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Conceptual differentiation of heat: The entropic promise of a post-Pyrocene world

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ABSTRACT __ Thermodynamics is thought to result from the conceptual differentiation (CD) of heat into energy, entropy, and heat. The form of CD that took place in the 19th century will be referred to as the CD of the "*energy-centric conception of entropy*" project. The conception is otherwise known as the concept of available energy (also, free energy, or exergy). The defining goal of the project is the harvesting of free energy for the maintenance of all living organisms and all human institutions. This leads to a fundamental "free energy" conundrum of human existence: to thrive in style, we need abundant free energy; such pursuit of individual wellness increases the *speed* of the whole (of which individuals and their environment are parts) falling into the abyss of chaos. We argue that the free energy conundrum results from *imperfection* in the CD of the energy-centric project. This paper and a previous one carry out CD to its logical conclusion; with that, it articulates a new thermodynamics (referred to as Unified Classical Thermodynamics [UCT]) under the masthead of "*entropy-centric conception of entropy*," i.e., "entropy growth drives all macroscopic processes," including reversible processes-like in-deterministically, suggesting solutions to the fundamental conundrum of human existence.

1. **Introduction:** the 1842-1872 MEH revolution and does "equivalence" imply "causation"?

In an address to the British Association in 1854, William Thomson declared that while physics has been the science of force, Joule's discovery of the conversion of heat into work is leading to "the greatest reform that physical science has experienced since the days of Newton," arguing that energy is becoming the primary concept on which physics is to be based [[1]: p. 58]. Physics is still the science of force, but Thomson had a point there: as a science of force, physics is not a complete theory of the microscopic and macroscopic worlds, missing a large part of macroscopic phenomena; to become that kind of theory, the primary concepts of physics need to be force *and* "energy as a generalized concept" [[2]: p. 327]. The missing part is the "energy consumption"-driven phenomena, the governing law of which is the first law of thermodynamics, "*energy can be neither created nor destroyed; only the form in which energy exists can be transformed from*

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one form into another" [3: p.44; 4]. The law statement is a sweepingly powerful statement evidencing that Thomson was correct that there was something new beyond force. But is it energy? More precisely, what does energy consumption mean? Since energy can be neither created nor destroyed, what is consumed is not energy but some form of energy; energy of one form is consumed to become energy of another form. So, the operative "part" of the above first law statement is "*the form in which energy exists can be transformed from one form into another.*" Since energy form and the direction of energy transformations are the purview of the second law of thermodynamics, this first law statement is not a statement of the first law per se but a statement of the combined first and second laws, with its essence being, in fact, the second law.

This paper begins with the assertion that thermodynamics has been led astray with "first law statements" and "statements concerning energy, and/or heat and work" that are really statements with core messages concerning entropy. Our focus on energy has been very much a misdirected project. The new physical idea discovered by Joule and Thomson was not energy, but entropy growth.

This assertion can be introduced from another viewpoint with a related example, a paper by Job and Lankau provocatively entitled "How harmful is the first law?" [5]. It turns out that Job/Lankau's critique is not directed at the first law if the law is defined strictly as a law of conservation of energy. Their critique is against the principle of *mechanical equivalent of heat* (MEH): "We are not questioning the principle of the conservation of energy, but its special formulation as part of the First Law of Thermodynamics—with the *equivalence of heat and work* as its central idea since 1850" [5: p.171]. That is, the first law is not the source of controversy if the law serves, strictly, as a *closure condition* for all thermodynamic processes or transformations. The title of the paper should have been "How harmful is the principle of the mechanical equivalent of heat?" MEH is the principle that motion and heat are mutually interchangeable and that a certain amount of work can produce the same amount of heat and vice versa. That is, whereas a first law can be defined as a closure condition without involving a causal relation of heat producing work, MEH is the principle claiming, by default, that a given amount of heat produces the same amount of work, a relation between cause and effect.

Now, it is important to get the timeline of *MEH* and the *first law* right. The corresponding issue is the origin of the concept of MEH: is it a consequence of some general idea (in this case, the principle of energy conservation [PEC]) or does the general idea derive from the establishment of MEH? In an influential 1959 article by Kuhn, "Energy conservation as an example of simultaneous discovery," Kuhn implies, as the title alludes to, that the 'formulation of PEC' conceptually preceded 'applications,' the principal example of which is MEH. Kipnis, in a masterful history of science study [6], contended otherwise with the conclusion:

> the development of PEC process did not start with a formulation of a general principle of energy conservation which stimulated the development of particular concepts, such as mechanical equivalent of heat. It will be shown that the opposite happened: it was the development of mechanical equivalent of heat which led to the general principle of energy conservation (GPEC) [6: p.2026].

The existence of the Kipnis article itself bears out that the development of MEH was the gripping "confrontation" narrative deserving the detailed and balanced scholarship of Kipnis. Once the development of MEH between 1845 and 1872 (we shall refer to this as the 1842-1872 MEH revolution) was successfully completed, quite a few scientists, as witnesses to the captivating drama, were becoming receptive to the idea of energy conservation, as Kuhn observed, calling it an example of simultaneous discovery.

We may make the following observations at this point in the story. The setting of the MEH story should include (an earlier) Carnot's competing theory of steam engines, which we shall refer to as the *co-existence theorem* or the *second fundamental theorem,* while the MEH in a *refined* form will be referred to as the *equivalence theorem* or the *first fundamental theorem* (the latter names, "the first…" and "the second…," are names used by Clausius [7: p.111]). With this background setting, our story is better interpreted, rather than as the evolution of MEH into the first law, as the reconciliation of Carnot's and Joule's competing ideas or their synthesis into TWO laws of thermodynamics, [8: Ch. 16], the first law and the second law. One insightful way to describe the synthesis project is to consider the investigative object at the beginning of the project to be *caloric*, the original notion of heat. In terms of heat, the original heat, therefore, the synthesis has been identified by Tisza as a project of *conceptual differentiation* (or bifurcation or splitting) of caloric (the original heat) into energy, entropy, and heat (the modern heat as a disorganized form of energy). [9; 10: p.22, pp.30-36] From the point of view of conceptual differentiation, the successful outcome should be the synthesis of the MEH and Carnot's co-existence theorem into the first fundamental theorem and the second fundamental theorem, which led to the clear formulation of the entropy law.

But this was not what happened: Instead of the refinement of the MEH cleansed of its heat to work causation implication and clear-cut differentiation of terms, we have an energy physics with a mixed bag of terms. Heat, or caloric, became the modern heat, Q, whereas a part of the original caloric became in the modern first law something represented by the "thermal component of the internal energy U." Instead of entropy being the centerpiece of the theory, free energy occurs in such a role (see Table 1 below). Both the MEH that Job and Lankau rejected and the first law statement in Paragraph One are deficient for the same reason: the idea of "equivalence" is not cleansed of the implication of "co-existence" or "causation" (see Sect. 2).

The main object of the present paper is the assertion that together with the two fundamental laws resulting from it, ***conceptual differentiation*** in itself is the cornerstone of the edifice of thermodynamics and, as the two law-statements in orthodox thermodynamics are found not to adhere to the conceptual differentiation requirement, steps for correcting deficiencies in orthodox thermodynamics are given to transform it into a coherent system of Unified Classical Thermodynamics (UCT), with entropy and entropy growth as its centerpiece. With the entropy-centric foundation secured for UCT, the introduction of *entropic indeterminateness* is made in Sect. 3 to be its signature characteristic, differentiating thermodynamics, as the science of "energy consumption"-driven phenomena, from the mechanical sciences. Sect. 4 offers an example of UCT's new application, providing a sustainable path for real "reversible-like" approaches for a post-Pyrocene world.

2. "Theorem of Equivalence of Transformations" vs. "the Second Fundamental Theorem"

The foundation of energy physics was laid by Thomson in 1852 by introducing the concept of available energy, [[11]: pp.511-514], also known as free energy or exergy. It can be said that the centerpiece of orthodox thermodynamics is free energy. (Mechanical energy makes the heavenly bodies go round. But energy, once energy was introduced as a general concept with mechanical energy as one example of it, does not make the bodies on the Earth go round; for example, little of the humungous amount of energy in the oceans can serve that purpose.) For the discussion of "energy consumption"-driven phenomena, therefore, the common saying of "energy makes the world go round," which is nonsensical, should be replaced with an improved version, "free energy makes the world go round."

Though the improved version is still problematic, free energy is based on the premise that only a part of energy is theoretically available for producing mechanical work; therefore, free energy should be by definition smaller than energy. The awkward fact is that this is not always true. [[2]: p. 331 (the paragraph at the bottom of the page begun with "A comment on the meaning of 'free')]. We may refer to the free-energy-as-the-centerpiece thermodynamics as the thermodynamics based on an "energy-centric conception of entropy":

> Though Thomson did "not even consecrate a symbol to denote the entropy" in his body of scientific and engineering work, he and his fellow North British scientists and engineers were talking about entropy, or more precisely, the energy-centric based entropy understanding: the idea that although the energy of a world (a system and all other parts that it interacts with) can never be destroyed, the free energy of the world (the maximum amount of work output in a reversible operation) can be wasted or dissipated. [[2]: p. 342]

We now dive into the claim of the "centerpiece of orthodox thermodynamics being free energy" by first explaining what we mean by an "energy-centric" conception of entropy.

By "energy-centric," we mean that the premise of orthodox thermodynamics as a theoretical system, in accordance with the first law statement in Paragraph One, is that energy, or more precisely, free energy, is the driver for all "energy consumption"-driven phenomena or processes. By referring to free energy, it brings into focus the importance of entropy and the second law. This focus, however, highlights entropic processes only in terms of their impediments or hinderances to mechanical processes and other free-energy-driven processes. Free energy is the central quantity of thermodynamics, whereas entropy plays an important but secondary role in thermodynamics.

We now refer to Job and Lankan, together with scientists with a similar position on this issue, [[12], [13]], as a group arguing against energy physics' "heat-as-energy" in favor of "Heat-as-Entropy." In another paper entitled

"Entropy and the Experience of Heat," [14], Fuchs et al. describe the approach as a scientific approach of "Experientially Natural form of Thermodynamics" (shortened as EN Thermo). We may name the group arguing that a thermodynamics-theory built on the premise of heat-as-entropy represents a theory in its experientially natural form, by the name of the EN Thermo School.

Foremost in their minds, the EN Thermo School views the advent of MEH, the 1842-1872 MEH revolution, with regret. In the aftermath of the revolution, heat became heat energy, a disordered energy. With that, "the name of an existing quantity [heat] was taken away from this quantity and given to another one [Q]. However, the old quantity was not given a new name, resulting in its disappearance from the scene" [12: p.9]—the regret of the loss of the experience of the old quantity heat. The second important point made by the EN Thermo School is the identification of entropy, rather than energy, for encapsulating the experience of heat (caloric). The second point is important because if the energy-centric approach of the MEH-based orthodox thermodynamics could encapsulate the experience of heat with the concepts of energy and free energy, the dissatisfaction of the EN Thermo School would have dissipated. But the EN Thermo School finds the energy-centric approach wanting.

The EN Thermo School is onto something on both points, especially on the second point. But their solution, the first point, to the second point by restoring the concept of caloric amounts to a counterrevolution of the 1845-1872 MEH revolution. The heat-as-entropy solution by restoring the concept of caloric denies the necessity of conceptual differentiation in the formulation(s) of the two laws of thermodynamics by Clausius and Thomson (though their treatments bear common features, they are by no means identical, as we see in the following). The necessity of conceptual differentiation and the shortcoming in how Thomson and his fellow North British physicists/engineers carried out differentiation are different issues. The EN Thermo School's critique (the latter issue) of the energy-centric approach of energy physics is correct, but its implied solution to energy physics' deficiency by denying the necessity of conceptual differentiation (the former issue) contradicts its tenet of an entropy-centric approach: an entropy-centric approach necessitates the conceptual differentiation of caloric into energy, entropy, and heat.

We can untangle this evaluation of energy physics and the EN Thermo, and the pros and cons of energy-centric approach, entropy-centric approach, and conceptual differentiation by taking the following steps.

The first step is the trimming down of the **first law statement** to become, "*Energy can be neither created nor destroyed; total energy stays the same in every transformation even though the energy of a system or subsystems may change."* Other than energy conservation and the fact that constant total energy is the closure condition for every transformation, the statement makes no mention of the nature of transformations.

The second step deals with the nature of transformations in accordance with Clausius' *Fourth Memoir* [[7]: pp.111-135]. That is, Clausius recognized that Joule's contribution and Carnot's contribution deal with two distinctive issues of transformations: Joule's dealt with the equivalence of heat and work that became the closure condition of constant total energy for all transformations, whereas Carnot's contribution was that of dealing with the nature of transformations, what brought about the transformations. The "two distinctive issues" were also referred to as two DisOrganized Energy (DOE) questions [[2]: p. 315].

There are two phases of the second step. The first phase is the refinement of *MEH*. We shall adopt the name *equivalence theorem* for the version of *equivalence of heat and work* without a commitment to how heat and work are interconverted into each other -- only the assertion that the appearance of heat is accompanied by the disappearance of work of equal amount and vice versa. The first phase of the step is the precondition for the second phase: preparing *equivalence theorem* and then updating Carnot's idea of coexistence of heat transmission and the production of work into the *Second Fundamental Theorem* as the dual foundations of the *mechanical theory of heat* [[7]]. Carnot's idea on heat and work is described by Kipnis, "…neither Carnot and Clapeyron nor Holtzmann and Thomson thought before 1850 that heat could be converted into work. Apparently, before 1850 they assumed a certain association between heat and work, such that the two existed independently of one another but could influence each other. For instance, Carnot's supposition that work was created by a mere transfer of heat by expanding gas, in fact, implied such a coexistence" [[6]: p.2032, Sect. 9].

With the refinement of MEH into "equivalence theorem," it was possible for Clausius to formulate Carnot's idea of the coexistence of heat transmission and work production into his Second Fundamental Theorem, which we shall refer to as the *coexistence theorem*. The preamble of which is the assumption that there exist two kinds of dissymmetric or irreversible transformations in nature, transformations of natural direction or what Clausius referred to as positive direction, and those of unnatural direction or negative direction. The Second Fundamental Theorem, as stated by Clausius, is the assertion,

> all transformations occurring in nature may take place in a certain direction, which I have assumed as positive, by themselves, that is, without compensation; but that in the opposite, and consequently negative direction, they can only take place in such a manner as to be compensated by simultaneously occurring positive transformations [7: p.364].

Clausius was clear that for every kind of dissymmetric transformation, a subdivision of each kind into two can be made in accordance with the directions of individual transformations. Those of positive direction can exist by themselves. But in the opposite (negative) direction, the transformation can take place only in coexistence with another transformation of positive direction, “they can only take place in such manner as to be compensated by simultaneously occurring positive transformations.”

Clausius then considered the limiting case to investigate quantitatively the details of cyclic processes involving transformations in *reversible coexistence* in a six-step cycle (his invention of a modified Carnot cycle) [7: p.119]. He was able to devise a system of assigning for each transformation its *equivalence-value* and referred to the condition of their reversible coexistence as the condition of *equivalence*, the condition that “algebraical sum [of equivalence-values of the transformations of a reversible cyclical process] is zero” [7: pp.127-129]. This case of reversible cyclical process was appropriately referred to as the *theorem of the equivalence of transformations* [TET].

The second fundamental theorem and TET are two different theorems, the former asserts the idea of coexistence, first introduced by Carnot, and the latter the idea of equivalence, the quantitative expression of Carnot’s idea that has been made to be consistent with the equivalence theorem.

Clausius’ extraordinary insight was marred by one problem: he never used the term *coexistence*. This is reflected in the fact that he has not consistently made clear the distinction between the second fundamental theorem and TET. In fact, while he mentioned both terms in the Fourth Memoir, the Memoir treated both terms synonymously with the same theorem-statement, the TET statement as a replacement statement as given in [7: pp.125-126 (bottom of p. 125 and top of p.126)]. The Fourth Memoir is all about TET.

Only by the Sixth Memoir, there, as he noted,

> In a memoir published in the year 1854…I deduced a theorem which is closely allied to, but does not entirely coincide with, the one first deduced by S. Carnot… I have called it the Theorem of the Equivalence of Transformations. I did not, however, there communicate the entire theorem in the general form [7: p.218]

—Clausius began writing about the statement of a theorem in the general form as a distinctive statement from the TET statement, calling it the Second Fundamental Theorem. Clausius then followed with the treatment of the second fundamental theorem in the Seventh Memoir and the Ninth Memoir; the above statement of the Second Fundamental Theorem is from the Ninth.

In a nutshell, while TET is deservedly famous, it is the coexistence theorem that gives rise to the second law for engineering thermodynamics. Whereas TET, serving beautifully as the foundation for equilibrium thermodynamics, is not sufficient by itself to be the foundation for engineering thermodynamics. Because they highlighted TET over the role of the coexistence theorem, Clausius himself and Gibbs, who followed him, did not carry out the obvious extension of their approach to make their theories applicable to energy physics and engineering thermodynamics. Nor did they attempt to unify the two separate sciences, engineering thermodynamics and Gibbsian equilibrium thermodynamics. The extension and unification have been carried out by stressing the role of the coexistence theorem in a recent paper on Unified Classical Thermodynamics (UCT) [2].

As reported (the last paragraph of Sect. 1), the centerpiece of UCT is entropy and entropy growth [2]. The theory also introduced *entropy growth potential* [3]. A comparative summary of three theoretical systems of thermodynamics, energy physics, EN Thermo, and UCT, is given in Table 1.

Table 1-Three theoretical systems of thermodynamics, *suggesting that the de facto centerpieces of all three systems are* ***entropy***

	Energy physics	Experientially Natural Thermodynamics (EN Thermo)	Unified Classical Thermodynamics (UCT)
Centerpiece	Free energy	Old heat (caloric)	Entropy & entropy growth as the sole agent
De facto centerpiece	**Entropy**	**Entropy**	**Entropy**
Background setting to 1845	Equivalence of heat and work	"Caloric falling through a temperature difference"	Carnot: *coexistence* of heat transmission and heat-to-work transformation Joule: *equivalence* of heat and work
The 1842-1872 MEH Revolution	Energy physics is the product of the Revolution	The EN Thermo School views the Revolution with regret	Confirm the Revolution for its cause but view its aftermath as resulting from getting its true cause wrong
Conceptual differentiation (CD)	Yes: conceptual differentiation is the answer to the resolution of the Revolution; but Thomson's energy physics did not achieve *complete* CD (see reference to "free energy falling")	Scientists of the School view "caloric falling" as its central metaphor, which is not unlike energy physics' "free energy falling"	The good news is that Clausius/Gibbs have laid the foundational approach, which can be carried out to its logical completion to achieve the goal of *complete* CD
Best way to characterize the centerpieces of the three systems	Energy-centric conception of entropy	Heat, the manifestation of entropy flow, is the Force of Macroscopic Nature	Entropy-centric conception of entropy
What makes the world go round?	Free energy makes the world go round, with entropy growth serving as the hinderance to the going	Caloric makes the world go round	Entropy growth drives all macroscopic processes: the dissipation of entropy growth potentials and impediment of mechanical processes spontaneously, and the production of reversible-like transformations interventionistically

In energy physics (orthodox thermodynamics), free energy is the driver for macroscopic processes but not the sole driver for all processes; while entropy growth, in association with the degradation of free energy, manifests the dissipation of entropy growth potentials and impediment of mechanical processes. Energy physics is generally identified with engineering thermodynamics; though it is accepted to be consistent with equilibrium thermodynamics as well, there has been no seamless unification of the two branches under the paradigm of energy physics. In UCT, the driver and the dissipation agent are unified into a single agent, entropy growth. The **second law statement** is, "*Entropy always grows; entropy growth drives all macroscopic processes: the dissipation of entropy growth potentials and impediment of mechanical processes spontaneously, and the production of reversible-like transformations interventionistically*" [[2]]. The identification of entropy growth as the sole agent makes it possible to unify two branches of thermodynamics with their different defining problems, the "determination of the equilibrium states" and the "motive power of heat," by bringing engineering thermodynamics under the framework of equilibrium thermodynamics, see paper [[2]: Sects.6-7].

The comparative summary of Table 1 further highlights the following points about the three systems: For all three theoretical systems, energy physics, UCT [[2]], and the experientially natural form of thermodynamics [[14]], the centerpieces are de facto *entropy.* For energy physics, the situation is best described as, because of imperfection in achieving conceptual differentiation, its entropy conception is an energy-centric conception of entropy in the form of free energy. For the experientially natural form of thermodynamics, its attempt to deny the necessity of conceptual differentiation is mis-guarded, but its emphasis on entropy, or on heat as entropy (heat as a Force of Nature), serves a useful purpose as a "didactic approach at high school and university [and general public levels]" [[12]: p.15] to thermodynamics. By carrying out the logical completion of Carnot/Clausius' coexistence theorem and Gibbsian thermodynamics, UCT transforms energy physics' centerpiece into an entropy-centric conception of entropy.

For problems to which energy physics is applicable, the shortcoming of energy physics is not that calculations based on free energy give the wrong answers, but that the energy-centric conception of entropy leads to the inference that "there is a *continuous* and *irrevocable* qualitative degradation of free energy into bound energy [underline added; bound energy is energy which is no longer available for the purpose of producing mechanical work]" ([[15]]: p.6). The entropy-centric conception of entropy, though it allows continuous degradation, does not infer an *irrevocable* degradation of free energy [[2]: p. 326 ("free energy dissipates spontaneously, not universally")]. The causality concept highlighting the foundational difference of UCT from energy physics, which still carries the *efficient-causation* (or *physical necessity*) tradition of Newtonianism, as introduced below, will explain possibility free from *irrevocable* degradation.

3. **Entropic indeterminateness and innovation in reversible-like processes**

Nicholas Georgescu-Roegen's 1971 book, *The Entropy Law and the Economic Process* (TEL/TEP), [15], is a seminal work in the field of *ecological economics*, in which he offers a pessimistic analysis of the sustainability of human economic activities resulting in material and free-energy degradation as governed by the entropy law. We need to appreciate G-R's thinking with discretion: exercising critical evaluation of "*irrevocable* degradation of free energy," which is squarely based on energy physics and is defective, while at the same time appreciating and embracing his inventiveness of thinking outside the (Newtonian) box.

His acceptance of "irrevocable degradation of free energy" is a mistake. But his thinking outside the box against Newtonianism can be invaluable for navigating a path away from the aftermath of Newcomen's invention of steam engines, leading to the three-century-practice of *third-fire* (see Sect. 4). What follows is a very brief discussion in this section and Sect. 4 on the aftermath and the entropic solution to which.

In a new review of the 1971 TEL/TEP by Greene [16], Greene summarizes G-R's contrasting entropic thinking from the mechanistic (Newtonian) thinking in four points [16: 376]. In the following, these four are grouped into three highlights (the second and third points are herewith combined into Highlight-2):

1 Physics discovered two worlds: The mechanistic world is reversible, whereas the entropic world is directional or dissymmetric (though it has been emphasized in [2: page 342, Point 4] that dissymmetric is not unidirectional).
2 "Locomotion" vs. "transformations": In the reversible world, mechanics knows only locomotion (which is governed by *equation of motion* or *governing equation*), whereas transformations in the dissymmetric world are true qualitative changes not reducible to locomotion as determined by equations of motion.
3 Entropic indeterminateness: Mechanics describes locomotion as a physical necessity, i.e., deterministically, whereas the Entropy Law, as Georgescu-Roegen noted,

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> determines neither when (by clock-time) the entropy of a closed system will reach a certain level nor exactly what will happen … All we can say about the process as time goes by [is that] its total energy

remains constant while the distribution of this energy becomes more even … This leaves some substantial freedom to the actual path and time schedule of an entropic process … We may refer to it as entropic indeterminateness [[15]: p. 12].

The study of transformations points to a new kind of causality, causal necessity [[3]: Sects. 10.4 and 10.5], manifesting a new concept in thermodynamics, entropic indeterminateness. In the UCT second law statement, the part "*the dissipation of entropy growth potentials and impediment of mechanical processes spontaneously*" is an example of physical necessity, while "*the production of reversible-like transformations interventionistically*" is an example of causal necessity. Note that for processes of physical necessity, we may refer to them as processes governed by laws, but for processes of causal necessity, they cannot be said to be governed by laws since laws in these latter cases do not determine, strictly speaking, these processes.

All three highlights are manifestations of how our entropic world differs, characteristically, from the mechanistic world, but only Highlight-3, entropic indeterminateness, represents the bringing-about of these characteristic differences into *actionable* possibilities rather than merely observational remarks. In the following, we consider the example of how mechanical engineers deal with these issues in their application of the second law.

In A Treatise [[3]: Chapter 10], a curious situation was noted: of the two general laws of thermodynamics, only the differential equation of the first law of thermodynamics is used as a *governing* differential equation. "The customary inclusion of the *second laws of thermodynamics* serves no concrete purpose" [[3]: p.277]. This is because when the first law serves as a governing differential equation, for example, for heat transfer problems, [[3]: Eq. (196); herewith labeled as Eq. (1)]

$$\rho c_p \left(\frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T\right) = -\nabla \cdot \vec{q}'' + T\beta \frac{Dp}{Dt} + \left(\bar{\bar{\boldsymbol{\tau}}} : \vec{V}\right) + \dot{q}_{ext-heating} \quad (1)$$

the constitutive laws in the equation, Eq. (1), *ensure* that the processes described by the equation satisfy the second law. Here the constitutive laws are Fourier's law of heat conduction, $\vec{q}'' = -k\nabla T$, and Stokes' law of viscosity for $\bar{\bar{\boldsymbol{\tau}}}$. With these constitutive laws, Eq. (1), though customarily referred to as the energy equation, is in fact a governing differential equation

– similar to the first law statement in Paragraph One – representing both the first law and the second law: the constitutive laws in (1) collectively *are* the second law, which does not need to be included with a separate statement.

Correspondingly, starting with the first law in application to a control volume, mechanical engineers have been using, for problems of reversible-like processes, the following equation, [3: Eqn. (199/111); herewith labeled as Eq. (2)],

$$\dot{Q}_{cv} - \dot{W}_{shaft} - \dot{W}_{resistive} = \frac{\partial}{\partial t}\int_{cv} e\rho d\mathcal{V} + \int_{cs} \rho\left(h + \frac{V^2}{2} + gz\right)\vec{V}\cdot d\vec{A} \tag{2}$$

Note the work term, $\dot{W}_{resistive}$, is an example of a constitutive term in accordance with Joule resistive heating; however, the shaft-work, $\dot{W}_{shaft}$, of a reversible-like process is not represented by any constitutive law. The theoretical foundations for problems of reversible-like processes include *both* general laws of thermodynamics, the first law as (2) and the second law in a separate statement.

The second law in a separate statement is required for setting the maximum value for $\dot{W}_{shaft}$. However, **no law of nature, including the second law, can determine the *actual* value of shaft work**. Whereas Eq. (1) is a governing equation for spontaneous processes, Eq. (2) is not a governing equation. In the case of mechanical engineering, human designers generated the design of the real machine; while any design obeys all laws of nature, it is design, not laws of nature per se, that determines the shaft-work output.

Human design, in the context of the second law in accordance with the above considerations, is an example of a "higher principle" in the scheme of Polanyi's dual control. [17] Poincaré made a similar observation,

> [These thermodynamic laws] can have only one significance, which is that there is a property common to all possibilities; but in the deterministic hypothesis there is only a single possibility, and the laws no longer have any meaning. In the indeterministic hypothesis, on the other hand, they would have meaning, even if they were taken in an absolute sense; they would appear as a limitation imposed upon freedom [18: pp.122-123].

In which, Poincaré articulated his reading of the meaning of the second law to be human freedom exercised via entropic indeterminateness. Both

Poincaré and Polanyi made a similar argument as G-R did, i.e., entropic thinking points to, in addition to spontaneous processes in the preferred positive direction, which are deterministic, the existence of indeterministic (indeterminate), reversible-like processes. The latter are novel or "true happenings" beyond the prediction or control of—though always compatible with—all laws of nature.

4 The entropic promise of a post-Pyrocene world

The property that enables "energy consumption"-driven phenomena to transcend the second law while in fact obeying it, [[19]: xiv; Ch. 4], as Monod called the property of gratuity for living organisms to transcend the laws of chemistry, will be referred to as the entropic promise. Here, we offer an example of the entropic promise via UCT's application.

The story of fire and the myth of Prometheus are integral to the story of *Homo sapiens*. The fire historian Stephen Pyne structures his history of fire in three phases [[20]]: "first-fire" is the natural fire, a natural phenomenon that existed before the appearance of humans; "second-fire" is the anthropogenic fire; "third-fire" is the industrial fire. Pyne makes a compelling case that Earth is a fire planet, telling an epic history of the evolutionary and ecological roles of the first-fire. The term "Pyrocene" is proposed to provide a narrative of how humans, with the development of the anthropogenic second-fire, have been in the second stage of this history interacting with fire. At the very end of the second stage, a transition from the anthropogenic second-fire into the industrial third-fire phase emerged with the practice of burning fossil (lithic) biomass. Pyne prefers to use the term "industrial combustion" to describe the third-fire, to emphasize that the Enlightenment scientific approach to fire phenomena led to the disappearance of the phenomena with all their complexity into the neatly categorized processes (mixing, ignition, combustion) and components (fuel reactants, oxidizer, input chamber, furnace). The scientific approach to fire phenomena turning it into combustion processes made it possible to scale up third-fire into unsustainable industrial combustion.

We have suggested that the entropy law per se does not *determine* the impossibility of sustainable human economic activities. As a fire planet, Earth will continue to exist with the first-fire and the second-fire as necessary events for their evolutionary and ecological roles. What cannot continue is the continuation of human economic development based on industrial combustion.

There is indeed a broad consensus of necessity for energy transition, a reason for which is commonly given as that the resources for third-fire, fossil (lithic) biomass, are finite. We articulate here the same necessity for a different reason: instead of the unsustainability of the resources for third-fire, we argue that the phenomena themselves, the third-fire, are not sustainable. The continuation of third-fire will ultimately lead to the collapse of the fire planet, a failure to keep the planet *far from equilibrium*.

Following from the writings of Schrödinger (*What is Life*, 1944) and Prigogine (1977 Nobel Prize), there has been a vast literature on the necessity of keeping living organisms away from thermodynamic equilibrium by keeping their entropy low. Despite the second law which asserts the inevitable growth of entropy for isolated systems, it is possible for individual living organisms as open systems to do so: by exporting entropy that is produced in the interior of organisms to be disposed of in the environment.

Space considerations limit us from a satisfactory treatment of the topic in its full context, except to state that the main point of this section is to ask the question: what are the consequences of exported entropy by individual organisms—by extension, the consequences of exported entropy by individual economic units? That is, not only do individual organisms need to be kept *far from equilibrium* but also the whole ecosystem, to which the individual organisms belong, must be kept *far from equilibrium.*

Surprisingly, this question has never been addressed. We surmise that this is due to a lack of true understanding of reversible processes. It is noted in paper [[2]: page 339],

> Thermodynamics began with a focus on … heat and work and with Carnot's … [treatment of their interconversion as] reversible processes. The analysis in this paper … suggests, however, that this historical background of thermodynamics contains, by linking heat and the discussion of reversibility so closely, a misleading notion of the true nature of reversibility. Any discussion of heat necessitates the involvement of heat release that is intrinsically irreversible. "Reversible" use of heat, such as in the Carnot cycle … only idealizes the part involving heat transmission, leaving the irreversible heat release hidden from consideration.

Fire, both first-fire and second-fire, is a spontaneous, irreversible process. The invention of the third-fire was thought to be undergirded by reversibility idealization: for the first time in human history, humans discovered a *new* way of using fire, a reversible way of using the third-fire in addition to the second-fire for heat, light, and cooking. It turns out that the Carnot reversibility is a false idealization: because of the energy-centric conception of entropy in energy physics, there remains at its core a big part of the third-fire that is intrinsically irreversible.

The good news is: The theoretical understanding made by Carnot/Clausius/Gibbs, updated into UCT [[2]], shows that the essence of the invention of coal-fired steam engines was not the discovery of a new form of <u>energy</u> in coal, but the discovery of <u>dissymmetry</u> in the burning of coal, i.e., there is entropy growth potential (EGP) in any transformation of positive direction. We find EGP in coal and other fossil fuels in the form of *stock* EGP, as well as in renewable phenomena in the form of *natural* or *ongoing* EGP. [[3]: Sect.8.7.2]

In the UCT theoretical system, a reversible event requires a heat reservoir. [[2]] Such an event necessitates coexistence between a transformation of positive direction and a "work production" transformation of negative direction. When the two transformations are in equivalence, i.e., reversible coexistence, with each other, the event yields a reversible work,

$$W_{rev-event} = T_{res} \cdot EGP \tag{3}$$

where $W_{rev-event}$ is the work output of the reversible event, T_{res} is the temperature of the heat reservoir.

For the case of the Carnot-Clausius cycle (with $T_{res} = T_0$: indicating that the heat reservoir is here used as both a reservoir for heat and a heat sink), Eq. (3) takes the form,

$$W_{rev-event} = T_0 \cdot EGP(T_0) \tag{4}$$

Note that in this case $EGP(T_0)$ is a function of $T_0 (= T_2)$, and equals (see [[2]]: p. 338, Eq. [48]),

$$EGP(T_0) = \frac{-Q_1}{T_1} + \frac{Q_1}{T_2} = \frac{-Q_1}{T_1} + \frac{Q_1}{T_0} \tag{5}$$

It follows that $W_{rev-event}$ is,

$$W_{rev-event} = T_0 \cdot \left(\frac{-Q_1}{T_1} + \frac{Q_1}{T_0}\right) \left[= Q_1 \left(1 - \frac{T_0}{T_1}\right)\right] \tag{6}$$

Instead of looking at $Q_1\left(1-\frac{T_0}{T_1}\right)$, the demarcation of the two DOE questions—"*what* drives the reversible event?" in (5) and "what *closure condition* the transformations of the reversible event are subject to?" in $T_0\left(\frac{-Q_1}{T_1}+\frac{Q_1}{T_0}\right)$ — identifies the **dual roles** that the heat reservoir plays: as a heat sink for the EGP driving force, as shown by (5), and as a heat source-reservoir for the heat extract mechanism made possible by the driving force, as shown by (6). Note that EGP, due to the role of the reservoir as a heat sink, is a strongly increasing function of decreasing T_0; reversible work in this case has a complicated relationship with the temperature of the heat reservoir, T_0.

It should be emphasized that a large part of low-temperature heat in association with this case is heat disposed to the reservoir serving as a heat sink—necessitated in this case as a result of the burning of fossil fuels rather than an intrinsic role of the heat reservoir.

For other kinds of EGPs, as shown in examples in [2], and in renewable phenomena in the form of *natural* or *ongoing* EGP, however, the driving force EGPs do not need a heat sink and the temperature of the reservoir can be any arbitrarily one, T_X (because EGP is not dependent on T_X, the subscript X indicates that the heat reservoir, used as a reservoir for heat extraction only, can be one of an arbitrary temperature, T_X),

$$W_{rev-event}=T_X\cdot EGP \tag{7}$$

Unlike the above "reservoir as a heat sink" case, reversible work in (7) is simply proportional to the temperature of the heat reservoir.

In paper [2], we find many examples of heat reservoirs serving as sources for heat extraction only:

> "The reversible realization of all these cases represents 'transformations of heat into work' in which the extraction of heat from the surroundings, rather than heat being discharged into them, is the dominant mechanism … Demand for a sizable heat sink is an option, resulted from the technological choice [of third-fire], rather than a necessity, in accordance with physics.
>
> "Calling heat discharged to heat sink waste heat may be misleading. In the Carnot/Clausius account, the discharged heat is 'reversibly' necessary. That the equivalence theorem demands, cumulatively,

prodigious production of heat to be disposed is also an incorrect scientific interpretation of the theorem. In the scheme of true reversibility, the necessity of the discharged heat results from irreversibility of combustion heat release. Prodigious production of heat to be disposed requiring **sizable heat sink** is not demanded by the equivalence theorem but is the consequence of failing to achieve reversibility in the Carnot/Clausius account, as the philosophical accord of the Industrial Revolution" [2: p. 340].

The philosophical accord of the 21st century is the Carnot/Clausius/Gibbs account [2] for achieving true reversible-like transformations driven by *natural* or *ongoing* EGP—progressing from the era of third-fire since Newcomen's steam engine of 1712 towards in the 21st century, a post-Pyrocene world at far from equilibrium.

5 Conclusion

This year, 2024, is the bicentennial anniversary of the 1824 publication of Carnot's magnum opus, *Reflections on the Motive Power of Fire*, which eventually led to the introduction of entropy by Clausius in 1865. In the interim years, Thomson introduced the concept of available energy (free energy, or exergy) under the premise of "*energy-centric conception of entropy*." With the introduction of free energy, energy physics is undergirded by the dual foundations of free energy, the concept, and the energy conversion doctrine, which we may refer to as the *conversion doctrine of free energy*. While free energy dissipates continuously and spontaneously, it is the conversion doctrine that infers the tenet of "a *continuous* and *irrevocable* qualitative degradation of free into bound energy" [15: p.6].

This is the fundamental conundrum of human existence. To exist, we need free energy, and to thrive in style, we need abundant free energy. Such pursuit of individual wellness increases the speed of the whole (of which individuals and their environment are parts) falling into the abyss of chaos.

***Table 2**-Evolution of "heat as a substance doctrine" to the "conversion doctrine of free energy" to the premise of "entropy growth drives all macroscopic processes," including reversible-like processes indeterministically*

	Caloric theory	**Energy physics**	**Unified Classical Thermodynamics (UCT)**
Centerpiece	Heat	Free energy	Entropy & entropy growth
De facto centerpiece	**Entropy**	**Entropy**	**Entropy**
Background setting to 1845	Heat is conserved (**Heat as substance doctrine**)	Equivalence of heat and work, in which total energy is conserved	Carnot: *coexistence* of heat transmission and heat-to-work transformation Joule: *equivalence* of heat and work
The 1842-1872 MEH Revolution	The idea of heat conservation was overthrown	Energy physics is the product of the Revolution	Confirm the Revolution for its cause but view its aftermath as resulting from getting its true cause wrong
Conceptual differentiation (CD)	The EN Thermo School, Caloric theory's modern version after renouncing its doctrine, is noted for denying the necessity of CD	In the Fourth Memoir, Clausius treated TET and the 2nd fund. theorem synonymously. Only beginning with the 6th Memoir, did he make a clear statement of the 2nd fund. theorem.	UCT has carried out CD to its logical completion by restoring the 2nd fundamental theorem to its privileged position
Equations of motion, which determine the processes of "locomotion"	The EN Thermo School implicitly considers laws to be equation-of-motion	There remains a subscription to the mechanistic thinking among some thermodynamicists that laws of nature are equations of motion	The first and the second laws are not equations of motion. **Entropy growth drives all macroscopic processes, including reversible-like processes indeterministically**
Epistemological status of the theory: how do we understand *free energy*?	With a hint to Wittgenstein, the EN Thermo School emphasizes that the structure and use of language are central to understanding and communicating scientific concepts	Thermodynamic laws are observational laws. Energy physics is based on the dual foundations of the concept of free energy and **the conversion doctrine of free energy** (which supplants the substance doctrine of the Caloric theory)	In UCT, a giant epistemological step is taken: with entropic indeterminateness, thermodynamic laws have meaning beyond being observational. Correspondingly, the central UCT critique of energy physics will be the rejection of the conversion doctrine

A previous paper, [2], proposes a new theoretical system of thermodynamics in terms of the conceptual centerpiece of "*entropy-centric conception of entropy*." We refer to this formulation as UCT, the unification of engineering thermodynamics into a framework generalized from the basic equilibrium thermodynamics framework [[2]: Sects.6-7]. This paper articulates that thermodynamic laws have meaning beyond being observational and that the signature characteristic of UCT is entropic indeterminateness, which differentiates UCT from the determinist mechanical science. While "locomotion" changes are deterministic, "transformation" changes, especially of the reversible-like kind, manifest true happening not subject to the determination of thermodynamic laws, though always obeying them. These new understandings are summarized in Table 2. With entropic indeterminateness, it is suggested in the Table that the central UCT critique on energy physics (i.e., orthodox thermodynamics) will be the rejection of the conversion doctrine; an outline of its implications will be given in another paper.

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> The law of conservation of energy, also known as the first law of thermodynamics, states that the energy of a closed system must remain constant—it can neither increase nor decrease without interference from outside. The universe itself is a closed system, so the total amount of energy in existence has always been the same. The forms that energy takes, however, are constantly changing. Potential and kinetic energy are two of the most basic forms, familiar from high school physics class: Gravitational potential is the stored energy of a boulder pushed up a hill, poised to roll down. Kinetic energy is the energy of its motion when it starts rolling. The sum of these is called mechanical energy. The heat in a hot object is the mechanical energy of its atoms and molecules in motion. In the 19th century physicists realized that the heat produced by a moving machine was the machine's gross mechanical energy converted into the microscopic mechanical energy of atoms. Chemical energy is another form of potential energy stored in molecular chemical bonds. It is this energy, stockpiled in your bodily cells, that allows you to run and jump. Other forms of energy

include electromagnetic energy, or light, and nuclear energy—the potential energy of the nuclear forces in atoms. There are many more. Even mass is a form of energy, as Albert Einstein's famous $E = mc^2$ showed. Fire is a conversion of chemical energy into thermal and electromagnetic energy via a chemical reaction that combines the molecules in fuel (wood, say) with oxygen from the air to create water and carbon dioxide. It releases energy in the form of heat and light. A battery converts chemical energy into electrical energy. A nuclear bomb converts nuclear energy into thermal, electromagnetic and kinetic energy. As scientists have better understood the forms of energy, they have revealed new ways for energy to convert from one form to another.

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