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## **Fuel cells and electrolysers in future energy systems**

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## **Abstract**

Efficient fuel cells and electrolyzers are still at the development stage. In this dissertation, future developed fuel cells and electrolyzers are analysed in future renewable energy systems. Today, most electricity, heat and transport demands are met by combustion technologies. Compared to these conventional technologies, fuel cells have the ability to significantly increase the efficiency of the system while meeting such demands. However, energy system designs can be identified in which the fuel savings achieved are lost in technologies elsewhere in the system.

This dissertation is based on the fact that the improvements obtained by implementing fuel cells depend on the specific design and regulation possibilities of the energy system in which they are used. For the same reason, some applications of fuel cells add more value to the system than others. Energy systems have been identified, both in which fuel cell applications create synergy effects with other components of the system, as well as in which the efficiency improvements achieved by using fuel cells are lost elsewhere in the system.

In order to identify suitable applications of fuel cells and electrolyzers in future energy systems, the direction in which these systems develop must be considered. In this dissertation, fuel cells are analysed in the context of energy systems that are gradually changing from the current design, with large amounts of fossil fuel combustion technologies, to a future design based on 100 per cent renewable energy. The conclusions of the analyses refer to the application of fuel cells and electrolyzers to such future renewable energy systems and should thus be seen in this context.

In future energy systems, there is a risk that improvements in efficiency are lost, because the system design is not equipped for utilising the full potential of fuel cells. If fuel cells replace gas turbines in combined heat and power (CHP) plants, the improvements may be lost, because a larger part of the heat demand must now be met by boilers. In integrated energy systems with large heat pumps, however, the decreased heat production from fuel cells at CHP plants can be met by heat pumps instead of by boilers using heat storages. In such applications, a synergy is created between the components of the system and the full potential of the fuel cells is utilised. Fuel cells induce higher fuel savings in integrated energy systems with large shares of intermittent renewable energy than in conventional energy systems. Thus, they are important measures on the path towards future 100 per cent renewable energy systems.

In locally distributed CHP plants with district heating grids, fuel cells are especially promising in terms of replacing conventional gas turbines. Fuel cells have higher efficiencies than these, also in part load. Fuel cells should not be developed for base load operation, but for flexible regulation in energy systems with large amounts of intermittent renewable energy and CHP plants. Base load plants are not required in such energy systems. With such abili-

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ties fuel cells can replace steam turbines. Synergy can be created by using fuel cells in renewable energy systems, because the number of operation hours decreases and the lifetime of the cells becomes less significant.

Hydrogen micro-fuel cell CHPs in individual households are not suitable for renewable energy systems. This is due to the high losses associated with the conversion to hydrogen and the lower regulation abilities of such systems. In a short-term perspective, natural gas micro-fuel cell CHP may spread the CHP production more than locally distributed fuel cell CHPs are capable of doing. This can potentially increase the efficiency of the energy system and displace the production at coal-fired power plants; however, there is a risk that the production at more efficient fuel cell CHP plants is displaced. In the long term, however, it should be considered which fuels such technologies can utilise and how these fuels can be distributed. Natural gas is not an option in future renewable energy systems and the demand for gaseous fuels, such as biogas or syngas, will increase significantly. Hence, fuel cell CHP plants represent a more fuel-efficient option in terms of using such scarce resources. Heat pumps are more fuel and cost-efficient options in terms of meeting the heat demand in individual houses.

Both fuel cell and battery electric vehicles are more efficient options than conventional internal combustion engine vehicles. In terms of transport, battery electric vehicles are more suitable than hydrogen fuel cell vehicles in future energy system. Battery electric vehicles may, for a part of the transport demand, have limitations in their range. Hybrid technologies may provide a good option, which can combine the high fuel efficiency of battery electric vehicles with efficient fuel cells in order to increase the range. Such hybrid vehicles have not been investigated in this dissertation.

In the short term, electrolyser hydrogen is not suitable for fuel cell applications; and in the long term, some applications of electrolysers are more suitable than others. Other energy storage technologies, such as large heat pumps in CHP plants and battery electric vehicles, should be implemented first, because these technologies are more fuel and cost-efficient. Electrolysers should only be implemented in energy systems with very high shares of intermittent renewable energy and CHP; but in a 100 per cent renewable energy system, they constitute a key part, because they displace fuels derived from biomass. In such applications, electrolysers should be developed to have the highest possible efficiency, the most flexible regulation abilities, and the lowest investment costs possible.

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