INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 35 (2010) 6097–6107

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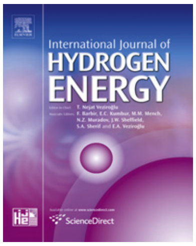

Rail transportation by hydrogen vs. electrification – Case study for Ontario, Canada, II: Energy supply and distribution

G.D. Marin [1], G.F. Naterer*,[2], K. Gabriel [3]

University of Ontario Institute of Technology, Faculty of Engineering and Applied Sciences, 2000 Simcoe Street North, Oshawa, Ontario, Canada L1H 7K4

ARTICLE INFO

Article history:
Received 17 January 2010
Received in revised form
6 March 2010
Accepted 19 March 2010

Keywords:
Hydrogen train
Thermochemical hydrogen production
Copper–chlorine cycle
Electrolysis

ABSTRACT

Locomotives offer an efficient mode of transportation when compared to buses, personal vehicles or airplanes for mass transportation over frequent intercity distances. For example, a Bombardier Regina EMU train with 272 seats and a load factor of 53% will consume under 0.07 kWh/passenger-km, which is typically much lower than corresponding values for other transportation modes in similar circumstances. European countries have invested significantly over the years in train electrification. Environmentally friendly methods of transferring power to the wheels are direct electrification and hydrogen fuel cells. Various methods to produce hydrogen for utilization with fuel cell train operation are examined in this paper.

This companion paper of a 2-paper set examines the overall impact of energy supply (hydrogen vs. electricity) and distribution on rail transportation, specifically in terms of costs and overall GHG emissions for a case study of GO transit along the Lakeshore corridor in Toronto. Although electrification of train services simplifies some aspects of the operation, when considered over the Lakeshore corridor alone, electrified trains lose their flexibility to serve cities outside the Lakeshore corridor. Hydrogen fuelled trains can provide a smoother transition and interoperability by operating the same routes and stations served by diesel trains today, without being limited to the Lakeshore corridor. This paper evaluates technological, operational and economic aspects of the electrification of the Lakeshore corridor, versus hydrogen train operation, including infrastructure requirements to provide service to a substantial ridership increase projected for the years 2015–2031. Various methods of hydrogen production and distribution are presented and analysed, in order to evaluate the overall life cycle of GHG emissions and costs for various train alternatives.

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* *Corresponding author.*

E-mail addresses: gabriel.marin@uoit.ca (G.D. Marin), greg.naterer@uoit.ca (G.F. Naterer), kamiel.gabriel@uoit.ca (K. Gabriel).

[1] Ph.D. Candidate, Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, Canada, L1H 7K4.

[2] Associate Dean, Canada Research Chair Professor, Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, Canada, L1H 7K4.

[3] Professor, Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, Canada, L1H 7K4.

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doi:10.1016/j.ijhydene.2010.03.095

Nomenclature

AMPCO	Association of Major Power Consumers in Ontario
CO_2	carbon dioxide
EPA	Environmental Protection Agency
EMU	electric multiple units
FRA	Federal Railroad Administration
GHG	greenhouse gas
GO	Public Transit Operation Toronto
GTA	Great Toronto Area
GT-MHR	gas turbine modular helium reactor
HOEP	hourly Ontario energy price
IESO	independent electricity system operator
MTU	multi-traction units
OPA	Ontario Power Authority
OPG	Ontario Power Generation
PEMFC	proton exchange membrane fuel cell
RTRI	Railway Technical Research Institute
SMR	steam methane reforming
$/p-km	dollars per passenger-km
VLTJ	Vemb–Lemvig–Thyborøn Jernbane (Danish railway)
C_{th}	cost of thermal energy, $/GJ
C_{ng}	cost of natural gas, $/GJ
C_e	cost of electrical energy, $/GJ
C_{cp}	capital charges, $/GJ
C_{dt}	cost of distribution, $/GJ
C_{CO_2}	cost of emissions, $/GJ
C_{ds}	cost of dispensing, $/GJ
C_f	fixed operational cost, $/GJ
C_v	variable, non-fuel cost, $/GJ
Epm	energy required by the prime mover, J
Eth	energy required to generate hydrogen via thermochemical Cu–Cl cycle, J
Ee	energy required to generate hydrogen via electrolysis, J
eel	Energy required to power the trains via electrification, J

Greek

ηfc	efficiency of fuel cell power package, %
ηc	efficiency of compressor, %
ηth	efficiency of thermochemical process, %
ηe	efficiency of electrolytic process, %
ηpp	efficiency of turbine conversion to electrical power, %
ηt	efficiency of transmission and distribution of electric energy, %

1. Introduction

Electrification of train operations is considered an effective way to significantly reduce GHG emissions from commuter transportation. This study is a companion paper of a 2-paper set, which examines the impact of energy supply and distribution on the feasibility of hydrogen vs. electrification for passenger trains. It specifically focuses on a case study of GO transit in the Greater Toronto Area (GTA) that considered improvements and expansions along the Lakeshore train corridor aimed at reducing up to 300 million car trips off GTA roads by 2031 [1,2] as well as reducing the carbon quota per person in the GTA in half.

A case study prepared for Metrolinx, the Crown Corporation responsible for the strategic development of mass transportation in the GTA, estimated that passenger demand projections for the Lakeshore corridor are expected to grow by 90% for Lakeshore East, and 65% for Lakeshore West between 2007 and 2031, respectively [3,4]. The Benefit Case Analysis investigated and recommended the expansion and electrification of train services in the Lakeshore corridor, increasing to 24 trains by 2015 and 44 by 2031 [4]. The expanded system will see an increase capacity of GO transit demand in the Lakeshore corridor by a factor of 3 by 2015, and by 4.6 times by 2031, in relation to service levels existing in 2008.

At peak hours, the Lakeshore train service carries 12,320 passengers using a fleet of diesel locomotives with 10–12 bi-level railcars with a total capacity per train of 1540 passengers commuting between Hamilton and Toronto, and the plan is to increase this capacity up to 21,460 passengers by 2031 [4]. The case study estimated that this increase in capacity will represent the removal of approximately 18,000 vehicles from Toronto highways every weekday during peak hours. The potential net GHG elimination results from more efficient train operation when compared to emissions from personal vehicles. At 3.07 kg GHG/kg diesel [5], a diesel train produces approximately three or more times the GHGs emitted by the equivalent number of vehicles. Electrification can provide a cleaner alternative, depending upon the source of electrical energy. The sustainability and ease on the environment of electric trains is limited only by the source of electrical power; while a train that operates on hydrogen can potentially rely exclusively on sustainable and clean sources. The average energy consumption of a GO diesel train is 5 L per 100 km [6], what translates to approximately 0.18 GJ/km. This contrasts with the yearly based average estimated for 2031 of 0.086 GJ/km required to power a train by electrification, based on utilization of the Bombardier ALP-A46 with 10 by-level coaches in the Lakeshore route [3].

Fuel cells are a promising alternative to train electrification, which will be studied in this paper, together with several options for the production of hydrogen, and its impact on train operation. Hydrogen can be produced from natural gas via steam reforming; from electricity via electrolysis [7], or from thermal energy via thermochemical processes [8]. Hydrogen powered train operation is currently under consideration by several transit operations around the world, and preliminary evaluations have been undertaken. The European Hydrogen Train feasibility study [9] proposed the development of a prototyping hydrogen train in Denmark with the participation of academic, government and fuel cell and train technology manufacturing organizations. The study identified the bases for a future agreement and proposed two high visibility tracks in Denmark for the operation of the prototypes. The Railway