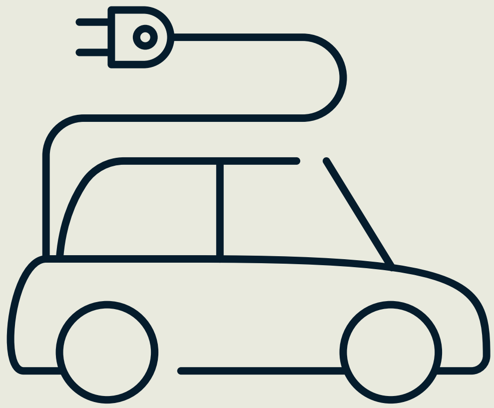
Global Innovation Needs Assessment

Zero carbon road transport

December 22, 2021



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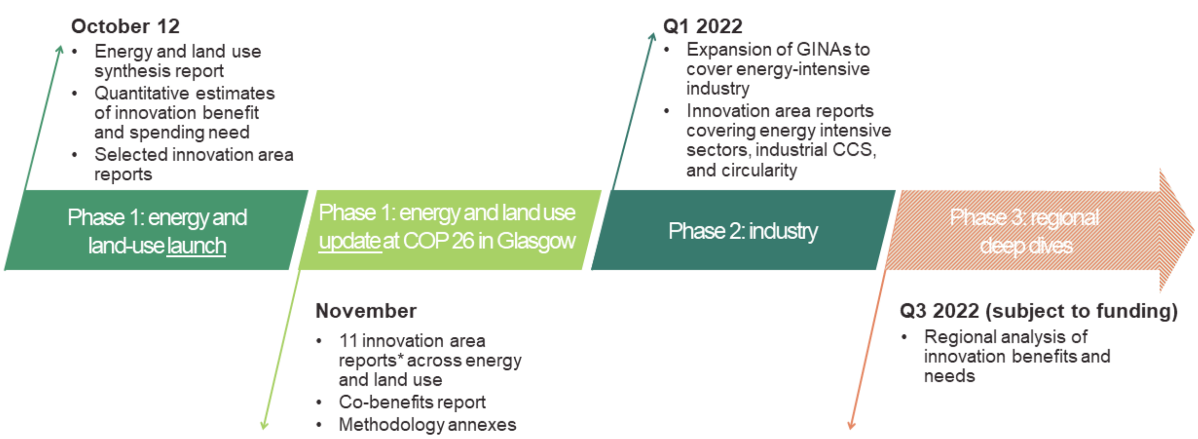
The findings and views expressed across this project do not necessarily reflect the views of the ClimateWorks Foundation, the Government of the United Kingdom, or Mission Innovation.

The Global Innovation Needs Assessments

The Global Innovation Needs Assessments (GINAs) is a first-of-its-kind platform for assessing the case for low-carbon innovation. The GINAs take a systemwide perspective, explicitly modeling the impact of innovations across the global economy. Uniquely, the analysis quantifies the economic benefits of low-carbon innovation and identifies the public investments—from research and development to commercialization—needed to unlock these benefits. The analysis is divided into three phases: Phase 1, global energy and land use; Phase 2, global industry; and Phase 3, regional deep dives.

The GINAs analyses neither assess all relevant technologies nor evaluates all relevant factors for policy judgments. Instead, they provide a novel evidence base to better inform policy decisions. The Phase 1 analysis examines climate mitigation technologies in energy and land use, ranging from demand response to protein diversification, to model the economic value of related innovation investment. Later phases expand this research. Like all technologies, adoption poses risks and potential downsides; some technologies in the analysis remain controversial. Which innovations to invest in is ultimately a policy judgment. This analysis provides no policy recommendations regarding investment in specific technologies.

Phases of the Global Innovation Needs Assessments



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Phase 1 GINA outputs

All GINAs reports and other GINAs outputs are available on the GINAs website at https://www.climateworks.org/report/ginas/.

The suit of outputs for Phase 1 of the Global Innovation Needs Assessments

1. **Energy and land use synthesis report:** slide-based summary for policymakers and executives
   Synthesis of the findings across the innovations considered in energy and land use

2. **Energy and land use and agriculture innovation reports:** in-depth quantitative analysis for industry and policy analysts

   - **Wind power** – Offshore and onshore wind turbines
   - **Low carbon hydrogen** – Electrolyzers and gas reforming with CCS
   - **Solar power** – Utility-scale and distributed PV
   - **Low carbon fuels** – 2nd generation biofuels, synthetic fuels (H_2 + CO_2)
   - **Nuclear power** – Small modular and large-scale advanced reactors
   - **System flexibility** – Battery storage, power-to-X, demand response
   - **Buildings** – Heat pumps, building fabric
   - **Power CCS** – CCS in power generation (coal, gas, and biomass)
   - **Zero-carbon road transport** – Battery electric vehicles, fuel cell electric vehicles
   - **Protein diversity** – Novel protein-rich food and feed
   - **Decarbonizing agrochemical inputs** – Innovative fertilisers and pesticides
   - **Yield enhancing technologies** – Digital agriculture and vertical farming
   - **Irrigation** – Improved irrigation methods and systems

   The selected innovation areas were selected for their potential for further innovation and the potential magnitude of the associated system benefits. Their selection here is because they could play a key role in a net zero pathway but does not imply that an optimal net zero pathway necessarily includes them. Further notes on the rationale behind their selection is provided in the methodology annex on the GINA website

3. **Co-benefits of innovation report:** qualitative analysis of the environmental and other non-economic benefits of net-zero innovation

4. **European case study:** analysis of jobs and growth benefits in Europe specifically

5. **Methodology annex:** description of the modeling approach

Executive summary

In a 1.5°C world, road transport would need to cut at least 90% of emissions relative to 2020 by 2050, marking an era of unprecedented transformation in the sector with far-reaching consequences for many aspects of life. In 2020, road transport was responsible for 16% of CO_2 emissions from energy and industry, not including upstream emissions from fossil fuel production (IEA 2021d). Net-zero-by-2050 scenarios call for at least a 90% reduction in those emissions, or an 8.8% average annual reduction (IEA 2021c). Because road transport has fundamentally shaped our cities, economies, and ways of life, transformation of the sector needs to realize emissions ambitions while advancing affordable mobility to sustainably meet the varied needs and demand of an increasing global population and rising incomes. Technological change is key to this transformation. In its absence, expected increases in passenger and freight kilometers could mean that road transport emissions grow more than the 2010–2019 annual average of 1.5%.

Behavioral and modal shifts are needed, and they provide benefits beyond decarbonization, but the major driver of a zero emissions road transport sector is zero emission vehicles (The Climate Change Commitee 2021). Battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) provide great potential for meaningful emissions reduction at scale, and they can provide sustainable and affordable mobility services alongside low carbon e-fuels and other transport modes like public transport, rail, bicycles, scooters, walking, and micromobility (Searle et al., 2021). The uptake of these two technologies is best exemplified by battery electric cars, with their cost and energy efficiency, and fuel cell trucks with their range and quick refueling. In general, electrification of the sector, through battery electric vehicles, is likely to dominate many road transport segments, including commercial cars and light-, medium-, and heavy-duty freight. FCEVs may have targeted applications in heavy-duty freight trucks and off-road vehicles.

Sales of zero emission vehicles are rising rapidly, especially in regions with strong policy support. However, due to the nature of vehicle stock turnover, these vehicles represent only 1% of the global fleet. On a total cost of ownership basis, BEVs are already less expensive than internal combustion engine (ICE) vehicles in some markets, but their capital costs remain higher in most markets and vehicle segments because of their higher production costs. These capital costs limit producers' margins on BEV sales, particularly high-volume, non-luxury BEV sales.

Innovations have already provided significant cost reductions for zero emission vehicles; further innovations could make battery electric cars 50% of total car stock by 2035. With strong demand for zero emission vehicles, particularly BEVs, market-based investment into innovation is expected to continue. However, speeding the innovation cycle through public investment in RD&D and commercialization could deliver significant benefits. By 2050, capital costs for BEVs and FCEVs could drop 50% through large cost reductions in batteries and advanced manufacturing of fuel cells. Building on the momentum that in 2020 drove the share of BEV car sales to 3% (and higher in regions with strong policy support), innovations could propel deployment to the scale required for net zero.

By 2050, the global car and heavy-duty truck market could be dominated by BEVs and FCEVs, respectively (IEA 2021c; IRENA 2021).

Mass market deployment of BEVs and FCEVs would reduce energy system costs by $0.5 trillion per year on average between now and 2050. Any cost reduction in these vehicles would represent significant savings in decarbonizing the energy system and would also lower the need for early deployment of costly and still immature mitigation measures. Between now and 2050, innovation in ZEVs could provide a cumulative discounted savings of $5 trillion. The benefits of these technologies are expected to scale with the rate of modeled deployment in the early half of this century. For example, BEVs could makeup over 90% of car stock by 2050.

Deployment would also increase business opportunities across new low-carbon automotive value chains worth $0.7 trillion in GVA and associated with 9 million direct jobs by 2050. The automotive market is very competitive and internationally traded. Capturing market share in a leading area of the market represents a significant business opportunity; the market for the manufacture of motor vehicles and bodies (coachwork) alone is estimated at $1.8 trillion and at $0.8 trillion for BEV cars and FCEV trucks, respectively. Capturing BEV and FCEV market share would require early investment and collaboration between the public sector and the private sector. Many of the jobs in the value chain are highly transferable from the existing manufacturing industry, making a just transition achievable.

To realize GVA and employment benefits, annual public spending of $3.7 billion in commercialization is needed between now and 2035 to build on large private sector spending. Demand-pull and supply-push policies, including zero emissions vehicle mandates, stringent CO_2 standards, differentiated taxation, and purchase incentives, have attracted large private sector research, development, and deployment (RD&D) and commercialization spending. The private sector is well equipped and increasingly incentivized to invest in innovation. However, there is a role for public sector spending, particularly commercialization spending, in market segments that remain less attractive or viable for the private sector.

Public benefits (i.e., energy system cost savings)	Cumulative 2021–2050, undiscounted: $14 trillion Cumulative 2021–2050, discounted at 5% p.a.: $5 trillion Annual average 2021–2050, undiscounted: $0.5 trillion
Business opportunities	2035: GVA $0.3 trillion, supporting 5 million direct jobs 2050: GVA $0.7 trillion, supporting 9 million direct jobs
Public spending required	Commercialization, annual average 2021–2035: $3.7 billion per year RD&D, annual average 2021–2035: $0.5 billion per year

1. Zero carbon road transport and the energy system

1.1 Current role in the energy system

Decarbonizing road transport is critical to transforming the energy sector and limiting global warming increase to 1.5°C. In 2020, the transport sector as a whole was responsible for a fifth of combustion-related CO_2 emissions from energy and industry, amounting to $7GtCO_2$ (not including upstream emissions from fossil fuel extraction, refining, and distribution) (IEA 2021d). Road transport contributed to more than 75% of these emissions (IEA 2021d). Unlike aviation and shipping, road transport, including both passenger vehicles and road freight, has viable options for decarbonization available now. In net-zero scenarios, emissions from road transport are expected to decrease at least 90% in the next 30 years, despite increased freight activity and passenger travel (IEA 2021c).

Limiting global warming increase to 1.5°C will require a portfolio that includes an accelerated uptake of zero emission vehicles in addition to measures that induce fuel switching, increased efficiency, and changes in travel behavior (IEA 2021a). Shifting away from ICE powertrains to battery electric and fuel cell vehicles powered by clean electricity and hydrogen will play a significant role in decarbonizing road transport, providing emission and local pollution reductions greater than those possible with efficiency improvements alone.[1] Emissions of BEVs and FCEVs are dependent on the embodied emissions of the energy carriers, electricity and hydrogen, which are already cleaner than oil-based combustion in most cases, and will likely further decarbonize alongside other sectors as part of a 1.5°C transition.[2]

Behavioral and modal shifts are needed, and they provide benefits beyond decarbonization, but the major driver of a zero emissions road transport sector is zero emissions cars, trucks, buses, and two- and three-wheelers. BEVs and FCEVs, when fueled by low-carbon energy carriers, hold meaningful emissions reduction potential and can provide sustainable advanced mobility services alongside low-carbon e-fuels and other transport modes such as public transport, rail, bicycles and walking. In general, electrification of the sector, through battery electric vehicles, is likely to dominate many road transport segments, including commercial cars and light-, medium-, and heavy-duty freight. FCEVs may have targeted applications in heavy-duty freight trucks and off-road vehicles.

Uptake of BEVs and FCEVs is best exemplified by passenger cars and long-distance, heavy-duty freight trucks.[3] These road transport segments showcase the relative benefits of each zero emissions technology.[4] With over 1 billion passenger cars in the world, decarbonizing this segment will have an important impact on road transport emissions. Compared with internal combustion vehicles, battery electric cars are increasingly cost competitive, particularly in terms of car operation costs, and are three to five times more energy efficient from tank to wheel than internal combustion engines (IEA 2020). BEVs make up less than 1% of passenger car stock, as Figure 1 shows. Heavy-duty trucks are responsible for more than half of total truck freight CO_2 emissions. In 2020, only 3,185 heavy-duty fuel cell trucks—less than 0.01% of total heavy-duty freight truck stock—were in circulation (IEA 2021a).

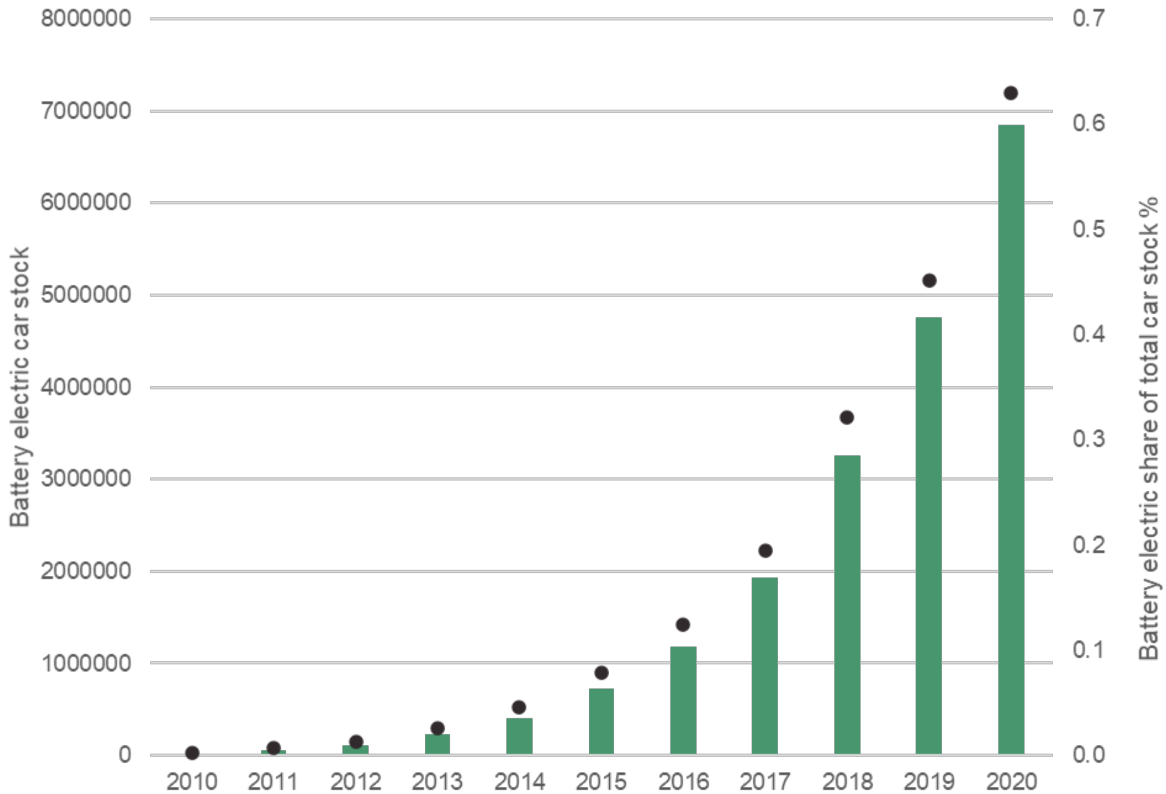
[1] Efficiency in road transport covers both technological efficiency of ICEs and optimized routes with connected and automated vehicles.

[2] Electric vehicles provide emissions reductions even with fossil fuel-dependent grids because of the high efficiency of electric motors.

[3] Heavy-duty trucks are defined as freight vehicles with a gross weight greater than 15 tonnes, driving more than 100000km per year. These trucks account for two-thirds of road freight activity in tonne-km, and half of total truck CO_2 emissions (IEA 2020).

[4] Electrification, through battery electric vehicles, is expected to be deployed across most road transport segments, including light-duty commercial vehicles and light- and medium-duty freight trucks. FCEV uptake is still uncertain and varies across scenarios; FCEV technology could be applied to heavy-duty trucks (IEA 2021c).

Figure 1. Battery electric cars are increasing in number but amount to less than 1% of car stock.



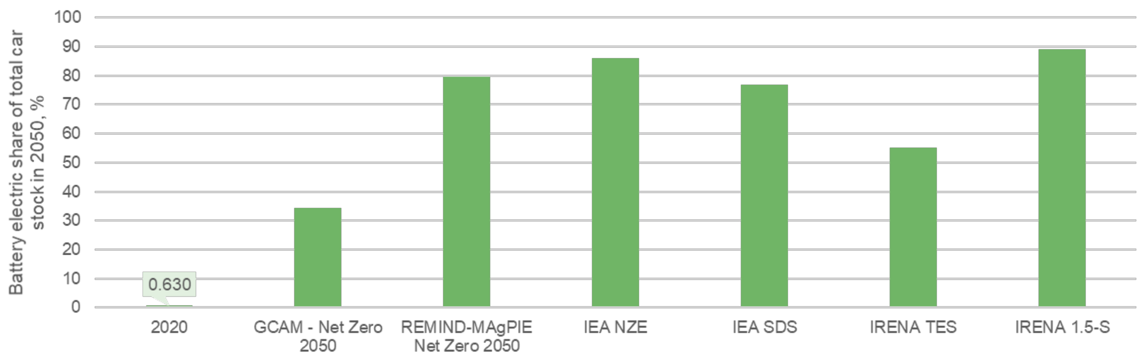
Source: Vivid Economics using IEA (IEA 2021a).

Driven by policy measures and technology advances, momentum for zero emissions road transport is growing: in 2020, battery electric cars represented 3% of total sales, with much higher rates in regions with strong policy support. Sales vary by region. China retains the greatest stock of BEV cars, but in 2020 the EU experienced the largest annual increase in sales. Sales in emerging and developing countries are lower for many reasons, including a large secondhand import market (UNEP 2020). Automotive manufacturers are responding to interest with an increasing array of models. The number of BEV car models has risen from 50-plus in 2015 to just under 250 in 2020 (IEA 2021b). China, with a relatively unconsolidated automotive market, offers the most models. Expansion of models has been particularly notable in the SUV car segment and is consistent with the historical trend of increasingly large cars.

1.2 Future role and deployment potential

Across 1.5°C scenarios, BEVs increase to represent from 34% to 90% of the car stock by 2050. Figure 2 below displays the 2050 BEV share of total passenger car stock from selected scenarios compatible with the Paris Agreement. The scenarios vary in terms of both the pace at which global emissions decline and the relative size of mitigations across sectors and energy sources. IEA, NZE, and IRENA 1.5-S reflect ambitious passenger car emissions reductions by 2050—reductions that in IRENA TES and GCAM Net Zero occur after 2050.

Figure 2. Across the most ambitious scenarios, battery electric cars dominate by 2050.



NZE = net zero emissions by 2050. SDS = sustainable development scenario. TES = transforming energy scenario. 1.5-S = 1.5°C scenario.
Notes: IEA, SDS and IRENA TES are below-2-degrees scenarios. The other scenarios shown are 1.5°C scenarios, generally featuring net-zero emissions between 2050 and 2060. To calculate share of stock for IRENA 1.5-S and TES, total car stock from IEA NZE and SDS, respectively, was used.
Source: Vivid Economics based on NGFS, IEA, and IRENA (NGFS 2020; IEA 2021c; 2021d; IRENA 2020; 2021).

By 2025, 1.5°C scenarios project a six-fold increase in the BEV share of total car sales. By 2025, most scenarios expect 25% of car sales to be BEV sales, a significant step up from the 3% reached in 2020. In the most ambitious scenarios (IEA, NZE), more than 45% of car sales are BEV sales in 2030. By 2050, at least 80% of sales are BEV sales across all scenarios. However, regional variation is expected. NZE projects that in emerging and developing countries BEV sales make up only a 50% share of sales by 2050 due to the existing secondhand market (IEA 2021c; UNEP 2020).

Innovation can deliver significant benefits in supporting the transition to BEVs in cars and FCEVs in heavy trucks. Innovation can facilitate the deployment of these vehicles by reducing their cost and addressing other barriers. Notably, innovation will occur not just through RD&D but also through large-scale commercialization of improvements.

2. Innovation opportunities

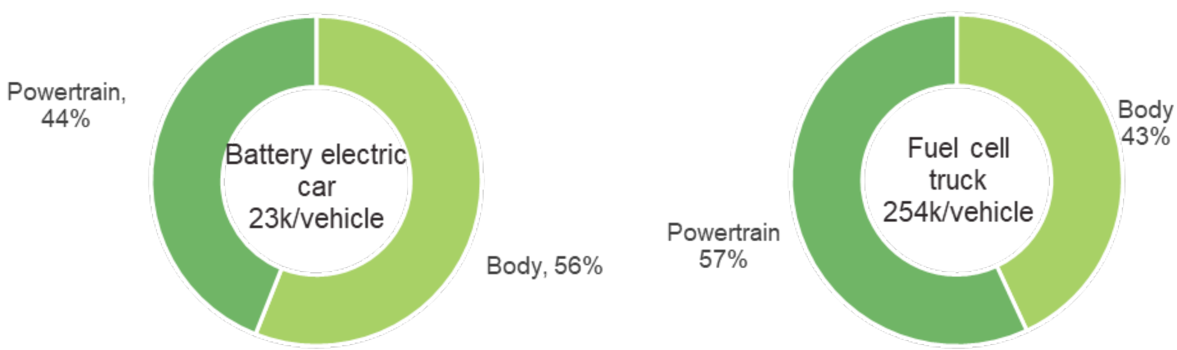
2.1 Costs and deployment barriers

Large-scale BEV and FCEV deployment is hindered by high capital costs and concerns about driving range and refueling infrastructure. BEVs are between 1.5 to 2.6 times more expensive than alternative diesel combustion vehicles, depending on the mile range of the BEV (NREL 2020). FCEV HGVs are 2.3 times more expensive than diesel HGVs (NREL 2021). Total cost of ownership, which considers ongoing operational costs like maintenance and fuels, usually reflects a lower price differential between low-carbon powertrains and ICE vehicles.[5] Total cost of ownership for BEVs is approaching price parity with that for ICE vehicles. Maintenance is much lower for BEVs than for ICE vehicles because BEVs have fewer parts to be replaced and don't require a regular change of fluids like engine oil. In the future, BEVs' energy costs could be lowered by energy policies and integration of cheap renewables on the grid. Nonetheless, higher capital costs are a deterrent to BEV purchase and deployment. For FCEV trucks, higher utilization and longer lifetimes mean operating costs like fuel and maintenance are a greater factor in total cost of ownership. Co-innovation of low- or zero-carbon hydrogen production to bring down the costs of hydrogen could significantly reduce the total cost of ownership for FCEV heavy trucks. Beyond cost, uptake of both BEVs and FCEVs is hindered by concerns about driving range limitations and difficult recharging and refueling options.

The high capital costs of BEVs and FCEVs are largely driven by powertrain differences, chiefly batteries and hydrogen fuel cells. Compared with an ICE engine, a BEV powertrain is a simpler system with fewer parts, but it has some higher-cost components: battery packs, electric motors, and power electronics. FCEVs feature a fuel cell stack and hydrogen tanks on top of the electric motor and battery. Batteries and fuel cells are made of expensive critical materials, including cobalt, lithium, and nickel, and their production is only now reaching scale (BNEF and T&E 2021). BEVs use six times more of these minerals than ICE vehicles. Fuel cells require platinum, the demand for which may be offset by decreasing demand for catalytic converters in ICE vehicles. In 2020, powertrains amounted to 45% and 60% of the overall capital expense of BEV cars and FCEV trucks, respectively. Other components of the powertrain, such as transmission, e-motor, and power electronics, as well as general assembly make up a smaller share of costs.

[5] Total cost-of-ownership calculations are sensitive to assumptions about future prices of hydrogen and electricity.

Figure 3. Powertrain components contributed significantly to capital cost of BEVs and FCEVs in 2020.



Source: Vivid Economics based on UBS and FCHJU (UBS 2017; Fuel Cells and Hydrogen Joint Undertaking and Roland Berger 2020)

Barriers beyond vehicle cost constrain the uptake of BEVs and FCEVs. Among the most significant of these barriers are the following:

- **Limited public recharging and refueling infrastructure.** On-demand charging is particularly a concern for consumers without access to at-home charging. Heavy-duty trucks may need rerouting to guarantee refueling at appropriate times during a long-distance journey.
- **Perceptions of hydrogen supply and price variability.** Hydrogen supply must meet potential demand from many other sectors, fueling consumer worry.
- **Uncertainty of reward for providing power system flexibility, which affects BEV operating costs.** Depending on electricity market rules, BEVs can provide demand-side response (vehicle to grid or grid to vehicle), but whether power systems will cope with and reward all contributors remains uncertain.

2.2 Key innovations

By 2050, innovation in BEV cars and FCEV heavy trucks could further drive down capital costs by 25% and 29%, respectively. Table 1 below summarizes the 2020 cost estimates for both technologies, alongside 2050 estimates under high- and low-innovation scenarios.[6] The scenarios are constructed from an extensive review of cost reduction studies for BEVs and FCEVs. There is some cost reduction even in the low-innovation scenario due to market-driven technological improvements and commercialization in the near term. The high-innovation scenario sees additional reductions both in capital and operating costs.

Table 1. BEV and FCEV cost assumptions under high- and low-innovation scenarios

Technology	Cost component	2020	2050 low innovation	2050 high innovation	% further cost reduction under high innovation	% further TCO reduction under high innovation
BEVs	Capex $/Vehicle	23,048	15,235	11,413	25%	10%
	Opex $/Vehicle/year	199	199	190	4%	
FCEVs	Capex $/Vehicle	254,069	151,070	106,728	29%	17%
	Opex $/Vehicle/year	19,397	11,533	8,148	29%	

Source: Vivid Economics based on IEA, Bloomberg New Energy Finance, Oliver Wyman, FCHJU and Transport & Environment (IEA 2020; Bloomberg New Energy Finance and Transport and Environment 2021; Ruffo 2020; Fuel Cells and Hydrogen Joint Undertaking and Roland Berger 2020; Transport & Environment 2020).

[6] The scenarios do not explicitly identify the individual technology drivers of cost reductions. Instead, the scenarios represent an informed judgment about the scope of cost reductions with and without government support for RD&D and commercialization.

Bringing existing technologies to large-scale operational size, through mass commercialization, will be an important driver of cost reductions for BEVs and FCEVs. Over the last 10 years, the price of lithium-ion battery packs decreased 89% to $140/kWh, driven by the growing scale of battery manufacturing facilitated by increasing orders and new pack designs (Henze 2020). Prices could drop to $60/kWh by 2030 (BNEF and T&E 2021). Additional BEV and FCEV cost reductions could be generated by bringing to market second-generation BEV and FCEV technologies, like new battery chemistries. RD&D alone will not achieve the cost reductions in the high-innovation scenario.

Key innovations focus on the powertrains of both technologies:

- **Improving cost and performance of vehicle batteries**. Approaches to reducing battery cost include decreasing material costs in existing lithium-ion batteries or moving to new battery chemistries like NMC 811 and NMC 9.5.5. Better integration of battery packs, including thermal control systems, and lighter pack materials could further improve efficiency and costs, as could improving manufacturing. Solid-state batteries are likely to be relatively expensive, but their costs could fall quickly once supply chains are built out in the 2030s.

- **Developing advanced manufacturing techniques and using innovative materials for fuel cells.** New cell materials that reduce or eliminate the need for precious metals, could decrease the costs of all fuel cell plates and catalysts. Shifting to high-volume and highly automated production techniques, for example by developing tape casting, expanded metal cutting, hydroforming, and additive manufacturing processes, would also deliver capital cost reductions.

- **Increasing on-board hydrogen storage.** Increasing the volumetric energy density of hydrogen would deliver cheaper and simpler on-board hydrogen storage, freeing space for freight. Technologies include metal hydrides and porous sorbents and ammonia.

Other innovations could further support deployment:

- **Improving electric motors**. Using novel and cheaper materials for magnets and load-bearing parts can reduce the costs of motors. For example, aluminum could substitute copper in magnets.

- **Better charging and refueling.** Improving price and business models would reduce operating costs and address charging limitations. New models can encourage vehicle-to-grid demand response, minimize planning and construction barriers, and incentivize smart charging.

- **Repurposing and recycling**. Creating an economically viable value chain for the second life of BEV and FCEV materials, for example, selling used batteries into stationary storage installations, increases sustainability and critical material depletion, and also leads to reduced capital depreciation of vehicles as assets.

3. Benefits of innovation

3.1 Low-cost decarbonized energy

Box 1 System benefits and low-cost decarbonized energy

Lower energy costs are unlocked by the system benefits of innovation. System benefits of innovation refer to the net reduction in costs across the entire energy system as a result of technology RD&D *and* commercialization. In the context of this report, system benefits are calculated as the difference in the total system costs of a high-innovation scenario and those of a low-innovation scenario, whereby:

- System costs are all capital, operating, and fuel costs within the global energy system.
- Low-innovation scenario represents market-driven progress in the absence of government support.
- High-innovation scenario represents progress driven in part by government support of RD&D and deployment (i.e., commercialization).

This metric provides an aggregate estimate of how innovations in selected technologies can reduce system costs after least-cost optimization of all energy carriers and technologies from both the supply and the demand sides.

Increased innovation in BEVs and FCEVs could reduce annual system costs by $0.5 trillion a year on average between now and 2050. In both the low- and high-innovation scenarios, global energy system costs start at about $48 trillion in 2020 and begin to diverge noticeably by 2030, when the (undiscounted) annual system costs in the high-innovation scenario are $230 billion lower than those in the low-innovation scenario. This differential is reflected in 14% more BEV cars in the high-innovation scenario in 2030. By 2050, the gap in annual system costs increases by 2.5, with savings in the high-innovation scenario reaching more than $600 billion. Table 2 below displays the system benefits from 2021 through 2050 in the high-innovation scenario for zero-carbon road transport as measured by the cost savings of that scenario compared with those of the low-innovation scenario.

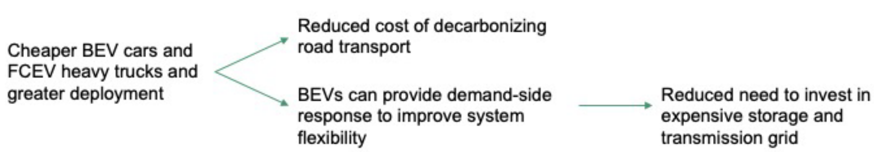
Table 2. System benefits of innovation in zero carbon transport

System benefits	2021–2050, cumulative, undiscounted	2021–2050, cumulative, discounted 5%	2021–2050, annual average, undiscounted
High innovation in BEV cars and FCEV heavy trucks	$14 trillion	$5 trillion	$0.5 trillion

Note: Discounting reduces the present value of future benefits.
Source: Vivid Economics.

Strong innovation in road transport benefits the energy system by reducing the cost of low-carbon transportation and by providing system flexibility. As illustrated in Figure 4, innovation benefits trickle through both the road transport and the power sectors. Innovation in BEVs and FCEVS lower the cost of their uptake and drive deployment, in turn reducing the carbon cost through decreased reliance on carbon-intensive road transport modes. Additionally, BEVs, charging either at home or at a stationary charging location, can take and give electricity to the grid at optimal times, effectively serving as short duration electricity storage. FCEVs, by serving as an end use of hydrogen, also add flexibility, reducing the need to invest in power system flexibility technologies like large-scale stationary battery storage or transmission and distribution grid adaptations.

Figure 4. Impact of innovation on the energy system.



Source: Vivid Economics.

Decarbonized road transport with BEVs and FCEVs could deliver additional benefits in the form of reduced local air pollution. Air pollutants that escape from ICE vehicles, including particulate matter ($PM_{2.5}$ and PM_{10}), ozone, and nitrogen dioxide, have a negative impact on human health, increasing morbidity and mortality. The WHO estimates that some 7 million deaths are attributable to outdoor and indoor pollution annually (World Health Organization 2021). Lowering particle presence could provide monetary value through reduced human health costs and increased labor productivity. BEVs and FCEVs have zero tailpipe emissions of air pollutants. Although they do have some non-exhaust PM emissions from brake and tire use, their deployment significantly reduces air pollution.

3.2 Jobs and Growth

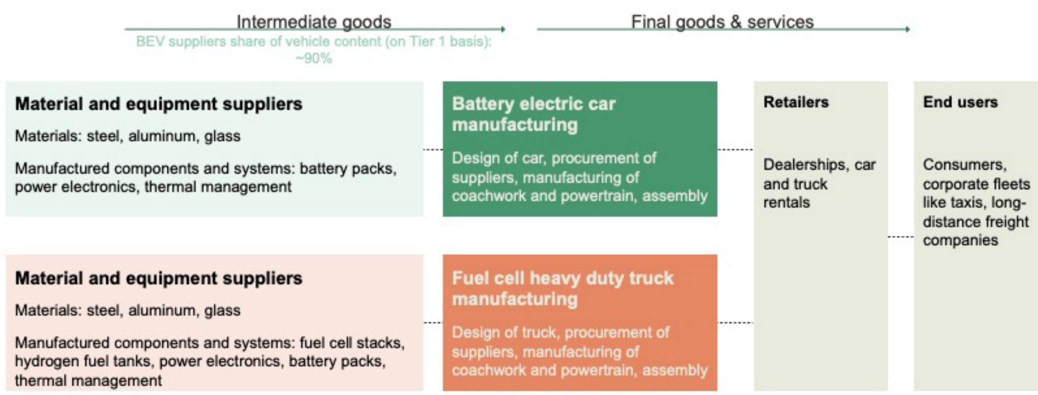
The rise of BEVs and FCEVs in an extremely globalized and competitive automotive manufacturing market involves both risks and opportunities for businesses. In Europe and North America, the automotive market is a long-standing oligopoly competing on small margins and strategic market moves. These traditional original equipment manufacturers (OEMs) have strong supply chains that have allowed improvements in the cost and attractiveness of their models. However, BEVs and FCEVs are a step change from established operations, requiring new suppliers and manufacturing processes. The rise of pure play electric vehicle companies, whether in the United States or in less consolidated markets like China, reflects the opportunities in the sector and the risk to legacy players that do not move to strengthen their position in this growing market. With lower production costs in the long run and high demand, BEVs and FCEVs represent large potential profitability, while ICE vehicles lose value at a speed that OEMs need to manage. Ultimately, market leadership will be determined by the companies that make the best advantage of their technology and manufacturing abilities.

Both new and existing players in the automotive sector have committed to large investments in BEVs and FCEVs. Major automotive OEMs have pledged to double or triple their 2020 R&D and capital expenditure on electric vehicles (Bullard 2021). These investments are directed at strategic areas of BEVs and FCEVs. The powertrain of the car, like batteries and fuel cells, is typically supplied neither by automotive manufacturers nor their traditional suppliers. For the 90% of BEV vehicle content that originates from suppliers, on a tier-1 level, more than 50% does not come from the traditional automotive supply chain. Accordingly, traditional suppliers and OEMs may not be well positioned to manage a transition to EVs with their existing processes. New entrants also have to contend with choices about in-house manufacturing of components and new relationships with suppliers (UBS 2017). Gaining leadership in this market involves vast amounts of spending on innovation, both in terms of RD&D and capital expenditure, to ensure that new technologies are deployed at scale.

The rapid deployment of BEV cars and FCEV trucks could significantly increase annual investments in electric vehicles, which could reach $2.7 trillion in 2050. This figure is estimated from the high-innovation scenario described in Section 3.1, which is comparable to other 1.5°C warming scenarios in terms of the scale of BEV and FCEV stock. Under this scenario, the average annual construction rates for BEV cars and FCEV trucks reach about 26 million and 2 million, respectively, in 2030. Total BEV car and FCEV truck stock would be 1.7 billion and 0.1 billion, respectively, in 2050.

New pure electric vehicle entrants and existing players acting innovatively can capture valuable market share, with direct GVA in the manufacture of BEV cars and FCEV trucks reaching $276 billion in 2050. Initially, powertrains contribute heavily to this GVA; innovation in batteries and fuel cells drives down costs and increases the share of these components to GVA. BEV cars represent a larger absolute opportunity than FCEV trucks because of their higher deployment. This opportunity can be seized by players that invest heavily in cost reductions and technology improvements and that capitalize on existing assets to capture the market with cheaper and better models.

Figure 5. Simplified value chain for battery electric cars and fuel cell trucks.

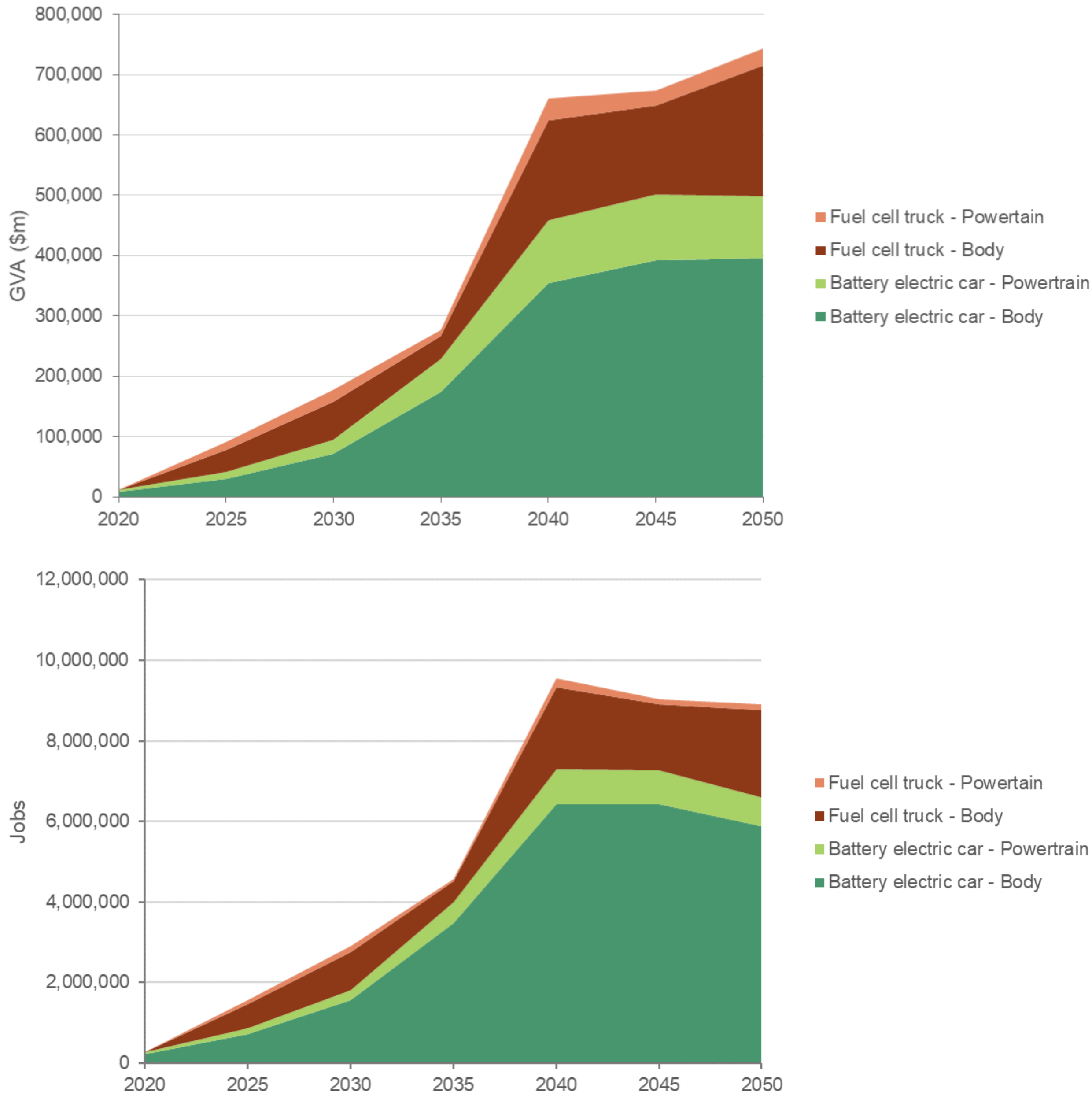


Note: The dark colored blocks represent the scope of business opportunities quantified in this section.
Source: Vivid Economics.

By 2050, the EV market will be associated with 9 million jobs, many of which will require no new skills. Most of these jobs are in the vehicle body, a consequence of the decreasing costs and labor intensity of manufacture. Therefore, workers in this part of the value chain will transition easily to EV manufacture. There will be employment impacts in the auto industry beyond this part of the value chain, however. Companies making and maintaining parts for ICE vehicles (for example, spark plugs and exhaust systems) may no longer be needed. But there may be new opportunities in battery and fuel cell manufacture.[7] These relatively small suppliers for ICE vehicles, which are often very specialized, may have relatively small scope to adapt. Total employment outcomes will be shaped in part by national and business characteristics and support for reskilling.

[7] Compared with ICE vehicles, BEVs have much lower maintenance and service needs in terms of parts, fuels, and inspections, creating a potentially significant challenge for companies downstream. For example, dealerships make almost half of their profit from after-sales parts and service (UBS 2017).

Figure 6. GVA and jobs directly supported by global deployment of BEVS and FCEVs.



Source: Vivid Economics.

4. The case for supporting innovation

Demand pull policies will play an important role in driving innovation and realizing benefits, but their absence in certain markets keeps the scale of innovation smaller than that needed for net-zero emissions. Policies that signal an end to ICE vehicles, like fuel economy standards and 100% zero emission vehicle sale mandates, have helped garner early investment in BEV and FCEV technology and infrastructure. Countries with fuel economy standards have a higher growth in the share of zero emission vehicles than countries that don't have these standards, especially when the standards are well designed. Purchase incentives, through subsidies and tax rebates (at purchase of registration) have further increased the competitiveness of these vehicles. In 2020 alone, governments globally spent $14 billion in incentives (IEA 2021b). Municipal policies mandating zero emission zones or circulation fees based on emissions have spurred technology deployment while reducing local air pollution. In countries where road vehicles are mostly imported secondhand, policies include emission standards for used vehicles, selective bans, or targeted taxes (UNEP 2020). These policies have driven investment but have been implemented in only some markets because car models can be expensive to develop, and investments in low-carbon road transport innovation are risky if demand is uncertain. Innovation may not materialize without partnerships with governments to address key cost and infrastructural barriers to deployment.

Commercialization spending of some £3.7 billion a year between now and 2035 could play a strategic role in incentivizing innovation in markets with significant policy and technology gaps. Additional private spending in innovation could be co-leveraged by public spending, especially commercialization. Possibilities involve joint ventures with OEMs to develop locally appropriate charging infrastructure. Public spending on RD&D will also need to increase 30% from current levels, reaching $0.5 billion per year on average over the next 15 years. This spending would likely be directed to batteries (IEA 2021c). Although government spending can initially cover a broad set of innovation areas, a focus on the most promising technologies and applications might be needed to maximize its impact.

Realizable benefits are far greater than the commercialization spending currently funded by governments. With annual undiscounted energy system savings of $0.5 trillion between 2021 and 2050, the scale of government spending is markedly small. The potential for jobs and growth in new low-carbon value chains only strengthens the case for government support.

Achieving a transition in road transport will involve building out critical supply chains in batteries and materials and considering circularity. High levels of BEV and FCEV deployment will require a significant scaling up of supply chains for batteries, fuel cells, and refueling infrastructure. In the IEA's NZE, battery manufacturing needs to double every two years instead of every three to four years (IEA 2021c). Demand for critical materials, like lithium, nickel, copper, graphite, and cobalt grows. In a 100% BEV world, demand for lithium and cobalt could increase by 2500% and 2000%, respectively (UBS 2017). Lastly, electricity and hydrogen production also need to meet the additional demand from road transport.

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