Corso Di Laurea Magistrale In Advanced Design

Sessione marzo 2025 | Anno Accademico 2024/2025

Tesi di laurea magistrale in Advanced Design

WINNING THE RACE TO 2050 ZERO EMISSIONS GOAL:

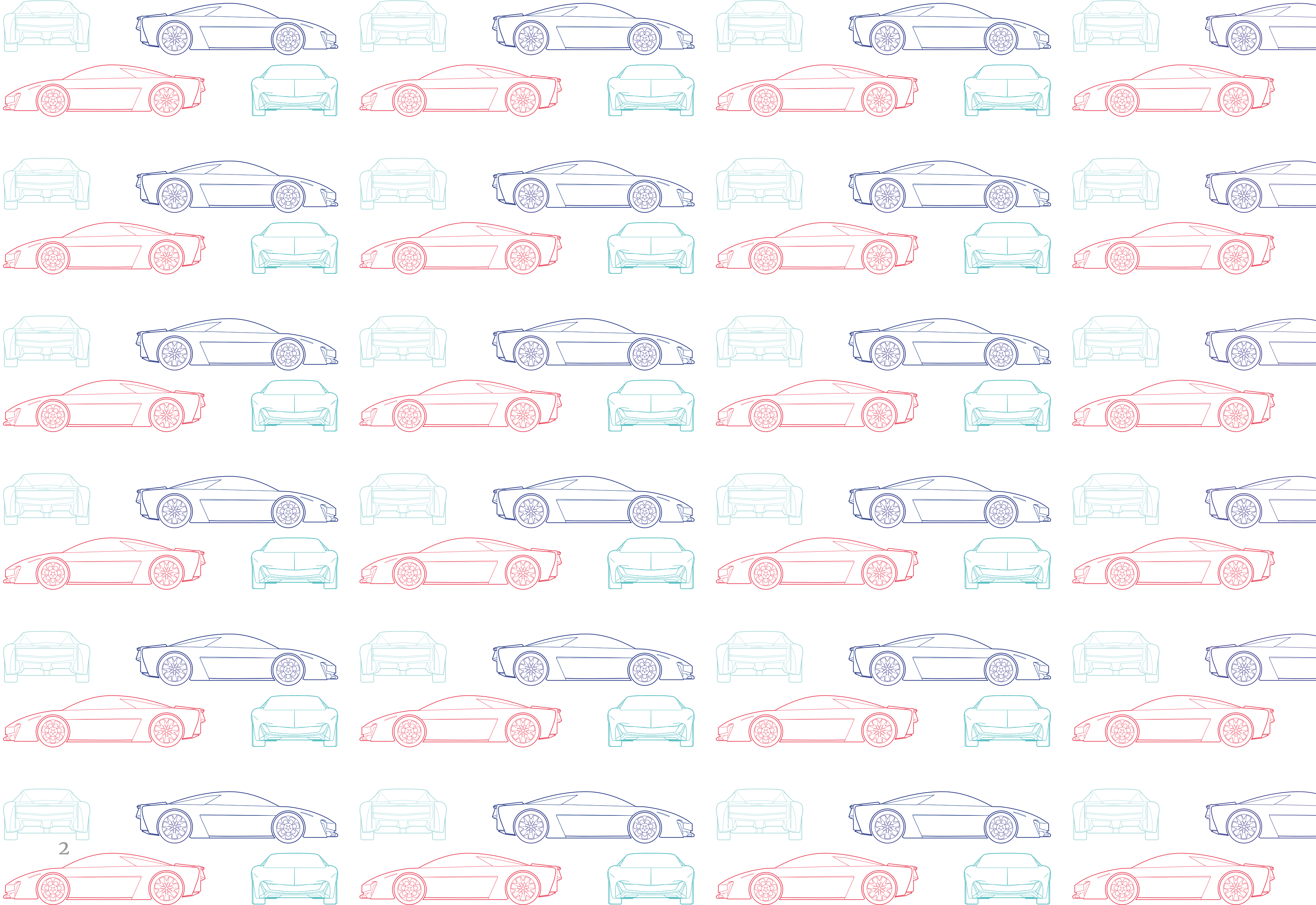
INTEGRATING ALTERNATIVE FUELS, SMART MOBILITY, AND TRANSPORTATION ACCESS TO DECARBONIZE THE MOBILITY SECTOR.

Presentato da: Davide Cardi

Correlatore: Professor Leonardo Frizziero (UNIBO); Co-supervisor: Ali Ahad (LTU); Co-supervisor: Boris Fabris; Co-supervisor: Justin Famularo (LTU); Co-supervisor: Donald Reimer (LTU); Assistant supervisor: Curzio Pagliari (UNIBO)

Advanced Design

Lawrence Technological University



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Clean energy, Safety, Future mobility, Innovation, Design

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ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

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Indice

Abstract

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The future of personal transportation, while uncertain, presents significant opportunities for innovation and transformation. The ongoing digitalization of the automotive sector marks the most profound shift in its 140-year history, driven by advancements in technology, declining costs, increased urbanization, and a growing demand for more efficient mobility solutions (Llopis-Albert et al., 2021). Consumers increasingly seek digital services, such as online sales, car-sharing, and peer-to-peer lending platforms, reflecting a preference for more convenient and personalized experiences (Llopis-Albert et al., 2021). However, the sector faces substantial environmental challenges, as personal transportation remains a major contributor to air pollution (Lee et al., 2021).

Urbanization amplifies the critical issue of air quality. Poor air quality has been shown to adversely affect public health (Hua et al., 2022) and is a major driver of environmental degradation (Tao et al., 2021). Global warming exacerbates these issues, causing increasingly severe harm to human populations, ecosystems, and biodiversity (Dawood et al., 2023).

In the United States, evolving health protection priorities in air quality management underscore the need for stricter regulatory measures. Advanced statistical methodologies have revealed that pollutant exposures previously deemed safe are, in fact, harmful to human health (Godish, 2014)

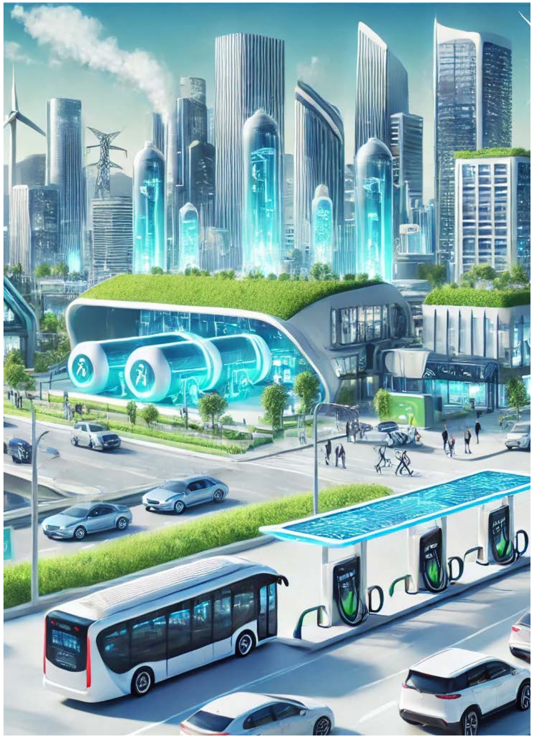
Several transformative trends are reshaping the automotive industry, requiring substantial investments and the adoption of new business models. Emerging actors and technologies are turning vehicles into "network nodes on wheels" (Mitchell et al., 2010). Concurrently, heightened environmental concerns and stringent regulatory requirements aimed at protecting ecosystems are compelling Original Equipment Manufacturers (OEMs) to prioritize the development of innovative propulsion technologies. Government support and funding (Teece, 2018) is accelerating the transition from internal combustion engines to environmentally friendly alternatives, such as electric and hydrogen-powered systems, in line with the objectives of the green revo-

lution (Edwards et al., 2008). This transformation aligns with growing consumer expectations for reduced pollution and sustainable mobility solutions (Chapman, 2007; Hickman & Banister, 2005). Vehicles are increasingly integrated into users´ lifestyles, becoming lifestyle features themselves.
This analysis seeks to advance the design and innovation of the vehicles of the future by examining the automotive industry´s impact on urban and natural environments, demographic trends, and the evolution of future cities. A central focus of this research is hydrogen, a fuel that, alongside Battery Electric Vehicles (BEVs), has the potential to achieve the decarbonization demanded by the transportation sector. Hydrogen fuel cell technology offers a compelling solution for reducing emissions, particularly in applications where BEVs face limitations. Hydrogen´s high energy density and rapid refuelling capabilities make it a critical component of future mobility solutions. Together with BEVs, hydrogen fuel cells are poised to play a pivotal role in reducing dependence on fossil fuels and minimizing the environmental impact of vehicular emissions. This dual approach leverages the strengths of both technologies, providing a comprehensive pathway to achieving a cleaner and more sustainable transportation system (Anderson C. D. & Anderson J., 2010; McKinsey, 2024a).
The urgency of these developments is underscored by alarming global health statistics. As of 2024, 7,064,380 deaths have been attributed to the COVID-19 pandemic (WHO, 2024a). Meanwhile, deaths from ambient and household air pollution total nearly 7 million annually (WHO, 2024b), with the Middle East, Northern Africa, and China being the most affected regions (Ritchie & Roser, 2024). Notably, 99% of the global population is exposed to unhealthy levels of particulate matter, with significant negative health impacts associated with such exposure (WHO, 2023a).
Addressing air pollution, identified as the second-highest risk factor for noncommunicable diseases, remains a critical priority for protecting public health (WHO, 2024b).

Introduction

Since 1880, global average temperatures have risen by approximately 1.17 °C (2.11 °F) over the past century, highlighting the severe impact of climate change on the planet (NASA, 2024). Climate change is arguably the most pressing environmental issue humanity has ever encountered (Midilli et al., 2005). This research aims to innovate mobility systems and accelerate the transition to renewable energy sources for vehicle propulsion. The journey toward decarbonization is arduous but urgently necessary, as scientific evidence indicates that we are nearing a point of no return (Aengenheyster et al., 2018). Excessive resource consumption driven by human activity, such as water, fossil fuels, and forests, currently exceeds natural replenishment rates (Wang & Azam, 2024)
Personal vehicles contribute significantly to the emission of harmful substances, posing a threat to ecosystems (Godish, 2014; Hua et al., 2022). This has prompted legislators to promote alternatives to petroleum-based fuels and to restrict access to urban centres for vehicles whose byproducts are not environmentally friendly. A system of carrots and sticks (Mitchell et al., 2010) like the one in Singapore would be optimal to achieve the public consent in public acceptance towards a shift to more sustainable mobility. Manufacturers and governments are increasingly investing in alternative fuels. For instance, in 2019, the Chinese government shifted its focus from battery technology to hydrogen production, a priority also recognized by the European Commission, which has identified clean hydrogen as essential for the energy transition. France and Germany have each pledged €9 billion toward fuel cell technology. Although hydrogen is currently considered costly and complex by the automotive sector, Germany's mechanical engineering industry underscores its expertise in hydrogen storage and electrolysis and advocates for increased government support. While hydrogen remains less competitive for passenger vehicles, it holds significant potential for trucks, buses, and industrial applications, with costs projected to decrease as production scales (Simonazzi et al., 2020).
Motorization is synonymous with progress (Barakati et al., 2024). As a result, govern-

ments implement policies to increase vehicle accessibility, leading to rising vehicle ownership trends in developing nations and regions experiencing population growth and economic prosperity (Tao et al., 2021; Yang, 2019). In this context, a report by McKinsey & Company (2016) predicts that regulatory pressure on vehicle emissions will intensify and that adoption rates for alternative fuel vehicles will be highest in densely populated cities with stringent emission standards and consumer incentives for sustainable mobility options.



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Digital transformation

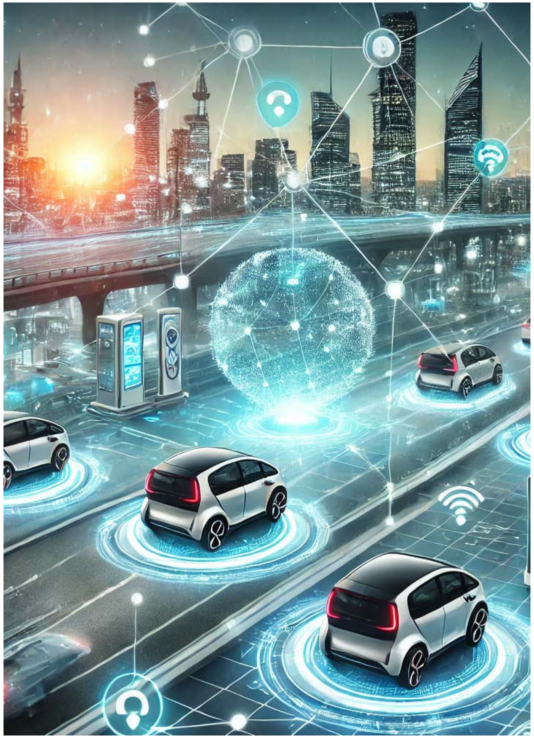
Digital Transformation in the Automotive Industry: A Complex Ecosystem of Connectivity and Innovation

The digitalization of the automotive industry is accelerating as manufacturers and technology providers work to transform vehicles into highly interconnected systems. This shift is driven by urbanization and the expansion of digital infrastructures, which are reshaping vehicle connectivity and urban transportation needs. As cities become increasingly networked, automobile manufacturers are compelled to innovate, creating vehicles that are more connected to the internet and capable of communicating with one another to enhance urban mobility (Automotive Skills Development Council: Automotive Training Certification Centre - ASDC, n.d.).

The push for interconnected vehicles coincides with broader technological trends, including the rise of shared, autonomous, and electric vehicles (Llopis-Albert et al., 2021). These innovations collectively represent disruptive forces in the automotive sector, bringing forth “diverse mobility, autonomous driving, electrification, and connectivity” as core trends that are expected to significantly reshape industry revenue streams and user expectations (McKinsey & Company, 2016, p. 5). Notably, the convergence of these technology-driven trends is anticipated to expand revenue pools by up to 30%, with new services and business models like car-sharing and vehicle connectivity leading the way (McKinsey & Company, 2024b).

The adoption of shared autonomous vehicles (SAVs) demonstrates the potential impact of these changes. Studies indicate that each shared vehicle could replace up to 13 private cars, reducing road congestion and minimizing the need for parking spaces (Zhang et al., 2015), parking space competes with urban land for more essential and pedestrian-friendly uses (Mitchell et al., 2010). Moreover, SAVs are projected to make transportation more economical, with savings estimated at around $6,000 annually for American households participating in shared mobility programs (Anderson et al., 2016). In a case study in

Singapore, a fleet of SAVs demonstrated the feasibility of meeting personal mobility needs with a vehicle pool size that is one-third of the total passenger vehicles currently in use, further underscoring the efficiency of shared autonomous transportation models (Spieser et al., 2014).
The digital transformation in automotive extends beyond connectivity and shared mobility; it also s an industry-wide shift toward automation and artificial intelligence (AI). These technologies are integral to autonomous driving systems, data analytics, and vehicle maintenance, which enhance both performance and user experience (Celaschi, 2015). Currently, approximately 64% of companies in the mobility sector are developing AI applications to optimize these functions, transforming vehicles into platforms where users can access real-time, personalized navigation and other digital services (McKinsey & Company, 2024b). Advanced driver-assistance systems (ADAS) are expected to facilitate this transition by enabling gradual automation, preparing both consumers and regulatory bodies for an era in which cars can



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assume greater control from drivers (McKinsey & Company, 2016).
This transition is not without its challenges. Concerns over pricing, security, and consumer understanding are pivotal in shaping the pace of ADAS and autonomous technology adoption, while regulatory pressures aimed at reducing emissions are also accelerating shifts toward electrification and sustainability in vehicle manufacturing (Anirudh et al., 2022).
These technological advancements are, in turn, driving automakers to explore partnerships across sectors. Strategic alliances, such as those between Volkswagen and Argo AI and Fiat Chrysler and Waymo, illustrate that traditional automotive expertise alone is insufficient to navigate digital transformation (Simonazzi et al., 2020).
In conclusion, digital transformation in the automotive industry is fostering an ecosystem of connectivity, autonomy, and shared mobility. These changes are expected to yield not only a more sustainable, economically viable mode of transportation but also a more personalized and responsive driving experience. For both automakers and consumers, the evolution toward digital automotive solutions presents unprecedented opportunities and challenges, making adaptive strategies essential for navigating this dynamic landscape.

how might we decrease emissions, deriving from **energy** production plants and the **transportation** sector, in order to mitigate the negative effects on the ecosystem?

Hydrogen

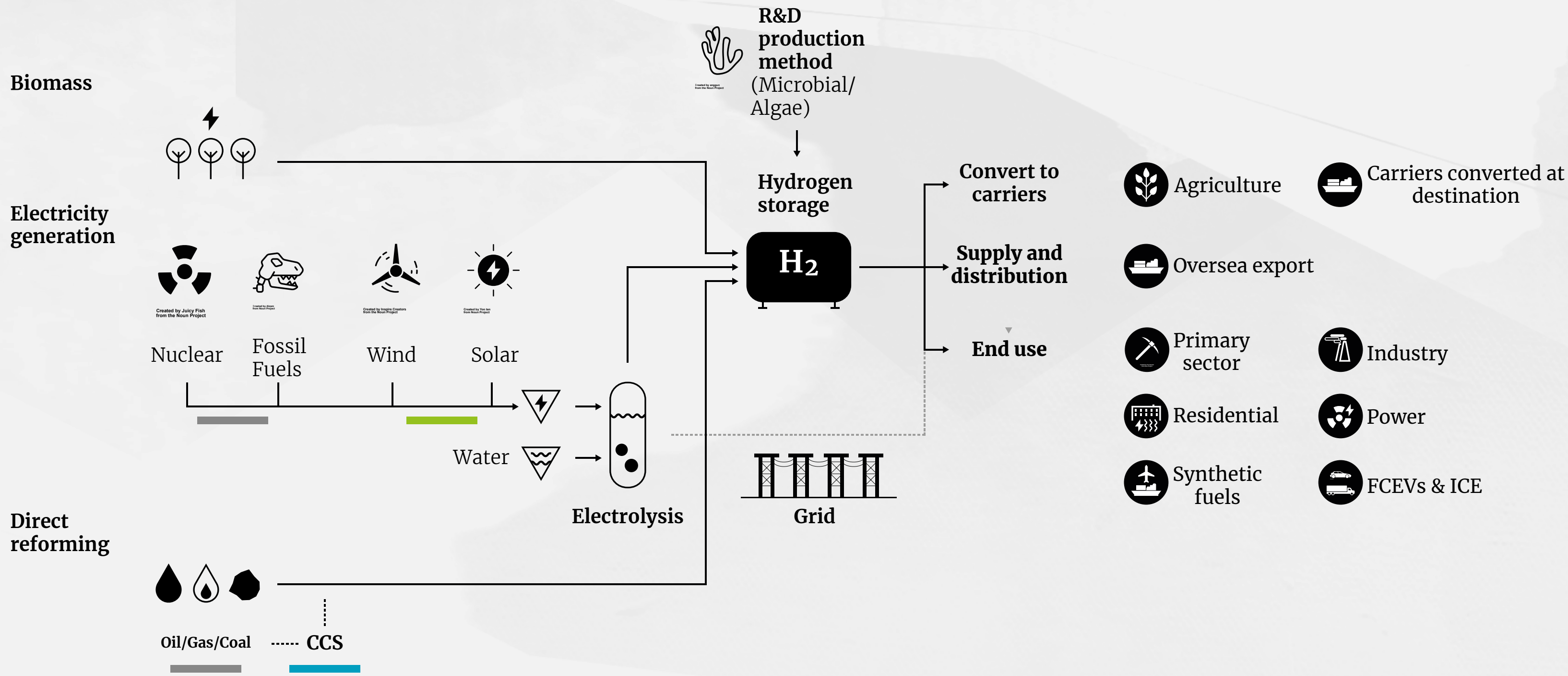
Picture by David Kopacz retrieved from Pexels. Hydrogen is one of the most abundant elements in the Universe and is the fuel of stars.

Hydrogen Scenario Analysis

Hydrogen and battery electric vehicles (BEVs) are poised to collaboratively drive the decarbonization of the private transportation sector. Hydrogen's role as a zero-emission fuel source offers dual functionality: it could power fuel cell electric vehicles (FCEVs) directly and serve as an energy carrier for generating electricity for BEVs. Presently, however, the production of BEV batteries requires considerable energy, much of which is derived from fossil fuels, thereby offsetting some environmental benefits by generating emissions indirectly (Albatayneh et al., 2023). Additionally, the manufacturing of batteries relies heavily on finite metal resources, and the value of BEVs often declines as batteries age, despite advancements in battery efficiency and energy density. Projections suggest that battery production costs may decrease by approximately 52% by 2030, enhancing the economic viability of BEVs over time (Colthorpe, 2021). Simultaneously, fuel cells present a solution to range anxiety, offering drivers longer travel distances on a single charge and a refuelling process that is faster than recharging batteries (Albatayneh et al., 2023). As the learning curve for BEVs continues to advance alongside expanding infrastructure, electric vehicles are becoming more accessible and affordable. This trend is expected to extend to hydrogen fuel cells, with continued technological improvements and scaling likely to reduce costs significantly in the coming years (Albatayneh et al., 2023). Together, hydrogen and electric vehicle technologies hold the potential to replace gasoline and diesel-powered vehicles, significantly reducing harmful emissions within the transportation sector. It is crucial that policymakers prioritize a sustainable transition that considers economic, social, and environmental impacts to ensure accessibility and equity in adopting these clean energy solutions. Hydrogen fuel represents a promising alternative to carbon-based fuels, particularly within the private transport sector, where it can address pressing environmental and energy challenges (Edwards et al., 2008). Current energy scenarios project that hydrogen's role will range from niche applications to widespread integration across transportation, industry, and residential sectors. In an ideal "Global Sustainability" scenario, hydrogen could fulfil up to 100% of transport energy demand by 2050, contingent on substantial investments in infrastructure and production innovations (Dutton et al., 2004)). The global demand for energy is projected to continue its upward trajectory, primarily driven by rapid economic development in China, India, and other developing nations, with ICE vehicles accounting for one third of the annual U.S.A. energy consumption(Mitchell et al., 2010) This rising demand is likely to exert upward pressure on oil prices (Barbir, 2009). Moreover, oil and gas reserves are distributed unevenly across the globe, with a significant concentration in politically unstable regions, particularly in the Middle East and certain Arab countries. This geographic concentration of energy resources is expected to persist as a source of political tension and may even lead to conflicts over remaining reserves (Barbir, 2009). Traffic congestion exacerbates energy consumption and environmental degradation. In 2009, congestion caused urban

Americans to travel 4.8 billion hours more and to purchase an extra 3.9 billion gallons of fuel, resulting in a congestion cost of $115 billion (Schrank et al., 2011). The average vehicle occupancy remains low, with an average of 1.67 persons per trip according to the 2017 National Household Travel Survey (Federal Highway Administration [FHWA], 2017). Low occupancy rates contribute to increased numbers of vehicles on the road, intensifying traffic congestion and associated emissions. Vehicle exhaust emissions have been widely proven to be a main source of urban air pollution. Urban sprawl leads to an increase in both commuting distance and commuting time, which in turn increases the utilization rate of private cars and further aggravates air pollution (Tao et al., 2021). The rising rate of car ownership exacerbates fuel consumption and air quality issues. Hydrogen is a fuel widely considered a promising solution to current energy challenges. It is inherently non-toxic, and its combustion produces no pollution or greenhouse gases (Barbir, 2009). Hydrogen produced from non-fossil-fuel sources is sustainable and renewable, enabling renewable energy integration into transport, enhancing energy security, supporting local economies, and promoting distributed energy generation infrastructure (Edwards et al., 2008). Hydrogen may supply up to 18% of global energy consumption by 2050 and help cut yearly carbon emissions by six gigatons (Albatayneh et al., 2023). The United States Department of Energy will invest up to USD 100 million over five years (2022–2026) in hydrogen and fuel cell research and development (Albatayneh et al., 2023). The coming decade will see greater use of "Green Power" to ensure less dependence on fossil fuels and to prevent environmental degradation (Jain, 2009). Increasing regulatory pressure against vehicle emissions is accelerating the adoption of cleaner energy sources. Adoption rates will be highest in developed, dense cities with strict emission regulations and consumer incentives (McKinsey & Company, 2016). Education is the best way to spread the new paradigm. People should be knowledgeable about issues of energy, environment, and their values, interactions, and potential consequences, so that they can make ap-

Hydrogen production



Benefits **Society** **Environment** **Economy** **Energy security**

propriate and timely decisions (Barbir, 2009). Air pollution causes nearly 7 million deaths annually, with the Middle East, Northern Africa, and China being the most affected regions (World Health Organization [WHO], n.d.; Ritchie & Roser, 2024). Pollutants such as particulate matter (PM), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) have detrimental health effects (WHO, 2024b). Policies aimed at reducing air pollution include promoting clean technologies, improving urban planning, and transitioning to low-emission transportation options (WHO, 2024b). Hydrogen plays a crucial role in the transportation sector. Transitioning to hydrogen fuel can significantly reduce pollutants, especially in urban areas where vehicle emissions are a primary source of air pollution. The average global temperature has increased by almost 1°C in the last century, with climate change posing significant environmental problems (Midilli et al., 2005; NASA, 2024).

The combustion of fossil fuels for transportation is a key contributor to greenhouse gas emissions, and hydrogen offers a clean alternative. In conclusion, hydrogen presents a viable and sustainable alternative to fossil fuels for the transportation sector. Its adoption can address energy security concerns, reduce greenhouse gas emissions, and mitigate the health impacts of air pollution. Strategic investments, regulatory support, and public education are essential to facilitate the transition to a hydrogen-based energy system. The pathways for hydrogen adoption vary based on different geopolitical and economic contexts. Dutton et al. (2004) studied four scenarios: The "World Markets" scenario projects that hydrogen would remain a niche fuel, primarily driven by private market forces with limited regulation. Under a "Provincial Enterprise" model, hydrogen adoption is encouraged by national self-sufficiency goals, particularly within transportation. The "Global Sustainability" pathway envisions hydrogen as a central energy carrier, integrated into transportation and residential sectors to support broad sustainability objectives. Finally, the "Local Stewardship" scenario anticipates community-driven hydrogen use, emphasizing local energy resilience and decentralized applications. To support these scenarios, policies promoting hydrogen for both public transportation and light goods vehicles by 2050 are essential, alongside investments in refuelling infrastructure and fuel cell technology (Lovins & Cramer, 2004). As an energy carrier, hydrogen has notable environmental advantages, including its ability to emit only water as a byproduct during fuel cell operation. Its widespread adoption would contribute to a substantial reduction in urban air pollutants and greenhouse gas emissions, bolstering local air quality and supporting long-term decarbonization goals (Edwards et al., 2008). In regions like India, for example, a hydrogen-based energy economy could reduce reliance on Middle Eastern oil imports, enhance energy security, and create lasting scientific and industrial employment opportunities (Jain, 2009). Additionally, hydrogen offers a clean alternative to petroleum, which often requires invasive extraction methods that harm ecosystems. Unlike oil spills, which can devastate marine life, hydrogen disperses quickly into the atmosphere, posing minimal environmental risk (Jain, 2009).

Hydrogen production and storage present significant technical challenges. Currently, hydrogen is largely produced from fossil fuels; however, a shift to renewable-based electrolysis could make hydrogen a fully sustainable fuel (Ball & Wietschel, 2009). Efficient storage solutions—such as high-pressure tanks, cryogenic storage, and solid-state methods—are critical for its widespread adoption. To achieve parity with gasoline in the market, production costs for hydrogen and fuel cells must decrease significantly, alongside investments in an efficient infrastructure for distribution and refueling (Albatayneh et al., 2023). Projections indicate that hydrogen could supply up to 18% of global energy needs by 2050, potentially reducing annual carbon emissions by six gigatons (Albatayneh et al., 2023). However, challenges remain, including the need to lower hydrogen production costs, enhance storage efficiency, and improve the affordability and durability of fuel cells (Barbir, 2009). For hydrogen-fueled vehicles to become viable in the consumer market, a robust, accessible refueling infrastructure must be developed, similar to the advancements achieved in battery electric vehicles (Lovins & Cramer, 2004). In summary, the successful integration of hydrogen into the global energy system could significantly enhance energy security, reduce environmental impact, and provide socioeconomic benefits. Nevertheless, realizing a hydrogen-based economy will depend on coordinated investments in technology, infrastructure, and policy.

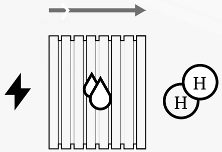
Hydrogen production

Hydrogen has emerged as a promising energy carrier for sustainable transportation, attracting significant attention as the global automotive and energy sectors transition towards greener alternatives. Its high energy density and zero-emission profile make it a viable alternative to traditional fossil fuels in transportation. Fuel Cell Electric Vehicles (FCEVs) exemplify this potential by using hydrogen to generate electricity in fuel cells, emitting only water vapor as a byproduct. This positions hydrogen as a competitive option for applications requiring long ranges and heavy loads, such as freight trucks, trains, and ships (Sharma & Ghoshal, 2015). Additionally, microbial or algae hydrogen production offers a decentralized and renewable solution for hydrogen supply. These systems can complement existing renewable energy infrastructures and provide localized hydrogen production for FCEVs in regions lacking large-scale hydrogen networks (Bhatia et al., 2022; Xiang et al., 2020). Hydrogen production from fossil fuels, particularly natural gas via Steam Methane Reforming (SMR), remains the most common method, accounting for approximately 80% of global hydrogen production (Sharma & Ghoshal, 2015). While economically viable, SMR contributes to significant carbon emissions, limiting its sustainability. Blue hydrogen, derived from SMR coupled with carbon capture and storage (CCS), presents a cleaner but transitional solution (Albatayneh et al., 2023). Coal gasification and partial oxidation processes also produce hydrogen but are associated with high emissions and environmental concerns (Edwards et al., 2008).

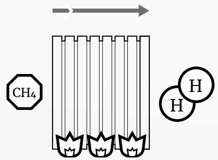
Electrolysis of water, powered by renewable energy sources such as wind, solar, and hydropower, is considered the cleanest and most sustainable method for hydrogen production (Sharma & Ghoshal, 2015). Green hydrogen, produced entirely through electrolysis using renewable energy, eliminates greenhouse gas emissions, offering a pathway to zero-carbon energy systems. Although cost-prohibitive today, declining renewable energy costs are expected to make electrolysis more competitive, with future hydrogen costs projected to range between \$3-\$4/kg (Edwards et al., 2008). Hydrogen can also be produced from biomass via thermochemical or biochemical processes, such as gasification and microbial electrolysis cells (Xiang et al., 2020). Biological production methods leverage microorganisms to break down organic material, providing a cost-effective and sustainable source of hydrogen. These methods align with circular economy principles by utilizing agricultural waste or other organic substrates for energy generation (Bhatia et al., 2022). Technologies like high-temperature electrolysis and photoelectrochemical water splitting are emerging as innovative solutions to enhance hydrogen production efficiency. Nuclear energy also offers potential for large-scale hydrogen production via thermal conversion or high-temperature electrolysis, though concerns about radioactive waste and safety persist (Edwards et al., 2008).

Hydrogen-powered FCEVs highlight hydrogen's zero-emission potential and its suitability for heavy-duty and long-range applications, further underscoring its pivotal role in future transportation systems (Sharma & Ghoshal, 2015). However, the hydrogen economy faces several challenges. The current production cost of green hydrogen, ranging from $5–$7/kg, is significantly higher than fossil-based hydrogen, which costs $1–$2/kg. Advancements in electrolysis technology and decreasing renewable energy costs are expected to bridge this gap (Edwards et al., 2008). Additionally, establishing a global hydrogen supply chain requires substantial investment in production facilities, storage solutions, and distribution networks. Innovative technologies, such as liquid organic hydrogen carriers (LOHCs), are being developed to facilitate transportation and storage (Albatayneh et al., 2023). Energy efficiency also presents a challenge, as energy losses in converting electricity to hydrogen and back into electricity impact its competitiveness. Improving the efficiency of electrolysis and fuel cell technologies is critical for hydrogen's viability as an energy carrier (Sharma & Ghoshal, 2015).

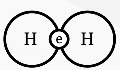
Despite these challenges, hydrogen represents a transformative opportunity for the transportation sector, offering a sustainable and versatile alternative to fossil fuels. Projections indicate that hydrogen could supply up to 18% of global energy needs by 2050, potentially reducing annual carbon emissions by six gigatons (Albatayneh et al., 2023). Strategic investments in research, development, and international cooperation are essential to realize hydrogen's full potential as a cornerstone of the 21st-century energy economy. Hydrogen's adoption can address energy security concerns, reduce greenhouse gas emissions, and mitigate the health impacts of air pollution. By addressing economic, technological, and infrastructural challenges, hydrogen can play a central role in achieving a zero-emission future and fostering a sustainable global energy system.



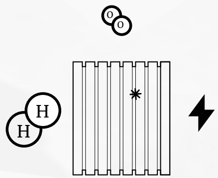
During H_2 production electrolyzers use electricity, derived from wind or solar power, to produce green H_2 and O_2 from H_2O.
This process is *carbon-free*



Today the main technology for H_2 production, is Steam Methan Reforming (SMR).
This process has emissions.



Hydrogen stores ***electric energy*** via the binding electrons of H_2 molecules.



Fuel cells split the electron from H_2, the resulting energy is converted into electricity. For this to happen there needs to be O_2. The byproduct of this reaction is H_2O.

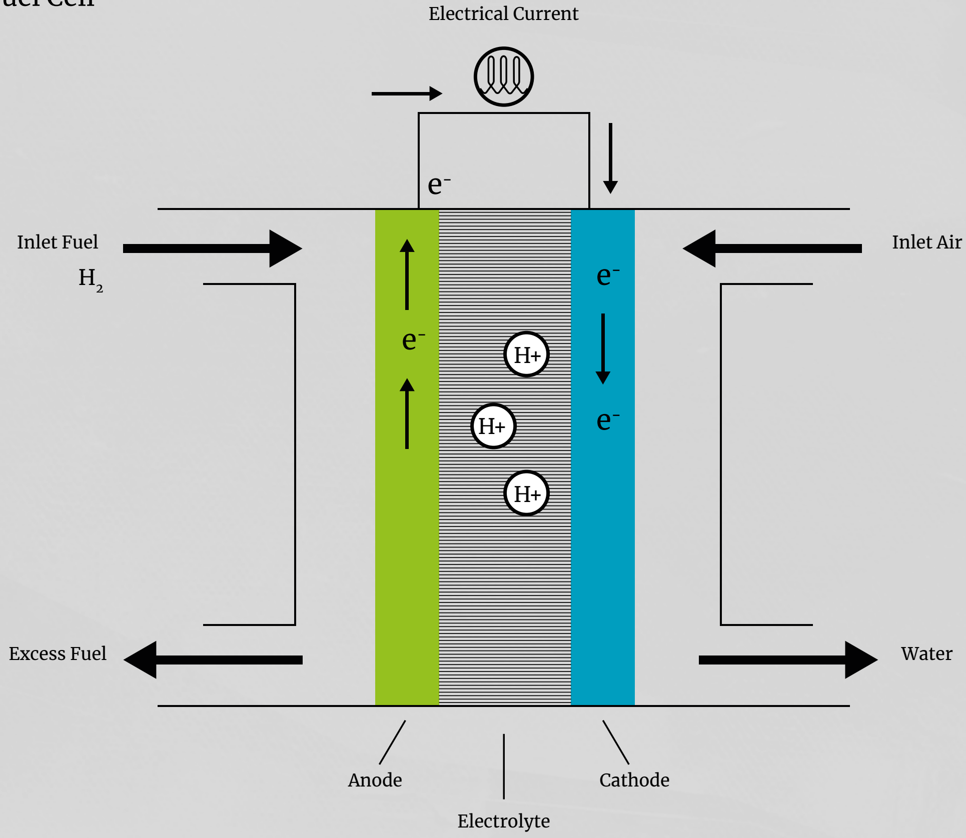
Comparative Analysis of BEVs and FCEVs: The Role of Hydrogen in Sustainable Transportation

Hydrogen has emerged as a versatile and promising energy carrier capable of powering a wide range of applications, from electric vehicles to electronic devices and fuel cells. Unlike traditional batteries, hydrogen fuel cells do not require external recharging and remain functional as long as hydrogen is supplied, making them an efficient and sustainable alternative for various energy needs (Albatayneh et al., 2023). One significant advantage of Battery Electric Vehicles (BEVs) is the accessibility of charging infrastructure; any standard electrical outlet can serve as a charging point. In contrast, Fuel Cell Electric Vehicles (FCEVs) require the establishment of entirely new hydrogen refueling infrastructure, which poses a significant hurdle for widespread adoption (Albatayneh et al., 2023). FCEVs utilize hydrogen to produce electricity through a fuel cell, generating only water as a byproduct, making them an environmentally friendly option. On the other hand, BEVs rely on lithium-ion batteries to store electricity, which powers their electric motors. The smaller battery in FCEVs compared to BEVs lowers vehicle weight, enhancing efficiency and performance (Albatayneh et al., 2023). Compressed hydrogen's higher energy density and the ability to refuel within minutes give FCEVs a distinct advantage for long-distance travel compared to BEVs. However, advancements in battery technology have significantly improved BEV performance. Modern BEVs can achieve real-world ranges exceeding 400 kilometers, with the latest models employing 800V battery systems capable of charging up to 200 kilometers in approximately 15 minutes (Albatayneh et al., 2023). While BEVs have become popular for their high efficiency, low emissions, and lower operating costs, they face challenges such as limited range, long charging times, and the weight and cost of batteries. Conversely, FCEVs' reliance on hydrogen production and distribution infrastructure, as well as associated costs, remains a critical factor limiting their market penetration (Barbir, 2009). Both BEVs and FCEVs are benefiting from global regulatory frameworks aimed at reducing greenhouse gas (GHG) emissions and promoting cleaner vehicles. Tax credits, subsidies, and other incentives have been instrumental in driving demand for these technologies. Governments and industries are increasingly recognizing hydrogen's potential to decarbonize transportation while reducing pollution from traditional fossil fuels (Albatayneh et al., 2023; Barbir, 2009). Hydrogen is a synthetic fuel that can be produced from diverse energy sources, including fossil fuels, nuclear energy, and renewables. Its versatility extends to nearly all sectors currently reliant on fossil fuels, with transportation emerging as a critical area where hydrogen can deliver immediate environmental benefits (Barbir, 2009). The success of hydrogen as a sustainable fuel hinges on advancements in production, distribution, and cost reduction technologies, all of which are pivotal for its integration into the energy economy (Albatayneh et al., 2023). Hydrogen and electricity are poised to play complementary roles in the future of sustainable transportation —to quote Mitchell et al. (2010) "any renewable pathway to electricity is a renewable pathway to hydrogen [...] each technology is important to the success of the other". BEVs are currently more accessible due to existing infrastructure and technological maturity, whereas FCEVs offer unique advantages for long-distance and heavy-duty applications. Strategic investments in hydrogen infrastructure and continued innovation in both technologies are essential to achieving a decarbonized transportation sector.

Fuel Cells: Key Technology in the Hydrogen Economy

Fuel cells represent a cornerstone of sustainable energy technologies, offering remarkable versatility and efficiency across diverse applications. From powering electric vehicles to functioning in combined heat and power (CHP) systems, fuel cells demonstrate their potential to revolutionize the transportation and energy sectors. A hydrogen fuel cell operates by harnessing the chemical reaction between hydrogen and oxygen to produce electricity, with water vapor and heat as the only byproducts. The fundamental structure includes an anode, a cathode, and an electrolyte membrane. Hydrogen gas supplied to the anode undergoes electrochemical dissociation, releasing electrons and forming positively charged hydrogen ions.. The electrons travel through an external circuit, generating electric current, while the hydrogen ions migrate through the electrolyte to the cathode, where they combine with oxygen and the electrons to form water vapor and heat (Albatayneh et al., 2023; Edwards et al., 2008). Proton Exchange Membrane (PEM) fuel cells are particularly suited for automotive applications. These systems operate at temperatures of 80–85°C, allowing for efficient electricity generation. However, the limited dispersion of waste heat necessitates larger radiators, increasing cost, weight, and aerodynamic drag (Lovins & Cramer, 2004). Fuel cells can achieve efficiencies of up to 65%, significantly surpassing the 25% efficiency of ICEs. Moreover, fuel cells are not constrained by the limitations of the Carnot cycle, enabling them to convert fuel into electricity with twice the efficiency of traditional engines (Edwards et al., 2008). In combined heat and power (CHP) systems, fuel cells can achieve overall efficiencies exceeding 85% by utilizing both electrical and thermal energy (Yu et al., 2023). Such systems are particularly valuable in stationary applications, further enhancing their sustainability (US EPA, 2024). Hydrogen as a fuel also offers unparalleled environmental benefits. Unlike fossil fuels, hydrogen combustion or use in fuel cells produces no carbon emissions, making

Fuel Cell


Electrical Current
e⁻
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Inlet Air
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H+
H+
H+
e⁻
Excess Fuel
Water
Anode
Electrolyte
Cathode

it a critical technology for addressing climate change and improving air quality (Hordeski, 2008). The adoption of hydrogen energy could profoundly benefit Earth's biological systems by reducing pollutants that negatively impact ecosystems. In the transportation sector, Fuel cells provide a compelling alternative to batteries. While BEVs leverage the existing electrical grid, PEM fuel cells mitigate long recharging times by offering rapid refueling. Instead, they offer rapid refueling and increased energy density, making them ideal for long-distance travel and heavy-duty applications (Albatayneh et al., 2023). However, consumer adoption remains a challenge, with concerns about vehicle costs, driving range, and infrastructure availability (Llopis-Albert et al., 2021). Fuel cells also alleviate grid pressures associated with simultaneous vehicle charging during peak times, a growing concern as BEV adoption increases (Chen et al., 2016). As the infrastructure for hydrogen production and distribution develops, FCEVs are poised to complement BEVs in creating a comprehensive zero-emission transportation network. Despite their advantages, fuel cells face several barriers to widespread adoption. Building a hydrogen production and refueling network requires significant investment, while the high costs of PEM fuel cells and hydrogen production technologies remain prohibitive for mass-market adoption. Additionally, the reliance on rare and expensive materials, such as platinum catalysts, contributes to the high production costs of fuel cells. Future research must focus on reducing these costs through material innovation, improving the efficiency of hydrogen production, and developing scalable infrastructure solutions. Fuel cells represent a transformative technology in sustainable energy, delivering superior efficiency and environmental advantages. By overcoming current limitations, such as infrastructure and cost challenges, hydrogen-powered fuel cells can become a cornerstone of the global energy transition, playing a pivotal role in decarbonizing transportation and other energy-intensive sectors.

The Safety of Hydrogen as a Fuel: A Comprehensive Review

Hydrogen has emerged as a promising alternative to fossil fuels, offering the potential for significant reductions in greenhouse gas emissions, but concerns surrounding its safety have often been a barrier to widespread adoption. Hydrogen possesses unique physical and chemical properties that set it apart from traditional fossil fuels like gasoline and methane. Its low density, which is only 6.9% that of air, and high diffusivity, which is four times greater than air and twelve times greater than gasoline, enable it to dissipate rapidly in the event of a leak, significantly reducing the risk of fire or explosion. This characteristic is in stark contrast to heavier fuels, which form persistent and hazardous flammable clouds when leaked (Veziroğlu & Şahin, 2019; Sharma & Ghoshal, 2015). Additionally, hydrogen is inherently non-toxic and environmentally benign. Unlike fossil fuels, hydrogen leaks do not threaten soil or water quality, and its combustion produces only water vapor, making it one of the cleanest energy sources available (Hordeski, 2008; Sharma & Ghoshal, 2015). Hydrogen's fire and explosion risks are mitigated by its rapid dispersion properties, with studies showing that hydrogen has a safety factor of 1, which is higher than methane (0.8) and gasoline (0.53). While hydrogen's flammability range is wider than that of traditional fuels, advancements in storage and transport technologies, including leak-proof containment systems and advanced sensors, have effectively mitigated these risks (Edwards et al., 2008; Hordeski, 2008). Public perception of hydrogen safety is often skewed by historical incidents like the Hindenburg disaster, which are frequently misinterpreted. However, modern hydrogen technologies, as demonstrated by NASA's research and automotive advancements from companies like BMW, demonstrate that hydrogen can be safer than gasoline in many accident scenarios. Hydrogen's rapid dispersion upon leakage minimizes the likelihood of prolonged fires, further enhancing its safety profile (Hordeski, 2008).

Hydrogen can be transported safely through

pipelines and stored in pressurized tanks or cryogenic systems, with advances in material sciences enhancing the durability and reliability of storage systems to reduce leakage risks during transport (Edwards et al., 2008; Sharma & Ghoshal, 2015). In confined spaces, hydrogen-driven vehicles pose a lower risk compared to gasoline-powered vehicles. Gasoline leaks typically result in extensive flammable vapor clouds, while hydrogen's rapid dispersal, combined with its lack of toxic emissions, makes it a safer choice for urban and industrial applications (Sharma & Ghoshal, 2015; Veziroğlu & Şahin, 2008).
The integration of hydrogen into the energy economy is guided by stringent international standards and regulations. These protocols cover hydrogen refueling stations, vehicle storage systems, and transportation networks, ensuring safety across all aspects of hydrogen utilization (Edwards et al., 2008; National Research Council, 2008). Hydrogen's unique properties, such as its rapid diffusivity, non-toxic nature, and clean combustion, position it as a superior alternative to conventional fuels in terms of safety and environmental impact. By addressing misconceptions about hydrogen safety and continuing to innovate in storage and transport technologies, hydrogen can play a pivotal role in the global transition to sustainable energy. Its ability to provide a safer, cleaner, and more efficient energy solution underscores its potential as a cornerstone of the future energy landscape.

System	Density (g/cm^3)	H atoms per unit volume ($\times 10^{22}/cm^3$)	Weight % hydrogen
Liquid H_2	0.07	4.2	100.0
Gas	0.008	0.5	100.0
H_2O (Liquid)	1.0	6.7	11.2
H_2O (Liquid)	0.6	6.7	18.0
$FeTiH_2$	5.6	6.2	1.9
$LaNi_5H_6$	6.5	7.0	1.4
VH_2	5.0	11.2	2.1
MgH_2	1.4	6.7	7.6

Table 1: Hydrogen concentration in different systems. (Jain, 2009)

Hydrogen Storage: Challenges, Solutions, and Future Directions

The efficient storage of hydrogen is a cornerstone of its utility as a clean energy carrier, particularly in the transportation sector. Hydrogen's low density and high energy per unit mass necessitate innovative storage methods to achieve technical and economic viability.

Hydrogen storage is categorized into three main approaches: high-pressure gas storage, cryogenic liquid storage, and solid-state storage, each presenting unique challenges.

1. High-Pressure Gas Storage:
   Hydrogen is compressed to pressures of 700–800 bar in composite tanks. While this method is widely used in fuel cell vehicles, it requires significant energy input—up to 20% of hydrogen's energy content for compression. The public perception of safety surrounding high-pressure storage remains a challenge (Dutton et al., 2004; Sharma & Ghoshal, 2015).

2. Cryogenic Liquid Storage:
   Hydrogen is liquefied at cryogenic temperatures (21 K), allowing for higher energy density. However, the liquefaction process consumes up to 40% of hydrogen's energy content. This method is energy-intensive and faces hurdles related to thermal insulation and boil-off losses during transport (Edwards et al., 2008; Sharma & Ghoshal, 2015).

3. Solid-State Storage:
   Hydrogen can be stored in metal hydrides, adsorbed on materials with high surface areas, or chemically bonded in compounds. Metal hydrides provide compact and safe storage at ambient conditions, acting as a "sponge" for hydrogen absorption and desorption under slight temperature and pressure variations. Nanostructured materials and hybrid systems hold potential for improving storage efficiency (Jain, 2009; Sharma & Ghoshal, 2015).

Key Requirements for Hydrogen Storage Systems

Effective hydrogen storage systems must meet the following criteria:

1. High Hydrogen Density:
   To ensure adequate range for fuel cell vehicles.

2. Reversible Release/Charge Cycles:
   Compatibility with fuel cell temperatures (70–100°C).

3. Rapid Kinetics:
   Fast hydrogen release and uptake with minimal energy barriers (Albatayneh et al., 2023; Dutton et al., 2004).

Energy Penalties and Public Perception

The energy penalties associated with compression and liquefaction remain significant, affecting hydrogen's overall energy efficiency. For example, compression consumes approximately 20% of hydrogen's energy content.
Liquefaction consumes up to 40% of hydrogen's energy content (Sharma & Ghoshal, 2015; Edwards et al., 2008).

Public perception and acceptability of pressurized and cryogenic hydrogen storage remain critical barriers. Alternatives such as solid-state storage and chemical bonding methods are gaining traction due to their inherent safety and efficiency (Sharma & Ghoshal, 2015; Jain, 2009).

Table 2: Hydrogen storage comparison.

Method	Operating Conditions	Energy Penalty	Advantages	Challenges
High-Pressure Gas	700–800 bar	20%	Established technology	Safety concerns
Cryogenic Liquid	21 K	40%	High energy density	Insulation, boil-off losses
Metal Hydrides	Ambient conditions	Minimal	Compact, safe	Weight, cost of materials
Nanostructures	<100 K	TBD	High potential for efficiency	Experimental
Chemically Bonded	Ambient pressure	TBD	Long-term storage	Complex recovery processes

Advances in Storage Technologies

Nanotechnology presents transformative opportunities for hydrogen storage. Nanostructured materials with high surface areas enable multifunctional performance, such as low-energy dissociation of hydrogen molecules and rapid diffusion of atomic hydrogen. These advancements may address the challenges of energy penalties and public perception, facilitating scalable hydrogen storage solutions (Sharma & Ghoshal, 2015; Jain, 2009).

Fuel	Specific Energy (kWh/kg)	Energy Density (kWh/dm³)
Liquid hydrogen	33.3	2.37
Hydrogen (200 bar)	33.3	0.53
Liquid natural gas	13.9	5.6
Natural gas (200 bar)	13.9	2.3
Petrol	12.8	9.5
Diesel	12.6	10.6
Coal	8.2	7.6
NH_3 BH_3	6.5	5.5
Methanol	5.5	4.4
Wood	4.2	3.0
Electricity (Li-ion battery)	0.55	1.69

Table 3: Energy content comparison of different fuels (Edwards et al., 2009).

Conclusion on Hydrogen Storage

In conclusion, regarding this energy source it is possible to state that:

Hydrogen possesses the highest gravimetric energy density among all energy carriers, with a lower heating value (LHV) of 120 MJ·kgğ at 298 K, compared to 44 MJ·kgğ for gasoline (Allendorf et al., 2022). When used in a fuel cell, hydrogen produces only water as a byproduct, making it a pollution-free energy source. Additionally, hydrogen fuel cell engines exhibit significantly higher efficiency, converting approximately 65% of the fuel into usable energy, whereas conventional internal combustion engines utilizing fossil fuels achieve only about 25% efficiency (Edwards et al., 2008).

For instance, over a driving distance of 100 km, a conventional vehicle with an internal combustion engine (ICE) typically consumes around 6 kg of gasoline, while a hydrogen-powered ICE requires only 2 kg of hydrogen. This efficiency is further enhanced in fuel cell electric vehicles (FCEVs), which need just 1 kg of hydrogen to cover the same distance (Schlapbach & Züttel, 2001).Zhang and Wu (2017) highlight hydrogen as "a potential energy source to effectively address the future energy crisis," emphasizing its role as a safe, clean, and renewable alternative. However, the intermittency of renewable power sources underscores the necessity for large-scale energy storage solutions capable of sustaining extended periods of energy demand. The low volumetric energy density of hydrogen remains a major barrier to its widespread adoption. At the 700-bar pressure utilized in commercially available fuel cell electric vehicles, hydrogen's volumetric energy density is only 27 gH_2·Lğ falling short of the 50 gH_2·Lğ ultimate target set by the U.S. Department of Energy (DOE) for light-duty vehicles (DOE, 2017)

In addressing hydrogen storage challenges, trade-offs between hydrogen release thermodynamics and reversible capacity are critical considerations, particularly when evaluating metal hydrides for transportation applications. Minimizing both storage system volume and weight remains a paramount objective in achieving practical and efficient hydrogen-powered mobility solutions.

Metal hydrides excel here; their volumetric capacity is at least double 700-bar pressurized gas. Hydrogen stored in metal hydrides is also safer, and weight is not a concern. Jain (2009) with Zhang & Wu (2017) assert that it is the only practical option for applications such as stationary power, portable power, and transportation. In their paper, they discuss the characteristics of various hydride systems, identifying Li-Mg-N-H systems, which have a high hydrogen storage capacity (> 5 wt% H), as particularly promising.
The application of nanotechnologies to hydrogen storage for light-duty vehicle applications offers significant benefits in terms of both the quantity of hydrogen stored and the energy carrier's properties within Li-Mg-N-H systems (B. Zhang & Wu, 2017). Zhang and Wu (2017) further emphasize that "among these materials, Li-Mg-N-H combination systems are regarded as one of the most promising candidates for vehicular applications due to their relatively high capacity and theoretically moderate operating temperature."

Nanotechnology can enhance the surface properties of hydrogen storage tanks through the incorporation of ultra-high surface area nanoporous materials into metal hydrides. These advancements improve the mechanical stability, rigidity, and load-bearing capacity of the hydride, significantly increasing the efficiency of hydrogen storage within these systems.
The use of nanostructured materials, particularly ultra-high surface area nanoporous materials, enables greater absorption and storage efficiency of hydrogen (Saeed et al., 2024).
Hydrogen presents a viable alternative to battery-electric propulsion for larger vehicles, such as family-sized cars and buses.

The Abundance and Historical Significance of Hydrogen: A Cosmic and Terrestrial Perspective

Hydrogen, the simplest and most abundant element in the universe, makes up approximately 75% of baryonic matter, while helium accounts for the remaining 25% (Albatayneh

Table 4: Metal hydrides properties:
(Target Explanation Document: Onboard Hydrogen Storage for Light-Duty Fuel Cell Vehicles (US DOE, 2017).)

Mobility						
Light-duty vehicle	Small	0.008	0.078	0.76	365	0.56
Long-haul truck	Medium	0.24	0.8	60	365	5.4
Refuel medium-duty fleet	Large	0.83	NA	1,000	365	41.7
High-speed ferry	Very Large	4.9	17	1,000	365	2.083
Regional fuel depot	Extreme	41.7	NA	50,000	365	2,083
Stationary						
Telecom backup	Small	0.003	0.2	3.5	3	0.14
Seasonal microgrid storage	Medium	0.027	85	130	130	1.6
International shipping	Large	0.48	NA	575	365	24
Hospital backup	Large	0.59	99	709	7	100
Data centre backup	Very Large	20	1,048	30,000	3	1,250
Grid-scale long-duration storage	Extreme	100	1,000	120,000	42	5,000
Steel mill DRI	Extreme	250	NA	300,000	365	12,500

those with the highest gravimetric capacities also exhibit slow dehydrogenation rates et al., 2023). This distribution corrects earlier misconceptions that hydrogen constituted 90% of all cosmic atoms. Predominantly found in molecular forms such as water (H_2O) and methane (CH_4), rather than its diatomic gaseous form (H_2), hydrogen's cosmic presence underscores its fundamental role in shaping the universe (Albatayneh et al., 2023). Beyond its abundance, hydrogen is the primary fuel for the sun and other stars, where nuclear fusion converts approximately 600 million tons of hydrogen into helium every second, highlighting its fundamental role in stellar energy dynamics. On Earth, hydrogen's significance extends to its historical discovery and physical properties. First observed in 1766 by Henry Cavendish as "inflammable air" produced from the reaction of zinc with sulfuric acid, hydrogen was later named by Antoine Lavoisier, who derived its name from the Greek words "hydro" (water) and "genes" (creator), recognizing its role in producing water upon combustion with oxygen (Hordeski, 2008). Physically, hydrogen is the lightest and simplest naturally occurring element, composed of one proton and one electron, with no neutrons in its most common isotope, protium. These characteristics make it integral not only to chemistry but also to sustainable energy systems due to its high energy content and potential applications. Hydrogen's abundance on Earth, particularly as a primary component of water, underscores its biological and ecological significance, as water makes up approximately 60% of the human body. The future of hydrogen lies in its potential as a transformative energy carrier. It is increasingly recognized for its role in reducing reliance on petroleum and diversifying energy sources, with projections suggesting significant inroads within 5 to 10 years in replacing fossil fuels, particularly those sourced from geopolitically sensitive regions like the Middle East (Hordeski, 2008). This anticipated shift aligns with global efforts to establish sustainable energy systems and mitigate climate change impacts, positioning hydrogen as a cornerstone in the ongoing energy revolution.

The Automotive Industry

Radical Transformation

The global automotive industry is undergoing a radical transformation, driven by the convergence of technological, social, environmental, and geopolitical forces. These changes are reshaping markets, altering consumer preferences, and challenging traditional business models. The emergence of hydrogen as a viable fuel source represents both a solution to the industry's sustainability challenges and an opportunity for innovation and growth.

Key Drivers of Transformation

1. Technological Advancements:
   Advancements in hydrogen fuel cells, electrification, and vehicle connectivity are redefining the industry. Hydrogen fuel cell vehicles (FCVs) are particularly promising due to their high energy efficiency, zero-emission profiles, and suitability for long-range and heavy-duty applications (Edwards et al., 2008; Hordeski, 2008). However, the high cost of platinum catalysts and the need for durable, efficient systems remain critical challenges (Simonazzi et al., 2020).

2. Electrification and Digitization:
   The shift towards electrified and software-defined vehicles has turned batteries and semiconductors into key industry control points. More than one-third of a battery electric vehicle's (BEV) value lies in its battery. This trend demands new capabilities in development and manufacturing, altering traditional supply chains and increasing competition from tech companies like Tesla and BYD (McKinsey & Company, 2016).

3. Urbanization and Consumer Preferences:
   The increasing urbanization of global populations is driving demand for compact, fuel-efficient vehicles suited to city environments. Urban consumers prioritize connectivity, low emissions, and reduced congestion, pushing automakers to

innovate in vehicle design and digital integration. It also requires collective will to implement new transportation solutions (Mitchell et al., 2010).

Emerging Trends and Opportunities

The automotive industry's transformation includes several disruptive trends that present both challenges and opportunities:

1. Shift Towards Shared Mobility:
   Consumers are increasingly moving away from private car ownership toward shared mobility solutions, driven by cost savings and environmental concerns. Mobility-as-a-service (MaaS) platforms like Uber and Zipcar are reshaping the industry landscape (McKinsey & Company, 2016).

2. Hydrogen's Role in Decarbonization:
   Hydrogen presents a pathway to achieving carbon neutrality, particularly for heavy-duty and long-range transport. Advances in hydrogen production, storage, and distribution systems are critical to scaling this technology. Hydrogen-powered vehicles provide higher energy density and faster refueling times than BEVs, making them more suitable for commercial applications. (Sharma & Ghoshal, 2015).

3. Autonomous and Connected Vehicles:
   Autonomous vehicles (AVs) promise enhanced safety, efficiency, and convenience, potentially reducing traffic congestion and vehicle emissions. The integration of advanced sensors, AI, and vehicle-to-everything (V2X) communication is accelerating this trend (McKinsey & Company, 2024b).

Challenges and Industry Responses

1. Economic and Supply Chain Pressures:
   The commoditization of vehicle components and increased reliance on centralized computing systems are driving cost pressures. Companies must adopt scalable production models and focus on incremental technological improvements to maintain competitiveness (McKinsey &

Company, 2016).

2. Geopolitical and Regulatory Dynamics: The automotive industry operates within a highly volatile international trade environment. Protectionist policies and trade conflicts lead to economic inefficiencies and hinder global cooperation, highlighting the need for regionalized production strategies (Simonazzi et al., 2020).

3. Public Perception and Adoption Rates: Consumer reluctance to adopt new technologies such as FCVs and BEVs often stems from high upfront costs, limited infrastructure, and concerns about range and reliability. Investment in hydrogen refueling stations and public awareness campaigns is essential to address these barriers (Hordeski, 2008).

The automotive industry's transformation is both an opportunity and a challenge. Integrating hydrogen technology, electrification, and digital innovation is crucial for ensuring sustainability and competitiveness in a rapidly evolving market. By addressing economic, regulatory, and technological barriers, the industry can leverage these disruptions to redefine mobility for a cleaner, more connected future.

Technology	Advantages	Challenges	Applications
Hydrogen FCEVs	High energy density, fast refueling	High cost of catalysts, limited infrastructure	Urban mobility, heavy-duty vehicles
BEVs	Low emissions, high efficiency	Battery cost, long recharge times	Long-range, passenger vehicles

Technology	Advantages	Challenges	Applications
AVs	Enhanced safety, reduced congestion	Regulatory hurdles, public trust	Urban fleets, logistics
Shared Mobility	Reduced vehicles, ownership costs	Scalability, integration	Urban and suburban areas with existing systems

Table 5: Comparative Analysis of Emerging Automotive Technologies

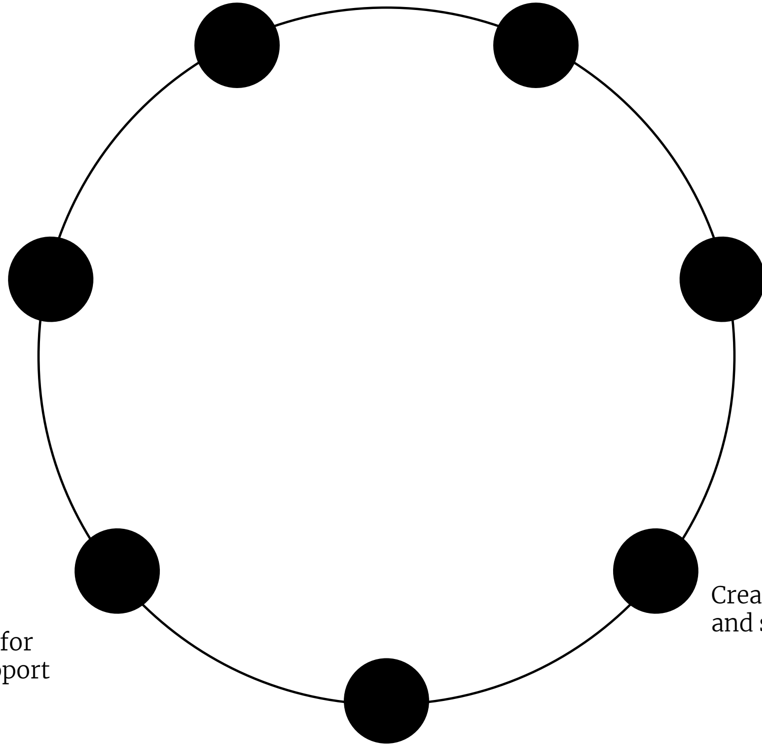
The Value Shift in the Automotive Industry: A New Era of Innovation and Competitiveness

The automotive industry is undergoing a transformative period characterized by significant disruptions and opportunities driven by new social, technological, environmental, and geopolitical challenges. These dynamics are reshaping a saturated market and creating entry points for new players. Key trends include the regionalization of production, the dynamic evolution of nations´ comparative advantages, and heightened competition due to the emergence of disruptive technologies like hydrogen. Governments worldwide are racing to adapt to these changes, while the industry navigates deep uncertainty in a complex and ambiguous global landscape. Product commoditization, coupled with reduced value from traditional internal combustion engine (ICE) drive trains, poses risks to OEM profitability. This situation is further compounded by a volatile international trade environment, production dispersal, and the diminishing relevance of incumbents´ traditional competencies in mastering digital innovation (Simonazzi et al., 2020). The shift to software-defined vehicles, or "computers on wheels," requires upgradability and continuous consumer-focused innovation to keep pace with rapidly evolving technological demands (McKinsey & Company, 2016).
Urbanization and sustainability are central to the industry's transformation. Increasingly urbanized populations have driven demand for smaller, more fuel-efficient vehicles tailored to city driving. Automakers are focusing on innovative designs that prioritize efficiency, safety, and environmental sustainability. With urban areas becoming more interconnected, the development of connected vehicles integrated with the internet and other transport networks is critical for real-time traffic management and reducing congestion.
Concurrently, advances in electric and hybrid technologies, as well as hydrogen fuel cells, address the urgent need to reduce emissions, offering vehicles that emit only water vapor as a byproduct.
These technological and social shifts are

paralleled by a fundamental change in consumer relationships with automobiles. Disruptive trends such as shared mobility, electrification, and autonomous vehicles (AVs) indicate a move away from private car ownership towards mobility-as-a-service models. Emerging competitors like Tesla and tech giants such as Apple and Google have added complexity to the competitive landscape, challenging traditional OEMs to compete on multiple fronts (McKinsey & Company, 2016). Autonomous vehicles, with their potential to enhance commuting convenience and productivity, further exemplify this paradigm shift.
Electrification has become a pivotal focus, with batteries now accounting for over a third of a BEV's value. As vehicles transition to centralized computing systems, components like sensors, ECUs, and energy management units are becoming commoditized, leading to efficiency gains but also intensifying competition based on scalability and incremental improvements (Cornet et al., 2023).
The average consumer demographic also underscores regional disparities, with Chinese automotive buyers averaging 34 years of age compared to 58 in Europe, reflecting differing adoption rates of cutting-edge technologies such as AVs and fuel cell vehicles (FCVs). European manufacturers can leverage their economic and technological strengths, with three times the revenue and five times the EBIT of their Chinese counterparts, to act decisively and maintain leadership (Cornet et al., 2023).
Hydrogen represents a transformative opportunity in this landscape. Its high energy density and zero-emission profile make it a promising alternative to fossil fuels. Hydrogen-powered FCVs offer rapid refueling and extended ranges, addressing limitations faced by BEVs. However, significant investment in hydrogen infrastructure and advancements in production technologies are required to achieve scalability and affordability. Regions with established innovation ecosystems, such as Europe, are well-positioned to integrate hydrogen solutions into their mobility strategies, contributing to a sustainable and decarbonized transportation future (Sharma & Ghoshal, 2015).

The automotive industry's path forward demands bold action and substantial investment. Strengthening R&D capabilities in software, batteries, and hydrogen technologies, alongside adapting to evolving consumer trends, will be critical. By embracing sustainability, electrification, and centralized computing, the industry can navigate the challenges of commoditization and digital transformation, ensuring continued relevance and leadership in the global market. The time to act is now, as the stakes for competitiveness and innovation have never been higher.

Alphabet and Apple may enter the electric vehicle (EV) market, leveraging consumers' growing preference for experience over traditional vehicle quality, as noted by Perkins and Murmann (2018). This shift presents a strategic opportunity for IT firms to redefine mobility through software-driven innovation and seamless user experiences.
The automotive industry is undergoing a fundamental transformation in its business model, a transition that could be as competence-destroying as any disruptive technology (Teece, 2018). To remain competitive, organizations must anticipate these structural shifts and strategically align with emerging trends. As Du et al. (2024) suggest, the industry is progressively moving towards a subscription-based business model, necessitating a forward-thinking approach that integrates digital services, connectivity, and personalized mobility solutions.



A road that can help the European automotive industry remain competitive, developed by McKinsey & Company (2020)

Behavioral Change in Urban Mobility

David Banister, in his book Unsustainable Transport: *City Transport in the New Century* (2006), along with Robin Hickman (2005), examines the behavioral transformations projected to shape mobility habits in densely populated urban areas between 2020 and 2030 under the "smart social" scenario. Many of these anticipated shifts are currently materializing, validating their projections. A key trend highlighted in their research is the increasing restriction of access to specific urban areas based on vehicle type, alongside a growing preference for high-occupancy vehicles, car-sharing services, and traffic management policies. These behavioral adaptations contribute significantly to reducing CO_2 emissions.

Camilleri et al. (2022) further highlight the link between individual mobility habits and transportation mode choices. Their study underscores the importance of changing societal behaviours and urban planning paradigms to foster more sustainable and desirable transportation alternatives. This suggests that the successful transition toward sustainable mobility is not solely dependent on technological advancements but also requires a fundamental shift in public perception and policy-driven behavioural interventions.

Pareliussen, J. et al. (2022) state:
"The United Kingdom reduced emissions by 40% from 1990 to 2019—one of the largest reductions in the OECD and the highest among G20 countries—while GDP increased by 78%.Greenhouse gas emissions per unit of GDP were reduced almost by a factor of three since 1990."

Human activities and mobility are inherently interconnected, and this complex interdependence reinforces the prevalence of private car ownership (Spurling et al., 2013). Moreover, as Mitchell et al. (2010) highlight, various factors—such as comfort—significantly influence the decision-making process when choosing a car.

Pictures created using DALL-E.

Therefore, in vehicle design, it is essential to consider these key attributes while integrating features that promote cost-effectiveness. The relatively low average traffic speeds in urban areas and the typical daily driving distances present substantial opportunities for both mass and cost reduction.
To achieve the desirable transport futures outlined by Gössling et al. (2018), the mobility industry must align with the increasing restrictions imposed by governments and policymakers. These regulatory efforts are crucial for transforming cities into healthier environments where people are not exposed to harmful pollutants.
In defining the goal of my project, I emphasize maintaining the fundamental concept of the car, despite its adaptation to a service-o-

riented mode of use. This approach aligns with the argument presented by Gössling et al. (2018), who emphasize that for change to be widely accepted, it must be perceived as both rational and appealing. Familiarity plays a crucial role in facilitating the transition toward more sustainable mobility lifesty-les, particularly given that cars remain the preferred mode of passenger transport and contribute approximately 6% of global CO_2 emissions (Stern, 2007), positioning Vehicles as major contributors to pollution (Lee et al., 2021).
As travel demand is projected to increase (Camilleri et al., 2022), and mobility continues to serve as a marker of social status, cars will remain an integral part of transportation for a significant portion of the population. This trend is further reinforced by increasing global instability. Furthermore, the total distance traveled by individuals is expected to double by 2050 (ITF, 2017).
Although vehicle weight has increased by 3.6% between 2005 and 2014 (Gössling et al., 2018), policies are shifting toward lighter and more efficient transportation solutions.
Accordingly, the vehicle I am designing is a compact and lightweight car that aligns with these evolving policy directives.
Additionally, the integration of autonomous vehicles (AVs) could enable individuals to adopt a more rational approach to mobility (Lin, 2015), facilitating daily activities and potentially reducing time spent commuting or in the workplace.

Environment & Health

Hydrogen, Air Pollution, and the Global Automotive Industry: Challenges and Opportunities

Air pollution is a critical global concern, responsible for approximately 7 million deaths annually, making it one of the leading contributors to non-communicable diseases worldwide (World Health Organization [WHO], 2024b). Urban areas, characterized by dense populations and significant vehicle usage, are particularly affected. Vehicle exhaust, tyre wear, and road surface degradation are major contributors to urban air quality deterioration, exacerbating respiratory and cardiovascular conditions (Hua et al., 2022). In response, the European Green Deal aims to combat climate change by reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. The transport sector contributes to GHG emissions, with 23% of the total CO2 emissions and 61% of the global oil consumption (IEA, 2021) and they are still growing (IEA, 2023). Road transport also accounts for 73% of the world's CO2 emissions (IEA, 2020). A key component of this strategy is addressing particulate matter (PM), a hazardous pollutant heavily linked to vehicle operations. Urban transportation significantly contributes to PM levels, with road dust accounting for 60-65% of urban PM2.5 and PM10 concentrations (Hua et al., 2022). Regulations targeting vehicle emissions are accelerating the adoption of clean transportation technologies, with cities en-forcing strict emission standards and offering consumer incentives to transition toward sustainable mobility solutions (McKinsey & Company, 2016). Emerging technologies, such as battery-electric vehicles (BEVs) and hydrogen fuel cell elec-tric vehicles (FCEVs), are central to this shift. BEVs, powered by renewable electricity, and FCEVs, emitting only water vapor, are pivotal in reducing urban air pollution and achieving net-zero emissions targets (Sharma & Ghoshal, 2015).

Hydrogen emerges as a transformative energy carrier, offering a clean, non-toxic, and renewable alternative to fossil fuels. It appears to be the most viable solution to effectively

address concerns surrounding range anxiety, the convenience of rapid refueling, and the elimination of pollutant emissions in mobility applications. (MItchell et al.,2010). By 2050, hydrogen could contribute up to 18% of global energy consumption, reducing annual carbon emissions by six gigatons (Albatayneh et al., 2023). Its combustion does not produce greenhouse gases, making it a cornerstone for decarbonizing the transportation sector (Barbir, 2009). The local production of hydrogen enhances energy security by reducing reliance on imported fossil fuels and aligns with the goals of initiatives like the European Green Deal (Edwards et al., 2008). Urbanization poses significant challenges, including increased vehicle demand, air pollution, and greenhouse gas emissions. Urban sprawl intensifies these issues by lengthening commuting distances and elevating car ownership rates (Tao et al., 2021).
Hydrogen-powered vehicles, particularly FCEVs, provide a sustainable alternative by utilizing renewable energy to produce hydrogen, thereby reducing the environmental impact of urban transportation. Investments in hydrogen technology are critical for advancing its adoption. Governments and private entities are prioritizing research and development, exemplified by the U.S. Department of Energy's allocation of $100 million for hydrogen and fuel cell advancements from 2022 to 2026 (Albatayneh et al., 2023). These investments address key barriers such as infrastructure development and the high costs associated with hydrogen production. Effective policies to mitigate air pollution span multiple sectors, including transporta-tion, energy, urban planning, and waste management.

Strategies include promoting public transit, cycling, and low-emission vehicles; expanding renewable energy sources like solar, wind, and hydropower; designing compact, green cities to enhance energy efficiency; and implementing advanced recycling methods and biogas production technologies (WHO, 2024b). As the final instance, vehicles need to work as a system and the technology is already available (MItchell et al.,2010).

Hydrogen's potential to transform the automotive industry is unequivocal. It represents a sustainable energy solution capable of addressing the dual challenges of urbanization and climate change. Through strategic investments and robust poli-cies, hydrogen can play a central role in achieving global sustainability objectives, ensuring cleaner air and healthier urban environments.

Parameter	Hydrogen	Gasoline	Diesel
Emissions	Water vapor only	CO_2 , NOx, SOx	CO_2 , NOx, PM
Energy Efficiency	Up to 65%	~25%	~30%
Safety Factor	1 (highest)	0.53	0.8

Table 6: The safety factor refers to the hazardous nature of emissions at the point of use, with 1 indicating no hazardous emissions at the point of use.

Demographic & Congestion

City populations and wealth are increasing together, and they become less and less liveable unless mobility changes. Also, cities account for 75% of the world's energy consumption. The population in 2050 of people over 65+ years old will exceed that of people under 5 years old, translating to a high number of elderly drivers. (Mitchell et al., 2010)

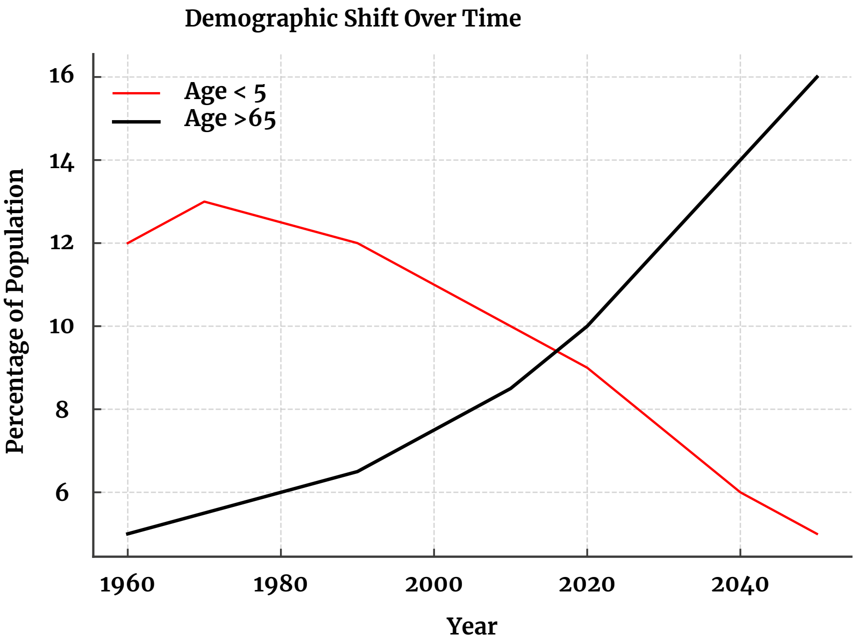
75% of Americans might satisfy range needs by having a 50-mile daily range granted by a 25-mile range vehicle recharged at work (Mitchell et al., 2010). Other countries have lower average travel distances. Hydrogen powered vehicles could drop workers off at the office and autonomously go back to refilling stations or pick up other people if the vehicle is shared, eventually returning to the refuelling station. A smaller range of miles allows the vehicle to be as efficient as possible in terms of lightweight and satisfying people necessities. Ninety-eight percent of people need less than 110 miles a day of range to commute. Rethinking vehicle design requires addressing the negative externalities discussed by Mitchell et al. (2010, p.13) in Reinventing the Automobile, particularly those affecting the environment and human health, to design a vehicle that suits better human activities and necessities.

Each day, 18 million barrels of oil are consumed globally for automobile transportation. Roadway collisions result in approximately 1.19 million fatalities annually, with pedestrians comprising 21% of these deaths and cyclists accounting for 5% (WHO, 2023b). Additionally, in densely populated urban centers, average travel speeds often fall below 10 miles per hour, exacerbating traffic congestion and inefficiencies. This extensive reliance on fossil fuel-powered vehicles contributes signif-icantly to environmental degradation, with road transportation emitting approximately 2.7 billion tons of carbon dioxide annually, further accelerating climate change and urban air pollution (Mitchell et al., 2010).

Traffic congestion is a multifaceted issue that significantly impacts urban centers globally, driven by factors such as population growth, economic development, and reliance on personal vehicles. Its repercussions extend beyond inconvenience, manifesting as wasted time, increased fuel consumption, elevated costs, and heightened air pollution. In 2009, urban Amer-icans experienced 4.8 billion additional travel hours and consumed 3.9 billion extra gallons of fuel, resulting in a total con-gestion cost of $115 billion, which rose to $101 billion by 2010, with the average commuter losing 34 hours annually to de-lays and wasting 14 gallons of fuel (Schrank et al., 2011). Larger urban areas faced even more severe impacts, with peak-period delays averaging 44 hours annually and fuel wastage reaching 20 gallons per commuter. Moreover, congestion has become a pervasive issue, extending beyond traditional rush hours, with approximately 40% of delays occurring during off-peak periods. This exacerbates challenges for personal travel and freight logistics, creating significant economic repercus-sions for industries reliant on timely transportation

(Schrank et al., 2011).
Vehicle occupancy plays a critical role in traffic patterns. The average vehicle occupancy rate in the U.S. varies by trip type and vehicle category, with an overall average of 1.67 persons per trip according to the 2017 National Household Travel Survey (FHWA, 2017). Vans exhibit the highest occupancy at 2.1 persons per trip, followed by SUVs and crossovers at 1.7, and cars at 1.4 (U.S. Department of Energy, 2024). Low occupancy rates exacerbate congestion by increasing the number of vehicles on the road relative to the number of travelers. Conversely, higher vehicle occupancy during road trips, driven by group travel dynamics, could reduce the number of vehicles required for long-distance travel. However, larger vehicles like RVs, while accommodating more passengers, occupy more road space and contribute to congestion on narrower or less-developed routes (My Financing USA, 2023).
The financial burden of traffic congestion continues to rise. By 2020, national congestion costs were projected to reach $175 billion, with delays totaling 7.7 billion hours and 3.2 billion gallons of wasted fuel (Schrank et al., 2011). Environmental consequences are equally concerning, with emissions of particulate matter (PM), carbon monoxide (CO), and nitrogen diox-ide (NO_2) contributing to urban air pollution and associated health risks (WHO, 2024b). Without substantial interventions, traffic congestion is expected to worsen. Population and employment growth will continue to drive transportation demand, while infrastructure expansion may not keep pace. Average annual commuter delays were projected to increase to 41 hours by 2020, with proportional rises in fuel wastage and economic costs (Schrank et al., 2011).
Mitigating traffic congestion necessitates a multifaceted approach. Key strategies include investing in mass transit systems to reduce reliance on personal vehicles, encouraging carpooling and high-occupancy vehicle (HOV) lanes to optimize road space, implementing smart traffic management through real-time monitoring and adaptive signal controls, and promoting cleaner vehicles like electric and hydrogen-powered options to mitigate environmental impacts. Urban plan-

ning initiatives, such as developing compact, transit-oriented urban areas, can further reduce travel distances and dependence on cars (Schrank et al., 2011; WHO, 2024b). Traffic congestion remains a critical challenge for urban areas, with profound econom-ic, environmental, and social implications. However, leveraging technological innova-tions, enacting policy reforms, and fos-tering behavioural changes can pave the way for more efficient and sustainable transportation systems.



MItchell et al., 2010)

Hydrogen Economy

Hydrogen and the Automotive Industry: Challenges and Opportunities.

The transition towards sustainable mobility has catalysed significant developments in the automotive industry, emphasizing the integration of electric propulsion vehicles and hydrogen as a clean energy carrier. Oil remains affordable, while alternative fuels are often perceived as costly (Chapman, 2007). Hydrogen, the most abundant element in the universe, has emerged as a promising solution to address energy and environmental challenges in modern transportation systems (Albatayneh et al., 2023). Its potential is particularly compelling for decarbonizing hard-to-electrify sectors such as heavy-duty transport and industrial applications (Simonazzi et al., 2020). Hydrogen, as an energy carrier, provides high energy density, versatility, and compatibility with renewable energy sources, making it a central element of global energy transition strategies (Barbir, 2009; Dou et al., 2017). The declining cost of renewable energy sources, including wind and solar, has contributed to significant reductions in the cost of producing green hydrogen. Between 2009 and 2023, wind power costs decreased by 89%, while solar power costs fell by 70%, paving the way for cost-effective hydrogen production (Birol, 2019, as cited in Albatayneh et al., 2023).
By 2050, green hydrogen is projected to achieve cost parity with fossil fuels, driven by advancements in electrolysis and scaling production technologies (Dogliani et al., 2024).
The integration of hydrogen into the automotive industry encompasses more than fuel cells, extending to manufacturing innovations, policy frameworks, and new stakeholder dynamics (Simonazzi et al., 2020). Hydrogen Fuel Cell Vehicles (FCEVs) are particularly suited for long-range and high-payload applications, such as trucks and buses. Emitting only water as a byproduct, they contribute to cleaner urban environments (Hordeski, 2008). However, FCEVs encounter challenges regarding hydrogen storage, fueling infrastructure, and cost. For instance, while hydrogen offers an energy content of 33.6 kWh/kg, nearly double that of gasoline, the

overall efficiency of hydrogen systems remains lower than that of battery-electric vehicles (BEVs) (Albatayneh et al., 2023). Infrastructure development, such as establishing hydrogen fueling stations, is essential for the widespread adoption of FCEVs. Initiatives like California's Hydrogen Highway Program, which aims to establish 200 stations, underscore the need for substantial investment and public-private collaboration (Hordeski, 2008). Governments worldwide are promoting hydrogen through significant investments and supportive policies. The European Commission has identified clean hydrogen as a critical element of the energy transition, with Germany and France allocating €9 billion each to hydrogen initiatives (Simonazzi et al., 2020). Achieving cost targets of $2–$3/kg for green hydrogen is essential for widespread adoption (Edwards et al., 2008). Despite its potential, hydrogen technology faces several technical and economic barriers. The cost of producing and storing hydrogen remains a significant hurdle, with a levelized cost target of €4/kg being essential for competitiveness (Kindra et al., 2023). Furthermore, 50-60% of fuel cell issues are attributed to impurities in hydrogen, necessitating advancements in purification and storage technologies (Hordeski, 2008). The hydrogen economy is at an inflection point and could represent a $1.6 trillion industry by 2050, driven by technological innovations and supportive policies (Dou et al., 2017). However, its success depends on overcoming entrenched fossil fuel systems and fostering consumer acceptance through education and transparent communication (Barbir, 2009). Collaborative approaches, including cross-sector alliances with technology firms, are crucial for advancing innovations in hydrogen storage, fuel cells, and mobility services (Weber-Rymkovska et al., 2017, as cited in Simonazzi et al., 2020). Integrating hydrogen production with renewable energy systems can mitigate geopolitical risks associated with fossil fuel dependence while enhancing energy security (Edwards et al., 2008). Hydrogen represents a transformative opportunity for the automotive industry, enabling zero-emission mobility and strengthening energy resilience. While challenges related to cost, infrastructure, and technological maturity persist, strategic investments and international cooperation are poised to accelerate hydrogen adoption. As the automotive sector evolves, hydrogen's role as an energy carrier will likely expand, fostering a sustainable future for global transportation. Hydrogen is emerging as a transformative force in the global energy landscape, playing a pivotal role in decarbonizing industries and transportation to achieve net-zero emissions. Its versatility and potential applications in hard-to-abate sectors such as heavy industry, long-haul transportation, and aviation underscore its strategic importance. McKinsey & Company (2023a) projects that hydrogen could account for up to 18% of global energy demand by 2050, with annual revenues from the hydrogen economy potentially reaching trillions of dollars globally. The path to achieving these milestones is being shaped by substantial policy support and investment, particularly in the United States, Europe, and China, where subsidies and tax incentives aim to reduce production costs and accelerate adoption (McKinsey & Company, 2023a). One of the most critical factors for hydrogen's success is its cost competitiveness. Green hydrogen, produced through water electrolysis powered by renewable energy, is expected to see costs decline to $1–$2 per kilogram by 2030 in regions with abundant renewable energy resources. Technological advancements and economies of scale are reducing costs. Meanwhile, blue hydrogen, derived from natural gas with carbon capture and storage (CCS), is considered a transitional solution but faces long-term challenges as green hydrogen becomes more economically viable (McKinsey & Company, 2023a). Hydrogen applications extend across multiple sectors. In transportation, fuel cell electric vehicles (FCEVs) present significant potential, especially for long-haul trucking and logistics where hydrogen's high energy density provides advantages over battery electric alternatives. However, the widespread adoption of FCEVs will depend on investments in hydrogen refueling infrastructure. In the industrial sector, hydrogen is critical for decarbonizing processes such as steel production and ammonia synthesis. Technologies like hydrogen-based Direct Reduced

Iron (DRI) for steelmaking are expected to grow significantly as industries pivot toward more sustainable practices (McKinsey & Company, 2023b).
Infrastructure development remains a critical challenge for the hydrogen economy. Regions with access to low-cost renewable energy, such as the Middle East, North Africa, and Australia, are positioned to become global hubs for hydrogen production. However, developing efficient hydrogen storage and transport solutions—such as liquid hydrogen carriers and pipelines—will be crucial for scaling its deployment globally. These advancements must address energy losses in the hydrogen value chain, as converting electricity into hydrogen and back into usable energy is inherently less efficient than direct electrification in certain applications (McKinsey & Company, 2023a).
Despite these challenges, hydrogen's long-term prospects remain strong. Achieving its full potential requires more than $100 billion per year in global investments in infrastructure and technology by 2030. These investments are complemented by policy frameworks and global cooperation aimed at enabling a competitive and sustainable hydrogen economy. Hydrogen is not only a key pillar in achieving net-zero emissions but also a potential driver of economic growth, energy security, and innovation across multiple industries.

The transition to electrified and hydrogen-powered public transport systems involves significant initial capital expenditures, encompassing vehicle acquisition, infrastructure upgrades, and energy grid enhancements. Electric buses, for example, cost approximately £340,000–£440,000, a notable increase compared to conventional diesel buses (sustainable bus, 2021). Hydrogen-powered buses tend to be even more expensive due to the complexity of fuel cell technology. Additionally, retrofitting existing transport networks to accommodate charging infrastructure or hydrogen refueling stations presents another financial challenge (Uthman Opeyemi Abdullahi et al., 2024).
Despite the high upfront costs, long-term operational savings contribute to offsetting

these investments. Electric buses benefit from lower fuel costs—since electricity is generally cheaper than diesel—and require less maintenance due to fewer mechanical components. Similarly, hydrogen fuel cell buses hold the potential for fuel cost reductions as hydrogen production efficiency improves. The total cost of ownership of zero-emission buses is projected to decrease over time, driven by advancements in battery technology, economies of scale in hydrogen production, and policy incentives favoring sustainable transportation.

Table 7: cost of hydrogen (Kindra et al., 2023).

Hydrogen Production Method	Advantages	Disadvantages	Efficiency (%)	Cost USD/kg
Steam Methane Reforming (SMR)	Established technology	By-product: CO, CO_2	74-85	2.27
Dark fermentation | Photolysis	Near zero CO_2 emissions Used in waste management	Low generation of H2 Need for a huge reactor	60-80	2.57
Coal Gasification	Established technology Cheap raw material	Fluactuating H2 quality High emissions without CCS	30-40	1.8-2.0
Pyrolisis	Established technology Cheap raw material Near zero CO_2 emissions	Fluactuating H2 quality due to quality and seasonal availability	35-50	1.6-1.7
Thermolysis	Near zero CO2 emissions By-product: O_2	High capital investment High temperature	20-45	8.0-8.40
Electrolysis (Renewable Energy)	Established technology By-product: O_2 Near zero CO_2 emissions	High capital investment	70	10.30

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PROJECT

Goal

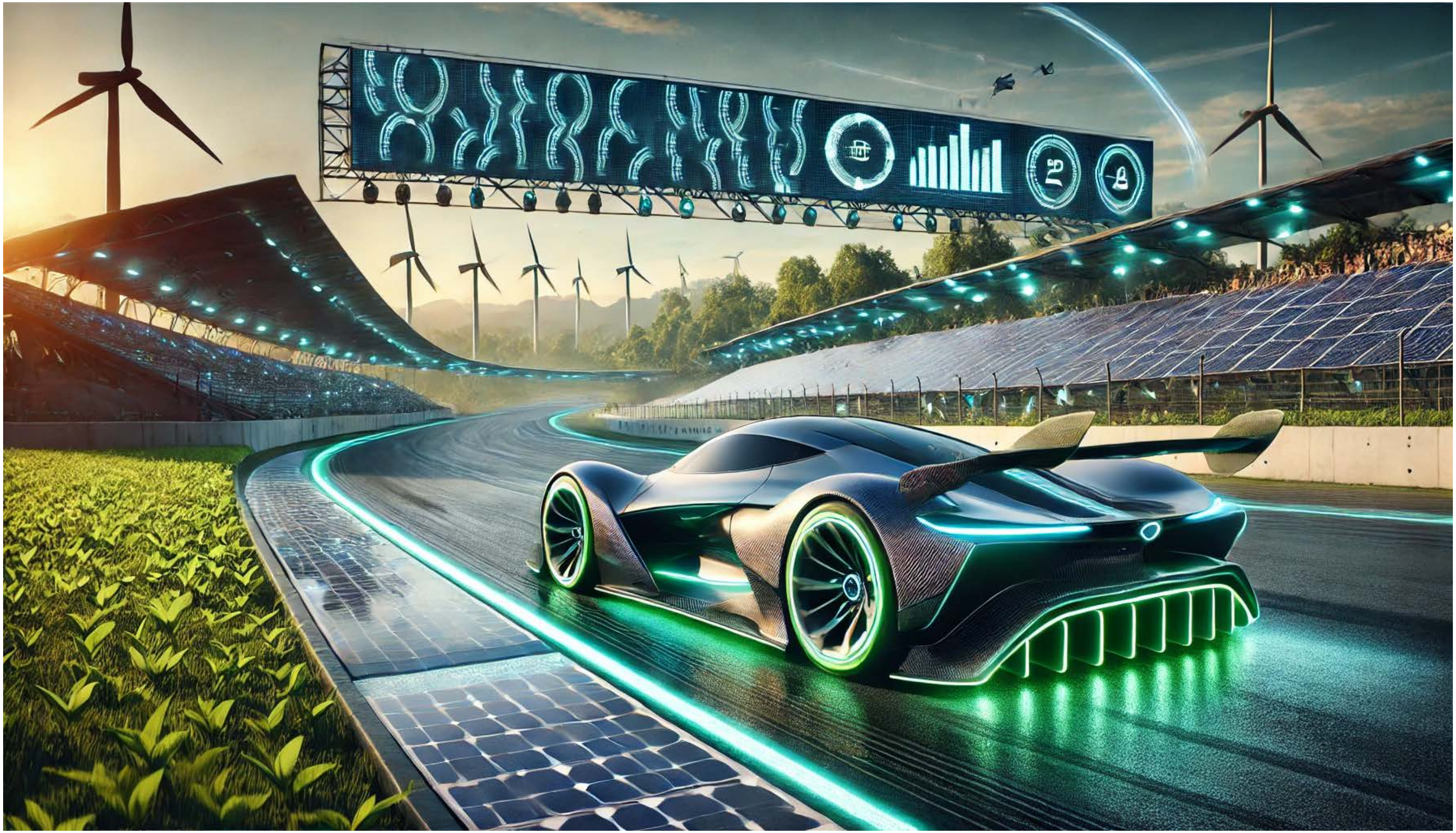
Achieving desirable future scenarios requires adopting a systemic perspective on the transportation sector and urban mobility (Patten et al., 2002). In this context, the four interrelated dimensions discussed by Gössling in Desirable Transport Futures (2018) must be considered when addressing mobility, as they play a crucial role in shaping sustainable and effective transportation strategies.
The design and implementation of a hydrogen-powered sports vehicle aim to introduce hydrogen technology compellingly, leveraging its performance and desirability to build public trust and interest in this alternative fuel. This initial step is crucial for demonstrating hydrogen fuel's reliability and safety while addressing concerns about refueling convenience. The project simultaneously involves the development of a compact hydrogen-powered city car, translating the appeal and innovations of the concept sports car into a more practical format for urban use. By adopting a compact design similar to Internal Combustion Engine (ICE) vehicles, the city car addresses environmental impact, efficiency, traffic congestion, and parking challenges in densely populated areas.
As suggested by Mitchell et al. (2010) in the book reinventing the automobile, the first steps would be "the development of imaginative, carefully conceived pilot projects". This project seeks to capture public imagination by transforming what seems impossible into a tangible reality. Just like Mitchell et al.'s project on USVs, this one will not be science fiction.
The dual approach addresses critical issues such as pollution and emissions, aiming to foster public appreciation of hydrogen through a desirable and accessible vehicle. The vehicles employ advanced hydrogen storage solutions, including Toyota's fuel cells and metal hydrides, ensuring safety and efficiency. The initiative bolsters the early development of the hydrogen economy by advancing hydrogen production hubs and affirming its safety for the environment, human health, and economic sustainability.
Automotive brands are increasingly positioning themselves as lifestyle entities, aligning

with aspirational marketing trends. Consumers are seeking vehicles that resonate with their personal values, such as sustainability and innovation (Snyder, 2005). Brands like Tesla and BMW exemplify this shift by emphasizing luxury and advanced technology to attract buyers (Loureiro, 2016). Furthermore, societal changes, including the rise of single-person households and shifting consumer behaviors, are reshaping automotive design and marketing strategies to adapt to these new lifestyles (Oh et al., 2016).
The GM hydrogen campus project serves as a parallel inspiration, illustrating how hydrogen technology can be integrated into infrastructure. This energy-autonomous campus will generate hydrogen to supply residential and grid needs while hosting a track for testing hydrogen-powered vehicles. This setup aims to attract automotive enthusiasts and tourists by offering zero-emission driving experiences in a concept car. The campus serves as both a research hub and energy supplier, showcasing the financial and practical advantages of hydrogen technology while fostering a sustainable energy ecosystem.

Hydrogen technology plays a pivotal role in achieving net-zero carbon emissions. By supporting the transition to alternative fuels, hydrogen-powered vehicles, particularly in high-performance and urban contexts, address CO_2 emissions from transportation, including motorsport events that significantly contribute to climate change (Triantafyllidis, 2018). Hydrogen offers a sustainable, scalable solution for future transportation and energy systems (Ball & Wietschel, 2009), demonstrating that innovation in mobility can align with the urgent demands of environmental sustainability. This project harnesses hydrogen's potential to reshape public perception and position it as a cornerstone of the green revolution.
The mindset underpinning this project is rooted in principles of innovation, efficiency, and visionary design, aiming to effectively introduce a new and transformative technology to the automotive market. Drawing inspiration from Hypercar, Inc.'s design philosophy, the project adopts a "clean sheet" approach, setting clear and ambitious product requirements while emphasizing whole-system

thinking. This methodology prioritizes lightweighting and efficiency, leveraging the 'beneficial mass spiral', where a lighter body reduces the need for heavier components, creating a cascading effect that minimizes overall vehicle mass and enhances performance (Lovins & Cramer, 2004).
By rejecting incrementalism—which risks stagnation—the project is driven by bold goal statements that prioritize essential needs over secondary features, ensuring a streamlined development process (Lovins & Cramer, 2004). By addressing technical challenges such as the thermal management of PEM fuel cells—known for their efficiency but requiring advanced cooling solutions—the design maintains a balance between technical feasibility and aspirational innovation.
In alignment with the vision that nanotechnologies, robotics, and digital logic will shape the future, this project aims to create a vehicle that is both functional and compelling, capturing public imagination and fostering broader acceptance of cutting-edge technologies (Koster, 2023).

This integrated and ambitious approach ensures the project transcends traditional barriers, reshaping the automotive landscape for a sustainable and efficient future.



Picture created using DALL-E.

Vision

This project proposes a vision of a hydrogen-based technology park (Palmieri, 2015), where projects related to hydrogen applications are developed, including raising awareness among people about the technology to facilitate its adoption.
Toyota has initiated a similar project, developing a self-sufficient energy campus with the potential to enter the renewable energy production market.
The following are the requirements for energy supply:
"Construction has begun on a flexible microgrid that features energy sources available today, including a 230-kW solar photovoltaic system, a 1-MW stationary proton exchange membrane (PEM) fuel cell generator, 325-kW solid oxide fuel cell (SOFC), and an onsite 500-kWh battery energy storage system. The microgrid is designed to support the campus' energy needs, allowing it the ability to operate off-grid. The system is expected to be fully operational by 2026." - (Toyota Newsroom, 2024).

To achieve widespread hydrogen adoption, fueling stations and infrastructure must be established. "A study by GM estimates that $10 billion to $15 billion would pay for 11,700 fueling stations in major urban areas." - (Hordeski, 2008), with a station every 25 miles, capable of sustaining 1 million hydrogen vehicles

As Albatayneh et al. (2023) report, The United States Department of Energy will invest up to USD 100 million over five years (2022–2026) in hydrogen and fuel cell R&D, the Hydrogen Fuel Technology Organization supports several projects investing 100 million dollars. "The The European Union has earmarked USD 430 billion to create 70 green hydrogen projects by 2030 in order to meet its Green Deal objectives" (Albatayneh et al., 2023).
This means that both BEVs and FCEVs would benefit from tax incentives and supportive policies.
"While many car manufacturers are focusing on battery electric vehicles, a few, such as Toyota, Hyundai, and General Motors, are still pursuing hydrogen fuel cell technology,

which can offer zero-emission driving but is less efficient than battery electric vehicles." - (Albatayneh et al., 2023), which is one of the key reasons GM was chosen as the project's inspiration.
The primary challenges associated with traditional and currently utilized vehicles include inefficiency, harmful environmental and health-related emissions, traffic congestion, accidents involving vulnerable road users, and the extensive space required for parking. To effectively address these issues, it is necessary to adopt a new automotive DNA, as outlined by Mitchell et al. (2010) in Reinventing the Automobile. In essence, future vehicles will be characterized by lightweight construction and interconnectivity—not only with each other but also with urban infrastructures to create a fully integrated and intelligent transportation ecosystem. By 2030, 80% of global wealth will be concentrated in cities, making it imperative for mobility solutions to align with these demographic and economic shifts.

Reinventing the Automobile suggests that it is time to accept a trade-off in personal mobility to mitigate the highly negative externalities of car-centric transportation, which, despite its drawbacks, remains a cornerstone of societal progress.
The next generation of automobiles will embody the following characteristics:

- Electrically powered utilizing electric motors and drawing energy from electricity and/or hydrogen.
- Electronically controlled and intelligent, utilizing advanced software for seamless operation.
- Interconnected, not only among vehicles but also with urban infrastructure, enhancing efficiency and safety.

The use of high-performance materials with lower weight and reduced material consumption is a crucial compromise to make these vehicles viable. Structural innovations will extend beyond the vehicle itself to include advancements in component manufacturing, significantly reducing overall weight while

maintaining durability and performance.
As outlined on page 7 of Reinventing the Automobile (Mitchell et al., 2010), cars will no longer function as isolated devices but will evolve into extensions of users' lifestyles. Vehicles will become deeply integrated with personal networks and social interactions, mirroring the role of digital platforms in contemporary society. Enhanced vehicle connectivity will enable a more interactive and seamless mobility experience, akin to how social networks have transformed communication.

A key solution involves offloading vehicle mass to a fixed infrastructure that manages connectivity and traffic flow.

This transition optimizes energy efficiency, traffic flow, and urban space utilization. The driving experience will be redefined, enabling passengers to disengage from driving and engage in other activities while the vehicle autonomously navigates to its destination. Small, intelligent, and electrically driven vehicles with sophisticated software will function as platforms rather than conventional automobiles (Mitchell et al., 2010). The integration of wheel motors will enhance vehicle compactness and maneuverability, making them better suited for urban environments. Additionally, cities adopting mobility-on-demand systems could reduce vehicle idle time from 80% to 20%, substantially decreasing parking infrastructure requirements (Mitchell et al., 2010).

The future of vehicle design will be revolutionary, encompassing interior architecture, material selection, and production methodologies. The insights from Reinventing the Automobile serve as a foundation for redefining transportation in alignment with sustainability, efficiency, and user-centric innovation.

Backcasting to a sustainable future

To achieve the global target of zero-emissions by 2050, it is essential to adopt new behavioral patterns and advance technological innovations, particularly in the transportation sector. The development and deployment of vehicles powered by battery-electric energy, as well as those utilizing hydrogen through either fuel cells or internal combustion engines, represent critical pathways toward sustainable mobility. The transition to alternative fuels in transportation is of paramount importance in mitigating the negative externalities associated with the release of hazardous substances into the atmosphere by conventional fossil-fuel-powered vehicles.

The transition to zero-emission vehicles offers significant environmental and public health benefits, as previously discussed; however, several limitations hinder their widespread adoption. Among the most critical barriers are public perception, high costs, and the lack of adequate infrastructure and industrial capacity to support large-scale deployment.
At present, battery electric vehicles (BEVs) face considerable challenges in competing with conventional vehicles, and there is growing concern that discontinuation of public subsidies for the development and adoption of this technology could halt progress in the transition to electric mobility and alternative fuels more broadly. Despite these challenges, BEVs have demonstrated strong potential in transforming certain mobility sectors, particularly in categories of micro mobility where they have proven to be more cost-competitive and user-friendly.

As outlined in Pathway to a Sustainable Future by Chapman (2007), achieving large-scale adoption of new technologies that are both costly and unfamiliar to the public requires progression through several intermediate stages. These stages facilitate the gradual integration of emerging technologies into the economy and various sectors, including production, energy supply, and transportation, allowing them to gain traction and establish a foothold in the market.

Modern mobility presents severe yet often invisible problems that result in disastrous consequences. The primary challenges associated with vehicle use, particularly fossil-fuel-powered vehicles in urban areas, are their detrimental effects on human health and the environment. These impacts stem from the emission of toxic pollutants through exhaust gases and the noise pollution generated by these vehicles, which is both harmful and disruptive for individuals exposed to urban traffic. Additionally, mobility-related issues extend to the economic costs and inefficiencies caused by traffic congestion, as well as the extensive use of public space for parking and vehicle lanes, which limits the availability of land for alternative urban functions.
However, these challenges are deeply rooted in societal habits and historical urban planning decisions. The widespread adoption of automobiles has profoundly influenced city development, leading to an urban structure that increasingly relies on private vehicle ownership. This dynamic has resulted in a process of co-evolution between car dependency and urban planning, where cities have been designed in ways that reinforce the necessity of personal vehicle use (Tao et al., 2021).

To create safer, quieter, and more efficient cities, it is essential to intervene across multiple aspects of daily life to ensure sustainable urban development (Chapman, 2007) and achieve the desired future. Fundamentally, behavioral change and travel habits play a more critical role than technological solutions, as behavioral adaptation is the key factor, whereas technology itself is not the defining element. As described by Camilleri et al. (2021) in the scenarios presented in their study, urban planning should prioritize shifts in habits that have the potential to reshape cities, making them more livable without the necessity of private vehicle ownership. The study was conducted through workshops with stakeholders from various societal and industrial sectors.
Furthermore, the adoption of non-polluting technologies in transportation is imperative, alongside improvements in public mobility

services such as buses, metro systems, and other innovative transport solutions, as well as the expansion of micromobility options. These measures address the increasing demand for multiple modes of transportation, which are becoming an integral part of contemporary mobility habits.
As Chapman (2007) states, "any renewable pathway to electricity is a renewable pathway to hydrogen", emphasizing the interdependency of these energy sources in the transition toward sustainable mobility. To achieve the global zero-emissions target, hydrogen and electric technologies should be seen as complementary rather than competing solutions.

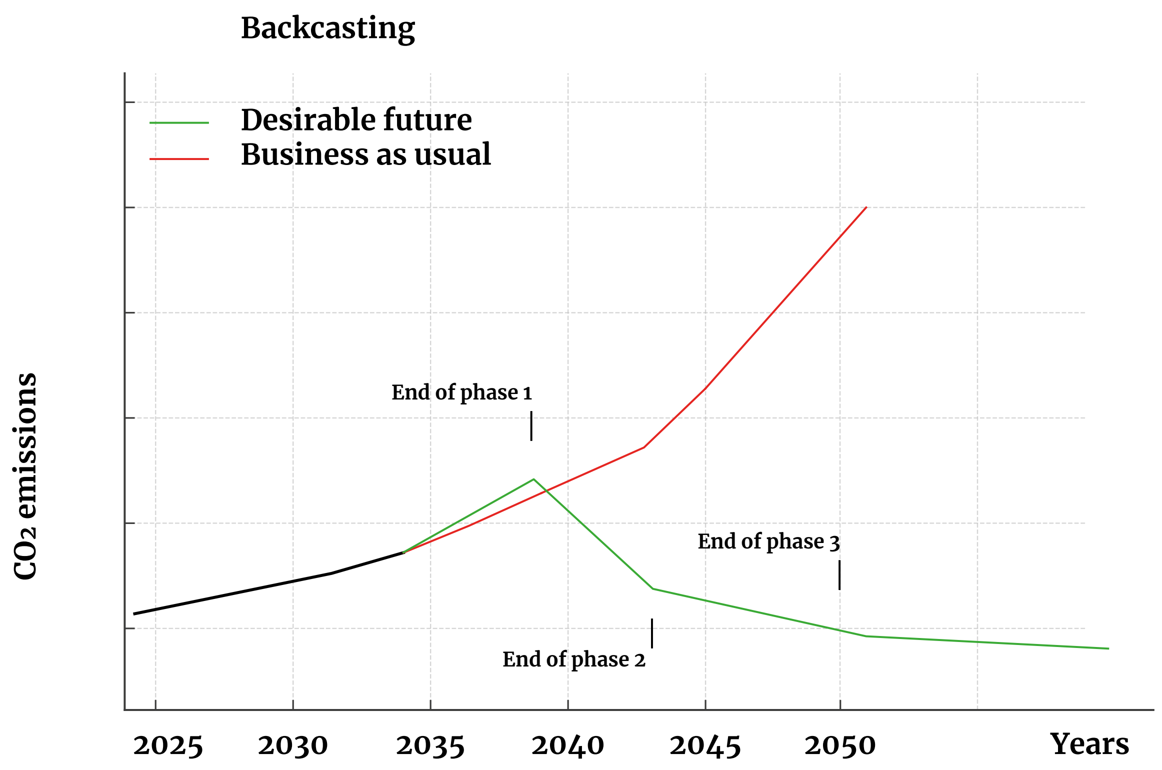
Hydrogen technology offers significant and competitive potential; however, before its large-scale adoption in small and mid-sized vehicles—which is expected to occur in the coming decades—it is essential to progress through several intermediate phases. Hydrogen deployment should first focus on fleet adoption in sectors ideal for long-haul, heavy-duty applications, and stationary energy systems. This transition must be supported by targeted policies and public incentives to facilitate both the adoption and development of hydrogen technologies, ensuring a sustainable and economically viable pathway for their broader implementation.
In the initial phase of establishing a hydrogen-based economy and laying the groundwork for its future adoption, hydrogen production will primarily rely on steam methane reforming (SMR), resulting in emissions comparable to those generated by other fossil fuels used to power gasoline or diesel vehicles. The costs associated with infrastructure development and fuel distribution will be significant. However, the increasing presence of battery-electric vehicles (BEVs) will drive the expansion of a new energy infrastructure network and the growth of renewable energy production. This transition will enable hydrogen production from renewable sources, ultimately contributing to the reduction of emissions from the energy production sector.

As As hydrogen propulsion technology advances, along with improvements in pro-

duction, distribution, and storage, the costs of blue hydrogen (enabled by CCS in the SMR process) and green hydrogen (through methods such as photosplitting) will gradually decrease. Simultaneously, advancements in hydrogen storage, including the implementation of solid-state storage technology via metal hydrides, and the integration of fuel cells in private vehicles will further drive the viability of hydrogen-powered mobility.
Hydrogen technology can enhance energy security and enable decentralized energy production, even in regions without conventional resources. This would create new markets while facilitating the integration of hydrogen into the growing energy demands (Sharma et al., 2015) of increasingly energy-intensive societies. For instance, a hydrogen production facility could be established in a remote village in a developing country where energy supply is nonexistent, enabling the generation of electricity essential for the community's sustenance. Over time, as the community produces surplus energy beyond its immediate needs, it could begin selling the excess, thereby generating revenue and increasing local economic prosperity.
In the final phase, hydrogen-powered vehicles will be fully competitive in all aspects, from cost efficiency to performance and convenience. Nations will achieve energy autonomy through the development of hydrogen production centers and the widespread adoption of fuel cells for stationary applications. The previously cited studies highlight the numerous societal benefits associated with the transition to hydrogen as an energy source for both buildings and road transportation.
The advancement of hydrogen technology will not only enhance energy efficiency but also reshape mobility habits and create new opportunities for travel experiences. Hydrogen storage in portable cylinders will enable various applications, revolutionizing activities such as camping, where hydrogen could be used both for transportation and to power appliances once tents are set up.
Autonomous vehicles would enable seamless travel, ensuring a safe return home before proceeding to a refueling station. Additionally, they could function as designated drivers

in social settings, reducing the risk of accidents.
Future mobility, prioritizing sustainability and public health, will primarily rely on electric or hydrogen-powered propulsion systems with zero emissions and minimal noise pollution. This transformation will allow travelers to access protected areas where noisy and polluting vehicles are prohibited, enabling them to experience pristine destinations in tranquility and without ecological disruption.

Applying Robinson's (1990) backcasting methodology, a desirable scenario was outlined, demonstrating a substantial reduction in CO_2 emissions when graphically represented. This approach focuses on identifying the necessary actions to achieve a predetermined goal by working backward from the desired future state.
Three key stages can be identified in this transition. Beginning with the final stage—2050, when global CO_2 emissions must reach net zero—energy production, consumption, and the fuels used to power vehicles must be entirely clean and derived from renewable sources. By this time, strict policies and regulations will have mandated the use of non-polluting fuels in large, densely populated cities, accelerating the adoption and development of new technologies. Additionally, society will have embraced subscription-based mobility solutions, such as Mobility-as-a-Service (MaaS), which will have expanded significantly over the previous stages as they are more convenient than owning a vehicle and allow multiple modes of transportation. MaaS will be widely implemented, reducing the number of private vehicles on the streets, fostering greener urban environments, and increasing the number of pedestrian areas, which are also safer compared to earlier phases.
As a result, air pollution will be minimal, with neither vehicles nor buildings contributing to harmful emissions. Consequently, breathing air in megacities with millions of inhabitants will no longer pose health risks. Achieving this final state requires systemic transformations in energy infrastructure, transportation technologies, and policy frameworks to establish a fully sustainable mobility and energy system.


Backcasting
Desirable future
Business as usual
CO2 emissions
End of phase 1
End of phase 2
End of phase 3
2025
2030
2035
2040
2045
2050
Years

The transition involves multiple sectors working together to achieve these objectives. A coordinated effort across energy production, transportation, urban planning, policy development, and technological innovation will be essential to ensuring a seamless and effective shift toward sustainability. The integration of these sectors will facilitate the widespread adoption of clean energy sources, the implementation of efficient mobility solutions, and the development of infrastructure capable of supporting a zero-emission future.

MaaS provides citizens with an autonomous vehicle that picks them up from a designated location and transports them directly to their destination. Once the trip is completed, the vehicle autonomously picks up another passenger or group of passengers, offering the possibility of carpooling to optimize efficiency. After fulfilling its service cycle, the vehicle returns to a refueling station located on the outskirts of the city, in areas strategically chosen for safety, optimal land use, and the integration of energy production, fuel storage, vehicle parking, and refueling operations.

Both public mobility systems and MaaS play a crucial role in reducing the number of vehicles on urban roads, streamlining traffic flow, and making trips more efficient.

By this phase, the advantages of autonomous shared vehicles powered by alternative fuels will be well established. The financial burden of car ownership will be eliminated, as users will no longer bear costs related to purchasing, insurance, and maintenance. Refueling will become more cost-effective through the implementation of advanced energy pricing algorithms, optimizing consumption and reducing overall expenses. Additionally, parking constraints will be significantly minimized, as the need for individual parking spaces will be largely eliminated. This shift will remove the inefficiencies and inconveniences associated with traditional parking, including the time-consuming process of searching for a spot, maneuvering, paying fees, walking between the parking location and the final destination, and the pressure of time restrictions.
Eliminating these inefficiencies will make

Table 8: Projected Running Cost Of Fcevs (Albatayneh, 2023)

urban mobility more seamless, efficient, and user-friendly, enhancing transportation convenience and accessibility. Crucially, travel time will no longer be passive but can be used for personal activities, work, rest, or social interactions, further improving urban mobility's efficiency and convenience. Mobility will become universally accessible and affordable as companies transition from vehicle sales to subscription-based services. This transition will enable a more flexible and user-centric approach to transportation,

Hydrogen Production Method	**Current Cost per kg (USD)**	**Predicted Cost per kg (USD)**
Steam Methane Reforming (SMR)	1.5 - 2.5	1.0 - 1.5
Coal Gasification	2.0 - 3.5	1.5 - 2.0
Electrolysis (Renewable Energy)	2.5 - 7.0	1.0 - 3.0
Biomass Gasification	3.0 - 5.0	2.0 - 3.0
Photoelectrochemical (PEC)	20.0 - 30.0	10.0 - 15.0

Running cost of FCEVs will be competitive with BEVs when the cost of Hydrogen is below 1.5 USD/kWh where vehicles are designed to meet specific needs, align with different lifestyles, and cater to particular activities. Prioritizing functionality and adaptability will enhance mobility efficiency, minimize resource consumption, and improve user experience. This shift will contribute to a more sustainable and inclusive transportation system, ensuring that all individuals, regardless of economic status, have reliable access to mobility services tailored to their requirements.

In the second phase, building on the first stage´s groundwork, key technologies such as fuel cells, hydrogen production, and renewable energy sources will be deployed, enabling large-scale green hydrogen production. As early adopters embrace hydrogen-powered vehicles, their widespread acceptance is further facilitated by innovative designs and the association of these vehicles with social status, making them increasingly desirable to a broader segment of the population.
Advancements in hydrogen storage, particularly the development of Li-Mg-N-H systems in metal hydride tanks, will be crucial for mobility applications. Alongside nanotechnology innovations, these advancements will contribute to reducing both volume and weight, allowing for more compact and efficient vehicle designs in the coming years. These innovations will further accelerate hydrogen´s adoption as a mainstream energy carrier, improving its feasibility and market competitiveness.
The introduction of purpose-built vehicles will redefine how individuals experience mobility. Enabled by on-demand service models, these vehicles will be available for single-use purposes, eliminating the financial burden of ownership, the risks associated with vehicle loss of value, and the need for maintenance. This shift will not only increase accessibility but also enhance user convenience, ensuring that transportation solutions are tailored to individual needs while promoting sustainability and resource efficiency.

In the initial phase, as previously mentioned, hydrogen will primarily be deployed for heavy-duty and long-haul transportation, as well

as for stationary energy systems.
During this period, the construction of hydrogen distribution infrastructure will begin, first a new system of pipelines will be implemented then refueling stations and so on, while production will still rely on conventional, polluting processes. At the same time, policies will be introduced to restrict access to urban areas, particularly in densely populated zones, allowing entry only to non-polluting vehicles and public transportation. In this phase, hydrogen will be sold primarily to fuel freight truck fleets for road transport and to power stationary applications, including residential buildings and public infrastructure. Additionally, hydrogen-powered public transportation will be implemented, ensuring cleaner and more sustainable urban mobility.

As these policies take effect, resistance from certain sectors of the public is expected. However, a well-structured awareness campaign will be launched to facilitate acceptance by highlighting the long-term benefits of these measures, particularly in terms of public health and environmental sustainability. This initiative will aim to shift deeply ingrained habits while emphasizing the necessity of change for collective well-being.
The transition will be further supported by a reliable and efficient public transportation system, complemented by shared vehicle services. By providing seamless, accessible, and efficient mobility alternatives, this plan will help individuals navigate urban spaces without reliance on private, polluting vehicles, ensuring a smoother and more widely accepted transition to sustainable transportation.
As an alternative to fossil fuel-powered vehicles, a small, shared vehicle will emerge, characterized by high efficiency due to its lightweight construction and a design that prioritizes the actual mobility needs of individuals. However, those restricted by law from accessing regulated urban areas may initially resist this transition, expressing dissatisfaction with the imposed limitations. Over time, as micro mobility solutions expand and become more affordable, people will increasingly shift away from car dependency, gradually embracing more sustainable and efficient transportation alternatives. The

primary focus will be on enhancing desirability, raising public awareness, disseminating information, and promoting behavioral change. Encouraging widespread acceptance of hydrogen and alternative mobility solutions will require strategic efforts to make these technologies not only practical but also appealing to consumers. Public outreach campaigns, education initiatives, and policy-driven incentives will play a crucial role in fostering a shift in mindset, ensuring that individuals recognize the benefits of sustainable mobility while gradually adapting their transportation habits to align with a zero-emission future.

My project builds upon the previous considerations and proposes a structured plan for the transition to alternative fuels, beginning with the construction of a hydrogen production center. The energy production and consumption characteristics of this facility will align with those of Toyota's Hydrogen Headquarters (Toyota Newsroom, 2024).
This center will serve as a hub for hydrogen production and energy distribution, generating and selling energy derived from renewable sources such as solar and wind power. Additionally, it will integrate cutting-edge hydrogen production methods, including biohydrogen derived from algae and microbial processes. Beyond energy production, the facility will support extensive research and development (R&D) projects focused on hydrogen technology.
Moreover, the hydrogen production center will be utilized as a base for an autonomous vehicle fleet, addressing the increasing demand for Mobility-as-a-Service (MaaS) in future transportation scenarios. By facilitating the adoption of hydrogen-powered mobility solutions, this initiative will contribute to the broader transition toward sustainable and efficient urban transportation systems.
A crucial aspect of this project is engaging people with hydrogen technology and demonstrating both its safety and high-performance potential as the fuel of the future.

This will be achieved through the development of an attractive and compelling vehicle designed to effectively introduce a new technology, as highlighted by Koster (2023).

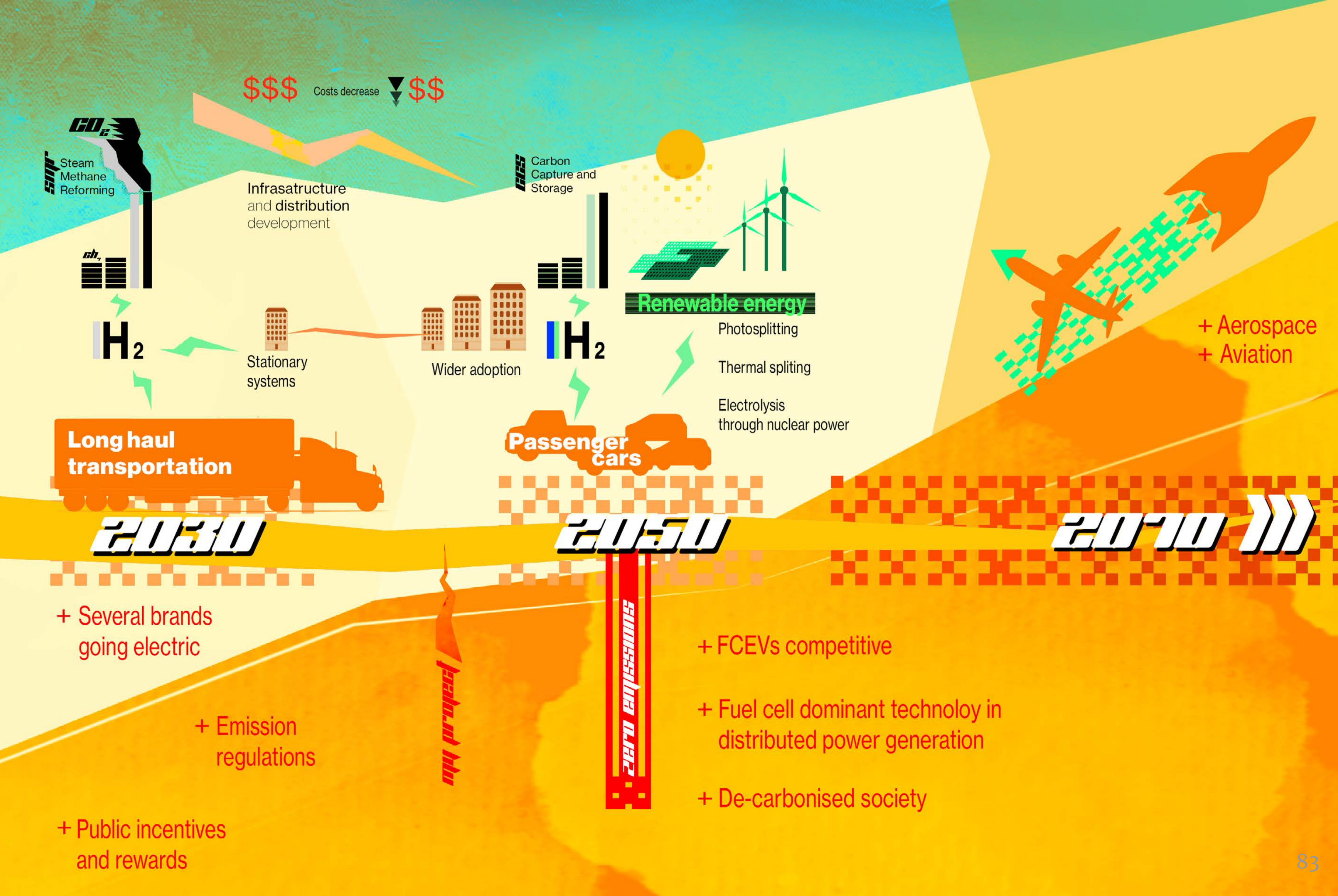
The goal is to create desirability by delivering performance that surpasses that of traditional combustion-engine vehicles.
To advance this objective, a concept car will be available for test drives on a dedicated circuit at the hydrogen research center, offering an interactive experience that familiarizes users with hydrogen-powered mobility while generating funding for R&D projects in hydrogen technology. In terms of performance, hydrogen is more efficient than gasoline, delivering a higher energy yield within a smaller storage volume. Consequently, hydrogen fuel tanks provide longer driving ranges than their gasoline counterparts while eliminating harmful emissions.
This vehicle serves as a tangible demonstration of the transformative impact of hydrogen innovation in the automotive sector. It showcases advancements such as reduced hydrogen storage tank size, enhanced fuel efficiency, and modular design, contributing to the development of a scalable hydrogen vehicle architecture. This concept follows the precedent set by GM's 2002 AUTOnomy project, which pioneered a hydrogen-based skateboard chassis—a flexible platform for future hydrogen-powered vehicles. Through these innovations, the project aims to accelerate the transition to sustainable mobility by proving the viability and advantages of hydrogen propulsion.

Another key aspect of this project is the design of an urban vehicle that merges the aesthetics and technologies of the concept car with the challenges automotive design and industry are facing. The outcome is a compact, lightweight, zero-emission vehicle with autonomous driving capabilities, designed within a Mobility-as-a-Service (MaaS) framework to enhance urban transportation efficiency.
The vehicle is designed to accommodate two passengers at a time, reflecting real-world travel patterns, as the average car occupancy per trip is approximately 1.6 passengers. Prioritizing efficiency and sustainability, it will be significantly lighter than conventional vehicles on the road today. According to Mitchell et al. (2010), compact urban vehicles can weigh less than 1,000 pounds and

measure under 100 inches in length, making them three to four times less space- and mass-intensive than traditional automobiles. Additionally, lower speeds in urban environments significantly reduce the energy impact of potential collisions, particularly between vehicles of similar design.
To maximize efficiency and reduce weight, the vehicle's range will be limited to under 100 miles, aligning with urban commuters' needs and accommodating daily mobility requirements (Mitchell et al., 2010). The vehicle's value will primarily derive from its advanced software, which will be central to optimizing performance, safety, and user experience.
Externally, the vehicle is designed to be visually inviting, fostering familiarity and accessibility. Inside, it will provide a secure and private space for passengers, ensuring both safety and comfort in a vehicle purpose-built for the evolving landscape of urban mobility.
General Motors (GM) is a key innovator in hydrogen technology, with an extensive portfolio of patents and projects in alternative fuels for automobiles. The company is frequently referenced in discussions on advancements in sustainable mobility. Alongside Toyota, GM is among the primary private investors in hydrogen research and development, complementing significant governmental initiatives worldwide. Notably, China has begun shifting its subsidies from battery-electric vehicles to hydrogen-powered technologies (Simonazzi et al., 2020).
According to Albatayneh et al. (2023), substantial global investments are currently underway to accelerate the development of hydrogen and fuel cell technologies. In the United States, the Department of Energy has committed up to $100 million for hydrogen and fuel cell research and development between 2022 and 2026. Similarly, the Hydrogen Fuel Technology Organization is supporting numerous initiatives focused on fuel cell electric vehicles, hydrogen production, storage, and infrastructure expansion.
In Europe, the European Union has allocated $430 billion to fund 70 green hydrogen projects by 2030, aligning with the objectives of the European Green Deal. McKinsey & Company projects that by 2050, hydrogen

could fulfill up to 18% of global energy demand, generating billions in annual revenue. Consequently, the hydrogen market is poised to play a crucial role in the future of the automotive sector, reshaping energy consumption and facilitating the large-scale adoption of zero-emission mobility solutions.

Timeline Hydrogen technology development and adoption.


$$$ Costs decrease $$
CO2
Steam Methane Reforming
Infrasatructure and distribution development
Carbon Capture and Storage
Renewable energy
H2
Stationary systems
Wider adoption
H2
Photosplitting
Thermal spliting
Electrolysis through nuclear power
Long haul transportation
Passenger cars
+ Aerospace
+ Aviation
2030
2050
2070
zero emissions
+ Several brands going electric
+ Emission regulations
+ Public incentives and rewards
+ FCEVs competitive
+ Fuel cell dominant technoloy in distributed power generation
+ De-carbonised society

Relevant Projects

ULEZ

London has become a leader in public transport electrification, operating over 500 electric buses and implementing the Ultra Low Emission Zone (ULEZ) to reduce urban air pollution. Since 2019, ULEZ has led to a 44% drop in roadside NO_2 levels, demonstrating the effectiveness of emission regulations and electric bus adoption.

Glasgow, focusing on hydrogen-powered transport, introduced hydrogen fuel cell buses in 2020, offering a range of over 300 km per refueling. The city's investment in Scotland's first hydrogen refueling facility aligns with its goal of becoming carbon-neutral by 2030. Glasgow's approach highlights hydrogen's role in complementing electric bus systems for a resilient, sustainable transit network.

Despite its effectiveness in reducing harmful emissions, ULEZ remains unpopular among residents in various regions worldwide.

Graffiti in Gunnersbury Park, west London, expressing opposition to the 2023 expansion of the ULEZ to cover Outer London

California Hydrogen Highway Program

California's Hydrogen Highway program seeks to develop 200 hydrogen fueling stations to facilitate the widespread adoption of fuel cell electric vehicles (FCEVs). This initiative demonstrates the state's commitment to clean energy and sustainable transportation solutions (Hordeski, 2008).

Hypercar by Lovins and Cramer

The Hypercar concept by Lovins and Cramer redefines vehicle design with ultralight construction, minimal aerodynamic drag, and integrated systems that reduce propulsion power needs by two-thirds. The enabling technologies include advanced composites for the body structure, integrated digital control systems, and hybrid-electric propulsion based on fuel cells, paving the way for energy-efficient vehicles (Lovins & Cramer, 2004).

2004: Gov. Arnold Schwarzenegger fuels a hydrogen fuel cell vehicle before signing the California Hydrogen Highway Network initiative during a ceremony at a refueling station on the University of California Davis campus. (AP Photo/Steve Yeater)

GM Autonomy Platform

GM's Autonomy concept, introduced in 2002, showcased a modular hydrogen-powered skateboard platform. This platform integrates a compact hydrogen fuel cell, in-wheel electric drive motors, and drive-by-wire electronic controls. The innovative design allows for the attachment of various lightweight vehicle bodies, offering unmatched flexibility and modularity (Autoblog, 2002; Jalopnik, 2020)

The GM AUTOnomy – The industry-changing vehicle and platform pioneered and developed by Adrian Chernoff. Picture courtesy of General Motors Company.

Toyota H2HQ Microgrid

Toyota's Hydrogen Headquarters incorporates an advanced microgrid system designed for energy independence and sustainability. It integrates a 230-kW solar photovoltaic system, a 1-MW stationary proton exchange membrane (PEM) fuel cell generator, a 325-kW solid oxide fuel cell (SOFC), and a 500-kWh battery storage system. The system is designed to operate off-grid and is expected to be operational by 2026 (Toyota Newsroom, 2024).

PACCAR and Toyota Collaboration

Toyota's collaboration with PACCAR's Kenworth brand in 2017 resulted in the development of 10 hydrogen-powered trucks. These trucks successfully demonstrated zero-emission capabilities in heavy-duty applications through the "Shore to Store" ZANZEFF project, showcasing the viability of hydrogen fuel cells for freight transport (Toyota Newsroom, 2024).

Chevrolet Sequel

The The Chevrolet Sequel, an all-wheel-drive hydrogen fuel cell vehicle, integrates advanced "by-wire" electronic controls for throttle, steering, and braking. Its unique skateboard chassis integrates propulsion, braking, and hydrogen storage systems, allowing a range of 300 miles per tank and an eight-minute refueling time. The Sequel's advanced cooling system addresses high ambient temperatures during hydrogen-to-electricity conversion.

The GM Concept car Chevrolet Sequel x-ray view. Picture courtesy of General Motors Company.

Hyperion XP-1

The Hyperion XP-1 hydrogen-electric hypercar exemplifies cutting-edge hydrogen technology in high-performance automotive engineering. With four axial-flux electric motors, a hydrogen fuel cell, and supercapacitors, it achieves a top speed of 221 mph and a range of 1,016 miles. Its futuristic design includes solar-panel-covered aerodynamic wings and a lightweight carbon-titanium monocoque chassis (Hyperion, 2024).

The Hyperion XP1. Picture courtesy of Quattroruote magazine.

Alpine Alpenglow HY6

The Alpine Alpenglow HY6 hydrogen-powe-red concept car merges high performance with sustainability. Powered by a 3.5-liter V6 twin-turbocharged hydrogen combustion engine, it features lightweight carbon-fiber construction and advanced aerodynamics for a top speed exceeding 330 km/h. Designed for competitive racing, this vehicle aligns with future hydrogen-powered car regulations for events like the 24 Hours of Le Mans.

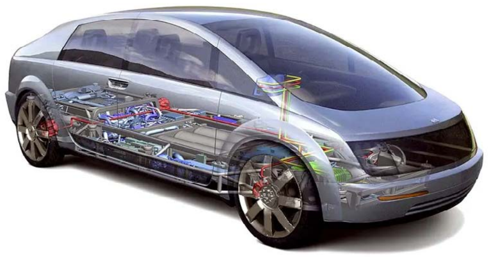
Pininfarina H2 Racing Car and Apricale

Pininfarina's H2 Racing Car highlights the potential of hydrogen in motorsports. Me-anwhile, the Pininfarina Apricale, developed in collaboration with Viritech, combines a hydrogen fuel cell with a lightweight battery system for a top speed of over 200 mph. It employs graphene-enhanced hydrogen storage for improved energy density and structural efficiency.

Alpine Alpenglow Hy6 Concept (2024). Image courtesy of NetCarShow.com.

Pininfarina Apricale. Image courtesy of NetCarShow.com.

2002: HY-WIRE Concept by General Motors Company, exterior view with xray and interior view.



HY-WIRE GM
Unveiled at the 2002 Paris Motor Show, the General Motors (GM) Hy-Wire marked a major breakthrough in automotive design by integrating hydrogen fuel cell technology with a drive-by-wire system. This innovative approach allowed for electronic control of steering, braking, and acceleration, eliminating traditional mechanical linkages. (WIRED, 2002)
The vehicle's architecture utilized a flat "skateboard" chassis, consolidating all propulsion and control components, including the fuel cell stack and electric motor. This design enabled the attachment of various body styles atop the chassis, offering flexibility and ease of customization.
The Hy-Wire's hydrogen fuel cell system provided electricity to power the electric motor, emitting only water vapor as a byproduct, thereby underscoring GM's commitment to sustainable transportation solutions.
Drive-by-wire technology enhanced vehicle control, enabling designers to rethink interior layouts.

Ferrari Hydrogen Engine

Ferrari's hydrogen innovation includes a patented six-cylinder hydrogen engine with multiple tanks for optimized storage and aerodynamics inspired by WWII aviation. This hybrid design integrates a rear internal combustion engine and front electric motor, exemplifying Ferrari's approach to combining performance with sustainability.

Ferrari Roma (2022). Picture by Tyler Cemmensen.

Chevrolet Equinox

Since its 2005 debut, the Chevrolet Equinox has undergone multiple redesigns to remain competitive in the compact SUV segment. The 2025 Equinox comes in three trims—LT, RS, and Activ—featuring a turbocharged 1.5L four-cylinder engine delivering 175 hp and 184 lb-ft of torque, paired with a CVT and front-wheel drive for optimal efficiency. Inside, the Equinox provides a spacious cabin for five passengers, featuring user-friendly technology like Apple CarPlay and Android Auto. Safety is emphasized with automated emergency braking, lane-keeping assist, and rear parking sensors. Competing with the Honda CR-V, Toyota RAV4, and Ford Escape, the Equinox blends performance, comfort, and technology, ensuring it remains a strong contender in the compact SUV segment.

ID.BUZZ VolksWagen

The Volkswagen ID.Buzz is an innovative electric minibus that combines iconic design with advanced technology, inspired by the legendary Bulli. Powered by a sustainable battery-electric drivetrain, it features cutting-edge driver assistance systems, including Travel Assist, which leverages cloud-based swarm data for advanced autonomous driving, enabling lane changes and adaptive speed control with minimal driver input.
The Park Assist Plus system allows the vehicle to learn and autonomously replicate parking maneuvers, while identifying suitable spaces and performing automated parking. Standard safety features include automatic emergency braking, Driver Alert System, Lane Assist, and Car2X traffic monitoring.
The ID.Buzz embodies Volkswagen's commitment to sustainability and innovation, providing a safe, efficient, and eco-friendly mobility solution tailored for urban and intercity travel.

VW I.D. Buzz Concept. Image's copyrightholder: VolksWagen

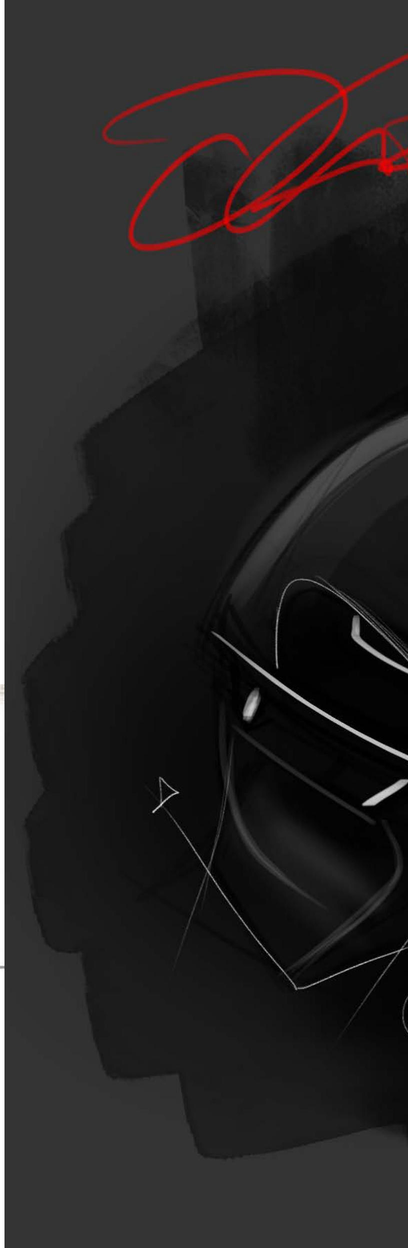
Methodology for Concept Development

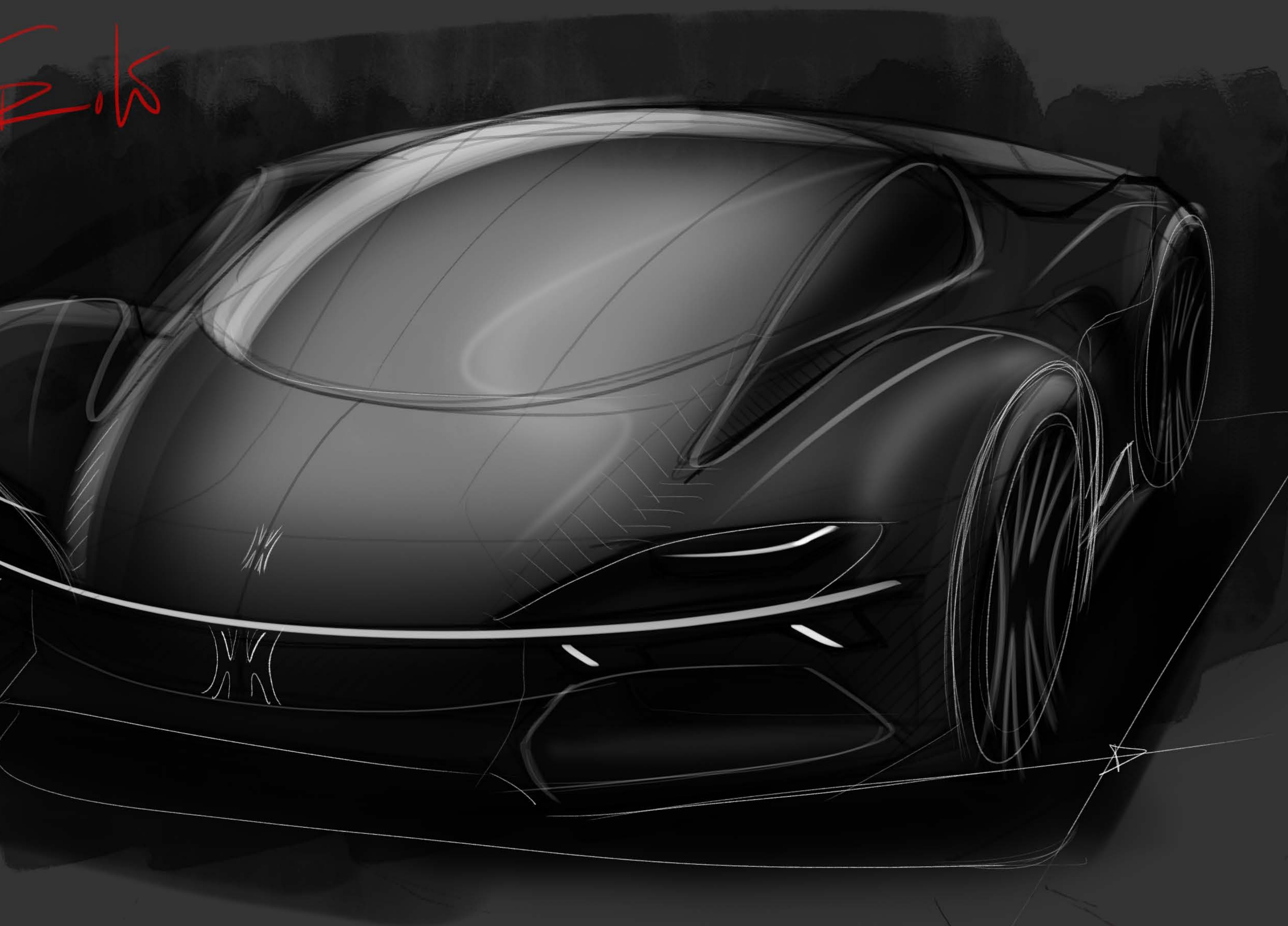
This project's journey was an engaging exploration of the dynamic automotive industry, driven by curiosity, challenges, and ambition. It began with a deep dive into the industry's intricate landscape, where a meticulous review of the literature unveiled a mosaic of emerging trends. Each trend suggested a future of mobility filled with potential and innovation, yet fraught with complexity. Among these, hydrogen technology emerged as a transformative force—a fuel capable of redefining sustainability and mobility.
But as compelling as this promise was, the challenges ahead were daunting. Technical constraints, infrastructure challenges, and economic barriers formed a complex web requiring strategic navigation.
During my time at Lawrence Technological University, I developed several vehicle design concepts with varying styles, initially created as hand-drawn sketches. To efficiently transition from 2D sketches to 3D models, I implemented a streamlined method for rapidly generating three-dimensional models, enabling a more comprehensive evaluation of the concepts beyond traditional 2D drawings or blueprints.
This process was greatly expedited using a Blender add-on that integrates ergonomic assessments aligned with automotive industry standards. The software employs parametric modeling, positioning occupants based on the H-point (Macey & Wardle, 2014) while factoring in key vehicle dimensions such as wheelbase, length, width, and height. The add-on was developed by the Drawings and Methods Research Group at the Department of Industrial Engineering (DIN).

After the 3D modeling phase, faculty members from LTU's Department of Design, including Professors Justin Famularo and Kohl Kohrman (Stellantis), alongside Professors Ahad Ali and Don Reimer from the Department of Engineering, selected the Cadillac design for further refinement.
Throughout this process, General Motors Corporation (GM) emerged as a key innova-

tor.
Renowned for its audacious spirit, GM has consistently ventured where others hesitated, tackling formidable uncertainties with bold innovation. It became clear that Cadillac, GM's epitome of luxury and technological excellence, was the ideal choice to anchor this vision. Its storied legacy and commitment to pushing the boundaries of design and engineering resonated perfectly with the ambitions of this project.
Selecting Cadillac was a pivotal decision that reshaped the project's direction. It marked the beginning of an immersive study into the brand's essence—a deep exploration of its history, its identity, and the values that make it an icon of refinement and innovation. Each discovery along the way brought new layers of insight, shaping the concept and infusing it with purpose. This journey extended beyond a mere process; it became a narrative of discovery, marked by bold decisions and a commitment to vision and persistence. It involved analyzing past, present, and future trends in Cadillac's design language and consumer preferences, alongside a critical evaluation of concept cars to uncover innovative opportunities. After conducting an in-depth Stylistic Design Engineering (SDE) (Frizziero et al., 2021) analysis, the concept development for the hydrogen-powered sports vehicle followed a structured, design-driven methodology.
The next phase involved segment identification, strategically positioning the vehicle within the sports segment to meet high-performance enthusiasts' expectations while prioritizing sustainability. This was followed by the identification of key design lines and determining areas for innovation to align with modern aesthetic and functional demands. The creative process included emotive sketches, aimed at capturing the vehicle's spirit and character, complemented by more refined sketches, a technique I learned from my mentor Boris Fabris, to explore precise forms and proportions. Detailed 2D drawings were created, emphasizing ergonomic and technical aspects, following Macey & Wardle's H-point (2014) methodology to optimize driver and passenger positioning for comfort and performance.

Integrating virtual reality (VR) sketching enabled an immersive evaluation of design volumes and spatial relationships, ensuring a dynamic and realistic concept assessment. The mesh was subsequently imported into Blender to refine dimensions and theoretical parameters. This iterative approach seamlessly blended creativity with technical precision, forming the foundation for an innovative and visually compelling hydrogen sports vehicle concept.





Sketching

Sketching and prototyping are fundamental in the early stages of conceptual automotive design, where aesthetics and functionality intersect to produce vehicles that resonate with consumers. These processes bridge abstract concepts and tangible outputs, fostering creativity and facilitating iterative exploration of form and function. Hand-drawn sketches, a fundamental tool in design, provide a crucial medium for tackling creative and exploratory design challenges. They enable designers to cognitively engage with their concepts, fostering the emergence of innovative ideas that might otherwise remain unrealized (Gernsbacher & Derry, 2022; Suwa et al., 2022).
In the context of automotive design, the creation of sketches involves key elements such as line types, graphical features, surface articulation, and layout (Wu et al., 2023). Line types play a significant role in defining the morphological identity of a vehicle. These lines combine to form graphical features like the iconic double-kidney grille of BMW or Audi's hexagonal grille, which contribute to the vehicle's aesthetic and brand identity. Additionally, the surface properties of a car, reflecting light and shadow, and the curvature and concavity of the body, serve as primary visual cues in exterior design. Layout, as the principle of organizing graphical features, ensures the integration of design elements into a cohesive and recognizable form, enhancing the overall perception of the vehicle (Wu et al., 2023).
Prototyping, whether in physical or virtual form, serves as an essential extension of sketching by bringing conceptual designs into tangible or interactive realities. These prototypes play a vital role in confirming design objectives and promoting the adoption of innovative ideas. The tangible nature of prototypes, regardless of whether they are physical or digital, enables stakeholders to interact with the design in a manner that effectively merges conceptual vision with perceived reality. Research highlights that well-crafted prototypes can elicit emotional and cognitive reactions akin to those experienced with fully realized products, further underscoring their value (Mangiarotti, 2015).

Moreover, the acceleration of computational tools in design has introduced human-machine hybrid intelligence as a method for generating and evaluating car forms. These tools enhance design efficiency, enabling the exploration of multiple solutions through rule-based algorithms. However, computational design lacks the intuitive creativity and psychological depth of human cognition, reinforcing the irreplaceable value of traditional sketching and designer-driven prototyping in capturing nuanced aesthetics and brand-specific characteristics (Wu et al., 2023).

In automotive design, aesthetics significantly influence consumer desirability and brand perception, often determining the commercial success of a vehicle. Attributes such as fuel efficiency or performance can be quantitatively measured, but aesthetic and brand-related qualities remain subjective and harder to evaluate. This subjectivity underscores the importance of iterative sketching and prototyping in refining designs to align with both consumer expectations and brand identity, ensuring that vehicles are not only functional but also emotionally resonant and commercially viable. By facilitating an iterative dialogue between creativity and technical precision, sketching and prototyping remain fundamental to developing innovative and aesthetically compelling automotive designs.

Branding

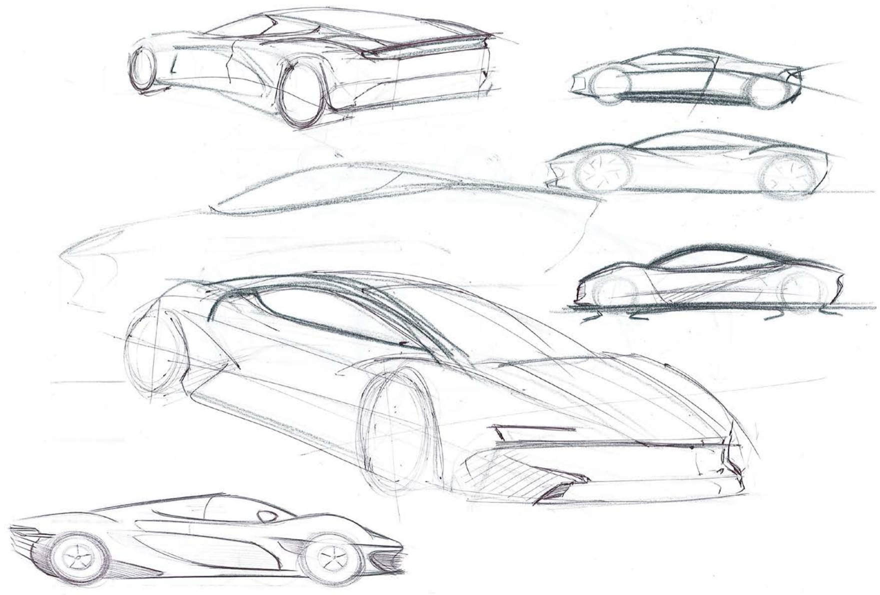
Branding and aesthetics play a crucial role in the automotive industry, shaping consumer perceptions and influencing purchasing decisions. Kreuzbauer and Malter (2005) highlight that aesthetics can influence up to 60% of a consumer's vehicle purchase decision. This underscores the essential role of design as a conduit for brand identity and market success.

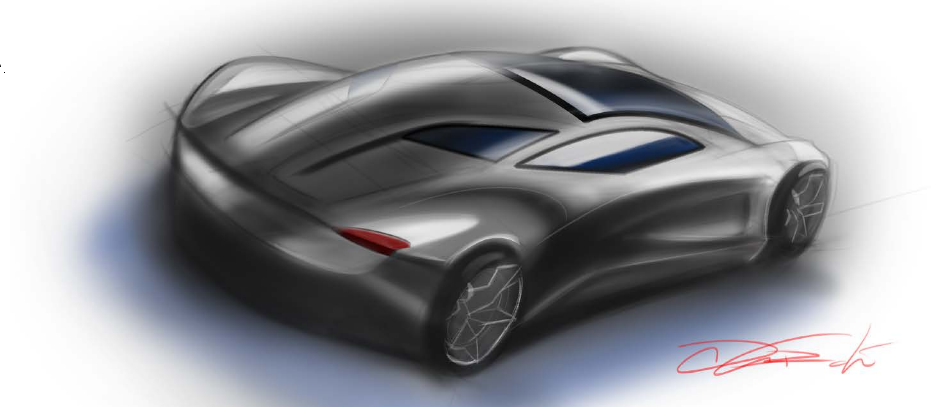
A car's front-end design is pivotal in branding, incorporating elements like logos, headlights, and grilles to reinforce brand recognition and emotional appeal (W. Yang et al., 2020). Tovey et al. (2003) emphasized that sketches, particularly those focusing on form lines, are integral to conceptual automotive design, providing the foundation for cultivating

aesthetic and brand identity. These design elements serve not only as functional features but also as critical tools for conveying a brand's ethos and values.
McCormack et al. (2004) introduced the concept of shape grammars, highlighting the role of design in maintaining brand coherence. This methodology involves distilling complex vehicle forms into simplified geometric representations, enabling designers to experiment with aesthetic features while ensuring brand consistency. For instance, historical studies of Buick vehicles revealed that isolating key features and their interrelations could effectively capture the essence of the brand and support its evolution.
Brand identity is a multifaceted concept, incorporating organizational, product, personality, and symbolic dimensions (Mindrut et al., 2015). Maintaining a consistent brand identity offers a competitive edge, fostering consumer loyalty and emotional connections with the brand (Rinaldi et al., 2023). These connections develop through visual consistency in logos, colors, and forms, strengthening the brand's presence over time.

In the automotive industry, where novel technological features are increasingly commoditized, aesthetics and branding have become pivotal differentiators (Warell, 2001). A well-executed design not only enhances the visual appeal of a vehicle but also communicates the manufacturer's values and the product's functionality to the consumer (Monö, 1997). This dual role of design—conveying utility and reinforcing brand identity—highlights its centrality to the automotive sector's strategy.
Data-driven approaches to design, such as the GP22 dataset developed by Lee et al. (2022), demonstrate the intersection of technology and aesthetics. This dataset, comprising over 1,400 vehicle profiles, provides a systematic framework for analyzing and refining design features. Key elements like body shape, greenhouse, and wheel proportions contribute to the perception of luxury and prestige, emphasizing the importance of proportions such as the dash-to-axle ratio.
Branding also extends beyond visual identity to encapsulate emotional resonance and consumer aspirations. Audi's assertion that

design significantly influences purchase decisions aligns with the broader understanding that aesthetics shape consumer judgment and brand perception (Bloch, 1995; Page & Herr, 2002). Strategic tools like shape grammars allow companies to explore the limits of their brand identity, balancing historical references with modern innovations (McCormack et al., 2004).
In conclusion, the integration of branding and aesthetics in automotive design is paramount for achieving consumer engagement and market differentiation.
By employing methodologies like shape grammars and data-driven design tools, automotive manufacturers can harmonize functional requirements with brand aspirations, ensuring long-term market relevance.





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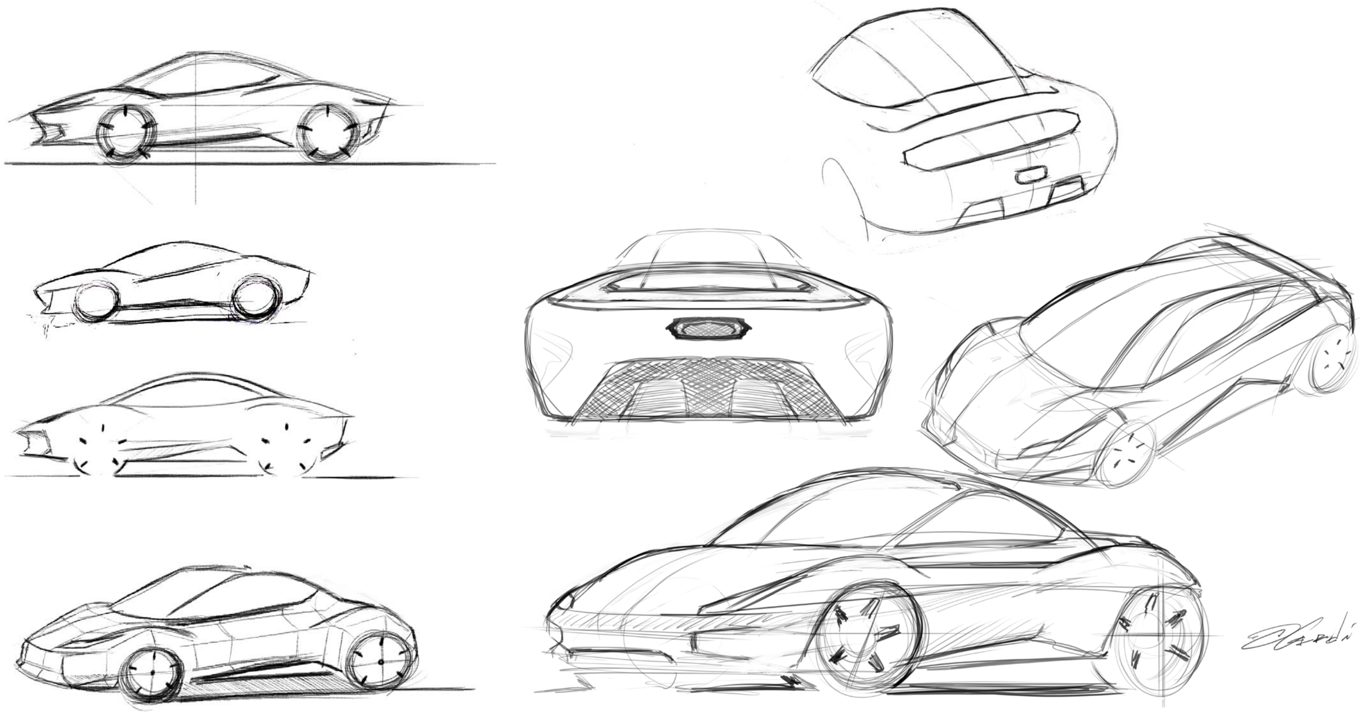

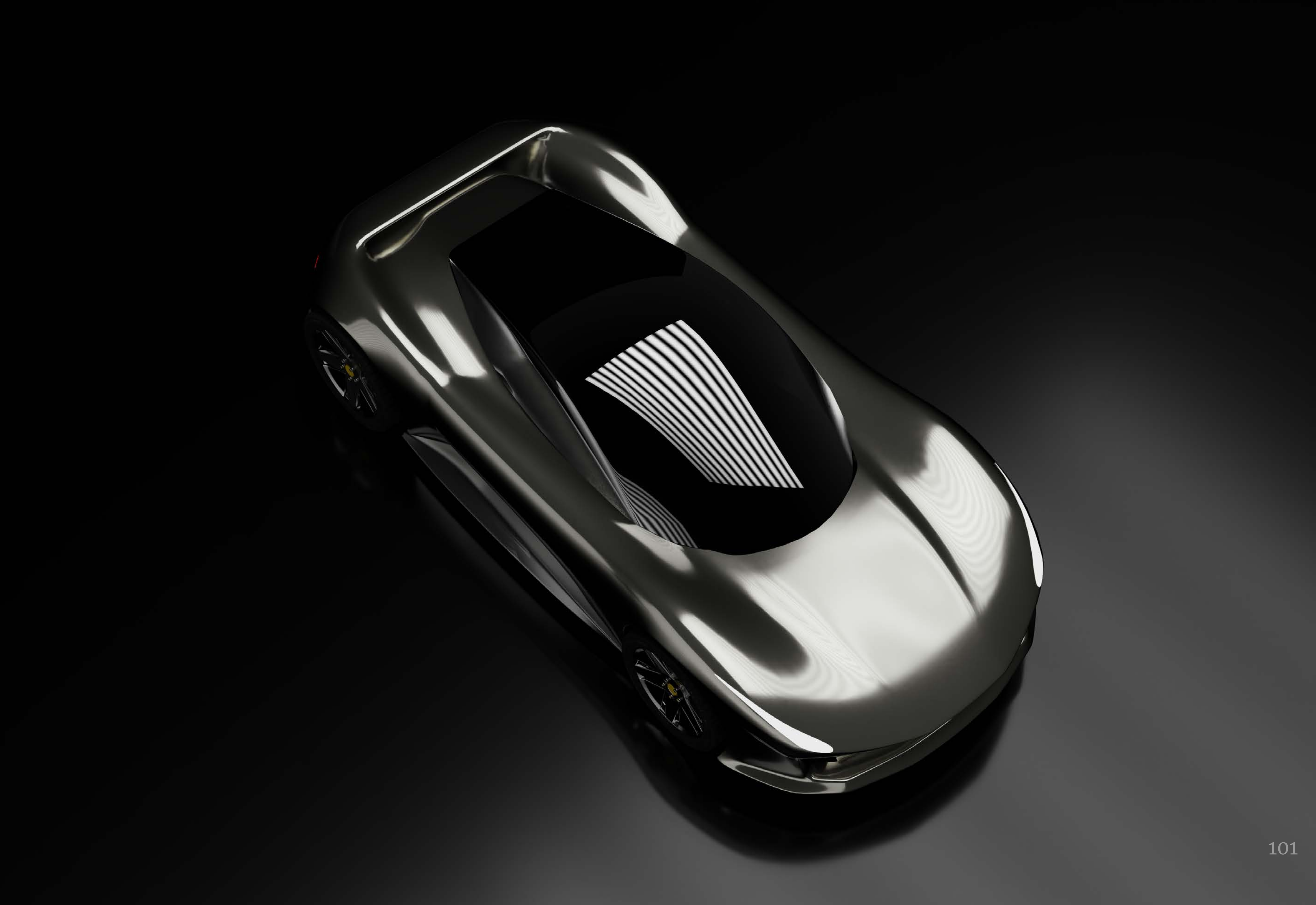

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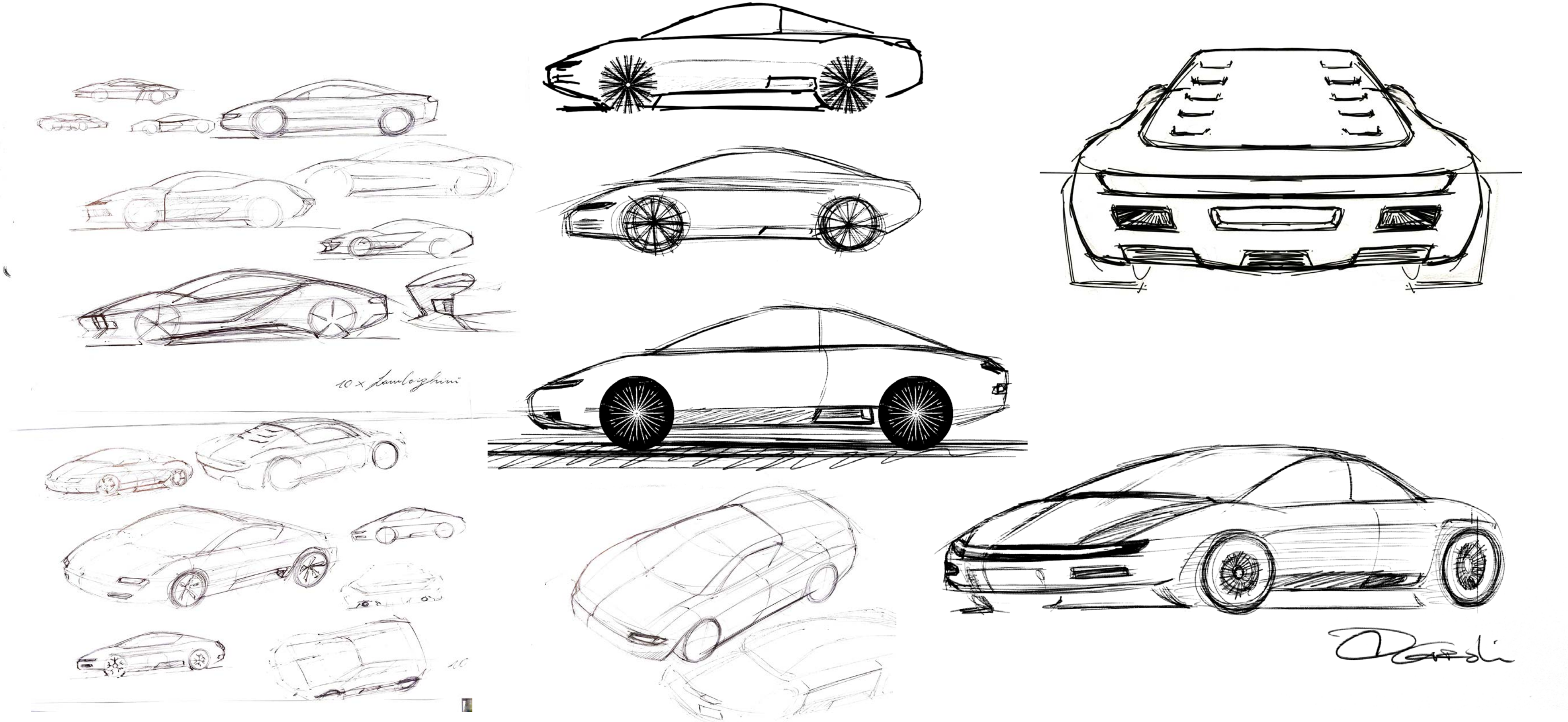

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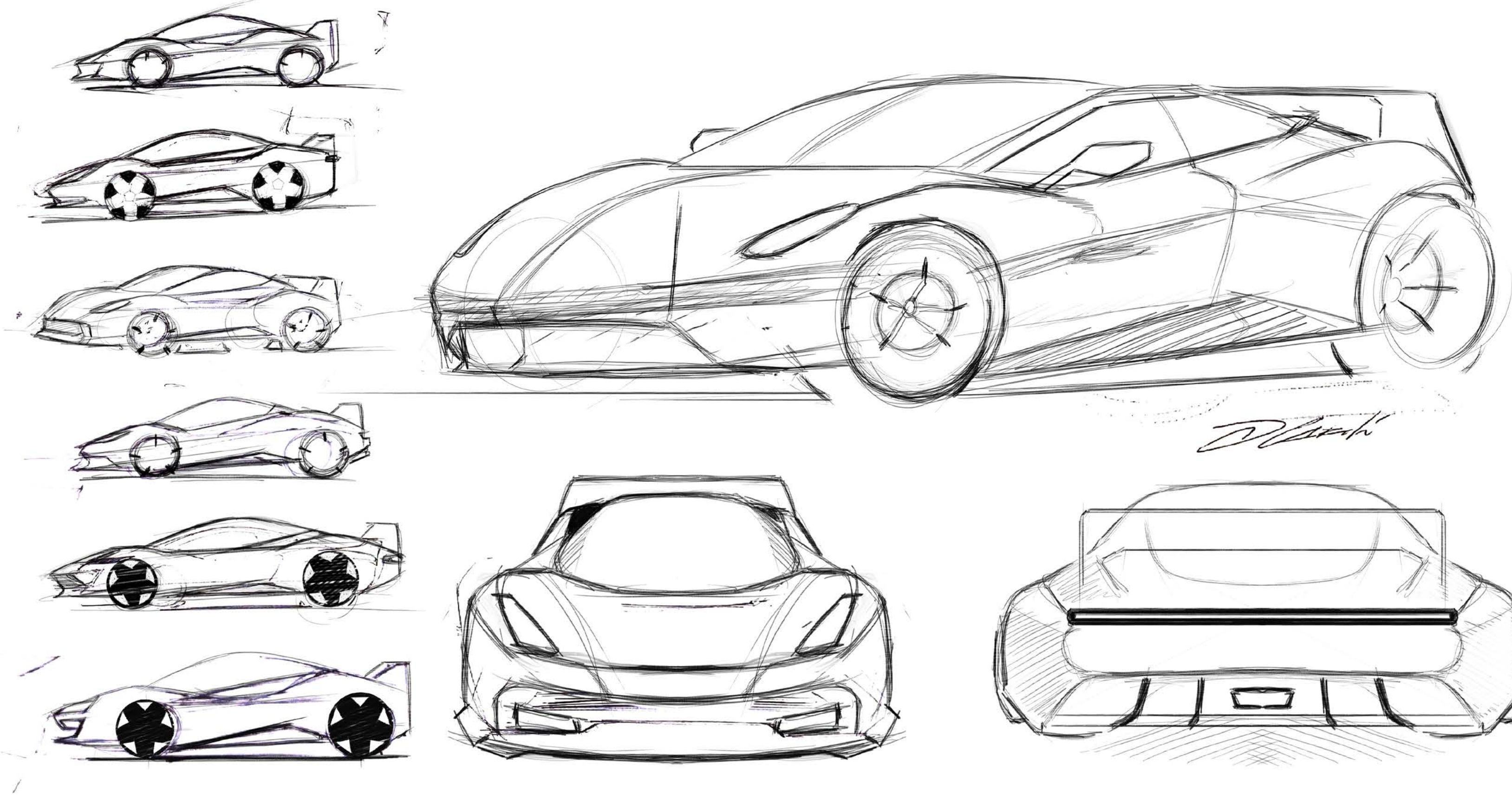
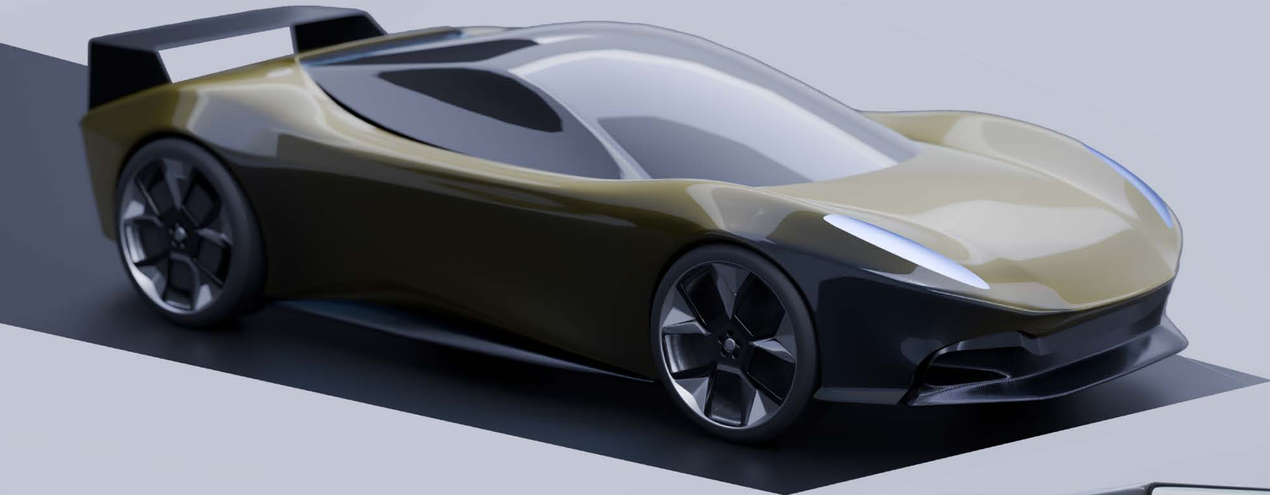




Hydrogen-Powered Sports Vehicle: A Conceptual Approach with Stylistic Design Engineering

Designing Innovation

The design of a hydrogen-powered sports vehicle integrates engineering innovation with stylistic excellence, utilizing advanced methodologies such as Stylistic Design Engineering (SDE) to create a sustainable yet high-performance automobile. SDE combines engineering precision with design creativity to align technical specifications with market expectations, particularly in niche segments such as hydrogen-powered sports cars (Donnici et al., 2020; Frizziero et al., 2021). This methodology ensures that each design element enhances both performance and aesthetic appeal.
The results are presented in tables at the end of this chapter.

The SDE framework, as applied to this project, integrates customer requirements, quality function deployment (QFD) (Akao, 1990), and advanced design matrices to create a concept that addresses the core demands of the target demographic (Frizziero et al., 2019).

Hydrogen-powered sports vehicles must be lightweight, aerodynamically optimized, and efficient, featuring robust fuel storage systems and outstanding performance characteristics (Chapman, 2007; Lovins & Cramer, 2004). The application of QFD prioritizes customer expectations, allowing the design team to translate conceptual preferences into tangible technical specifications (Frizziero et al., 2021).
To appeal to car enthusiasts who are often skeptical of green technologies, the vehicle must match or exceed the performance of conventional gasoline-powered sports cars. This approach aligns with the "six-question method" (Who, When, Where, What, Why, How), which aids in defining the vehicle's market positioning. The car is designed as a track-focused, manually driven sports vehicle, providing users with a unique opportunity to experience sustainable high-performance driving in an aesthetically striking package.

The design incorporates a mid-engine layout, rear-wheel drive (RWD), and an extended wheelbase (approximately 2650 mm) to op-

timize stability, handling, and performance. A low center of gravity and wide track enhance cornering stability and high-speed behavior, ensuring an exhilarating yet controlled driving experience.
Aerodynamic efficiency is critical, featuring a reduced drag coefficient (Cd) and optimized weight distribution to lower rotational inertia and enhance maneuverability.
Benchmarking and top-flop analysis offer valuable insights into existing hydrogen and electric sports vehicles, identifying opportunities for enhancement. Key advantages, such as extended range, aesthetic appeal, and advanced performance metrics, are incorporated into the design, while potential drawbacks, including high maintenance costs and technological complexity, are mitigated through innovative engineering solutions (Frizziero et al., 2022).

Powertrain Considerations

The powertrain is central to the vehicle's performance and sustainability. Key components—including the engine, transmission, driveshaft, differential, and axles—are optimized for minimal weight and maximal efficiency. This strategy enhances propulsion, fuel efficiency, and overall performance while addressing common powertrain issues such as fluid leaks, gear slippage, and vibrations. The lightweight construction of the powertrain aligns with the concept of the "beneficial mass spiral," where reduced weight in one area leads to cascading weight reductions across the entire vehicle (Lovins & Cramer, 2004).

Alignment with Market and Environmental Goals

he hydrogen-powered sports vehicle represents the future of sustainable transportation, integrating technical innovation with environmental responsibility. Hydrogen fuel cells, known for their efficiency and clean operation, provide the propulsion system, ensuring zero carbon emissions and positioning the vehicle as a flagship for green automotive technology. By addressing urbanization challenges and consumer preferences, this project contributes to the broader goal of transitioning toward sustainable solutions.

Cadillac

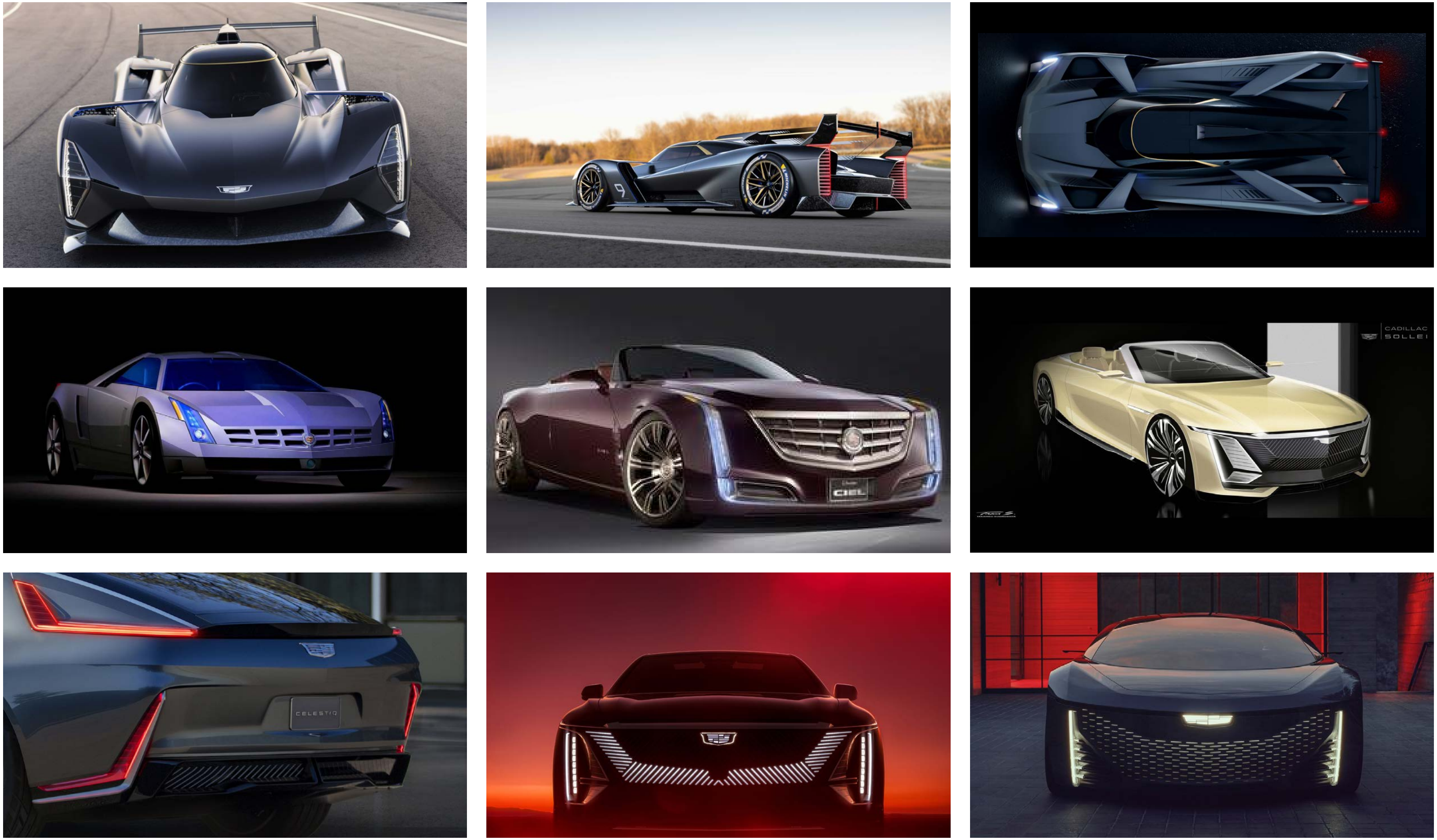
Cadillac, established in 1902 in Detroit, Michigan, stands as an enduring symbol of American luxury and innovation in the automotive industry. Named after Antoine de la Mothe Cadillac, the French explorer and founder of Detroit, the brand quickly distinguished itself through precision engineering and advanced technology. Cadillac's pioneering spirit was evident as early as 1908 when it became the first car manufacturer to win the Dewar Trophy for its demonstration of interchangeable parts, setting a new standard for mass production. The brand's groundbreaking introduction of the electric starter in 1912 revolutionized automotive design, making vehicles more accessible and practical. Throughout its history, Cadillac has been synonymous with bold design, dramatic proportions, and intricate detailing, creating a visual identity that is both distinctive and instantly recognizable. Signature elements such as the vertical taillights, long hoods, and the iconic Cadillac crest have communicated prestige and sophistication, cementing Cadillac's reputation as a symbol of success. The evolution of the Cadillac grille, with its prominence and elegance, embodies the brand's ability to balance tradition with modernity, while chrome accents, elongated silhouettes, and advanced lighting systems have consistently set Cadillac apart in luxury aesthetics. A hallmark of Cadillac's history is its relentless pursuit of excellence in engineering and design. The introduction of the V8 engine in 1915 established an industry benchmark, while the tailfins of the 1948 models, inspired by aeronautics, revolutionized automotive design worldwide. During the mid-20th century, Cadillac became a cultural icon, epitomizing the American dream and serving as the vehicle of choice for dignitaries, celebrities, and discerning consumers. Models such as the Eldorado and Fleetwood achieved legendary status, further solidifying Cadillac's legacy. In recent years, Cadillac has embraced sustainability and innovation through electrification and autonomous technologies, as seen in the launch of the all-electric Cadillac Lyriq. This transition reflects the brand's commitment to maintaining its luxurious identity while addressing modern environmental concerns. Known for its "Art and Science" design philosophy, Cadillac seamlessly integrates sculptural beauty with cutting-edge technology, ensuring that its vehicles appeal to traditional luxury buyers and modern innovators alike. Cadillac's legacy is not only rooted in its aesthetic recognition and technological advancements but also in its ability to adapt to changing consumer preferences while maintaining its core identity. Representing more than just automobiles, Cadillac embodies a legacy of excellence, innovation, and American ingenuity, redefining luxury and shaping the future of driving with every milestone.

Cadillac Vistiq (2026).

Cadillac Reference Images

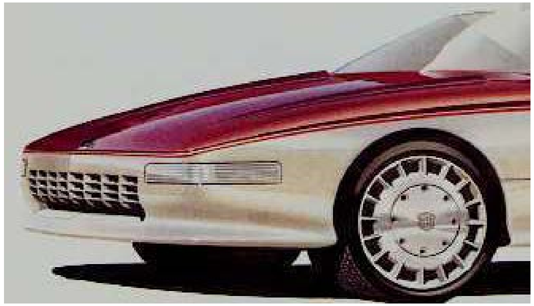
Cadillac Opulent Velocity (2024), pictures courtesy of Cadillac.

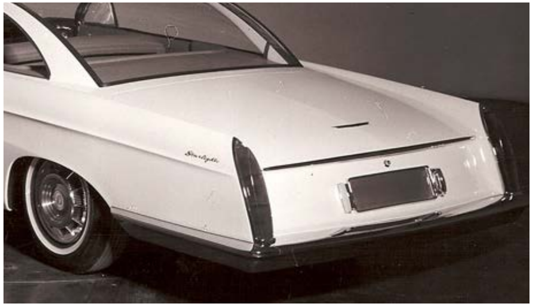
Cadillac Project GTP Hypercar (2024), Cadillac Cien (2002), Cadillac Ciel (2011), Cadillac Sollei (2024), Cadillac Celestiq (2022), Cadillac Innerspace (2022) Pictures courtesy of Cadillac.



Cadillac Details To Understand Brand Dna Elements

Cadillac vehicles, pictures courtesy of Cadillac.





ON THIS BENCH
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Cadillac Cien

The Cadillac Cien, unveiled in 2002 to commemorate the brand's centennial, stands as a pinnacle of automotive innovation and design excellence. The car is mentioned because it represents the heritage my concept embraces and carries on. The name "Cien," meaning "one hundred" in Spanish, pays homage to this historic milestone. Designed by Simon Cox, the Cien features a mid-engine, rear-wheel-drive configuration, underscoring its focus on high-performance dynamics. The body, crafted entirely from carbon fiber, ensures exceptional lightness and structural rigidity, while the dramatic scissor doors enhance the vehicle's theatrical and avant-garde aesthetic.

At the heart of the Cien lies the Northstar XV12 engine, a 7.5-liter V12 powerhouse delivering an impressive 750 horsepower and 610 Nm of torque. This engine, visible through a transparent panel in the rear decklid, incorporates cutting-edge technologies such as the "Displacement on Demand" system, which allows for the deactivation of half the cylinders to optimize fuel efficiency during low-performance demands. Paired with a six-speed semi-automatic transmission, operated via Formula 1-inspired paddle shifters, the drivetrain delivers seamless and precise gear changes, epitomizing high-performance engineering.

The Cien's design draws inspiration from the F-22 Raptor fighter jet, evident in its sharp lines and aerodynamic profile. The carbon fiber monocoque not only reduces overall weight but also enhances aerodynamic efficiency. Advanced features such as a speed-sensitive active rear spoiler and a removable hardtop seamlessly blend functionality with aesthetic refinement, further elevating the vehicle's innovative appeal.

Despite its favorable reception and the excitement it generated, the Cadillac Cien never reached production. The primary barriers were the prohibitive development costs and a projected retail price of approximately $200,000, which would have significantly constrained its market potential. Consequently, General Motors opted not to pursue mass production.

Nonetheless, the Cien has cemented its legacy in popular culture, with notable appearances in the 2005 film The Island and video games such as Gran Turismo and Midnight Club 3: DUB Edition Remix. These appearances underscore the enduring influence of its design and technological advancements.
In conclusion, the Cadillac Cien exemplifies the brand's commitment to harmonizing luxury, performance, and cutting-edge technology. Although it remains an exercise in design and engineering, its impact resonates in the aesthetic and technological evolution of subsequent Cadillac models, reinforcing the marque's position as a trailblazer in the automotive industry.

Cadillac Cien (2002).

Supercar

Six Questions table

Who	What	Location	When	Why	How
Performant	Performant	Performant	Safe	Sustainable	Sustainable
Safe	Sustainable	Appealing	Maneuverable	Fast	Fast
Appealing	Appealing	Advanced	Autonomous	Advanced	Advanced
Luxurious	Safe		Stable	Comfortable	Comfortable
Sustainable	Loud		Performant		
Loud			User-Friendly		

User?: Car enthusiast interested in high performance vehicles who are usually skeptical to new green technologies.

Need?: Show a technology's potential to be a compelling option on the market and be an opportunity to introduce a green technology with analogue performance to gasoline powered vehicles, with all its benefits and removing all its disadvantages.

Location?: Car shows and trakcs

When is it used?: Very seldom, on the weekend or even a once in a lifetime experience (when the user goes to the racetrack to try a sports car) - leisure time.

Why is it used?: Have a sustaiable lifestyle with all the advantages of driving a sports vehicle and to display an alternative fuel for future vehicles.

How is it powered/driven?: Hydrogen powered vehicle, manually driven on track.

Dependency | Independency table

	Performant	Safe	Appealing	Luxurious	Fast	Sustainable	Maneuverable	Stable	Reactive	Autonomous	Advanced	Comfortable	User-Friendly	Loud
Performant		0	0	0	9	0	3	3	3	0	0	0	0	0
Safe	0		0	0	3	0	0	3	0	3	0	1	1	0
Appealing	0	0		0	1	1	0	0	0	0	3	3	1	9
Luxurious	0	0	9		0	0	0	0	0	0	1	3	1	1
Fast	9	0	0	0		0	3	9	3	0	0	0	0	0
Sustainable	1	0	0	0	0		0	0	0	0	0	0	0	0
Maneuverable	3	0	0	0	3	0		3	1	0	0	0	1	0
Stable	1	0	0	0	1	0	3		1	3	0	0	0	0
Reactive	3	0	0	0	9	0	1	1		0	0	0	0	0
Autonomous	0	0	0	0	0	0	0	0	0		3	1	1	0
Advanced	1	0	0	1	0	9	0	0	0	3		1	3	0
Comfortable	1	1	0	3	1	0	0	0	0	1	0		0	0
User-Friendly	0	3	1	0	0	0	0	0	0	1	0	3		0
Loud	1	0	1	0	3	0	0	0	0	0	0	0	0	

Most independent parameters are: Performant, Appealing, Luxurious, Fast, Advanced

Relative Importance table

	Performant	Safe	Appealing	Luxurious	Fast	Sustainable	Maneuverable	Stable	Reactive	Autonomous	Advanced	Comfortable	User-Friendly	Loud
Performant	1	2	1	2	1	1	1	1	1	2	2	2	2	0
Safe	0	1	1	1	0	2	1	1	0	2	0	2	1	2
Appealing	1	1	1	1	1	0	1	1	1	2	2	2	2	1
Luxurious	0	1	1	1	0	0	0	0	0	2	0	1	2	0
Fast	1	2	1	2	1	1	2	1	1	2	2	2	2	2
Sustainable	1	0	2	2	1	1	1	1	1	2	2	2	2	2
Maneuverable	1	1	1	2	0	1	1	1	2	2	2	2	1	2
Stable	1	1	1	2	1	1	1	1	1	2	2	1	2	1
Reactive	1	2	1	2	1	1	0	1	1	2	1	1	2	2
Autonomous	0	0	0	0	0	0	0	0	0	1	1	0	0	1
Advanced	0	2	0	2	0	0	0	0	1	1	1	1	1	2
Comfortable	0	0	0	1	0	0	0	1	1	2	1	1	2	1
User-Friendly	0	1	0	0	0	0	1	0	0	2	1	0	1	1
Loud	2	0	1	2	0	0	0	1	0	1	0	1	1	1

Most relatively important parameters are: Performant, Fast, Sustainable, Maneuverable, Stable, Reactive

Table 10

What | How table

Parameters considered as highly dependent if they positively improve that performance.

What | How	Lightweight	Aerodynamic	RWD	Direct Steering Ratio	Length	Width	Height	Wheelbase (Short)	Wheelbase (Long)	Engine	Wheels (Large)
Performant	9	9	1	1	1	1	3	1	1	9	0
Appealing	0	3	0	0	3	3	3	0	0	0	3
Fast	9	9	0	3	1	1	3	0	1	9	1
Maneuverable	1	3	1	0	3	3	1	3	1	0	3
Stable	1	3	9	0	3	3	9	0	9	0	9
Reactive	9	3	9	9	3	1	3	9	3	9	1
Total	29	30	20	13	14	12	22	13	15	27	17

Long

Wide

Short

Wheels (Small)	Treack (Wide)	Treack (Narrow)	RWD Traction	RWD AWD	Centre of Mass (Low)
0	1	1	1	3	1
1	0	0	0	1	1
1	3	1	3	3	3
3	3	1	0	3	0
0	9	3	3	0	9
9	1	3	3	0	1
14	17	9	10	1	20

Long wheelbase: Greater stability at high speeds and on straight roads.
Wide track: Better lateral grip and stability in curves.
Reduced height: Lowers the center of gravity, improving stability and dynamic behavior.
Greater length: Improves straight-line stability, but may compromise agility.
Longer front overhang: Can improve aerodynamic distribution.
Rear (RWD): Better traction in acceleration and balance in curves.
Tire width: Wider tires increase traction and lateral grip, but worsen aerodynamic efficiency.
Larger diameter wheels: Improve stability, but may compromise agility.
Downforce: Generated by splitters, diffusers, and wings; it improves cornering grip and high-speed stability.
Steering ratio: Should be direct to favor responsiveness.
Center of gravity: Should be as low as possible to maximize stability.

Table 11

Benchmark table

Car Name	Brand	Year	Length [mm]	Width [mm]	Height [mm]	Wheelbase [mm]	Front Track [mm]	Rear Track [mm]	Power [hp]	Weight [kg]
Bugatti Tourbillon	Bugatti	2026	4671	2051	1189	2740	None	None	1775.0	1995
Ferrari SF90	Ferrari	2020	4710	1972	1186	2560	1679	1652	None	1570
Koenigsegg CC850	Koenigsegg	2023	4364	2024	1127	2700	None	None	1385.0	1385
Aston Martin Valhalla	Aston Martin	2022	4560	1950	1200	2720	None	None	998.0	1550
Ferrari KC23	Ferrari	2023	4633	2045	1090	2700	1650	1650	1275.0	1305
McLaren W1	McLaren	2025	4630	2070	1180	2680	None	None	750.0	1399
McLaren 750S	McLaren	2023	4569	1930	1196	2670	None	None	750.0	1389
Rimac Nevera	RIMAC	2024	4750	1986	1208	2745	None	None	2107.0	2150
Ferrari F80	Ferrari	2025	4840	2060	1138	2665	1701	1660	1200.0	1525
Hyperion XP1	Hyperion	2021	4.812	2000	1140	2700	None	None	2038.0	1032
Pininfarina H2	Pininfarina	2018	4730	1956	1113	2968	None	None	653.0	1430
Pininfarina Apricale	Pininfarina	2021	None	None	None	None	None	None	None	1000
Cadillac Cien	Cadillac	2002	4457	1975	1110	2750	1632	1726	760.0	1451
Lamborghini Rev	Lamborghini	2024	4947	2033	1160	2779	1720	1701	1015.0	1772
McLaren Artura	McLaren	2022	4539	2080	1193	2640	1650	1613	671.0	1498
GAC AION Hyper	GAC	2024	4538	1988	1238	2650	None	None	None	1980
Lotus Emira	Lotus	2021	4410	1900	1230	2580	None	None	405.0	1405
Lamborghini Tem	Lamborghini	2025	4706	1996	1201	2658	1722	1670	920.0	1715

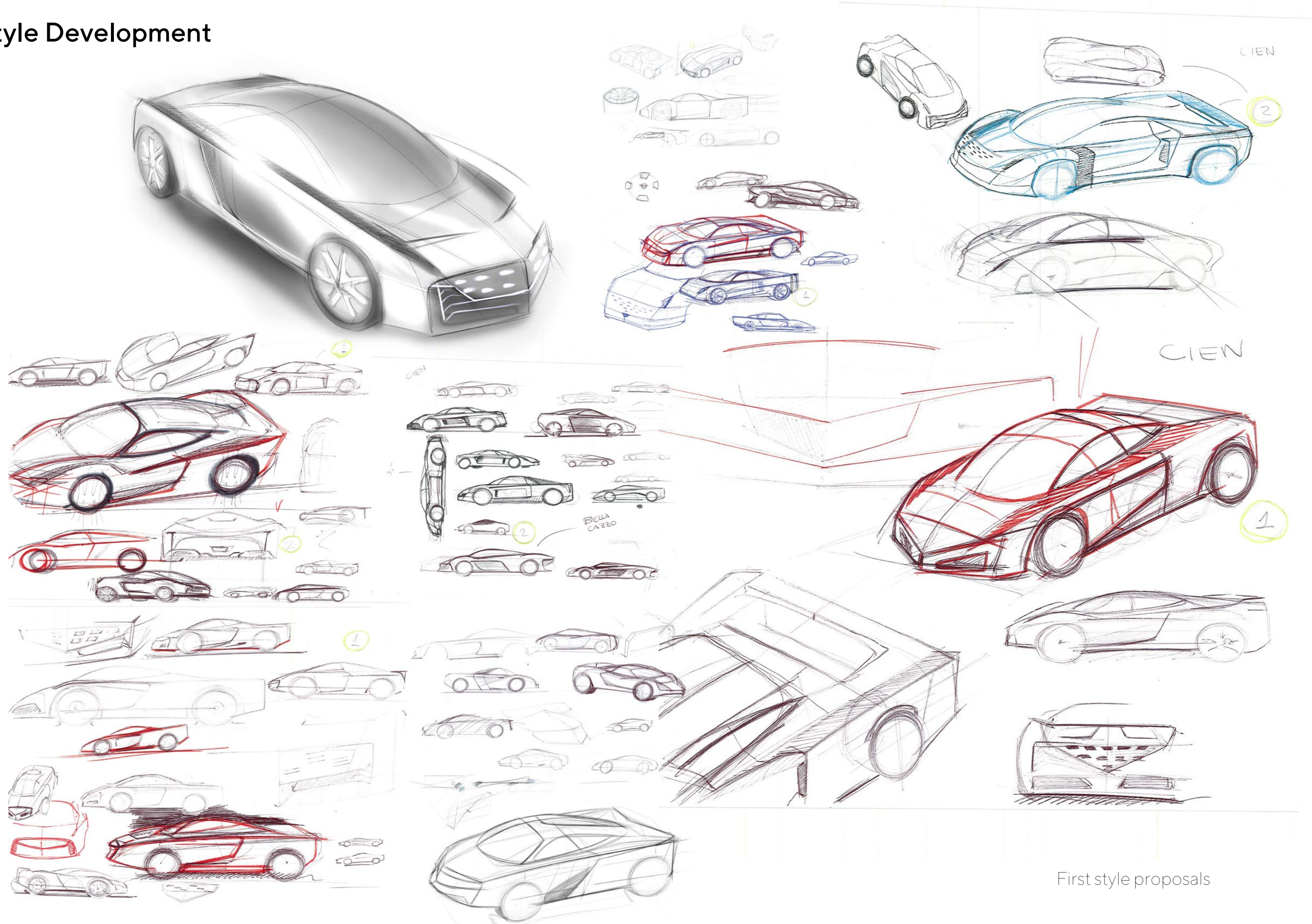
IDEAL			4750	2000	1100-1200	2650	>1722	>1726	>2038	1000-1200

Top Speed [km/h]	Traction	0-100 km/h [s]	CO2 Emissions	Front Wheels	Rear Wheels	Top	Flop	D
445	None	2	Hybrid	None	None	1	0	
340	AWD	2.5	154 g/km	fr255/35 zr 20” j9,5ont	315/30 ZR 20” J11.5	0	1	
430	RWD	2.5	Gasoline	20” x 9.5” - 265/35 – 20”	21” x 12,25” - 325/30 – 21”	0	1	
436	None	2.5	Hybrid	None	None	0	0	
350	None	3	Gasoline	None	None	1	1	
350	None	2.7	Hybrid	None	None	0	0	
332	RWD	2.8	Gasoline	None	None	0	0	
412	Full Electric	1.85	Full Electric	20"	21”	1	0	
350	AWD	2	Hybrid	285/30 R20”	345/30 R21”	0	0	
355	AWD	<2.2	0	21"	22"	1	0	
300	None	3.4	0	None	None	0	0	
None	None	2.2	0	None	None	0	0	
365	Rear Traction	3.5	Gasoline	245/35R19"	335/30R21"	1	0	
>350	AWD	2.5	Hybrid	265/35 ZR20”	345/30 ZR21”	2	0	2
330	None	3	108 g/km	235/35/R19”	295/35/R20”	1	0	
1224	Rear Traction	1.9	Full Electric	None	None	0	1	
290	None	4.3	Gasoline	None	None	0	3	
343	AWD	2.7	108 g/km	Sport 255/35 ZR20”	Sport 325/30 ZR21”	1	0	

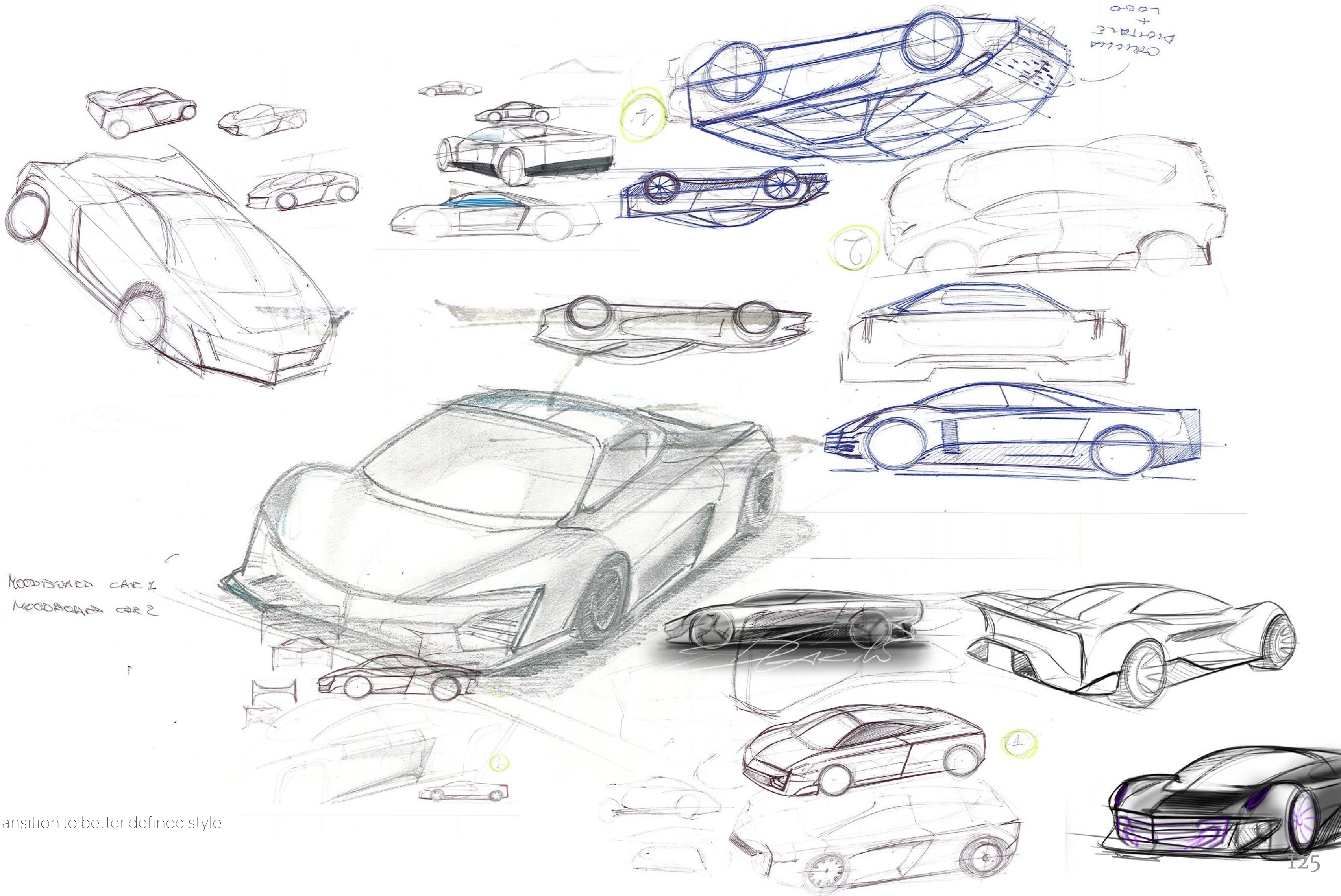
>445	4 traction wheels	0	0	285/30 R20”	345/30 R21”

Table 12

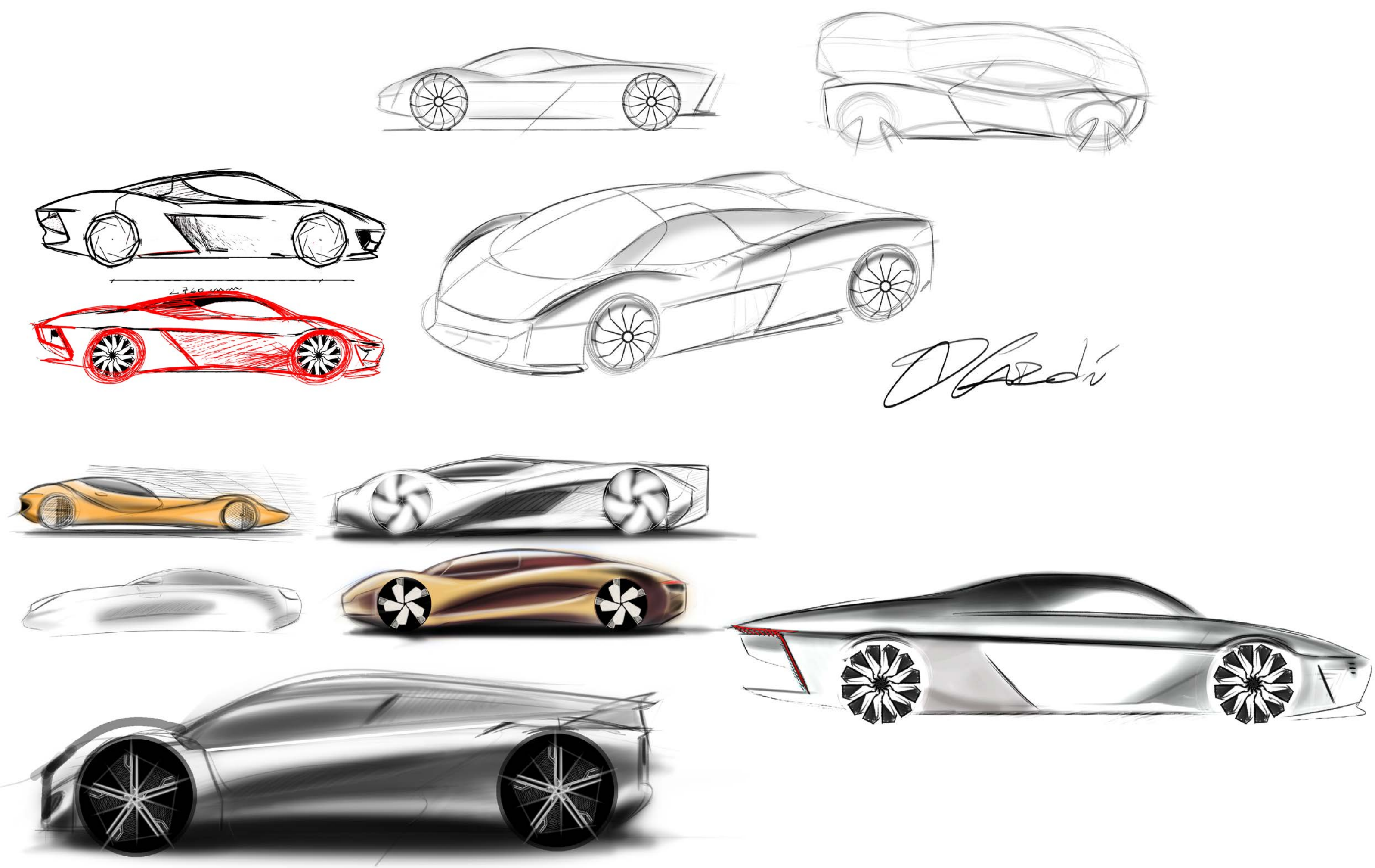
Style Development

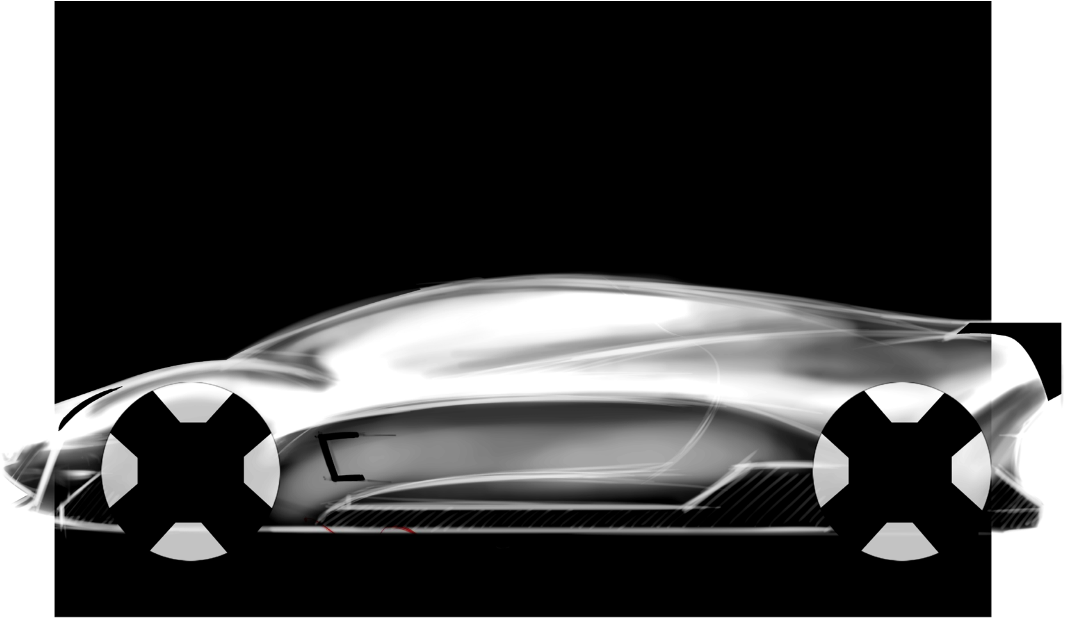


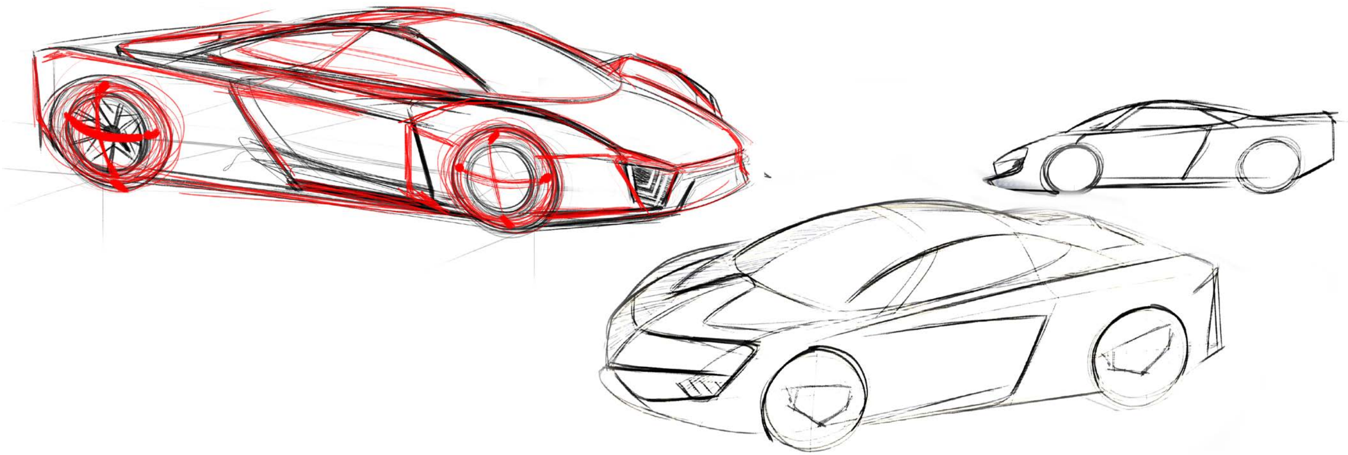
First style proposals



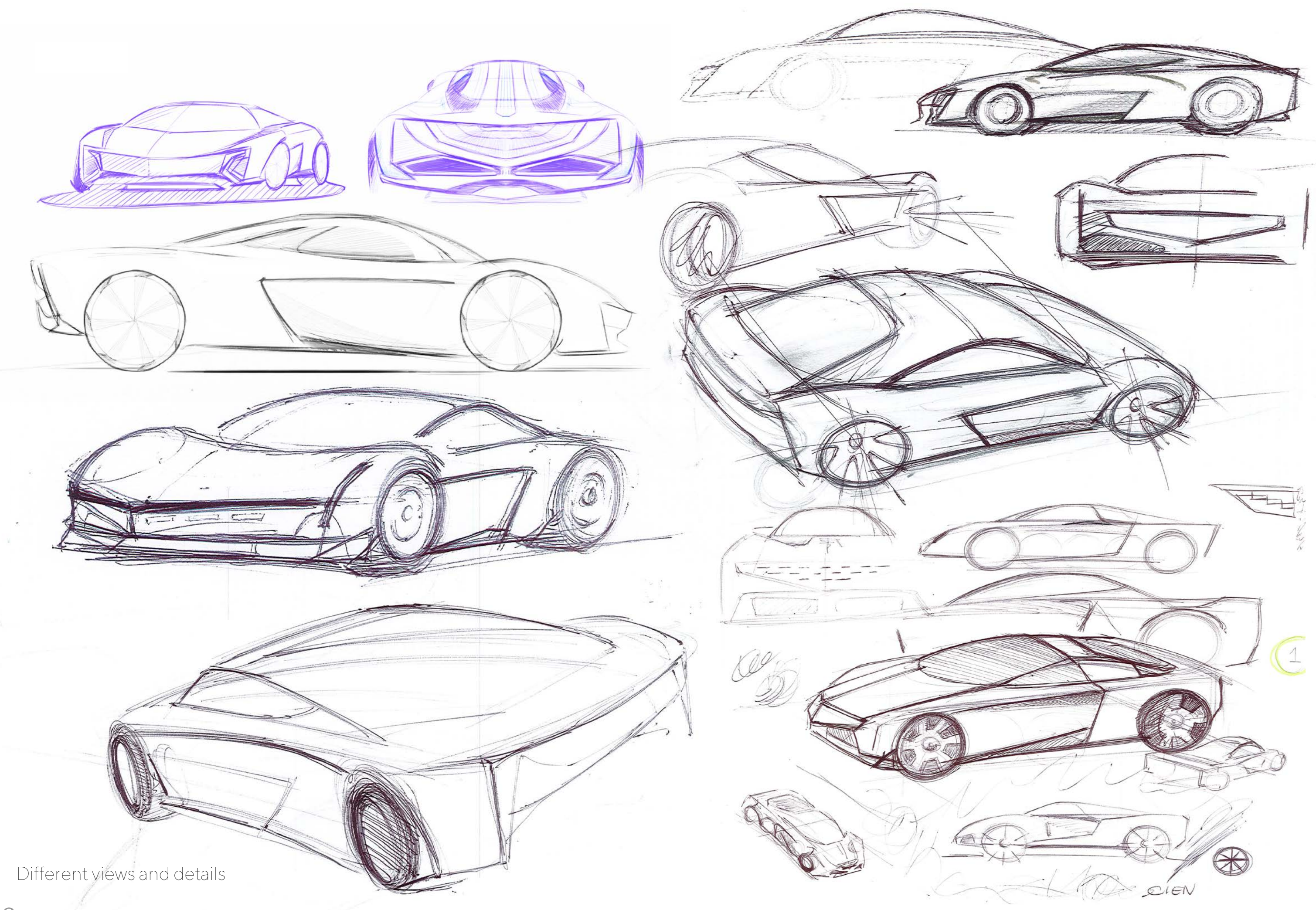
Transition to better defined style



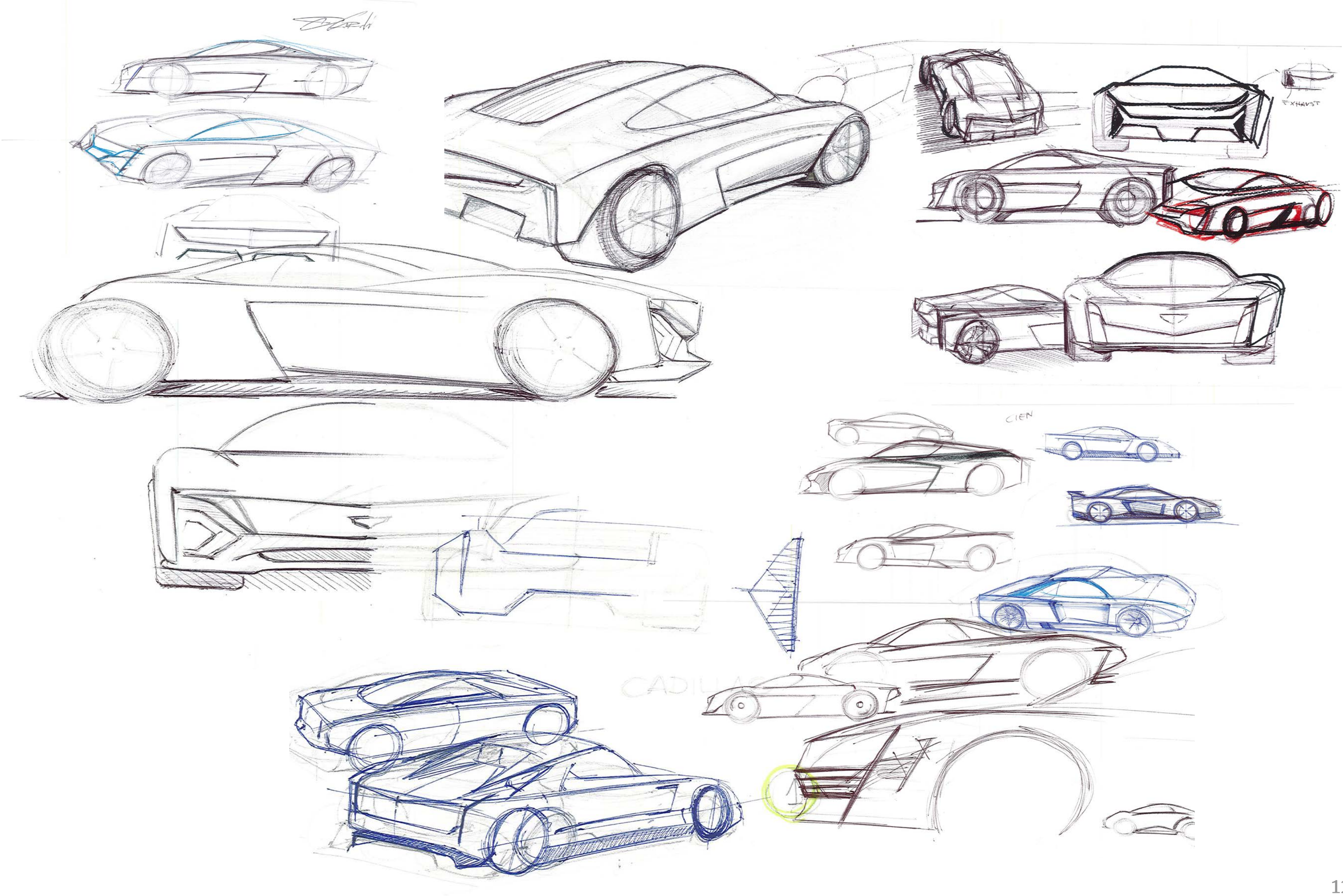


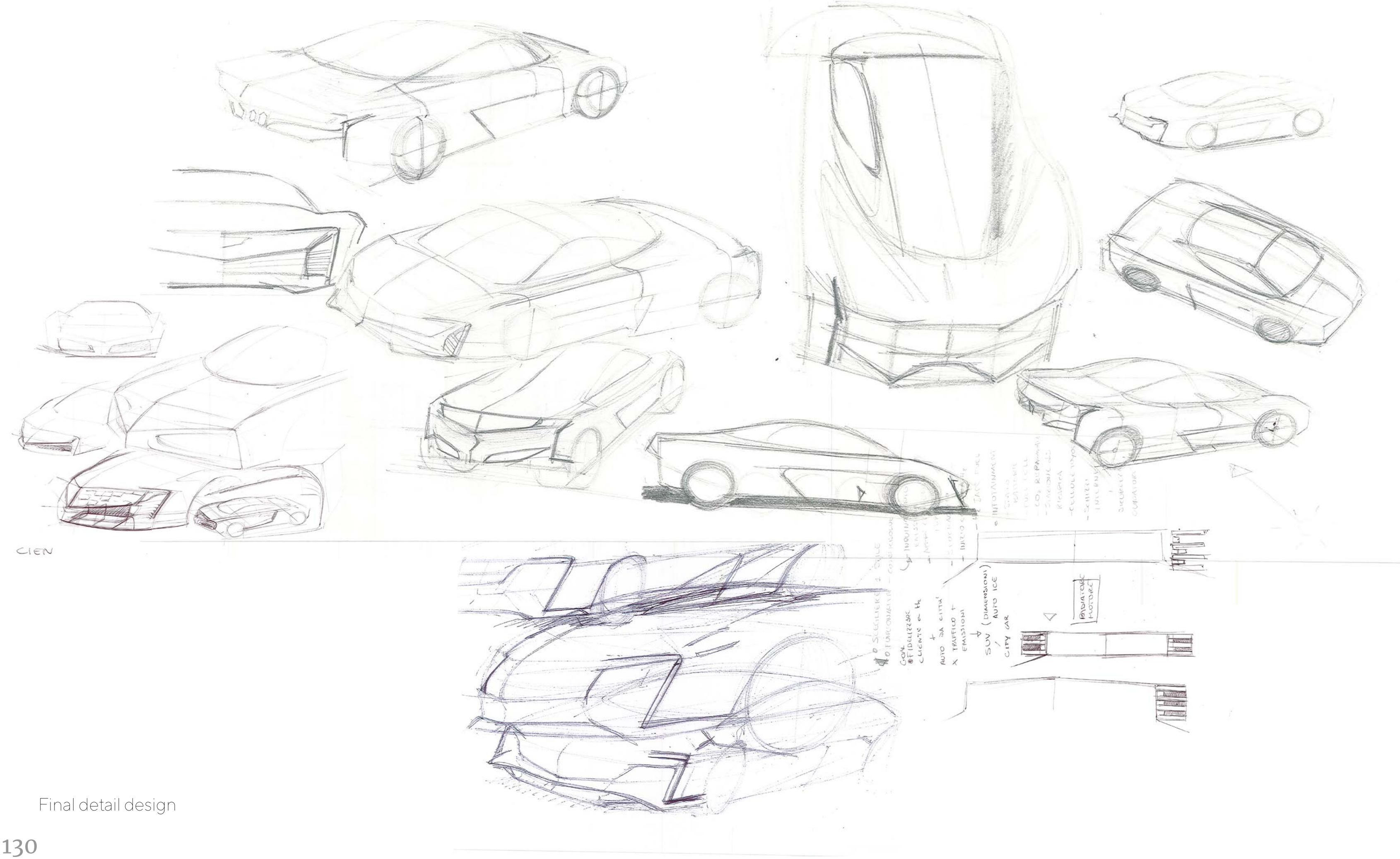


Design variations

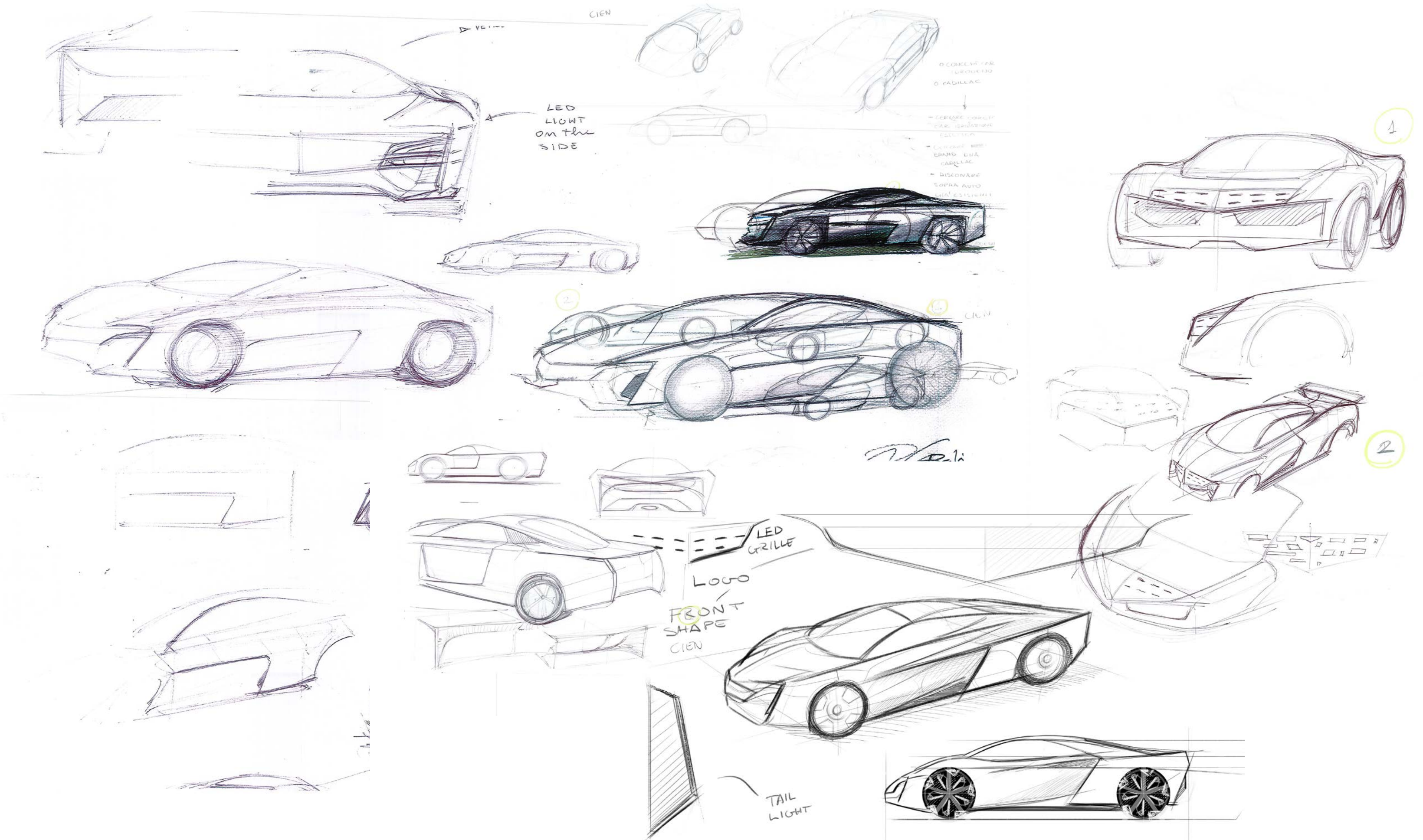


Different views and details

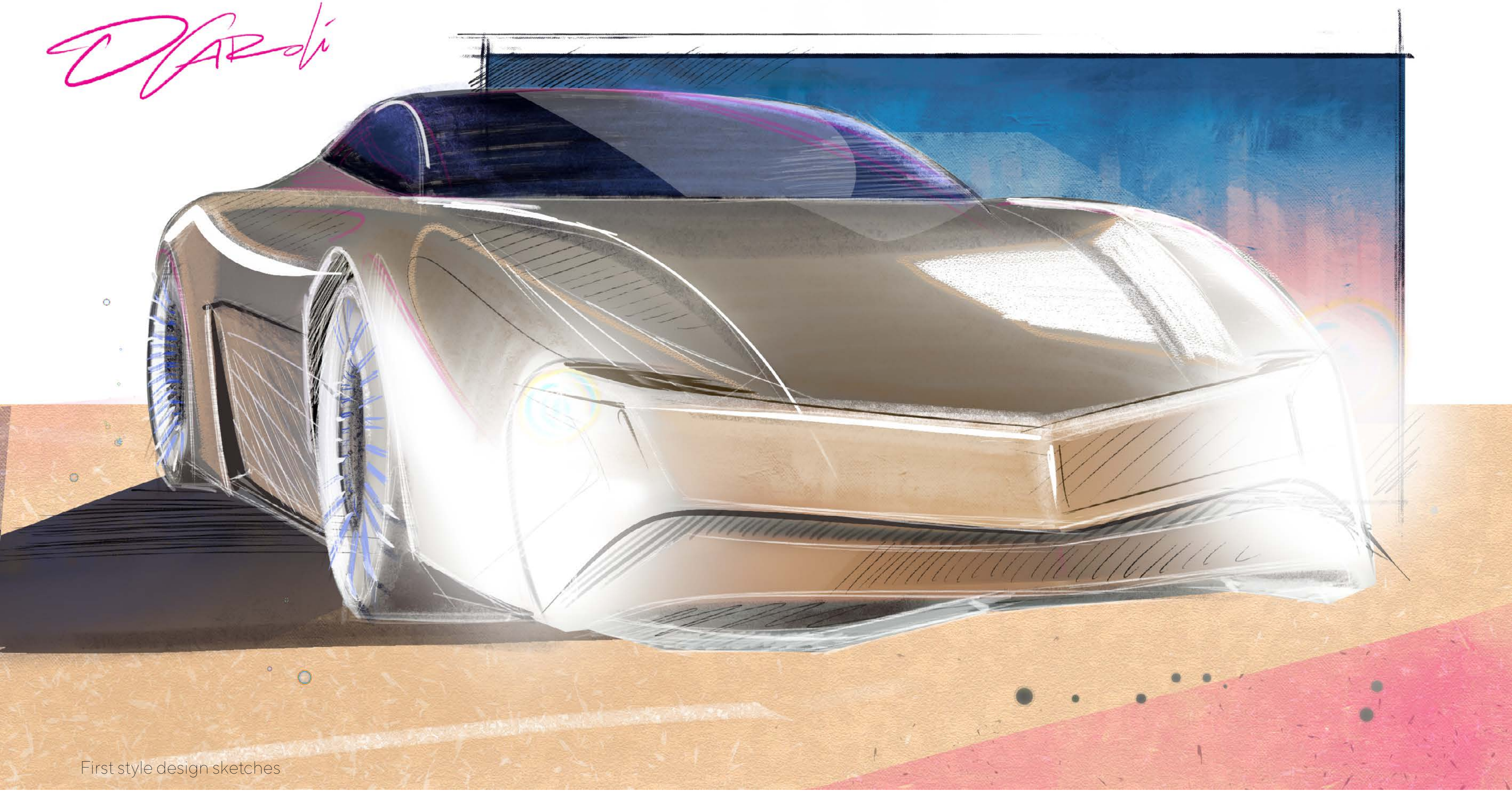

EXHAUST
CIEN



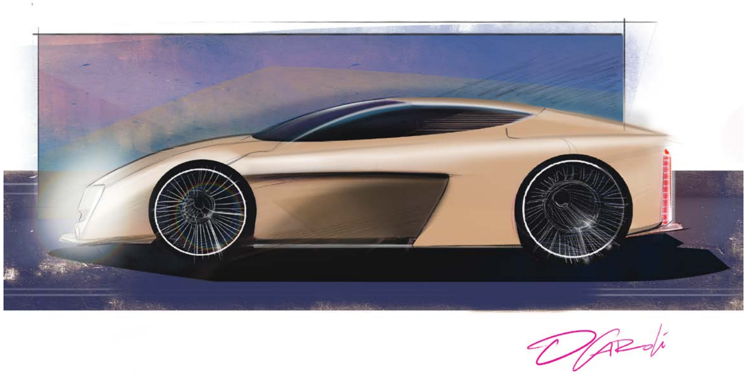
Final detail design

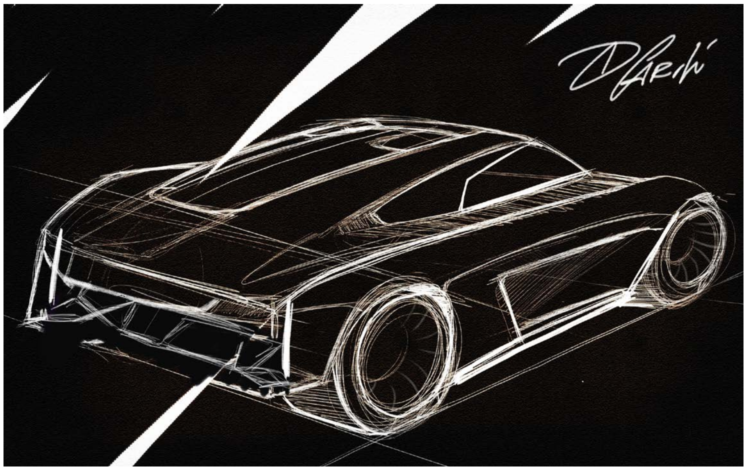

CIEN
LED LIGHT on the SIDE
CIEN
LED GRILLE
LOGO
FRONT SHAPE
CIEN
TAIL LIGHT

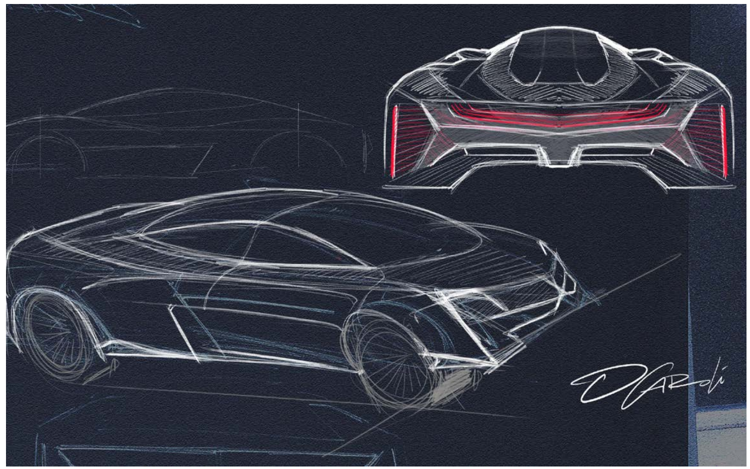
First Concept



First style design sketches







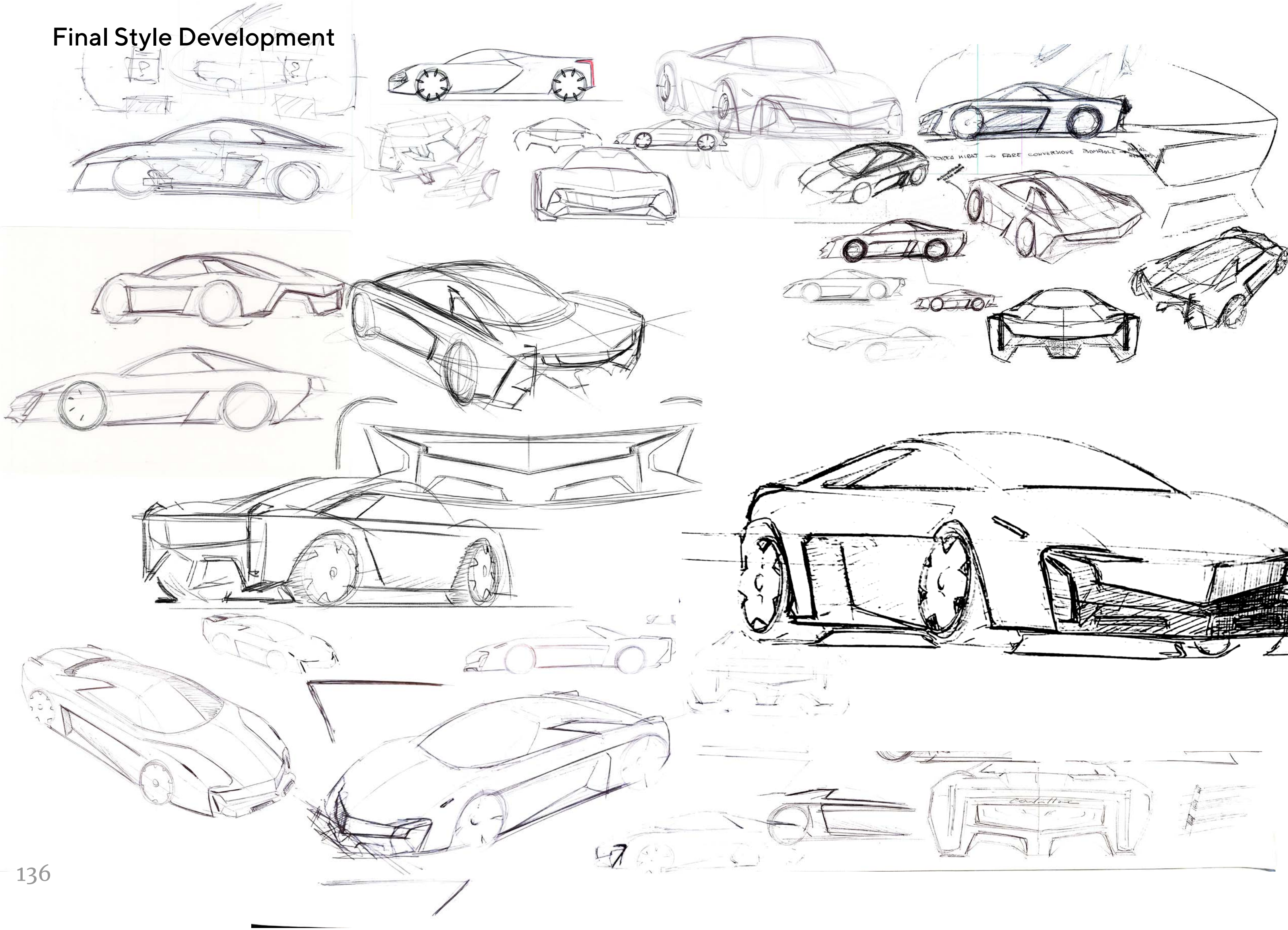
First style design sketches

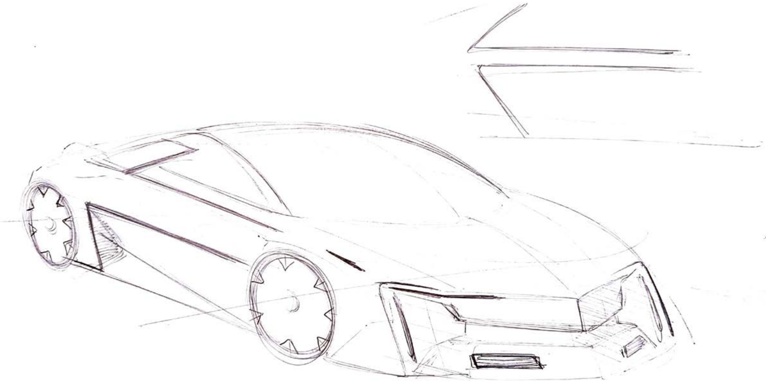
Final Presentation at LTU

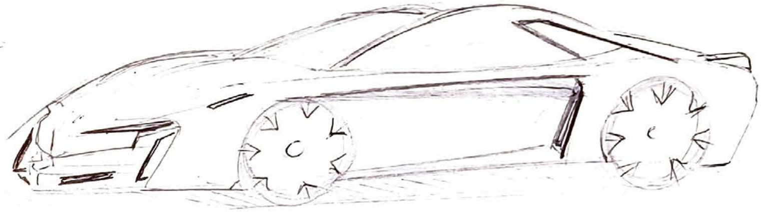
Prototype of the first style, displayed during the last presentation at LTU

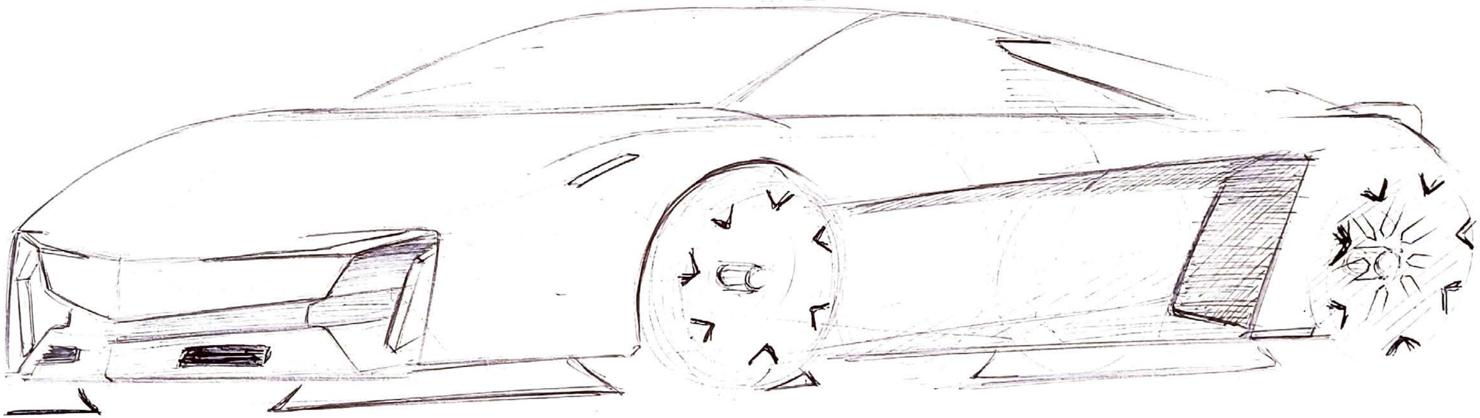
Picture of the prototype with professors Ali Ahad and Donald Reimer

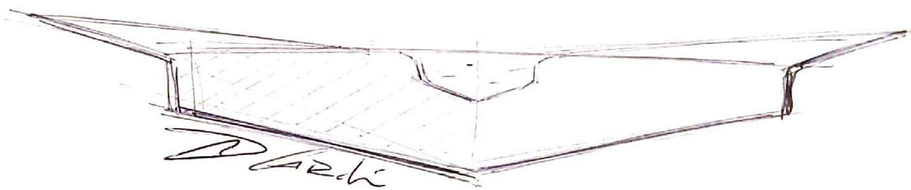
Final Style Development





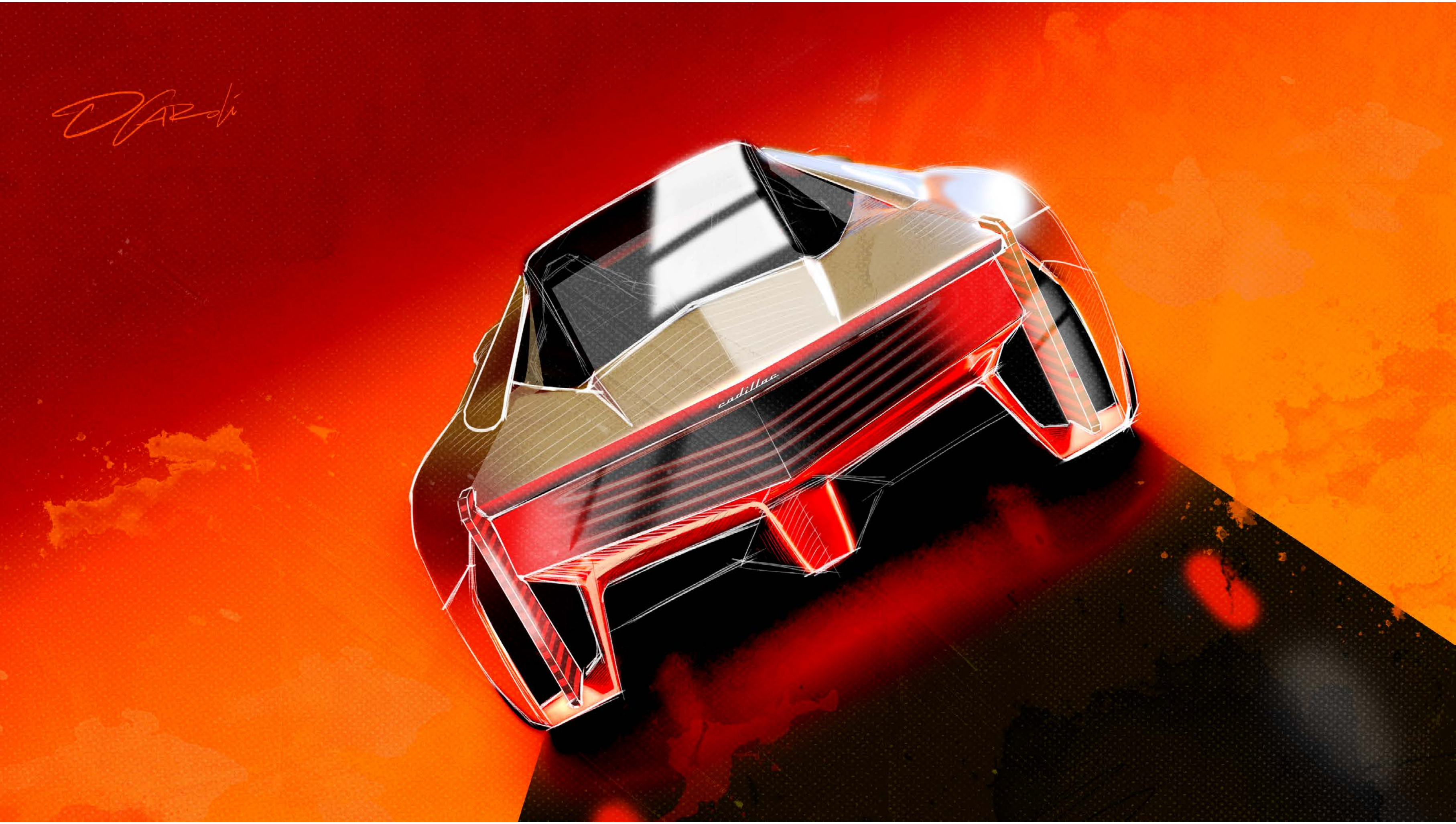


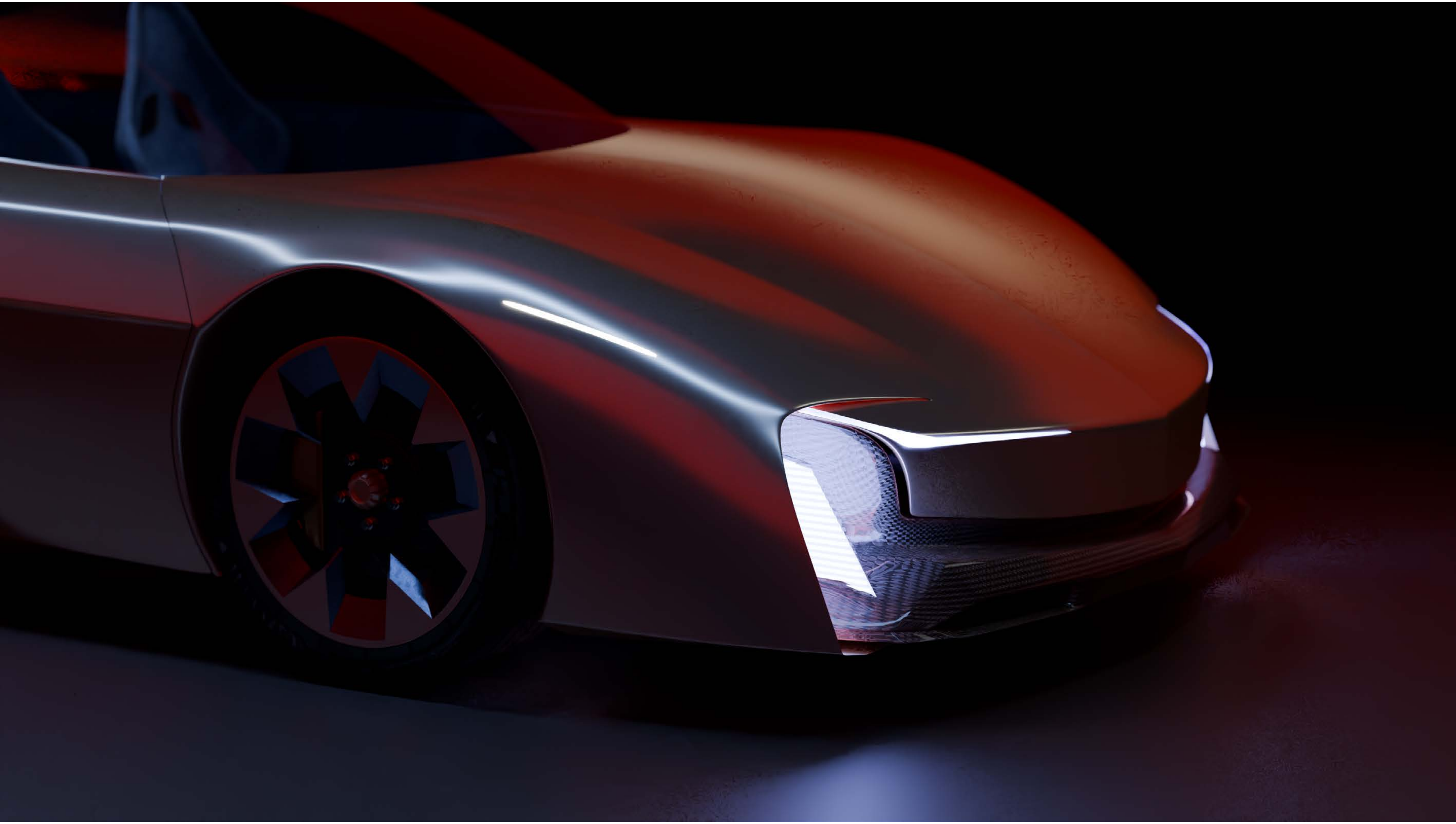


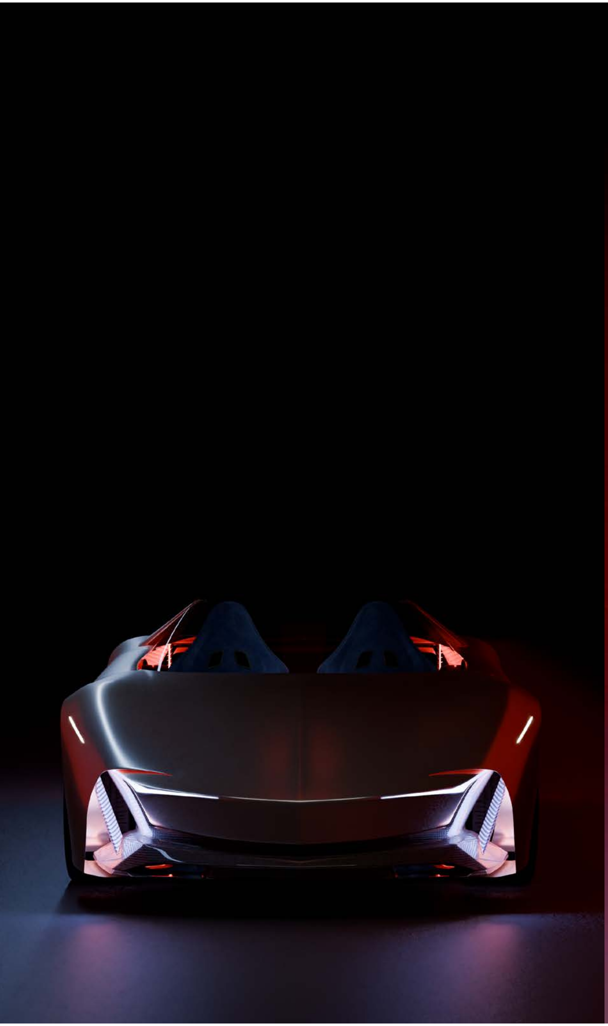


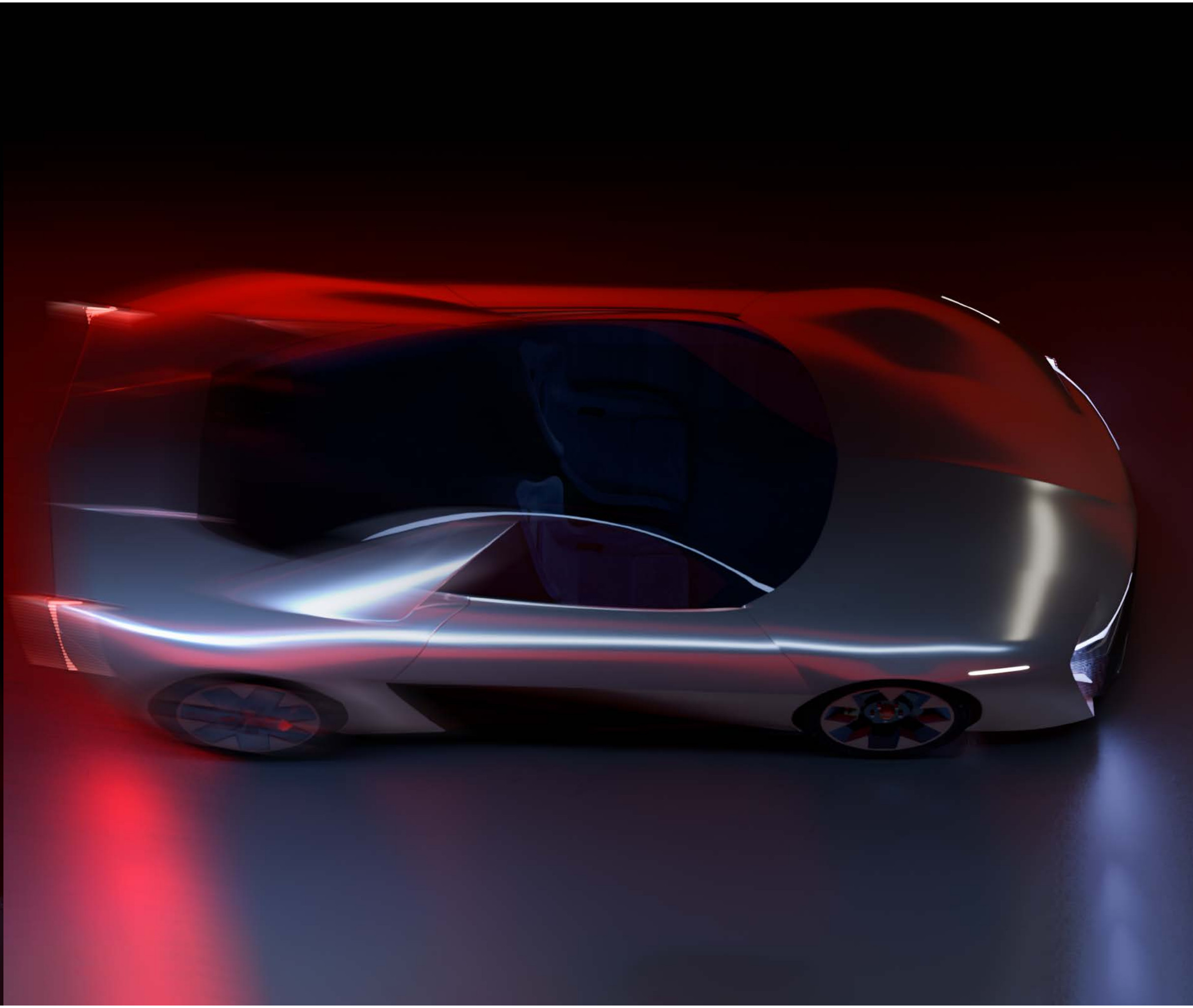
After the first prototype some changes were considered, translating into new improvements on the design

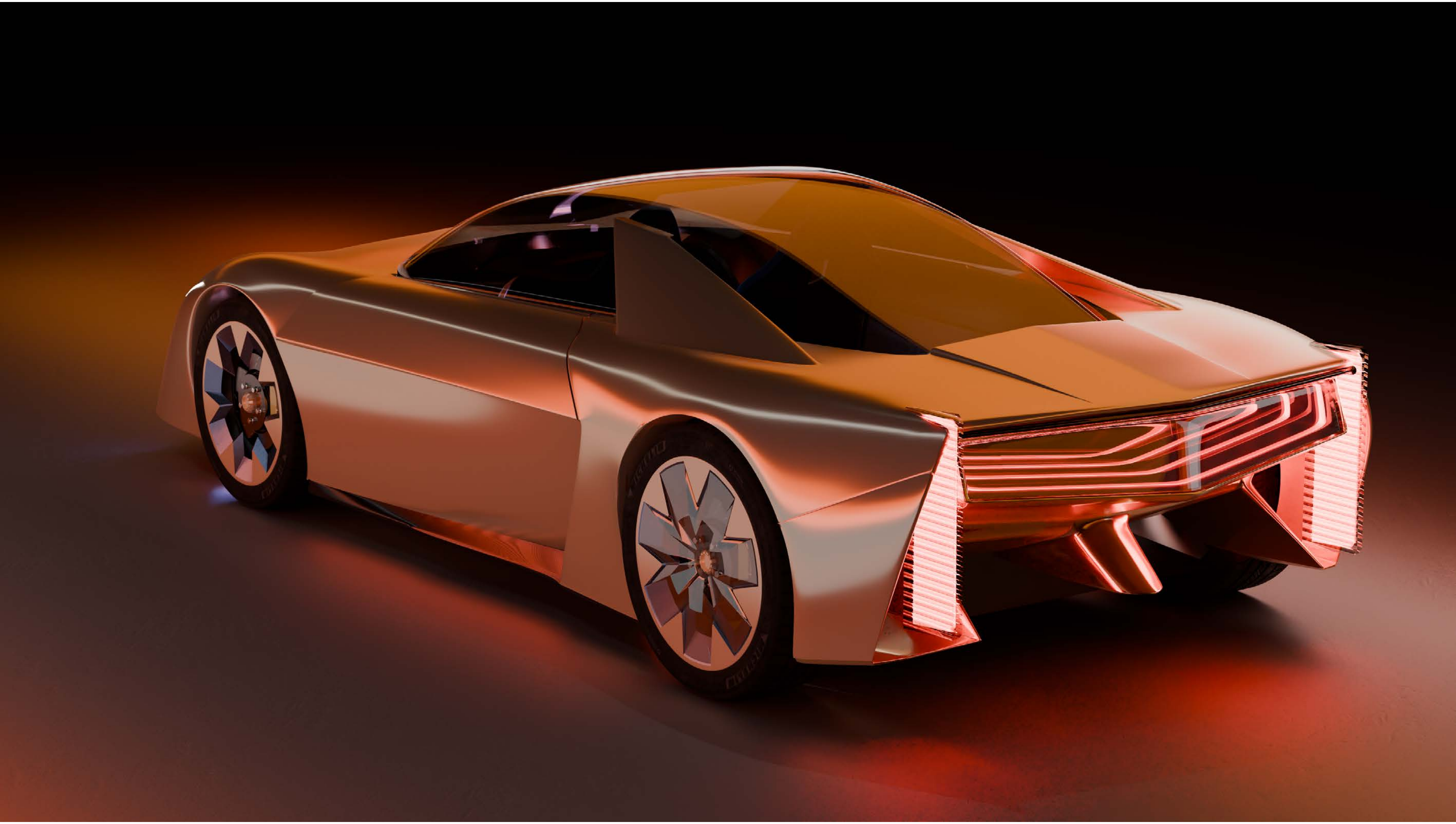
Final Concept – Speed of Light

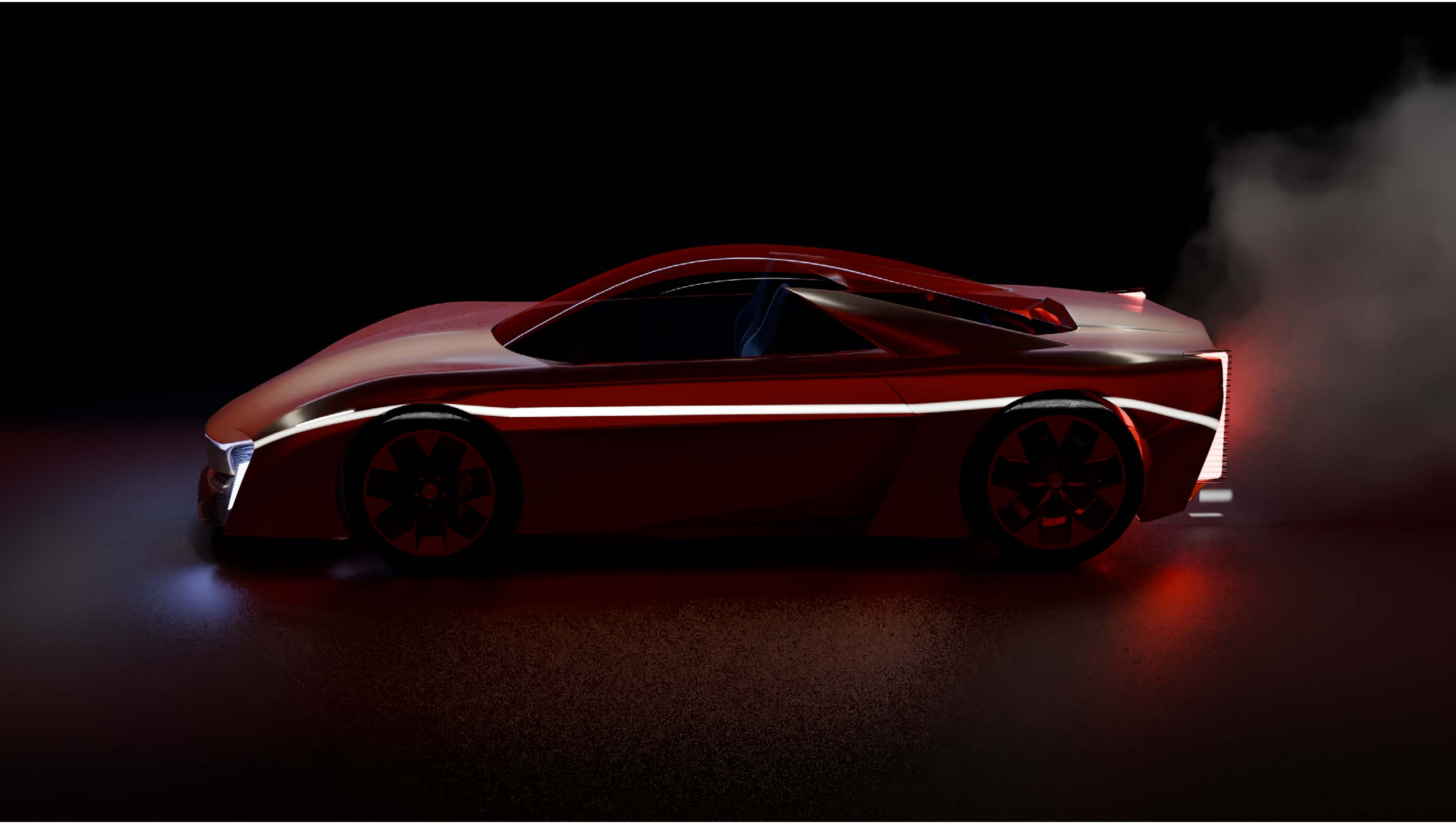


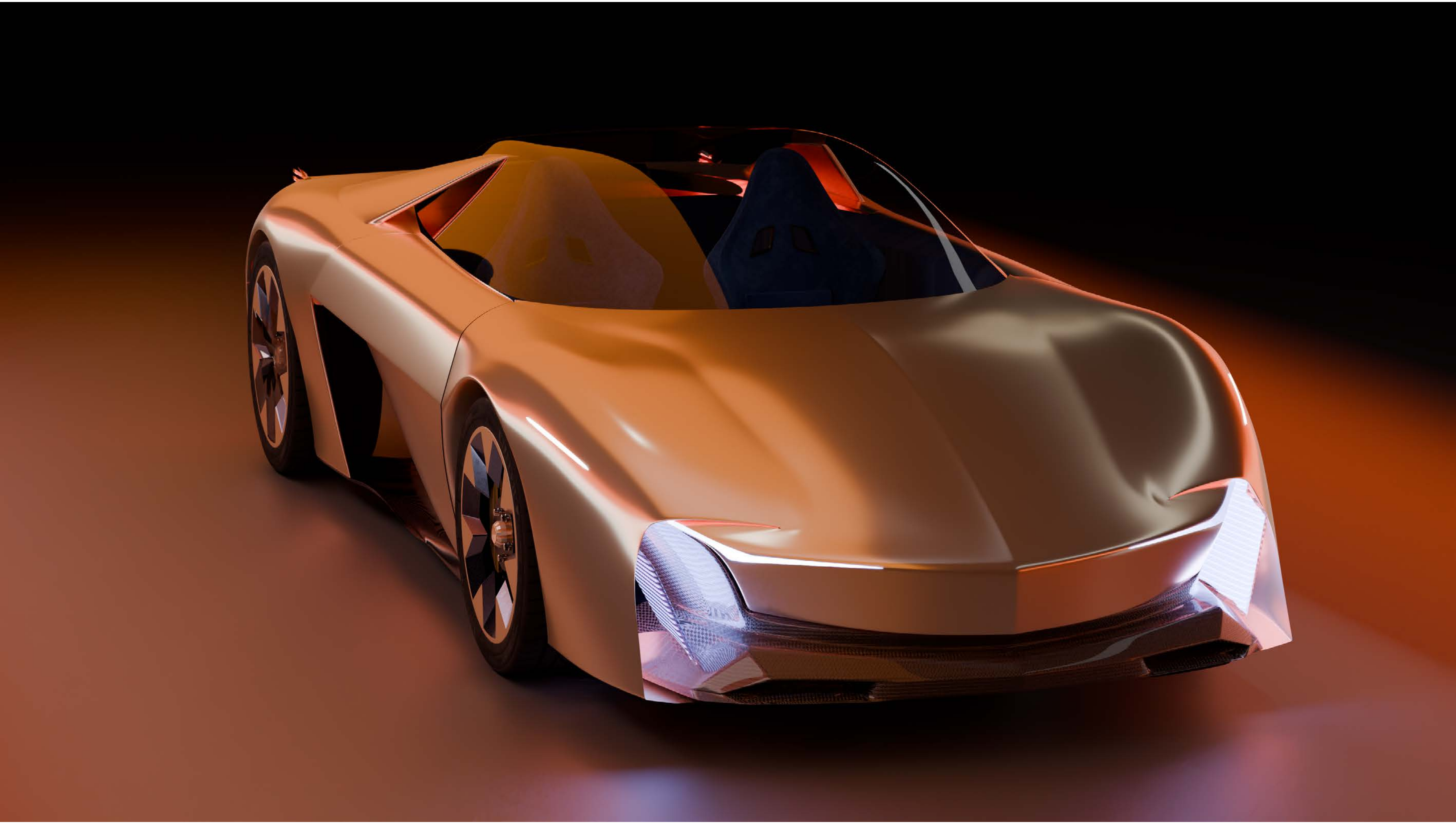


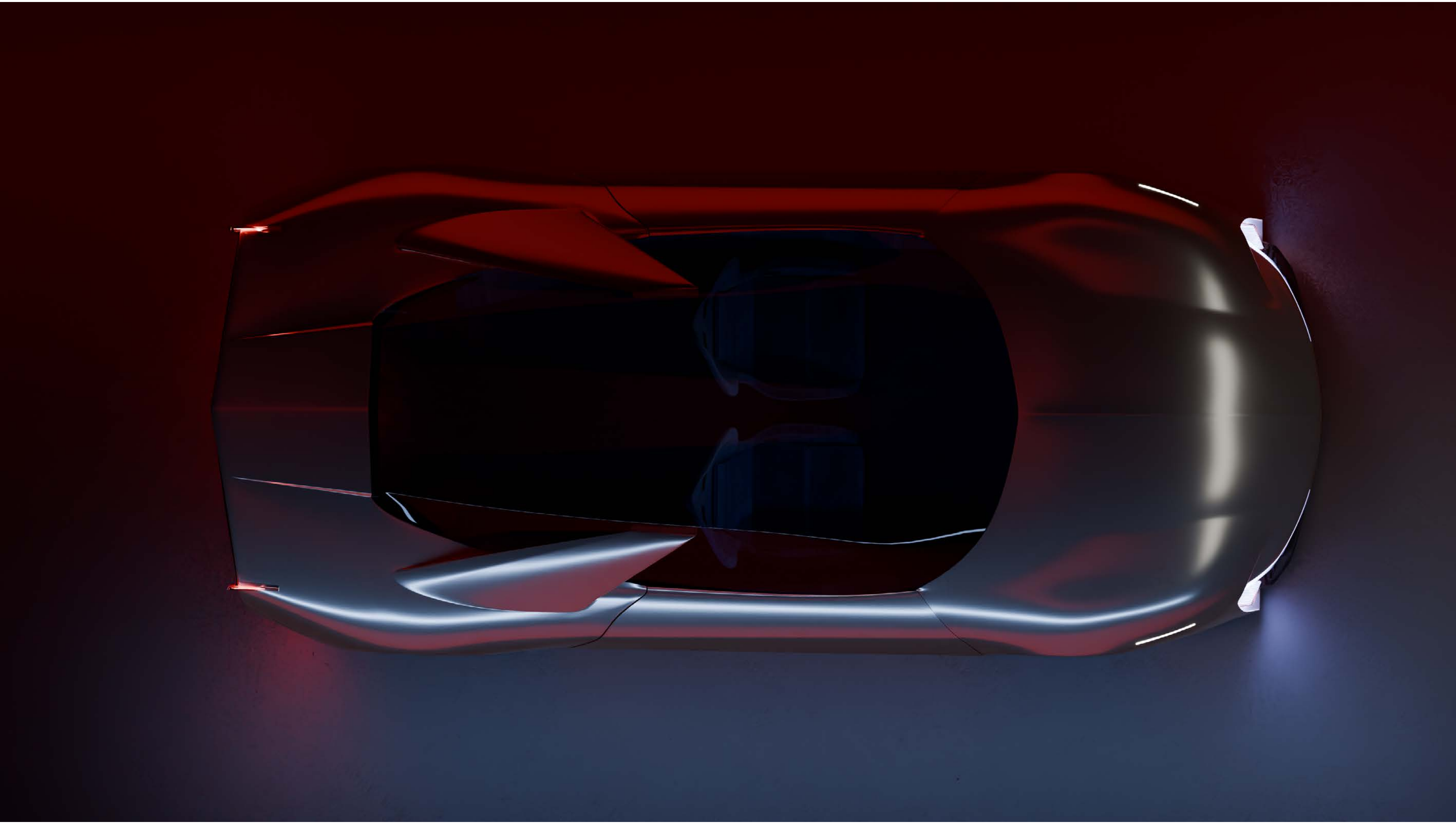


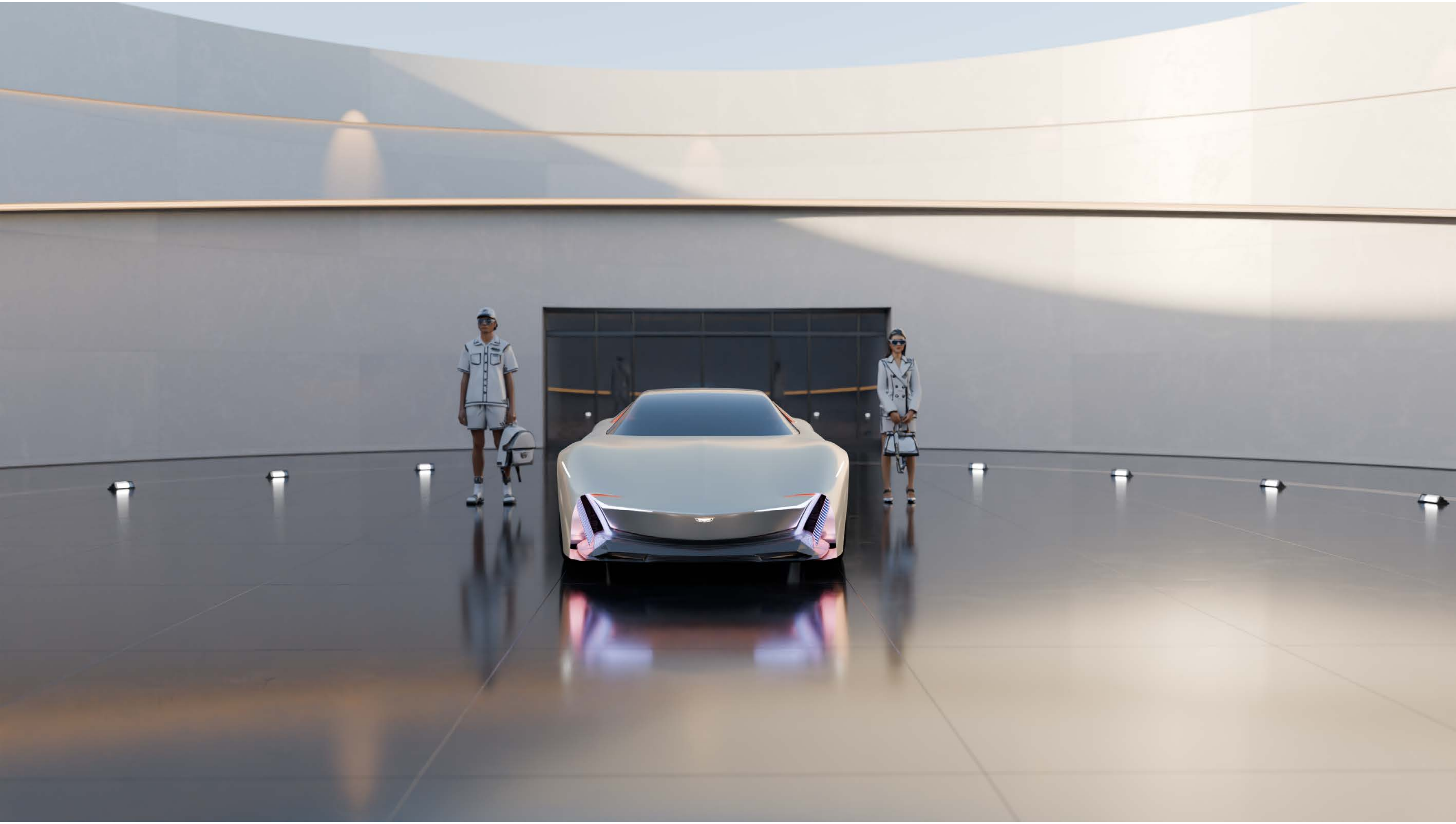


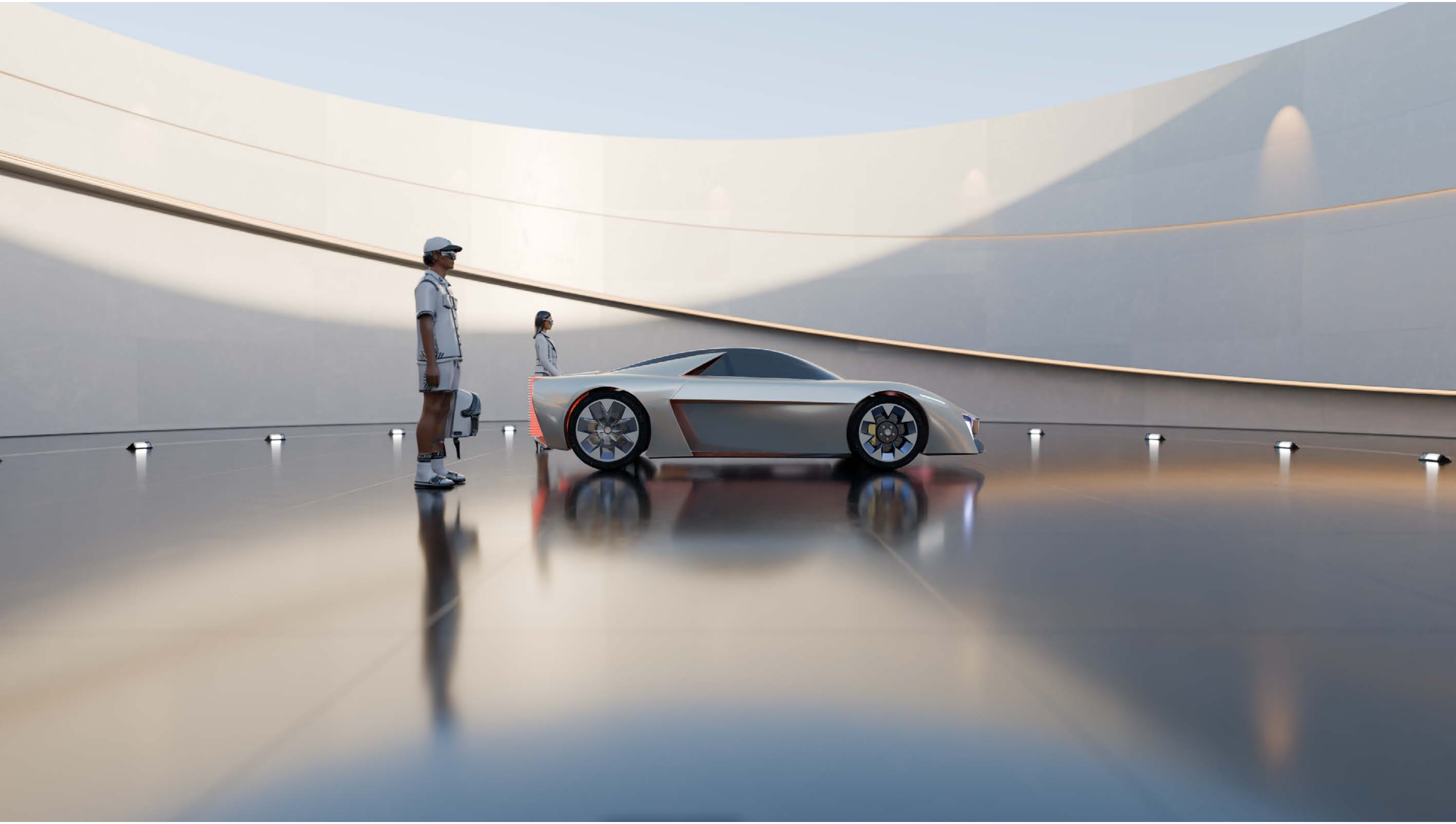




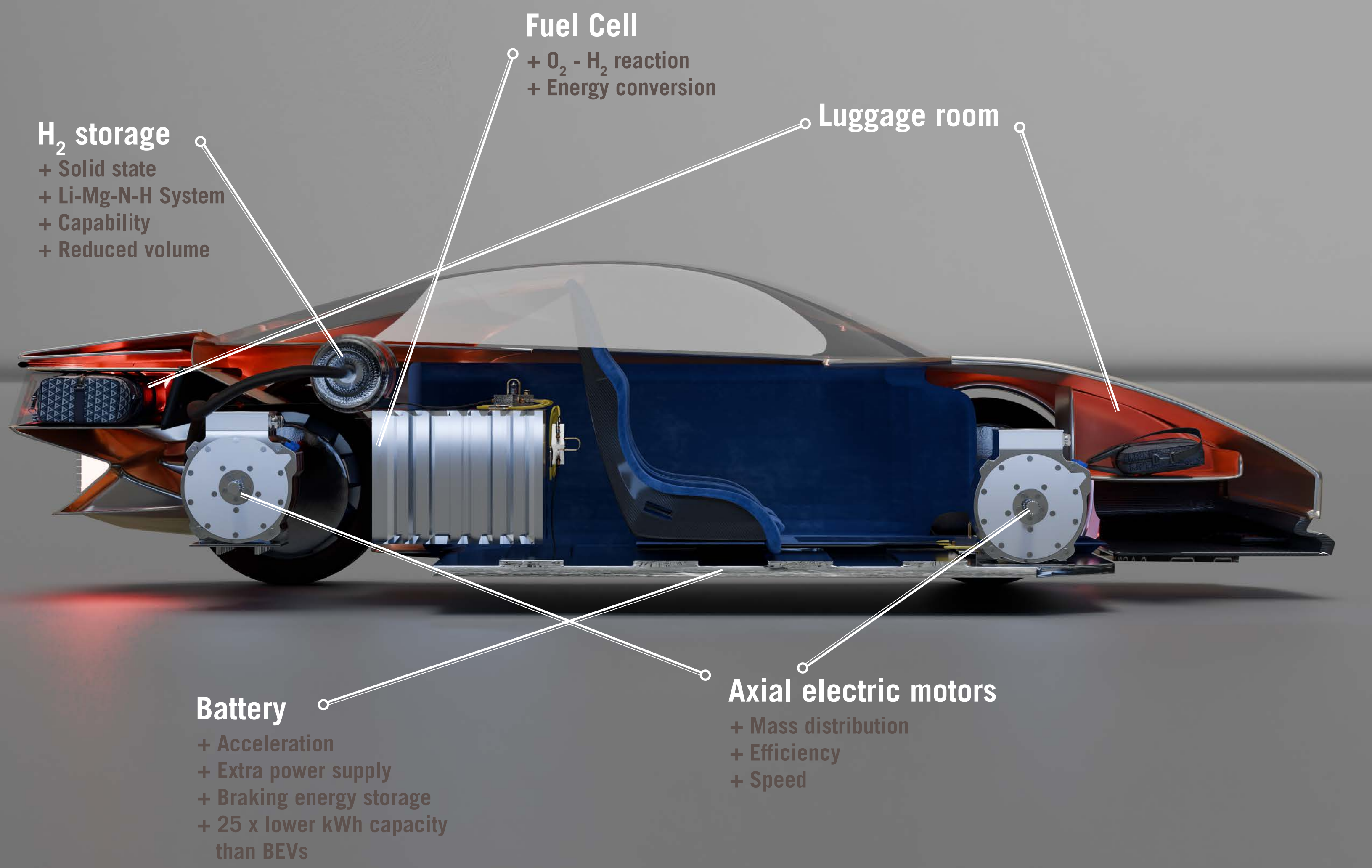


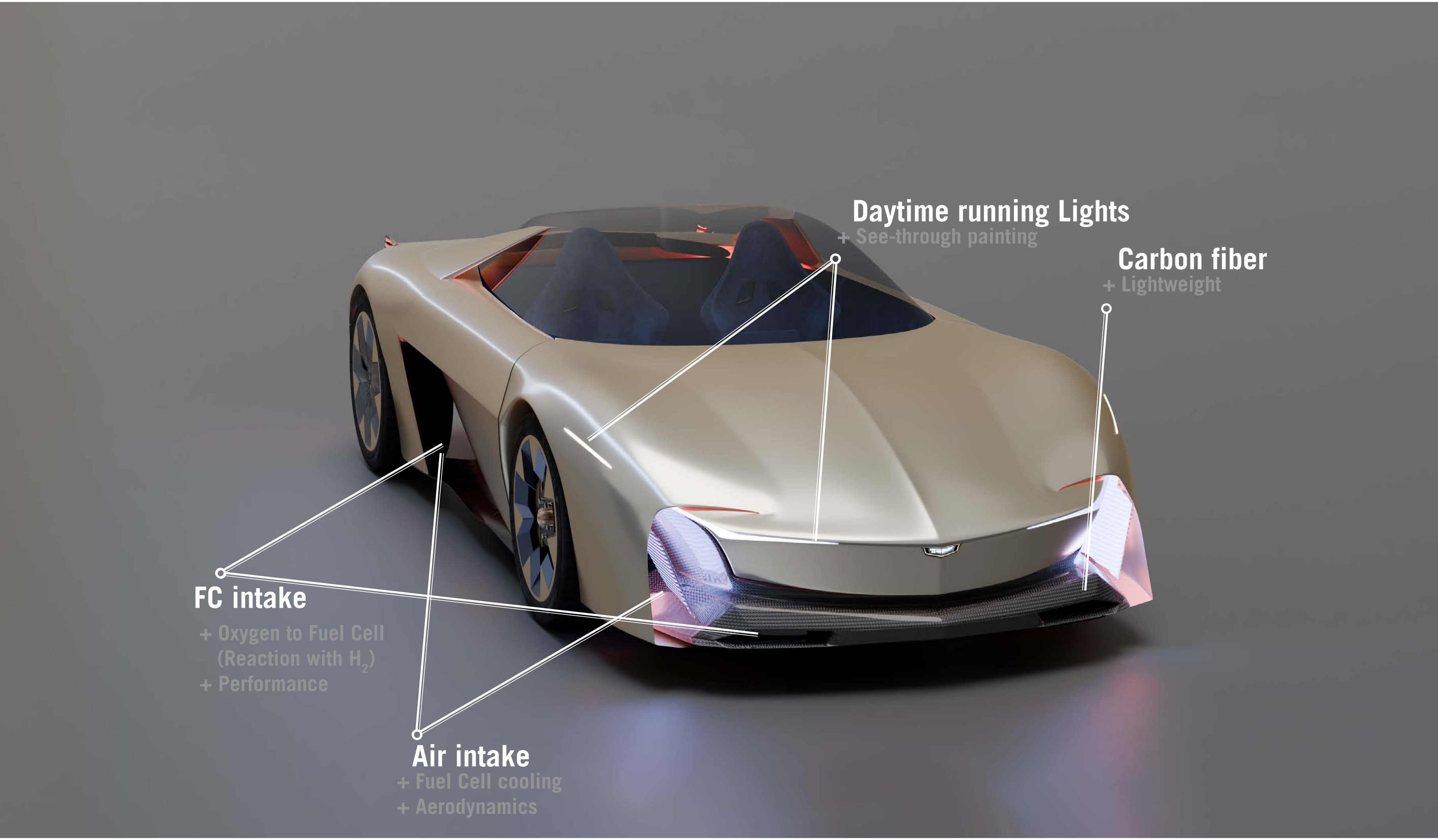


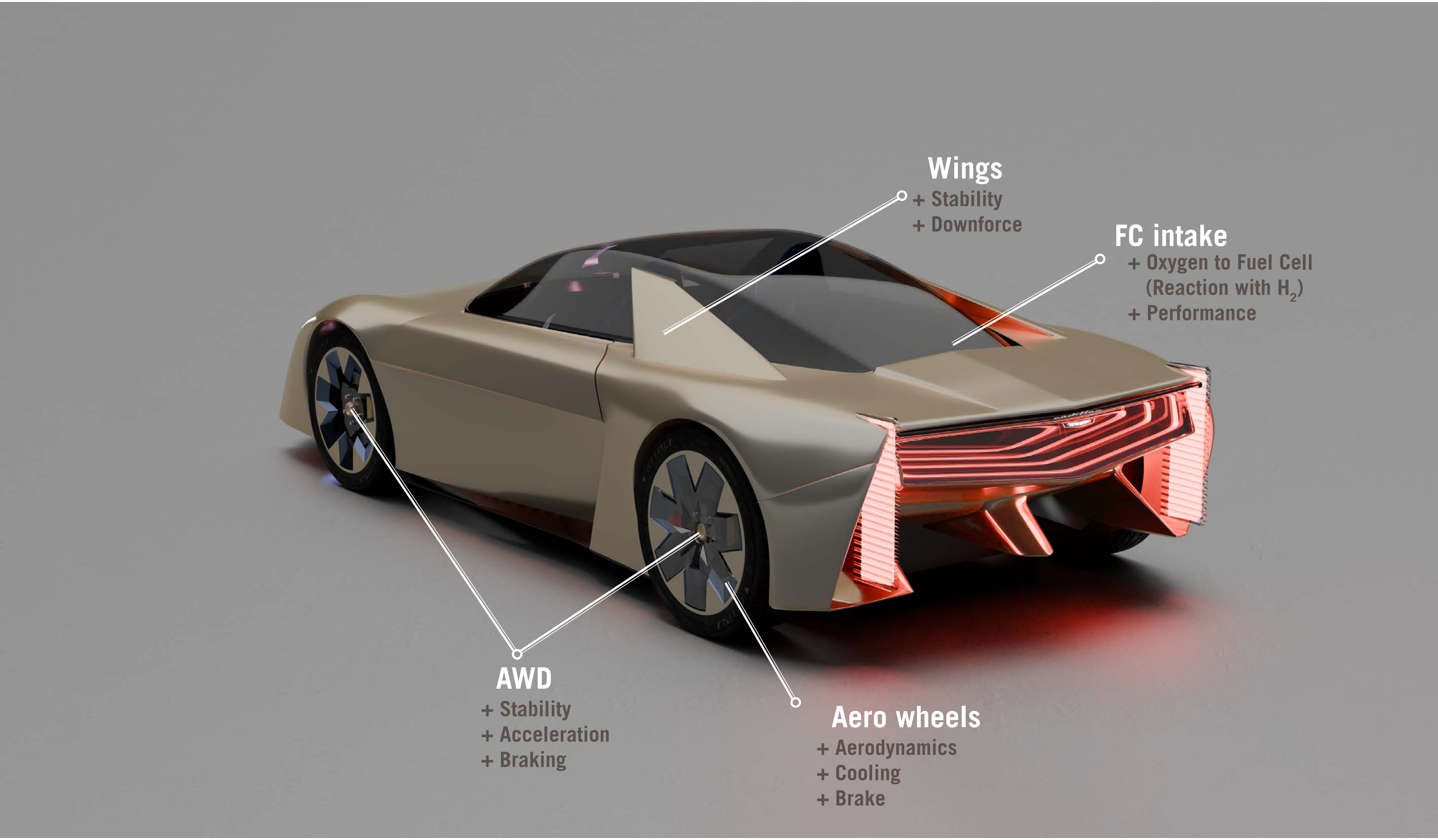




Product Architecture – Speed of Light




Daytime running Lights
+ See-through painting
Carbon fiber
+ Lightweight
FC intake
+ Oxygen to Fuel Cell
(Reaction with H_2)
+ Performance
Air intake
+ Fuel Cell cooling
+ Aerodynamics


Wings
+ Stability
+ Downforce
FC intake
+ Oxygen to Fuel Cell
(Reaction with H_2)
+ Performance
AWD
+ Stability
+ Acceleration
+ Braking
Aero wheels
+ Aerodynamics
+ Cooling
+ Brake

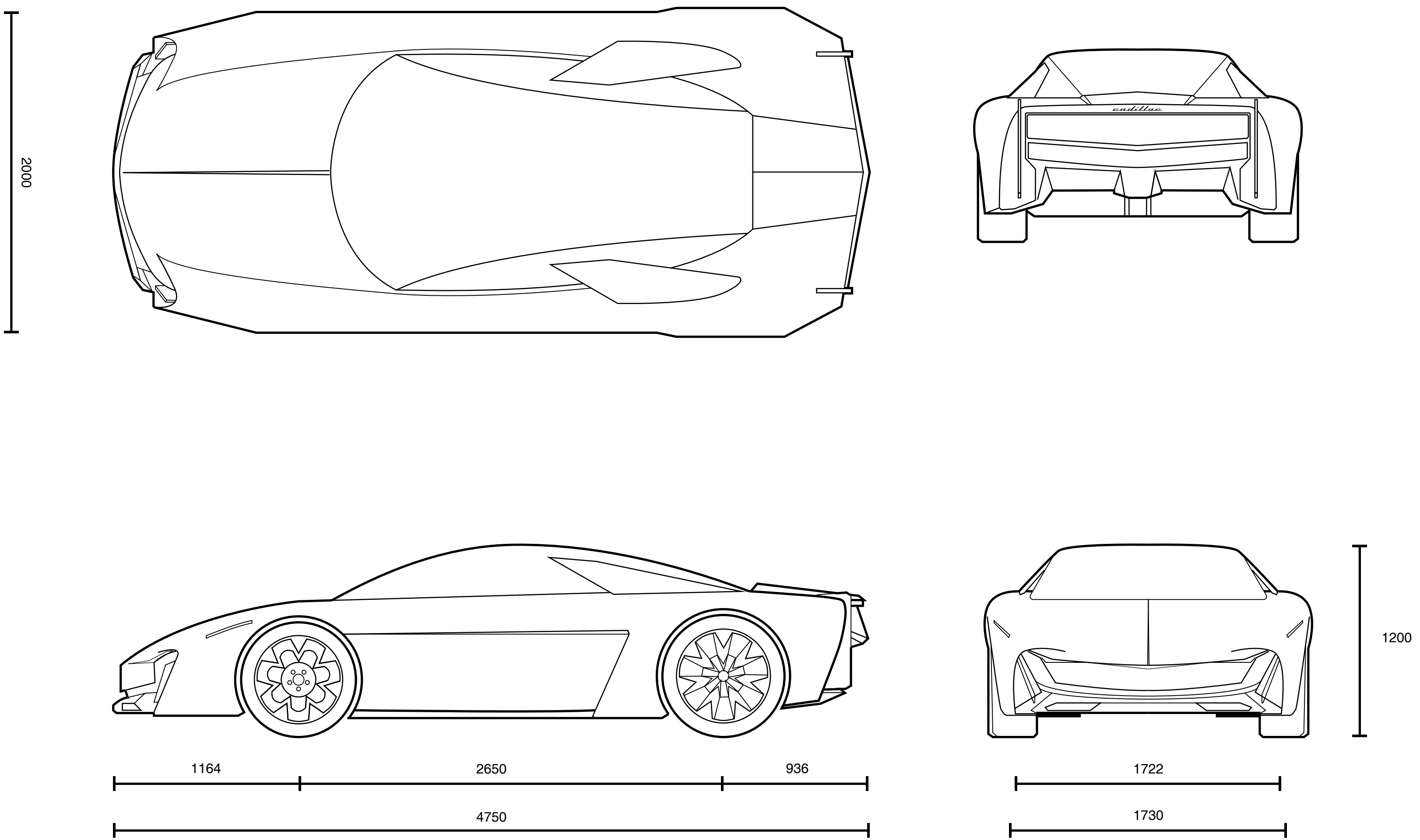
Powertrain and Chassis

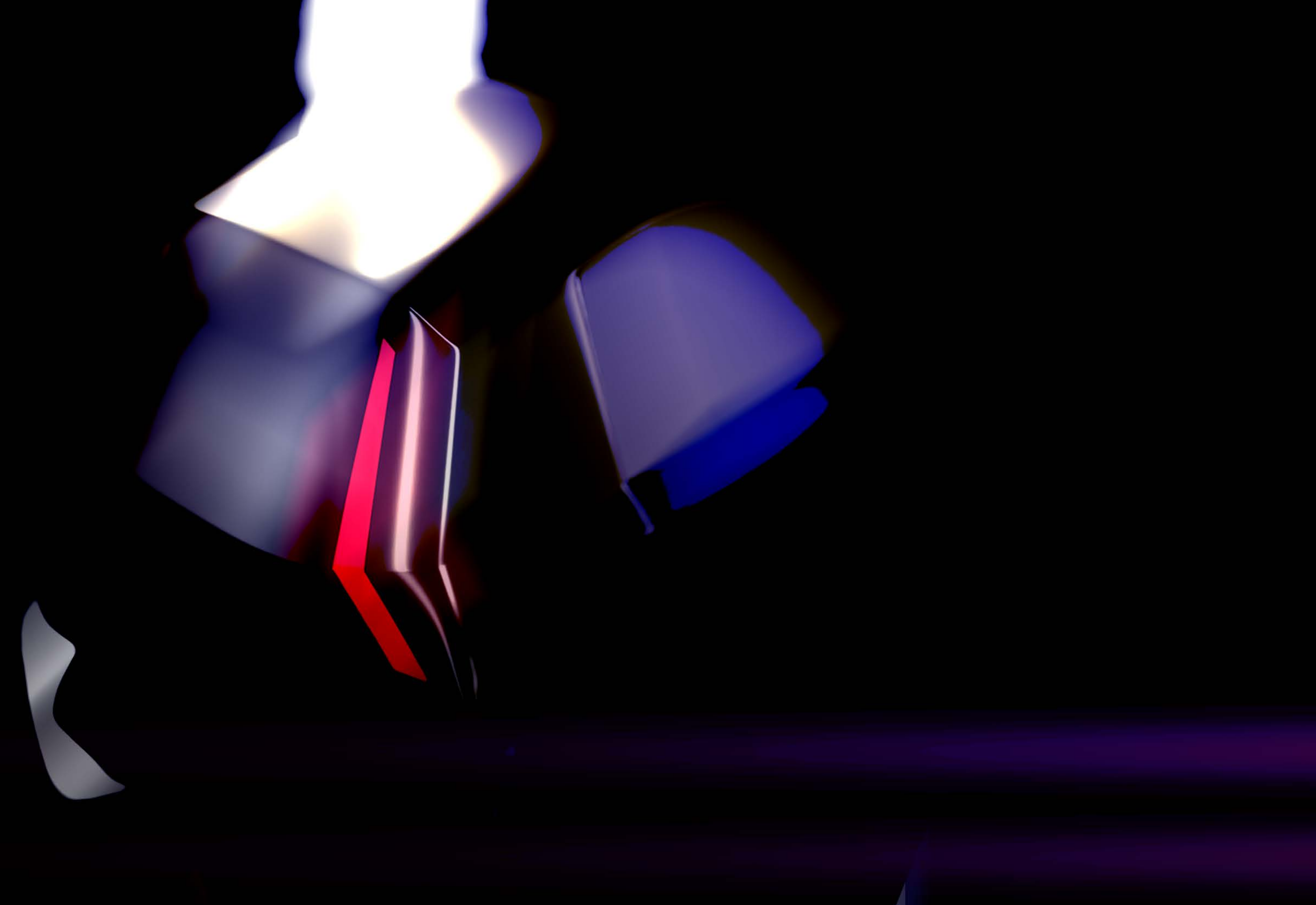
Engine: The engine is the heart of the powertrain, generating power through the combustion of fuel.

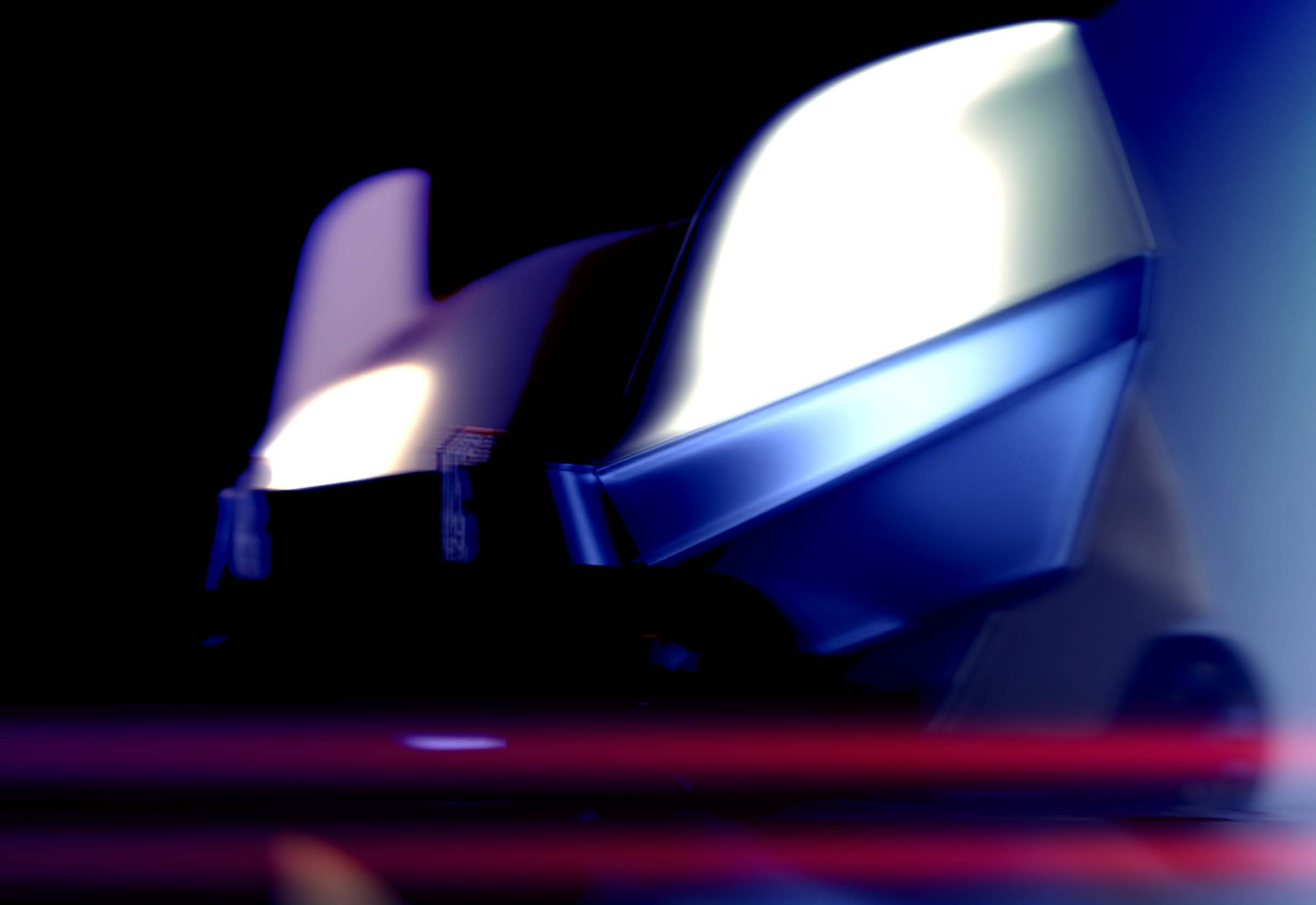
All-wheel drive (AWD) in sports vehicles designed for track use enhances performance, safety, and driving dynamics by improving traction and acceleration through power distribution across all four wheels, which optimizes grip, particularly in low-adhesion conditions such as wet or dirty asphalt, reducing wheel slippage during acceleration and enabling more effective corner exits while also contributing to greater stability in high-speed turns by minimizing understeer or oversteer tendencies, especially when combined with advanced torque vectoring systems that dynamically adjust power distribution for enhanced precision, further improving braking efficiency and torque allocation as AWD systems aid in maintaining stability during deceleration and corner entry, ensuring a more balanced weight distribution and optimized grip on all four wheels, thereby increasing overall control and safety, particularly on tracks with variable conditions where AWD provides superior handling compared to rear-wheel or front-wheel drive configurations, and supporting high-performance vehicles by effectively managing power output to the ground, especially in models with significant horsepower, thereby reducing excessive wheel spin and ensuring optimal power utilization, though it is important to acknowledge that AWD systems introduce additional weight, which can impact agility and fuel efficiency while also potentially reducing the direct steering feel that some drivers prefer in rear-wheel-drive vehicles for a more engaging driving experience, making AWD particularly advantageous for high-performance track vehicles operating in variable conditions while rear-wheel drive may remain preferable for those seeking a more responsive and dynamic driving experience on dry asphalt surfaces.

Blueprint - Speed of Light

Unit of Measure: mm







SDE

Six Questions table

Who	What	Location	When	Why	How
Comfortable	Non pollutant	Non pollutant	Safe	Sustainable	Sustainable
Customizable	Compact	Compact	Maneuverable	Autonomous	Non pollutant
Smart	Autonomous	Advanced	Autonomous	Advanced	Advanced
Functional	Safe	Smart	User-Friendly	Comfortable	Autonomous
Sustainable	Smart		Appealing	Smart	

User?: A worker/resident of a modern metropolis, forced to use multiple modes of transportation for commuting in a city where certain vehicle categories are not allowed, who prefers the convenience of personal transport over public transit.

Need?: A vehicle that allows movement in restricted areas of the city, reduces traffic congestion, produces zero emissions at the point of use, decreases accidents and fatalities from crashes, and reduces energy consumption.

Location?: Dense urban areas in developed countries around the world that share green technology infrastructure, emission standards, transportation regulations, and citizens' lifestyles (e.g., New York City, Singapore, Los Angeles, London, Beijing, etc.), typically referring to the commute between residence and workplace.

When is it used?: Workdays, during commuting hours. During office hours, the vehicle remains unused by the user.

Why is it used?: To relax, commute more efficiently, and enhance the quality of daily journeys, benefiting from all the advantages that autonomous vehicles connected to each other and the city have to offer.

How is it powered/driven?: A vehicle that allows movement in restricted areas of cities.

Table 12

Dependency | Independency table

	Comfortable	Customizable	Smart	Functional	Sustainable	Non Pollutant	Safe	Compact	Autonomous	Advanced	User-Friendly	Maneuverable	Appealing
Comfortable		0	0	1	0	0	1	9	0	0	0	0	0
Customizable	3		3	0	0	0	0	0	0	1	1	0	1
Smart	0	3		0	3	1	9	0	3	9	9	9	9
Functional	0	3	0		0	0	0	0	0	3	3	0	3
Sustainable	0	0	0	0		9	0	0	0	3	0	0	0
Non Pollutant	0	0	0	0	9		0	0	0	9	0	0	0
Safe	0	0	3	0	0	0		3	3	1	0	0	0
Compact	3	3	0	3	3	1	3		0	0	0	3	0
Autonomous	0	0	9	0	1	0	3	0		9	1	0	1
Advanced	0	0	9	3	0	0	3	0	3		0	0	0
User-Friendly	0	0	1	3	0	0	0	3	1	0		0	0
Maneuverable	0	3	0	0	0	0	1	1	1	0	0		1
Appealing			3	0	0	0	0	0	0	1	1	0	

Most independent parameters are: Smart, Sustainable, Safe, Compact, Advanced

Table 13

Relative Importance table

	Comfortable	Customizable	Smart	Functional	Sustainable	Non Pollutant	Safe	Compact	Autonomous	Advanced	User-Friendly	Maneuverable	Appealing
Comfortable	1	2	0	2	2	1	1	2	1	1	2	2	2
Customizable	0	1	0	1	1	0	0	0	0	0	1	0	0
Smart	2	2	1	2	1	1	1	2	1	1	2	2	2
Functional	0	1	0	1	2	1	0	2	0	0	2	1	1
Sustainable	0	1	1	0	1	1	0	1	0	1	2	2	2
Non Pollutant	1	2	1	1	1	1	0	2	0	1	0	2	2
Safe	1	2	1	2	2	2	1	2	1	2	2	2	2
Compact	0	2	0	0	1	0	0	1	0	1	2	2	2
Autonomous	1	2	1	2	2	2	1	2	1	1	2	2	2
Advanced	1	2	1	2	1	1	0	1	1	1	2	1	1
User-Friendly	0	1	0	0	0	2	0	0	0	0	1	0	0
Maneuverable	0	2	0	1	0	0	0	0	0	1	2	1	0
Appealing	0	2	0	1	0	0	0	0	0	1	2	1	1

Most relatively important parameters are: Comfortable, Smart, Safe, Autonomous

What | How table

Parameters considered as highly dependent if they positively improve that performance.

What | How	Lightweight	Range [km]	Price	Height	Length	Width	Horse power	Doors [n.]	Fuel consumption	Seats [n.]
Comfortable										
Smart										
Safe										
Autonomous										
Compact										
Advanced										
Total										

Table 14

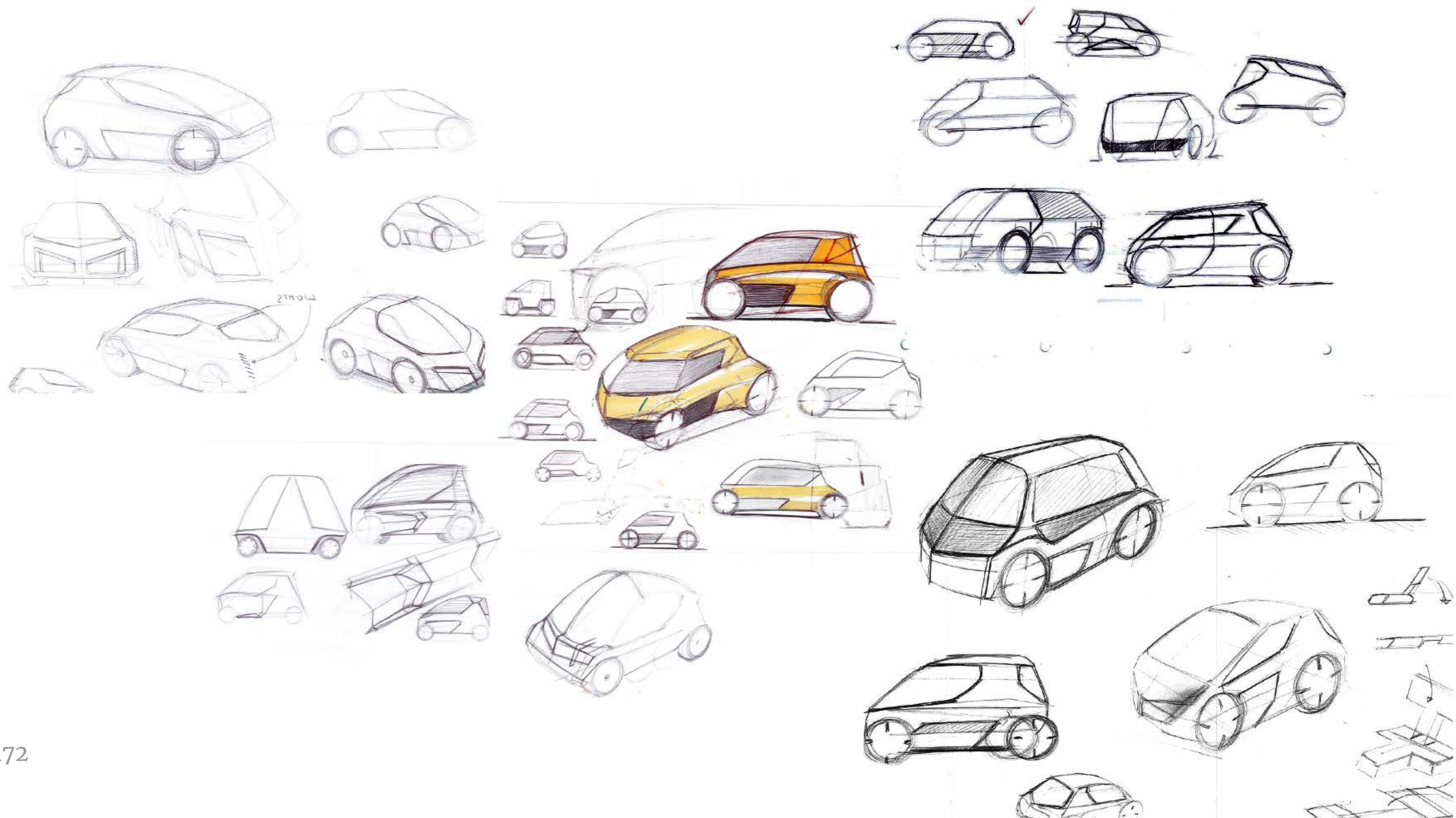
Benchmark table

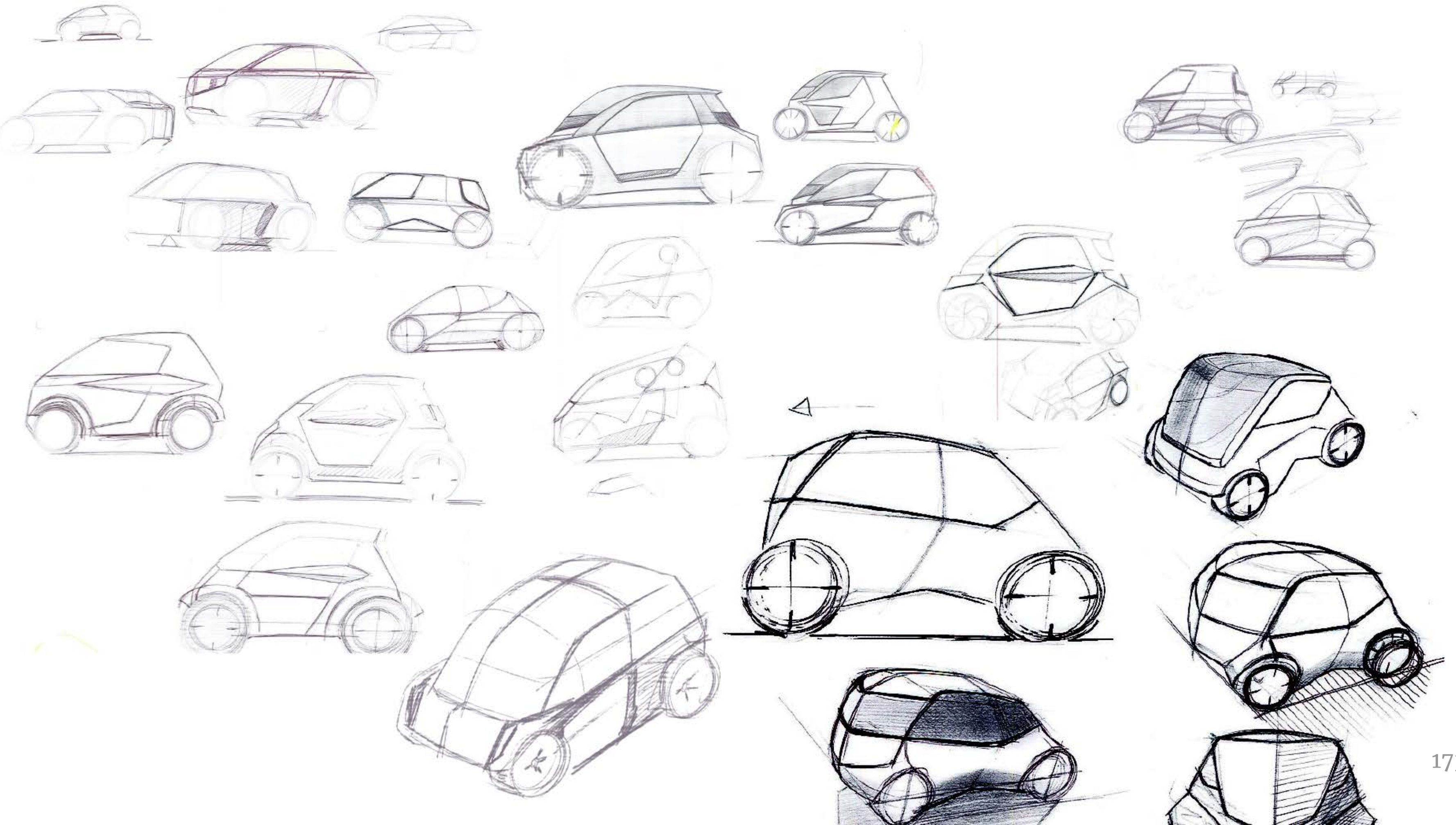
Car Name	Brand	Year	Length (mm)	Width (mm)	Height (mm)	Wheelbase (mm)	Top Speed [km/h]	Range [km]	Power (hp)	Weight (kg)
Fiat Mio	Fiat	2010	2519	1520	1440	1720	70	100	20	500
Aixam City	Aixam	2023	2685	1500	1445	1800	45	75	8	425
Microlino	MMS	2023	2519	1473	1501	|	90	230	17	513
XEV YOYO	XEV	2021	2530	1500	1560	1680	80	150	13	450
Citroën Ami	Citroën	2020	2410	1390	1520	1720	45	75	8	471
Fiat Topolino	Fiat	2023	2410	1390	1520	1720	45	75	8	471
Mobilize Duo	Mobilize	2024	2430	1300	1460	1720	80	140	16	490
Fiat 500e	Fiat	2020	3632	1683	1527	2322	150	320	117	1350
Cadillac Urban Luxury Concept	Cadillac	2010	3835	1730	1445	2466	120	|	110	850
Smart ForTwo EQ	Smart	2020	2.695	1.663	1.555	1.873	130	135	82	1.170
Aston Martin Cygnet	Aston Martin	2011	3078	1680	1500	2000	170	|	97	988
Renault Twizy	Renault	2012	2337	1191	1461	1686	80	100	17	474
Ford Ka	Ford	2019	3929	1695	1525	2489	170	|	85	1081
Fiat Pandina	Fiat	2022	3653	1643	1551	2300	160	|	70	940
GAC City Pod	GAC	2021	3200	1550	1600	2100	100	250	35	750
Mini Vision Next 100 Concept	Mini	2016	3800	1720	1420	2500	200	300	150	1200
Triggo Car	Triggo	2021	2600	1480	1520	1700	90	100	15	400
Fiat Phylla	Fiat	2008	2990	1600	1500	2000	130	220	50	750
GM Autonomy	GM	2002	4500	1900	1400	2700	130	500	110	1600
Toyota Winglet	Toyota	2013	300	300	1200	|	6	10	0,5	10
Suzuki SSC	Suzuki	2003	2500	1300	1500	1700	120	200	50	700
Citroën Oli Concept	Citroën	2022	4200	1900	1650	2800	110	400	136	1000

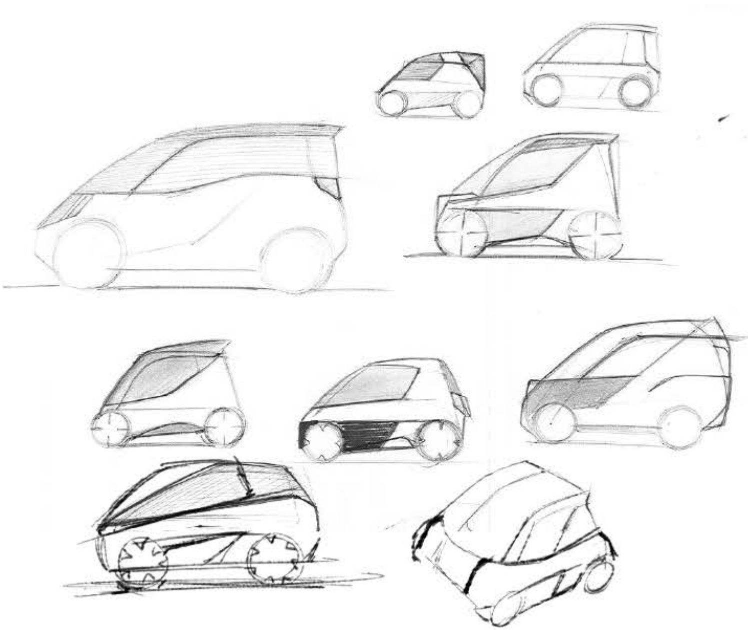
Table 15

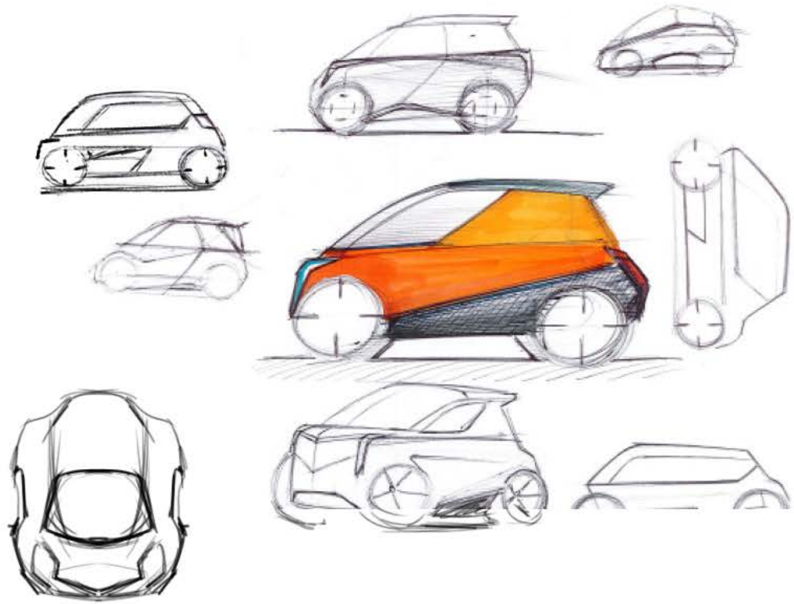
Price	Doors	Seats	CO2 Emissions	3D Printed Components	Notes	Top	Flop	D
Concept	2	2	0	No	Concept electric car for urban mobility	0	0	0
€13,000	2	2	0	No	Electric quadricycle, designed for European microcar standards	4	0	4
€15,000	1	2	0	No	Electric microcar, inspired by vintage Isetta design	0	1	-1
€14,000	2	2	0	Yes	Compact electric city car with swappable battery technology	2	0	2
€7,700	2	2	0	No	Electric quadricycle, compact design for urban mobility	3	0	3
€7,700	2	2	0	No	Electric quadricycle, derived from Citroën Ami	3	0	3
€8,000	2	2	0	No	Electric quadricycle, available in two speed configurations	0	0	0
€30,000	3	4	0	No	Battery-electric car, available in multiple trims and battery sizes	0	2	-2
Concept	4	4	|	No	Concept car for urban luxury and downsized future mobility	0	0	0
€24,000	3	2	0	No	Modello elettrico con batteria da 17,6 kWh.	0	0	0
€40,000	3	4	116	No	Luxury city car based on Toyota iQ	0	2	-2
€10,000	0	2	0	No	Compact car, available in petrol versions	1	0	1
€13,000	5	5	114	No		0	3	-3
€12,000	5	5	119	No	Compact and versatile city car, popular in Europe	0	1	-1
Concept	2	2	0	Yes	Electric urban concept car designed for shared mobility	2	0	2
Concept	2	4	0	Yes	Futuristic concept with autonomous and shared mobility focus	1	3	-2
€12,000	0	2	0	No	Electric urban vehicle with adjustable width for parking ease	1	0	1
Concept	4	4	0	No	Solar-electric hybrid concept focused on sustainability	1	0	1
Concept	4	4	0	No	Hydrogen-powered concept with modular architecture	0	3	-3
Concept	0	1	0	No	Personal electric mobility scooter for urban use	0	1	-1
Concept	2	2	0	No	Electric urban concept with compact design	0	0	0
Concept	4	4	0	Yes	Sustainable concept car with modular and recyclable materials	1	1	0

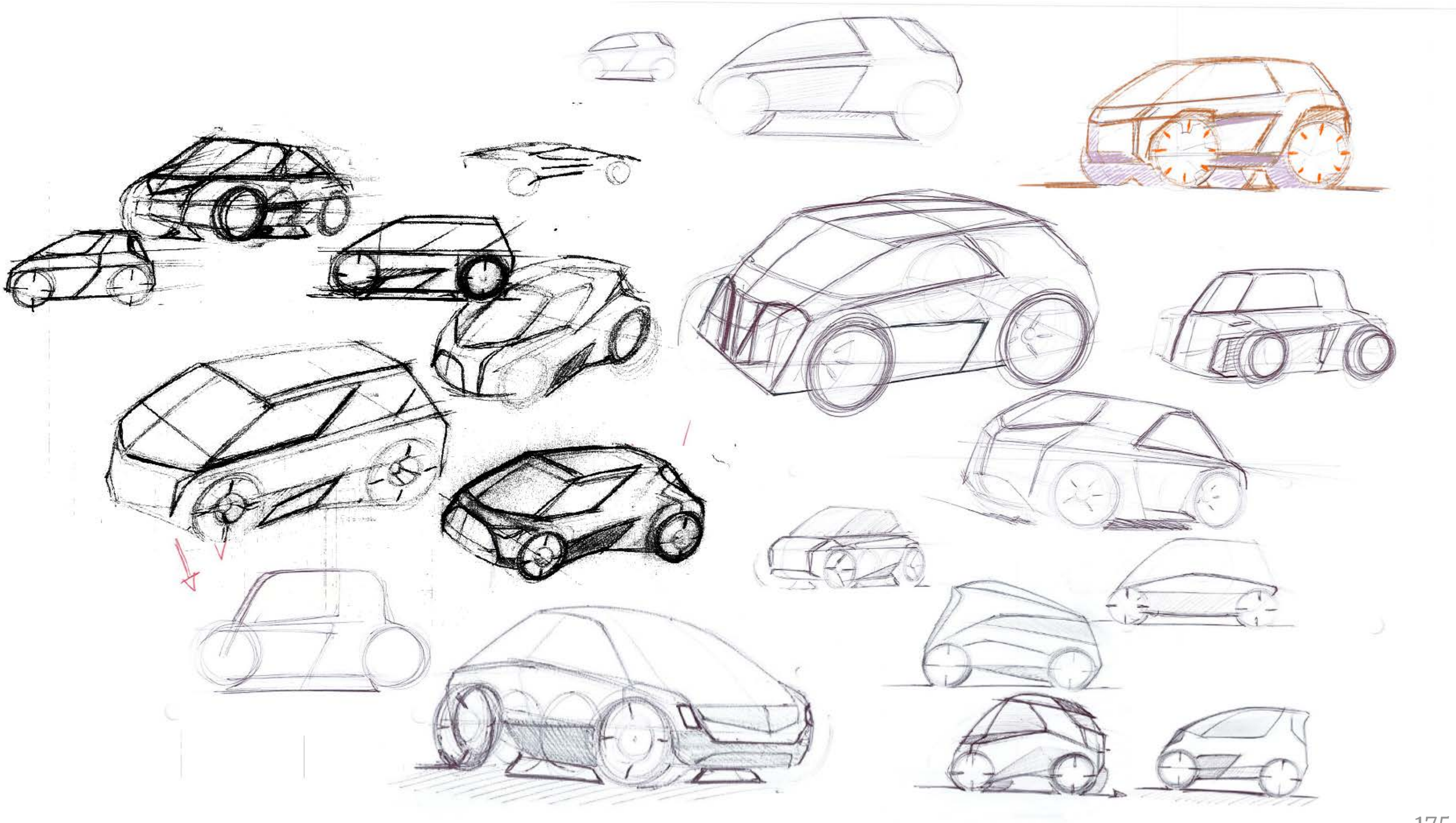
Style Development - Urban Vehicle

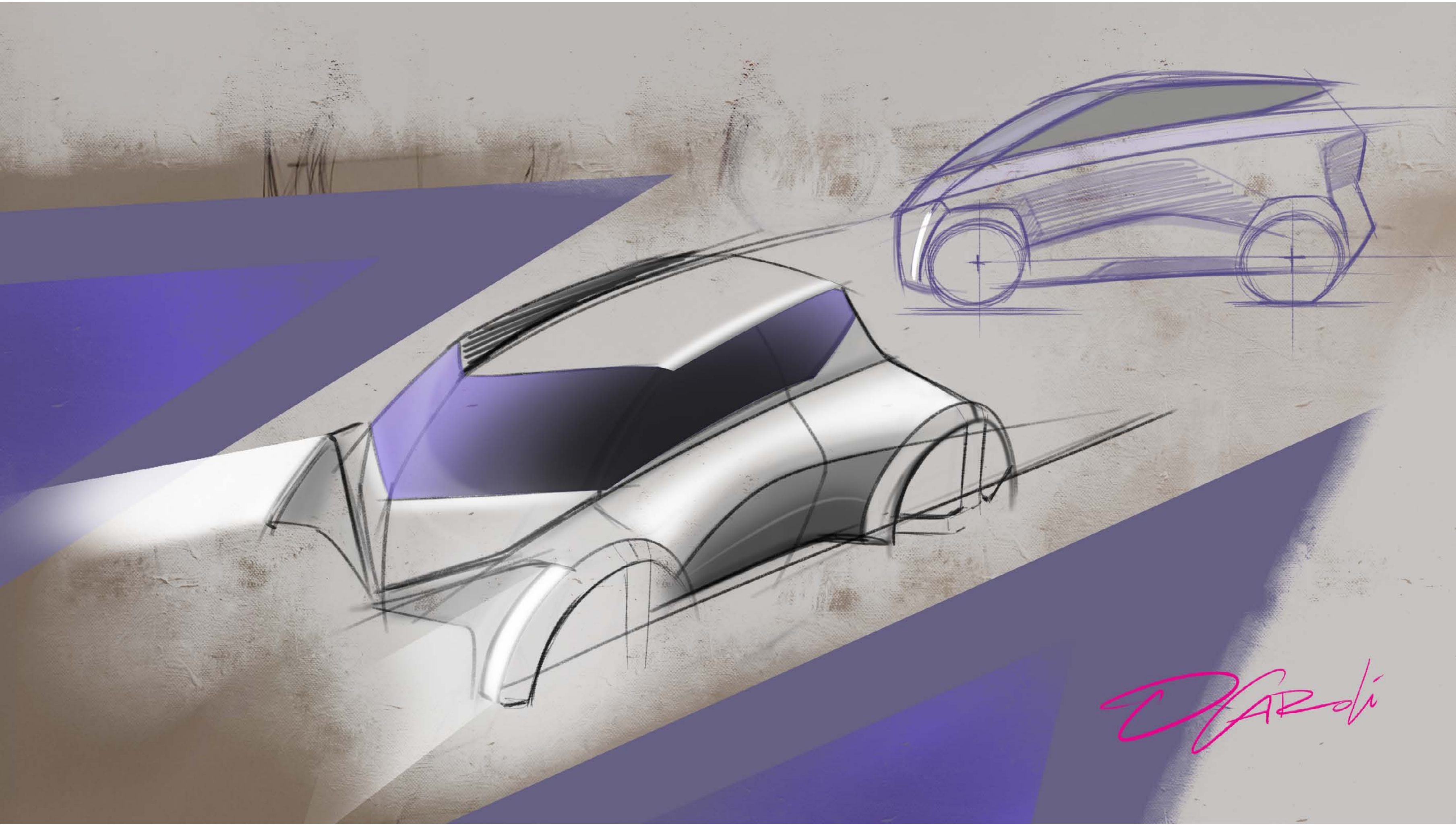


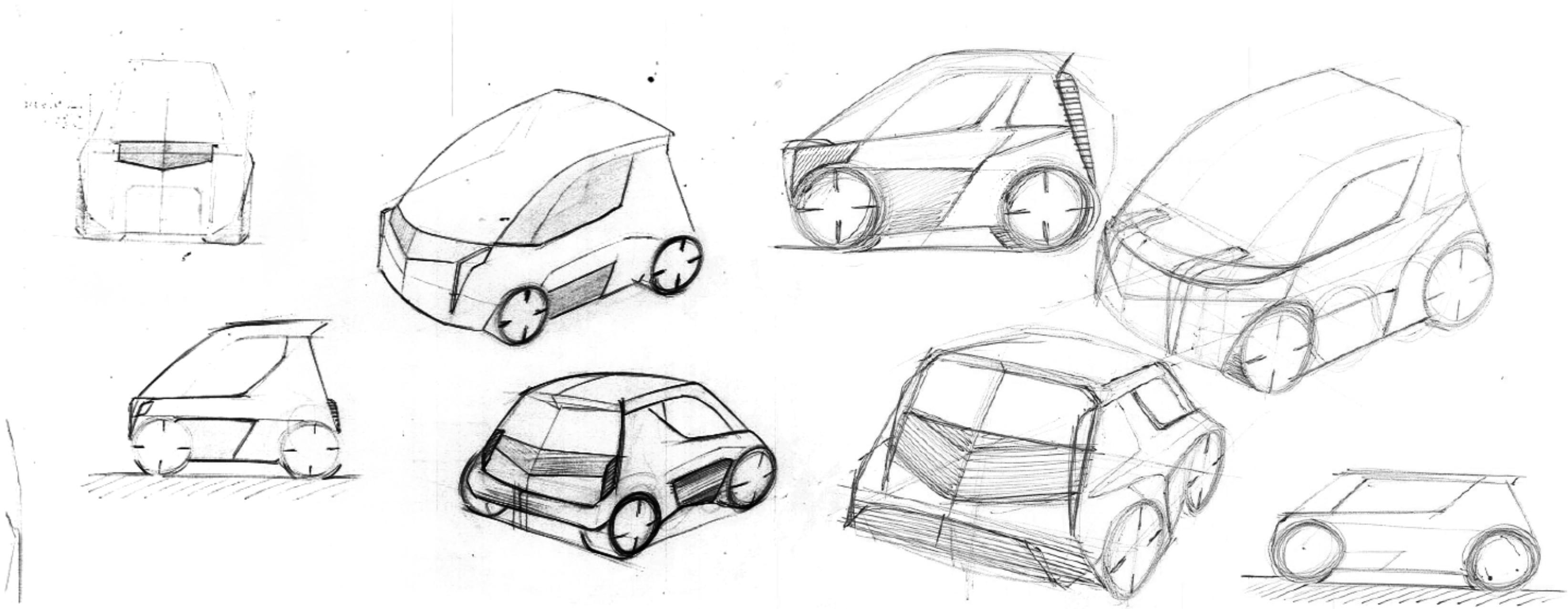


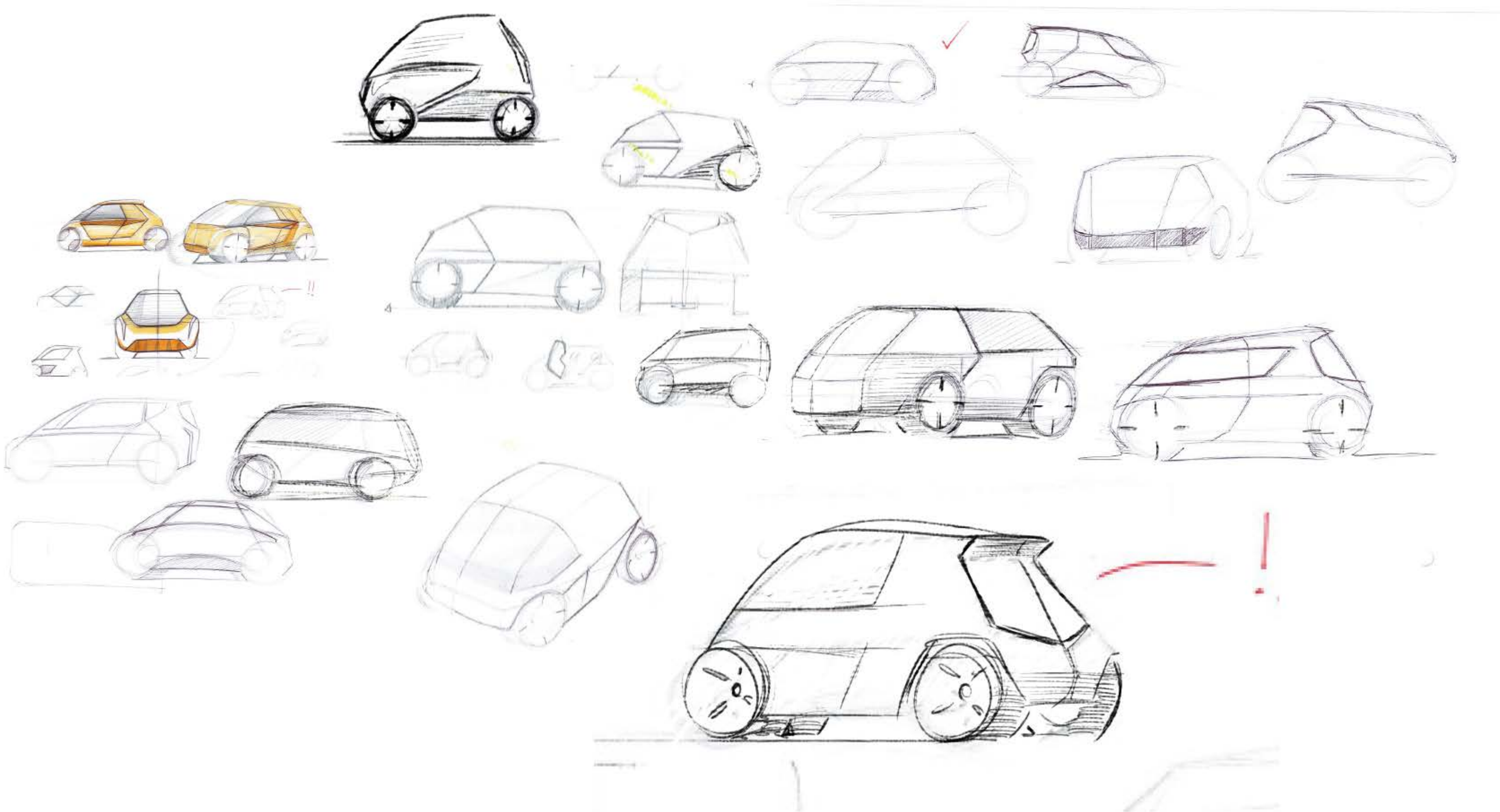




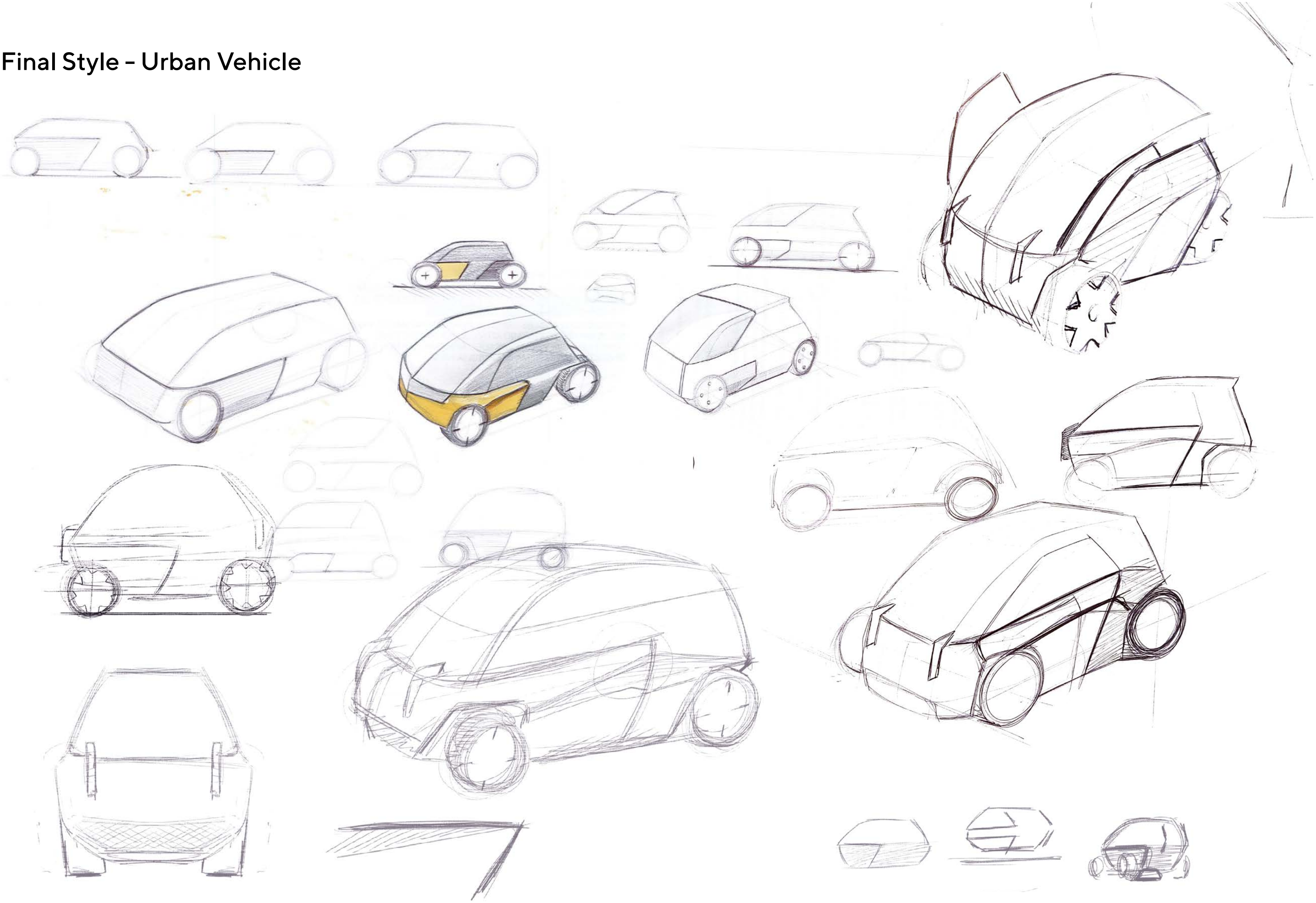


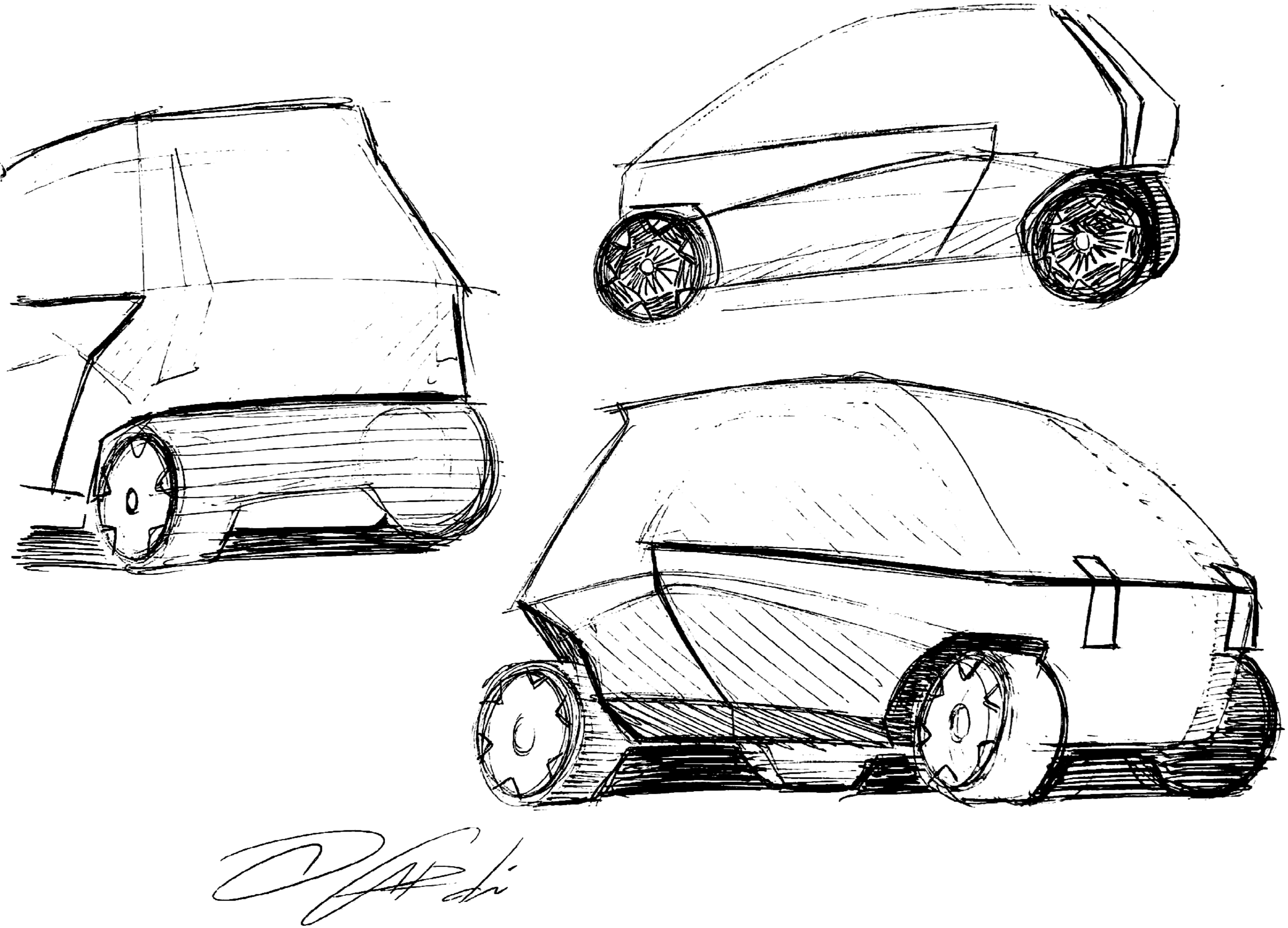


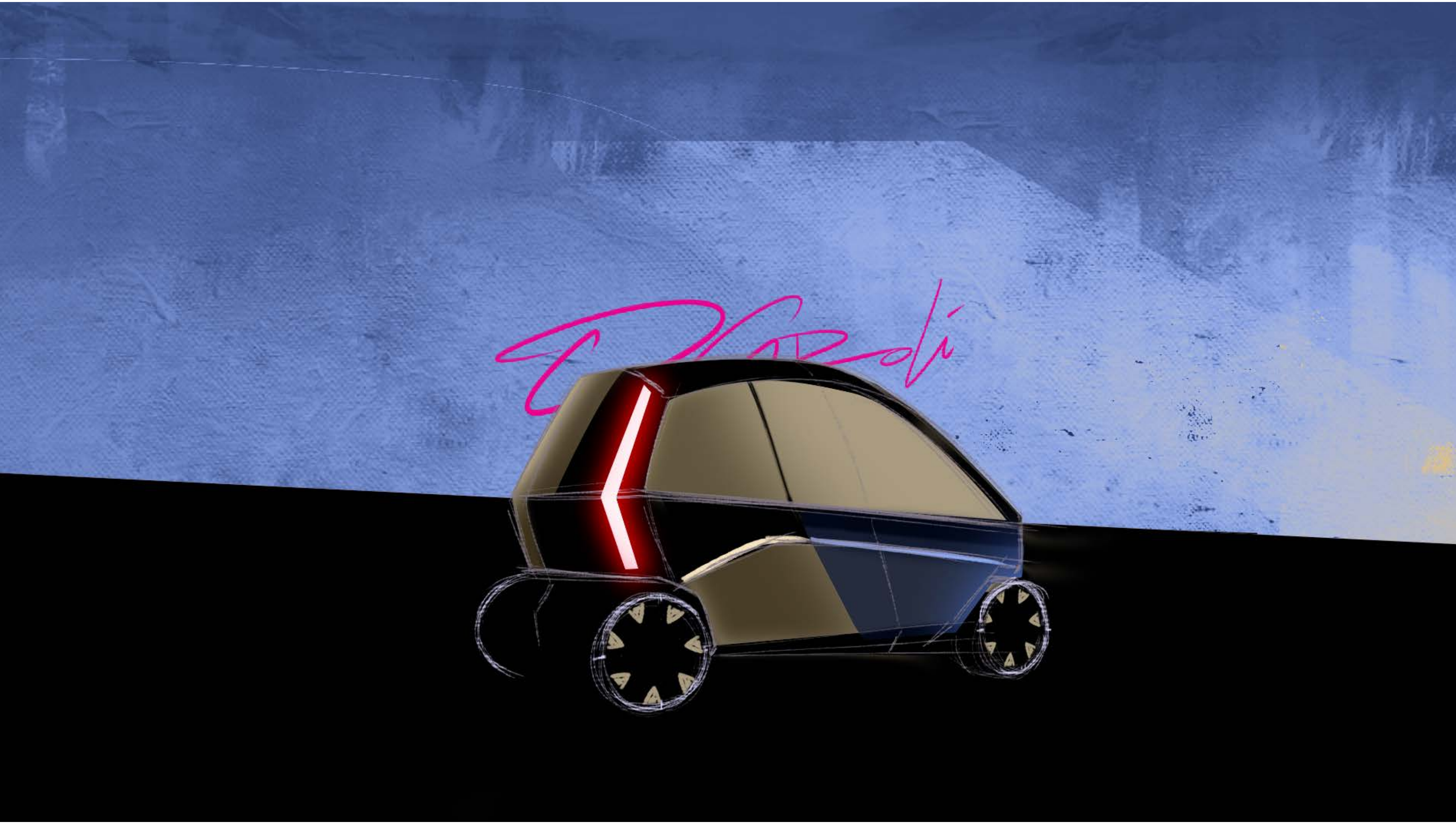




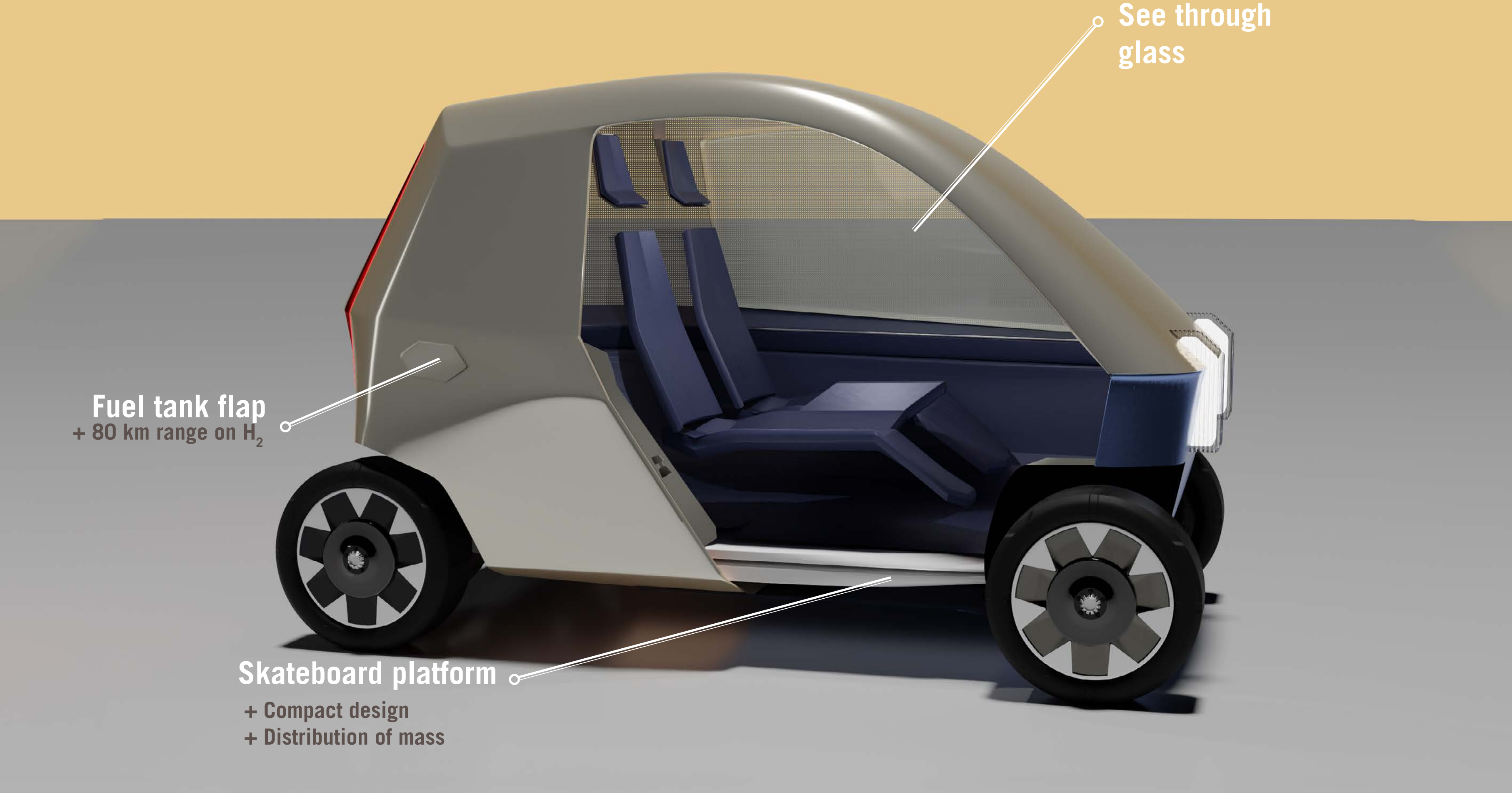
Final Style – Urban Vehicle

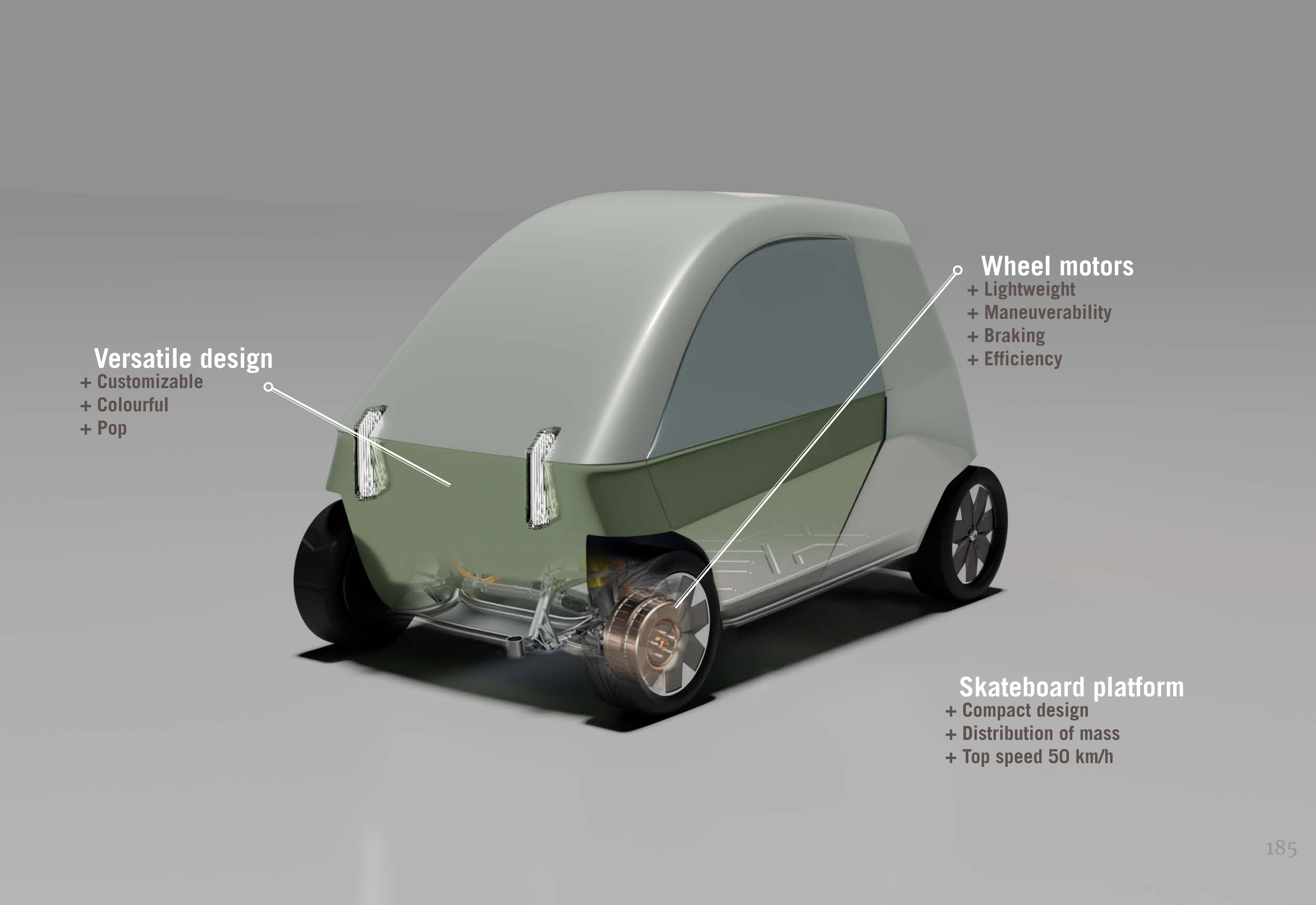


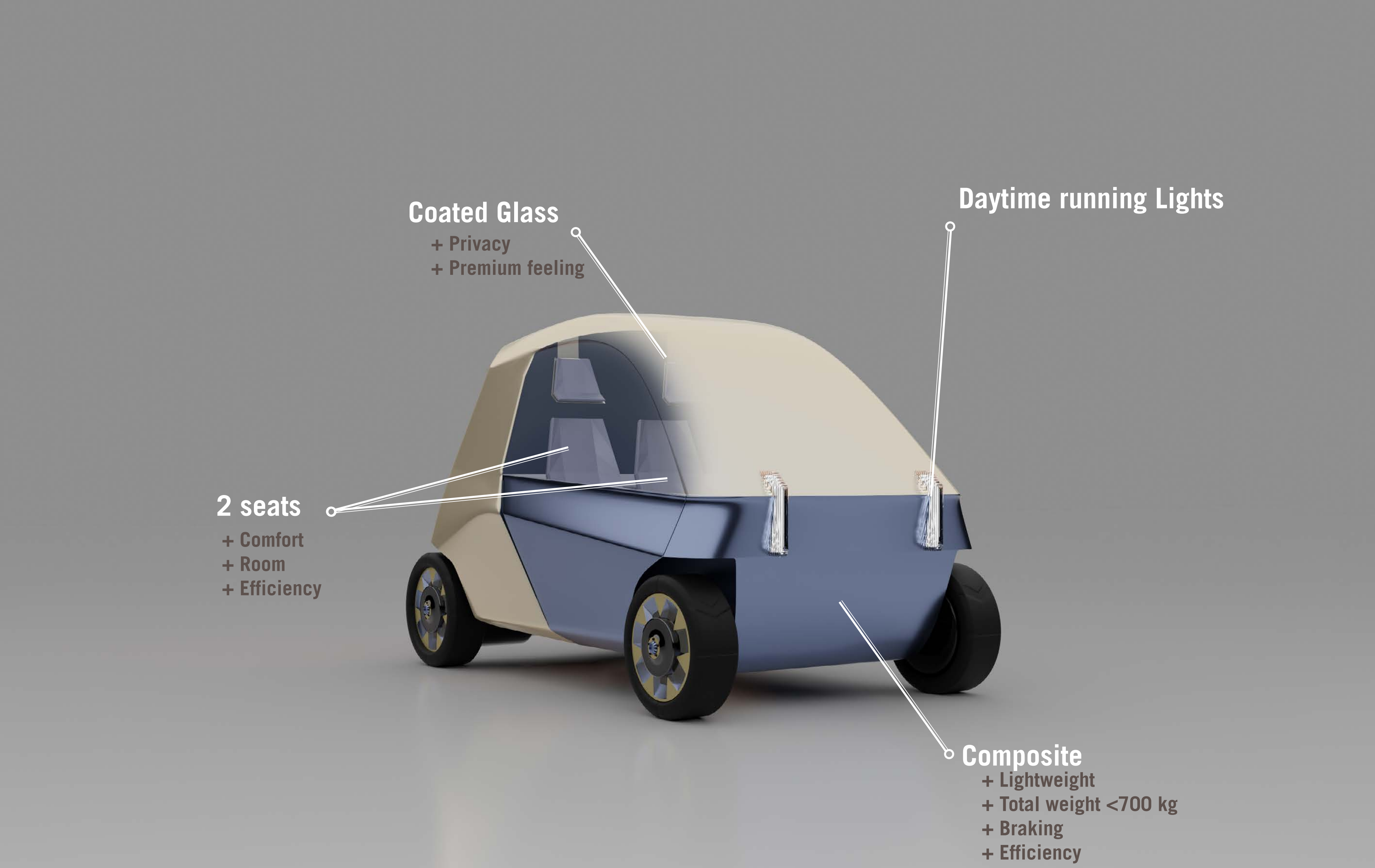




Product Architecture – Urban Vehicle

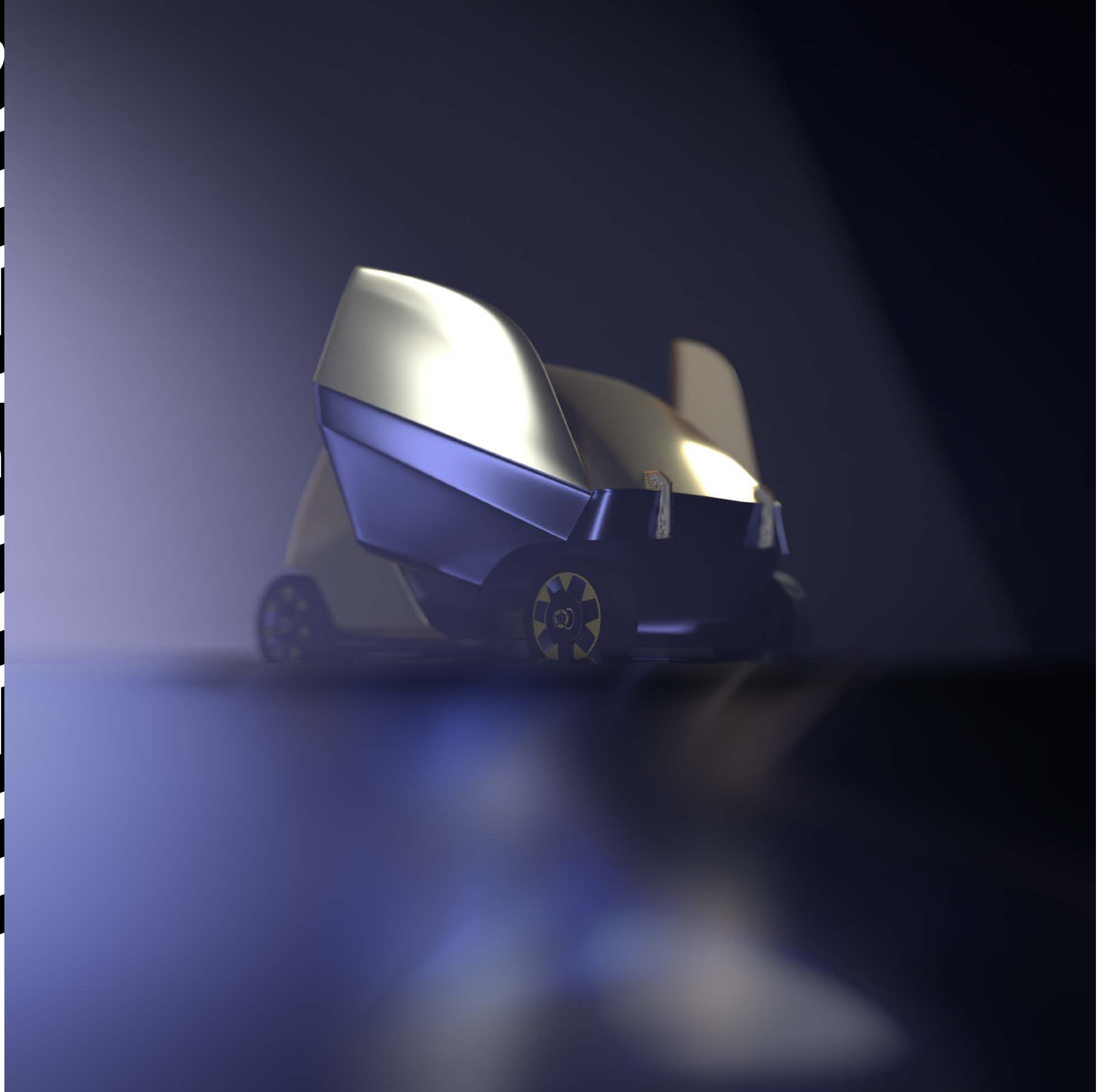


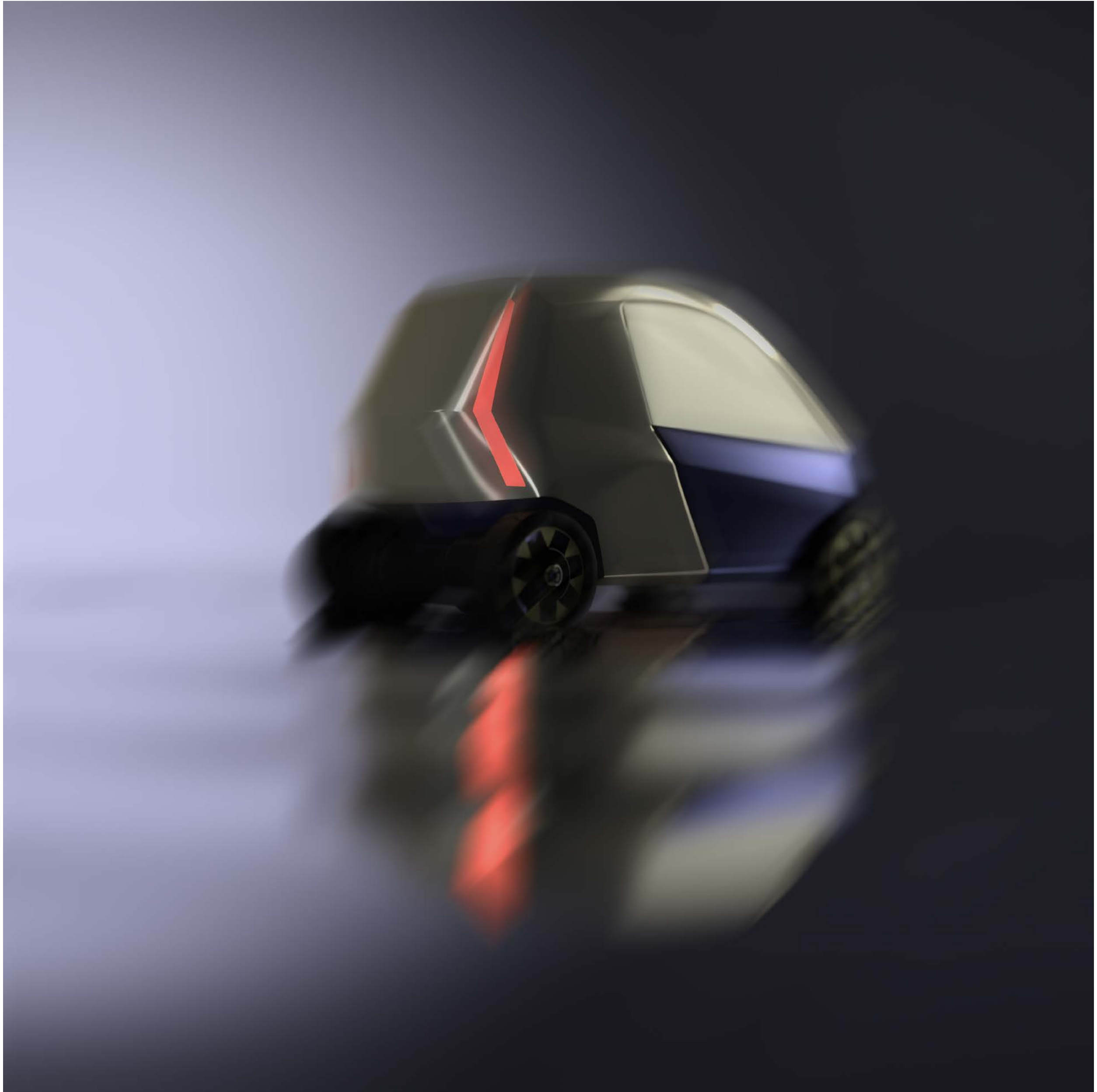

Versatile design
+ Customizable
+ Colourful
+ Pop
Wheel motors
+ Lightweight
+ Maneuverability
+ Braking
+ Efficiency
Skateboard platform
+ Compact design
+ Distribution of mass
+ Top speed 50 km/h


Coated Glass
+ Privacy
+ Premium feeling
Daytime running Lights
2 seats
+ Comfort
+ Room
+ Efficiency
Composite
+ Lightweight
+ Total weight <700 kg
+ Braking
+ Efficiency

RENDERS

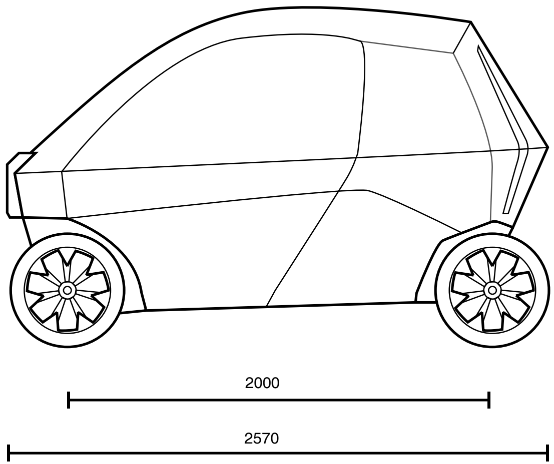
RENDERS

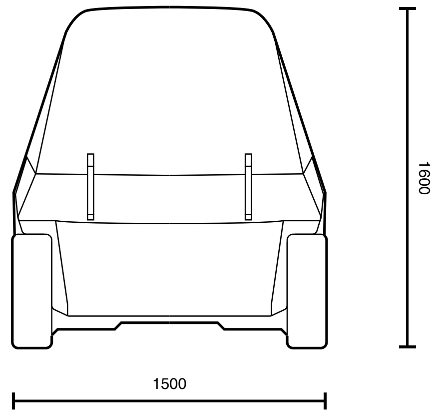


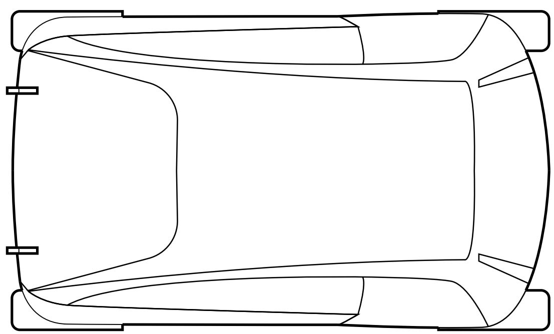


Blueprint - Urban Vehicle

Unit of Measure: mm







2050 mobility

Serivce

Cross Sectors Alliances

Affordable and Clean Transportation for All

Vehicles designed for

Autonomous Drive

Lifestyle

Safety

Shared Mobility

Efficiency

Multiple Modes of Transportation

Lightweight

0 Emissions

Value shift

Acknowledgements

I would like to thank some important people who believed in me and helped me improve professionally and as a person.
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In the United States of America I was introduced to professor Justin Famularo, I am really happy I had the chance to meet such a great person.
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Last but not least I would like to thank Curzio, the backbone of what I have learned.

Since the introduction of the automobile, cities and the vehicles that provide mobility have coevolved as a consequence. *"Streets have become dangerous, noisy sites of reduced air quality, with the consequence that their traditional role as public social space has diminished, and adjacent buildings, which might otherwise take advantage of natural ventilation, often have to be sealed up and air conditioned."*

(Mitchell et al., 2010)

With this project, I begin my commitment for a better future for our environment.

Bibliography

2002 GM Hy wire - Images, Specifications and Information. (n.d.). Retrieved March 10, 2025, from https://www.ultimatecarpage.com/car/1477/GM-Hy-wire.html

Aengenheyster, M., Feng, Q. Y., Van Der Ploeg, F., & Dijkstra, H. A. (2018). The point of no return for climate action: Effects of climate uncertainty and risk tolerance. Earth System Dynamics, 9(3), 1085–1095. https://doi.org/10.5194/ESD-9-1085-2018

Akao, Y. (1990). Quality Function Deployment in Process Industries. In Y. Akao (Ed.), Quality function deployment : integrating customer requirements into product design. Productivity Press. https://www.routledge.com/Quality-Function-Deployment-Integrating-Customer-Requirements-into-Product-Design/Akao/p/book/9781563273131

Albatayneh, A., Juaidi, A., Jaradat, M., & Manzano-Agugliaro, F. (2023). Future of Electric and Hydrogen Cars and Trucks: An Overview. In Energies (Vol. 16, Issue 7). MDPI. https://doi.org/10.3390/en16073230

Allendorf, M. D., Stavila, V., Snider, J. L., Witman, M., Bowden, M. E., Brooks, K., Tran, B. L., & Autrey, T. (2022). Challenges to developing materials for the transport and storage of hydrogen. Nature Chemistry, 14(11), 1214–1223. https://doi.org/10.1038/s41557-022-01056-2

Alpine's hydrogen-powered supercar of 2035. (n.d.). Retrieved March 10, 2025, from https://www.capricorn.coop/caphub/industry/2022/alpines-hydrogen-powered-supercar-of-2035

Anderson, C. D., & Anderson, J. (2010). Electric and hybrid cars: A history (2nd ed.). McFarland.

Anderson, J. M., Kalra, N., Stanley, K. D., Sorensen, P., Samaras, C., & Oluwatola, T. A. (2016). Autonomous Vehicle Technology: A Guide for Policymakers. Autonomous Vehicle Technology: A Guide for Policymakers. https://doi.org/10.7249/RR443-2

Anirudh, B., Mazumder, T. N., & Das, A. (2022). Examining effects of city's size and regional context on vehicle ownership levels in the Indian context. Transportation Research Part D: Transport and Environment, 108. https://doi.org/10.1016/j.trd.2022.103279

Automotive Skills Development Council: Automotive Training Certification Centre - ASDC. (n.d.). Retrieved March 10, 2025, from https://www.asdc.org.in/

Azwardi, Andaiyani, S., Igamo, A. M., & Wijaya, W. A. (2023). The Environmental Impacts of Natural Resources Depletion. Lecture Notes in Civil Engineering, 334 LNCE, 705–714. https://doi.org/10.1007/978-981-99-1403-6_47

Ball, M., & Wietschel, M. (2009). The future of hydrogen - opportunities and challenges. International Journal of Hydrogen Energy, 34(2), 615–627. https://doi.org/10.1016/j.ijhydene.2008.11.014

Banister, D. (2006). Review of "On the Move: Mobility in the Modern Western World" by Tim Cresswell. In Journal of Transport Geography (Vol. 14, Issue 6). https://www.routledge.com/Unsustainable-Transport-City-Transport-in-the-New-Century/Banister/p/book/9780415357906

Banister, D., Hickman, R., & Stead, D. (2007). Looking Over the Horizon: Visioning and Backcasting. Building Blocks for Sustainable Transport, 25–53. https://doi.org/10.1108/9780857245168-003

Barakati, P., Bertini, F., Corsi, E., Gabbrielli, M., & Montesi, D. (2024). Luxury Car Data Analysis: A Literature Review. In Data (Vol. 9, Issue 4). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/data9040048

Barbir, F. (2009). Transition to renewable energy systems with hydrogen as an energy carrier. Energy, 34(3), 308–312. https://doi.org/10.1016/j.energy.2008.07.007

Bhatia, L., Sarangi, P. K., & Nanda, S. (2022). Hydrogen Production through Microbial Electrolysis. Biohydrogen, 175–188. https://doi.org/10.1201/9781003277156-7

Bloch, P. H. (1995). Seeking the Ideal Form: Product Design and Consumer Response. Journal of Marketing, 59(3), 16–29. https://doi.org/10.1177/002224299505900302

Borthwick, W., & Perez-Sainz, A. (2006). Update on European Hydrogen and Fuel Cell RT-D&D Programmes European Commission Directorate General for Research Unit J-2 "Energy Production and Distribution Systems." Fuel Cells and Infrastructure Technologies Annual Merit Review.

Buchanan, R. (1992). Wicked Problems in Design Thinking. Design Issues, 8(2), 5. https://doi.org/10.2307/1511637

Camilleri, R., Attard, M., & Hickman, R. (2022). Future low-carbon transport scenarios: Practice theory-based visioning for backcasting studies. Sustainability (Switzerland), 14(1). https://doi.org/10.3390/su14010074

Cars: Hydrogen Electric XP1 Hypercar - Hyperion. (n.d.). Retrieved March 10, 2025, from https://www.hyperion.inc/xp1-car

Celaschi, F. (2015). Advancedesign points of view. Advanced Design Cultures: Long-Term Perspective and Continuous Innovation, 3–17. https://doi.org/10.1007/978-3-319-08602-6_1

Celi, M. (2015). Advanced design cultures: Long-term perspective and continuous innovation. Advanced Design Cultures: Long-Term Perspective and Continuous Innovation, 1–169. https://doi.org/10.1007/978-3-319-08602-6/COVER

Chandrasekhar, T., Reddy, P. C. O., Swapna, B., Veeranjaneya Reddy, L., Anuprasanna, V., Dakshayani, L., Ramachandra Reddy, P., & Reddy, M. C. (2024). Algae: the game-changers in biohydrogen sector. Critical Reviews in Biotechnology. https://doi.org/10.1080/07388551.2024.2387176

Chapman, L. (2007). Transport and climate change: a review. Journal of Transport Geography, 15(5), 354–367. https://doi.org/10.1016/j.jtrangeo.2006.11.008

Chen, T. D., Kockelman, K. M., & Hanna, J. P. (2016). Operations of a shared, autonomous, electric vehicle fleet: Implications of vehicle & charging infrastructure decisions. Transportation Research Part A: Policy and Practice, 94, 243–254. https://doi.org/10.1016/J.TRA.2016.08.020

Chernoff, A. (n.d.). GM Hy-Wire – Reinventing the Automobile – Inventor Adrian Chernoff. Retrieved March 10, 2025, from https://www.adrianchernoff.com/project/hy-wire/

Cheutet, V., Léon, J.-C., Chiara, ·, Catalano, E., Giannini, F., Monti, M., Falcidieno, B., Cheutet, V., Léon, J.-C., Catalano, C. E., Giannini, · F, Monti, · M, Falcidieno, · B, Giannini, F., Monti, M., & Falcidieno, B. (2007). Preserving car stylists' design intent through an ontology. International Journal on Interactive Design and Manufacturing (IJIDeM) 2007 2:1, 2(1), 9–16. https://doi.org/10.1007/S12008-007-0031-3

Colthorpe, A. (2021, December 1). BloombergNEF: Average battery pack prices to drop below US$100/kWh by 2024 despite near-term spikes. Energy-Storage.News. https://www.energy-storage.news/bloombergnef-average-battery-pack-prices-to-drop-below-us100-kwh-by-2024-despite-near-term-spikes/

Cornet, A., Heuss, R., Schaufuss, P., & Tschiesner, A. (2023). A road map for Europe's automotive industry.

Coskun, A., Zimmerman, J., & Erbug, C. (2015). Promoting sustainability through behavior change: A review. Design Studies, 41, 183–204. https://doi.org/10.1016/j.destud.2015.08.008

Crea, N. (2015). Advanced transportation design. Advanced Design Cultures: Long-Term Perspective and Continuous Innovation, 97–107. https://doi.org/10.1007/978-3-319-08602-6_7

D'Auria, M., Sanseverino, M., Cappadona, F., & D'Ippolito, R. (2013). Integrated Management of Automotive Product Heterogeneous Data: Application Case Study. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 8186 LNCS, 62–69. https://doi.org/10.1007/978-3-642-41033-8_11

Dawood, A., Alsehibani, A., Dawood, S., & Rehman, A. (2023). Prediction of Environmental Earth Surface Temperature using hybrid machine learning model. Proceedings - 2023 6th International Conference of Women in Data Science at Prince Sultan University, WiDS-PSU 2023, 127–132. https://doi.org/10.1109/WiDS-PSU57071.2023.00036

DOE. (2017). DOE Technical Targets for Onboard Hydrogen Storage for Light-Duty Vehicles | Department of Energy. https://www.energy.gov/eere/fuelcells/doe-technical-targets-onboard-hydrogen-storage-light-duty-vehicles

Dogliani, P., Ruas Rego Canha, A. N., Elberry, A. M., & Thakur, J. (2024). Multi-option analytical modeling of levelized costs across various hydrogen supply chain nodes. International Journal of Hydrogen Energy, 70, 737–755. https://doi.org/10.1016/j.ijhydene.2024.05.142

Donnici, G., Frizziero, L., Liverani, A., Buscaroli, G., Raimondo, L., Saponaro, E., & Venditti, G. (2020). A new car concept developed with stylistic design engineering (SDE). Inventions, 5(3), 1–22. https://doi.org/10.3390/inventions5030030

Dou, Y., Sun, L., Ren, J., & Dong, L. (2017). Opportunities and Future Challenges in Hydrogen Economy for Sustainable Development. Hydrogen Economy: Supply Chain, Life Cycle Analysis and Energy Transition for Sustainability, 277–305. https://doi.org/10.1016/B978-0-12-811132-1.00010-9

Du, J., Guo, M., Feng, T., Liang, G., & Yue, B. (2024). The Mechanism and Components of Subscriptions in the Business Model. Advances in Economics, Management and Political Sciences, 101(1), 1–6. https://doi.org/10.54254/2754-1169/101/20231701

Dutton, A. G., , A. L., Kelly, C., & Watson, J. (2004). The hydrogen economy: its long term role in greenhouse gas reduction. https://www.researchgate.net/publication/30415176

Edwards, P. P., Kuznetsov, V. L., David, W. I. F., & Brandon, N. P. (2008). Hydrogen and fuel cells: Towards a sustainable energy future. Energy Policy, 36(12), 4356–4362. https://doi.org/10.1016/j.enpol.2008.09.036

Federal Highway Administration (FHWA). (2017). 2017 National Household Travel Survey. U.S. Department of Transportation. http://nhts.ornl.gov

FHWA. (2017). National Household Travel Survey. https://nhts.ornl.gov/

Fischer, L., Rupalla, F., Sahdev, S., & Tanweer, A. (n.d.). Exploring consumer sentiment on electric-vehicle charging.

Frizziero, L., Donnici, G., Liverani, A., Alessandri, G., Menozzi, G. C., & Varotti, E. (2019). Developing innovative crutch using IDeS (industrial design structure) methodology. Applied Sciences (Switzerland), 9(23). https://doi.org/10.3390/app9235032

Frizziero, L., Donnici, G., Liverani, A., Maria, N., Ximenes, A., Seclì, A., & Ticca, M. (2022). Stylistic Design Engineering (SDE) applied to a New E-Segment Sport Sedan.

Frizziero, L., Santi, G. M., Donnici, G., Leon-Cardenas, C., Ferretti, P., Liverani, A., & Neri, M. (2021). An innovative ford sedan with enhanced stylistic design engineering (SDE) via augmented reality and additive manufacturing. Designs, 5(3). https://doi.org/10.3390/designs5030046

Garud, R., Jain, S., & Tuertscher, P. (2008). Incomplete by Design and Designing for Incompleteness. Organization Studies, 29(3), 351–371. https://doi.org/10.1177/0170840607088018

Gernsbacher, M. A., & Derry, S. J. (2022). Proceedings of the Twentieth Annual Conference of the Cognitive Science Society. Proceedings of the Twentieth Annual Conference of the Cognitive Science Society. https://doi.org/10.4324/9781315782416/PROCEEDINGS-TWENTIETH-ANNUAL-CONFERENCE-COGNITIVE-SCIENCE-SOCIETY-MORTON-ANN-GERNSBACHER-SHARON-DERRY

Glazer, A., & Hassin, R. (n.d.). ON THE ECONOMICS OF SUBSCRIPTIONS*.

Godish, T. G. (2014). Air Quality, 4th Edition. https://doi.org/DOI:10.1201/b17341

Gössling, S., Cohen, S., Higham, J., Peeters, P., & Eijgelaar, E. (2018). Desirable transport futures. Transportation Research Part D: Transport and Environment, 61, 301–309. https://doi.org/10.1016/J.TRD.2018.01.008

Greenblatt, J. B., & Shaheen, S. (2015). Automated Vehicles, On-Demand Mobility, and Environmental Impacts. Current Sustainable/Renewable Energy Reports, 2(3), 74–81. https://doi.org/10.1007/S40518-015-0038-5/TABLES/1

Hickman, R., & Banister, D. (2005). Visioning and Backcasting for UK Transport Policy.

Hordeski, M. F. (2008). Hydrogen & Fuel Cells: Advances in Transportation and Power. Fairmont Press.

Harrison, G., Gómez Vilchez, J. J., & Thiel, C. (2018). Industry strategies for the promotion of E-mobility under alternative policy and economic scenarios. European Transport Research Review, 10(2). https://doi.org/10.1186/s12544-018-0296-6

Heeraman, J., Kalyani, R., & Amala, B. (2024). Towards a Sustainable Future: Design and Fabrication of a Solar-Powered Electric Vehicle. IOP Conference Series: Earth and Environmental Science, 1285(1). https://doi.org/10.1088/1755-1315/1285/1/012035

Hua, T. K., Azarov, V., & Kutenev, V. (2022). Modern Invisible Hazard of Urban Air Environment Pollution When Operating Vehicles That Causes Large Economic Damage. https://doi.org/10.22541/au.166792121.16619205/v1

Iacobucci, R., McLellan, B., & Tezuka, T. (2018). Modeling shared autonomous electric vehicles: Potential for transport and power grid integration. Energy, 158, 148–163. https://doi.org/10.1016/j.energy.2018.06.024

IEA. (2020). World Energy Outlook 2020 – Analysis - IEA. https://www.iea.org/reports/world-energy-outlook-2020

IEA. (2021). Greenhouse Gas Emissions from Energy - Data product - IEA. https://www.iea.org/data-and-statistics/data-product/greenhouse-gas-emissions-from-energy

IEA. (2023, September). Road transport – Analysis - IEA. https://www.iea.org/reports/road-transport

ITF. (2017). ITF Transport Outlook 2017. https://doi.org/10.1787/9789282108000-EN

Jain, I. P. (2009). Hydrogen the fuel for 21st century. International Journal of Hydrogen Energy, 34(17), 7368–7378. https://doi.org/10.1016/j.ijhydene.2009.05.093

Kapdan, I. K., & Kargi, F. (2006). Bio-hydrogen production from waste materials. Enzyme and Microbial Technology, 38, 569–582. https://doi.org/10.1016/j.enzmictec.2005.09.015

Kindra, V., Maksimov, I., Oparin, M., Zlyvko, O., & Rogalev, A. (2023). Hydrogen Technologies: A Critical Review and Feasibility Study. In Energies (Vol. 16, Issue 14). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/en16145482

Koster, A. (2023). What Will the Dream Car of the Future Be Like? | Alex Koster | TED - YouTube. https://www.youtube.com/watch?v=TjNZhdEvVvo&ab_channel=TED

Kreuzbauer, R., & Malter, A. J. (2005). Embodied Cognition and New Product Design: Changing Product Form to Influence Brand Categorization*. Journal of Product Innovation Management, 22(2), 165–176. https://doi.org/10.1111/J.0737-6782.2005.00112.X

Lee, G., Kim, T., & Suk, H.-J. (2022). GP22: A Car Styling Dataset for Automotive Designers. http://arxiv.org/abs/2207.01760

Lee, J., Park, W., & Lee, S. (2021). Discovering the Design Challenges of Autonomous Vehicles through Exploring Scenarios via an Immersive Design Workshop. DIS 2021 - Proceedings of the 2021 ACM Designing Interactive Systems Conference: Nowhere and Everywhere, 322–338. https://doi.org/10.1145/3461778.3462119

Leonard, D., & Rayport, J. F. (2011). Spark innovation through empathic design. Managing Knowledge Assets, Creativity and Innovation, 355–369. https://doi.org/10.1142/9789814295505_0016

Liedtka, J. (2015). Perspective: Linking Design Thinking with Innovation Outcomes through Cognitive Bias Reduction. In Journal of Product Innovation Management (Vol. 32, Issue 6, pp. 925–938). https://doi.org/10.1111/jpim.12163

Lin, P. (2015). Why Ethics Matters for Autonomous Cars. Autonomes Fahren, 69–85. https://doi.org/10.1007/978-3-662-45854-9_4

Llopis-Albert, C., Rubio, F., & Valero, F. (2021). Impact of digital transformation on the automotive industry. Technological Forecasting and Social Change, 162. https://doi.org/10.1016/j.techfore.2020.120343

Lopes, J. (2024, January 27). Here Are The 2025 Chevy Equinox Specifications. https://gmauthority.com/blog/2024/01/here-are-the-2025-chevy-equinox-specifications/

Loureiro, S. M. C. (2016). Relationship Quality as a Function of Luxury Car Brand Image and Personality. Developments in Marketing Science: Proceedings of the Academy of Marketing Science, 695–699. https://doi.org/10.1007/978-3-319-19428-8_170

Lovins, A. B., & Cramer, D. R. (2004). Hypercars 1 , hydrogen, and the automotive transition. In Int. J. Vehicle Design (Vol. 35, Issue 2). www.rmi.org

Macey, Stuart., & Wardle, Geoff. (2014). H-point : the fundamentals of car design & packaging. 287. https://books.google.com/books/about/H_Point.html?hl=it&id=H_ProQEACAAJ

Mangiarotti, R. (2015). Advancedesign for product. Advanced Design Cultures: Long-Term Perspective and Continuous Innovation, 109–120. https://doi.org/10.1007/978-3-319-08602-6_8

McCormack, J. P., Cagan, J., & Vogel, C. M. (2004). Speaking the Buick language: Capturing, understanding, and exploring brand identity with shape grammars. Design Studies, 25(1), 1–29. https://doi.org/10.1016/S0142-694X(03)00023-1

McKinsey & Company. (2016). Automotive revolution – perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry. Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry

McKinsey & Company. (2020). Winning in the European Automotive Industry: A Micromarket Approach. McKinsey & Company. Retrieved from https://www.mckinsey.com.

McKinsey & Company. (2021). The Impact of COVID-19 on Future Mobility Solutions. McKinsey & Company. Retrieved from https://www.mckinsey.com.

McKinsey & Company. (2023a). McKinsey Global Energy Perspective 2023: Hydrogen Outlook. McKinsey & Compa-ny. Retrieved from https://www.mckinsey.com.

McKinsey & Company. (2023b). Spotlight on 2023: The Trends Transforming Mobility. McKinsey & Company. Retrieved from https://www.mckinsey.com.

McKinsey & Company. (2024a). Spotlight on mobility trends. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/spotlight-on-mobility-trends

McKinsey & Company. (2024b). What technology trends are shaping the mobility sector? McKinsey Center for Future Mobility. Retrieved from https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/what-technology-trends-are-shaping-the-mobility-sector

Midilli, A., Ay, M., Dincer, I., & Rosen, M. A. (2005). On hydrogen and hydrogen energy strategies: I: current status and needs. Renewable and Sustainable Energy Reviews, 9(3), 255–271. https://doi.org/10.1016/J.RSER.2004.05.003

Mindrut, S., Manolica, A., & Roman, C. T. (2015). Building Brands Identity. Procedia Economics and Finance, 20, 393–403. https://doi.org/10.1016/S2212-5671(15)00088-X

Mitchell, W. J., Borroni-Bird, C. E., & Burns, L. D. (2010). Reinventing the automobile : personal urban mobility for the 21st century. MIT press.

Monö, Rune. (1997). Design for product understanding : the aesthetics of design from a semiotic approach. 168.

My Financing USA. (2023). Statistics About Road Trips | My Financing USA. https://www.myfinancingusa.com/blog/statistics-about-road-trips/

NASA. (2024). Global Temperature | Vital Signs – Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/vital-signs/global-temperature/?intent=121

National Research Council. (2008). Transitions to Alternative Transportation Technologies: A Focus on Hydrogen. Transitions to Alternative Transportation Technologies-A Focus on Hydrogen, 1–126. https://doi.org/10.17226/12222

Oh, S., Han, Y., Nah, K., & Kwon, K. (2016). Development Direction Research Of Korean Lifestyle Brands Through Analysis For Global Lifestyle Brands - Focused On The Trend Analysis. International Business & Economics Research Journal (IBER), 15(2), 41–54. https://doi.org/10.19030/IBER.V15I2.9608

Page, C., & Herr, P. M. (2002). An Investigation of the Processes by Which Product Design and Brand Strength Interact to Determine Initial Affect and Quality Judgments. Journal of Consumer Psychology, 12(2), 133–147. https://doi.org/10.1207/S15327663JCP1202_06

Pareliussen, J. et al. (2022), "Policies to reach net zero emissions in the United Kingdom", OECD Economics Department Working Papers, No. 1742, OECD Publishing, Paris, https://doi.org/10.1787/f6625f01-en.

Patten, B. C., Fath, B. D., Choi, J. S., Bastianoni, S., Borrett, S. R., Brandt-Williams, S., Debeljak, M., Fonseca, J., Grant, W. E., Karnawati, D., Marques, J. C., Moser, A., Müller, F., Pahl-Wostl, C., Seppelt, R., Steinborn, W. H., & Svirezhev, Y. M. (2002). Complex Adaptive Hierarchical Systems. Understanding and Solving Environmental Problems in the 21st Century, 41–94. https://doi.org/10.1016/B978-008044111-5/50005-6

Penati, A. (2015). The role of humanistic disciplines in a pedagogy of advancedesign. Advanced Design Cultures: Long-Term Perspective and Continuous Innovation, 69–85. https://doi.org/10.1007/978-3-319-08602-6_5

Perkins, G., & Murmann, J. P. (2018). What Does the Success of Tesla Mean for the Future Dynamics in the Global Automobile Sector? Management and Organization Review, 14(3), 471–480. https://doi.org/10.1017/MOR.2018.31

pininfarina H2 speed at 2016 geneva motor show. (n.d.). Retrieved March 10, 2025, from https://www.designboom.com/technology/pininfarina-h2-speed-geneva-motor-show-2016-03-04-2016/

Ranscombe, C., Hicks, B., Mullineux, G., & Singh, B. (2011). Characterizing and Evaluating Aesthetic Features in Vehicle Design. ICORD 11: Proceedings of the 3rd International Conference on Research into Design Engineering, Bangalore, India, 10.-12.01.2011, 792–799. https://www.designsociety.org/publication/32424/Characterizing+and+Evaluating+Aesthetic+Features+in+Vehicle+Design

Rinaldi, M., Pertiwi, A. B., & Satyadharma, I. G. N. W. (2023). Perancangan Brand Identity Bandung Communication and Community (Bdgcom_Unity). Jurnal Informatika Ekonomi Bisnis, Diterbitkan(4), 1193–1198. https://doi.org/10.37034/INFEB.V5I4.749

Ritchie, H., & Roser, M. (2024). CO_2 emissions How much CO_2 does the world emit? Which countries emit the most? https://ourworldindata.org/co2-emissions#article-citation

Robinson, J. B. (1990). Futures under glass: A recipe for people who hate to predict. Futures, 22(8), 820–842. https://doi.org/10.1016/0016-3287(90)90018-D

Saeed, M., Marwani, H. M., Shahzad, U., Asiri, A. M., Hussain, I., & Rahman, M. M. (2024). Utilizing Nanostructured Materials for Hydrogen Generation, Storage, and Diverse Applications. Chemistry – An Asian Journal, 19(16), e202300593. https://doi.org/10.1002/ASIA.202300593

Schlapbach, L., & Züttel, A. (2001). Hydrogen-storage materials for mobile applications. www.nature.com

Schrank, D., Lomax, T., & Eisele, B. (2011). TTI'S 2011 URBAN MOBILITY REPORT. http://mobility.tamu.edu

Sharma, S., & Ghoshal, S. K. (2015). Hydrogen the future transportation fuel: From production to applications. In Renewable and Sustainable Energy Reviews (Vol. 43, pp. 1151–1158). Elsevier Ltd. https://doi.org/10.1016/j.rser.2014.11.093

Simonazzi, A., Jorge Carreto Sanginés, J., & Russo, M. (2020). The future of the automotive industry: dangerous challenges or new life for a saturated market? Institute for New Economic Thinking Working Paper Series, 1–34. https://doi.org/10.36687/inetwp141

Snyder, C. R. (2005). In Good Hands. Https://Doi.Org/10.1521/Jscp.21.2.113.22511, 21(2), 113–115. https://doi.org/10.1521/JSCP.21.2.113.22511

Spieser, K., Treleaven, K., Zhang, R., Frazzoli, E., Morton, D., & Pavone, M. (2014). Toward a systematic approach to the design and evaluation of automated mobility-on-demand systems: A case study in Singapore. Road Vehicle Automation, 229–245.

Spurling, N., Mcmeekin, A., Shove, E., Southerton, D., & Welch, D. (2013). Sustainable Practices Research Group Report, September 2013. 1 Interventions in practice: re-framing policy approaches to consumer behaviour. http://man.ac.uk/04Y6Bo]

Steinhübel, L. (1991). Urbanization, agricultural intensification, and environmental services: A spatial analysis.

Stern, N. (2007). The Economics of Climate Change: The Stern Review. The Economics of Climate Change: The Stern Review, 9780521877251, 1–692. https://doi.org/10.1017/CBO9780511817434

sustainable bus. (2021). BYD ADL delivered in London the 500th electric bus from the Enviro EV range - Sustainable Bus. https://www.sustainable-bus.com/electric-bus/500-byd-adl-electric-bus-london/

Suwa, M., Gero, J. S., & Purcell, T. A. (2022). The Roles of Sketches in Early Conceptual Design Processes. Proceedings of the Twentieth Annual Conference of the Cognitive Science Society, 1043–1048. https://doi.org/10.4324/9781315782416-188

Tao, A., Liang, Q., Kuai, P., & Ding, T. (2021). The influence of urban sprawl on air pollution and the mediating effect of vehicle ownership. Processes, 9(8). https://doi.org/10.3390/pr9081261

Teece, D. J. (2018). Tesla and the Reshaping of the Auto Industry. In Management and Organization Review (Vol. 14, Issue 3, pp. 501–512). Cambridge University Press. https://doi.org/10.1017/mor.2018.33

Tekkaya, A. E., & Min, J. (2020). Special Issue on Automotive Lightweight. In Automotive Innovation (Vol. 3, Issue 3, pp. 193–194). Springer Science and Business Media B.V. https://doi.org/10.1007/s42154-020-00117-x

Tovey, M., Porter, S., & Newman, R. (2003). Sketching, concept development and automotive design. Design Studies, 24(2), 135–153. https://doi.org/10.1016/S0142-694X(02)00035-2

Toyota Newsroom. (2024). Toyota Establishes Hydrogen Headquarters to Accelerate Advancement of Fuel Cell Technology - Toyota USA Newsroom. https://pressroom.toyota.com/toyota-establishes-hydrogen-headquarters-to-accelerate-advancement-of-fuel-cell-technology/

Triantafyllidis, S. (2018). Carbon Dioxide Emissions Research and Sustainable Transportation in the Sports Industry. C, 4(4), 57. https://doi.org/10.3390/c4040057

U.S. Department of Energy. (2024). FOTW #1333, March 11, 2024: In 2022 the Average Number of Occupants Per Trip for Household Vehicles in the United States Was 1.5 | Department of Energy. https://www.energy.gov/eere/vehicles/articles/fotw-1333-march-11-2024-2022-average-number-occupants-trip-household

US EPA. (2024, February 13). What Is CHP? | US EPA. https://www.epa.gov/chp/what-chp

Uthman Opeyemi Abdullahi, Adnan Adnan, & Abdullahi Ayobami Rafiu. (2024). Decarbonizing public transport systems in the UK: Initiatives and technologies for reducing carbon emissions. World Journal of Advanced Engineering Technology and Sciences, 13(2), 051–058. https://doi.org/10.30574/wjaets.2024.13.2.0505

Veziroğlu, T. N., & Şahin, S. (2008). 21st Century's energy: Hydrogen energy system. Energy Conversion and Management, 49(7), 1820–1831. https://doi.org/10.1016/J.ENCONMAN.2007.08.015

Veziroğlu, T. N., & Şahın, S. (2019). 21st century's energy: Hydrogen energy system. Alternative Energy and Ecology (ISJAEE), (4-6), 14-27. https://doi.org/10.15518/isjaee.2019.04-06.014-027

Wang, J., & Azam, W. (2024). Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries. Geoscience Frontiers, 15(2), 101757. https://doi.org/10.1016/J.GSF.2023.101757

Warell, Anders. (2001). Design syntactics : a functional approach to visual product form : theory, models, and methods. 271. https://books.google.com/books/about/Design_Syntactics.html?hl=it&id=mmkcNAAACAAJ

WIRED. (2002). GM's Hy-Wire Brakes Driving Mold | WIRED. https://www.wired.com/2002/09/gms-hy-wire-brakes-driving-mold/

World Health Organization (WHO). (2023a). World Health Statistics 2023: Monitoring Health for the SDGs, Sustainable Development Goals. Geneva: World Health Organization. License: CC BY NC SA 3.0 IGO.

World Health Organization (WHO). (2023b). Global Status Report on Road Safety 2023. Retrieved from https://www.who.int/teams/social-determinants-of-health/safety-and-mobility/global-status-report-on-road-safety-2023

World Health Organization (WHO), (2024a). World Health Organization 2024 data.who.int, WHO Coronavirus (COVID-19) dashboard > Deaths [Dashboard]. https://data.who.int/dashboards/covid19/deaths

World Health Organization (WHO). (2024b). Ambient (outdoor) air pollution. World Health Organization (WHO). https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

Wu, Y., Ma, L., Yuan, X., & Li, Q. (2023). Human-machine hybrid intelligence for the generation of car frontal forms. Advanced Engineering Informatics, 55. https://doi.org/10.1016/j.aei.2023.101906

Xiang, L. J., Dai, L., Guo, K. X., Wen, Z. H., Ci, S. Q., & Li, J. H. (2020). Microbial electrolysis cells for hydrogen production. Chinese Journal of Chemical Physics, 33(3), 263–284. https://doi.org/10.1063/1674-0068/cjcp2005075

Yang, J. (2019). The Impact of Urbanization Process on Civil Car Ownership in China.

Yang, W., Su, J., Zhang, S., Qiu, K., Su, P., & Zhang, X. (2020). Research on the intelligent design of the multidimensional form of a product under a brand cobweb constraint. International Journal of Arts and Technology, 12(4), 352–374. https://doi.org/10.1504/IJART.2020.112648

Yu, S., Fan, Y., Shi, Z., Li, J., Zhao, X., Zhang, T., & Chang, Z. (2023). Hydrogen-based combined heat and power systems: A review of technologies and challenges. In International Journal of Hydrogen Energy (Vol. 48, Issue 89, pp. 34906–34929). Elsevier Ltd. https://doi.org/10.1016/j.ijhydene.2023.05.187

Zhang, B., & Wu, Y. (2017). Recent advances in improving performances of the lightweight complex hydrides Li-Mg-N-H system. In Progress in Natural Science: Materials International (Vol. 27, Issue 1, pp. 21–33). Elsevier B.V. https://doi.org/10.1016/j.pnsc.2017.01.005

Zhang, W., Guhathakurta, S., Fang, J., & Zhang, G. (2015). Exploring the impact of shared autonomous vehicles on urban parking demand: An agent-based simulation approach. Sustainable Cities and Society, 19, 34–45. https://doi.org/10.1016/J.SCS.2015.07.006