IEooc_Methods1_Exercise1a: Energy measures and the energy supply chain

Goal: *Provide an overview of the salient energy and power measures and indicators. Calculate the different energy flows for the conversion from electricity to vehicle operation for different drive technologies, using efficiency measures for the processes involved.*

Application and exercise: Energy flows of different energy carriers and different stages of conversion in a systems context.

Energy can be supplied (converted, transported, and stored) to services via different pathways. The following scheme shows three different energy supply pathways from electricity at the point of generation to passenger vehicles (Fig. 5). For each of the three supply chains (battery electric storage, fuel cell vehicles, and synthetic fuels), the main conversion steps and their efficiencies (desired energy output divided by necessary energy input) are given.

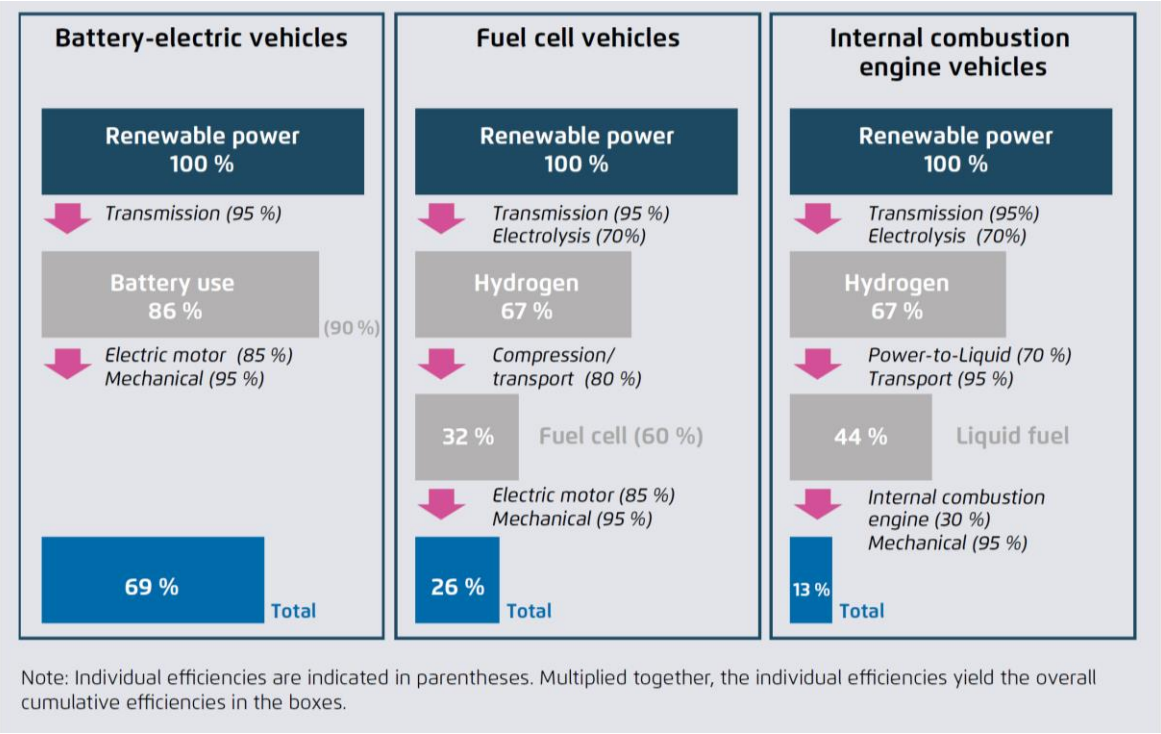

Figure 5: Efficiency in different energy conversion chains for passenger vehicles. Source: Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): The Future Cost of Electricity-Based Synthetic Fuels.

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Task: For a trip length of 1 km (longer distances simply scale with the distance), develop a MEFA system definition for each case and calculate the following energy flows: (1) the primary energy, (2) the final energy, and (3) the useful energy! Re-calculate the system efficiency as useful energy per primary energy! (already shown in Fig. 5) Interpret your findings!

Assumptions and additional data: Figure 5 only contains %-values. One reference energy flow must be given to scale the %-values to values in MJ: Assume that the final energy demand for battery-electric vehicles is 0.7 MJ/km (purchased electricity!). Assume further that the useful energy to propel the vehicle is the same for all cases! A fourth case can be constructed for internal combustion vehicles operated with gasoline as final energy, where 1.25 MJ of crude oil are needed for 1 MJ of gasoline.

Sample solution: First, the different conversion steps shown in Fig.5 are described as processes in a MEFA system (Fig. 6). Here, energy conversion efficiency data are provided for the four processes, electricity generation, transmission & charging, the vehicle battery, and the electric engine & drive train, so these are included in the system with the connecting energy flows and losses at each stage.

Then, the final energy flow is identified as the flow from 'transmission & charging' to 'vehicle battery' and quantified as 0.7 MJ (final energy for 1 km driving).

> **To convert from % to MJ, we need both: A distance driven and an energy unit.**
> **All calculations are performed for a distance of 1 km driven.**
> All energy flows scale proportionally with the distance driven. For 100 km, all energy flows are 100 times larger etc.
> The base value to get from the % to the MJ level is the given final energy consumption of the battery electric vehicle of 0.7 MJ/km, which is the energy that is paid for, which is taken from the grid and loaded into the vehicle's battery.

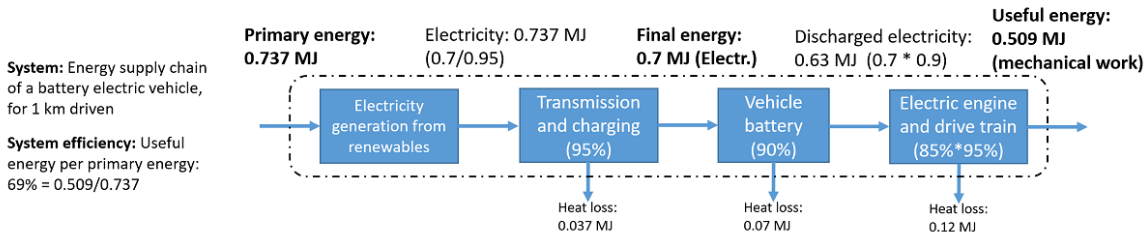

Figure 6: Energy flows for different drive trains: Solution for battery electric vehicles.

Starting from the final energy flow, the other energy flows are quantified using the %-values for the process efficiency given in Fig. 5. Energy values are calculated by multiplication (from final to discharged to useful energy), by division (from final to primary energy), and by the energy balance of the different processes (for the losses).

The calculations for the other to drive trains are done accordingly (Figs. 7 and 8). In each case, the reference flow is the useful energy of 0.509 MJ/km, which we assume is the same for all vehicle types.

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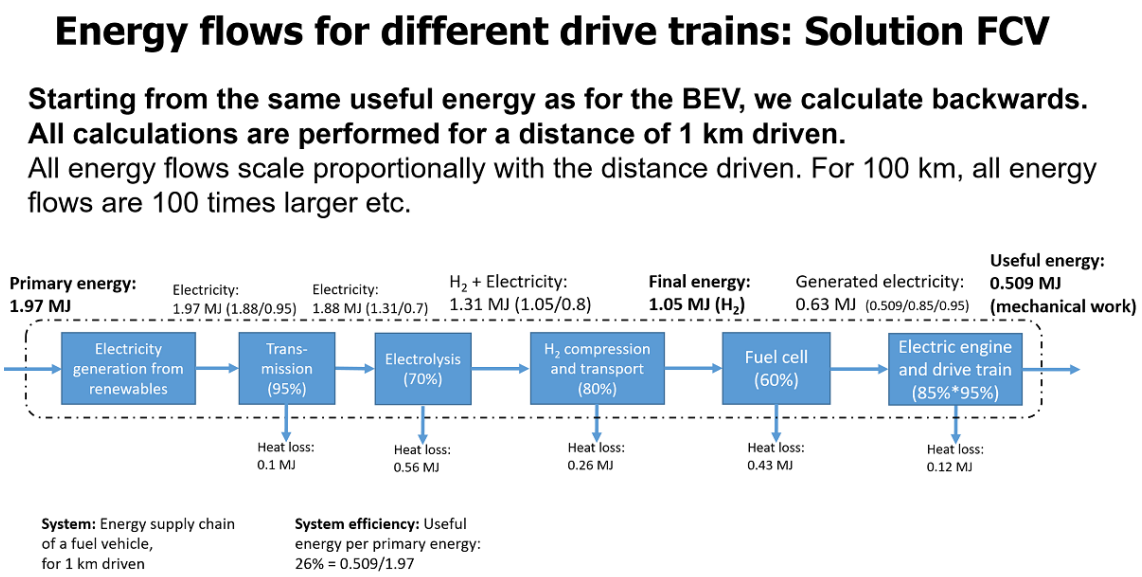

Figure 7: Energy flows for different drive trains: Solution FCV

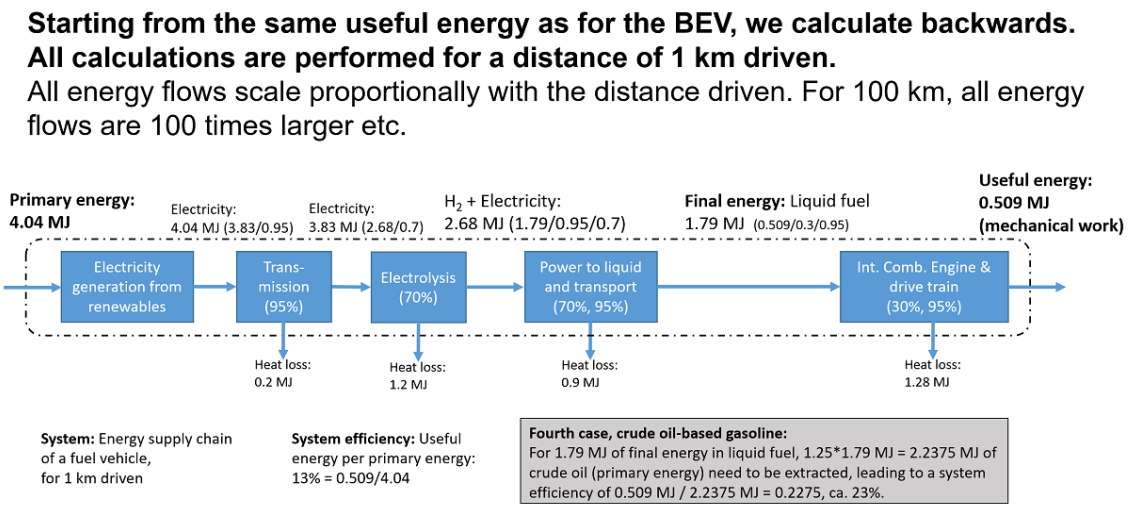

Figure 8: Energy flows for different drive trains: Solution ICE-V (synfuel)

The three systems in Figs. 6, 7, and 8 show the different energy flows at the different stages of conversion. Each energy flow is relevant, as it determines the size and the cost of the conversion device supplying it. Table 1 below lists the salient energy flows and the system-wide efficiencies.

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Table 1: Salient energy flows and the system-wide efficiencies for the four drive trains analysed. Functional unit: 1 vehicle-km driven.

	Primary energy, MJ	Final energy, MJ	Useful energy, MJ	System-wide efficiency, %
1. BEV (battery)	0.737	0.7	0.509	69
2. FCV (fuel cell)	1.97	1.05	0.509	26
3. ICEV-synfuel	4.04	1.79	0.509	13
4. ICEV-gasoline	2.24	1.79	0.509	23

The four different energy supply chain – drive train combinations have strikingly different overall energy conversion efficiencies. The costs and land use of the renewable options 1-3 directly scale with the primary energy flow, and there is almost a factor of six between the battery electric and the synfuel option. This huge difference cannot be ignored by policy makers. While other trade-offs, like material use, critical materials, infrastructure requirements, convenience for consumers also need to be taken into account, the much higher system efficiency (factor 5-6!) provides a strong case for battery electric vehicles. Demand-side solutions (such as by different urban design and transport modes) can be used in addition to BEV+RE to reduce the vehicle fleet size, which helps mitigate resource consumption of the vehicle fleet.

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