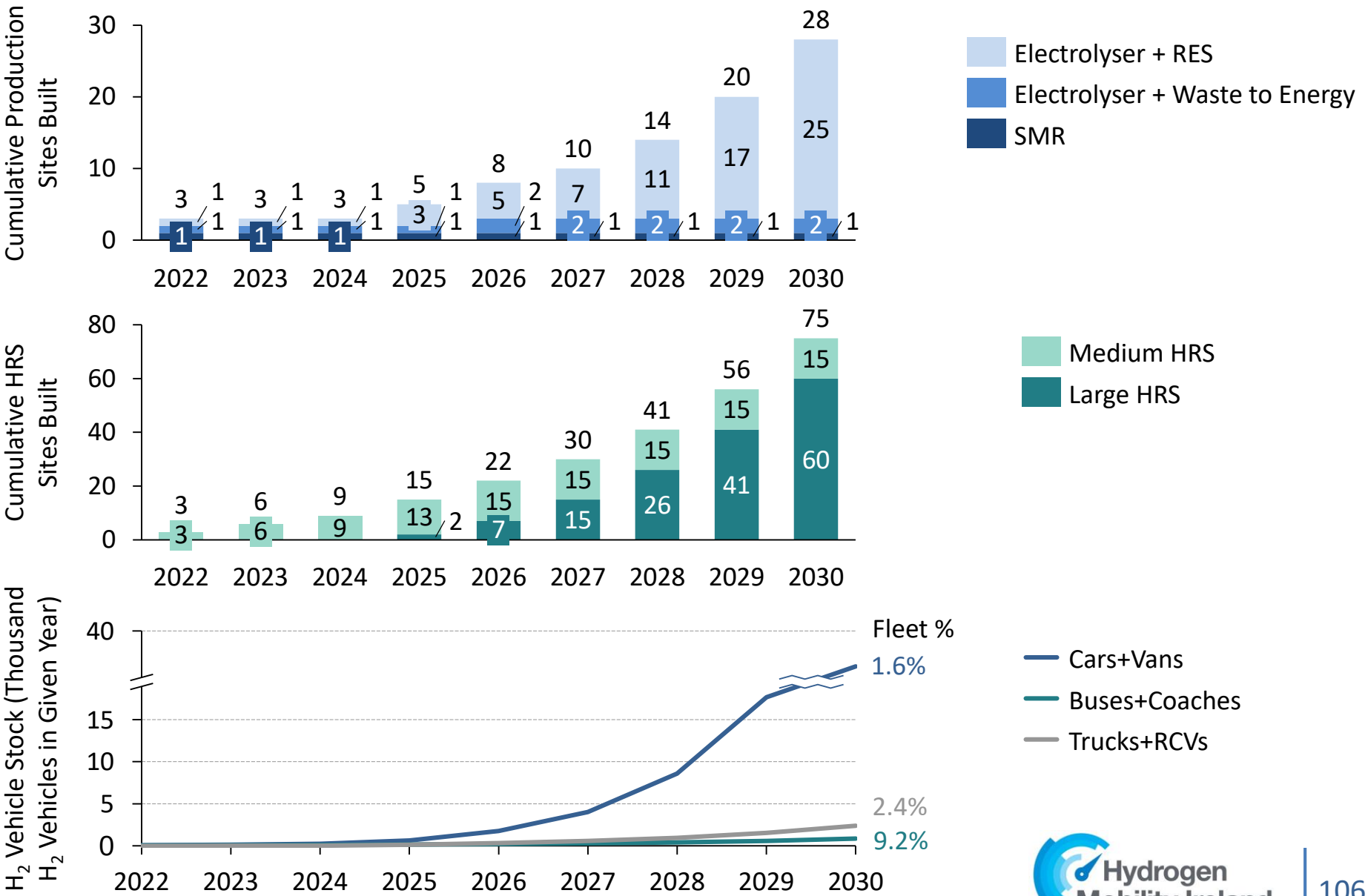
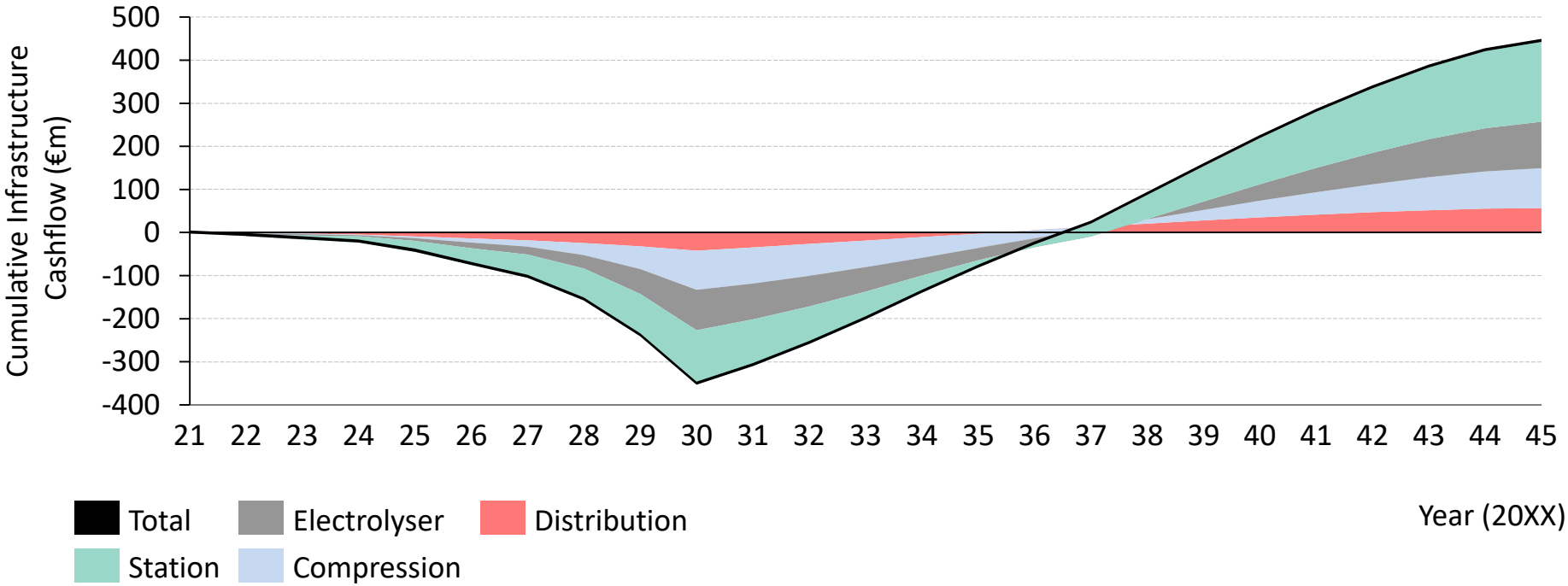
Recap: Hydrogen vehicles and infrastructure assumed under the high vehicle uptake scenario with the Match BEV production mix



Hydrogen Mobility Ireland

Delivering hydrogen infrastructure to support the high vehicle uptake scenario requires an investment of €350m by 2030

- Investment is required in stations, production sites, compressors and distribution trucks between 2021 and 2030 to support the rollout of hydrogen vehicles as outlined in the previous slide
- The cashflow assumes that the hydrogen price starts at €8.75 for Phase 1 sites and drop to between €5.50/kg and €6.35/kg, for brown and green hydrogen respectively, by 2030
- Delivering all this infrastructure will require a cumulative investment of €350m between 2021 and 2030



Note. This graph shows the cashflow for the Match BEV production scenario. In this scenario a small volume of hydrogen is expected to come from the Whitegate Oil Refinery reformer. This investment is not included in this chart because only a very small proportion of the hydrogen output of that reformer will enter the mobility market

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Policy support required for the successful uptake of hydrogen mobility in Ireland

The analysis has highlighted four areas of policy that would need to be updated to support hydrogen if hydrogen vehicles and infrastructure are to be successful in Ireland. These are:

1. The Extension of Current Low Emission Vehicle Policies (2022 – 2030)
   - Extension of the current battery electric vehicle (SEAI purchase grants, Vehicle Registration Tax (VRT) exemptions, reduced annual tax, recharging infrastructure capital support and 0% Benefit in Kind tax for company cars) and CNG vehicle (Accelerated Capital Allowances for refuelling stations) policies to hydrogen vehicles
2. Grants for Hydrogen Heavy Duty Vehicles (2024 – 2030)
   - There are currently no policies in place to support BEV heavy-duty vehicles, but these are likely to be needed for hydrogen vehicles as they offer specific benefits in this segment.
   - This section explores policy support to cover the additional capex for hydrogen vehicles
3. A Favourable Implementation of the Second Renewable Energy Directive (RED II) in Ireland (2022-2030)
   - The wording of RED II gives member states the freedom to support hydrogen produced from renewable sources (biomass and renewable electricity) with higher credit values either through multiple counting of credits or by including hydrogen as an advanced biofuel
4. Capital Funding for the First Commercial Demonstration of Hydrogen (Early Rollout Phase 2022-2023)
   - Capital grant funding from 2019-2023 from Ireland and the EU to help de-risk the planning and delivery of the Early Rollout project

1. The Extension of Current Low Emission Vehicle Policies (2022 – 2030)

BEVs have received incentives from the Irish government since 2011 and FCEVs are currently at the same level of deployment that BEVs were a decade ago. Our analysis of the cost of supporting light-duty FCEVs assumes that these vehicles receive similar levels of support.

Vehicle Registration Tax (VRT) Exemption

Battery electric cars and vans: Currently receive a €5000 VRT exemption in the Republic of Ireland. These will be in place until the end of 2021, at which point we expect this incentive to be reduced and then to be removed completely between 2025 and 2030.

Assumptions for FCEVs in our modelling: Recognising the earlier level of deployment of FCEVs, we assume VRT exemptions of; €5,000 in 2021, €5,000 in 2025 & €1,000 in 2030.

SEAI Purchase Grants

Battery electric vehicles: Currently also eligible for a purchase grant, which varies depending on the type and use of the vehicle. These grants will be in place at the levels shown below until the end of 2021 and we expect them to removed between 2025 and 2030:

- Private cars - €5,000
- Business cars, taxis and vans - €3,800
- Additional eSPSV Grant for Taxis - €7,000

Assumptions for FCEVs in our modelling:

- Private cars - €5,000 in 2021, €5,000 in 2025 & €1,000 in 2030
- Business cars, taxis and vans - €3,800 in 2021, €3,800 in 2025 & €950 in 2030
- Taxis receive additional eSPSV Grant - €7,000 in 2021, €3,500 in 2025 and €1,750 in 2030

1. The Extension of Current Low Emission Vehicle Policies (2022 – 2030)

These are the other incentives for low emission vehicles in Ireland which have less influence on the modelling shown in this report, or are not included

Accelerated Capital Allowance: Vehicles

Applies to cars used for business – companies can reduce their tax bill in the year of purchase by 12.5% of the purchase price of a battery electric car up to €24,000 (€3000).

Modelling assumptions: For both BEVs and FCEVs we assume that the value of this inventive will be; €3,000 in 2021 and €600 in 2025 and removed for all zero emission vehicle types by 2030.

Motor Tax

Zero emission vehicles in Ireland currently pay the lowest motor tax bracket of €120 per year.

Modelling assumptions: Motor tax for both BEV and FCEV vehicles will increase by one tax bracket every 5 years, leading to tax of: €120 in 2021, €170 in 2025 and €180 in 2030.

Other BEV policies not included in modelling:

0% Benefit in Kind (BIK): For BEVs there is 0% BIK tax on the first €50,000 of the pre-incentive purchase price of a company car, beyond this 30% of the purchase price is taxed at the employee's rate

Domestic Charger Grant: Up to €600 toward the installation costs of a domestic charge point for BEVs and plug-in hybrids.

Toll Incentive Scheme: BEVs receive 50% toll reductions up to annual totals of €500 (private) and €1,000 (commercial).

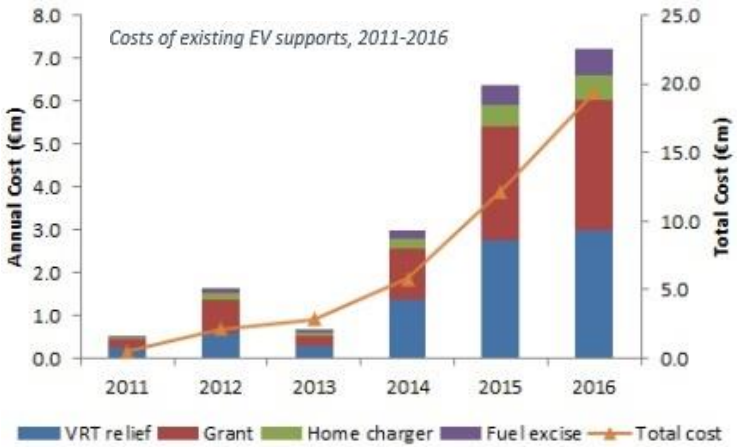
Public charging network: ESB has provided a national EV charging network which users have been able to access for free – charges are expected to be introduced in the near future.

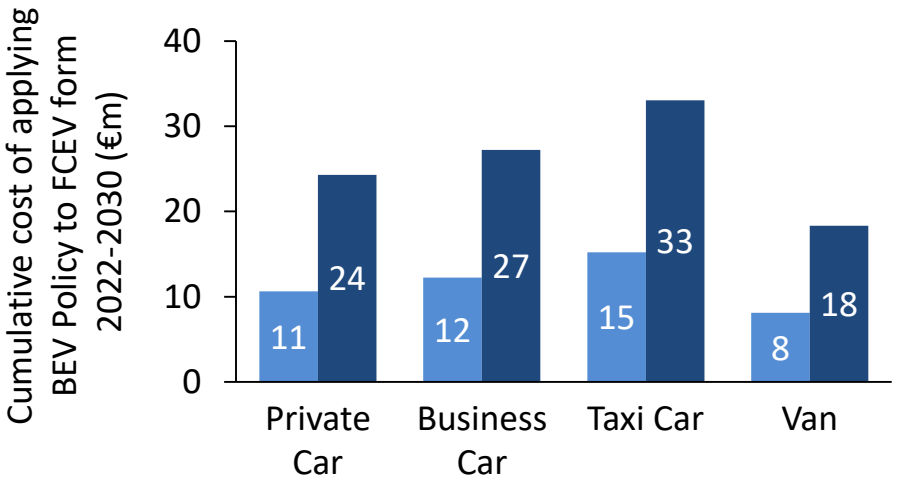
1. The Extension of Current Low Emission Vehicle Policies (2022 – 2030)

FCEVs are at the stage of deployment that BEVs were in 2011 when incentives were first introduced in Ireland to encourage their uptake. Extending these incentives to FCEVs would mean equal support is given to these two complimentary zero emission vehicle technologies.

Cumulative cost of policies to support BEVs

- At the end of 2016, the total cost of these EV incentives was €19.4m (excluding Accelerated Capital Allowance, the cost of the public charging network and supplying free public charging).
- The Low Emission Vehicle Taskforce's September 2018 Progress Report projects that under a low uptake scenario (starting with 8,000 EVs by 2020), by 2023 EV incentives will have cost c.€230m.





Cumulative cost of extending BEV policies to FCEVs from 2022 to 2030

- In the low uptake scenario, we expect these policies to cost the government €46m by 2030
- In the high uptake scenario, these costs would be €102m

Low Uptake
High Uptake

Hydrogen Mobility Ireland

2. Grants for Hydrogen Heavy Duty Vehicles (2024 – 2030)

There are currently no incentives for supporting heavy duty BEVs in Ireland, but this is a segment in which - particularly early on - hydrogen vehicles are expected to have an advantage.

Purchase grant assumptions for heavy duty vehicles

In order to quantify the cost of supporting the introduction of hydrogen vehicles in heavy duty segments, we have assumed that this support will primarily be in bridging the gap between the purchase price of conventional vehicles and their more expensive hydrogen counterparts. The level of purchase incentive for each type of vehicle is based on the following:

- **Buses:** In each year, the first 27 hydrogen buses purchased have an incentive equal to the cost difference between a FCEV and BEV expected in that year. This is the number of zero emission buses Ireland is required to purchase each year under the Clean Vehicle Directive and therefore any hydrogen buses purchased would be displacing BEV rather than diesel vehicles. Purchases beyond this level receive a grant equivalent to the price difference between an FCEV and diesel hybrid in that year.
- **Trains:** Purchase incentive is equal to the price difference between FCEV and diesel vehicles.
- **Trucks and RCVs**: Purchase incentive is the price difference between FCEVs and diesel hybrids.

Accelerated Capital Allowance: Refuelling Infrastructure

- Currently companies purchasing CNG refuelling equipment can apply for up to 100% of the equipment costs to be written off against the company's profit in the year of purchase. We have assumed a similar incentive scheme would apply to companies installing hydrogen refuelling equipment.

2. Socializing the costs of heavy-duty hydrogen vehicles can reduce the burden on government and ensure their deployment is cost effective

The purchase incentive for each heavy-duty vehicle is substantial, but there are several ways that these costs could be spread across the fleet

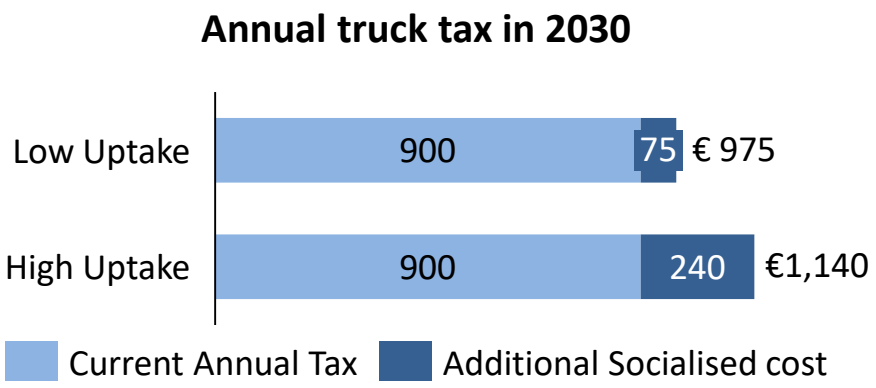
Socialising the cost of FCEV trucks across the truck fleet

In Ireland the 'polluter pays' principle is currently applied to light duty vehicles through differentiated annual tax brackets. The same principle has not yet been applied in the heavy duty segment as zero emission powertrains have not been available. As hydrogen trucks become an option for fleet operators, emission-based annual tax brackets could offer several benefits; socialising the cost to government of purchase incentives, providing an additional incentive for FCEVs through lower annual tax and allowing the tax gathered by government to remain constant as some vehicles are exempted.

Impact on annual truck tax from socialising the cost of zero emission vehicle incentives

The chart to the right shows the impact by 2030 on the annual tax paid by conventional trucks (over 3.5t unladen weight) in order to cover the cost of the purchase incentives for fuel cell trucks in the low and high uptake scenarios.

Note: This tax would need to be increased further if the policy was designed to support FCEV and BEV trucks



3. The Renewable Energy Directive and the Biofuels Obligation Scheme

The first Renewable Energy Directive (RED I) set renewable energy targets for EU member states to be met by 2020. Member states are currently in the process of translating the updated RED II into national legislation which contains updated criteria and 2030 targets

Renewable Energy Directive I

The Renewable Energy Directive was introduced in 2009 with a 2020 target for 20% of final energy consumption by EU member states to come from renewable resources. The Ireland specific RED I target is 16% of all energy consumption to be from renewable sources by 2020 with a sub-target of 10% of fuels used in the transport sector.

Biofuels Obligation Scheme (BOS)

The BOS is the primary mechanism through which Ireland aims to meet its RED I transport target. It is an obligation on fuel suppliers to provide a minimum proportion of biofuels in the fuels they supply – 11.111% by volume as of January 2019. It is administered by the National Oil Reserves Agency (NORA) through a certificate scheme – one certificate is issued for each litre of biofuel placed on the market that meets certain sustainability criteria, while two certificates are allocated for biodiesel produced from wastes. Most biofuels placed on the market under the scheme have qualified for double counting – 100% of biodiesel placed on the market in 2016-2018 received 2 certificates - meaning that less physical fuel has been placed on the market than the certificates represent. In 2018 just 11.3% of the biomass feedstocks for biofuel production originated in Ireland.

3. Updated criteria and targets for the Second Renewable Energy Directive (RED II)

RED II is a 'recast' version of the original directive, with 2030 targets of 32% of final energy consumption and 14% of transport fuels to be from renewable resources.

RED II 2030 targets for transport fuels

- Member states must require fuel suppliers to supply a minimum of 14% of transport fuels from renewable energy sources.
- Contribution of biofuels from **food and feed crop feedstocks** towards this target is to be capped at 7%, or 1% above a member state's fuel mix in 2020. If a country's cap is below 7%, they can reduce their overall target from 14% by the same amount.
- **Advanced Biofuels and Biogas** should be at least 0.2% in 2022, 1% in 2025 and 3.5% in 2030 of final energy consumption in the transport sector.

Transport fuels to be included

- Biofuels produced from food and feed crops – capped at 7%
- Biofuels produced from high indirect land use change risk feedstocks – capped at 2020 levels and reducing to zero by 2030
- Renewable electricity – minimum of 70% renewable content. When used directly in transport, the energy content counts multiple times towards RED II targets (4x for road and 1.5x for rail)
- Renewable liquid and gaseous transport fuels of non-biological origin – derived from renewable resources other than biomass (hydrogen included) – minimum 70% GHG reduction compared to fossil fuels in order to be counted towards RED II targets.
- **'Advanced Biofuels'** – made from a list of waste biomass feedstocks, included in annex. These can be double counted towards meeting RED II targets.

3. Hydrogen production options that could be included under RED II

Gas based routes: Reformation of biomethane feedstock could be included if the gas grid can be used to mass balance biogas as the source for the reformer. This may compete with other renewable energy policies as any biogas used for hydrogen production could also be used directly in CNG vehicles or for renewable heating.

Biomass gasification: Gasification of conventional biomass could count towards RED II targets, while gasification of waste-based biomass could be considered for "advanced" status.

Electrolyser routes: There are several criteria for including hydrogen produced with an electrolyser using renewable electricity under RED II:

- **Additionality** – renewable electricity used to produce hydrogen should be "adding to the renewable deployment or to the financing of renewable energy". This also means ensuring that the renewable generating capacity used "comes into operation after, or at the same time as, the installation producing [the hydrogen]"
- **PPAs with renewable generators** – Ordinary PPAs are insufficient - there must be a "temporal and geographical correlation" between the electricity generated and that used for electrolysis.
- **Congestion** – Hydrogen produced by a grid-connected electrolyser can only count as fully renewable when the "electricity generation and the fuel production plants are located on the same side in respect of the congestion"

Production options that do not meet the RED II criteria

- **Regular fossil reformation plant** – Should be excluded from any support towards meeting RED II targets as this is already a mature technology and does not meet emission thresholds.

3. Potential levels of support depending on implementation of RED II

Hydrogen in Ireland's Biofuels Obligation Scheme

- The certificates in this scheme are not publicly traded, but the obligation raises the pump price of a litre of diesel by €0.03, equating to a traded certificate price of ~€0.33/L biodiesel
- The scheme currently has a buy-out price of €0.45/L that suppliers would have to pay if they failed to meet their obligation (this has, except for in limited exceptional circumstances, never been paid). A future buy-out price to support 'advanced biofuels' would be twice the standard buy-out price (€0.90 per certificate).

Hydrogen in the UK Renewable Transport Fuel Obligation

- Renewable hydrogen receives 4.58 certificates/kg to account for the different energy density of gaseous and liquid fuels. The RTFCs have a traded price of ~20p/certificate and a buy-out price of 30p/certificate.
- The advanced biofuels (called 'development fuels' in the RTFO) have a buy out price of 80p/certificate and are double counted. This means renewably produced hydrogen receives up to £7.33/kg.

Options for hydrogen support in RED II implementation, counting hydrogen as:

Option 1: A single-counted renewable transport fuel	**4.58 * €0.33 =**	**€1.51/kg**
Option 2: A double-counted 'advanced biofuel'	**4.58 * 2 *€0.33 =**	**€3.02/kg**
Option 3: An RTFO-type 'development fuel'	**4.58 * 2 * €0.90 =**	**€8.24/kg**
Option 4: 4x the energy content when from renewable electricity	**4.58 * €0.33 * 4 =**	**€6.05/kg**

3. A Favourable Implementation of the Second Renewable Energy Directive (RED) in Ireland (2022-2030)

Due to the ambiguity around counting hydrogen towards RED II targets, there are opportunities for the directive to be implemented in a way that supports hydrogens use as a transport fuel.

There are 6 key ways that RED II could be implemented to support hydrogen:

1. **Include hydrogen produced from renewables as an 'advanced biofuel'.** Producing hydrogen from renewables is more expensive but allowing these fuels to be double counted towards RED II targets could help to socialise the cost of incentivising zero-carbon production.
2. **Adopt a flexible approach to the criteria for electrolytic hydrogen.** There is a need for clarity around the requirements for 'additionality', temporal and geographical correlation with renewable generators and alleviation of grid congestion in order to count as fully renewable.
3. **'Grandfather' policies to provide certainty for early investors.** Ensure that early investments are guaranteed access to support from RED II policies for a reasonable period.
4. **Consider a volume cap for renewable hydrogen.** Renewable hydrogen has the potential to be produced at huge scales from Irish resources. The risk of hydrogen dominating efforts to meet RED II targets at the expense of other options could be mitigated by reducing the certificate value for renewable hydrogen once certain volumes are achieved.
5. **Provide clarity on the inclusion of biomethane reformation and waste gasification.** These feedstocks could compete with decarbonisation efforts in other sectors such as heating.
6. **Provide clarity on options for counting renewable electricity inputs.** It is unclear whether the multipliers applied to renewable electricity used in road and rail transport could be applied to renewable electricity inputs for hydrogen used in transport.

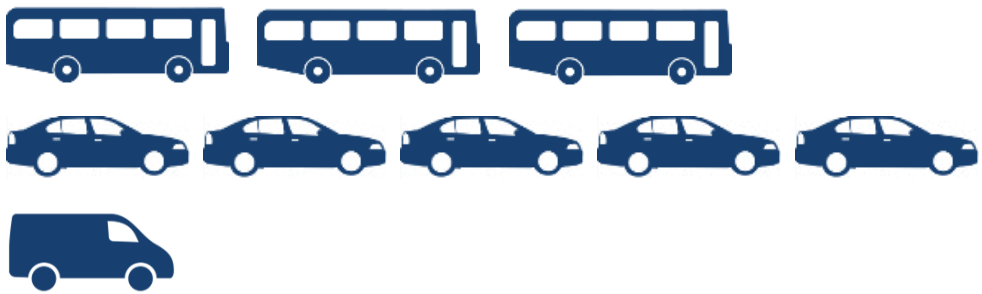
4. Phase 1 will cost €34m and will require €14m of government funding to support the purchase of vehicles and infrastructure

Vehicles: The proposed Phase 1 involves 30 buses, 50 cars and 10 vans, representing a total investment of €17.5m that will require government support of €6m of grant funding

30 Buses

50 Cars

10 Vans



Production and dispensing infrastructure: A €16.5m investment will also be required for the infrastructure to refuel these vehicles which will require €8m grant funding from the government

3 refueling stations

2 production sites

Electrolyser **Electrolyser**

Hydrogen Mobility Ireland

The policies suggested for Phase 2 are purchase grants and beneficial tax rates for FCEV and H_2 production support through the BOS

Phase 2: 2024-2030

- In Phase 2 government would face costs from the continuation of purchase grants, VRT exemptions and differentiated annual motor tax, first introduced in Phase 1
- As Phase 2 progresses the level of support given through these mechanisms would tail off as the cost of hydrogen vehicles comes down (see slide "The Extension of Current Low Emission Vehicle Policies (2022 – 2030)" earlier in this chapter)
- Hydrogen production would be supported with a hydrogen credit price in the region of €4/kg through the Biofuels Obligation Scheme (BOS). This will not result in a direct cost to government
- It is expected that these policies will support the uptake of hydrogen vehicles somewhere in the range between the low and high vehicle uptake scenarios (set out in the table below)

Total Hydrogen Vehicles Supported into the Market by 2030

Scenario	Cars	Vans	Buses	Coaches	RCVs	Trucks	Train Carriages	Ferries
Low	9,750	2,300	260	130	130	640	0	2
High	29,000	6,800	600	280	320	2,000	40	7

Supporting FCEV through purchase grants and differentiated tax rates in Phase 2 will cost government in the range of €87-270m

Phase 2: 2024-2030

The cost of supporting the purchase of hydrogen vehicles in Phase 2 will range from €87m to €270m, depending on vehicle uptake. This covers:

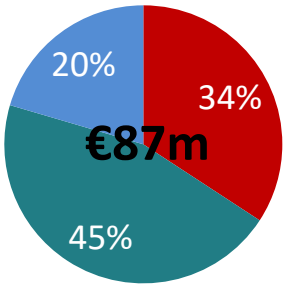
- LDV Support: Extension of current government LEV grants and tax exemptions to FCEV.
- HDV Support: New purchase grants for fuel cell buses, coaches, trucks and RCVs

This is a significant investment for government (although in-line with the projected minimum spend of €230m on BEV support between 2011-2023 according to LEVT's September 2018 Progress Report)

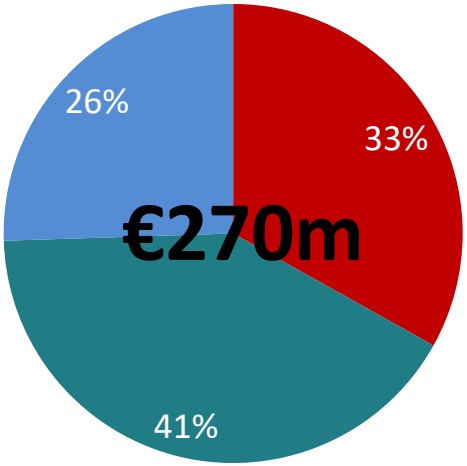
The additional cost of supporting green hydrogen production would be socialised via the BOS

- *Biofuels Obligation Scheme:* Hydrogen fuel price support will be socialised across all transport fuel users through the BOS costing petrol/diesel users less than 0.01€/l by 2030

Low vehicle uptake scenario



High vehicle uptake scenario



Light Duty Vehicles | Trucks and Buses | Trains and Ferries

Hydrogen Mobility Ireland

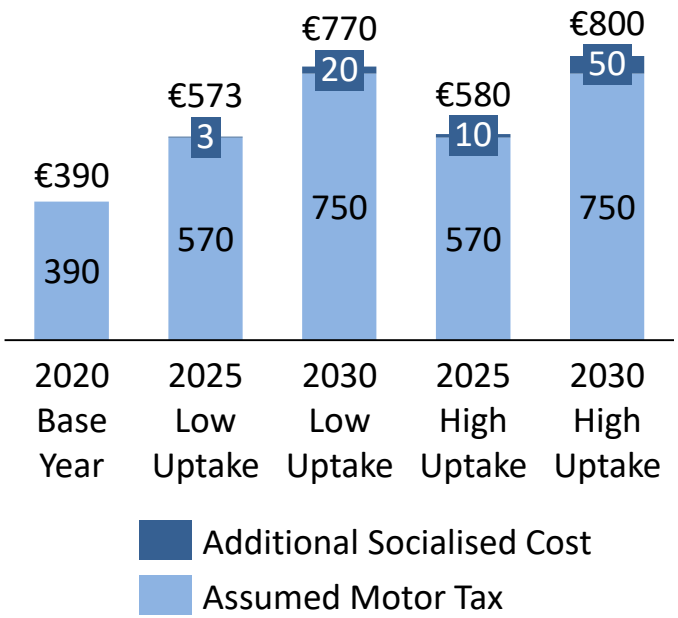
Socializing the costs of all hydrogen vehicle supporting policies across all polluting vehicles results in a very low cost per polluting vehicle

Spreading the cost of hydrogen vehicle grants across the fleet has a low impact on the annual Motor Tax paid by polluting vehicle owners

Socialising the cost of all FCEV incentives

- Cars in Ireland already pay an annual Motor Tax that is differentiated by vehicle emissions.
- Extending emission differentiated annual Motor Tax for all polluting vehicles from 2022 onwards could pay for the grants and tax exemptions offered in Phase 1&2 to FCEVs.
- As the cost is spread across a large number of vehicles, the annual Motor Tax would only need to be increased by €3-10 in 2025 and €20-50 in 2030, depending on FCEV uptake.
- The graph on the right demonstrates what this would look like for cars. The 'Assumed Motor Tax' is for a car that emits 140-155 gCO2/km – in our modelling we assume that for polluting vehicles this tax will increase over time to help maintain government tax income at a constant level as tax-exempt zero-emission vehicles enter the fleet.

Example of how car Motor Tax would need to change to support the cost of FCEV purchase policies



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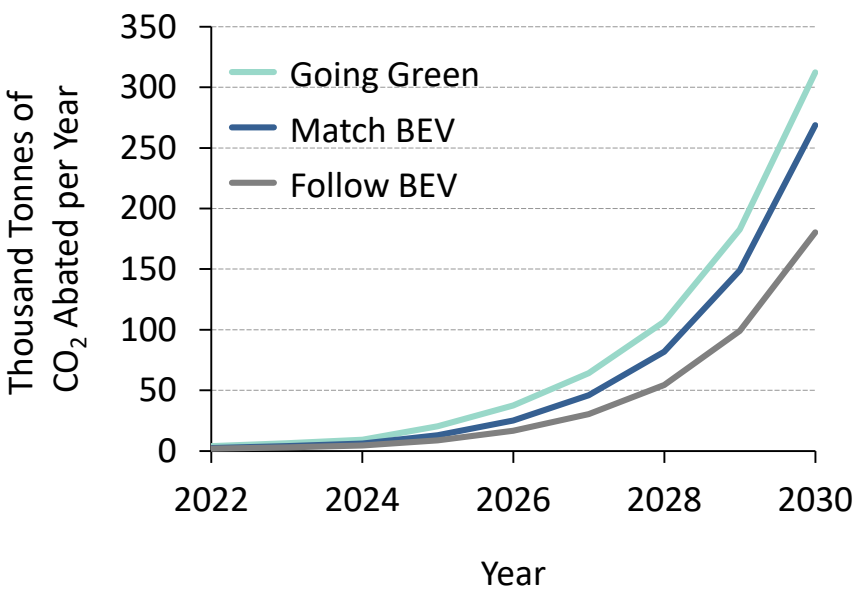
Hydrogen could abate 300 thousand tonnes CO_2 (~2% of transport emissions) in 2030 with the potential to significantly reduce emissions further in the 2030s

The cost to government of policy support to achieve these emissions reductions would be around €75/tonne CO_2 in 2030.

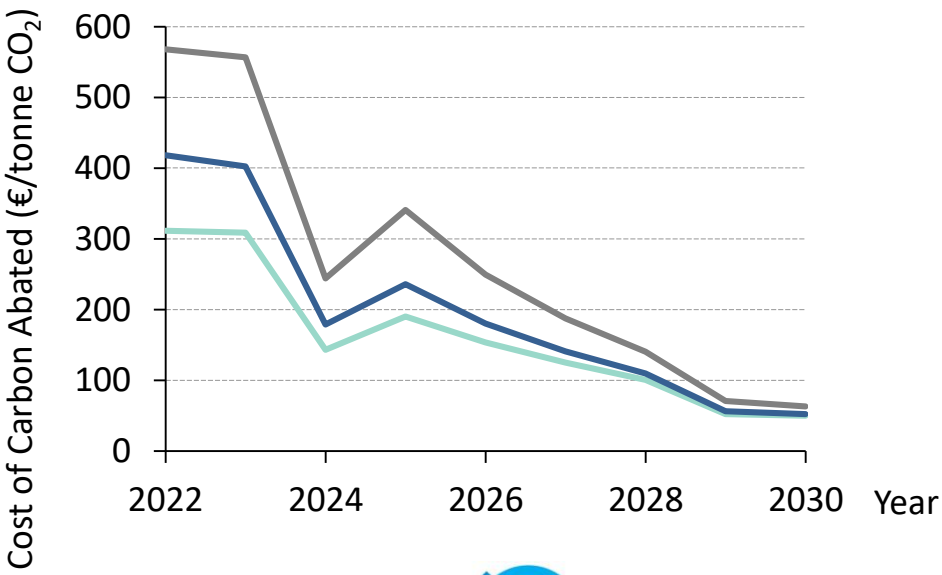
Total Annual CO_2 Abated

The CO_2 abated from the introduction of hydrogen will take time to ramp up as building up a significant number of hydrogen vehicles in the fleet takes several years of high hydrogen sales



Cost of CO_2 Abatement

The average cost of abating carbon through the introduction of FCEV from 2022-2030 ranges from 75 to 100 €/tonne CO_2 depending on the H_2 production mix scenario (average cost is skewed towards the 2030 cost as most vehicles are introduced in the late 2020s)



Note: This is far less than the government of the Republic of Ireland has spent on BEV support per tonne of CO_2abated (€250-350). https://assets.gov.ie/25107/eb5a541e3b614c94a3e47c8d068e72c9.pdf

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Introduction to the wider benefits of hydrogen in Ireland

This section will:

A. **Provide a qualitative review of the wider energy system impacts** from a move to hydrogen mobility, specifically the impacts on:
   - The Irish electricity system
   - The Irish gas network

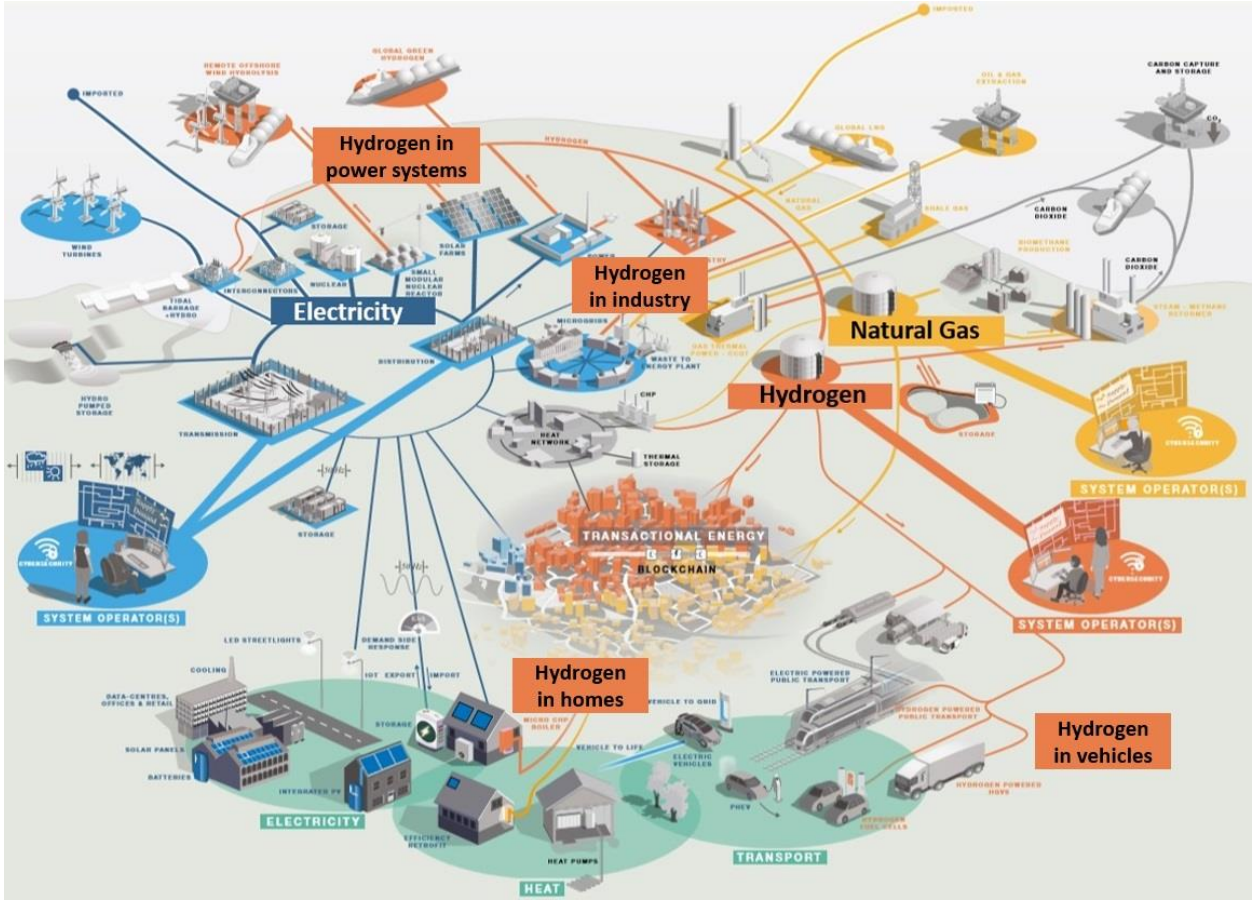
B. **Provide an analysis of the economic benefits of hydrogen as an indigenously produced fuel, focusing on three key economic impacts (estimated to be worth €240m by 2030):**
   - **Avoided imports of diesel -** Economic impact from the onshore production of hydrogen vs import of petroleum products

C. **Estimate the total air quality impacts (estimated to be worth €32m by 2030):**
   - Total pollution (PM, NOx, noise etc.) reductions achieved by the planned rollout of fuel cell electric vehicles relative to diesel/petrol incumbents.

D. **Estimate the total GHG emission impacts (estimated to be worth €52m in the Going Green scenario by 2030):**
   - The total CO2 involved in the production of hydrogen and the resultant reduction relative to diesel/petrol vehicles.
   - Use standard European cost-benefit analysis metrics to monetise GHG emission reduction impacts.

Hydrogen is an important decarbonisation technology option as it can play a role in many sectors and across the energy system

Hydrogen for transport can help to build demand to justify deployment of large scale production and bring down costs. It can then be a cost-effective decarbonisation option in other sectors that would be difficult to decarbonise with electricity alone. The wider role of hydrogen is currently being explored by the Hydrogen Ireland Association



- H_2 can be blended with natural gas on the grid and could eventually replace it.
- Potential to replace natural gas for heating in industrial processes and in people's homes.
- Can act as an energy store to manage higher penetration of renewables on grid
- Hydrogen for transport can help build-up experience and capacity in the industry, opening wider decarbonisation options

Source: Arup, Establishing a Hydrogen Economy Report, 2019. Available from: https://www.arup.com/perspectives/publications/research/section/establishing-a-hydrogen-economy-the-future-of-energy-2035

Hydrogen Mobility Ireland

Hydrogen is an important low carbon energy carrier that can support the electricity & gas network through the decarbonisation transition

Hydrogen Impacts on the Electricity Network

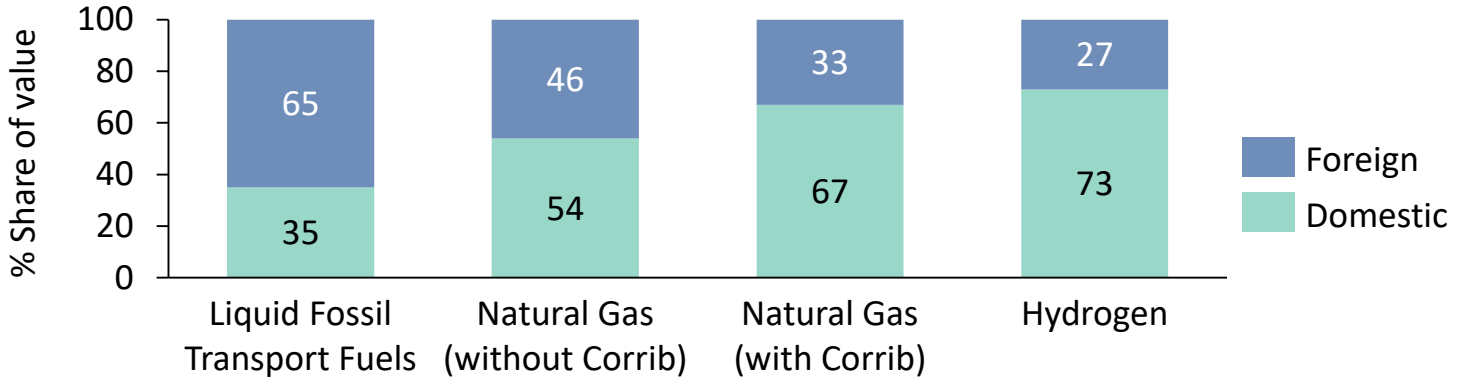
- Increased renewable capacity required to achieve Irish policy objectives
- Seasonal storage option for variable electricity generation
- Facilitating effective large scale renewable integration

Hydrogen Impacts on the Gas Network

- Enabling sectoral integration
- Decarbonisation of the gas grid
- Enabling the continued use of the gas grid infrastructure
- Investment in gas infrastructure stays relevant
- Substantial costs savings delivered to consumers

Hydrogen produced from domestic renewables has a far greater proportion of domestic value than imported fossil fuels

Hydrogen offers significant opportunities for capturing the value in transport fuels that currently leaves the Irish economy. Using Irish renewable resources to produce hydrogen could more than double the proportion of transport fuel value retained domestically



Assumptions

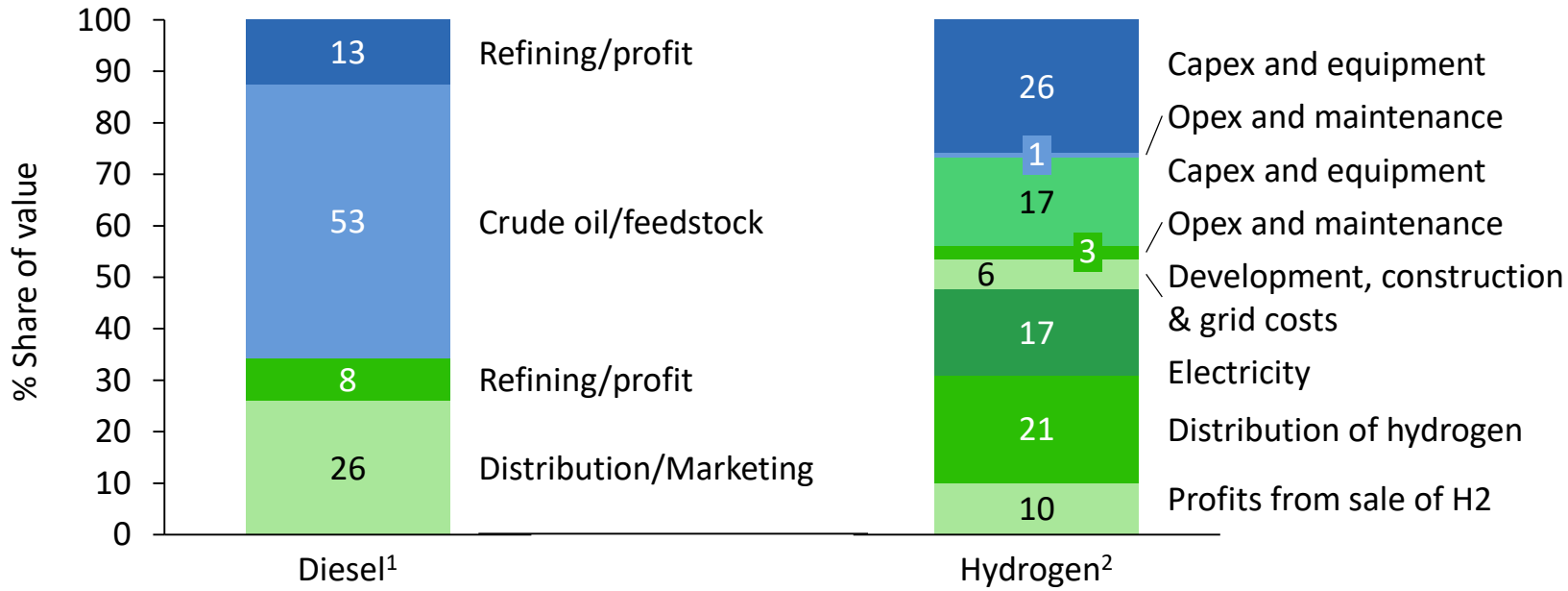
- Taxes and levies excluded.
- **Liquid fuels:** Fuel price breakdown is taken from the AA & RAC[1&2]. 100% of crude oil is imported. 40% of the value from refining is generated in Ireland[3]. All of the value generated in fossil fuel distribution remains in Ireland.
- **Natural gas:** 53% of Ireland's gas supply comes from the Corrib field – the rest is imported[4]. 50% of the value of Corrib gas is captured by government through taxes, or by Irish companies.
- **Hydrogen:** The cost breakdown for the CAPEX and OPEX of hydrogen production is set out in the appendix
  - Foreign companies produce the equipment, with 40% Irish content. 75% of O&M value remains in Ireland.
  - 100% of value generated through construction of infrastructure and the production and distribution of hydrogen remain in Ireland, as do profits from the sale of hydrogen – assuming €7.50/kg sale price.

1: AA, 2019, https://www.theaa.ie/aa/motoring-advice/petrol-prices.aspx
2: RAC, 2019, https://www.racfoundation.org/data/uk-daily-fuel-table-with-breakdown
3: Irving Oil, 2019, https://www.irvingoil.com/en-CA/discover-irving/operations
4: GNI, 2019, https://www.gasnetworks.ie/corporate/gas-regulation/system-operator/publications/Winter-Outlook-2018.pdf

The transport sector consumes €3.1bn/year (pre-tax) of fossil fuels in Ireland - €1bn of this value is retained in Ireland. Transitioning to hydrogen would increase the domestic value to €2.3bn annually

Assuming that the fuel for a future all-hydrogen transport fleet would be valued the same as fossil fuels are today, under the 'going green' production scenario, €2.3bn of the €3.1bn total fuel value would be retained in Ireland. €240m of this value would be realised by 2030 under the high vehicle uptake scenario

Breakdown of the value components in diesel and hydrogen produced from Irish wind



Foreign value components in fuel

Irish value components in fuel

1: RAC, 2019, https://www.racfoundation.org/data/uk-daily-fuel-table-with-breakdown

2: Hydrogen price breakdown is based on the hydrogen infrastructure CAPEX and OPEX presented in the appendix

Having hydrogen as a technology option by 2030 can help Ireland meet its carbon targets in the most cost effective manner

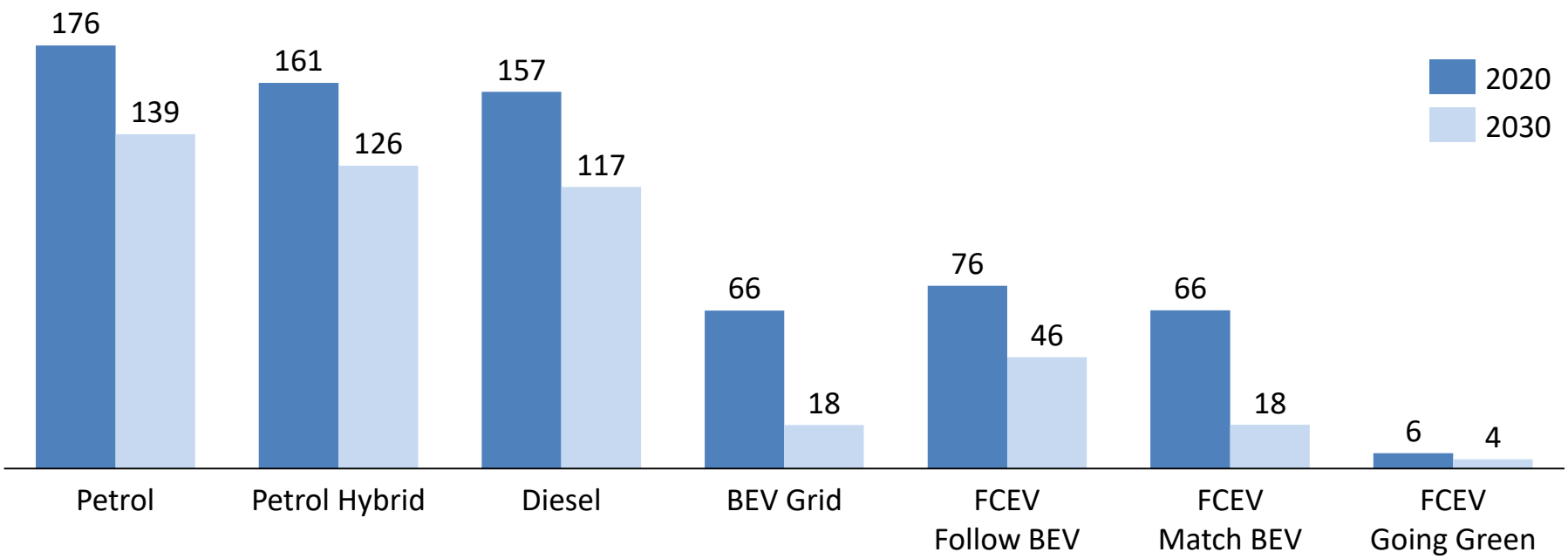
Hydrogen can help to cost-effectively decarbonise the wider economy

- **Facilitates the full-decarbonisation of the gas network in Ireland:** The development of a large-scale hydrogen production industry could allow hydrogen to replace natural gas on the grid in the long term. In the short term GNI has a target for 20% biomethane on the grid by 2030 and hydrogen could start to be blended on the grid at lower fractions (this will require a regulation change as hydrogen is currently limited in the grid to 0.1%)
- **Decarbonisation of industrial and domestic heat:** Appliances would need to be replaced to run on pure hydrogen, but this can help in systems that would otherwise be difficult or expensive to decarbonise, e.g. electrifying domestic heating in older buildings and heat intensive industrial processes.
- **Further decarbonisation of power sector:** Hydrogen can help to facilitate the increasing contribution of renewable energy sources to Ireland's electricity production. Hydrogen can act as a long-term energy store to help manage intermittency, but can also reduce the need for grid reinforcements necessitated by widespread electrification of transport and heat.
- **Decarbonisation of heavy duty vehicles:** Heavy duty vehicles such as large trucks, trains and ferries can be very difficult to decarbonise due their large size and often challenging operational profile. Hydrogen offers one of the only technology options for deep decarbonisation of these vehicle segments

Hydrogen can offer very low well to wheel GHG emissions. Here we present the emissions for cars but the pattern for other vehicle types is similar

- FCEV cars offer significant CO_2 emission reductions compared to conventional vehicles, regardless of production scenario
- By 2030, even with a heavily decarbonised electricity grid, CO_2 emissions from the 'going green' hydrogen production scenario are far lower than those for battery electric vehicles

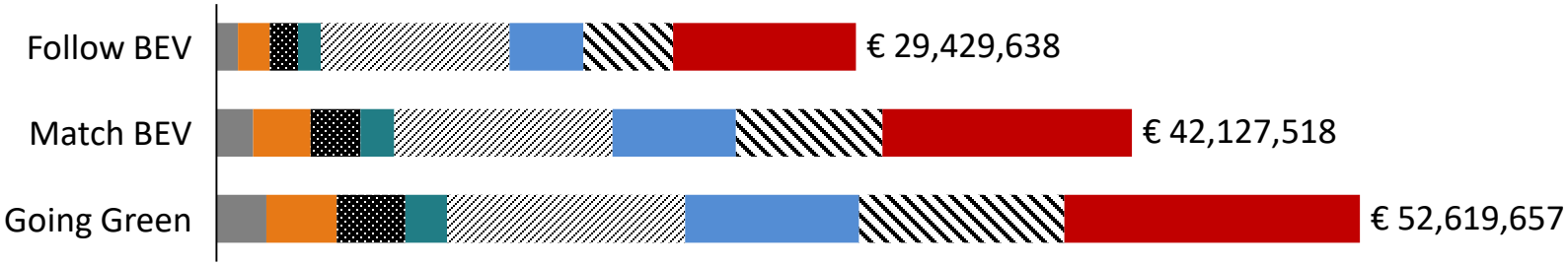
Fuel Production and Combustion Emissions for a D Segment Car (gCO2e/km)



Total savings from avoided CO_2 emissions in the high vehicle uptake scenario

The amount saved from avoided CO_2 emissions depends on the production scenario, but a high FCEV uptake in Ireland is expected to lead to €29-€53m in savings compared to the carbon costs associated with conventional vehicles

Total cost savings from avoided CO_2 emissions in the high uptake scenario 2022-2030 by vehicle type and H_2 production scenario

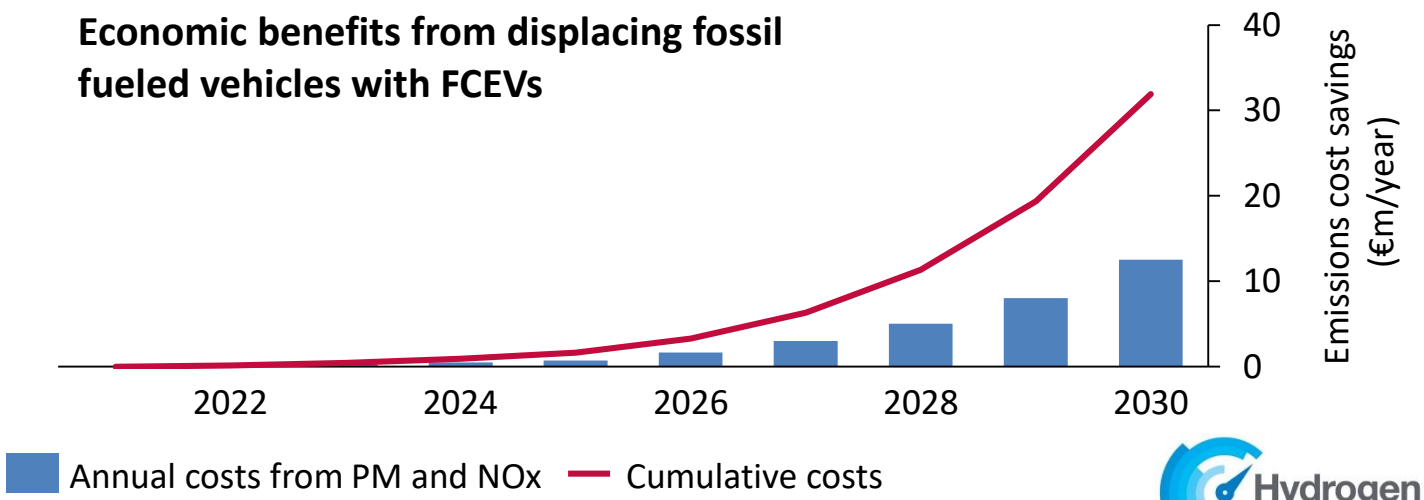


- This chart brings together all the CO_2 emissions savings of FCEVs compared to diesel alternatives until 2030, multiplied by the carbon prices shown in the previous slide.
- Cars receive the majority of the incentives discussed in this report, but produce just 25-30% of the benefits.
- Heavier duty vehicles such as trucks, vans and buses require relatively little incentive and provide around half the CO_2 emission reduction benefits.
- Trains only begin to feature in the uptake scenario in the final year, and rapidly make a significant impact on CO_2 reductions compared to diesel equivalents.

Ferries | RCVs | Vans (Large) | DD Buses
Trains | Coaches | Trucks (25t) | Cars

PM and NOx emissions cost reductions

By 2030, the high uptake scenario would lead to a total €32m of avoided PM and NOx emission costs by displacing the emissions from an equivalent number of diesel and petrol vehicles.

Assumptions:

- Costs are based on the Environmental Protection Agency's 2017 Integrated Modelling Project. As the pollution emissions savings are likely to mostly be in urban areas during the early rollout the cost figures for Dublin have been used for all emissions:
  - NOx: €9,350/tonne
  - PM: €67,650/tonne
- Private and business cars are 32% petrol and 68% diesel, all other vehicles considered are diesel only (based on Irish Bulletin of Vehicle and Driver Statistics 2017).
- Emissions calculated assuming Euro VI emissions (in gCO2/km) and based on mileage assumptions from project modelling.
- Based on the high vehicle uptake scenario, excluding ferries and trains.