How thermoelectrics improve the efficiency of cryogenic hydrogen supply chain

Development of a Test Bench for Cryogenic Thermoelectric Generators

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Introduction

Why cryogenic energy carriers are needed

In 2016, the EU imported around 53% of its energy needs [2]. In the future, the energy needs will be met by renewable sources in order to meet climate change targets. However, the EU's capacity for renewable energies is limited. Therefore, the EU will continue to import a large proportion of the energy it consumes. Established import routes based on chemically energy such as hydrogen or natural gas can still be used efficiently. To achieve high density for transport and storage, energy carriers such as hydrogen (LH2) or natural gas (LNG) are liquefied at low temperatures.

Cryogenic transport energy challenges

The energy required for liquefaction is up to 18% of the caloric value of hydrogen [2]. It is therefore essential to recover some of this energy in order to enable an efficient supply chain.

Increasing the efficiency of the entire supply chain

The utilisation of a Thermoelectric Generator to regasify LH2 or LNG enables the conversion of a part of the required heat flow into electrical energy. In contrast to the generation of heat flow for LNG regasification by burning LNG, for instance, this heat flow does not have to be generated separately. Instead, it can be sourced from the environment at a comparatively low Temperature level. The combined application of both processes enhances the overall efficiency of the renewable energy supply chain, see figure 1.

$$\eta_{TE} = \underbrace{\left(1 - \frac{T_k}{T_h}\right)}_{\text{Carnot}} \cdot \underbrace{\eta_{ZT}}_{\substack{\text{ZT efficiency} \\ f(\text{material, temperature})}} \qquad (1)$$

	Hot side	Cold site	ΔT	η_{th}
Cryogenic use	20 °C	-250 °C	270 K	**92%**
Conventional use	290 °C	20 °C	270 K	**48%**

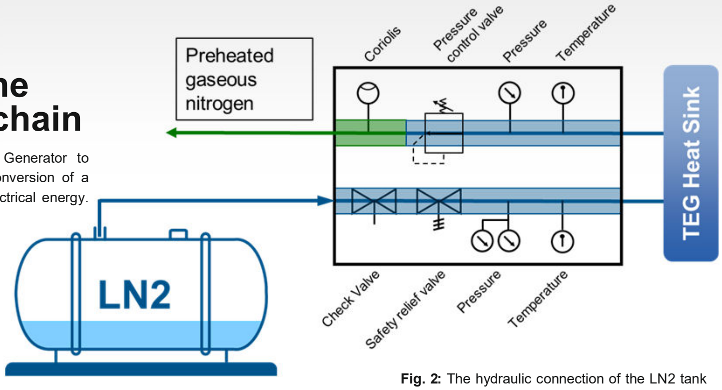


Fig. 2: The hydraulic connection of the LN2 tank and the measurement and control setup for the investigations on the Cryo-TEG.

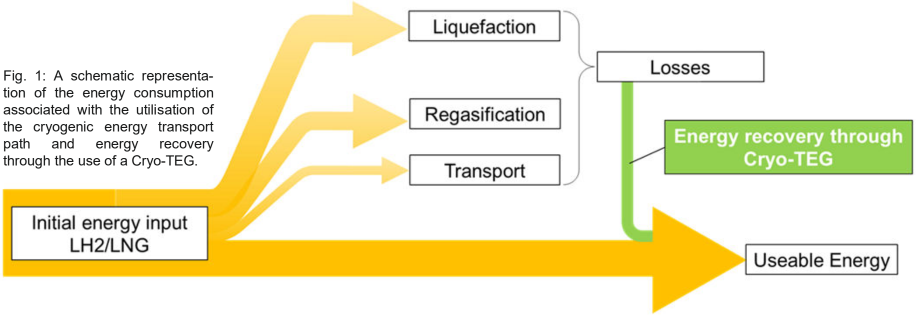


Fig. 1: A schematic representation of the energy consumption associated with the utilisation of the cryogenic energy transport path and energy recovery through the use of a Cryo-TEG.

Methodology

Test bench for cryogenic TEG

The cryogenic test bench establishes the boundary conditions for testing a wide range of cryogenic applications. These include LH2-powered vehicles (on- and offroad), LH2-powered aircraft, hydrogen filling stations, LNG terminals, and other infrastructure and vehicles. As shown in Fig. 2, the cryogenic TEG prototype is supplied by a nitrogen (substitute for LNG and LH2). The pressure and mass flow can be set and monitored using the control system. In combination with the temperature measurement, an energetic evaluation is possible. The cryogenic test bench, see Fig. 4. The cooling capacity is set by adjusting the pressure and mass flow rate of the liquid nitrogen. For example, with 3 g/s LN2, a temperature of around -150 ℃ can be achieved at the inlet of the TEG prototype.

Results and Discussion

Cryogenic TEG prototype with 0.5 W/cm² power density

The generic - to ensure technological transferability for the wide range of possible applications - Cryo-TEG is designed for a liquid nitrogen mass flow of 6.5 g/s LN2. A mean power density of 0.5 W/cm² is achieved in the simulation.

The heat flux into the cryogenic fluid, e.g. LH2 or LNG is utilized to vaporize the fuel and makes it usable for a combustion engine or a fuel cell. The utilisation of a Cryo-TEG enables the heat flux to be maintained at an ultra-low temperature level, in contrast to conventional applications. This results in a notable enhancement in Carnot efficiency, as shown by formula (1). This enables the conversion of heat flow into electricity with an efficiency of up to 7.8-13.8%.

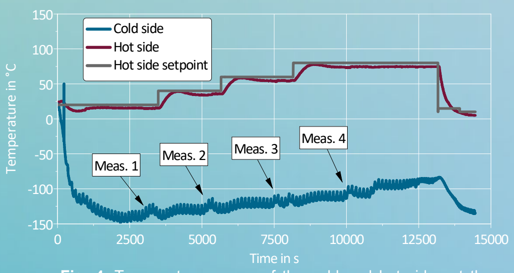


Fig. 4: Temperature curves of the cold and hot sides at the inlet of the TEG prototype from the start of the test procedure.

Fig. 5: The hydraulic connection of the LN2 tank and the measurement and control setup for the investigations on the Cryo-TEG.

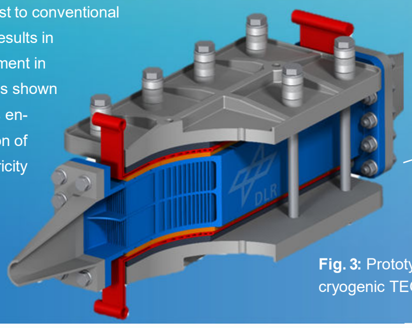
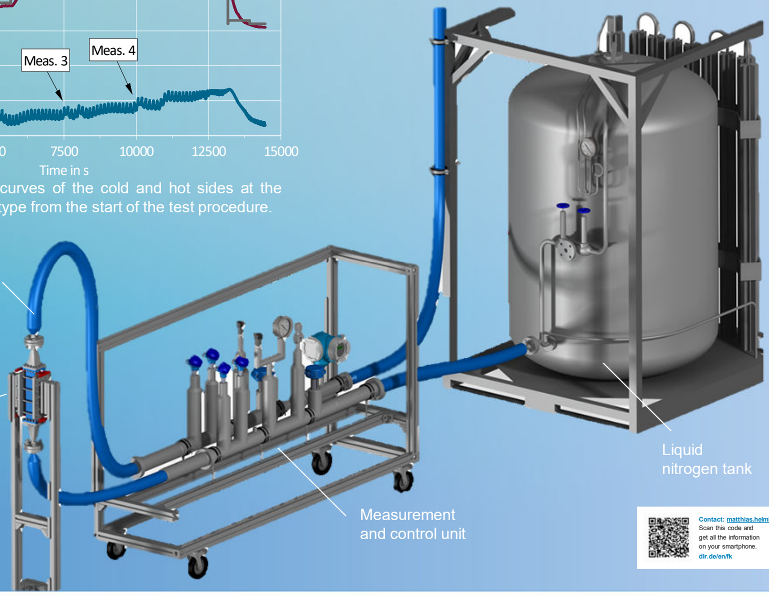


Fig. 3: Prototyp of the cryogenic TEG



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[2] BPB; Energieimport der EU-28; 9 July 2019; https://www.bpb.de/kurz-knapp/zahlen-undfakten/europa/135830/energieimport-der-eu-28/