International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0168

DEPLOYMENT OF ZERO-EMISSION TRANSPORTATION TECHNOLOGIES IN JAPAN BY 2050, A TECHNO-ECONOMIC ANALYSIS USING TIMES-JAPAN FRAMEWORK

Hadi Farabi-Asl[1*], Kenshi Itaoka[1], Andrew Chapman[1], Etsushi Kato[2], Atsushi Kurosawa[2]

[1] International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University, Japan

[2] The Institute of Applied Energy, Tokyo, Japan

ABSTRACT

In this study, we conducted a techno-economic analysis to estimate the deployment of zero-emission technologies (electricity and hydrogen) in Japanese transportation sector, considering the deep-decarbonization target by 2050. We used TIMES-Japan energy system analysis framework, which is following a whole-system approach. Results of calculations for energy demand of passenger and freight transportation by cars, buses, trucks, trains, airplanes, and ships are discussed after giving special attention to the capacities of low-emission technologies including renewables, nuclear, CCS, and hydrogen import in the supply side of energy system. Results of the calculations for the main scenario showed that zero-emission technologies would cover 75.6% of transportation energy demand in Japan by 2050, in order to achieve the 80% emission reduction target for the whole energy system.

Keywords: zero-emission, transportation, hydrogen, electric, TIMES-Japan, whole-system approach

1. INTRODUCTION

COP 21 long-term reduction pathways indicate deep, economy-wide emission reductions of 80% or more by 2050 [1]. In 2016, CO_2 emission from transportation sector in Japan reached to 223.3 $MtCO_2$, which is 21.6% of total emissions in final energy consumption. This value is 9.7 $MtCO_2$ higher than 1990 level [2]. Fig 1 shows the hybrid vehicle stock in Japan for 2003 - 2016. Both passenger and freight hybrid vehicles experienced sharp increase in the Japanese transportation market during last 13 years. On the other hand, Japan is aiming to conduct proper actions to "ensure that hydrogen becomes the trump card for mid- to long-term energy security and global warming countermeasures utilizing the technologies of Japan" [3]. The main use cases for hydrogen in Japan are transportation (in mid-term), and power generation (in long-term).

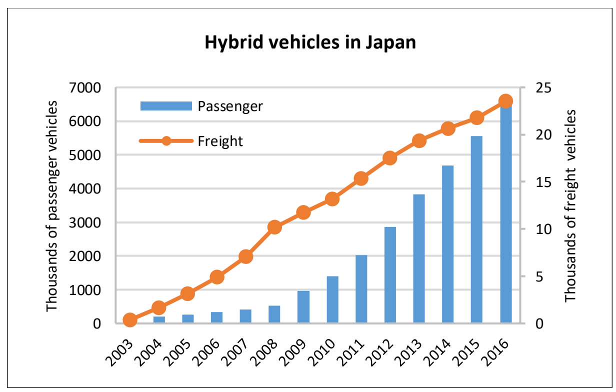

Fig 1 Hybrid pasenger and freight vehicles stock in Japan, 2003 - 2016

Japan has ambitious targets for reducing emissions in upcoming decades, aiming to cut 26% of emissions by 2030, compared to 2013 level. The target for reducing the emission from transportation sector is 28% by 2030 [4]. High deployment rate of zero-emission transportation technologies (electricity and hydrogen) will be necessary to achieve the mitigation targets in Japan for 2030 and beyond.

In this study, we analyzed the contribution of zero-emission transportation technologies in achieving emission reduction targets in Japan by 2050. We conducted a techno-economic analysis using TIMES-Japan framework with a whole-system approach. The upper bound capacity for main low-carbon technologies in the model including renewables, nuclear, CCS, and hydrogen import assigned according to domestic studies in Japan. Results of calculations in the energy supply for passenger and freight transportation in various categories (vehicles, trains, airplanes, and ships) analyzed and reported for the main scenario.

2. METHODOLOGY

2.1 TIMES-Japan framework specifications

Our work relies on TIMES-Japan framework following a cost optimization approach. TIMES-Japan is a regional model developed at the Institute of Applied Energy [5] using the TIMES modeling framework [6]. The model consists of a detailed energy system based on the MARKAL-JAPAN model [7], and an additional energy carrier of imported hydrogen has been incorporated [8]. The reference energy system in TIMES-Japan consists of 365 processes and 161 commodities. In each set of calculations, an optimized combination of renewable and nonrenewable energy sources on the supply side meet the energy demand for industrial production, transportation, residential and commercial buildings. The calculation period is 1990 – 2050, with 5-year time steps.

The CO_2 emission cap considered as an exogenous parameter to the model, aiming for 26% and 80% emission reduction in 2030 and 2050, respectively, compared to 2013 levels (247 $MtCO_2$ in 2050). Energy import prices in the model assumed to follow the Sustainable Development Scenario (SDS) of the World Energy Outlook 2017 [9]. Marginal cost of CO_2 reduction ($/$tCO_2$) is calculated and reported, which is the cost for reducing the last abated unit of energy system CO_2 for a defined abatement level. Ogimoto et al. [10] and Yamaguchi et al. [11] are the main referenced simulations for power systems and building energy demand in our study.

In this study, the carbon capture and storage (CCS) capacity in the model reaches to 100 $MtCO_2$ in 2050, starting from 0.2 $MtCO_2$ in 2020. We assumed that new nuclear power capacity will not be added to the energy system due to Fukushima nuclear incident in 2011; it means that existing nuclear power plants will continue their operation with lifetime of 50 years. The hydrogen import in the model is limited to a set amount as stipulated by Kawasaki Heavy Industries Ltd. to import hydrogen from Australia. The amount is 9 million ton in 2050, starting from 0.002 million ton in 2020 [12].

2.2 Modeling of transportation sector

The transportation sector in TIMES-Japan model is divided into passenger and freight usage. Passenger transportation is further categorized into railway, car, bus, airplane and ship. In a similar way, freight transportation is divided into railway, truck, airplane and ship. The input energy for transportation is mainly coming from light oil, electricity, gasoline, LPG, city gas, hydrogen, and jet fuel. The output of transportation processes is reported in annual person-km and ton-km units for the passenger and freight transportation use cases, respectively. Fig 2 shows the transportation categories in the model.

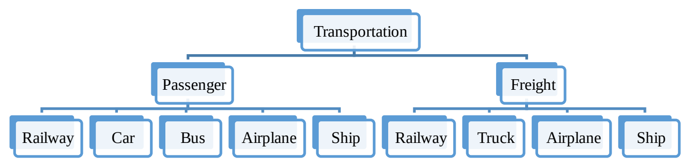

Fig 2 Categories of trasnportation in TIMES-Japan model

3. RESULTS AND DISCUSSION

Fig 3 shows the main results of calculation in primary and demand sides of energy system for 1990 – 2050. In 2050, share of fossil fuels in primary energy reduces to 35.6%, from 83% in 2020. Hydrogen covers 8.3% primary energy in 2050. Power generation in 2050 reaches to 1190 TWh, which is almost 200 TWh higher than current power generation. Renewables and nuclear cover 82% and 4% of power generation in 2050. Net CO_2 emission in 2050 is 247 $MtCO_2$, which is satisfying the 80% emission reduction target. The CCS capacity is fully deployed in 2050 (100 $MtCO_2$).

The average of energy system cost is 644 billion USD per year for 2020 – 2050. Marginal cost of CO_2 reduction in 2050 reaches to 781 USD/tCO_2, starting from 86 USD/tCO_2 in 2025.

Fig 4 shows the detailed results of transportation output by fuel, in passenger (in giga person-kilometer) and freight (in giga ton-kilometer) categories for various transportation technologies. Share of zero-emission technologies (electricity and hydrogen) increase significantly, especially from 2030.

In passenger car category, share of zero-emission technologies starts from 2.8% in 2020, reaching to 64% and 100% in 2045 and 2050, respectively. Hydrogen's share in passenger car is 63% in 2050. The freight truck category follows a similar pattern. Zero-emission technologies cover 95.6% of freight truck in 2050,

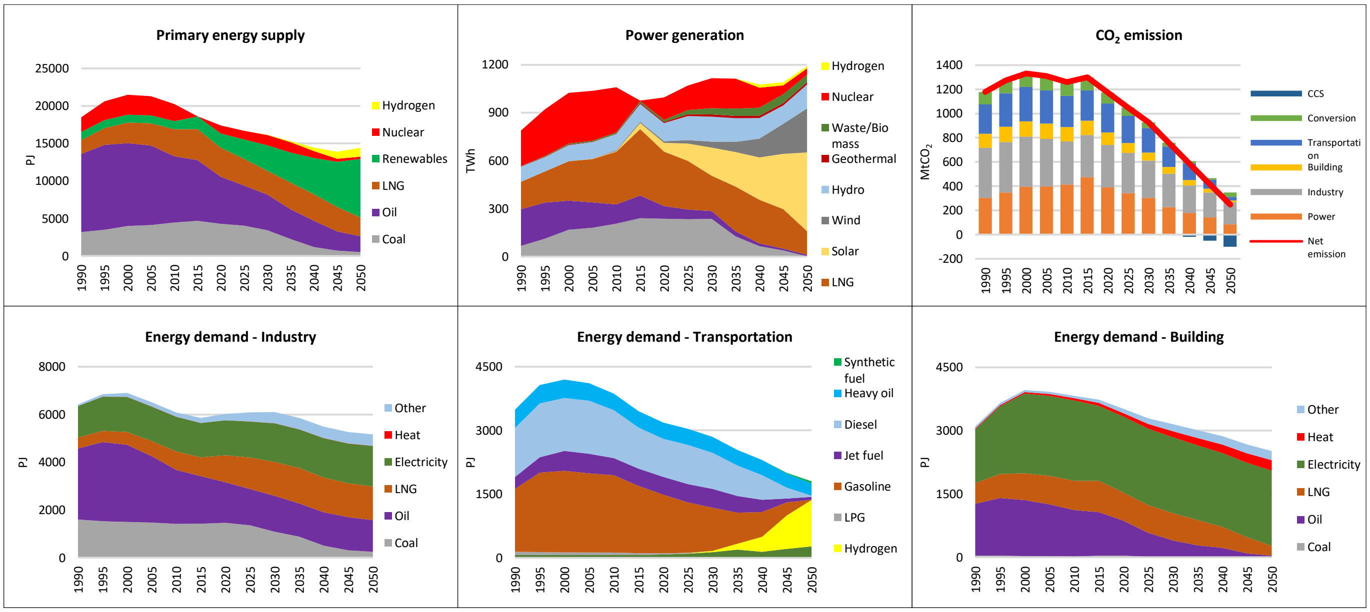

Fig 3 Main results of calculation in supply and demand sides of energy system in Japan, 1990 – 2050

starting from 0.9% in 2035. Share of hydrogen in freight truck category reached to 85.5% in 2050.

The main fuel source for passenger bus is light oil for early time steps of calculation, which partially replaces by hydrogen from 2030. Share of hydrogen in passenger bus is 68% and 100% in 2045 and 2050, respectively. Contribution of hydrogen in airplane transportation starts from 2035 and 2040 for freight and passenger categories, respectively. Share of hydrogen in passenger airplane category reaches to 28% in 2050.

In general, results of calculation for the whole transportation sector in Japan show that fossil fuel consumption decreases significantly in 2020 - 2050. For instance, share of gasoline decreases to 0.3% in 2050, from 45.8% in 2015. Diesel fuel experiences a similar pattern; its share is 28.0% and 1.5% in 2015 and 2050, respectively. Synthetic fuels cover 2.9% of transportation energy demand in 2050. In total, zero-emission technologies cover 75.6% of transportation energy demand in 2050, while their share is 2.4% in 2020. The share of hydrogen and electricity in transportation energy demand in 2050 expected to be 60.7% and 14.9%, respectively.

4. CONCLUSIONS

In this study, we investigated the future of zero-emission transportation technologies (electric and hydrogen) in order to achieve the emission reduction targets in Japan by 2050, with a whole-system approach. We assigned upper bounds for capacities and growth rates of low-emission technologies (e.g. renewables) in TIMES-Japan energy system framework and analyzed the results in supply and demand sides of system. The 80% emission reduction target achieved in the main scenario of calculations, with 644 billion USD per year for 2020 – 2050 as the average of annual energy system cost.

Results of calculations for the transportation sector showed that various categories including car and bus (for passenger transportation), truck and airplane (for freight transportation) experience high deployment rate of zero-emission technologies, mainly from 2030. Share of hydrogen in these categories would be higher than electricity. In total, zero-emission technologies would cover 75.6% of transportation energy demand in 2050, while their share is 2.4% in 2020. The highest share of zero-emission transportation technologies is 100% and 95.6% for passenger car and freight truck in 2050, respectively.

ACKNOWLEDGEMENT

This research was supported by the Environment Research and Technology Development Fund (2-1603) of the Environmental Restoration and Conservation Agency.

REFERENCE

[1] UNFCCC. Paris Agreement - Status of Ratification, 2018. http://unfccc.int/paris_agreement/items/9444.php, Accessed date: April 2018.

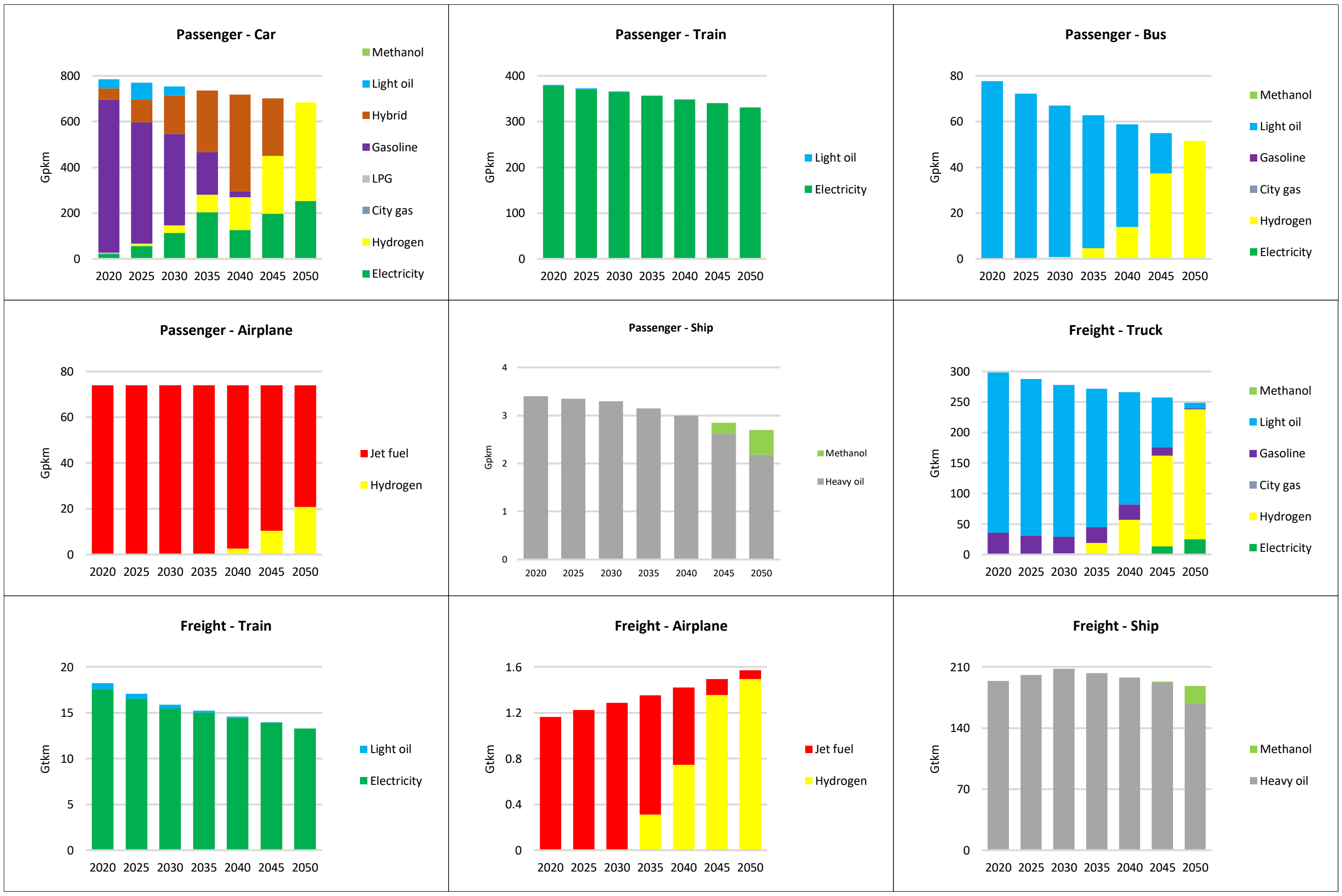

Fig 4 Transportation output by category and fuel

[2] EDMC. Handbook of Japan's and world energy and economic statistics. The Institute of Energy Economics, Japan, 2018.

[3] METI (Japanese Ministry of Economy, Trade and Industry). Strategic Energy Plan, 2018; (Provisional translation from Japanese to English).

[4] Kato E, Kurosawa A. Evaluation of Japanese energy system toward 2050 with TIMES-Japan, deep decarbonization pathways. Energy Procedia 2019; 158: 4141-4146.

[5] Kurosawa A, Hagiwara N. Long term energy system analysis of Japan after March 11, 2011. 3rd IAEE Asian conference, 2012, Japan.

[6] Loulou R, Remne U, Kanudia A, Lehtila A, Goldstein G. Documentation for the TIMES model - PART I, 2005. http://iea-etsap.org/docs/TIMESDoc-Intro.pdf.

[7] Sato O. A study on long-term energy scenarios for Japan, JAERI-Research 2005; 012. http://doi.org/10.11484/jaeri-research-2005-012 [in Japanese].

[8] Sugiyama M, Fujimori S, Wada K, Endo S, Fujii Y, Komiyama R, Kato E, Kurosawa A, Matsuo Y, Oshiro K, Sano F, Shiraki H. Japan's long-term climate mitigation policy: Multi-model assessment and sectoral challenges, Energy 2019; 167: 1120-1131.

[9] IEA. World energy outlook 2017.

[10] Ogimoto K, Iwafune Y, Kataoka K, Saitou T, Azuma H, Fukutome S. Power demand and supply analysis based on the Long-term Energy Prospects of Japan (III). Proc. 34th Conference on Energy, Economy and Environment, Japan Society of Energy and Resources 2018; 685-690 (in Japanese).

[11] Yamaguchi Y, Kimura S, Ikeda K, Ko Y, Kim B, Shimoda Y. Power demand and supply analysis based on the Long-term Energy Prospects of Japan: estimation of the electricity demand of commercial sector", Proc. 36th Annual meeting of Japan Society of Energy and Resources 2017; 169-174 (in Japanese).

[12] KHI (Kawasaki Heavy Industries, Ltd.). Hydrogen energy supply chain based on Victorian brown coal linked with CCS. Victorian Brown Coal Forum 2015, Japan.