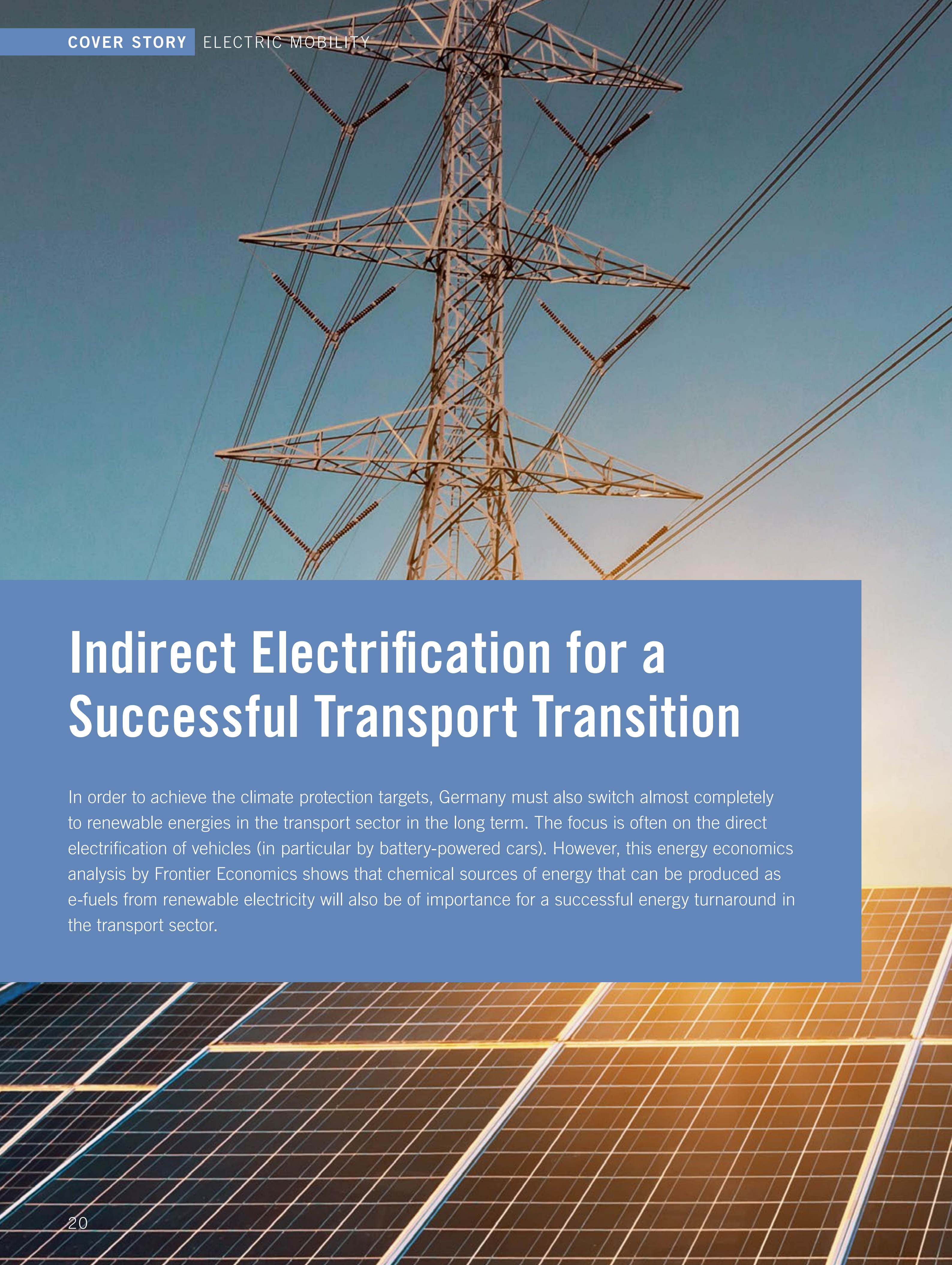

Indirect Electrification for a Successful Transport Transition

In order to achieve the climate protection targets, Germany must also switch almost completely to renewable energies in the transport sector in the long term. The focus is often on the direct electrification of vehicles (in particular by battery-powered cars). However, this energy economics analysis by Frontier Economics shows that chemical sources of energy that can be produced as e-fuels from renewable electricity will also be of importance for a successful energy turnaround in the transport sector.

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AUTHOR

Dr. David Bothe
is Associate Director with focus on energy and mobility at Frontier Economics Ltd. in Cologne (Germany).

DECISIVE TRANSPORT SECTOR FOR REACHING CLIMATE TARGETS

Germany has set itself ambitious climate protection targets: By 2050, the plan is to cut CO_2 emissions by 80 to 95 %, to below 1990 levels. While energy policy activities have focused especially on the electricity generation sector to date, it is becoming increasingly clear that the transport sector will be one of the keys to achieving Germany's climate targets – if only because of its large share of overall energy demand, **FIGURE 1**.

Of the annual final energy demand in Germany amounting to 2472 TWh (as of 2015), 728 TWh, that is around 30 %, is used in the transport sector. Of these, road traffic comprises by far the largest share (more than 70 %) – meaning that at around 500 TWh, road traffic accounts for about as much final energy demand as the entire electricity sector in Germany. Undeniably, given these figures, achieving the ambitious climate protection targets in Germany (and many other countries and regions) will be contingent on defossilizing the transport sector across the board.

ELECTRIFICATION VIA E-FUELS

In Germany, the switch to Renewable Energies (RE) is synonymous with the use of wind energy and photovoltaics in particular, given that other potential sources such as water power and biogenic energy sources have largely reached their production limits. Both remaining sources supply energy in the form of electricity. Converting the transport sector to (domestic) renewable energy sources will thus ultimately require electrifying the transport sector.

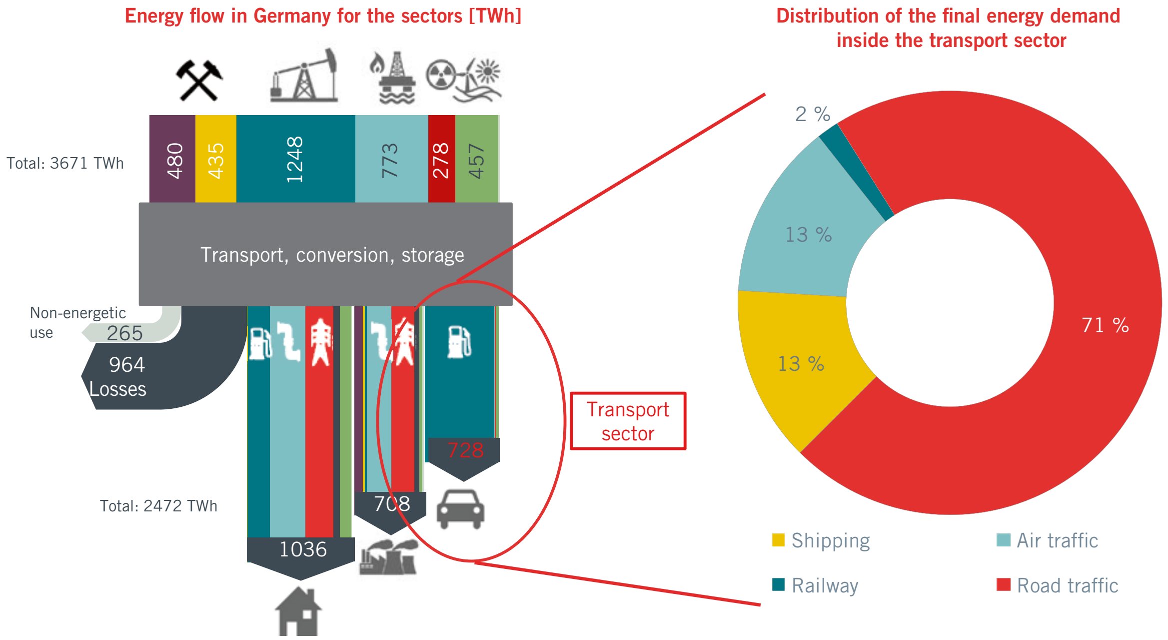

FIGURE 1 Final energy demand of the transport sector in Germany in 2015 in comparison to other sectors (left) and its distribution (right) (source: presentation of Frontier Economics based on figures provided by AG Energiebilanz e. V.) (© Frontier Economics)

Two basic options are available: direct and indirect electrification. The direct form uses the switch to a fleet which provides Battery Electric Vehicles (BEVs) or Plug-in Hybrid Electric Vehicles (PHEVs) vehicles; in this way electricity can be used directly as an energy source. A possible alternative, however, is indirect electrification: Here, so-called e-fuels (electricity-based synthetic fuels) allow electrical energy to be converted into chemical energy carriers. E-fuels, for example, can be used in conventional combustion engines.

SYSTEM COSTS AS THE DECISIVE CRITERION

In the energy policy debate, one objection which is often raised is that e-fuels need additional conversion steps that account for far greater energy losses. As **FIGURE 2** shows, direct electrification could achieve 69 % total efficiency in a well-to-wheel comparison. An exemplary e-fuel application will only bring 13 % of the generated energy "onto the road." All of which seems to point to direct electrification in contrast to the use of e-fuels, simply given by efficiency levels alone.

However, this argument fails to acknowledge the fact that the decisive criterion for using RE is ultimately not physical efficiency, but economic efficiency: Since RE are generally abundant,

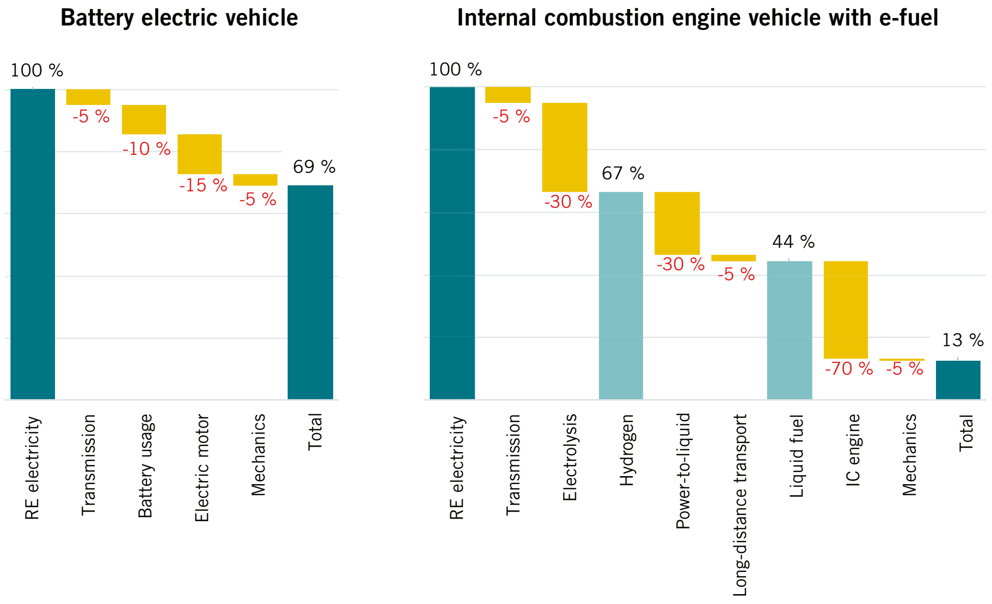

FIGURE 2 Conversion losses with exemplary drive technologies – comparison of BEV (left) and e-fuel vehicle (right) (source: presentation of Frontier Economics based on data of Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): Future Costs of Electricity-based Synthetic Fuels) (© Frontier Economics)

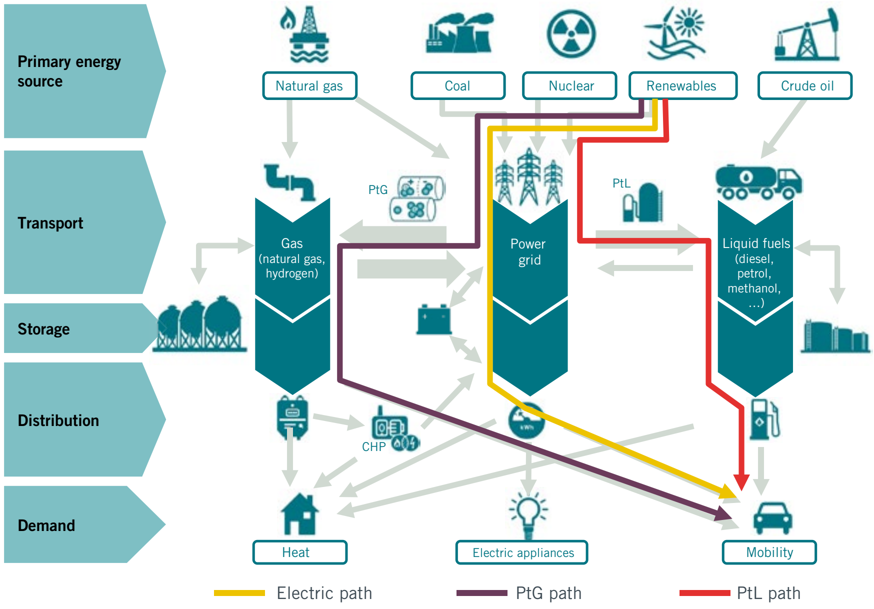

FIGURE 3 Energy supply chains in Germany with electric, Power-to-Gas (PtG) and Power-to-Liquid (PtL) path (source: presentation and data of Frontier Economics) (© Frontier Economics)

rather than efficiency, the decisive factor is which energy use path is cheapest and most technically and socially viable to implement.

So the question of which technology is best-suited for using renewable electricity for individual mobility in road vehicles must take into account every step involved in the energy supply chain (generation, conversion and transport) as well as the respective investment and upgrading requirements. Three paths are illustrated as an example in **FIGURE 3**: the use of synthetic liquid fuels, synthetically produced gas and direct electrification.

COST-CUTTING BY USING E-FUELS

This kind of systemic approach shows how conversion losses of e-fuels are often more than offset by the energy supply advantages that chemical energy sources offer. Recently, various studies [1, 2] have shown that an energy system using chemical energy sources such as e-fuels comfortably outperforms direct electrification of the heating and transport sectors in terms of cost. In the study [1], consulting company Frontier Economics shows that even if Germany targets a self-sufficient energy supply through an energy mix using e-fuels (gaseous and liquid) by 2050, investments of 250 billion euros can be avoided compared to a comprehensive electrification. In the recent Dena study [2], savings of up to 600 billion euros are predicted, for example through e-fuels, if the option of imports is also used.

The main cost advantages of e-fuels are their high energy density and the associated ease of storage, as well as the potential to use existing infrastructure and end applications for gaseous and liquid energy sources (thus avoiding expansion measures in the electricity sector). These features dictate overall system costs to a far greater extent than efficiency levels.

E-FUELS AS CRUCIAL ENERGY SYSTEM COMPONENT

FIGURE 4 shows a forecast of how electricity demand would turn out in Germany over the year (smoothed weekly) if the final energy demand were predominantly provided by switching to electrical technologies. The considerable seasonality of energy demand with two high peaks – particularly in winter – stands out, while generation of wind and solar electricity is produced relatively constant year-round (the reduced solar yield in winter tends to be offset by higher wind generation). In addition, for supply-dependent energy sources such as wind and solar power, provisions must always be made for downtime (for example days without any wind or sun). One major requirement for a renewable energy system is therefore the option to store energy in bulk (in the order of several 100 TWh) over long periods (several months).

FIGURE 5 compares the available storage technologies according to capacity and duration. It becomes clear that there is no foreseeable alternative to energy storage in chemical form – as gas or in liquid fuels – for the abovementioned requirements. Heavy technologies encumbered by fixed costs such as batteries or pumped hydro storage make no economic sense at such low turnover rates (in some cases

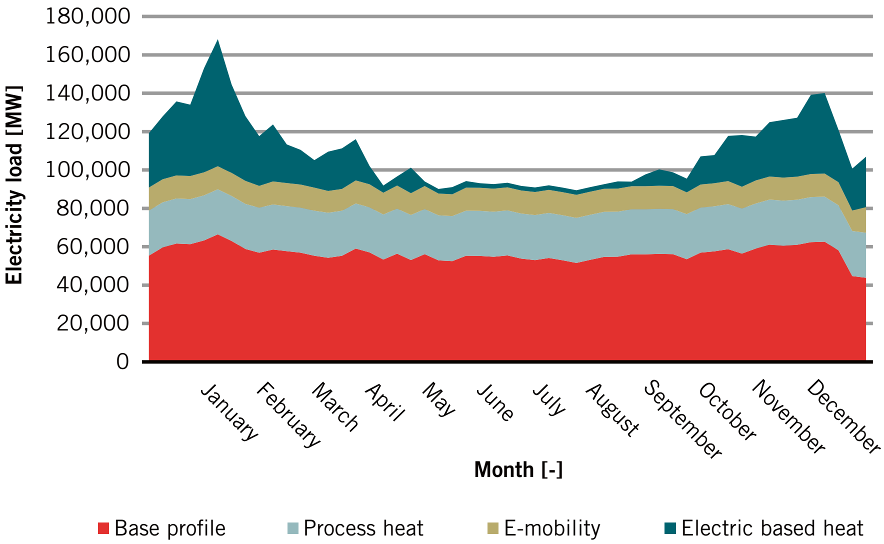

FIGURE 4 Smoothed electricity load profile for Germany with predominant electrification (source: presentation and data of Frontier Economics [1]) (© Frontier Economics)

only one storage turnover per year), despite lower conversion losses.

Leaving aside the pure cost aspect, there are also no capacities available: For example, Germany has a liquid energy source storage capacity of around 500 TWh [4], with a further 260 TWh in the gas sector [5]. The available pumped hydro storage – representing the largest electricity storage facility to date – currently provide only 0.04 TWh, equating to 0.005 % of the chemical energy storage. Nor are there any signs of battery storage getting anywhere near that figure in the near future. For comparison: In Germany today, the storage capacity of gas and liquid fuels available – solely in terms of energy content – equates to the battery capacity of over 23 billion (sic!) vehicles of the BMW i3 type.

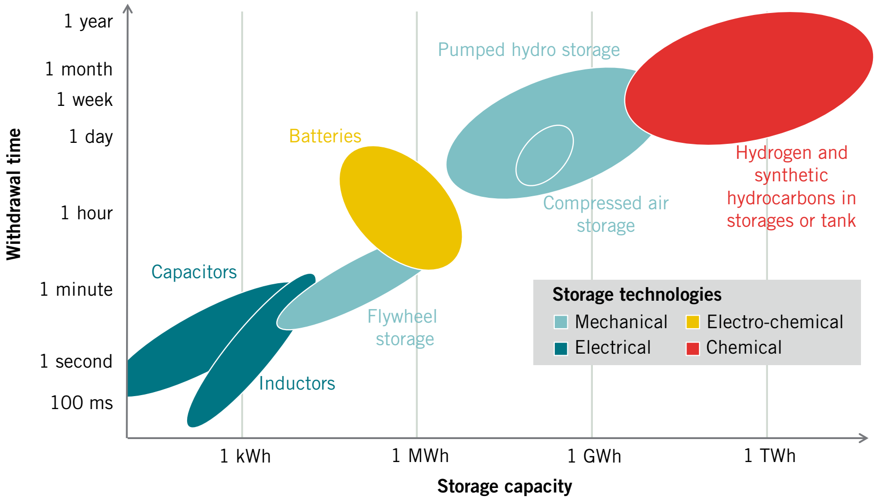

FIGURE 5 Comparison of storage technologies (source: presentation and data of Frontier Economics [1], primary source: Steiner et al. [3]) (© Frontier Economics)

AN OFTEN UNDERESTIMATED FACTOR: ACCEPTANCE

Apart from the economic and technical aspects, what people often forget is that the energy transition project can only succeed with broad support from society for this project. In this context, e-fuels offer further advantages over comprehensive electrification. Thanks to the possibility to keep using existing infrastructure for gas and liquid fuels and avoiding – what is often controversial – power line extension in the electricity sector.

Comprehensive electrification will require a considerable expansion of the grid: Computations by RWTH Aachen University show [1] that comprehensive electrification would require the length of electric circuits in the high-voltage grid to be more than doubled, equating, for example, to around 30 to 35 additional links from north to south throughout Germany. Distribution networks would face similar challenges if there were a need to install charging points nationwide.

Moreover, since low energy density hampers the transport of electricity over long distances, increasing electrification also requires a rise of the local generation of renewable electricity. In Germany, this would amount to a massive expansion of wind power (onshore and offshore) and photovoltaics: Models regularly predict an expansion of over 200 GW of onshore wind power [1]. This corresponds to a nationwide installation of wind turbines every 2.5 km, with foreseeable acceptance problems.

These few examples alone show that a comprehensive direct electrification would require a new infrastructure to be built up to levels far beyond what society would tolerate.

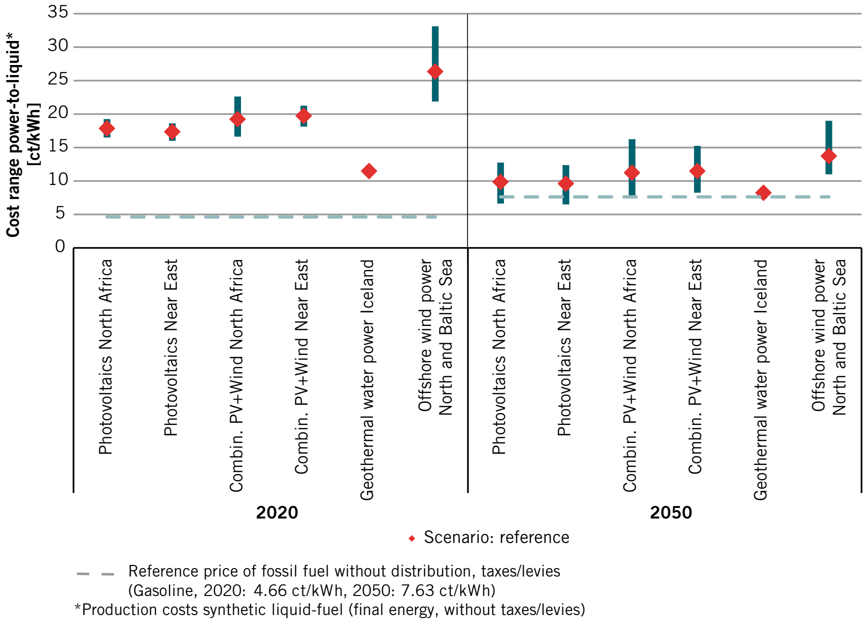

FIGURE 6 Cost range of synthetic fuels coming from different locations per input energy for 2020 and 2050 (source: presentation of Frontier Economics based on data of Agora Verkehrswende, Agora Energiewende and Frontier Economics [6]) (© Frontier Economics)

FURTHER COST REDUCTION THROUGH THE IMPORT OF E-FUELS

In this respect, it can be assumed that the import of – in future renewable – energy is needed if the energy and transport transition project is not to fail due to a lack of public acceptance. To import energy in bulk over long distances, however, chemical energy sources – similar to storage facilities – transportable via existing pipeline and tanker infrastructure are crucial. For your information: Germany meets around two thirds of its present-day energy requirements via these imports.

Importing e-fuels will also yield further economic advantages: In many regions of the world, renewable energies of sun, wind, water and biomass can be used much more easily and with fewer conflicts of use than in Central Europe – with corresponding cost advantages. Once converted to e-fuels, these energies can be used in liquid and gaseous form at comparatively low transport costs in Europe. A corresponding study [6] commissioned by Agora Energie- und Verkehrswende shows that overseas locations, such as North Africa, the Middle East or Iceland, can provide far cheaper e-fuels in the long term than German domestic production, **FIGURE 6**.

E-FUELS AN IMPORTANT PART FOR THE ENERGY AND TRANSPORT TRANSITION

In summary, a systemic approach shows that e-fuels have numerous advantages over direct electrification, including better storage capacity, scope to import and use existing infrastructure and the associated acceptance advantages. All of which more than outweigh possible disadvantages due to higher conversion losses. Even if the transport sector switches to almost 100 % renewable energies long-term, mixing electricity and e-fuels remains the most economical solution for the energy supply. This offers perspectives for the internal combustion engine, but also for alternative applications based on fuels such as hybrid systems or fuel cells.

To ensure efficient implementation of the overall energy and transport transition project in Germany, politicians and companies are called upon to realize wide-ranging solutions for de-fossilizing the transport sector and in particular, to refrain from unilaterally championing technologies such as direct electrification. In a fair competition of technologies, e-fuels in particular will contribute significantly to success.

REFERENCES

[1] Frontier Economics; et al.: Der Wert der Gasinfrastruktur für die Energiewende in Deutschland. Studie im Auftrag der Vereinigung der Fernleitungsnetzbetreiber (FNB Gas e. V.). Cologne, September 2017

[2] Dena: Leitstudie Integrierte Energiewende. Findings report. Berlin, June 2018

[3] Sterner, M.; Stadler, I.: Energiespeicher. Bedarf, Technologien, Integration. Berlin/Heidelberg: Springer-Verlag, 2014

[4] Bräuninger, M.: Die Rolle von Mineralöl als Energiespeicher in der Energiewende-Debatte. Discussion paper of the Economic Trends Research (ETR) Institute, April 2018

[5] LBEG: Untertage-Gasspeicherung in Deutschland. In: Erdöl, Erdgas, Kohle 133 (2017), No. 11, pp. 409-415

[6] Agora Verkehrswende; Agora Energiewende; Frontier Economics: Die zukünftigen Kosten strombasierter synthetischer Brennstoffe. Study. Cologne, March 2018