TRANSITION TO A 100% RENEWABLE TRANSPORT FUEL SYSTEM AND IMPLICATIONS FOR ECONOMIC COSTS AND GREENHOUSE GAS MITIGATION: A SIMULATION-BASED COMPARISON BETWEEN HYDROGEN AND ELECTRICITY

Ehsan Shafiei, School of Engineering & Natural Sciences, Iceland University, Phone +354 8672285, email: ehsan@hi.is
Brynhildur Davidsdottir, School of Engineering & Natural Sciences, Iceland University, Phone +354 8455234, email: bdavids@hi.is
Jonathan Leaver, Unitec Institute of Technology, New Zealand, Phone +649 8154321, email: jleaver@unitec.ac.nz
Hlynur Stefansson, School of Science & Engineering, Reykjavik University, Iceland, Phone +354 8256308, email: hlynurst@ru.is
Eyjolfur Ingi Asgeirsson, School of Science & Engineering, Reykjavik University, Iceland, Phone +354 5996385, email: eyjo@ru.is

Overview

Iceland is a global leader in utilizing renewable energy resources in which almost all of its electricity needs is generated from geothermal and hydro resources. While industrial, residential and commercial sectors are prevalent in the usage of these low-cost and low-carbon energy resources, the transport sector is still dependent on imported petroleum fuels. This study presents a simulation-based comparative analysis of electricity and hydrogen transitional pathways towards a 100% renewable transport fuel system in Iceland. The development path of the integrated energy and transport sectors as well as the potential impact of transition to renewable fuels are examined using the UniSyD_IS model of Iceland's energy system.

Methods

UniSyD_IS is a partial equilibrium system dynamics model with a high level of resource and technology specificity. It captures the interactions among supply sectors, energy prices, infrastructure development and fuel demand. Alternative fuel markets are simulated in the context of a market-based economic system. The fuel supply sector incorporates capacities and production costs of existing and future plants, and calculates the amount of energy that can be supplied at various wholesale prices. The future costs of renewable resources are modeled using supply curves in which unit generation cost is increased with cumulative installed capacities. The fuel pricing sector attempts to coordinate supply and demand by adjusting the market prices. The refueling infrastructure sector determines the station service availability as an important factor that conditions consumer preferences towards alternative fuels. Transport fuel demand is determined based on travel demand and vehicle stock. A multinomial logit model gives the probability that consumers adopt new vehicles based on their preferences towards different vehicles' attributes. For a detailed description of the UniSyD_IS model see [1-5].

Except for the imported gasoline and diesel fuels, the entire fuel supply system is modelled from renewable sources including hydropower, geothermal, wind, and waste biomass. Hydrogen is assumed to be produced by forecourt electrolysis technology. The transport fleet is divided into light (LDV) and heavy (HDV) duty vehicle fleets. Each fleet is composed of different vehicle technologies connected to either of gasoline, diesel, electricity, biofuels, and hydrogen fuels. The vehicle technologies are: internal combustion engine (ICE), hybrid electric (HEV), plug-in hybrid electric (PHEV), battery electric (BEV), and fuel cell (FCV). Technological improvement for vehicles is assumed to be exogenous as the vehicles sold in Iceland are influenced by what happens overseas. Hence, significant improvements are assumed in purchase prices and fuel economy of new fleets.

This study compares three transition pathways towards a fully or nearly-fully renewable transport fuel system: electricity (EV), hydrogen (H2), and mixed hydrogen–electricity (EVH2). These scenarios assume that no new petroleum fuel vehicles can be adopted after 2035, except for heavy-duty PHEV which is allowed to be viable in EV scenario until 2050. Each pathway is evaluated under two conditions: with and without biogas as a complementary renewable fuel. To evaluate the potential impacts of transition pathways, the scenarios are compared with a business-as-usual (BAU) case. In all scenarios, the oil price is assumed to grow from US$50/bbl to US$100/bbl and the carbon tax increases from US$20 to US$100 per tonne CO_2eq during 2015-2050.

Results

The simulation results are compared in terms of fuel mix, energy demand, GHG emissions, transition costs/benefits and mitigation cost. Figure 1 shows the comparison of the total fuel supply system cost and the transition net economic benefits. The energy supply cost consists of petroleum fuel imports, supply of alternative fuels, infrastructure development and Well-to-Tank emissions costs. The net benefit of each transition pathway is calculated based on the difference in total consumer cost between each scenario and the baseline BAU case. The consumer benefit reveals the overall energy and transport net benefit as it is composed of the overall cost of fuel supply chains (including Well-to-Wheels emissions) and vehicle ownership costs. Table 1 compares the scenarios in terms of different energy, economic and environmental indicators.

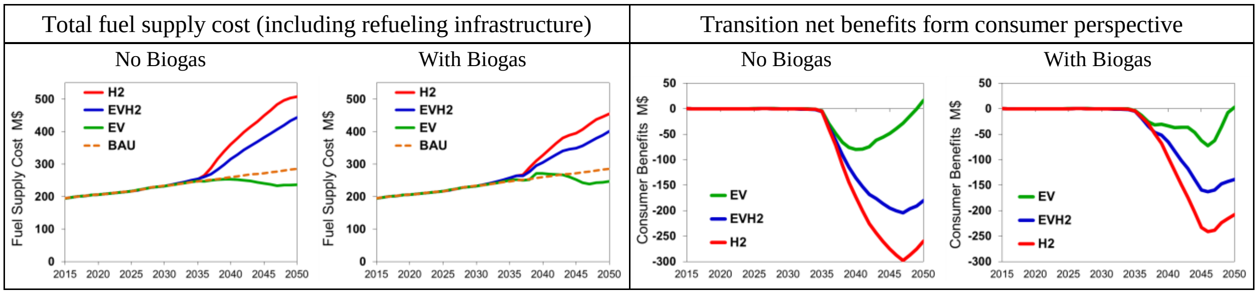

Figure 1: Comparison of transition cost/benefits (undiscounted) from energy supply and consumers perspectives

Table 1: Comparison of transition pathways with respect to energy, economic and environmental indicators

Indicators	BAU	EV		H2		EVH2	
		no biogas	with biogas	no biogas	with biogas	no biogas	with biogas
Share of renewable fuels by 2050 (%)	4	60	72	100	100	100	100
Fuel demand reduction by 2050 (%)	29	56	50	32	31	39	37
Annual emissions cut by 2050 (%)	32	79	83	89	91	90	93
Cumulative net present value of additional fuel supply cost (million US$)*	-	-74	-31	497	355	307	237
Cumulative net present value of additional consumer cost (million US$)*	-	196	137	762	533	563	376
Mitigation cost (US$/tonne CO_2eq)	-	42	26	142	92	101	64

* Compared tocost of the BAU scenario and assuming a discount rate of 5%

Conclusions

The EV transition pathway, due to the limited biogas resource potential and the assumed technological restriction of BEV for HDVs, cannot lead to a fully renewable transport system, but it could approach the Carbon-Neutral Scenario (CNS) of the Nordic Energy Technology Perspectives (i.e. more than 85% emissions reduction) with a low mitigation cost. Among the scenarios towards a 100% renewable fuels, the EVH2 scenario without biogas could be advantageous in reducing total fuel demand. However, the EVH2 scenario with biogas would be the most attractive pathway in terms of emissions reduction, economic benefits and mitigation cost. Biogas as a complementary renewable fuel increases the overall benefit and cost-effectiveness of all scenarios. All transition pathways to a fully renewable transport are costly in terms of total discounted net present values from both energy supply and consumer perspectives. However, the net annual returns are expected to increase during 2045-2050.

References

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