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HEIONTEC FAQ

Scientific evaluation

in light of generic AI assessments

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## 1. Why generic AI assessments can quickly prove to be wrong when it comes to innovations

Systems such as ChatGPT, Claude, or Gemini evaluate data using heuristic patterns ("electricity from ambient heat," "regeneration," "permanent") and assess it based on established and digitally most frequently found explanatory models (battery).

This then leads to comments such as "If the cell actually shows a voltage over a period of years, this is most likely due to very slow chemical decomposition of the electrodes (as in a normal battery)."

This is only correct if the system is based on a mechanism similar to that of a battery.

HEIONTEC wants to commercially exploit an innovative TEC-G cell. It is in the nature of innovations that they go beyond established systems and deviate from them.

Current scientific publications describe systems in which chemical reactions have been identified as the driving force for/by temperature changes.

Without reference to current, relevant literature, established and predominantly detectable battery reactions are considered 'correct' because there is more data available on them. This then results in an assessment in which established AI systems are led to the terms 'perpetuum mobile' via conventional battery mechanisms.

Consequently, thermo-electro-chemical systems are uncommon—but well known and researched.

The comment "If it's that simple chemically, then you should be able to build refrigerators with it, right?" is correct here; concepts for 'chemical refrigerators' have indeed been published in recent years. Below are a few articles that illustrate the current state of data:



## 2. Relevant literature

Overview 5 documents attached to this FAQ:

Ref.	Publication date	doi / Publisher / Journal / Short title
a1)	20190926	<a href="https://doi.org/10.1038/s41598-019-50118-y">https://doi.org/10.1038/s41598-019-50118-y</a> nature Scientific Reports   (2019) 9:13945 <b>"Electrochemical Redox Refrigeration"</b>
a2)	20211221	DOI: 10.1039/d1cc06121 Royal Society of Chemistry Chem. Commun., 2022, 58, 1203 <b>"thermoelectric energy harvesting from temperature fluctuations"</b>
b)	20220802	<a href="https://doi.org/10.3390/su14159483">https://doi.org/10.3390/su14159483</a> MDPI Sustainability 2022, 14, 9483 <b>"...Thermo-Electrochemical (TEC) Cell ... for Harvesting Low-Grade Heat Energy: A Review."</b>
c)	20241014	DOI: 10.1039/d4ya00368c Royal Society of Chemistry Energy Adv., 2024, 3, 2877 <b>"Evaluation of redox pairs for low-grade heat energy harvesting with a thermally regenerative cycle"</b>
d)	20251021	DOI: 10.1039/d5ra04858c Royal Society of Chemistry RSC Adv., 2025, 15, 39847 <b>"Thermodynamic insights into the interplay between calcium and iron(II) hydroxycarboxylates: impacts on solubility, speciation, and bioavailability"</b>

About the content:

a1) describes an electrochemical refrigerator with a cooling potential of around  $0.5\text{W}/\text{cm}^3$

a2) describes a solid-state-based TEC-G cell with  $P_{\text{peak}} \sim 30$  microwatts (Fig. 1d)

b) provides an initial overview of TEC-G systems

c) explains the principle of thermally regenerating redox cells, focusing on Fe(II)/Fe(III) systems

d) explains thermodynamics for endothermic, entropy-driven Fe(II) dissolution in complexes



### 3. Evaluation of the data situation and data sources

a1), a2) and b) illustrate that by mid-2022, TEC-G cells were already familiar and their suitability as a cooling reaction (a1)), as a chemical version of a Peltier element (b)) and as an energy source for electronics during temperature fluctuations (a2)) had been recognized.

Regenerative cycles for redox pairs are described in a 2024 review article as purely research subjects (c)); by that time, no laboratory prototype had been able to establish itself or gain acceptance as a product. A redox potential of 0.68V is specified for Fe(II)/Fe(III) combinations (Table 1, row 1).

Consequently, regenerative cycles for redox pairs can be assessed in 2024 as 'little researched and not yet economically relevant'.

Document d) is biochemically oriented and deals with the improved bioavailability of minerals; it is therefore outside the electrochemical field, but provides relevant thermodynamic information: The dissolution of Fe(II) ions via complexes (here: hydroxycarboxylates) is an endothermic process that is driven by entropy (see 1, abstract, image citation below):

higher solubility than iron(II) lactate. The thermodynamic analysis revealed that the dissolution processes were endothermic and entropy-driven. Additionally, the presence of iron(II) ions was found to enhance

Furthermore, the solubility of the metal complexes shows a proportional dependence on temperature: as the temperature rises, more salt is soluble.

Established AI systems will not perform a supplementary evaluation of documents a) to c) with document d) for general questions. The fundamentally different orientation of document d) makes this difficult.

The HEIONTEC TEC-G cells are based on the Fe(II)/Fe(III) redox pair; measurements by two different universities on parallel and also externally manufactured cells confirm consistency with the parameters according to document c).

Furthermore, complexing organic macromolecules are included.

When Fe(III) ions are converted to Fe(II) ions during current flow, the complexation of Fe(II) ions causes an endothermic process, as is known from d).

Conclusion: A temperature drop during current consumption is plausible and known from document d); the temperature will drop until no more Fe(II) can be formed/dissolved. Without external heat input, no more current will flow.

#### 4. Response from an AI focused on relevant data

One of the established AI systems was prepared with the documents listed.

The following question was asked:

Can electricity be generated in cycles using an endothermic reaction according to (d) as part of a thermally regenerating system according to (c)?

In addition to the usual warnings and requests to check further assumptions, the AI came to the following conclusion after an unusually long analysis of several minutes:

"Yes – but only if (d) is embedded in a real  $T$ -gradient system such as (c):

*Role of the endothermic reaction according to (d):*

*An endothermic reaction (e.g., an endothermic, entropy-driven solution or complex formation as in Ca/Fe hydroxycarboxylates with  $\Delta H > 0$ ,  $\Delta S > 0$ ) can in principle represent the "charging stage" of such a cycle:*

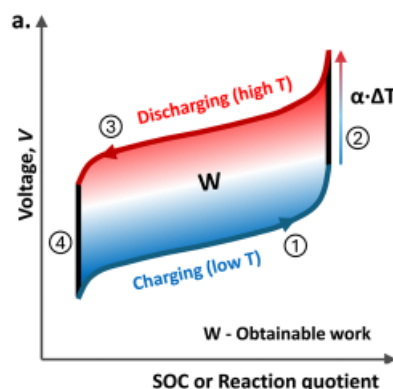
*The prerequisite is that this endothermic reaction is coupled to at least one electrochemically active redox pair with a finite thermogalvanic coefficient ( $\alpha = \partial E / \partial T$ ), so that the cell voltage between  $T_{\text{high}}$  and  $T_{\text{low}}$  changes measurably and a charging curve at  $T_{\text{high}}$  and a discharging curve at  $T_{\text{low}}$  are obtained (see Fig. 1 in the TREC paper).*

*Conclusion for your question*

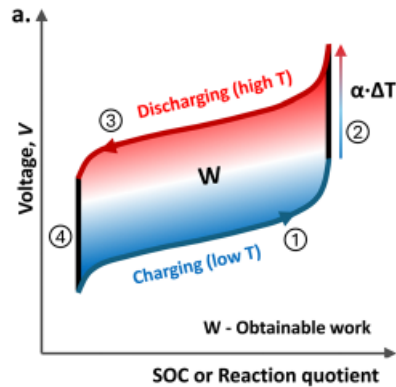
*Yes: An endothermic reaction such as (d) can be used as part of a thermally regenerating system such as (c) to generate electricity in cycles if there are at least two temperature levels ( $T_{\text{high}} > T_{\text{low}}$ ), (d) changes the chemistry/composition of a redox-active system in such a way that the cell voltage changes with  $T$ , and the reverse reaction in the cold phase closes the system again.*

"

In addition, Figure 1 of document c) is reproduced here:



## 5. CONCLUSION



Accompanying Figure 1 of document c), two ion-selective, inert electrodes are additionally assumed, which electrically couple two chemical equilibria with each other.

Reason: Unstable mixtures and electrolytes regularly dissolve/coat the electrodes in a short circuit within 48 hours to at least 80%; stable, inert electrodes show metallic luster/unchanged surfaces for months despite short circuits.

Explanatory model: At room temperature, Fe(III) can be reduced to Fe(II) on an inert, C-based electrode if the electrons at the counter electrode are obtained from macromolecules through the reaction  $H = H^+ + e^-$  and can flow to the C-based electrode.

According to Figure 1 above and document (d), the C electrode cools down until a cold, saturated Fe(II) solution is present; at the same time, the voltage drops to 0. There is then a thermal and chemical gradient between the electrodes.

The system then regenerates at low temperature, absorbs heat from the environment, and returns to its initial state.

In this respect, the system is consistent with existing explanatory models and known data and is also considered feasible by AI systems based on relevant literature. Current research is focused on verifying and validating the caloric effect, life expectancy, and cycle stability in order to identify initial, quickly addressable markets more specifically.



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