ZERO-EMISSION SOLUTION FOR A SMART MOBILITY HUB

MARKUS SIHVONEN & HANNA TAKALA
Häme University of Applied Sciences (HAMK), Finland

ABSTRACT
The road transport industry is facing increasing pressure to reduce its carbon footprint and transition towards eco-friendly solutions. One prominent approach has been the adoption of alternative energy sources for heavy vehicles, with electric trucks emerging as the most promising option due to their reduced emissions, lower fuel costs and improved performance. Concurrently, governments are introducing policies and directives aimed at significantly decreasing CO_2 emissions caused by road transport, often favouring the implementation of smart mobility hubs (SMH) as a means to mitigate the negative impact of road traffic on cities. In line with this movement, the MORE Industrial Park, a major SMH in southern Finland, is pursuing a development strategy to transform into an eco-industrial park with a mission to achieve an emission-free zone. This paper aims to propose a zero-emission first-/last-mile road transportation strategy for the MORE Industrial Park, which serves as a critical SMH for local industries in Hämeenlinna and Janakkala, Finland. The proposed solution suggests utilizing the latest ICT technologies, electric power trains, and the Mobility as a Service concept for sustainable mobility and logistics. The solution seeks to contribute to a greener and more efficient road transport industry in the region.
Keywords: smart mobility hub, sustainable mobility, CO_2-free transport, battery electric.

1 INTRODUCTION

The transport industry is experiencing a storm-like transition period. Digital technologies are changing how we see mobility and how goods and people will be transported in the very near future. The ever-faster, forward-moving climate change imposes strict zero-emission requirements for the vehicles we use in the logistic industry and in our everyday commutes. It is obvious that the smart mobility hubs (SMHs) that host needed technology enablers for easy and sustainable mobility are becoming important enablers for future transportation systems. A service platform hosted by an SMH brings new innovative mobility services for logistic and mobility users. It utilises the latest communication technologies to collect the needed mobility-related data, which is the base building block for the services. Whenever required, an SMH will be capable of enhancing mobility services by big data.

For an SMH to really benefit from new technologies, it must provide an infrastructure that integrates various technologies and services to enable efficient and sustainable mobility. It must provide fuelling capabilities for new, rapidly growing zero-emission vehicles used to provide mobility and logistic services. It should have capabilities to utilise smart road infrastructure that provides real-time mobility data. An SMH's infrastructure should support easy adaptability of forthcoming new technologies and services to ensure its feasibility for its community in the future.

The aim of the MORE Industrial Park is to achieve certified sustainable industrial park status. To reach that goal, companies and organisations in that area must have similar goals. Therefore, they should integrate circular economy principles into their operations, as well as using green energy and CO_2-free logistic services.

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2 SMART MOBILITY HUB

An SMH is in a centralised location, and it includes a virtual platform that integrates various smart and sustainable transportation services and technologies. It is seamlessly integrated into an urban environment by making it easily accessible. You can usually find it in key transportation nodes, city centres or commercial districts. It is a key component for multimodal transportation systems, information sharing, and it provides seamless connectivity for travellers and parcels. An SMH brings together multiple transportation modes into a single location. It prioritises sustainable transportation options by promoting sustainable mobility, such as the use of electric vehicles and zero-emission public transportation. It has a virtual platform that hosts services that enable travellers to easily access and switch between different modes of transportation based on their needs. SMH-hosted services will provide real-time information about transportation options, schedules, routes, traffic conditions and the availability of vehicles needed to complete the desired trip. Travellers can access this information via mobile apps or digital displays on well-equipped SMHs. An SMH enables seamless connectivity with other transportation systems and networks, including efficient logistic services. An important part of the seamless travelling experience is simple and easy payment and ticketing process. An SMH's virtual platform's service portfolio should include an integrated payment system for integrated multimodal transportation services. It eliminates a need for separate tickets and payment transactions for each mode of transport. An SMH's crucial task is to provide information for travellers with real-time updates, travel planning assistance and customised travel recommendations based on their preferences and travel patterns. Better-equipped SMHs will also offer wi-fi connectivity, rest areas, food and beverage options, parcel delivery services and customised services for high-capacity transport (HCT) vehicles [1].

2.1 SMH Service platform

The service platform is a digital infrastructure or framework that enables a deployment, management and usage of mobility services and applications. It facilitates integration of different mobility services and applications for seamless communication and data exchange [2]. This is the key capability for enabling interoperability among hosted mobility and logistic services. The service platform contains capabilities for an administrator to manage and monitor service discovery, version management, access control, security, performance monitoring and resource allocation. They are scalable and adaptable, allowing for the expansion of services and changing demands of mobility service users or local legislation. Most importantly, a service platform provides mechanisms for scaling up or down its resources based on usage patterns and enables a simple inclusion of new third-party mobility services. Therefore, an SMH service platform fosters a mobility ecosystem that provides framework for collaboration, partnership and innovation for local governments, companies and people.

2.1.1 Data

An SMH service platform collects data utilising various Internet of Things (IoT) technologies and networks. The IoT network can be used locally for mobility data collection or to collect mobility-related data nationally or even globally. A source and type of collected data depends on the intended end use of the data. Once the needed data is available in the service platform, various data analytic techniques are utilised to further analyse it. Information that is sought from the collected data can be, e.g., travel patterns, mobility user behaviour patterns and demand for mobility services at a specific time. Collected data can be used to optimise mobility operations, improve service quality experienced for a mobility user and identify development issues in an SMH. A service platform should support data-driven decision-making. Therefore, it can provide multiple delivery channels for data and services, such as the web, mobile apps and IoT devices. Since it enables deployment of mobility services across different platforms and devices, it ensures a consistent and optimised mobility service user experience.

2.1.2 Communication technologies

An SMH's service platform should support fast and reliable communication technologies, including high-quality data security solutions. It should have long-range communication capabilities offered by optic fibre solutions and 5G mobile networking technologies. Most common IoT networks should be supported to acquire IoT data, both nationally and globally. These are NB-IoT (narrowband IoT), LoRaWAN (long range wide area network), Sigfox and LTE-M (long-term evolution for machines).

NB-IoT devices can operate on a single battery charge for several years. The NB-IoT network has better communication range that cellular networks, such as 4G or 5G. It has a good material penetration capability, and it has security capabilities such as authentication and encryption of data. NB-IoT devices are very well suited for collecting raw environmental mobility data in congested areas and inside buildings [3].

The LoRaWAN technology is capable of transmitting data over several kilometres in open areas. LoRaWAN IoT devices can operate on batteries for several years, as well. Devices have low data rates, ranging from a few bytes to a few kilobytes per transmission. It has security features, such as end-to-end encryption, device authentication and data integrity checks. The LoRaWAN technology is well suited for collecting simple measurement readings, such as tracking assets or parcels in a smart city environment [4].

The Sigfox is a low-power, wide-area network (LPWAN) technology, designed for connecting IoT devices over long distances. It provides a global network infrastructure that enables devices to communicate with each other and with the cloud. A Sigfox device can operate several years on a single battery charge. Since it has truly global coverage, multiple roaming agreements are not needed. The Sigfox network operates on licensed spectrum and has its own proprietary network infrastructure. It has low data rates and typically up to 140 bytes per message. This is sufficient for global asset tracking applications in logistic services [5].

The LTE-M is a LPWAN technology, as well. It is a variant of the 4G LTE cellular network that is specifically designed for IoT applications. It has higher data rates, up to 1 Mbs, compared to many other LPWAN technologies. Therefore, it is suitable for mobility use cases that require real-time or near-real-time data transfer. It has encryption, authentication and other security features to safeguard data and prevent unauthorised access. The LTE-M network is a suitable solution for services that require a relatively high amount of data uploaded to the service platform, e.g., low resolution video [3].

An SMH service platform should be easily expandable by new, yet to emerge technologies such as the forthcoming 6th generation (6G) of mobile communication technology and new artificial intelligent (AI) solutions. The 6G technology will bring very fast vehicle-to-vehicle and vehicle-to-X communication capabilities, up to terabit-per-second (Tbps) data transfer speeds, extremely low latencies of 1 millisecond or less. Additionally, it will provide much greater capacity to support billions of connected devices, more efficient use of the spectrum and network resources, enhanced security and privacy features, and improved support for emerging technologies, such as quantum computing, holographic communications and satellite-based communications [6]. New AI solutions provide enhanced means to analyse vast amounts of collected mobility data, which enables new mobility service innovation.

2.2 Infrastructure

The purpose of an SMH infrastructure is to make it easy to combine various modes of transportation in a sustainable manner. It aims to improve transportation options, reduce congestion and enhance the overall user experience. It utilises the very latest technologies and services to achieve its intended goals. Since it facilitates seamless transfers between different sustainable modes of transportation, it provides well-designed interchanges and convenient access points to enable smooth transitions for travellers and parcels. For a true mobility as a service (MaaS) system, integrated, one-stop ticketing and payment systems are crucial. It allows users to purchase tickets and access multiple transportation services with a single payment method. An SMH promotes the use of zero-emission vehicles as well as the transition to zero-emission mobility. This is done by providing charging stations for EVs and alternative fuels for internal combustion engines. Also, new innovations, such as infrastructure for bicycle-sharing programmes, dedicated cycling lanes and pedestrian-friendly street design principles, are applied. An SMH should provide smart parking services and a system with its economic area that helps users find available parking spaces in real-time. In short, a sustainable user-centric approach is crucial in designing and building an SMH [1].

Often, an SMH is a key provider of logistic services for a given region. It ensures efficient, sustainable first- and last-mile package delivery. Importantly, it is a channel for the local industry to deliver their products to national and global clients. Therefore, an SMH must serve heavy transport, such as HCT vehicles. They depend on appropriate physical infrastructure and systems to support their operation. This includes highways, bridges, rest areas, weigh stations and other facilities designed to meet the unique needs of these large vehicles. Heavy-duty trucks rely on well-maintained roads and highways to travel safely and efficiently over long distances, including dedicated truck lanes and bypasses designed specifically to accommodate these large vehicles. Heavy-duty electric trucks need charging hubs along core routes, including both fast-charging and overnight charging hubs. Hydrogen- and gas-powered heavy-duty vehicles would need their own fuelling stations, as well as specific transportation and storage facilities required by the nature of these fuels [7].

3 FUEL FOR SMART VEHICLES

Traditionally, diesel has been the de facto fuel for heavy vehicles of every kind, because it is more energy-dense than gasoline. Also, lighter vehicles, in many cases, have favoured diesel engines due to their benefits over gasoline engines. Diesel engines are more efficient than gasoline engines, resulting in lower fuel costs. Because they are built specifically for heavy-duty use, diesel engines are well suited for heavy vehicles and vehicles that are used excessively. Unfortunately, diesel engines emit high levels of nitrogen oxides (NO_x), particulate matter (PM) and carbon dioxide (CO_2) [8]. NO_x emissions contribute to the formation of smog and acid rain and aggravate respiratory conditions, such as asthma. NO_x emissions are also major contributors to eutrophication, a process that occurs in bodies of water that are over-enriched with nutrients. Eventually, this leads to excessive growth of plants and algae, which reduces oxygen levels in the water [9]. When PM particles are inhaled into the lungs, they cause respiratory conditions, such as asthma and chronic obstructive pulmonary disease (COPD). Long-term exposure to PM can increase risk for heart disease and lung cancer [10]. Additionally, CO_2 is the primary greenhouse gas.

Clearly, finding new environmentally friendly fuels for vehicles of any kind is important. Currently, the mobility services and transportation sector are facing environmental, economic and energy challenges. The transportation industry must become environmentally sustainable. Potential new energy solutions for next-generation vehicles include bio diesel, natural gas, hydrogen and battery-electric fuel alternatives.

3.1 Biodiesel

Biodiesel is a type of diesel fuel made from renewable biomass sources, such as vegetable oils and animal fats. It is considered more environmentally friendly than traditional diesel fuel, which is made from non-renewable fossil resources. Biodiesel can be used in diesel engines without any modification. It can also be blended with traditional diesel fuel to create a lower-emissions blend. Biodiesel generally emits less particulate matter, sulphur oxides or hydrocarbons than traditional diesel. It also has a lower carbon footprint than traditional diesel, because the carbon dioxide it releases is absorbed by the biomass used to make it. However, biodiesel also contributes to environmental issues: for example, feedstock cultivation for biodiesel production contributes to deforestation and loss of wildlife habitats and can release pollutants into the air and water courses. Therefore, biodiesel's environmental impact depends on how it is produced and used [11].

3.2 Natural gas

Liquified natural gas (LNG) and compressed natural gas (CNG) are cleaner-burning alternatives to diesel, and gas trucks are also often less expensive to operate than diesel trucks. However, they require special storage and dispensing equipment, and the infrastructure for fuelling gas vehicles is not available in all practical means. While natural gas is considered cleaner than diesel, because it emits less CO_2 when burned, it is still a fossil fuel. Also, its extraction and transportation cause negative environmental impacts. The process of natural gas extraction releases methane, which is a very powerful greenhouse gas that has a much greater atmospheric warming effect than CO_2 [12].

3.3 Hydrogen

Vehicles that run on hydrogen fuel emit only water vapour as exhaust. It is created by extracting hydrogen from sources that include natural gas and water. There are several methods for extracting hydrogen, and they have very different environmental impacts.

In the steam methane reforming (SMR) method, methane (CH_4) reacts with steam (H_2O) to produce carbon monoxide and hydrogen (H_2). This is currently the most common method of large-scale hydrogen fuel production because of its high efficiency, relatively low cost and well-established technology. Unfortunately, it also has some major drawbacks, including emissions of CO_2, a greenhouse gas produced during the process [13].

The electrolysis method uses electricity to split water (H_2O) into hydrogen and oxygen (O_2). This is considered a clean and renewable way of producing hydrogen fuel if the electricity is produced by windmills or solar panels. However, this method of hydrogen production is energy-thirsty and can be relatively expensive [14].

The gasification method converts carbon-containing materials at high temperatures into carbon monoxide (CO), hydrogen and CO_2. One of the main benefits of gasification is that it can be used to convert a wide range of carbon-containing materials into useful products. It is considered a clean and sustainable method of producing hydrogen fuel because it uses biomass. It is a renewable resource, and CO_2 is consumed by plants as part of their natural growth process. Gasification technology is still in development and must resolve challenges that include high capital costs and low efficiency [15].

The photoelectrochemical method uses sunlight to split water into hydrogen and oxygen. This is a promising way of producing hydrogen fuel, but it is still in the research and development stage. The biological processes method utilises certain microorganisms to produce hydrogen. This method is still in the early stages of development but has the potential to become a sustainable way of producing hydrogen fuel [16].

A drawback of hydrogen fuel is in its complexity in storing. It must be compressed, liquefied or solidified for storage and transport to the point of use. As hydrogen is a highly compressible gas, it occupies a large volume at low pressures, making it challenging to store in large quantities. Compared to diesel, hydrogen fuel has a relatively high energy content. However, because of its low energy density, it takes a much larger volume of hydrogen to store the same amount of energy as diesel or natural gas. This makes it less cost-effective and more challenging to store and transport hydrogen in large quantities. Additionally, hydrogen is extremely flammable. Hydrogen storage requires expensive specialised infrastructure, such as high-pressure or cryogenic tanks. For these reasons, hydrogen cannot easily be used in small portable containers [17].

3.4 Battery electric

Future expectations for battery technologies revolve around increasing the average size of batteries, which would enable better performance and longer range per charge [18]. Furthermore, there is a growing focus on developing more sustainable battery materials in response to environmental concerns related to raw material mining and refining, geopolitical issues and limited material availability [19]. New battery structures, such as those integrated into the vehicle's structure, have emerged as rising trends in the industry, offering the advantage of requiring fewer materials and components [20], [21].

Existing liquid electrolyte lithium-ion batteries are the most widely used battery technology today because of their high energy density and long cycle life. Yet, research is ongoing to improve their energy density and safety capabilities. By the end of 2022, lithium-ion batteries had an energy density of about 500–700 Wh/litre [22].

Although traditional liquid electrolyte lithium-ion batteries currently dominate the battery technology, there are new potential battery technology alternatives in active development that will dramatically increase the performance of commercial batteries in the near future. These alternatives include solid-state, lithium-sulphur and lithium-oxygen batteries, all of which can offer advantages in terms of price, energy density, material availability and increase in lifecycle compared to existing commercial lithium-ion batteries [19].

Solid-state batteries are considered to be a very promising next-generation commercial battery technology. Rather than the liquid electrolyte found in existing lithium-ion batteries, they use a solid electrolyte, which can easily double the battery's energy density and increase its safety. They will also have a longer lifespan and better performance at high and low temperatures. When used in electric vehicles, a solid-state battery can outlive life span of an entire vehicle.

Lithium-sulphur batteries offer a high energy density that is about five times higher than existing commercial lithium-ion batteries. Unfortunately, current lithium-sulphur batteries cannot sustain many recharging cycles [23].

Lithium-oxygen battery technology has the potential to increase energy density of a battery as well. The technology involves using lithium metal as the anode and ambient air as the cathode. The oxygen from the air combines with lithium ions to form lithium peroxide (Li_2O_2) during the discharge process. During charging, the reverse reaction occurs, converting the lithium peroxide back to lithium ions and releasing oxygen back into the air [19].

4 CONCLUSION

In conclusion, the MORE Industrial Park's transformation into an eco-industrial park with a mission to become a zero-emission zone requires a well-defined and comprehensive strategy. The paper proposes a zero-emission first-/last-mile road transportation strategy to achieve sustainable mobility, with the smart mobility hub (SMH) at its core. This strategy encompasses the adoption of electric trucks, utilization of biodiesel, development of charging infrastructure and advanced ICT technologies.

Electric trucks powered by battery-electric energy represent the most promising zero-emission solution for heavy-duty vehicles in regions with established electric power grids. The rapid advancement of battery technology, including next-generation solid-state batteries, offers increased energy density and longer battery life cycles, making electric heavy-duty vehicles more viable than ever before. Therefore, the short- and long-term strategy for the MORE Industrial Park should prioritize the development of charging infrastructure and services for electric vehicles.

For less developed regions or areas lacking a well-developed electric power grid, biodiesel presents a cleaner and sustainable alternative to conventional fuels. Its compatibility with existing diesel engines and distribution networks makes it a practical solution for reducing mobility-related CO_2 emissions during the transition to electrified mobility and logistic services. Consequently, the short-term transition period strategy for the MORE industrial park should involve maintaining existing diesel fuel infrastructure while restraining the development of new infrastructure.

In addition to sustainable energy sources, the success of the smart mobility hub heavily relies on advanced ICT infrastructure and services. Embracing the latest digital and communication technologies, an SMH should establish a service platform capable of collecting comprehensive mobility data and leveraging cutting-edge AI solutions for analysis. This seamless and efficient logistics approach aims to make transportation safe, easy and sustainable, reflecting the core objectives of the MORE Industrial Park's development strategy.

In summary, the development strategy of the MORE Industrial Park must focus on the following key components:

- Maintenance and support of existing diesel fuel infrastructure to cater for biodiesel adoption.
- Enabling the utilization of biodiesel in heavy trucks to reduce dependence on fossil fuels.
- Development of robust charging infrastructure for electric vehicles to accelerate their adoption.
- Establishment of an advanced digital platform for collecting and sharing mobility data with third-party service developers.
- Innovating and developing new mobility services by applying MaaS concept fully.
- Continuous development of the latest ICT infrastructure and technologies to support a smart and sustainable mobility ecosystem.

By embracing these elements in the strategic plan, the MORE Industrial Park can pave the way for sustainable mobility and set an example for other regions seeking to reduce the carbon footprint of road transport. The combination of zero-emission road transport, SMH, and MaaS concept reinforces the potential of this solution to make a significant positive impact on urban environments and create a greener and more sustainable future for transportation and logistics.

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