

# East Asian Transportation

## Icebreaking into a low carbon future

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The energy transition paradigm consists in a substitution of fossil energy for renewable resources, and low carbon transportation is one of the most important issues within this process. The oil century introduced modern mobility to society and since then petroleum supply has been a key to control transportation services. Energy security and environmental issues, as well as business aspects of implementing innovative technological chains at national and international levels, are major drivers for decarbonisation of transportation services for East Asian economies. Policy, institutions and technological patterns toward lower carbon footprints for the transportation sector are overviewed in this article. The emphasis is on hydrogen technologies, the corresponding drivers and the ambitions of industrialised East Asian economies to establish hydrogen infrastructure at a national level. The major factors for hydrogen technologies and hydrogen infrastructure developments in China, Japan, South Korea and Taiwan are briefly discussed. The role of road transportation systems in such development is highlighted. Current energy consumption for transportation is described, some official documents are reviewed and a snapshot of recent developments is provided for each of these economies.

### 1. Introduction

Decarbonisation of transport relates to the structure of energy consumption in the transport sector, unless vehicle-mounted carbon capturing devices are considered. The structure of primary energy consumption in the world and final energy demand for transportation services in 2016 are shown in **Figure 1**. Obviously, the main pattern for transport decarbonisation is associated with substitution of petroleum for other energy carriers with lower carbon footprints. Such energy carriers are gas (primarily methane), electricity and hydrogen. Vehicles utilising the last two types of energy as input, provided that hydrogen is used as fuel for fuel cells (FCs), are called zero emission vehicles (ZEVs). However, it is necessary to take into account the origin of these energy carriers, since their source could be coal, oil or natural gas. The ultimate solution to the issue of transport decarbonisation is complete electrification of transport, including the use of so-called 'green' electricity and hydrogen, i.e. those originated from

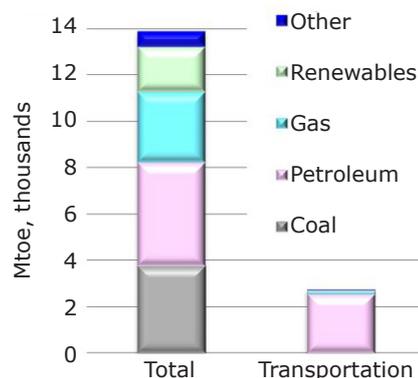


Fig. 1. World energy consumption in 2016. Mtoe = millions of tonnes of oil equivalent (1). IEA, All rights reserved

renewable or nuclear energy. The fact that water vapour has global warming potential is beyond the scope of the topic under discussion.

Transport decarbonisation patterns have several aspects: social, economic, technological and institutional. The social aspect is affected by fears of future crude oil supply exhaustion and anthropogenic impact on the environment. The economic drivers are profit-making for vehicle manufacturing and energy supply businesses and value-added ambitions for national governments, including substitution of energy import by establishing domestic innovative energy technology chains. The technological aspect relates to maturing and commercialisation of technologies for more effective utilisation of traditional fuels and the 'green' production, transportation and storage of electricity and hydrogen. The institutional factor refers to the regulatory mechanisms to reduce greenhouse gas (GHG) emissions associated with passenger and cargo traffic by all transportation modes, both at national and international levels. Other issues of technological and comparative socio-economic assessments of transport systems involving the shift from petroleum to gas fuel, improvements in vehicles' energy efficiency, introduction of biofuels, carbon capturing systems and rationalisation of transport services remain outside the scope of this article. Aspects of transport decarbonisation, related to the creation and development of hydrogen technologies in the industrialised economies of East Asia in recent years, will be considered further.

## 2. East Asian Economies as Forerunners

The East Asian economies of Japan, South Korea, China and Taiwan are among the global leaders in a number high-technology industries. More than half of cars, buses, trucks and more than 90% of newbuild ships in the world are produced in these economies (Figure 2 and Figure 3), and they hold significant share of the world's electric vehicles stock and sales, including infrastructure for charging battery electric vehicles (BEVs), see Table I and Table II. The industrial might of East Asian countries combined with energy resource shortage has led to their overwhelming dependence on coal, oil and gas imports. Taiwan, Japan and South Korea are characterised by extreme dependency on energy imports (Figure 4), while China is the world's largest energy importer (Figure 5).

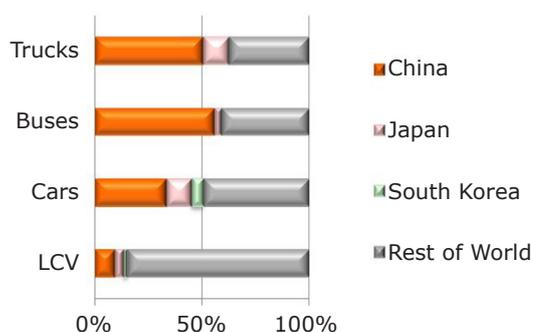


Fig. 2. World's vehicle production by major type and country of manufacturing, 2018 (2)

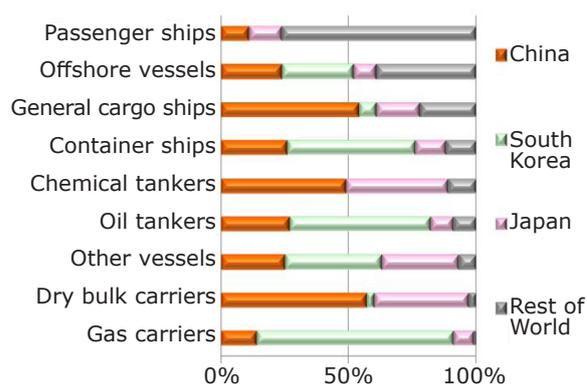


Fig. 3. Deliveries of new ships by major vessel type and countries of construction, 2017 (3)

The carbon footprint of transportation systems is usually measured from 'tank to wheel', i.e. GHG emissions from fuel and energy stored on-board the vehicle. Following this approach a BEV is considered a ZEV even in cases where the electricity stored in its battery is produced from coal or gas. However, 'tank-to-wheel' GHG emission is an important metric when strictly defined common transportation systems like roads, aviation, water and railways are considered. The respective share of these modes within the total final energy consumption for transport in four East Asian economies in 2016 and their share by energy consumed are shown in Table III.

The per capita GHG emissions from domestic transportation, and particularly those of road vehicles in South Korea, Taiwan and Japan are significantly higher than the world's average GHG emissions (Figure 6). As the International Energy Agency (IEA)'s report shows (7), the GHG emissions due to international bunkering are relatively small in comparison to domestic transportation emissions. However, it seems that a significant part of such emissions, induced by international marine and aviation traffic originated

**Table I Electric Car Stock and Sales in 2018 (4)<sup>a</sup>**

	World	China	Japan	South Korea	Share of China, Japan and South Korea in the world %
	millions				%
<b>Electric car stock (BEV and plug-in hybrid electric vehicle (PHEV))</b>	5122	2306	255	60	51
<b>Electric light commercial vehicle (LCV) stock (BEV and PHEV)</b>	244	138	8	–	60
<b>New electric car sales (BEV and PHEV)</b>	1975	1079	50	34	59
<b>New electric LCV sales (BEV and PHEV)</b>	80	54	0	–	68

<sup>a</sup> IEA, All rights reserved

**Table II Electric Vehicle Supply Equipment Stock in 2018 (4)<sup>a</sup>**

	World	China	Japan	South Korea	Share of China, Japan and South Korea in the world %
	Units				%
<b>Publicly accessible chargers (slow and fast)</b>	538,609	275,000	29,971	9303	58
<b>Publicly accessible slow chargers</b>	395,107	163,667	22,287	5394	48
<b>Publicly accessible fast chargers</b>	143,502	111,333	7684	3910	86

<sup>a</sup> IEA, All rights reserved

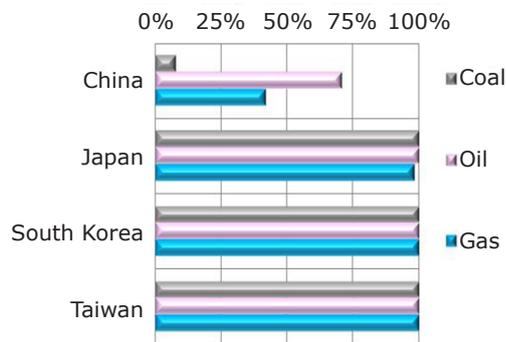


Fig. 4. Energy import dependency of East Asian economies in 2018 (5)

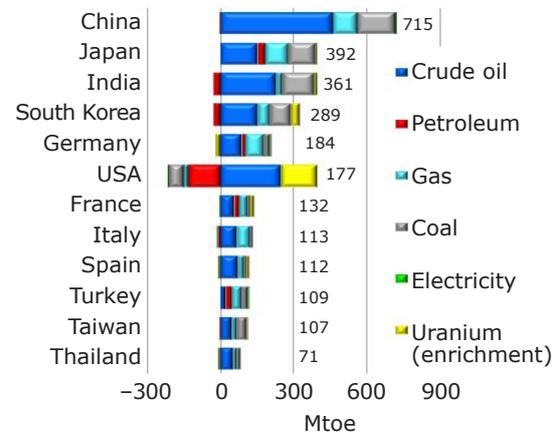


Fig. 5. Top 12 net energy importers in 2018 (5)

in East Asia, is attributed to the countries proportionally to the traffic within their economic zones, not by the site of actual fuel bunkering. This shows a strong link between international initiatives for GHG emissions reduction and energy policy drivers for the development of low-carbon technologies for mobile energy systems in East Asian economies.

It is clear that shifting from petroleum to natural gas and electricity will lead to lower carbon footprints. Electrification eventually will end up in zero 'tank-to-wheel' GHG emissions.

Importantly, vehicle electrification could be based on two approaches: (a) electricity generated outside the vehicle; and (b) electricity generated on board. The latter implies existence of fuel storage, electricity generator and power transmission within a single vehicle. If such a transport vehicle (ship, aircraft, locomotive, road or off-road vehicle) is fuelled by 'green' hydrogen or electricity, it is a true ZEV under the 'well-to-wheel' terms.

**Table III The Structure of Energy Consumption in East Asia<sup>a</sup> by Transportation Modes in 2016 (6)**

Indicator	Petroleum, Mtoe	Gas, Mtoe	Electricity, Mtoe	Total, Mtoe	Share by mode, %
<b>All modes</b>	397	29	13	439	100
<b>Road</b>	293	29	5	326	74
<b>Air<sup>b</sup></b>	51	–	–	51	12
<b>Water<sup>b</sup></b>	50	–	–	50	11
<b>Rail</b>	4	–	8	12	3
<b>Share by energy, %</b>	90	7	3	100	–

<sup>a</sup> Includes China, Japan, South Korea and Taiwan

<sup>b</sup> Includes international bunkering for aircraft and ships

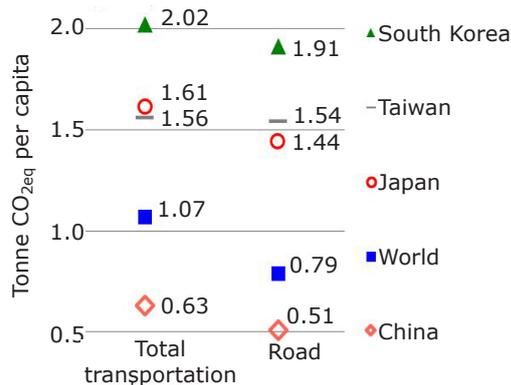


Fig. 6. The intensity of GHG emissions in East Asia in 2017 (7). Data sources: UN and IEA

East Asia is already a leader in FC electric vehicle (FCEV) production. Currently, there are more than 11,000 FCEVs in the world, and while most FCEVs are used in the USA, up to 85% of them have been produced in East Asia (8). East Asian economies are characterised by the widespread use of light vehicles for individual movement, such as mono-, bi- and tricycles, mopeds and motorcycles, thus different types of battery and FC scooters are under development (9).

Despite extensive railway electrification in East Asia, FC locomotives are being designed in Japan and South Korea. International aviation will not be a priority for the implementation of hydrogen technologies, while electric propeller aircrafts and drones could be powered by FC. Recent advances in liquefied natural gas (LNG) fuelled ships and its combination with FC technologies will bring new impetus to low-carbon powertrain development for water transport systems.

Electrification is the main option for ultimate decarbonisation for all types of transportation systems. The trends of transport electrification are determined by advances in storage of electricity

and hydrogen, and by improvements in onboard powertrain (the efficiency of the transformation of stored energy into mechanical work) for these types of energy carriers.

The *Johnson Matthey Technology Review* provides significant contribution to the FC and car batteries technologies development, which is recorded in the issue on the occasion of the 200th anniversary of the journal (10, 11).

Road vehicles are ideal for the development of hydrogen and electric battery technologies because:

- the lifespan of such vehicles is relatively short
- the vehicle cost is relatively low
- the share of the powertrain cost in total vehicle cost is higher
- requirements for weight compactness are much tighter than for ships, locomotives and aircraft
- learning experience is quickly gained for technologies and safety procedures due to the car fleet’s long operating hours
- the availability of hydrogen infrastructure for general use (shared with buildings and industry).

The main advantages of hydrogen technologies over those based on batteries are higher gravimetric density of onboard energy storage and the speed of vehicle refuelling (Table IV). Similar to battery-based transportation systems, progress in FC technologies needs intensive hydrogen infrastructure development.

The commercialisation of FCEVs and introduction of hydrogen infrastructure will lead to the creation of hydrogen mobility energy systems, the ultimate stage for all carbonless non-catenary electrified transportation modes. It is the start of the process of transitioning energy systems to full independence from fossil fuels.

The most worked out concept for a sustainable circular society within East Asian economies has

**Table IV Comparison of Fuel Cell Electric Vehicle and Battery Electric Vehicle Technologies in Terms of Mobility (12–14)**

Indicator	Tesla Roadster (BEV)	Toyota Mirai (FCEV)
<b>Weight</b>	Electric battery, 450 kg	2 tanks (~5 kg of H <sub>2</sub> @ 70 Mpa) = 128 kg; FC 114 kW = 56 kg
<b>Energy stored on board</b>	53 kWh	167 kWh
<b>Energy efficiency (at the wheel)</b>	96%	43% (LHV <sup>a</sup> )
<b>Gravimetric energy density of the energy delivered</b>	113 Wh kg <sup>-1</sup>	390 Wh kg <sup>-1</sup>
<b>Refuelling time</b>	Hours (tens of minutes for urgent charging)	3–5 min (routine procedure)

<sup>a</sup> LHV = lower heating value

Comprehensive strategy for establishing a sustainable circular society (three pillars and examples of relevant technologies)

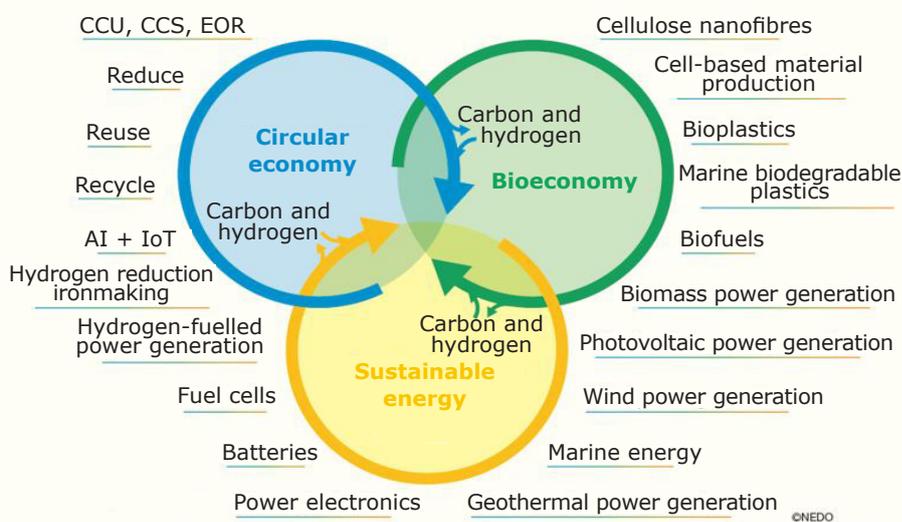


Fig. 7. The concept for a sustainable circular society in Japan, where hydrogen is instrumental as new energy carrier. CCU = CO<sub>2</sub> capture and utilisation; CCS = CO<sub>2</sub> capture and storage; EOR = enhanced oil recovery (injection of CO<sub>2</sub> to enhance oil production combined with CCS); AI = artificial intelligence; IoT = internet of things (15). Copyright NEDO

been developed in Japan (Figure 7) (15). Hydrogen technologies are an integral part of this concept, which introduces hydrogen as a new energy carrier 'electrofuel' (8), fungible to electricity.

Japan acts as an international icebreaker, capturing leadership positions in hydrogen energy systems development at a national level. This East Asian economy provides an example of energy institutions' reformation to decarbonise transportation by substituting petroleum for hydrogen. At the summit of the G20 leaders in Osaka in June 2019, the report "The Future of Hydrogen: Seizing Today's Opportunities" was presented (8). The report was prepared by the IEA on behalf of the Government of Japan.

The energy supply framework and policy drivers to reduce carbon intensity in the transport sector for China, Japan, South Korea and Taiwan will now be reviewed. Since the topic for discussion on

technological and institutional options to reduce carbon footprints of transport services in East Asia is very broad, the study will focus on programmes for hydrogen technologies and related institutional developments.

### 3. China

#### 3.1 Energy Consumption and Transportation Sector

Coal and crude oil occupied 66% and 20%, respectively, of China's total primary energy supply in 2016. The share of natural gas was only 6%, and the same niche was occupied by renewables. In 2016 the country imported 68% of crude oil and 36% of natural gas consumed (6). According to China's energy strategy, by 2030 at least 20% of primary energy supply should be provided by

renewables, and GHG intensity of gross domestic product (GDP) should be 60–65% lower than the 2005 level (16).

China’s road transport leads fuel consumption within the transportation sector, followed by aviation and water transport (Table V). The transport sector consumed 10% of the country’s total primary energy supply (6) and produced 844 million tonnes of GHG emissions in 2016 (9% of total anthropogenic GHG emissions in China in that year), including 698 million tonnes from road transportation. International marine and aviation traffic added another 31 million tonnes and 26 million tonnes of GHG emissions, respectively (7).

Diesel, gasoline and natural gas are the main types of fuel for road transport in China. Noteworthy, the role of vehicles using natural gas, the most carbon-efficient fossil fuel, is visible in the structure of fuel consumption and the structure of vehicle park by fuel type (Table VI). A good potential for fuel switching and decarbonisation exists in rail transport, such as railway electrification and introduction of LNG and hydrogen locomotives. However, the role of coal in electricity generation should be taken into consideration if ‘well-to-wheel’ carbon emissions for transportation are accounted, as the share of this carbon-intensive fuel in power plants energy mix is more than two-thirds (6).

### 3.2 Institutions

The National Development and Reform Commission under the State Council is a government institution responsible for energy strategy and the development of five year energy plans. The policy of promoting transport decarbonisation is conducted on a national level by The Ministry of Industry and Information Technology, Ministry of Commerce, Ministry of Ecology and Environment and the National Energy Administration. Provincial and municipality governments have similar bodies in charge of developing and conducting decarbonisation policy at their levels. In 2018 the China Hydrogen Alliance was established by state-owned China Energy Investment Corporation and 18 other sponsors. The aim is to enhance the development of China’s hydrogen sector by providing policy advice and serving as a platform to coordinate efforts for the development and commercialisation of hydrogen technologies. The alliance is supported and supervised by the Ministry of Science and Technology and other government bodies (18). The Society of Automotive Engineers of China, a national academic organisation founded in 1963, facilitates scientific and technical progress in the automotive industry. The society organises conferences, seminars and in-service training,

**Table V The Energy Consumption in Transportation Sector of China in 2016 (6)**

Indicator	Gasoline, Mtoe	Diesel, Mtoe	Kerosene, Mtoe	Fuel oil, Mtoe	Gas, Mtoe	Electricity, Mtoe	Total, Mtoe
<b>National transportation</b>	89.8	122.5	20.2	3.7	22.7	10.8	269.7
<b>Domestic air transport</b>	0.9	0.4	20.2	0.7	0.0	–	22.2
<b>Road</b>	87.2	102.4	–	0.0	22.7	4.8	217.1
<b>Rail</b>	0.1	3.2	–	0.0	0.0	6.0	9.3
<b>Inland waterways</b>	1.7	16.6	–	2.9	0.0	–	21.2
<b>International bunkering</b>	–	0.4	9	9	–	–	18.3
<b>Marine</b>	–	0.4	–	9.3	–	–	9.7
<b>Aviation</b>	–	–	8.6	–	–	–	8.6
<b>Share, %</b>							
<b>National demand</b>	33	45	8	1	8	4	100
<b>International bunkering to national consumption</b>	–	–	43	253	–	–	7

**Table VI Stock of Road Vehicles in China in 2017 (17)**

Fuel type	Gasoline	Diesel	Compressed natural gas	LNG
<b>Vehicles, million</b>	185.26	19.57	5.73	0.35

establishes relationships with foreign societies of automotive engineers and represents China in IEA's Electric Vehicles Initiative, IEA's Technology Collaboration Program on Advanced Fuel Cells and in other activities connected with 'new energy vehicles' technologies (19).

The energy development strategy action plan for the period 2014–2020, adopted by the State Council in 2014, declares fuel substitution and a robust development of electric vehicles, hybrid and natural gas vehicles and ships. The development of clean vehicle production, strengthening fuel consumption standards and environmental security standards on transport are also highlighted. The document also included hydrogen FCs in the 20 key technologies to be developed (20).

China's decarbonisation policy under consideration within Central Government is to ban sales and even production of internal combustion engine cars in the foreseeable future (21).

### 3.3 Major Recent Developments

China is a world leader in BEV stock (4) and sales (21) as well as in electric vehicle supply equipment stock (**Table II**). To date the FCEV technologies are mostly at the development stage. However, the characteristics of SAIC Motor's (a Chinese state-owned automobile manufacturer) newest FCEV model Roewe 950 are close to those of Toyota (Japan), Honda (Japan) and Hyundai (South Korea) (22). FCEVs in China are now at the early commercialisation stage, as their stock in the country accounts for just 63 units by the end of 2018 (23).

In 2013 China developed its first FC locomotive. In 2015 Tsinghua University, China, and Chinese state-owned rolling stock manufacturer CRRC Corporation Limited produced a FC tram. In 2016 CRRC's subsidiary produced a hybrid tram powered by hydrogen cells and a supercapacitor, which has been run on Tangxu Railway from October 2017 (22, 24). The same year CRRC awarded a contract to supply eight hydrogen FC trams for a new light rail line in Foshan (25). Luzhou, Taizhou and other cities are also planning to put into operation hydrogen-powered trams (22).

The Chinese hydrogen FC roadmap began to take shape in the late 1990s, however, research and development (R&D) activities had been carried out before (26). In 2015 the Chinese government prepared a strategy plan "Made in China 2025", where key strategic

high-technology industries were pointed out. The plan highlights the importance of BEVs and FCEVs and urges the development of a full value chain within the country's automobile industry (27). Currently, the supportive measures to promote FCEVs include:

- R&D financing, through national research projects and grants
- Financial incentives: central and local governments provide subsidies for FCEVs as well as hydrogen refuelling stations (HRSs) (28)
- Demonstrations have been organised to familiarise the public with FCEVs and to promote them since the Olympic Games in Beijing in 2008. Demonstrations have been organised on a daily basis in some cities (29)
- Themed industrial parks for hydrogen value chains, based on the cooperation between research institutes (private and government) and businesses, have been created in Handan (Hebei), Yunfu (Guangdong), Rufu (Jiangsu), Taizhou (Fujian), Chengdu (Sichuan) and Datong (Shanxi), while more intentions are stated in other areas (30, 31).

According to the roadmap, prepared by the Society of Automotive Engineers of China in 2016 (32), the cost of hydrogen commercial vehicles and passenger cars will decrease significantly (by 2.5 and 1.7 times, respectively) in the coming decade, FCEV stock will reach 5000 by 2020, 50,000 by 2025 and 1 million by 2030; there will be 100, 350 and 1000 HRS nationwide, respectively. Similar scope is defined in the "White Paper on China's Hydrogen Energy and Fuel Cell Industry", issued by China Hydrogen Alliance in 2019: the number of FCEVs will rise from 2000 in 2019 to 50,000 by 2025, to 1.3 million by 2035 and to 5 million by 2050. The number of HRS will grow from 23 in 2019 to 200 by 2025, to 1500 by 2035 and to 10,000 by 2050 (22).

Some features of transport decarbonisation in China:

- The transport decarbonisation drivers include not only environmental and energy security issues, but also capturing leading positions in the emerging global 'clean vehicles' market. ("Made in China initiative" (27))
- The effects of transport electrification and the use of hydrogen vehicles on carbon emissions are limited by the prevalence of coal in electricity generation and the dominance of coal gasification in hydrogen production (33).

## 4. Japan

### 4.1 Energy Consumption and Transportation Sector

Japan is crucially dependent on energy imports, and more than 80% of electricity in Japan is produced by thermal power plants (6). Almost 20% of anthropogenic GHG emissions in Japan is attributed to transport, including 17% due to road transportation services (7).

The fuel consumption in the Japanese transport sector is dominated by road vehicles, followed by aviation and sea traffic (Table VII). The fuel consumption of the international sector (international bunkering) significantly exceeds that of the national transport system. Rail transport in Japan is almost entirely electrified, which results in the lowest carbon intensity of all transportation modes.

At the end of May 2019 Japan had 82 million vehicles, including 62 million cars (of which 42 million are small and light), 14.4 million trucks (including 11.6 million LCVs), 0.23 million buses, 1.8 million special application vehicles and 3.7 million motorcycles. Sales of new BEV and PHEV, shared almost equally, reached some 50,000 in 2017–2018.

Japan is the third largest vehicle producer in the world after China and the USA. In 2018 11.9 million cars, more than 90,000 buses, 1.3 million trucks and 0.3 million LCV were manufactured in Japan. The share of hybrid cars production in 2014 to 2018 was between 17% and 20% (2, 4, 34–36).

### 4.2 Institutions

On 8th November, 2016, Japan adopted The Paris Agreement within the United Nations (UN) Framework Convention on Climate Change (37). The Government of Japan plans to reduce GHG emissions by 26% by 2030 and by 80% by 2050 (38, 39). The concept for a sustainable circular society in Japan, where hydrogen is instrumental as a new energy carrier, is at the core of the Japanese energy strategy (15). The action plan for the implementation of hydrogen society was elaborated in Japan after the 2011 Fukushima disaster (40).

Japan currently acts as an international icebreaker, capturing leadership positions in the hydrogen energy systems development at a national level. This East Asian economy provides an example of energy institutions reformation to introduce a 'new' energy carrier: hydrogen. The energy strategy for Japan is driven by necessity to secure the country's energy supply, to reduce imports of fossil fuels, to ensure compliance with the Paris Agreement and to catch the opportunity for development of a high-technology energy-related industrial sector, including powertrains and auxiliary equipment for mobility applications. The amended Strategic Energy Plan (41) with a vision to 2050 was adopted by the Government of Japan in July 2018. The document emphasises the challenges of energy transition and decarbonisation for "Japan's electric power, thermal, and transportation systems". In regard to transport sector policy the Government of

**Table VII The Energy Consumption in Transportation Sector of Japan in 2016 (6)**

Indicator	Gasoline, Mtoe	Diesel, Mtoe	Kerosene, Mtoe	Fuel oil, Mtoe	Gas, Mtoe	Electricity, Mtoe	Total, Mtoe
<b>National transportation</b>	39.6	24.5	4.4	1.0	0.8	2.0	72.4
<b>Domestic air transport</b>	–	–	4.4	–	–	–	4.4
<b>Road</b>	39.6	23.3	–	–	0.8	–	63.8
<b>Rail</b>	–	0.2	–	–	–	2.0	2.2
<b>Inland waterways</b>	–	1.1	–	1.0	–	–	2.1
<b>International bunkering</b>	–	–	7	4	–	–	11
<b>Marine</b>	–	–	0.1	4.5	–	–	4.6
<b>Aviation</b>	–	–	6.6	–	–	–	6.6
<b>Share, %</b>							
<b>National demand</b>	55	34	6	1	1	3	100
<b>International bunkering to national consumption</b>	–	–	152	438	–	–	15

Japan states it will apply the potential of technology innovations in electrification and hydrogenation.

The issue is that in order to introduce hydrogen as a new commercial energy carrier a complicated and extensive infrastructure along the whole hydrogen supply chain must be established, and many institutional and technical regulations should be introduced. Pointing out the importance of a holistic approach to complex energy issues at the consumer end:

“The [Government of Japan] will increase the possibility of efficient, stable and decarbonizing distributed energy systems that consolidate in a compact manner electricity, thermal, and transportation systems being established locally under demand-side leadership by effectively combining the downsizing and efficiency improvements in renewable energy, technological innovations in storage batteries and fuel cell systems, and progress in digitalization technology and smart grid technology that make supply-demand control at the local level possible.”

The Strategic Energy Plan does not exclude future introduction of biodiesel fuel “taking into consideration international trends”, while natural gas is expected to be increasingly used as fuel in the transportation sector, including ships. However, the strategic goal is to increase the ratio of next-generation vehicles in production by 50–70% by 2030. Under next-generation technologies advanced batteries, FCs and hydrogen high-pressure tanks are considered. The Strategic Energy Plan incorporates the Basic Hydrogen Strategy, adopted in December 2017 (42). Pursuant to the latter, Japan will accelerate an expansion of demand for hydrogen in transportation, concentrating on FCEV for cars, buses and trucks. In the spring of 2016 the national-scale showcase for hydrogen driven transportation systems was declared for the Tokyo Olympics in 2020. It is considered as a landmark for the country: “The 1964 Tokyo Olympics left the Shinkansen high-speed train system as its legacy. The upcoming Olympics will leave a hydrogen society as its legacy”, Yoichi Masuzoe, Tokyo Governor (43).

In March 2019 a hydrogen and fuel cell action plan was developed by the Government of Japan. It will coordinate and facilitate actions by industry, academia and government for hydrogen-related technology and infrastructure development up to 2030 (40, 44). While the primary object for hydrogen technologies in the transportation sector

are road vehicles, the next step is expected in developing shipping applications (40).

The New Energy and Industrial Technology Development Organisation (NEDO) is a major actor, responsible for design and implementation of the national hydrogen programme under guidance of the Ministry of Economy, Trade and Industry (METI). The Council for Electrified Vehicle Society was inaugurated in July 2019, “aiming to establish a society in which low carbonization, dispersed energy sources, robust vehicles and energy are integrated” to proactively engage the Government of Japan, METI, car manufacturers, energy companies and municipalities “in efforts for taking advantage of xEVs” (45).

### 4.3 Major Recent Developments

At the beginning of 2018 there were 2926 FCEVs in Japan, including 18 commercial buses in Tokyo. The next milestones are 40,000 FCEV in 2020, 200,000 in 2025 and some 0.8 million in 2030. Projections for FCEV stock in 2050 vary between 8 million vehicles for the reference scenario, to an optimistic 16 million. The number of city buses and fork-lifts should grow to 1200 and 10,000 in 2020 and 2030, respectively. Japan had 108 HRS nationwide as of June 2019; the number of HRS is expected to reach 160 in 2020, and double in the next five years (40).

Toyota planned to roll out 100 hydrogen FC buses to shuttle visitors between venues at the 2020 Tokyo Olympic Games. Then, for the Beijing Winter Olympics in 2022, “more than 1,000 buses are planned in partnership with Beiqi Foton Motor Co which aims to make the most of a push by China to start adopting the zero-emissions technology”. To date, “Toyota has sold fewer than 10,000 of the Mirai”, a reflection of “insufficient refuelling stations [network], consumer worries about resale values and concerns over the risk of hydrogen explosions”. However, the Japanese government “sees hydrogen as a key way to reduce its reliance on oil” (46). Japan’s Toyota is expanding semi-truck manufacturing in the USA in cooperation with Kenworth, utilising an upscaled version of the hydrogen powertrain in Toyota’s Mirai FC passenger car (47). The East Japan Railway Company tested its own version of a FC locomotive for the first time in 2017. In 2019, repeated tests were carried out with an improved version of the electric motor (48, 49).

## 5. South Korea

### 5.1 Energy Consumption and the Transportation Sector

While the energy supply of the transport sector in South Korea is 85% based on the consumption of petroleum products (**Table VIII**) (50), the passenger rail network is characterised by a high degree of electrification (51). Due to international bunkering activity in South Korea and the share of South Korea in global shipbuilding, implementation of low carbon technologies in marine transportation is an important driver for the country’s energy policy.

South Korea’s road fleet includes more than 23 million vehicles: 19.5 million cars and vans, 3.6 million trucks and 91,000 special vehicles. There are 53,071 EVs, 5890 PHEVs and 900 FCEVs in South Korea (4, 23, 52). Currently 18 HRS are operational in South Korea (53).

### 5.2 Institutions

As a technologically advanced economy and one of the world leaders in several energy-intensive industries, South Korea is facing the need to improve energy and environmental safety. Since 2008, the South Korean government has implemented a ‘green society’ policy.

In January 2019 the government announced the setting up of the development plan “Roadmap to Become the World Leader in the Hydrogen Economy” (54, 55). South Korean decarbonisation measures for the road transportation sector include several major options:

- significantly tighten the efficiency requirements for vehicles (the standards of fuel consumption

for new car models in 2020 is raised to 24 km l<sup>-1</sup>)

- stimulating demand for environmentally friendly cars by subsidising the purchase of electric cars
- development of the public transportation network and shifting the bus fleet structure in favour of electric and hydrogen systems
- increase the number of charging stations for electric cars (56).

The plan includes such goals as:

- to adopt the national law on hydrogen energy in 2019
- to reach a cumulative fleet of 6.2 million FCEVs by 2040
- to increase the number of HRS to 1200 by 2040
- to develop a network of hydrogen taxis in 10 major cities, starting from a pilot project in 2019 with the aim to reach 80,000 cars by 2040.

### 5.3 Major Recent Developments

New partnership H2KOREA was established to improve coordination between government agencies and private business. Members of H2KOREA are governmental and administrative authorities (Ministry of Trade, Industry and Energy, town councils of Ulsan, Incheon and Daegu), research institutions (Institute for Advanced Engineering and Korea Research Institute of Standards and Science) and industrial companies (Hyundai, Hyosung and Doosan Fuel Cell Co Ltd). The main goals for H2KOREA are state support and participation in the formation of legislation in the field of hydrogen technologies (57).

**Table VIII The Energy Consumption in Transportation Sector of South Korea in 2016 (6, 50)**

Indicator	Gasoline, Mtoe	Diesel, Mtoe	Kerosene, Mtoe	Fuel oil, Mtoe	Gas, Mtoe	Electricity, Mtoe	Total, Mtoe
<b>National transportation</b>	9.9	17.9	1.2	0.2	5.0	0.2	34.4
<b>Domestic air transport</b>	–	–	1.2	–	–	–	1.2
<b>Road</b>	9.9	17.5	–	–	5.0	–	34.4
<b>Rail</b>	–	0.1	–	–	–	0.2	0.3
<b>Inland waterways</b>	–	0.3	–	0.2	–	–	0.5
<b>International bunkering</b>	–	1.2	4.9	9.3	–	–	15
<b>Marine</b>	–	1.2	–	9.3	–	–	10.6
<b>Aviation</b>	–	–	4.9	–	–	–	4.9
<b>Share, %</b>							
<b>National demand</b>	28	51	4	–	14	1	100
<b>International bunkering to national consumption</b>	–	7	400	5426	–	–	45

The sales of Hyundai’s NEXO FCEV accelerated in 2019. While less than 1000 hydrogen cars had been sold annually since 2013, by May 2019 the cumulative number of sold vehicles since the start of 2019 had already exceeded this level (58).

In order to meet the government plans to purchase a total of 802 hydrogen buses for the police force by 2028, Hyundai Motor unveiled an upgraded version of a FC electric bus. A test-run of the vehicles will be conducted during 2020, and production will commence in 2021 (59).

Hydrogen powered drones are available for purchase in South Korea. It is announced that the drone’s flight time is up to 110 min and the payload is up to 3 kg (60).

Samsung Heavy Industries became the first shipbuilder to develop a crude oil tanker powered by FCs. The oil-based power generators in the tanker are replaced by solid oxide fuel cell (SOFC) using LNG as fuel. “Being the first shipbuilder to secure this marine FC technology illustrates that Samsung Heavy is highly likely to lead the market,” said Kyunghee KIM, Vice President of SHI International Corp, USA (61).

Hyundai announced key investments into three hydrogen companies to strengthen its leadership position in the global hydrogen FC ecosystem (62). South Korean Hyundai Motor Group is conducting research to create a hydrogen train; the completion of the project was announced for late 2020 (63).

## 6. Taiwan

### 6.1 Energy Consumption and the Transportation Sector

Taiwan has over 21 million vehicles, including 35,000 buses, 1.1 million trucks, 7 million cars and about 13.5 million motorcycles and scooters (64). The main fuel for road transport is petroleum products, and international bunkering for air and sea traffic overwhelmingly exceeded that of the national transport system (Table IX). Despite an almost complete absence of domestic shipbuilding, road vehicle and aviation manufacturing, there is plenty of room for efforts to shift energy demand in transportation from petroleum to natural gas, electricity and hydrogen, both for national and international transport systems.

### 6.2 Institutions

A new Taiwan government, formed in 2016, announced a course to strengthen the development of renewable energy and decarbonisation of transport with the widespread use of green technologies, including FC. There is no officially published energy strategy regarding renewable energy, with the exception of establishing the Taiwan Energy and Carbon Reduction Office in 2016. The main organisations responsible for shaping Taiwan’s carbon-free transport policy are the Bureau of Energy, Ministry of Economic Affairs,

**Table IX The Energy Consumption in Transportation Sector of Taiwan in 2016 (6)**

Indicator	Gasoline, Mtoe	Diesel, Mtoe	Kerosene, Mtoe	Fuel oil, Mtoe	Gas, Mtoe	Electricity, Mtoe	Total, Mtoe
<b>National transportation</b>	8.1	4.0	0.1	0.1	–	0.1	12.5
<b>Domestic air transport</b>	–	–	0.1	–	–	–	0.1
<b>Road</b>	8.1	3.9	–	–	–	–	12.1
<b>Rail</b>	–	–	–	–	–	0.1	0.1
<b>Inland waterways</b>	–	0.1	–	0.1	–	–	0.2
<b>International bunkering</b>	–	0.1	3	1	–	–	4
<b>Marine</b>	–	0.1	–	1.2	–	–	1.3
<b>Aviation</b>	–	–	2.7	–	–	–	2.7
<b>Share, %</b>							
<b>National demand</b>	65	32	1	1	–	1	100
<b>International bunkering to national consumption</b>	–	2	2861	1281	–	–	32

Environmental Protection Administration, Taiwan Hydrogen Industrial Development Alliance and the Taiwan Power Company. However, the proposed plans for the development of carbon-free transport face serious bureaucratic obstacles, caused by the national monopoly's unwillingness to deal with new participants in the electricity market (65).

In 2017 a governmental programme to reduce transport taxes for low-carbon vehicles was adopted, focusing on private cars and scooters. According to this programme, a significant increase in ZEV by 2025 should be achieved by introducing 6000 vehicles and 150,000 motorcycles and mopeds running on lithium-ion batteries. The subsidy mechanism is under discussion to motivate domestic companies working in the sphere of carbon-free transport.

Given the high density of the urban population and the number of agglomerations, the authorities of large municipalities are inclined to road extension, rather than infrastructure development for electric and hydrogen vehicles.

In 2015 the Environmental Protection Administration presented a plan for the development of a comfortable and safe urban environment. In 2018, there were already 1800 electric charging stations, and the plan is to increase their number to 5000 units over the next 5–7 years (66). A choice of scooters as a main target of carbon-free technology development looks justified by its convenience for transportation in the warm climate, as well as Taiwan's dependency on imported road vehicles.

## 7. Conclusions

Improving energy security and reducing anthropogenic environmental impacts are strategic issues for the energy policies of industrial economies in East Asia: China, Japan, South Korea and Taiwan. The transport sector is of particular importance, since it is pivotal in efforts to relieve peaking oil demand, and is instrumental in decarbonising final energy consumers.

The East Asian economies' thirst for energy security is the most important driver for transport decarbonisation. The next driver is a commitment to combat climate change, as a number of binding regulations and government programmes aimed at reducing GHG emissions have been adopted. Additional policy drivers are the role of China, Japan and South Korea in the world's vehicle

manufacturing and shipbuilding; as well as the size of the international ship and aircraft bunkering business in East Asia for passenger and cargo traffic.

There are considerable efforts within East Asian economies to develop policy towards low carbon energy supply infrastructure in general, and low carbon transportation systems in particular. The general trend is fuel substitution (petroleum to gas, internal combustion engine to more energy-efficient combinations of motor and powertrain) and electrification of transport vehicles, including advances in mobile energy systems, like hybrid and FC powertrains. The 'hydrogen society' concept combines renewable energy for green hydrogen production and its utilisation as the ultimate non-carbon fuel. While key hydrogen technologies have a wide range of applications in transportation, from tankers, locomotives and aircraft to hydrogen-driven monocycles, road transport applications are important at the commercialisation stage for a number of economic and technological reasons.

A scramble for capturing leading positions in the global ZEV market has become a distinctive feature of BEV, FCEV and hydrogen technologies development in the East Asian economies. They are at the forefront of the course to introduce hydrogen as new energy carrier, and it can be seen as the starting (icebreaking) position for transition of a petroleum-based transportation system into one ultimately independent from fossil energy. Japan, China and South Korea are already implementing regulation, energy institute transformation and transition from the pilot stage to the practical development of carbon-free mobility systems at a national level. Currently, the fundamentals for the competitive development of all low-carbon technologies have been created in East Asian economies in order to reduce the transport system's carbon footprint.

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