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Towards a sustainable strategy for road transportation in Australia: The potential contribution of hydrogen

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ABSTRACT

The use of oil in road transport contributes significantly to global greenhouse gas (GHG) emissions in addition to rapidly depleting this non-renewable resource. Emissions can be greatly reduced by the total replacement of petroleum-based vehicles with electric vehicles using a combination of hydrogen and battery energy storage technologies. This paper analytically reviews the potential reduction in Australian road transport GHG emissions through the total replacement of petroleum-fueled vehicles with hydrogen and battery electrical vehicles by 2050. If electricity for hydrogen production & storage and battery charging is sourced from the national electricity grid, it is estimated that emissions can be reduced by between 56% and 73% in 2050 compared to the Australian Government's Bureau of Infrastructure, Transport and Regional Economics (BITRE) projections, depending on the current range of government carbon price projections. Emissions can be reduced even further by supplementing grid electricity with standalone renewable electricity dedicated to hydrogen production and storage. It is found that there is more than sufficient renewable energy resources within Australia (particularly solar and wind) to meet the significant increase in the annual electricity generation that would be required to implement this strategy.

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1. Introduction

Globally, the future of road transportation will have a crucial bearing on efforts to move towards a sustainable energy strategy. Such a strategy must on the one hand address the severe constraints on greenhouse gas (GHG) emissions imposed by the imperative to avoid catastrophic climate change, and on the other guarantee energy security in the face of declining low-cost petroleum resources. On average, more than 90% of the global transport sector relies on oil [1]. Transportation alone consumes around 49% of oil production and is the most rapidly growing consumer of the world's energy [2]. According to 2013 IEA figures [3], the transport sector is the second-largest source of GHG emissions at the global level, by emitting about 7000 Mt CO_2 (in 2011) into the atmosphere, representing 22% of global CO_2-e emissions, with road transport as the largest contributor (about 5200 Mt CO_2-e).

Australia has some of the highest road lengths and freight levels per capita in the world [4]. The fuel consumption in the Australian transport sector, which comprises some 25% of national energy use (1512 PJ/year in 2011–2012) [5], is expected to reach nearly 2500 PJ/year by 2049–2050 [6]. The gap between demand and domestic oil supply in Australia has widened in the past ten years, leading to a tripling in imports of refined petroleum products [7]. According to the latest figures on Australia's greenhouse gas inventory, the transport sector was responsible for 16.7% of total Australian GHG emissions in 2013 (557 Mt CO_2-e) [8]. While road transport contributes significantly to Greenhouse Gas (GHG) emissions, these emissions could be greatly reduced by switching from petroleum-based fuels to cleaner energy sources.

Over the past few years, a number of studies have investigated the potential role of hydrogen energy used in fuel cell or internal combustion engine vehicles in substituting for petroleum fuels in road transport. We review some of the principal studies on the role of hydrogen in transport in Section 2 of this paper.

In an earlier work, we proposed six principles to guide the development of the role hydrogen obtained from zero-emission renewable energy sources might play across all sectors in a global context, but no quantification of hydrogen's contribution by task, sector or country was provided [9]. In the present paper, therefore, we apply these principles to a specific sector, road transportation, within a specific country, Australia, and develop a quantitative scenario of the possible share of hydrogen-powered vehicles of the road transport task over the period through to 2050. Our scope is limited to the technically-feasible contribution of hydrogen-powered vehicles – predominantly HFCVs – in the various subsectors of road transport, and an examination of the viability of supply of this hydrogen by electrolysis of water using a variety of renewable energy sources. In line with our earlier strategy [9], the scenario followed here embraces complementary use of hydrogen fuel cell and electric vehicles, with the mix determined by the particular requirements in terms of driving range and power of each subsector. We estimate the contribution of increased use of hydrogen fuel cell and electric vehicles to reducing transport, and in turn total national, greenhouse gas emissions in Australia.

A key factor in our scenario is the reduction of average vehicle energy intensity (i.e. MJ/km). This reduction depends on a number of factors including vehicle size and fuel/energy efficiency. Battery power, with higher round-trip energy efficiency in the short term but lower range, would be employed for shorter trips and smaller vehicles, while hydrogen power, with superior gravimetric and volumetric energy densities, would be used for longer driving range, and for heavier vehicles. It has been beyond the scope of this study to evaluate the economic benefits and costs of this scenario, although clearly such an evaluation will in the future also be needed using a full energy-economic model of the Australian economy.

In Section 2 we reviewed principal previous studies on the role of hydrogen in transport. Section 3 provides background on the current Australian national energy policy with particular emphasis on road transport. Proposed principles underlying a sustainable transport strategy and hydrogen's role within this are articulated in Section 4. The detailed scenario for substituting hydrogen fuel cell and electric vehicles into the various subsectors of road transport is described in Section 5, and this scenario evaluated in terms of its potential greenhouse gas emission reduction supported by a preliminary cost analysis in Section 6. Conclusions for the analysis are drawn in Section 7.

2. Review of previous studies on role of hydrogen in transport

A number of studies have investigated the potential role of hydrogen energy used in fuel cell or internal combustion engine vehicles in substituting for petroleum fuels in road transport. We review some of the principal studies on the role of hydrogen in transport in this section.

Intergovernmental Panel of Climate Change (IPCC) [10] assessed scientific, technological, environmental, economic, and social aspects of the contribution of six renewable energy (RE) sources – bioenergy, direct solar energy, geothermal energy, hydropower, ocean energy, and wind energy – to the mitigation of climate change. This IPCC report confirmed that RE resources can follow the growing global energy demand unlimitedly with solar energy to be potentially the biggest contributor. The IPCC report particularly highlighted this role in transport sector (i.e. hydrogen fuel cell vehicles) to complement the utilisation of RE resources in order to reduce greenhouse gas emissions. This special report included HFCVs in the mix of favourable options for lowering emission intensity in the road transport sector, along with biomass, hybrid petrol-electric and Battery Electric Vehicles (BEVs). While the report has studied how different technologies may compete with each other, it did not specify any clear winner due to the fact that transitioning issues towards every each of these technologies are different, complex and yet unclear before they are practiced at large scales. The key complexities (i.e. for all these technologies) mentioned by the report were about technology development, cost, infrastructure, customer acceptance, and environmental and resources impacts. Brey et al. [11] mentioned similar complexities specifically associated with hydrogen technologies in the study that they conducted for Spain. The well-to-wheel analysis reported by IPCC introduced the hydrogen fuel cell vehicles (i.e. where hydrogen is generated by electrolysis) and battery electric vehicles (where electricity is generated using renewables: i.e. zero carbon grid electricity) to be the only zero-emission technologies.

Another important recent study, on the potential role of hydrogen, was conducted by Balta-Ozkan and Baldwin [12], using MARKAL model. This study in particular focused on the potential role of hydrogen in meeting the demand for transport services in UK, by excluding any analysis of the use of hydrogen in providing storage on