We need to go beyond too narrow efficiency comparisons to fully understand the potential of hydrogen

Narrow view on hydrogen vs BEV

- BEV has a high efficiency of ~73%[1] ✗
- Hydrogen has **a low efficiency of ~31%**[1] ✗
- Production of (green) electricity is sufficiently available and highly efficient with only losses of about 5% for transport ✗
- **(Green) hydrogen is not available** and production highly inefficient with losses of about 40% ✗
- Efficiency is directly linked to costs & prices ✗

End-to-end and holistic perspective

- (Green) electricity is limited in Europe, roughly 30%[2] of energy needs to be imported ➡ **Import is essential**
- Solar in Germany has 50% of efficiency compared to Africa[1] ➡ **Hydrogen is holistically viewed efficient**
- Long distance transport of gas is magnitudes cheaper than of electricity and twice as efficient ➡ **Hydrogen is better positioned for import**
- Production and transportation chains are fundamentally different for electricity and hydrogen; thus, lower efficiency is not necessarily linked to higher costs * ➡ **Costs matter**
- Hydrogen has significant advantages for heavy vehicles and long-range requirements ➡ **Usability matters**

1) See following page for details; 2) dena/ewi Leitstudie (2018);
*Also note that transportation of electricity (~7 ct/kWh) is more expensive than its production (~6 ct/kWh) in Germany, also note that transportation of natural gas costs only about 1.5 ct/kWh (~20% of electricity)
Sources: Arthur D. Little

Efficiency with renewables is not that simple and should not be used as sole determinant - The efficiency gap narrows greatly with generation in Africa

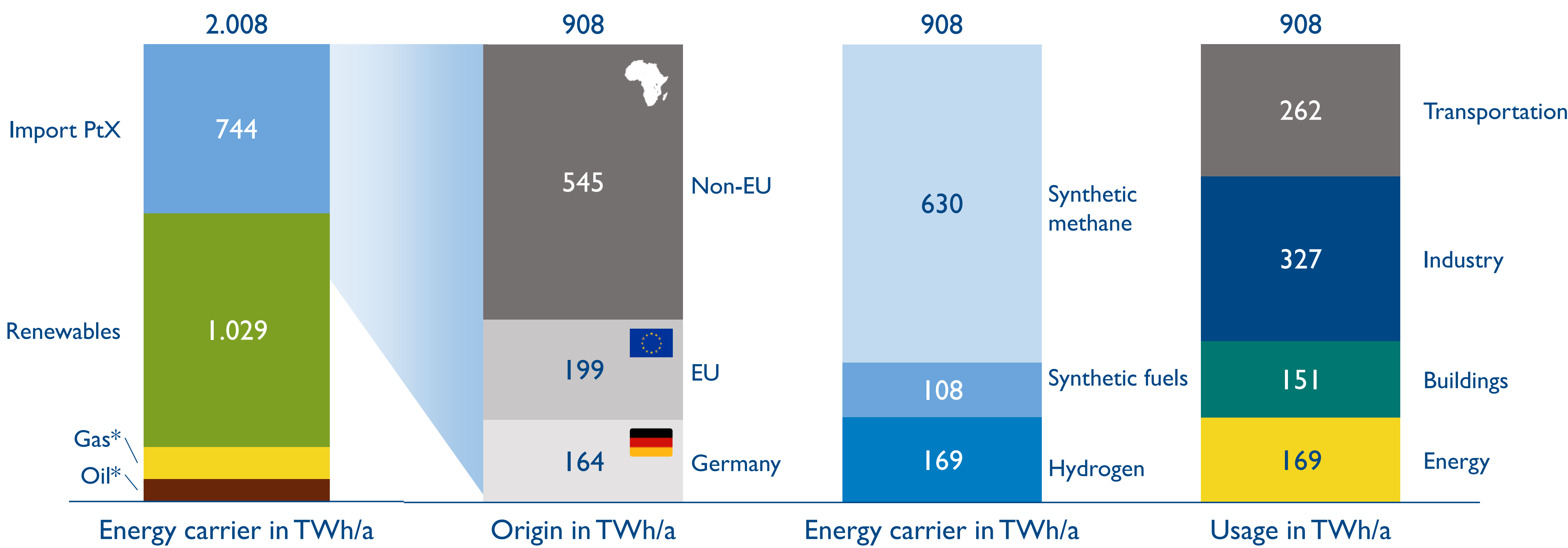
	BEV: Electricity 0% buffering	BEV: Electricity 100% buffering	BEV: Electricity import via H2	FCEV: Hydrogen	FCEV: Hydrogen
Energy at origin (1kWp solar panel for1 year)	1000 kWh	1000 kWh	2000 kWh	1000 kWh	2000 kWh
	0%	-30%[1] Electrolysis & CHP	-22% Electrolysis	-22% Electrolysis	-22% Electrolysis
Energy after production	1000 kWh	702	1560	780	1560
	-5% transport	-5% transport	-40%[2] Transport,CHP[1] & transport	-22% Transport	-30%[2] Transport
Energy at charging station	950 kWh	667 kWh	934 kWh	616 kWh	1092 kWh
	-10% charging	-10% charging	-10% charging	0%	0%
Energy in the vehicle	855 kWh	600 kWh	840 kWh	616 kWh	1092 kWh
	-15% motor	-15% motor	-15% motor	-49%[3] FC & motor	-49%[3] FC & motor
Power at wheels	**727 kWh**	**510 kWh**	**714 kWh**	**314 kWh**	**556 kWh**
Efficiency[4]	**100%**	**70%**	**98%**	**43%**	**76%**

1) 78% efficiency electrolysis and 90% efficiency CHP, assuming that heat of CHP is fully reused and in this calculation is available in form of electricity
2) Long range transport of hydrogen highly uncertain, here assumed with 10% loss (Popov et al (2019) shows ~90% efficiency for LOHC MCH transport), other methods likely with higher losses, pipeline likely with lower losses of 3%-5% (https://www.ingaa.org/file.aspx?id=10929)
3) 60% efficiency of fuel cell and 15% efficiency loss of DC/AC inversion and motor
4) Compared to base case no buffering Germany

Sources: globalsolaratlas.info, www.vcoe.at, Volkswagen, Expert interviews, Arthur D. Little

Germany needs to import 27% of energy in 2050 from non-EU countries and use it across all sectors

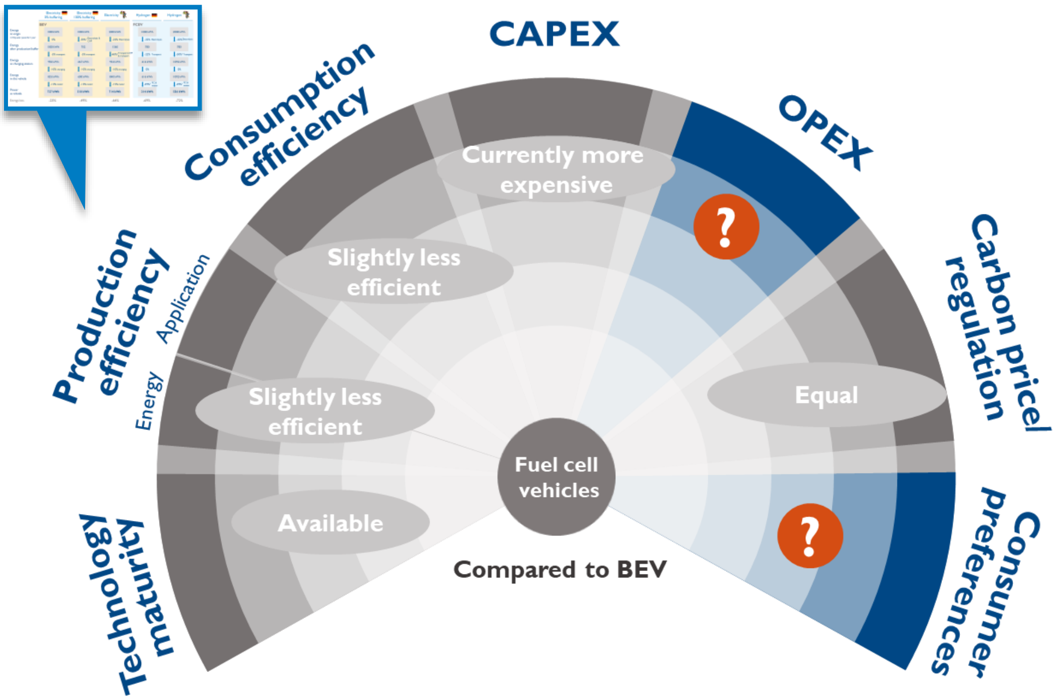
Primary energy consumption Germany 2050 in the 95% scenario



Source: dena/ewi (2018), Arthur D. Little Analysis
* conventional, biogenic and synthetic (PtX)

Green hydrogen is much needed and a reasonable energy supply. For each application costs and consumer preferences prevail in decision making

Holistic view



Source: Arthur D. Little

Conclusion

- Importing energy by means of H2 is essential and efficient
- Buffering of EU-electricity is generally inefficient (exceptions possible)
- E2E efficiency for mobile applications (e.g. trucks) is much better than assumed
- Coming from fossil fuels to renewables, efficiency needs to be rethought
- Instead of differences in efficiency, other criteria like cost and requirements are more important - plus CO2 of course
- Thus, a new holistic view on the energy system as whole highly indicates the suitability of H2 for many applications and a new gigantic upstream economy