Fuels for Transportation

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Abstract There is a need to reduce the amount of fossil energy used for transport, both because of the easily available fossil fuel is becoming sparser and because of climate concerns. In this article, the concept of “peak oil” is briefly presented. Second, a practical approach to reduction of fossil fuel use for transport elaborated by two British commissions is presented. A key feature is the introduction of electric cars. This raises the third issue covered in this article: namely, how battery technology is going to meet the increasing needs posed by the transport sector.

Keywords Oil supply · Battery · Electric car · Solar power · Lithium · Carbon dioxide

The amount of cheap, easily accessible oil is limited, and burning it increases the amount of anthropogenic carbon dioxide (CO₂). Between 50 and 60% of the oil produced is used for transport globally—in Sweden about 70% of the oil imported is used for transport. In the developed countries, transport is the second largest emitter of CO₂ (only power generation is larger). To be confident of achieving less than a 4° rise in temperature, and a strong probability of not more than 2°, by 2100, there is a need to reduce per capita CO₂ emissions to around 2 tonnes per annum by 2050. To reach this emission level one only needs to drive a car that emits 140 g CO₂ km⁻¹ (lower than the average in Sweden) an annual distance of 14000–15000 km. This is a level of personal mobility many of us take for granted, but it leaves nothing for other sources of CO₂ if we are to reach the annual two tonnes goal. Hence, what is done in the transport sector is going to decide whether or not we will be able to reduce global consumption of fossil fuels—

especially oil. It will also decide whether we will be able to come close to the goals for CO₂ emissions.

FOSSIL ENERGY IS A LIMITED RESOURCE

There is, however, another reason why we must limit the use of fossil energy, especially oil, for transport: The amount of easily available, relatively cheap oil is limited. This particular aspect has been explored extensively by Kjell Aleklett, head of the Global Energy Systems Group at Uppsala University in Sweden. Over the past 15 years he has explored the available and future oil resources and has come to the conclusion that these resources are so limited that maximal rate of production, so-called peak oil, may already have been reached. He has therefore founded an Association for the Study of Peak Oil and Gas, which can be found at www.peakoil.net.

In his presentation at the Royal Swedish Academy of Sciences' Energy 2050 symposium, Aleklett first pointed out that over the past 30 years the use of imported oil in Sweden has actually decreased by about one half, primarily because heavy oils used for heat production have been reduced by about 75%. By contrast, import of oil for use in transport has almost doubled, and comes mostly from Russia, Denmark, and Norway. Denmark and Norway are examples of regions where, according to Aleklett, the peak oil production occurred around year 2000 and production is in rapid decline. Also in Russia a peak is projected to occur now or very soon. The global pattern is more difficult to predict, but it is notable that in order to be able to predict an unabated source of oil the IEA is assuming vast undetected and unexploited oil resources to meet demand until 2030. Aleklett and coworkers recently concluded that the

“supply” of giant oilfields to meet projected oil demand may not be easy to achieve (Höök et al. 2009a).

In another recent paper Aleklett and co-workers analyze the idea that novel extraction methods would decrease the risk for oil depletion. This analysis it was found “that new technology and production methods have generally lead to high depletion rate and rapid decline. The historical trend points toward high decline rates of fields currently on plateau production. The peak production generally occurs before half the ultimate reserves have been produced in giant oil fields. A strong correlation between depletion-at-peak and average decline rate is also found, verifying that high depletion rate leads to rapid decline.” The conclusion drawn by Aleklett and co-workers is that some of the predictions of major international agencies are quite unrealistic (Höök et al. 2009b). He therefore concludes that the world’s energy production capacity has already peaked or will soon do so (see Fig. 1). One marginally positive consequence of this outlook is that the worst scenarios of IPCC for CO₂ production and hence for temperature rises cannot occur, because oil is limited.

In its “statement on oil” issued in 2005, the Energy Committee of the Royal Swedish Academy of Sciences was influenced by Aleklett’s arguments, but concluded that the ever increasing need for oil for transport would probably be met at least over the shorter term, but that the increasing global demand would mean higher prices and a need to use unconventional sources, the exploitation of which could lead to major environmental consequences (KVA 2005). International opinion is highly divided about when the peak will occur, but it is interesting to note that the UK Energy Research Center has recently clearly, stated that a peak will occur well before 2030 (Kerr 2009).

Fig. 1 Whereas WEO projects a continuing increase in oil production from a current level of about 82 million barrels/day the analysis of Aleklett and coworkers (Höök et al. 2009b) suggests that peak oil production may have been reached

REFORMING THE TRANSPORT SECTOR IS URGENT

Despite these considerations, the use of oil in the transport sector continues to grow. The implementation of new energy saving technology has so far not kept up with the increases in distance travelled. If we are to maintain the transport of goods and of people that has been so important for our current comfortable lifestyle, it is absolutely essential to reduce emissions from vehicles. The Energy Committee has concluded that several technologically simple methods can be used to decrease the use of energy by vehicles. These include decreased vehicle weight, decreased friction and drag, improved driving techniques (so-called eco-driving). In addition, increased public transport and combinations of road and rail transport provide possibilities for decreasing overall energy consumption. However, even though these methods are technically simple they do require efforts to develop new infrastructure. This means that it will take time before the full saving potential is realized. The Energy Committee has concluded that the mere introduction of the technology that exists already could reduce energy use for transport from 105 TWh in 2007 to about 60 TWh by 2050, even when allowing for a 10% increase in overall transport (KVA Mitigation statements 2010).

A major challenge is the development of alternatives to oil for long air and sea transport. To decrease the use of fossil fuels for transport, hydrocarbons of non-fossil origin such as second generation biofuels and methanol were discussed in other sessions of the symposium and will not be covered here. However, there is a problem in that the combustion engine has intrinsically poor efficiency. By converting to electric engines this fundamental problem could be eliminated. Hybrid technologies can be further improved and are especially interesting for the heavy transport sector.

To outline how the reliance on oil in transport could be reduced was the topic of the committee commissioned by the then Councillor of the Exchequer Gordon Brown, in March 2007. This “King review” was headed by Julia King, who has a distinguished background in academia and the aerospace and energy industry and is now the Vice-Chancellor for Aston University. The recommendations were published in October 2007 (http://www.hm-treasury.gov.uk/pbr_csr07_king_index.htm) and March 2008 (http://www.hm-treasury.gov.uk/bud_bud08_king_review.htm). It also formed an important background for recommendations of the UK Committee on Climate Change published in 2008 (<http://www.theccc.org.uk/reports/building-a-low-carbon-economy>).

With the global population predicted to grow to just over 9 billion people, meeting the climate goal of keeping

temperature rise below 2 degrees means that total CO₂ emissions per head can be no more than about 2.3 tonnes per year by 2050. Given the projections for road transport growth, this translates to a need to reduce carbon emission per km by 90%. Globally, today, there are about 13 cars per 100 people, a total of about 850 million vehicles. However, in North America there are 60 cars per hundred people, but the figure is less than 1 per hundred people in India and China. Even if the developing world only reaches half the level of today's US vehicle ownership by 2050, this means 3 billion cars. Some predictions suggest that we will already have reached 2 billion cars by 2020 (Sperling et al. 2008). The UK reviews concluded that, in the face of rapid increase in car ownership and distance traveled, such a steep reduction in CO₂ emissions CANNOT be achieved by simply introducing advanced technical solutions for conventional vehicles. They also concluded that switching to hydrogen as an energy carrier would be likely to involve too many technological changes at too many levels to be a truly valuable option over the near future. Changing to biofuels is in many technologically easy, but the problem is producing the necessary quantities in a sustainable way, without introducing competition with food crops or further forest clearance. Moving toward electric cars is altogether a very attractive proposition with few technological challenges (besides batteries, a subject addressed separately below). Indeed, the Committee on Climate Change advised the UK government to aim for 1.7 million electric cars and plug-in hybrids by 2020. Other European countries have also recently announced targets: the German government announced 1 million electric vehicles by 2020, the French Government twice that number.

Obviously it will be necessary to reduce the carbon intensity of grid electricity generation if a switch to electric vehicles is to be beneficial. In Sweden, we have already reached low carbon emissions to levels that the rest of Europe can only hope to achieve comparable levels by 2030 and 2050. Consequently, the introduction of electric cars should be an even higher priority in Sweden than in Britain. The arguments for rapid introduction of electric cars are:

- Some vehicles are already available: They are highly efficient, manage ranges between 60 and over 200 miles and plug-in hybrids offer even longer range extension.
- The extra load on the power system can be managed by utilizing available extra capacity and by exploitation of night-time trough and day-time dips which can also offer cost benefits.
- The infrastructure is not complex, but requires government intervention and subsidies. The sales of electric cars require a distribution net, and the cost

effectiveness of the distribution net requires usage by many electric cars.

In order to develop the market several policy measures are required including support for the development of a market, establishment of infrastructure, and setting up the necessary skills. The car manufacturers face a major challenge, since current technology is extremely well developed and new electric technology is going to provide a relatively minor part of overall profits for sometime. However, it is particularly at the level of the consumer that confidence in electric technology needs to be developed, and business models are required to make the cost structure more evidently beneficial, because of the high initial costs of the batteries. A particular concern among drivers is that current batteries provide a rather limited range, and drivers are afraid that they could become stranded with batteries drained and no possibility to recharge. Studies have shown that even current battery technology would suffice for more than 90% of all use of personal vehicles. There are also good case studies where techniques from the social sciences are used to improve driver confidence in the availability of recharging. These considerations have led to identification of the suburban commuter as the key target ground for the adoption of electric car technologies (Fig. 2).

It is very important that measures are taken very soon to introduce the new technologies, since the current life span of vehicles is close to 15 years. If only a minute fraction of today's vehicles are replaced by electric cars, it will not be possible to reach the emission goals set for the transport sector. This dilemma of the slow introduction of new technology plagues all aspects of the world's energy sector (Kramer et al. 2009).

SLOW PROGRESS IN BATTERY PERFORMANCE—BUT THERE IS HOPE

While electric cars have existed for more than a century the performance of batteries has evolved extremely slowly. J.M. Tarascon, Head of Research at Laboratoire de Réactivité et de Chimie des Solides (C.N.R.S.) at Université de Picardie Jules Verne in Amiens, compared the slow development of battery technology with Moore's law of explosive development of electronics: Moore's law for batteries is until today an almost horizontal line—their energy density (Wh/kg) has increased by a mere factor of 4 in 150 years. In contrast to submarines, whose displacement could tolerate a substantial weight of batteries, the picture for cars is a vicious circle. To carry the weight of heavy batteries the car needs to be bigger with a bigger engine which in turn needs more batteries. Conversely, if

Fig. 2 Typical car use in UK.
Data from Department of
Transport 2008

Typical car use

93% of trips and 62% of CO₂ emissions: trips less than 25 miles
97% of trips and 77% of CO₂ emissions: trips less than 50 miles

Source: DfT 2008

Suburban commuters

Commuting 1 to <100 miles

Committee on Climate Change 2009, Department for Transport 2008

one could increase the energy capacity of batteries, even a modest improvement would make a big difference in view of today's more effective electric motors with high-field permanent magnets. According to Tarascon, there is indeed light in the tunnel: the crucial point, at which the limitations to progress, has been so far is at the electrode interfaces where mechanical robustness has to be combined with high surface area and electrical current conductivity. Novel strategies based on a combination of bio-inspired

materials (organic renewable electrodes) and nanotechnology have led to substantial improvements, especially in the field of lithium-ion batteries. Thus, it is to be expected that electrodes will develop substantially in regard to materials with better conducting, surface and mechanical properties. The same is true for battery electrolytes, where polymer and gel-type electrolytes are being developed. In addition, new approaches based on lithium-air electrodes and lithium-sulfur systems were reported.

Fig. 3 A tentative future “Energy Chain” based on solar and nuclear energy converted and brought to the consumer as electricity, hydrogen, or hydrocarbon fuel

GENERAL CONCLUSIONS

A combination of the decline in oil production and monotonically increasing oil consumption will drive an increase in fuel prices and thereby at some time, in the not too distant future, allow more expensive energy alternatives to compete successfully. In particular, progress is to be expected in energy storage by novel energy-denser batteries, which is a prerequisite for environmentally friendly car transport for personal usage. Indeed, in the entire energy equation for a sustainable future, the need to develop novel ways to solve the energy storage problem is absolutely critical. Novel techniques for the rapid storage of energy are critically important if we are to develop many of the alternative sustainable energy sources such as wind and solar energy, which are inherently intermittent. It is interesting to note that a large park of battery-equipped cars that store electricity at times when it is most abundant, and hence cheapest, could provide an important part of the solution to the general storage problem.

Taken together with comments made in other contexts during the Energy Committee’s Symposium, a general conclusion appears to be that we urgently need to plan for the replacement of oil by realistic transportation alternatives. The alternative sources must be able to contribute both to *electric energy* (for train transport and—pending the development of high-energy density batteries—electrical cars) as well as to the production of *chemical fuels* needed for the propulsion of aviation transport. Chemical

fuels include methanol and higher hydrocarbons which, as suggested by George Olah, may be produced from water and CO₂ from the atmosphere, thus, in a CO₂ neutral process. In the general discussion, a plausible energy chain, from energy source to consumer, based on Olah’s proposal was presented; however, limited time for in-depth discussion prevented a thorough penetration of the implications (Fig. 3).

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