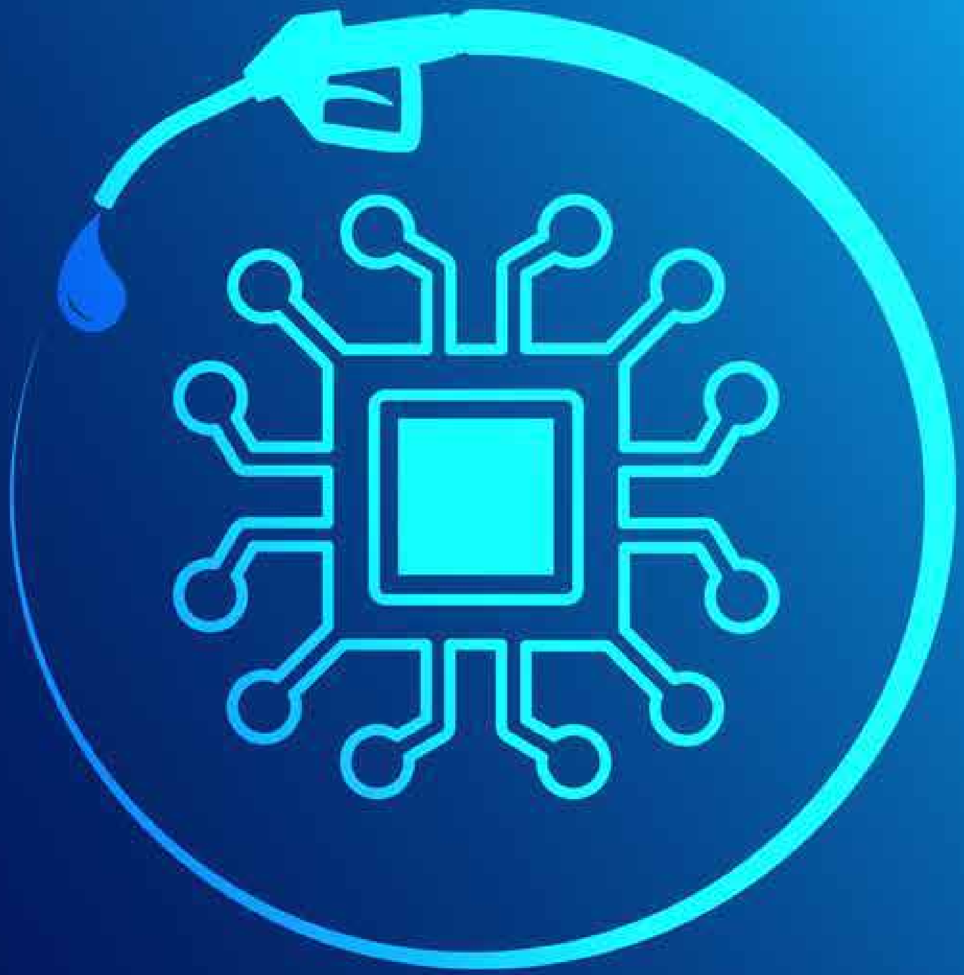
Piloting, MVA & FCT

Hydrogen refueling infrastructure within India is very nascent with only few live examples of the technology. Furthermore, these examples are mainly within PPP mode or private mode and not readily available for public use. In this chapter we shall be discussing market for H2 transport technologies coupled with global case study for user choices.



Market for hydrogen transport technology

Fuel supply and refueling infrastructure

There are four developed approaches to hydrogen refueling. Industry consultation during the "VoC" suggests that either decentralized electrolysis (the process of using electricity to split water to produce hydrogen), or hydrogen gas offtake from centralized facility (producing hydrogen for other applications by one of a variety of methods, as discussed in previous sections of the report.

Hydrogen refueling infrastructure within India is very nascent with only few live examples of the technology. Furthermore, these examples are mainly within PPP mode or private mode and not readily available for public use.

In most instances, the assessment of potential hydrogen trials and pilots has included the costs required to procure and implement hydrogen refueling technology. The assessment, however, leaves the technology used as deliberately generic – it does not specify whether the refueling is centralized, decentralized or the delivery method of the hydrogen fuel, where applicable. Our research suggests that the refueling technology choice is mostly agnostic to the use case and more dependent on the geographical and supply chain constraints of each specific project.

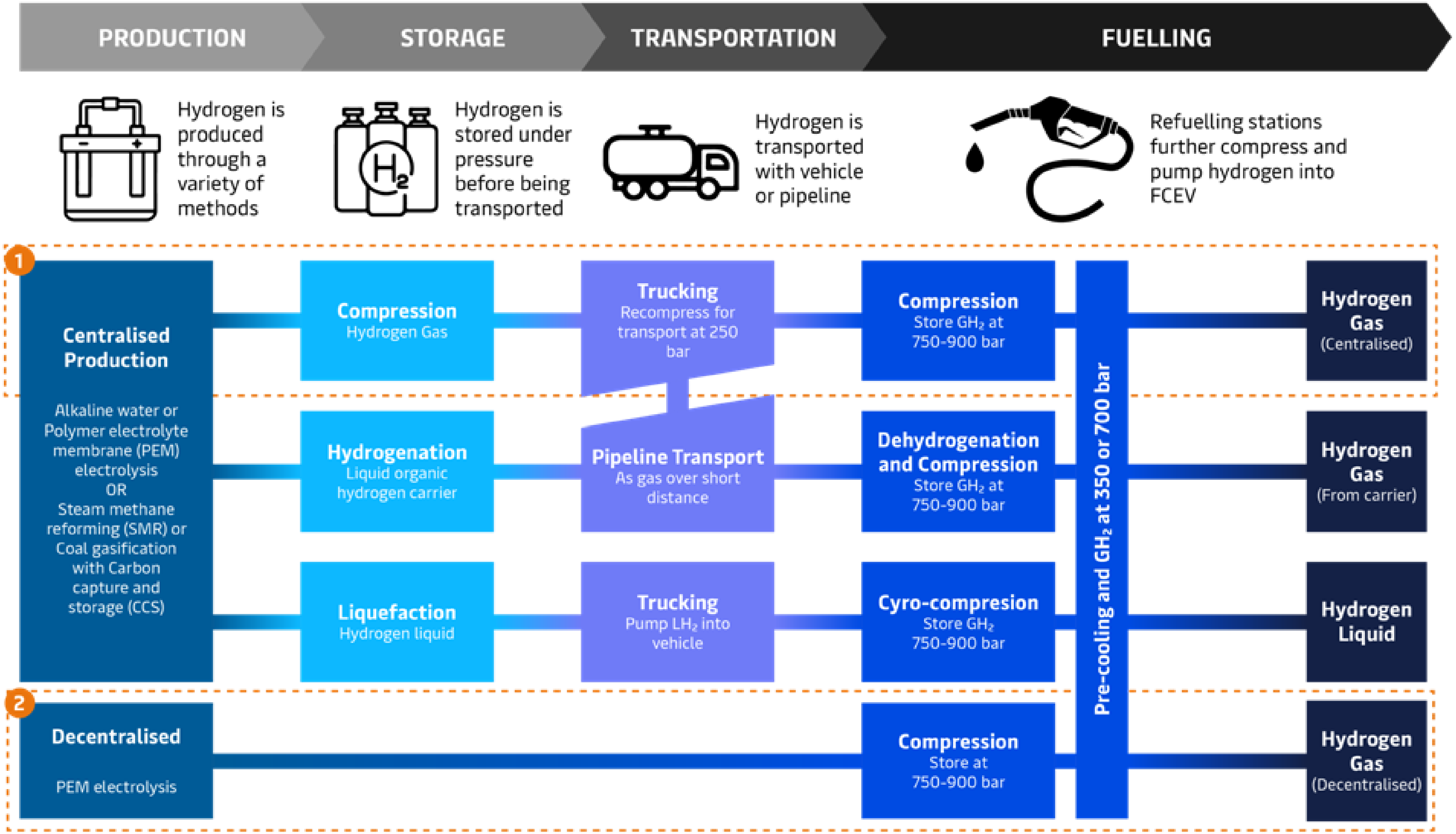
For the most part, however, these considerations are downstream of this study and therefore not considered in detail when determining the relative strengths and weaknesses of each hypothetical project.

Table: Key consideration for choice of hydrogen refueling technology

Location	▪ A centralized hydrogen supply chain relies on the availability of road transport (tanker trucks) to transport gaseous hydrogen to refueling stations ▪ Decentralized electrolysis can be based anywhere, but will require substantial site footprint for production and compression
Energy Supply	▪ Creating green hydrogen requires readily accessible renewable energy sources ▪ Decentralized electrolysis may be favorable on sites which have excess renewable energy production (e.g., rooftop solar at a warehouse, or a solar farm adjacent to a mine site)
Hydrogen Supply	▪ Hydrogen is currently produced and used in industrial applications ▪ Opportunities to interact with this supply chain would be advantageous, but most industries do not use green hydrogen

Source: eninrac research & Channel checks

Exhibit: Possible hydrogen (as a transport fuel) production pathways for India



Source: eninrac research & Channel checks

The market for hydrogen transport technology

The opportunity for implementing hydrogen as a transport technology spans across multiple modes. Each application has different characteristics, and these affect the opportunities for implementing trials, demonstrations and pilots. The methodology had a four-point central framework as defined below:

Exhibit: Methodology for transport technology in India

Source: eninrac research & Channel checks

Exhibit: Methodology expansion for transport technology in India

1 International market scan	An international market scan based on desktop research of international opportunities relating to Hydrogen for Transport
2 Identify four preferred modes	Based on the likelihood of success in the Indian market, the study identified four transport modes for further analysis and development of pilots and trials
3 Consider opportunities & constraints	For each of the four transport modes, additional research was undertaken to develop scalable hypothetical project options for pilot or trial.
4 Consider key success criteria	Each of the hypothetical projects was assessed against a set of key success criteria to identify which of the projects presents as a preferred pilot or trial for deployment in India

Source: eninrac research & Channel checks

Defining successful piloting

A pilot or trial of an emerging technology can have several factors which determine whether it is a success within the market. Technology pilots are undertaken for several reasons. For example, a new technology may be piloted to prove the operational performance and test the user experience. Alternatively, the pilot may aim to create end user awareness and encourage broad adoption of a new technology. Key themes that are considered central to the success of the hydrogen for transport in India.

Table: Key success criteria for hydrogen for transport

Strategic growth	The ability for the project to advance the strategic interests of India's hydrogen economy. This considers elements such as: ▪ How well the opportunity can support the GoI to build a clean, innovative and competitive Indian hydrogen industry that is a major global player by 2030 ▪ The value the opportunity contributes to the broader hydrogen value chain ▪ How well the opportunity progresses the hydrogen agenda across commercial, regulatory, technological and social dimensions
Addressable market	The ability for the project to grow the use case beyond the life of the trial, including: ▪ The likelihood of the use case being undertaken more broadly within the relevant transport sector in India ▪ Ability to increase the volume of vehicles from a supply and infrastructure perspective
Relative performance	The competitiveness of the hydrogen use case compared to both the incumbent technology and alternative technologies. This will consider: ▪ The cost competitiveness of the technology relative to alternatives ▪ The availability and supply of the technology relative to alternatives ▪ The technical and operational characteristics relative to alternatives
Procure & implement	The ability to procure and implement the relevant trial technology, where: ▪ Indian specific operations will be considered in terms of procurement methods, standards and modifications ▪ Appetite of industry partners and user groups to facilitate implementation ▪ Capability (and perception) of proposed industry partners ▪ Appetite of the local value chain to facilitate implementation
User adoption	The ability for the project to influence the perception and behavior of the use case audience, including: ▪ The direct target market of the proposed use case ▪ The broader Indian public perception of the Hydrogen for Transport opportunity

Source: eninrac research & Channel checks

Multi-criteria analysis

The success criteria which hold central for India as indicated in the previous section were used to qualitatively score of the 9 hypothetical projects, building in the priorities of the GoI and National Hydrogen Mission by assigning a weighing criterion.

Exhibit: Multi-criteria analysis rationale & scoring

A pair wise ranking assessment determines the relative priority of each success factor

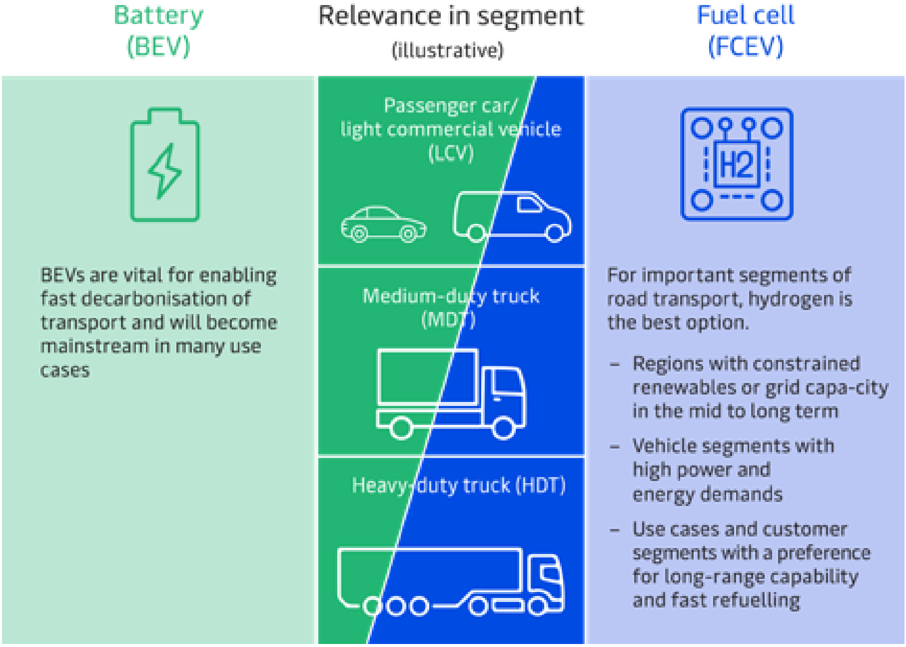
Criteria	Weighing
Strategic growth	**30%**
Addressable market	10%
Relative performance	**40%**
Procure & implement	15%
User adoption	5%

Source: eninrac research & Channel checks

Role comparison of BEVs and FCEVs

Hydrogen, however, has some advantages that make it more suitable for certain scenarios. In regions with a structural renewable electricity constraint and the need for imports, it makes sense to keep hydrogen as a molecule for as long as possible instead of converting it into grid electricity. Furthermore, hydrogen is well positioned for wherever large amounts of energy are needed for the vehicle performance due to the higher energy storage density of fuel cell systems. This is why we expect adoption both in passenger vehicles and, at a large scale, in commercial vehicles. Given the broad consensus on the role of hydrogen in heavy duty transportation, the following analyses focus mainly on passenger vehicles.

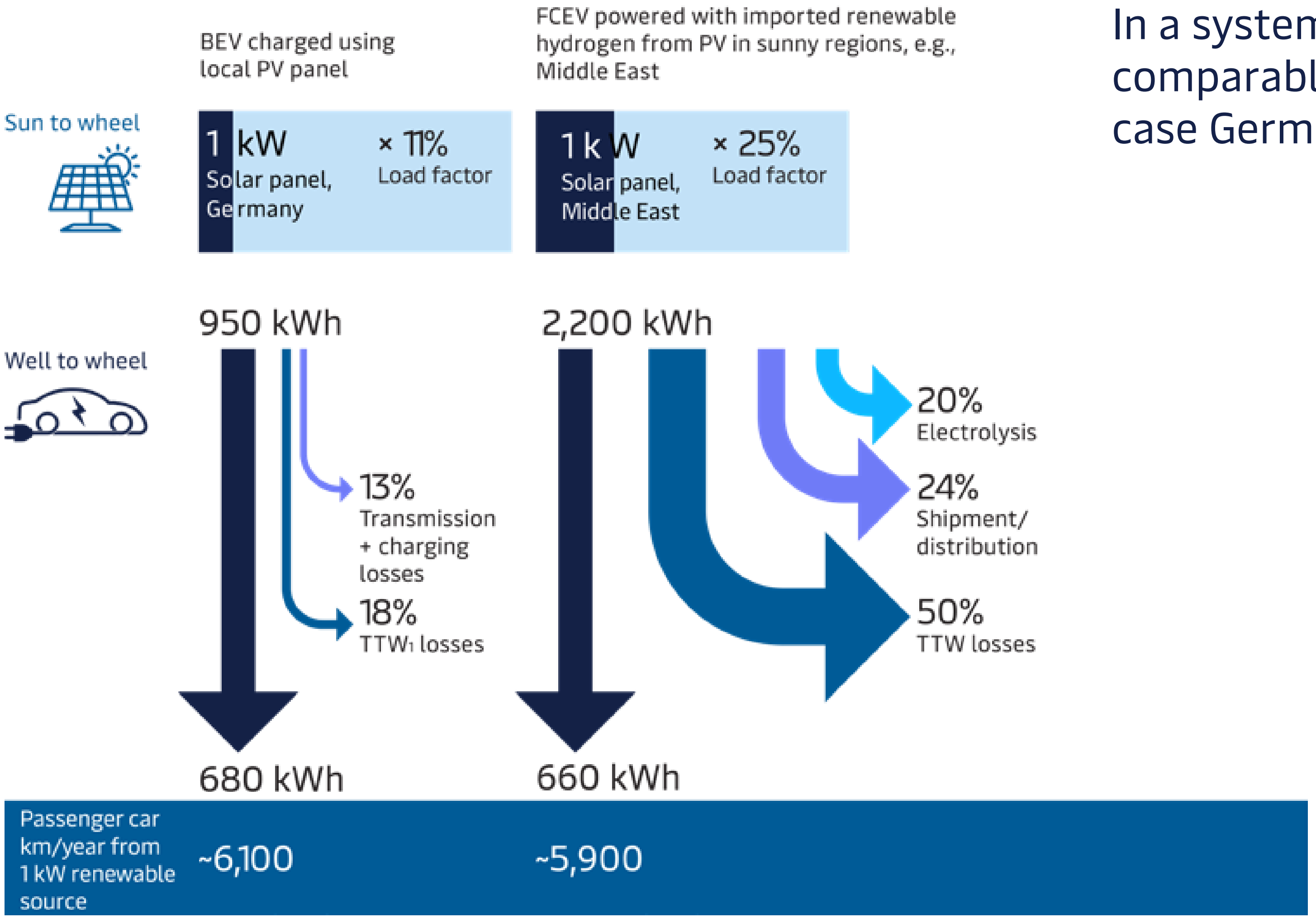
Exhibit: Mix of vehicle types required for India



Source: eninrac research & McKinsey

Exhibit: Illustrative pathway example: exact efficiency of each component can vary dependent on context

In a systemic view, BEVs and FCEVs have comparable sun-to-wheel efficiencies: case Germany



Source: eninrac research & McKinsey

Fuel cell technology & FCEV application

Broadly speaking, a fuel cell is an electrochemical reactor that converts the chemical energy of a fuel and an oxidant directly to electricity. More recently, the word fuel cell has been used almost exclusively to describe such a reactor using hydrogen as the primary source of energy. Hydrogen has a long history of being used as fuel for mobility. More than 200 years ago, hydrogen was used in the very first internal combustion engines by burning the hydrogen itself, like burning gasoline today. Fuel cells are typically categorized by the type of electrolyte used. Typical types of fuel cells electrolytes include Proton Exchange Membrane ("PEM"), Alkaline fuel cell ("AFC"), Phosphoric Acid Fuel cell ("PAFC"), Solid Oxide Fuel Cells ("SOFC") and Molten Carbonate Fuel cell ("MCFC")

Exhibit: Illustrative pathway example: exact efficiency of each component can vary dependent on context

Fuel cell type	Electrolyte type	Operating temperature (°C)	Catalyst type	Key advantage	Key weakness	Application
PEM	Proton exchange membrane	50-100	Platinum	Quick start, works at room temperature	Sensitive to CO, reactants need to be humidified	Vehicle power, portable power
AFC	Alkaline	90-100	Nickel/Silver	Quick start, works at room temperature	Need pure oxygen as oxidant	Aerospace & military
PAFC	Phosphoric acid	150-200	Platinum	Insensitive to CO_2	Sensitive to CO & slow start	Distributed generation
SOFC	Solid oxide	650-1000	LaMnO3/LaCoO3	Air as oxidant, high energy efficiency	High operating temperature	Large distributed generation, portable power
MCFC	Molten carbonate	600-700	Nickel	Air as oxidant, high energy efficiency	High operating temperature	Large distributed generation

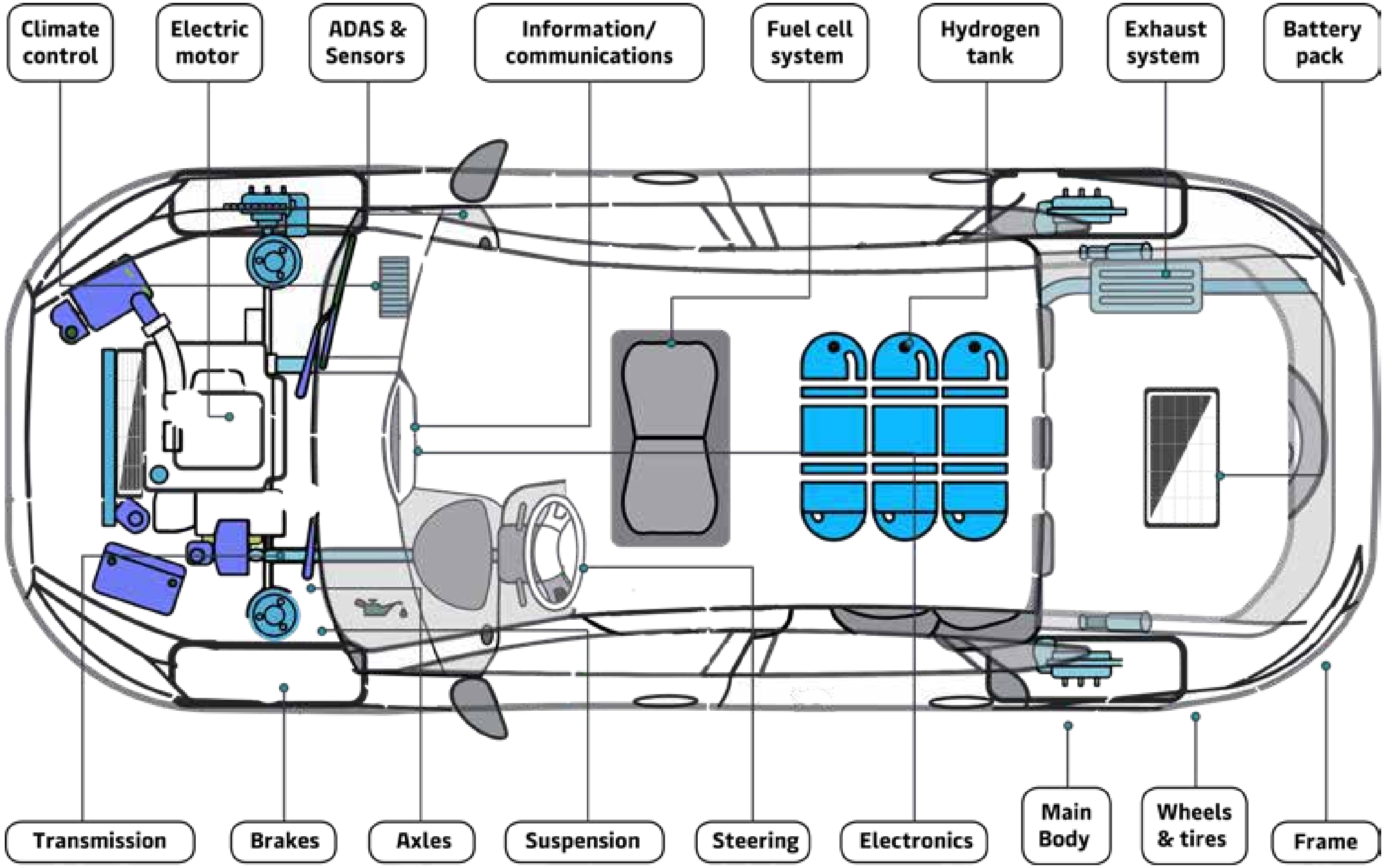
Source: eninrac research & Channel checks

Exhibit: Current and future number of FC vehicles by type and geography

		Passenger vehicles	Buses & coaches	Trucks	Forklifts	Refueling stations
USA	Current	7271	35 active, 39 development	Prototype test	>30,000	~ 42 online
	Target		5,300,000 FCEVs on US roads by 2030		300,000 by 2030	7,100 by 2030
China	Current	0	2000+	1500+	2	23
	Target	1,00,000 by 2030	11,600 commercial vehicles by 2023			500 by 2030
Europe	Current	~1,000+	~76	~100	~300	~152
	Target	3,700,000 by 2030	45,000 fuel cell trucks by 2030			~3,700 by trucks
Japan	Current	3,219	18	N/A	160	127;10 in progress
	Target	800,000 by 2030	1,200 by 2030		100,000 by 2030	900 by 2030

Source: eninrac research & Channel checks

Exhibit: FCEV Components



Source: eninrac research & Channel checks

TCO & User choices

TCO – USA Case Reference

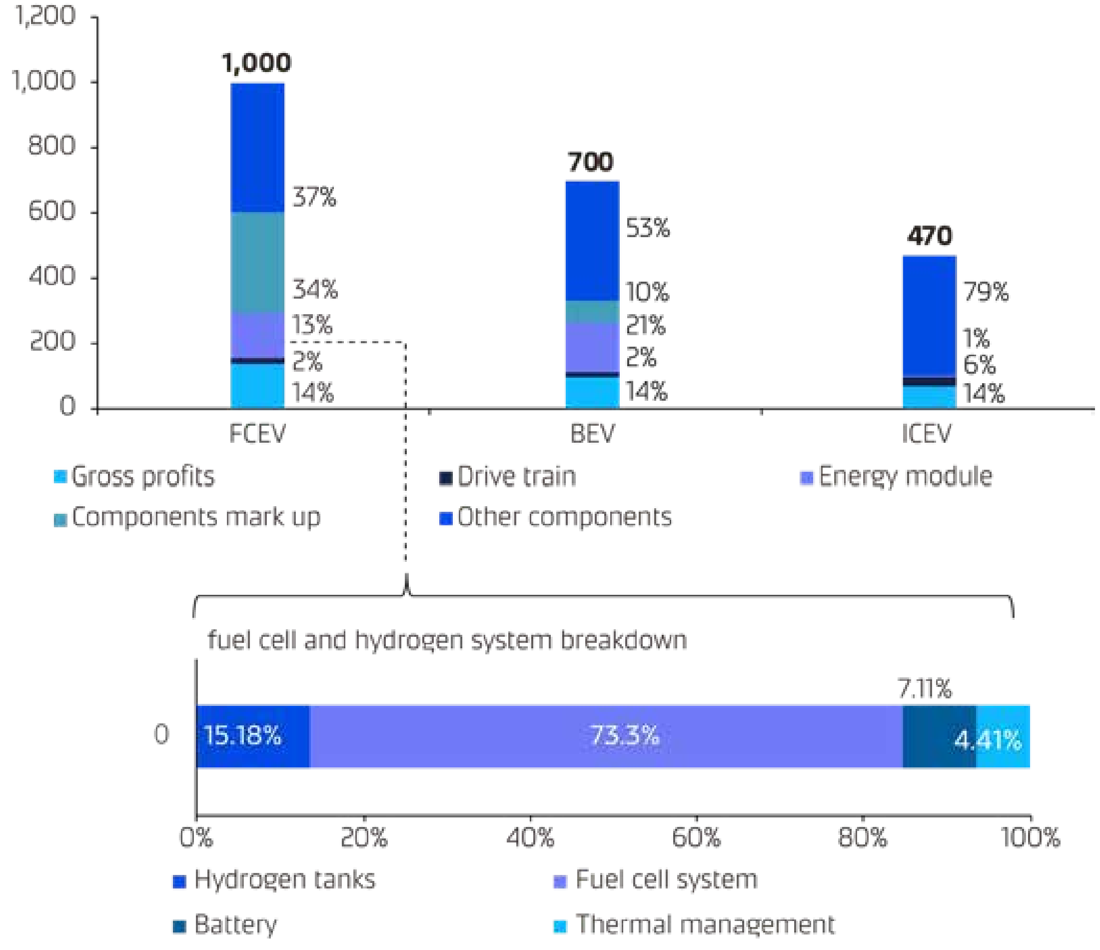
Here, we present a case study showcasing the Total Cost of Ownership (TCO) outcomes for the United States.

As evident from the illustration, the most significant disparities in costs arise from the energy module. The current pricing of the fuel cell system remains high, at roughly USD 1,500 per kilowatt (kW), constituting about 73% of the energy module expenses and approximately 13% of the overall cost of the fuel cell vehicle. Alongside the fuel cell system itself, the hydrogen tanks contribute to around 15% of the costs within the energy module. Collectively, these two constituents contribute the most to the cost escalation in comparison to the other two vehicles. Nevertheless, in line with the trajectory of nascent technologies, the costs of these components are steadily diminishing.

Apart from the energy module, noteworthy contributions to the overall pricing of FCEVs and BEVs come from the mark-up costs on components. Nonetheless, as anticipated, these component expenses are more modest for BEVs, owing to their earlier adoption and closer proximity to widespread market availability.

The collective viewpoint of industry experts we consulted indicates that FCEVs could achieve full economies of scale in approximately a decade. This achievement would lead to the removal of this supplementary component mark-up.

Exhibit: Total Cost of Ownership (TCO) outcomes for the United States



Source: eninrac research & Channel checks

Truth is ever to be found in the simplicity, and not in the multiplicity and confusion of things

- Sir Isaac Newton

WRITE OR CALL TO US

at connect@eninrac.com / nsharma@eninrac.com

+91 9319048963 / +91 9319047963

NCR : 3rd floor, Joy Tower, C-20, 1/1A, C Block, Phase 2, Industrial Area, Sector 62, Noida, Uttar Pradesh - 201301