Hydrogen Mobility Europe

Emerging Conclusions

1/5 Introduction










element energy

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FCH | FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

This document provides an interim summary of H2ME results

- The H2ME initiative is a **flagship European project**, deploying hundreds of fuel cell hydrogen cars, vans and trucks and the associated refuelling infrastructure, across 8 countries in Europe.
- It will **create the first truly pan-European network, and the world's largest network of hydrogen refuelling stations.**
- The project is made up of two phases, H2ME (1), which started in 2015, and H2ME-2, which will end in 2022. Over the course of these two phases, **more than 1400 vehicles and 45+ hydrogen refuelling stations** will be deployed.
- The project is being supported by the European Union through the Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU) but is driven by the **continuous engagement of the industry.**
- This documents provides a **summary of the project status, highlights key achievements and also suggests some of the emerging issues** which need to be tackled by the fuel cell vehicle sector as it moves towards a commercially viable mass market proposition.
- This is a living document that will be updated as the project progresses. It is intended to:
  - Give first hand information to stakeholders, policy-makers etc.;
  - Align H2ME partners on the common themes emerging from the early demonstration results;
  - Serve as a basis for additional dissemination materials.

Detailed contents overview 1/2

Hydrogen Mobility Europe

1. Introduction

- **Why is hydrogen mobility important?**
  - Perspectives for society and policy makers
  - Perspectives for early adopters (private customers, fleet manager and local authorities)
  - Perspectives for energy providers
  - Perspectives for car OEMs
- **Societal challenge for transport sector**
  - Transport is the only sector with rising CO2 emissions
  - How does hydrogen fit into today's green mobility efforts
- **How it works ?**
  - What is a Fuel Cell Electric Vehicle (FCEV)?
  - What is a Hydrogen Refuelling Station (HRS)?
- **Commercialisation**
  - Status
  - Technical advancements
  - Remaining barriers

2. **Project Overview**

- **Hydrogen Mobility Europe**
  - Project partners
  - Overview H2ME (1) & H2ME 2
  - Overarching objectives
- **Deployment overview & targets**
  - Vehicles deployment overview
  - Refuelling infrastructure deployment strategy
  - Deployment timeline
- **National strategies – H2ME & broader context**
  - Germany
  - UK
  - France
  - Scandinavia
  - Netherlands

3. Demonstration activities

- **Deployment to date**
  - Total HRS deployed
  - Total vehicles deployed
  - Countries of deployment
- **HRS in the project**
  - Technical Specifications
  - Project snapshot
  - Performance case study
- **Vehicles in the project**
  - Technical Specifications
  - Project snapshot
  - Performance case study

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Detailed contents overview 2/2

4. **Update on deployment strategies and case studies**

- **Overview strategies**
  - Ownership models and characteristics for refuelling stations
  - Characteristics of vehicle deployments
- **National, regional and local case studies**
  - Country level infrastructure network – H2Mobility Deutschland (Germany)
  - Regional planning - Zero Emission Valley in the Auvergne Rhône Alpes region (France)
  - City scale approaches

5. Project achievements and Emerging conclusions

- **Project Achievements**
  - Update on sector and European effort
  - Advancements on the state-of-the-art
- **Emerging conclusions HRS**
  - Technical advancements (HRS)
  - Commercial strategies for HRS
- **Emerging conclusions vehicles**
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  - Commercial strategies for vehicles
- **Recommendations for policy makers**
  - Recommendations for hydrogen mobility initiatives
  - Recommendations for maturing the supply chain
  - Recommendations for policy and funding
- **Summary conclusions**

Public Resources

- This document provides an overarching summary of the activities undertaken in the project. However, more detailed reports are available on the H2ME website (https://h2me.eu/reports/).
- Key reports available are :
  - Hydrogen Refuelling Stations Safety, Regulations, Codes and Standards. Lessons Learned: Interim Report 3, H2ME2 Deliverable 5.20, Cenex
  - Well to Wheels environmental impact assessment, H2ME (1) Deliverable 4.19, Cenex
  - Hydrogen fuel retailing Interim Report, H2ME (1) Deliverable 2.4, H2ME 2 Deliverable 6.7, Element Energy
  - Yearly Vehicle and Infrastructure Performance Report 3 (2015-2019), H2ME (1) Deliverable 4.12, H2ME 2 Deliverable 5.3, Cenex
- The website will be updated with the most recent project reports as, and when, finalized and accepted by the consortium.

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Hydrogen Mobility Europe

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How it works ?	What is a Fuel Cell Electric Vehicle (FCEV)? What is a Hydrogen Refuelling Station (HRS)?
Commercialisation	Status Technical advancements Remaining barriers

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Why is hydrogen mobility important?

Hydrogen Mobility Europe

- **Environmental Improvements** – using hydrogen as a fuel in the transport sector will ***reduce emissions and improve local air quality***, thus addressing both climate change and a major public health issue whilst at the same time meeting EU legal requirements.

- **Energy Security** - ***as hydrogen is widely available*** and can be produced from a variety of local renewable and other energy resources, it offers ***independence from energy imports.***

- **Economic Development** - The expansion of this new sector provides the opportunity to ***create new local businesses and jobs, promote wider economic growth, and maintain Europe's technology leadership.***

- **Grid Balancing-** generating hydrogen from electrolysis can ***enhance energy efficiency*** as well as help ***incorporate renewable energy into the energy mix*** by providing grid balancing services- the process of using excess electricity when energy supply temporarily exceeds demand.

- **Energy storage** – generating hydrogen from electricity helps further ***incorporate renewable energy into the energy mix*** by providing a higher storage capacity option compared to batteries.

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Why is hydrogen mobility important?
… perspectives for society and policy makers

Hydrogen Mobility Europe

M1 Wind Hydrogen Station, UK
@ITM power

Local Air Quality improvements

- **A solution today for cities and regions**
  - Vehicle operation producing ***zero tailpipe emissions.***
  - … while offering fast refueling and long driving range.

A 'swiss army knife' for meeting energy and climate change policies

- **A solution making the energy transition feasible**
  - The technology is ***needed to meet targets for CO_2 reduction and accommodate increases in Renewable Energy (RE) production.***
  - FCEVs have **significantly lower *GHG emissions*** compared to conventional vehicles, and can be ***zero-emission*** when hydrogen is generated from renewable energy.
  - ***Electrolysis can be used as a grid balancing tool, mitigating increased costs and electricity demand*** for network operators ***from increases in RE production and BEV sales.***

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Why is hydrogen mobility important?
… perspectives for early adopters

Hydrogen Mobility Europe

Daimler GLC F-Cell, Hamburg Police Service , Germany @Daimler

Toyota Mirai, Hype, France @Toyota

Renault Kangoo Z.E Hydrogen (by Symbio), France @Symbio

Zero emissions, zero compromise

- **A solution today for fleets and private customers**
  - Among zero emission (ZE) powertrains, ***FCEVs provide the longest range and shortest refuelling times.***
  - FCEVs provide a ZE emission powertrain option that ***does not limit productivity or operation.***

Supporting operation today and in the future

- **A solution to contribute to climate change mitigation efforts today while preparing for future regulations.**
  - FCEVs produce ***zero tailpipe emissions*** and ***can be zero-emission*** when hydrogen is generated from renewables.
  - They can support drivers and organisations in demonstrating their ***commitment to addressing air quality and reducing CO_2 emissions.***
  - *Use of FCEVs today* ***prepares for future air quality/GHG policies introduced by national or city governments****, while demonstrating leadership in sustainable transport*

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Why is hydrogen mobility important?
… perspectives for energy providers

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Preparing for the future

- **Hydrogen can be easily stored when produced by water electrolysis, providing two key benefits to the grid:**
  - the flexibility to adapt to larger demand and peak demand on energy networks.
  - the flexibility to balance demand and supply as there is increasing penetration of renewable generation.
- The technology is ***needed to meet targets for CO_2 reduction and the expected increases in Renewable Energy (RE) production.***
- ***Electrolysis can be used as a grid balancing tool, mitigating increased costs and electricity demand*** for network operators ***from increases in RE production and BEV sales***

A potential new source of revenue

- Due to the speed at which water electrolysers can vary their output (and hence electricity demand), it is possible that the ***provision of grid balancing services such as frequency responses or balancing services can be monetised.***

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Societal challenge : Transport is the only sector with rising CO2 emissions

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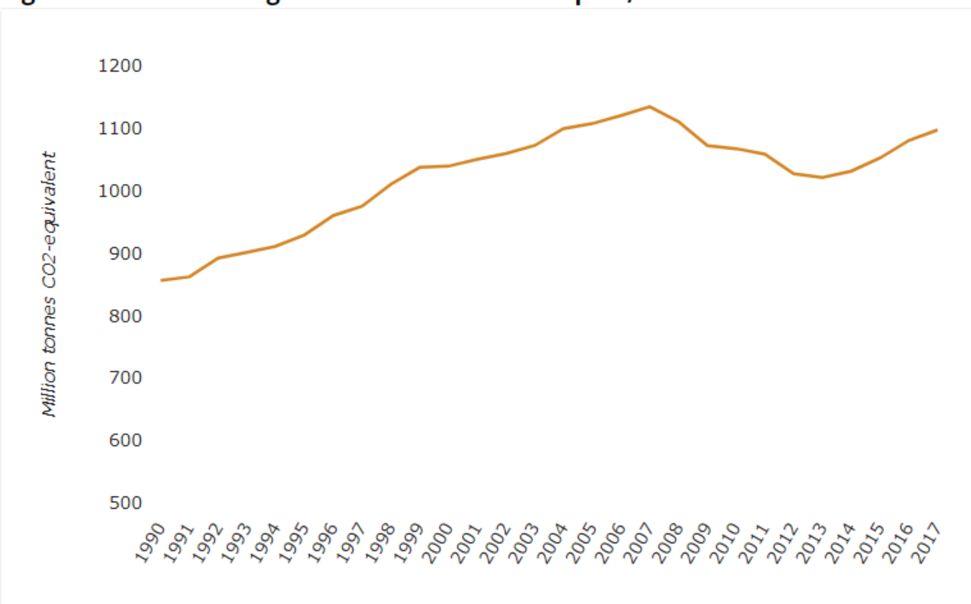
- **Transport emissions : 27% of all emissions in the EU;** a rising figure: + 26% compared with 1990
- **Road transport accounts for 72 %** of total greenhouse gas emissions of the sector (EEA, 2018b)
- **Air pollution responsible for over 400,000 premature deaths annually in Europe (EEA, 2019)**

Figure 1. Greenhouse gas emissions from transport, EU



- **Policy ambitions**: Transport White Paper 2011: 30% CO2 emissions reduction by 2030 and 60% CO2 by 2050 (compared with 1990 levels)
- **Air Quality Directive**: sets max. air pollution limit in each Member State
  → infringements procedures launched by the EC against Member States.
- **The Directive on Alternative Fuels Infrastructure (2014/94/EU)** sets mandatory targets for alternative fuels infrastructure deployment.

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Source: H2Haul project / JIVE project

Societal challenge : How does hydrogen fit into today's green mobility efforts ?

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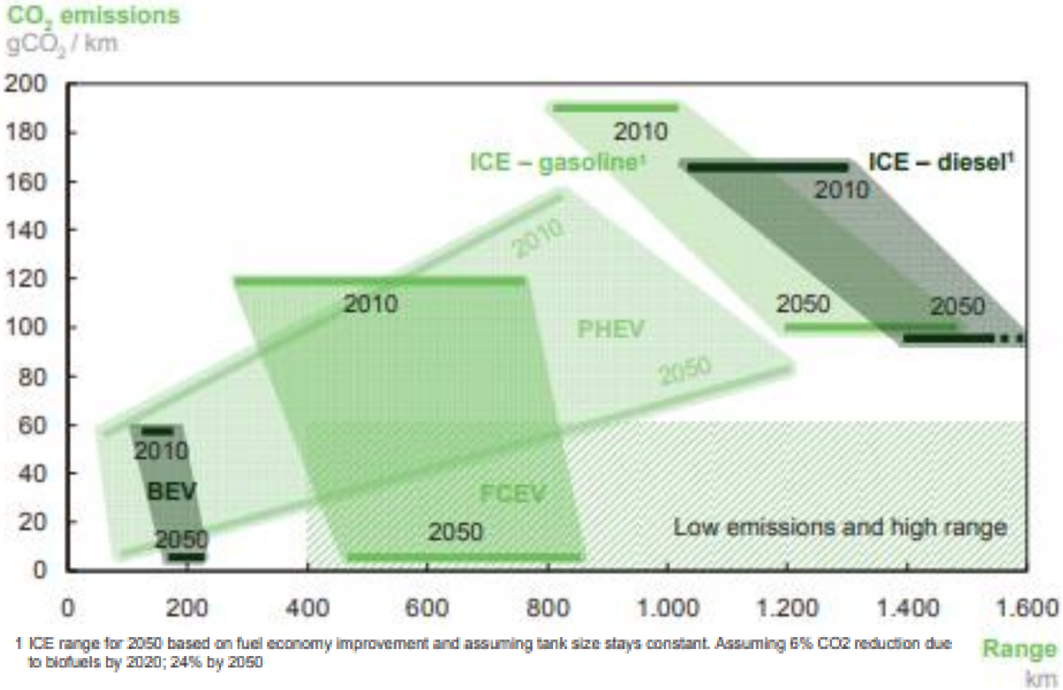
Fuel Cell Electric Vehicles (FCEVs) are complementary to existing green mobility solutions.

FCEVS are better suited to longer trips and heavy duty applications



Graph illustrating the current and expected CO2 emissions for different powertrains in the C/D segment. *It is notable that BEVs and FCEVs can achieve significantly low CO_2 emissions, but BEVs are limited by range*

Battery Electric Vehicles (BEV) and hybrid Electric vehicles (PHEV) have become the leading green mobility solutions in recent years in terms of market progression and technological advancements. However, there remain some challenges e.g. long range, continuous use, and heavy duty applications that today they cannot fully address. **FCEVs offer a viable solution to meet these challenges.**

Though historically a single powertrain (ICE) has dominated, **multiple complementary powertrain solutions are now needed**. The complementary nature of these technologies is furthered by the fact that progress in BEV, PHEV, and FCEV development benefit each other due to their many shared components and development options.

Source graphs: *FCH JU, A portfolio of power-trains for Europe: a fact-based analysis.*
https://www.fch.europa.eu/sites/default/files/Power_trains_for_Europe_0.pdf

What is a Fuel Cell Electric Vehicle (FCEV)?

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- **FCEVs run on hydrogen gas as a fuel**. ***A highly efficient fuel cell transforms the hydrogen directly into electricity to power the electric motor(s).***
- FCEVs produce **zero harmful tailpipe emissions**, with ***water vapour*** being their ***only exhaust.***
- FCEVs offer a **long distance driving range** ***comparable to conventional petrol and diesel cars*** and vans, whilst providing a smoother, quieter and more responsive driving experience.
- **Refuelling time is comparable to conventional petrol and diesel cars** ***(3 to 5 minutes).***

FCVs are as safe, if not safer, than traditional gasoline vehicles
The carbon-fibre hydrogen tanks of the vehicles have withstood highly demanding crash, fire, and ballistic testing, and thanks to these high safety standards, FCEVs can meet the strict safety and quality regulations of the countries where they are being deployed (Europe, Japan, Korea and the USA).

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How it works ?

A fuel cell powertrain generally comprises the following components: ***fuel cell stack, hydrogen tanks, battery and power electronics, and electric motor.*** Various configurations of the fuel cell stack and battery are possible.

In Hydrogen Mobility Europe, two configurations are used. The full fuel cell vehicles (FCEVs) make use of ***a fuel cell dominant system*** (where all energy comes from the hydrogen fuel cell and the battery helps regulate the output and absorb energy from regenerative braking) and ***a fuel cell range extender mode (RE-FCEVs)*** use energy from the hydrogen fuel cell as well as from a battery which can also be plugged in and charged from the grid.

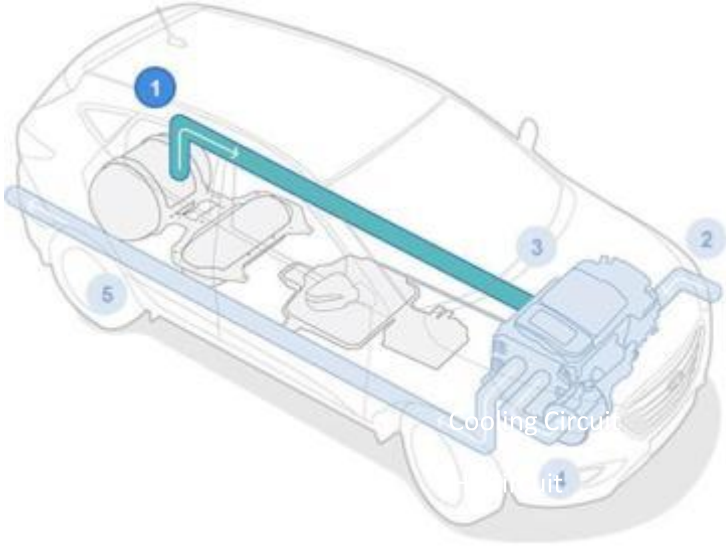
Step 1 Hydrogen stored in the tank is supplied to the fuel cell stack

Step 2 An inflow of air is supplied to the fuel cell stack

Step 3 The reaction of oxygen in the air and hydrogen in the fuel cell stack generates electricity and water

Step 4 Generated electricity is supplied to the electric motor

Step 5 Water is emitted



What is a Hydrogen Refuelling Station (HRS)?

Hydrogen Mobility Europe

- Aside from the actual vehicle ***the creation of a fuelling station network is essential*** to the market development of these new vehicles.
- ***At the moment there is a limited number of HRS*** in each of the partner countries, though networks are growing.
- Hydrogen (H_2) can be produced off site or on site and provide grid balancing services.

Off site production

In **off-site production** hydrogen is delivered to stations by tanker or pipeline, in the same way that fuel is delivered to petrol stations. It has the advantage of **allowing large scale production at low costs**. Currently the majority of hydrogen comes from natural gas but in the medium term low carbon sources for production are planned.

On site production

On-site production generates hydrogen by electrolysis, in the best case with the aid of renewable electricity. These stations have the potential to offer **clean fuel from renewable energy** as well as eliminating the need for fuel deliveries.

+

Grid balancing & servicing

Grid balancing helps match energy supply to demand. At certain low energy usage times energy supply can temporarily exceed demand, often resulting in this energy getting wasted. This **'excess' energy can be used** in the electrolysis of water to make hydrogen.

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Commercialisation
Status

HRS: Hydrogen Refuelling Station
FCEV: Fuel Cell Electric Vehicle
RE-EV : Range-Extended Electric Vehicle
OEM : Original Equipment Manufacturers

- A large international effort over the past few decades by industry and governments has developed hydrogen vehicle technology to the point where they are ready for a first commercial roll-out.
- FCEVs and HRS are currently in the ***early stages of market ramp-up***. A mature (i.e. self-sustaining) market is expected to be reached in the 2020s with expected sales of tens of thousands of vehicles/year and a growing HRS network across Europe.
- ***Vehicles are available today in Europe from some car OEMs*** (Hyundai, Symbio/Renault, Toyota), while others have started small trials (Honda and Daimler) and a number of other OEMs are also planning to launch FCEV models in the coming years (Audi, BMW).

Fuel cell dominant models

Tucson Fuel Cell
Hyundai

Nexo Fuel Cell
Hyundai

Mirai FCV
Toyota

Clarity Fuel Cell
Honda

Fuel cell GLC
Daimler

Range extender model

Renault Kangoo Z.E Hydrogen
Symbio

Commercialisation
Remaining barriers

HRS: Hydrogen Refuelling Station
FCEV: Fuel Cell Electric Vehicle
RE-EV : Range-Extended Electric Vehicle

Hydrogen Mobility Europe

Remaining barriers to be overcome include:

- The number of FCEVs on Europe's roads is limited. As a result, the early HRS have a ***low utilisation*** which limits revenues for early investors. This in turn means that ***limited infrastructure*** remains a key barrier to uptake of FCEVs. More research and ***development is needed to mature the HRS supply chain.***

- Despite production costs for FCEVs falling significantly in recent years, ***FCEVs are still more expensive*** than conventional cars. In the future, FCEVs are expected to offer a cost-competitive alternative to long range electric vehicles for zero emission driving.
- Today, FCEVs are starting to provide competitive Total Cost of Ownership only for specific fleets which value the advantages of hydrogen fuel, such as taxis in polluted urban centres and urban delivery vehicles.

- Achieving the mass market will require fuel cell vehicles manufacturers to ***reduce prices through economies of scale*** (10,000s of vehicles per year).
- This large market for vehicles will then justify commercial deployment of hydrogen stations to expand the network.
- The ***H2ME*** initiative is designed to support this early phase of roll-out for Europe.

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Technical advancements (HRS)
… and remaining barriers to be overcome

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Improvements achieved to date

- ***Common standards*** have been agreed.
- ***Safety*** standards are in place.
- ***Hydrogen can be produced cost-effectively*** at both small and large scale from centralised or decentralised production.

Though HRS are already capable of serving the needs of customers today, further development in the following areas is required:

Further technical advancements required

- Improvements in ***supply chain maturity (e.g. spare parts availability, number of suppliers)***.
- Further improvements in ***availability and other areas relating to hydrogen fuel retailing*** e.g. fuel quality assurance and accurate fuel metering
- ***Demonstration of ability to provide electrolyser grid balancing services.***

Needed commercial advancements

- ***Reduction in hydrogen production costs and cost of water electrolysers***.
- **Refinement of customer experience** e.g. billing and payment methods, user friendliness of stations etc.
- ***Demonstration of ability to monetise electrolyser grid balancing services.***

The H2ME initiative is designed to demonstrate the technical early phase of roll-out for Europe and address the remaining commercial barriers - to date significant improvements have already been made in several of these areas.

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Sources: *FCH JU Review Days 2017 | FCH JU, A portfolio of power-trains for Europe: a fact-based analysis.* https://www.fch.europa.eu/sites/default/files/Power_trains_for_Europe_0.pdf

Technical advancements (vehicles)

… and remaining barriers to be overcome

Hydrogen Mobility Europe

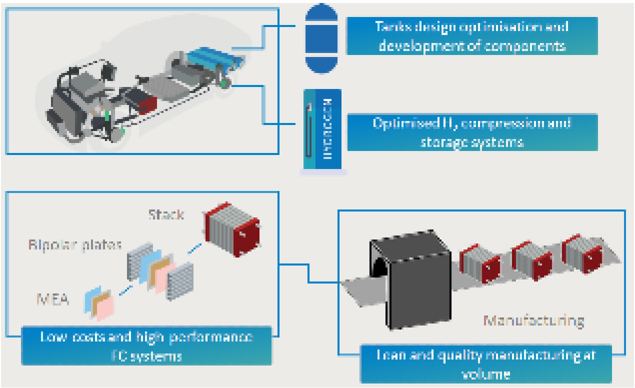
Improvements achieved to date

- Increase of H_2 storage capacity (700 bar) – resulting in ***increased driving ranges***.
- ***Safety*** concerns have been addressed.
- ***Cold start*** down to -25ºC and optimised ***heat management strategy***.
- ***Durability*** improvements.

Though FCEV are already capable of serving the needs of customers today, further development in the following areas is required:

Further technical advancements required

- ***Improvements in design*** (e.g. component count, reduced stack size)
- ***Reduction in raw material*** usage in vehicle production (e.g. platinum).



Needed commercial advancements

- ***Economies of scale***
- Improvement in ***production technology***
- Increase in # of ***FCEV models*** offered by OEMs

→ ***reduction in vehicle costs.***

The H2ME initiative is designed to demonstrate the technical early phase of roll-out for Europe and address the remaining commercial barriers - to date significant improvements have already been made in several of these areas.

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