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The race to solve the sustainable transport problem via carbon-neutral synthetic fuels and battery electric vehicles

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Ilkka Hannula and David M Reiner

We explore carbon-neutral synthetic fuels (CNSFs) as sustainable alternatives to petroleum distillates that currently dominate the transportation sector, and show how CNSFs compare with battery electric vehicles (BEVs) as alternatives to reduce vehicle emissions.

Decarbonisation will require a shift to alternative fuels, new powertrains or a combination, although most studies have focused on one option or another. Drawing on the International Energy Agency's 2°C scenario (2DS), we frame the challenge of the '100 EJ Problem', i.e, how to: 1) maintain current (~100 EJ/yr) level of transport energy demand despite a projected 60 % increase in travel by 2050; and 2) decarbonise the remaining fuel mix to achieve significant emission savings relative to 2010. The problem is that we have already undergone numerous hype cycles associated with alternatives (Melton et al, 2016), all of which currently remain very costly, and so these different options deserve particular scrutiny. We offer what we believe is the first serious effort to compare the two major synthetic fuel options, namely advanced biofuels and electrofuels, to battery electric vehicles (BEVs).

The potential for large volumes of captured CO_2 has led many authors to explore opportunities for carbon dioxide capture and utilisation (CCU). Some options, such as enhanced oil recovery (EOR) have been used commercially for over three decades, but many other ideas for using CO_2 are uneconomic or at an exploratory stage, such as producing fuels from carbon dioxide and electricity (also known as electrofuels or 'CCU fuels'), which date back to Agrawal et al (2007). Assessments of the potential for CCU differ widely and there have been a number of recent articles that have been sceptical of the potential for CCU in general (Mac Dowell et al, 2017) and of CO_2 conversion to fuels in particular (Abanades et al, 2017). We offer a CCUS hierarchy akin to the well-known waste hierarchy to provide a clearer understanding of the available choices.

The possibility of producing electrofuels has received increased attention in the wake of growing volumes of subsidised renewables on the system (notably in Germany), in the hopes of somehow making use of the abundant, low cost electricity (at least as measured by spot prices). Although there have been a growing number of scientific studies, it is only recently that the very first assessments of the costs of electrofuels have begun to be produced in a more comprehensive fashion (Dimitriou et al, 2015; Brynolf et al 2018).

Electrofuels are not the only synthetic fuels under development. Biofuels have seen extensive deployment over the last twenty years and there has been interest in the potential for biorefineries (Alamia, et al, 2017) and of transport biofuels (Ahlgren et al 2017). Traditional bio-ethanol and biodiesel have fallen afoul of concerns over sustainability and food security, leading to what Lynd (2017) describes as a need for a 'strategic reset'. In the last few years attention in both policy and academic circles has centred on various advanced biofuels. Synthetic biofuels currently offer relatively comparable costs to BEVs, but have seen relatively little progress in terms of new investments in large-scale demonstration projects.

The two main synthetic fuel alternatives have largely been considered in silos. One of us (in Hannula (2015)) has offered a detailed comparison of the process economics of different synthetic fuels, but we felt it is vital to offer a higher-level technical, economic and policy comparison with each other and, crucially, with BEVs. We also draw on lessons from the BEV experience in setting targets as an analogue for policy measures that could be taken to encourage further deployment of synthetic fuels. The rise of battery electric vehicles (currently supported by very generous subsidies such as those outlined in Figenbaum et al, 2015) has led to studies both documenting the falling battery costs (Nykvist & Nilsson, 2015) and exploring the economics of BEVs (Newbery & Strbac, 2016). We build on these last two studies and that of Covert, Greenstone and Knittel (2016) to develop equal-cost curves that allows us to compare BEVs, biofuels and electrofuels in a clear, consistent and transparent manner under different assumptions for oil price, carbon price and battery price.

Aside from the contributions in terms of framing the problem, a few of our results are worth highlighting: although BEVs are clearly preferable for shorter ranges, CNSFs are competitive for longer ranges, even if the current BEV targets for 2022 set by the US Department of Energy are met. Thus, rather than assuming that advances in BEVs will eventually win out over the longer term, CNSFs are better placed to compete in certain niches such as longer distance or for air or marine travel. From the perspective of solving the 100 EJ Problem, scenarios that rely heavily on electrofuels are particularly problematic given their need for enormous quantities of low-cost and ultra-low carbon electricity. We find that all three options are significantly more expensive than conventional vehicles using fossil fuels, and would require carbon prices in excess of \$250/tCO_2 or oil prices in excess of \$150/bbl to become competitive.

Contact d.reiner@jbs.cam.ac.uk
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