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Prototyping of Self-Sufficient Electric Traction Systems

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Abstract

This work presents the development of an electric traction system powered by a net-zero emissions energy supply. Although the final traction element remains a conventional electric system, the key innovation lies in its power source. The main challenge is to create an energy supply that is not only carbon-neutral but also self-sufficient, viable, and reliable. To address this, we propose a disruptive shift: replacing conventional electrically powered engines with Self-Sufficient Power Machines (SSPMs). This approach eliminates the need for an external electric supply and enables autonomous railway cars to integrate SSPM-based resources to power all services, including traction and critical systems. Since it requires no external power input, it offers unlimited autonomy—an essential advantage for eliminating external energy supply systems, which represent a significant cost.

Results from a generic case study using eight cascaded power units operating at temperatures between 330 K and 750 K confirm the system's self-sufficiency. The calculated net positive output of 859 kJ/kg-cycle, after accounting for feedback heat, demonstrates the system's ability to sustain its own operation while generating a substantial amount of useful work.

Keywords: Self-Sustaining Power Generation, Cascaded Coupled Power Units, Electric Traction Systems, Vacuum-Induced useful work, Thermodynamic Disruption.

Nomenclature related to general sVsVs cycles and SSPG and electric traction systems

Acronyms	**Description/Context**
Cont, cont	Subscript of contraction process: A form of compression (volume decrease) achieved by cooling a TWF, which generates a **pull** force while increasing internal energy and pressure.
CTF	HTF for cooling: Cooling Transfer Fluid (conventionally, thermal oil)
E_i	Energy input (heat and/or work)
EM	Electromagnetic
E_o	Energy output (heat and/or work)
EP	Electric Power
TEP	Total real or effective electric power (the effective generator output power)
NEP	Net electric power: NEP=TEP-qi_feedback (available useful EP)
Exp, exp.	Subscript of expansion process: A form of expansion (volume increase) achieved by heating a TWF, which generates a **push** force while decreasing internal energy and pressure.
FCF	Forced convection fan (recirculation fan of the TWF)
FP	Feed pump (feed compressor of the TWF)
Gen	Electric Power Generator: alternator or generator
H, L	Subscript of High, Low: i.e. T_L with L subscript of T_{low}, T_H, with H subscript of T_{high}
HTF	Heating Transfer Fluid for heating TWF (conventionally, liquid as thermal oil or gas)
Is_eff	Isentropic efficiency: (open processes). Losses inherent to real gas adiabatic exp/comp.
LF	Losses factor (include thermo-mechanical and thermo-hydraulic losses)
ETS	Electric Traction System
PU	Power Unit driven by the thermal cycle sVsVs or VsVs cycle

qi_feedback(PU1)	Electric power as heat added to the first cascaded PU. qi_elect_PU1 = (h_2-h_1) of PU1
RF	Heat recovery factor (heat transfer losses including heat leaks)
sp	State point of any stationary point state of a thermal cycle
SSPM	Self-Sustaining Power Machine, Self-Sufficient Power Machine
SSPG	Self-Sustaining Power Generator, Self-Sufficient Power Generator
Suct, suct.	Subscript of suction process: A form of expansion (volume increase) achieved by adding useful work to the system by means of a **pull** force, while decreasing internal energy and pressure.
TWF	Thermal Working fluid (a gas with high adiabatic expansion coefficient such as helium or ar gon)
sVsVs	sequential processes of the cycle sVsVs: Isentropic **s**, Isochoric **V**, adiabatic **s**, Isochoric **V**, adiabatic **s**: [**sVsVs**]
TF (%)	Heat transfer losses due t heat recovery effectiveness
LF (%)	Losses factor (thermal and mechanical irreversibilities)
η_{th} (%)	Cycle thermal efficiency [w_n/qi]
Symbols/units	***description***
p(bar)	pressure
q_i(kJ/kg)	specific heat in to a cycle process
q_{i23} (kJ/kg)	Input heat to cycle process 2-3
q_o(kJ/kg)	specific heat out from a cycle process
q_{o4-5} (kJ/kg)	output heat from cycle process 4-5 in a sVsVs cycle
q_{rec}	Recovered heat from cycle process 4-5 in every sVsVs cycle-based PU
Cp(kJ/kg-K)	specific heat capacity at constant pressure
Cv(kJ/kg-K)	specific heat capacity at constant volume
s(kJ/kg-K)	specific entropy
S_{sys}(kJ/kg-K)	specific entropy of a thermodynamic system
S_{surr}(kJ/kg-K)	specific entropy of the surroundings of the system
S_{gen}(kJ/kg-K)	specific entropy generated in a thermodynamic process
S_{qrec}(kJ/kg-K)	specific entropy exhibited by the recovered heat to be regenerated to feed the first PU
h(kJ/kg)	specific enthalpy; h=Cp.T; T=f(T)
T(K)	Absolute temperature
T_H(K)	top cycle temperature
T_L(K)	bottoming cycle temperature
u(kJ/kg)	specific internal energy
v(m^3/kg)	specific volume
V(m^3)	volume
w(kJ/kg)	specific work
w_i(kJ/kg)	specific work input

$w_{i12} = w_{iFP}$	Input work to the Feed Pump: $w_{iFP} = \Delta h_{12} = h_2 - h_1 = Cp \cdot (T_2 - T_1)$
w_o(kJ/kg)	specific work out
w_{oexp} (kJ/kg)	Output expansion work due to previously added heat
w_{ocont} (kJ/kg)	Output contraction work due to previously extracted heat
w_{oexp34} (kJ/kg)	Output expansion work w_{o34} due to previously added heat
$w_{ocont51}$ (kJ/kg)	Output contraction work w_{o51} due to previously extracted heat
w_n (kJ/kg)	Net useful work (w_{oexp} + w_{ocont}) = (w_{o34} + w_{o51}) in an VsVs thermal cycle
q_{rec}/PUi(kJ/kg	Heat recovered from every PU from cooling cycles processes
η_{th} (%)	Cycle thermal efficiency (w_n/qi)

1. Introduction

The amount of CO_2 emitted annually by industry in general, and electric traction systemsin particular [1], r, is significant enough to justify a paradigm shift in the use of technologies and services for both industrial production and propulsion, including their associated services. Fortunately, a disruptive, innovative, and environmentally friendly technological solution has been developed to mitigate and ultimately eliminate this problem. Given the availability of these technologies, it can be implemented at reasonable costs.

1.1 The Proposed Solution

Based on the comments and data above, the consequences of emissions, which unfortunately tend to increase, are too high and costly. The preceding comment reveals the imminent need for a truly disruptive decision: a radical shift in the energy paradigm worldwide that affects the fundamental principles of thermodynamics; obtaining work through vacuum-induced thermal contraction, achieved by cooling or heat extraction; that is, useful mechanical work is performed by extracting heat rather than adding it. The rate of useful work obtained through thermal contraction achieved by cooling-induced vacuum can ultimately approximate the amount of useful work obtained by adding heat. In fact, it represents almost twice the amount of work relative to the heat added.

To mitigate these risks and their consequences, a disruptive paradigm shift is proposed: replacing conventional Electric Traction Systems (ETS) with self-sustaining thermoelectric power plants capable of supplying energy without incurring any of the risks associated with the conventional electric supply systems. The proposed techniques do not require fossil, renewable, nuclear, or any other type of fuel. They are produced onboard and are technically feasible and cost-effective.

The reason this principle hasn't been applied earlier, that is, at the beginning of the industrial era more than two centuries ago (when the fundamental principles of thermodynamics were formulated), is due to the neglect of elementary physical concepts. This is probably because the solution adopted was based on heat transfer from a given potential to a lower one to produce work through adiabatic expansion, without considering other possible principles such as reverse heat transfer—from lower to higher temperatures—which gives rise to work by thermal contraction, one of the fundamental pillars of this proposal based on energetic self-sufficiency.

This technique leads to a reconsideration of the energy balances that affect the first law of thermodynamics and exergy, or available useful energy. This is only due to the effect of the vacuum-induced useful contraction work, which accounts for the energy balance without the necessity of added heat, or in other words, this is solely due to the effect of the useful contraction work induced by the vacuum, which explains the energy balance without the need for added heat. This phenomenon violates the conventional fundamental principles of physics, especially thermodynamics, including quantum fundamentals.

1.2 The Self-Sustaining Power Machine

The concept of Self-Sustaining or Self Sufficient Power Machines or (SSPMs) has been introduced and described in previous references. Previously to the mentioned contribution, a disruptive advance was necessary: doing useful output mechanical work by contraction of the thermal working fluid [2-3]. With such contribution it is possible to increase the thermal efficiency in more than 90% of the thermal efficiency exhibited by doing output work only by adiabatic expansion. However, the concept of self-sufficiency stems from a disruptive advance based on the contribution of useful work obtained by thermal contraction of a working thermal fluid at zero cost [4-7], while from here the leap to energy self-sufficiency is made based on the cascade coupling of several power units associated with an efficient heat recovery to be fed back to the first power unit of the cascade. [10-12]. In short, it consists of a disruptive, technically and economically viable alternative solution that allows for the in situ intensive generation and supply under demand./or dissipation of heat to the environments.

1.3 The proposed power units based on Pulses-based Gas Turbines [6], Patent [20]

The proposed SSPM is composed by a cascade of PUs. Every PU consists of a disruptive Self-Sustaining Power Machine (SSPM) composed of cascaded power units (PUs). Each PU consists of a Pulse Gas Turbine (**PGT**). The prototyping design task involves a singular thermal cycle (sVsVs) associated to each PU, characterized by doing useful work by in the same way as the known VsVs cycle. The main characteristics of the sVsVs cycle responsible for driving each of the PUs of an SSPM include:

(a) Adiabatic expansion of a Thermal Working Fluid (TWF) due to previous heat addition,

(b) Adiabatic contraction of a TWF previously cooled by heat extraction and, [2-3]

(c) Upgrading recovered heat by increasing thermal potential by heat superposition techniques, and

(d) Efficient use of the heat recovered from each upstream PU to feed the first PU downstream.

The fact of achieving useful mechanical work with the above-mentioned procedures by adding only heat to produce expansion work undergoes an excess of useful mechanical work greater than the amount of added heat, which gives rise to a SSPM enabled to defy Perpetual Motion Machines (PMM) of second kind.

In the proposed configuration, the heat released from each PU due to the cooling of the TWF is efficiently recovered and reused in the first PU in the cascade. Results have been verified through two case studies carried out on a SSPM simulated prototype [6], being conducted using air and helium as real gases.

The significant differences of the presented technology based on the proposed PGT technology [6], compared to Rankine, ORCs, and Brayton cycles used in the most advanced power plants are summarized in the following points:

There are no phase changes of the TWF (such as helium, dry nitrogen, dry air, among other TWFs, which means that the heats of vaporization and condensation are not present.

The tasks of adding and extracting heat to/from the cycle are carried out at constant volume. This is possible by alternately operating with two or more heating and cooling isochoric reservoirs, which operate under forced convection heat transfer.

No conventional feed pumps are required because there are no phase changes. Instead, a low-pressure TWF feed compressor is used, where the low-pressure compression is due to the fact that during the time the working fluid is being pumped from a low-temperature fluid reservoir to a high-temperature fluid reservoir, it exhibits suction and discharge pressures very close to each other.

Cooling turbine blades is not required in any case.

An installation based on a cascade coupling structure of a group of PGTs with respect to the heat transfer fluid (HTF) temperature mechanically coupled on the same rotating shaft contributes to an effective waste heat recovery system based on the following facts:

1 Effective recovering and use of low-grade heat exhausted from the connected upstream turbines.

2 The thermal efficiency of a PGT cycle is independent of the range between high and low temperatures since it does not obey Carnot constraints. Contrary to Carnot, indeed, efficiency is higher for low-temperature ranges (T_H-T_L) which implies high temperature ratios (T_L/T_H). This characteristic also contributes to the increase of the residual heat utilization factor.

Given that the efficiency of each individual PGT is significantly higher than in conventional Rankine cycles-based steam turbines, associated to the fact that the heat utilization factor is also greater, the overall efficiency is significantly increased.

In summary, the key innovations and contraction, the efficient recovery and reuse of contraction heat, and the strategic selection of the TWF and number of PUs, consist of the utilization of thermal contraction to generate work, the specialized thermal cycles that leverage expansion working fluids - all of which contribute to the SSPM's remarkable improvements in thermal efficiency and self-sufficiency. Consequently, the proposed power and propulsion architecture presents characteristics that challenge the most advanced technologies including modern nuclear reactors.

By not using any type of fuel, some significant equipment, associated tasks, and some drawbacks cease to exist, among which the following stand out:

-- Overhead Line System: This method makes use of overhead wires that supply electricity to the train through the medium of a pantograph. A pantograph is a device mounted on the roof of the train that collects the power from the overhead lines. It is a very common method used for electric trains worldwide.
-- Third Rail System: In this system, the train power is supplied through a third rail run alongside or between the tracks. The train collects power from the third rail using a sliding shoe or a pickup shoe. This system is in use with most the subway and metro systems.
The direct consequence of eliminating the aforementioned infrastructure is, in fact, a significant saving in the installation and maintenance costs of said infrastructure.

1.4 Purpose & Roadmap

With the aim of providing technical means for energy supply to assist all types of industrial activities in all areas associated with the marine transport, the following sections will describe two key topics: energy self-sufficiency and propulsion for marine transport. Therefore, the work is organized according to the following structure: Section 2: Modeling of an SSPM with cascaded pulse gas turbines, based on references [8-12] and [13-18]. Section 3: Modeling of the ship's propulsion system. Section 4: Analysis of results. Section 5: General conclusions and implications.

2. Modeling a SSPM with cascaded Pulse-based Gas Turbines

The proposed marine propulsion-based SSPM consist of a set of cascaded power units made up of gas turbines operating on barothermal impulses (PGT) driven by known thermal cycles of the sVsVs type [6], [20]

2.1 Brief description of the PGT structure and operating modes

The Power Generation Units (PUs) for the proposed Self-Powered Power Plant (SPPP) prototype are based on the PGT (Pulsed Gas Turbine) technology patented under application number P202000032 and publication number ES2851381. The PGT scheme is illustrated in Figure 1a.

The PGT structure is composed at least of four main subsystems:

- Heat supply system, responsible for heating the thermal working fluid (TWF) which gives rise to puss forces enabled to do useful expansion work,

- Heat extraction system, responsible for cooling the TWF which gives rise to a vacuum responsible for pull forces enabled to do useful contraction work,

- Heat recovery system enabled to recover the cooling heat released from the heat extraction system which will be feed back to the internal heat supply system,

- Pulse-based gas turbines (PGT) itself,

- Thermal working fluid pump feeding system,

- Systems circuits and controlled valves and, - advanced control equipment.

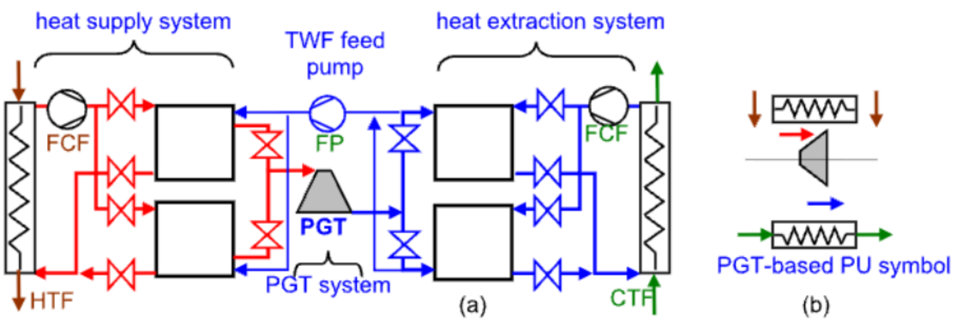

Figure 1. Illustration of the PGT based on the patent application number P202000032 and publication number ES2851381, [16], [20]. Figure 1(a) depicts the main subsystems including the heat supply system, the heat extraction system, the TWF feeding system and the PGT machine. Figure 1 (b) illustrates the symbol used to represent the PGT-based PU depicted in Figure 1(a).

Figure 1(a) depicts an expansion-contraction heat scheduling scheme equipped with two reservoirs for heating and cooling, which operate in an alternating and intermittent sequence. Figure 1(b) presents a symbolic scheme representing each power unit within the self-powered power plant.

The PGT prototype shown in Figure 1(a) consists of one or more closed-circuit gas turbines designed for installation in power plants, where they are coupled via a common shaft to all rotating machines in the system.

Each PGT operates intermittently based on barothermal pulses. These pulses are generated within dedicated reservoirs and are of two types:

Positive barothermal pulses involve a pressure increase above an equilibrium (reference) pressure, associated with the temperature rise from isochoric heating.

Negative barothermal pulses involve a pressure decrease below the equilibrium pressure, associated with the temperature drop from isochoric cooling.

These pulses are applied to the gas turbine from high-pressure and low-pressure reservoirs, respectively, driving its operation.

2.2 Modeling a PGT-based sVsVs Cycle

Let us begin by clarifying the acronym for the thermal cycle under study: the sVsVs cycle, implemented in a Pulse-based Gas Turbine (PGT) system. The letters in the acronym denote the thermodynamic transformations between successive state points. Here, "s" represents an open isentropic (constant entropy) process, and "V" represents an open-isochoric (constant specific volume) process. Thus, sVsVs describes a sequence of five processes: isentropic, open-isochoric, isentropic, open-isochoric, and isentropic.

Processes of the sVsVs Cycle:

The cycle, illustrated in Table 1, and Fig. 2 consists of the following transformations between state points:

Process 1–2: Open isentropic compression. TWF is transferred from the cold TWF reservoir to the hot TWF reservoir. During this process, the suction and discharge pressures of the compressor or feed pump are almost equal since they only differ in the effect of the load that the mass transfer of the TWF from the cold reservoir to the corresponding hot reservoir entails.

Process 2–3: Closed isochoric heat addition. Heat addition is carried out by means of TWF closed process recirculation under forced heat transfer. The mathematical model of this process is considered the same as if it were an open process due to the flow work required for forced convection heat transfer.

Process 3–4: Open adiabatic-isentropic expansion. Mechanical work is performed by hot TWF open process expansion. The useful mechanical work done by the expansion of the TWF in an open process is due exclusively to the prior addition of heat from a hotter source.

Process 4–5: Closed isochoric heat extraction (no heat rejection). Heat extraction (cooling) is carried out by means of TWF closed process recirculation under forced heat transfer. The mathematical model of this process is considered the same as if it were an open process due to the flow work required for forced convection heat transfer

Process 5–1: Open adiabatic-isentropic contraction. Mechanical work is performed by cold TWF open process contraction. The useful mechanical work done by the contraction of the TWF in an open process is due exclusively to the prior extraction of heat to a cooler heat sink.

These processes are described in detail below:

Process 1–2:

This corresponds to an open, adiabatic, and isentropic compression process driven by a feed pump or gas compressor. It is classified as an "open" process because it involves mass transfer. The work input to the compressor for this adiabatic-isentropic process is given by:

$$w_{i12} = w_{iFP} = \Delta h_{12} = h_2 - h_1 = Cp \cdot (T_2 - T_1) \quad (1)$$

Process 2-3:

Correspond to a open-isochoric heat addition process in which the working fluid is heated.

$$q_{i23} = \Delta h_{23} = h_3 - h_2 = Cp \cdot (T_3 - T_2) \quad (2)$$

Process 3-4:

Correspond to open adiabatic expansion process in the PGT which undergoes mass transfer while volume increases. Thus the thermal energy in the form of enthalpy is converted into mechanical work, provided that the PGT rotates freely doing expansion work.

$$w_{o34} = w_{o\exp 34} = h_3 - h_4 = \Delta h_{34} = Cp \cdot (T_3 - T_4) \quad (3)$$

Process 4-5:

Correspond to open-isochoric heat addition process in which the working fluid is heated without work done because of the constant volume process

$$q_{o45} = \Delta h_{45} = h_4 - h_5 = Cp \cdot (T_4 - T_5) \quad (4)$$

Process 5-1:

Correspond to open adiabatic contraction-based compression process. Thus the thermal energy in the form of enthalpy is converted into mechanical work by contraction (TWF volume decreases in the cold PGT reservoir), provided that the PGT can move freely to permit the contraction-based compression work.

$$|w_{o51}| = |w_{ocont51}| = |h_5 - h_1| = Cp \cdot |(T_5 - T_1)| = Cp(T_1 - T_5) \quad (5)$$

Table 1: Illustration of an sVsVs thermal cycle execution sequence according to equations (6)-(12) and T-s and p-V diagrams og Fig. 2.

sp	Process task	Sequential sVsVs cycle processes	Thermal-model
1-2	Feed pump (FP). work in	Open adiabatic-isentropic	$w_{i12} = \Delta h_{12}$
2-3	Heating the TWF	Open isochoric heat addition	$q_{i23} = \Delta h_{23}$
3-4	Expansion work out	Open adiabatic-isentropic expansion	$w_{o\exp 34} = \Delta h_{34}$
4-5	Cooling the TWF	Open isochoric heat extraction	$q_{o45} = \Delta h_{45}$
5-1	Contraction work out	Open adiabatic-isentropic contraction	$w_{ocont51} = \Delta h_{51}$

In Table 1 it is depicted the thermal model corresponding to each cycle process of the sVsVs cycle, highlighting the active heating and cooling phases by means of a sVsVs thermal cycle execution sequence described by equations (6)-(12) and T-s and p-V diagrams of Fig. 4. The analysis of the T-s diagrams depicted in the Fig. 2 (a) and (b) gives rise to the thermal models depicted in Table 1.

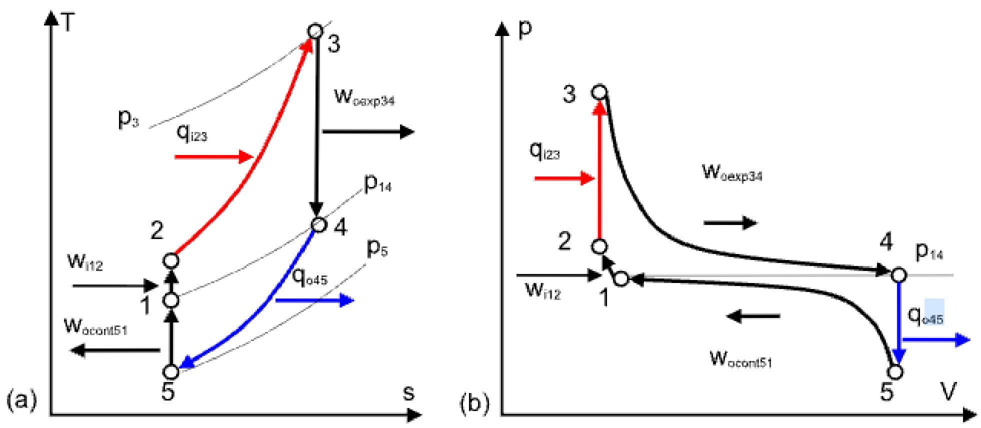

Figure 2. Single PGT-sVsVs hybrid (closed & open processes) thermal cycle. (a): T-s diagram. (b): p-V diagram

The sVsVs thermal cycle is hybrid due to be composed by closed and open processes. While heat transfer is carried out by adding and extracting heat by means of isochoric closed processes, the rest of processes involving work undergo mass transfer. Consequently, the open process-based heat-work interactions are modeled by using enthalpies.

2.3 sVsVs analysis

2.3.1 Conventional thermodynamic basis

In any thermal cycle, the conventional thermodynamic analysis given by the energy balance $q_i - q_o = w_o$, the thermal efficiency $\eta_{th} = w_o/q_i$ cannot reach the value of the Carnot factor $(T_H - T_L)/T_H$ except for the Carnot cycle, where the thermal efficiency is equal to the Carnot factor, satisfying Carnot's theorem as well as the first and second laws of thermodynamics.

I2.2.2 Thermal-contraction effects

However, for a thermal cycle involving heat-work interactions driven by thermal contraction, two distinct pressure regimes must be considered:

1 When the expansion pressure exceeds the reference pressure, expansion work results from positive pressure achieved by heat addition to the working fluid.

2 When the contraction pressure falls below the reference pressure, the work of contraction results from the negative pressure (relative vacuum) achieved through cooling by heat extraction.

2.3.3 Experimentally observed behavior

As shown in Fig. 2, the vacuum induced by cooling during process 4–5 is responsible for:

a) an increase in internal energy during process 5–1, and

b) the performance of useful work during process 5–1.

Because these two phenomena —simultaneous internal energy rise and useful work output— have not been previously considered in conventional thermodynamic analysis, the following modeling analysis of thermodynamic processes involving mechanical work by thermal contraction is required. The analysis of the PGT-sVsVs thermal cycle is based on the first law of thermodynamics, yielding the energy balances derived in the preceding section.

2.3.4 Self-sufficiency abilities: necessary conditions

The advantage of this disruptive achievement lies in the fact that the work obtained during the contraction phase does not require the addition of thermal energy; instead, it is accompanied by the extraction of heat, which can be recovered. This characteristic alone contributes to an almost twofold increase in thermal efficiency. Moreover, the heat recovered during the cooling process can be regenerated and reinjected into the system, further enhancing overall performance.

Fundamentally, the key lies in adiabatically increasing internal energy while simultaneously delivering useful mechanical work, coupled with the systematic recovery of the cooling heat rejected by each processing unit (PU). The ability to harvest and reuse this cooling heat at every stage is essential to achieving self-sustaining operation.

In summary, the strategic arrangement of a cascade of processing units that perform both expansion and contraction work, together with the efficient recovery and reutilization of the heat rejected during the cooling of each cascaded PU, constitutes the core approach for attaining energetic self-sufficiency.

2.3.5 sVsVs math-model

Input heat

The amount of heat added at closed isochoric heat transfer process

$$q_{i23} = \Delta h_{32} = Cp \cdot (T_3 - T_2) \tag{6}$$

Output heat

heat extracted at closed isochoric heat transfer process

$$q_{o45} = \Delta h_{45} = Cp \cdot (T_4 - T_5) \tag{7}$$

Input work

The input work in the sVsVs cycle is due to the pumping effort of the feed compressor. In order to simplify the analysis without loss of generality, the amount of work done on the feed compressor to transfer the working fluid from the cold reservoirs to the hot reservoirs is

$$w_{i12} = \Delta h_{21} = h_2 - h_1 = Cp \cdot (T_2 - T_1) \qquad (8$$

Output work

The work done by expansion along the process 2-3 due to the isochoric heat added is

$$w_{o34} = w_{o\exp 34} = \Delta h_{34} = Cp \cdot (T_3 - T_4) \tag{9}$$

The work done by contraction along the process 5-1 due to the isochoric heat extracted is

$$w_{o51} = w_{ocont51} = \Delta h_{51} = Cp \cdot (T_1 - T_5)$$
(10)

Net useful work

$$w_n = w_{o\exp 34} + | w_{ocont51} | - \Delta h_{12} = \Delta h_{34} + \Delta h_{51} - \Delta h_{12} \tag{11}$$

Therefore, the thermal efficiency is given by the ratio of the mechanical work to the input heat, yielding

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o34} + | w_{o51} | - \Delta h_{12}}{\Delta h_{32}} = \frac{\Delta h_{34} + \Delta h_{51} - \Delta h_{12}}{Cp \cdot (T_2 - T_1)} = \tag{12}$$

2.3.6 Comparison between both thermal efficiencies (based on expansion and based on expansion + contraction)

Thermal efficiency of a cycle that operates by performing useful work output only through an adiabatic expansion in a converter or actuator based on the adiabatic heat-work interaction. This corresponds to a conventional thermal cycle that converts heat into work using a converter or actuator that employs a cylinder or turbine as the converter.

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o34} - \Delta h_{12}}{q_i} \tag{13}$$

Thermal efficiency of a sVsVs cycle that operates with both adiabatic expansion work and adiabatic contraction work. This corresponds to an unconventional thermal cycle that converts heat into work using both, a converter or actuator that employs a cylinder or turbine to convert heat into work output by adiabatic expansion and work output by adiabatic contraction. Therefore using Eq. (9) to define expansion work and Eq. (10) to define contraction work yields

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o34} + | w_{o51} | - \Delta h_{12}}{q_i} \tag{14}$$

The result of comparing Eq. (13) and (14) yields

$$\frac{w_{o34} - \Delta h_{12}}{q_i} < \left| w_{o34} + | w_{o51} | - \Delta h_{12} \right| \tag{15}$$

Because of

$$\left| w_{o34} - \Delta h_{12} \right| < \left| w_{o34} + | w_{o51} | - \Delta h_{12} \right| \tag{16}$$

When comparing the thermal efficiency (13) between that of a conventional thermal cycle in which the work output is due only to the expansion work induced by the addition of heat and the thermal efficiency (14) of a non-conventional and therefore disruptive thermal cycle that involves the addition of two useful work outputs —expansion work and contraction work generated by vacuum induced by heat extraction— it can be observed that the thermal efficiency of the cycle equipped only with expansion exhibits a thermal efficiency incapable of reaching the limit established by Carnot's theorem. However such thermal efficiency is always lower than the thermal efficiency of the disruptive cycle enabled to produce work by expansion and contraction, which not only does it exceed the thermal efficiency l8imit established by Carnot, but its energy balance does not align with the useful energy balance for conventional cycles —cycles that convert heat to work only by adiabatic or isothermal expansion— that is, they lack the ability to do useful work by contraction, which affects the definitions of the first law of thermodynamics (FLT). The restrictions on thermal efficiency imposed by Carnot's theorem are inviolable. This is because it is only applicable to Carnot cycles and related cycles such as Ericsson and Stirling. Their affinity stems from the common characteristic of operating between two isotherms, one of high temperature and the other of low temperature. However, Carnot's theorem does not impose any efficiency limits on cycles other than Carnot, Ericsson, or Stirling.

2.3.7 Relevant comments on the framework for addressing Second Law concerns

Following the significance of entropy changes through the T-s diagram depicted in Fig. 2(a), with reference to the set formed by the cascade of PUs, the significance of this disruptive achievement becomes clearer when examined through a Second-Law thermodynamic framework. The mechanical work obtained during the contraction phase is not derived from the input of additional thermal energy, but rather from a controlled extraction of heat associated with the cooling effect of the process. Crucially, this heat is not discarded to the environment; instead, it is recovered and made available for reuse. From a strict thermodynamic standpoint, this does not negate the Second Law, since entropy is neither destroyed nor reduced, but redistributed and managed within the system boundaries. The immediate consequence is a substantial improvement in effective thermal efficiency, approaching a near doubling when considered at the system level.

Furthermore, the regeneration and reintegration of the recovered cooling heat ensures that entropy production associated with heat rejection is minimized locally and prevented from dispersing irreversibly into the surroundings. While entropy generation remains unavoidable, its spatial and functional localization allows the system to operate closer to reversible limits than conventional architectures. In this sense, the performance gain arises not from circumvention of thermodynamic limits, but from a more complete internal utilization of available exergy that is normally wasted.

At the core of the concept lies the adiabatic increase of internal energy concurrent with the delivery of useful mechanical work, combined with the systematic recovery of heat released through cooling in each processing unit (PU). Importantly, no step in this process implies a spontaneous conversion of heat into work without compensation. Instead, each PU participates in an orchestrated balance of work, heat transfer, and entropy flow, such that the entropy increase mandated by the Second Law is consistently offset by internal heat reutilization rather than external rejection.

The behavior of entropy is then discussed in the face of the challenges posed by obtaining work due to thermal contraction induced by vacuum or a pressure lower than the reference pressure at the start and end of cycle, **explicitly embedding an entropy-balance narrative** consistent with the Second Law, including the global inequality $\Delta s_{sys} + \Delta s_{surr} \geq 0$

The significance of this groundbreaking achievement becomes clear when analyzed using an explicit Second Law entropy balance. During the contraction phase, useful mechanical work is produced without the need for an external input of thermal energy. Instead, the process is accompanied by a controlled heat extraction associated with cooling. Importantly, this heat is not irreversibly dissipated into the environment but is recovered and retained within the system boundaries for later reuse. As a result, the process does not violate the Second Law, since entropy is neither destroyed nor reduced; rather, it is redistributed and managed internally.

For each processing unit (PU), the entropy balance can be expressed as $\Delta s_{(PU)} = \int \delta q_{rec} \cdot T + S_{gen}$ where δq_{rec} denotes the recoverable heat extracted during cooling, and $S_{gen} \geq 0$ is the entropy generated by unavoidable irreversibilities. When the PU is considered in isolation, entropy production is strictly non-negative, fully consistent with the Second Law. However, by reinjection the recovered heat into downstream or upstream processes within the same architecture, the associated entropy flux remains internal rather than being dispersed into the surroundings.

At the system level, the global entropy balance becomes $\Delta s_{sys} + \Delta s_{surr} \geq 0$

In the proposed configuration, Δs_{sys} accounts for the cumulative entropy changes across all cascaded PUs, while Δs_{surr} is minimized by reducing net heat rejection to the environment. Because the majority of the heat associated with cooling is recovered and reutilized internally, the entropy increase of the surroundings is substantially lower than in conventional thermal architectures. The inequality remains satisfied at all times, but the entropy production is spatially confined and functionally exploited rather than lost.

The effective gain in thermal efficiency therefore arises from improved exergy utilization, not from any spontaneous conversion of heat into work without compensation. Mechanical work production is always accompanied by corresponding entropy generation, yet the strategic internal circulation of recovered heat allows the system to operate closer to reversible limits. In practical terms, this translates into a higher fraction of the internally available energy being converted into useful work, while irreversible entropy export is deferred or reduced.

In summary, the cascade arrangement of processing units performing coordinated expansion and contraction processes —combined with systematic recovery, regeneration, and reinjection of cooling heat— constitutes a thermodynamically consistent pathway toward energy **self-sufficiency**. The Second Law is fully respected: the total entropy of the combined system and surroundings does not decrease. Self-sustaining operation emerges as a consequence of entropy management and internal heat reuse, rather than as an exception to fundamental thermodynamic constraints. The concept of self-sufficiency in the context of thermal machines requires extending the definition of the principle of conservation of energy and, consequently, the first law of thermodynamics to include the effects of the conversion of heat to useful mechanical work by thermal contraction.

2.3.8 Kelvin–Planck and Clausius compliance disclaimer

The Kelvin-Planck statement of the second law of thermodynamics asserts that *"it is impossible to create a cyclic engine that converts 100% of heat from a single reservoir into net work"*.

The Clausius statement of the second law of thermodynamics asserts that *"it is impossible to construct a device operating in a cycle that transfers heat from a colder body to a hotter body without external work input*".

On the basis of the statements of Kelvin-Planck and Clausius, the fact of achieving a heat engine enabled to operate without an external energy source on a cycle does not violate the second law in the statements of Kelvin Planck or in that of Clausius.

It is emphasized that, while the proposed architecture conforms to either the Kelvin-Planck or Clausius statements of the Second Law of Thermodynamics, the condition of self-sufficiency does not require an external heat source. According to the two statements of Kelvin-Planck and Clausius, **there is no reference to the prevailing need for an external heat source**. This means that *the existence of self-sufficient machines does not necessarily have to violate the second law of thermodynamics*.

In particular, the system does not operate by extracting heat from a single thermal reservoir and converting it entirely into work, nor does it induce net heat transfer from a colder body to a hotter one without external compensation. All work-producing stages are accompanied by corresponding entropy generation and compensating heat flows, and at no point is mechanical work obtained from heat alone without an associated entropy increase. Heat recovery and reinjection occur exclusively within the system boundaries and serve to reduce irreversible external heat rejection, not to abolish it. Consequently, the apparent performance gains arise from internal heat reutilization, exergy preservation, and entropy flow management across multiple interacting control volumes, rather than from any prohibited thermodynamic process. When evaluated as a closed system interacting with its surroundings, the overall operation remains fully compliant with both Kelvin–Planck and Clausius formulations of the Second Law.

2.4 How to achieve a high amount of contraction work relative to expansion work.

To achieve a similar dimensional structure in all PGT-based rotary actuators capable of converting heat into work with the same actuator volume but at different temperatures and pressures, a constant temperature jump or drop (TD) is used between each of the PUs that make up the PU cascade.

Each Power Unit (PU) completes one PGT cycle by executing two sequential sVsVs thermal cycles. These cycles operate in a complementary manner: while one sVsVs cycle performs mechanical work through expansion and contraction, the other simultaneously undergoes heat addition and extraction.

To proceed with the study of the SSPM, it is essential to characterize each PU based on the properties of its thermal cycle. This analysis focuses on the behavior of the PGT-sVsVs cycle with respect to the isochoric temperature drop T_D, defined as $T_D = T_3 - T_1$. The goal is to identify a constant temperature drop that ensure acceptable performance for the complete SSPM which involves each PU within an operating range suitable for cascade integration downstream in the SSPM.

The ratio RW of the mechanical work done by contraction to expansion of the TWF is expressed as:

$$WR = \frac{w_{ocont}}{w_{o\exp}} \tag{17}$$

Essentially, the ratio between the work of contraction and the work of expansion given by Qq. (17) increases as the temperature drop T_D decreases. So, to clarify this concept, for each PU, the ratio RW depends on T_D such that when T_D tends to zero, WR tends to one. The ratio of contraction to expansion work cannot be equal to one. If the temperature drop between each cascaded PU approaches zero, the ratio WR tends to one. In this limit, T_1=T_3, meaning no heat transfer occurs, and consequently no power can be developed. As T_3 approaches T_1, the amount of useful work obtained from cooling relative to the expansion work increases, which enhances thermal efficiency. However, achieving this requires increasing the number of PUs. Consequently, it is necessary to determine an optimal or at least most convenient temperature jump that maximizes net profit by balancing improved efficiency against the higher cost associated with adding more PUs.

2.5 Thermodynamic volume of each PU

Every prototype requires a design task which include the answer to how to fit low-volume power units (PUs) and self-sufficient power machines (SSPMs) inside a train car. The is, the design criteria are subject to space constraints, such that each power unit must occupy a reduced volume, and consequently, the volume of each SSPM is also reduced to fit within a train car. Therefore, it is proposed to reduce the volume of actuators and expansion and contraction reservoirs by increasing the reference pressure. The reference pressure for implementing the prototype of a self-sufficient power machine (SSPM) that fits inside a train car for the proposed case study is 60 bar.

2.6 Integration of the PGT sVsVs cycle into a cascade of PUs to implement a SSPM

A systematic methodology to implement a cascaded group of PUs operating with a constant temperature difference T_D is proposed [15]: The cases studied comprehend eight T_D values applied on the study of 4 SSPMs-based case studies operating by means of thermal cycles of the type PGT-sVsVs, where top temperature T_3 is fixed in 750 K for the first PU of the proposed SSPM and the corresponding temperature T_1 according the chosen. T_D.

By processing the data of Table 2 according to the thermodynamic model of the proposed thermal cycle described along equations (1-6) and (7-12), a useful set of data is obtained as results of the analysis, as function of the constant T_D for each case which is depicted in Table 3. The mentioned results include the high and low temperatures, the specific flows of input heat and output heat, as well as useful mechanical work, and with the aim of comparison purposes the thermal efficiency and Carnot factor is also depicted.

Every cascaded PU-based structure is configured according to the scheme depicted in Fig. 1. Observing Fig.3 it can be noted that while the heat supply system includes a set of cascaded heat exchangers to supply heat to all cascaded PUs of the SSPM, the cooling heat from the reservoirs responsible for the vacuum is extracted from them in a cascade and recovered to be fed back into the internal heat supply system. The unique circuit responsible for the circulation of the HTF enabled to add and extract heat to/from the hot and cold reservoirs is essential to achieving self-sustainability capabilities.

Fig. 3 illustrates the main components of a SSPM composed of cascaded PUs made of rotary actuators based on PGTs [5], [18], [19]. Among the main parts, each PU shows:

- Two TWF's expansion reservoirs for heat addition

- Heat addition piping responsible for raising the TWF pressure and temperature by means of the HTF circulation

- TWF recirculation ducts via a recirculation compressor for heat addition to the TWF by forced convection

- A gas turbine-based rotary actuator that operates using pressure and temperature pulses (PGT)

- Two TWF contraction reservoirs for heat extraction cooling

- HTF extraction circuit piping or ducts from the reservoirs responsible for generating a vacuum

- TWF recirculation circuit piping or ducts via a recalculating compressor for heat extraction from the TWF by forced convection

- Recirculation pump for HTF (thermal oil or equivalent)

- Recirculation rotary feed compressors to activate forced convection heat transfer to/from the HTF (thermal oil) to/from the TWF of any PU of the SSPM.

- Feed Pump for each PU —not represented in the figure

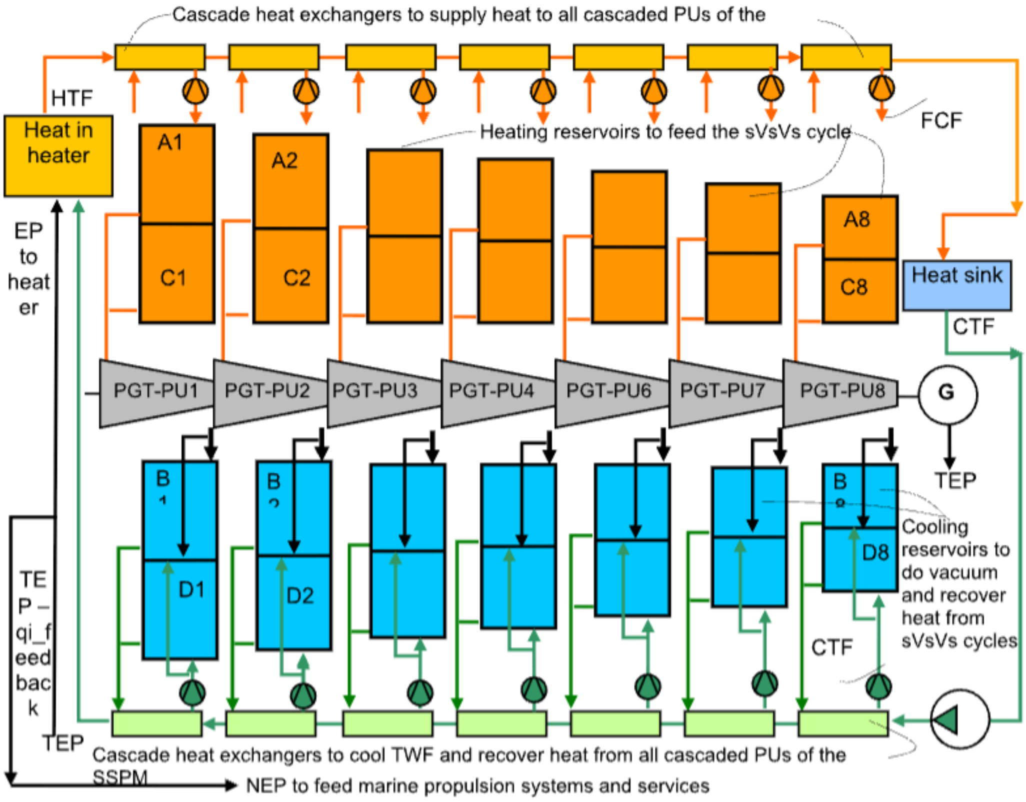

Figure 3. Illustration of a feasible structure for a SSPM composed of seven cascaded PGT-based PUs, showing some of the most significant components: [5], [18], [19]

With regard to the structure depicted in Fig.4 it is worth noting that the volume of the TWF tanks, both hot and cold, for each power unit (PU) is different; however, the volume of each PGT-based rotary actuator for each PU is identical. This design strategy allows for a significant reduction in the manufacturing and maintenance costs of the rotating machines, as they are identical because they only have to withstand relatively small temperature and pressure changes, which implies minimal thermal variations under steady-state operating conditions.

Therefore, the next section on design addresses the proposed case studies that take into account the aforementioned observation.

Since the ship power technology based on SSPMs must replace conventional propulsion systems including fossil fuels-based combustion engines and nuclear power, which will be the power source for ship propulsion systems, we will call such self-sustaining power systems "self-sustaining power generators" (SSPG).

Comparing the contents of Figs. 3 and 4, it is observed that the energy distribution strategy is adapted to drive a generic electric railway traction system. The aforementioned strategy indicates that any SSPM that satisfies an energy demand is susceptible to adaptation to any industrial application that is not limited by the excess volume or weight of the plant.

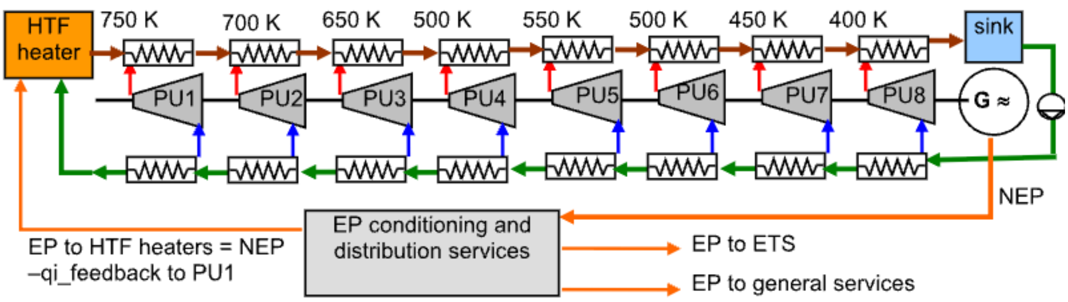

Figure 4. Symbolic illustration of an SSPM structure composed of eight cascaded PGT-based processing units showing a schematic of electrical power distribution. [5], [18], [19]

2.7 Case studies on a SSPM

In the proposed case study, an SSPM is composed of 8 PGT-based PUs conditioned by the sVsVs cycle is considered. Using equations 6 to 13, the data depicted in table 2 is obtained. And using dta from Table 2 the information shown in Table 3 is obtained. In this table, computation data and results for helium as working fluid is depicted. Along the analysis real TWF data used belongs to the database provided by Lemmon E. W., et all, (2007), [13]. In Table 2 main results from cycle data is depicted. For the studied case a top temperature of 1000 (K) is chosen, while the temperature difference or drop T_D is assumed as 100 K between each cascaded PU. This means that every SSPM is completed by means of 7 PGT-based PUs. Considering helium as TWF, thermal and mechanical losses are grouped as losses factor (LF) = 0.9 which is interpreted as a thermal efficiency of 90 (%), while isentropic losses (I_eff) are assumed as 0.9 which contributes to an efficiency of 90 (%).

2.7.1 SSPM composed by 7 PUs each driven by a PGT-sVsVs cycle using helium and T_D: 100 K

The number of PUs in each SSPM is associated with the operating temperature range (T_H-T_L =750-350K) and the temperature drop $\mathbf{T_D}$ between each cascaded PU, such that if an operating temperature range between 750 and 350 (K) is chosen, the number of possible 100 K jumps is the ratio between range and temperature jump; that is (750-350)/0 = 8 PUs as depicted in Fig. 4. Therefore Table 2 depicts the results for each PU.

Table 2: Processed data for a SSPM composed by 8 cascaded PGT-based PUs into the temperature range of 750-350 K.

sp	T(K)	p(bar)	v(m³/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg. K)
PU 1; TD = 50 K						
1	700.00	60.00	0.2449	2189.30	3658.90	23.907
2	706.94	61.50	0.2414	2211.00	3699.34	23.907
3	750.00	65.22	0.2414	2345.40	3919.90	24.092
4	725.41	60.00	0.2537	2268.50	3803.62	24.092
5	684.00	56.58	0.2537	2139.30	3574.80	23.907
PU 2; TD = 50 K						
1	650.00	60.00	0.2277	2033.50	3399.40	23.522
2	656.39	61.50	0.2243	2053.50	3436.73	23.522
3	700.00	65.58	0.2243	2189.60	3660.60	23.723
4	675.62	60.00	0.2365	2113.30	3545.13	23.723
5	633.60	56.28	0.2365	1982.20	3313.10	23.522
PU 3; TD = 50 K						
1	600.00	60.00	0.2104	1877.60	3139.90	23.107
2	605.95	61.50	0.2073	1896.20	3174.68	23.107
3	650.00	65.97	0.2073	2033.80	3401.20	23.326
4	625.86	60.00	0.2193	1958.20	3286.81	23.326
5	583.50	55.95	0.2193	1826.00	3053.00	23.107
PU 4; TD = 100 K						
1	550.00	60.00	0.1931	1721.70	2880.40	22.655
2	555.41	61.50	0.1903	1738.70	2912.07	22.655
3	600.00	66.42	0.1903	1877.90	3141.90	22.896
4	456.00	60.00	0.2021	1803.10	3028.41	22.896
5	533.30	55.56	0.2021	1669.40	2792.30	22.655
PU 5; TD = 50 K						
1	500.00	60.00	0.1758	1565.80	2620.90	22.161

2	504.98	61.50	0.1733	1581.40	2650.12	22.161
3	550.00	66.97	0.1733	1722.10	2882.60	22.428
4	526.42	60.00	0.1850	1648.20	2770.46	22.428
5	483.40	55.10	0.1850	1513.80	2533.20	22.161
PU 6; TD = 50 K						
1	450.00	60.00	0.1586	1409.90	2361.40	21.614
2	454.47	61.50	0.1563	1423.90	2387.62	21.614
3	500.00	67.64	0.1563	1566.20	2623.30	21.913
4	476.70	60.00	0.1678	1493.10	2512.24	21.913
5	433.00	54.51	0.1678	1356.60	2271.40	21.614
PU 7; TD = 50 K						
1	400.00	60.00	0.141320	1253.90	2101.80	21.002
2	403.92	61.50	0.139260	1266.20	2125.02	21.002
3	450.00	68.49	0.139260	1410.30	2364.10	21.340
4	426.87	60.00	0.1506	1337.70	2253.58	21.340
5	383.00	53.85	0.1506	1200.60	2011.60	21.002
PU 8; TD = 50 K						
1	350.00	60.00	0.124060	1097.90	1842.20	20.309
2	353.45	61.50	0.122270	1108.70	1862.64	20.309
3	400.00	69.57	0.122270	1254.30	2104.90	20.696
4	377.07	60.00	0.1334	1182.40	1995.01	20.696
5	333.00	53.01	0.1334	1044.50	1751.70	20.309

2.7.2 Main results of a SSPM of 7 PGT-based PUs derived from data in Table 3.

Table 3 illustrates the main results of the SSPM of 7 PGT-based PUs, including the most relevant data from the studied SSPM. Therefore, to facilitate understanding of the results in Table 3, the meanings of the relevant SSPM parameters are illustrated in the following list:

Table 3: Results the cascaded PUs from data processed in Table 3

PU	1	2	3	4	5	6	7	8	Total
LF(%)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.00	0.90
Is_eff(%)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
T_3_sVsVs	750.00	700.00	650.00	600.00	550.00	500.00	450.00	400.00	
T_1_sVsVs	700.00	650.00	600.00	550.00	500.00	454.47	400.00	350.00	
qi_top/PU(kJ/kg)	220.56	223.87	226.52	229.83	232.48	235.68	239.08	242.26	1608.01
q_{o45}(kJ/kg)	228.82	232.03	233.81	236.11	237.26	240.84	241.98	243.31	1650.85
q_rec(kJ/kg)	228.82	232.03	233.81	236.11	237.26	240.84	241.98	243.31	1337.19
mean_rec_T(K)	712.71	662.81	612.93	503.00	513.21	463.35	413.44	363.54	
w_{i12}(kJ/kg)	40.44	37.33	34.78	31.67	29.22	26.22	23.22	20.44	243.33

w_{o34}kJ/kg)	104.65	103.92	102.95	102.14	100.93	99.95	99.47	98.90	812.92
W_{o51}(kJ/kg)	75.69	77.67	78.21	79.29	78.93	81.00	81.18	81.45	633.42
RW(%)	72.33	74.74	75.97	77.63	78.21	81.04	81.61	82.36	
$w_{n=}w_{o34}+W_{o51}-w_{i12}$(kJ/kg)	139.90	144.26	146.38	149.76	150.63	154.73	157.43	159.91	1203.00
η_th/PU	63.43	64.44	64.62	65.16	64.79	65.65	65.85	66.01	64.850
V_{reserv}(m3/kg)/PU)	0.2414	0.2243	0.2073	0.1903	0.1733	0.1563	0.1393	0.1223	1.332
V_{tot} (m3/kg)/PU)	0.2537	Total	0.2193	0.2021	0.1850	0.1678	0.1506	0.1334	1.415
ΔV_actb(m^3)	0.0124	0.90	0.0120	0.0118	0.0117	0.0115	0.0113	0.0111	0.083
p_{ref}(bar)/PU	60.00	0.90	60.00	60.00	60.00	60.00	60.00	60.00	
$\Delta p = p_{23}-p_{45}$(bar)	3.72	4,08	4.47	4.92	5.47	6.14	6.99	8.07	
qi_feedback_PU1=(h_3-h_5) (kJ/kg-cycle									345.10
Output net work (kJ/kg-cycle)									857.90

The useful work performed by each PU should ideally be approximately equal across all units of the SSPM. However, when designing a plant to operate with a temperature drop of 50 K between PUs, which is excessively high to maximize self sufficiency and minimize the number of PUs in the SSPM, there is some deviation in the net work out between PUs, also due to the Feed pump work required to feedback the TWF in each PU of the SSPM. This results in excessive differences between the individual work outputs of each PU, as shown in Table 4, and Fig. 5. These results are due to the fact that the net work of each power unit (PU) is different, being relatively high for the first PU, PU1, and considerably lower for the last PU, or PU8. This results in the net work of each unit being relatively normal at approximately 300 kJ/kg for the first unit, UP1, and considerably higher for the last unit, UP7, at approximately 325,000 kJ/kg

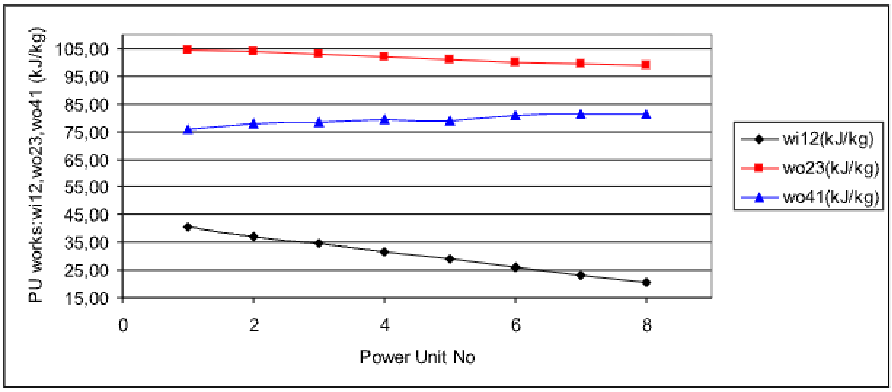

Figure 5. illustration of the input feed pump work, output expansion and output contraction works for the eight cascaded PUs

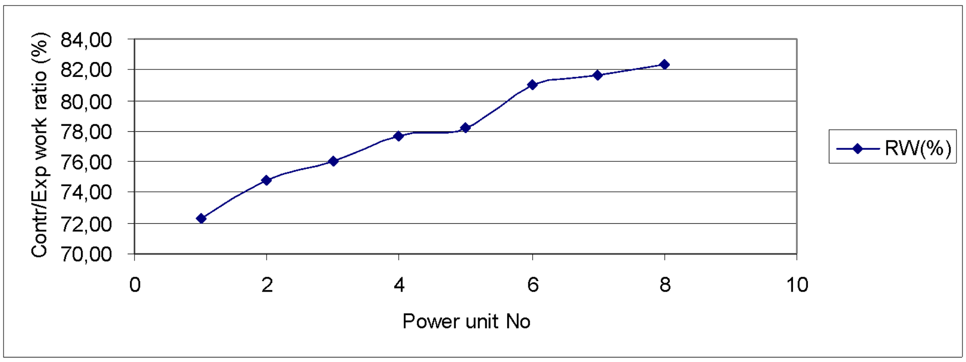

Figure 6. illustration of the contraction/expansion ratio in each cascaded PU

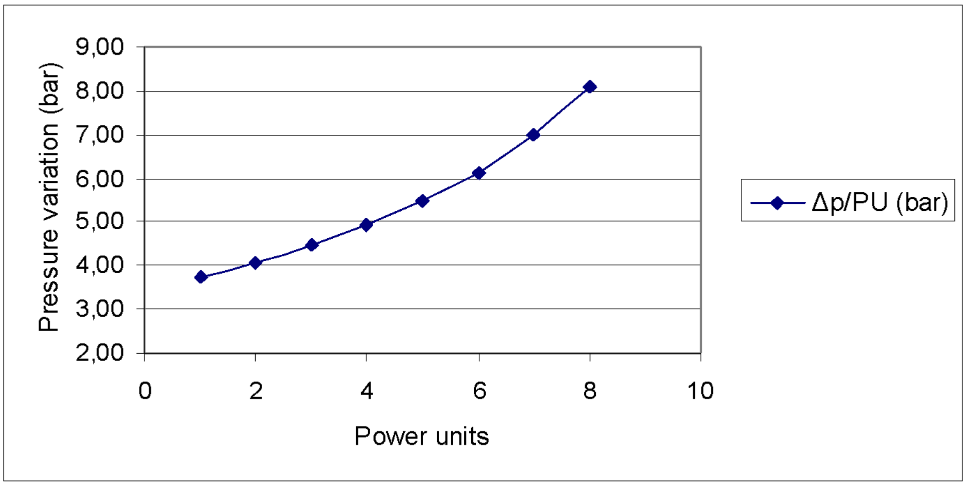

Figure7. illustration of the pressure variation (bars) into each PU. Evolution of expansion pressure: $\Delta p_{exp} = p_H - P_{ref;}$; Evolution of expansion pressure: $\Delta p_{cont} = P_{ref} - p_L$.

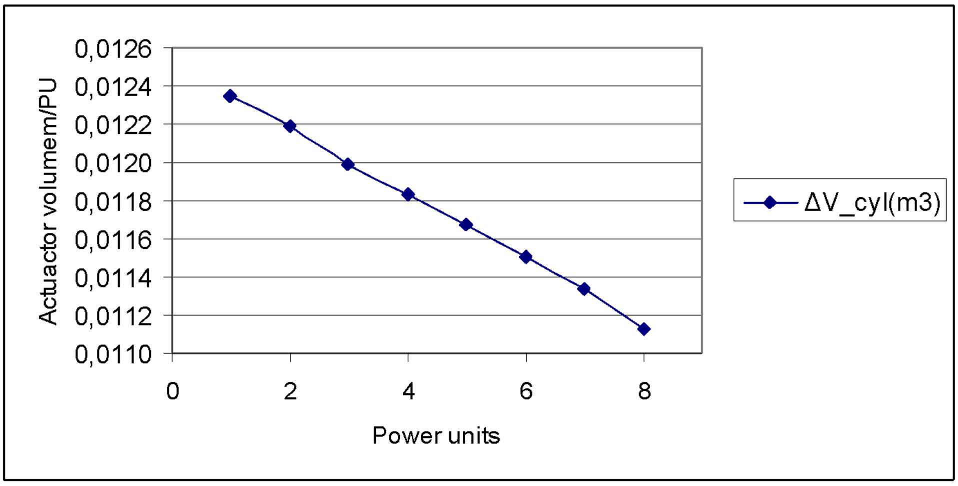

Figure8. illustration of the volume (m^3) assigned to each PGT-based turbine

Table 4: Concept description of the results derived from processing cycle data from table 3 with data of Table 2 for a SSPM composed of 8 PGT-based PUs

NPUs/SSPM: number of PUs/SSPM	8
T_D (K): constant temperature drops between cascaded PUs	50
LF (%): mechanical and thermal losses	0.9
Is_eff (%): isentropic efficiency of each actuator (PGT)	0.9
∑qi_PUi/SSPM(kJ/kg): total heat inlet to the SSPM PUs	1608.01
$\sum qo\_{45}$(kJ/kg): total cooling heat output/SSPM	1650.85
∑q_rec(kJ/kg): total heat recovered/SSPM= qo_{45}	1337.19
$\sum wi_{12}$(kJ/kg): input feed pump work	243.33
$\sum Wo_{34}$(kJ/kg): expansion output useful work/SSPM	812.92
$\sum Wo_{51}$(kJ/kg) contraction output useful work/SSPM	633.42
RW: average ratio of contraction to expansion work	≈78
∑w/PU (kJ/kg-cycle): $\sum Wo51 + \sum Wo_{34} - \sum wi_{12}$ = net SSPM useful mechanical work/SSPM	1203.00
η_{th}/SSPM: Average thermal efficiency of PUs/SSPM	65

$\sum V_{reserv}$(m^3/kg)/PU): Reservoir volume /SSPM	1.332
$\sum V_{tot}$ (m^3/kg)/PU): Total thermal volume of the SSPM; $\sum V_{reserv}+\sum\Delta V_{\_act}$	1.415
$\sum\Delta V_{\_act}$ (m^3) = $\sum V_{tot}-\sum V_{reserv}$: actuator volume consisting of PGT-based turbines	0.083
p_{ref}(bar)/PU: initial pressure of the sVsVs cycle	60
qi_feedback (PU1) = h_3-h_5(kJ/kg-cycle (Amount of heat added to the PU1)	345.10
$\sum$w/PU (kJ/kg-cycle) —qi_feedback (PU1w_n/SSPM = output useful work of the SSPM	857.90

Given the interdependence between the critical and common parameters inherent in all the PUs of the SSPM case study, which are relevant to the key analyses and conclusions regarding the prototype design, the following parameters are considered useful for analyzing the results using the data presented in Table 4. Among all the relevant data presented in Table 4, the total useful work per cycle is essential. However, it is also important to determine the total work output delivered by each SSPM, the feedback heat added to the first PU of the cascaded PUs, and the net useful work output as a function of the constant temperature drop (TD) set at 50 K, for a fixed reference pressure chosen to be the same for each PU of the designed SSPM.

3 Scaling SSPM dimensions to meet power demand in ETSs

To meet the energy demands of ETSs applications, it is necessary to satisfy the needs of energy support to the following essential services:

-- Redundant main propulsion power equipment including electric traction generation —at least two SSPMs are needed.

-- Onboard electrical power demand including hotel services, air conditioning, etc.

-- Autonomous emergency power supply services —i.e.

By proportionally scaling the volume of the hot and cold PU tanks of the SSPM's TWF to meet the power demand, the approximate plant volume and weight can be estimated.

Ideal power is usually estimated from the specific work (the corresponding input or output work done per unit time) of one kg of TWF per second (s). That is, the product of the mass flow rate ($\dot{m}$ =mfr) of TWF and the specific work w_n.

$$P = Power = \dot{m}\cdot w_n \; [(kg/s)\cdot(kJ/kg)] \rightarrow (kJ/s) \rightarrow kW \tag{18}$$

Where $\dot{m}$ is the mass flow rate of the THF, and w_n. is the net output wrk delivered by the SSPM during a cycle.

3.1 Modeling a SSPM-based MPS through PGT-based PUs and the sVsVs Cycle

The objective of the propulsion modeling task is to determine the actual electrical power demand to satisfy two basic needs such as sufficient propulsive thrust and, electrical power to meet the total demand of resource exploitation tasks.

Ideal power is usually estimated from the specific work (the corresponding input or output work done per unit time) of one kg of TWF during a second (s). That is, the product of the mass flow rate ($\dot{m}$ =mfr) of TWF and the specific work. When specific work is expressed by means of an enthalpy change, power is expressed according to previous Eq. (14) as $P = \dot{m}\cdot w$.

As shown in Figs. 8-13, it is depicted the ideal power ideally delivered by an SSPM designed according to specified required characteristics.

The real adiabatic expansion and contraction of the TWF along the processes carried out in the SSPM exhibit inherent losses due to irreversibilities. Depending on the design profile and operating conditions, these losses can exceed 20%. However in real situations the input power (P_{in}) according Eq. (15), which means the required power to satisfy a given traction power under ideal conductions, is the ratio of the specific thermodynamic work to the overall traction efficiency (η_T). Therefore, the input power is described considering the propulsion efficiency as

$$P_{IN} \approx \frac{P}{\eta_T} = \frac{\dot{m} \cdot w}{\eta_T} \tag{19}$$

However, in this approach, these losses are disregarded, and therefore the ideal case will be assumed.

Core Innovation: The PGT moves away from traditional constant-pressure combustion turbines. It operates intermittently using simultaneous "barothermal pulses"—positive pressure pulses from isochoric (constant volume) heating and negative pressure pulses from isochoric cooling.

Table 5 shows the total thermodynamic volumes of the SSPMs. Thermodynamic volume is important for estimating the volume occupied by each SSPM, but also as data for estimating the weight associated with the reservoirs responsible for a high proportion of the volume of each SSPM. Table 6 illustrates the fundamental data for proceeding with the scaling procedure for the case study.

Table 5: Illustration of the SSPM parameters relevant for the case study used to analyzing the power scaling methodology depicted in Table 6.

NPU	8
Feedback heat (kJ/kg): qi_feedback(PU1) = h_3-h_5(kJ/kg-cycle)	345.1
work/cycle (kJ/kg): ∑w/PU (kJ/kg-cycle) — qi_feedback(PU1) (kJ/kg)	857.9
Thermal V(m^3)/SSPM:	1.425
T_D (K)/PU (K)	50

The data in Table 6 are interpreted such that, with reference to case studied, for a TWF flow rate of 1 kg/s and a cycle time of 1 second, a thermodynamic volume of 1.425m^3 is required to obtain 0.8579MW of power. Likewise, for a TWF flow rate of 10 kg/s and a cycle time of 1 second, a thermodynamic volume of 14.25 m^3 is required to obtain 8.579 MW of power. Once the total energy demand is known, dimensional scaling is carried out, which estimates, among other data, the total thermodynamic volume, which allows for an approximate estimate of the total mass of SSPM.

Table 6: Dimensional scaling results of SSPM plants according to the case study results.

SSPM cycle (s)	1	2	3	4	5	6
$\dot{m}$ (kg/cycle): **1**; Total Thermal Vol (SSPM) = $\dot{m}$ *V_SSPM (m^3): 1.**415**						
$\dot{m}$ (kg/s-cycle)	**1.00**	0.50	0.33	0.25	0.20	0.17
P(MW)	**0.8579**	0.43	0.29	0.21	0.17	0.14
$\dot{m}$ (kg/s-cycle): **5**; Total Thermal Vol (SSPM) = $\dot{m}$ *V_ SSPM (m^3): **7.075**						
$\dot{m}$ (kg/s-cycle)	5.00	2.50	1.67	1.25	1.00	0.83
P(MW)	**4.2895**	2.14	1.43	1.07	0.86	0.71
$\dot{m}$ (kg/s-cycle): **10**; Total Thermal Vol (SSPM) = $\dot{m}$ *V_SSPM (m^3): **14.15**						
$\dot{m}$ (kg/s-cycle)	**10.00**	5.00	3.33	2.50	2.00	1.67
P(MW)	**8.579**	4.29	2.86	2.14	1.72	1.43
$\dot{m}$ (kg/s-cycle): **15**; Total Thermal Vol (SSPM) = $\dot{m}$ *V_SSPM (m^3): **21.22**						
$\dot{m}$ (kg/s-cycle)	**15.00**	7.50	5.00	3.75	3.00	2.50
P(MW)	**12.87**	6.43	4.29	3.22	2.57	2.14
$\dot{m}$ (kg/s-cycle): **20**; Total Thermal Vol (SSPM) = $\dot{m}$ *V_SSPM (m^3): **28.3**						
$\dot{m}$ (kg/s-cycle)	**20.00**	10.00	6.67	5.00	4.00	3.33
P(MW)	**17.16**	8.58	5.72	4.29	3.43	2.86
$\dot{m}$ (kg/s-cycle): **25**; Total Thermal Vol (SSPM) = $\dot{m}$ *V_SSPM (m^3): **35.37**						

$\dot{m}$ (kg/s-cycle)	**25.00**	12.50	8.33	6.25	5.00	4.17
P(MW)	**21.45**	10.72	7.15	5.36	4.29	3.57

3.2 Re-scaling the plant by changing the reference pressure of the cycle sVsVs

The design volume approximately follows a linear function inverse to the pressure (higher pressure means lower volume and vice versa). This thermodynamic property can be used to scale the design of a prototype without significant computational effort.

Table 7 represents also the scaling data for the case of cycle variation. This is useful for the general case of asynchronous engines. Therefore, in Figures 8-13 it is depicted the profile of the power (MW) as a function of mass flow rate (kg/s) and cycle time (s) for a given reference pressure (bar) and v_{tot} (m^3).

The volume obtained for a design can be reduced or enlarged simply by modifying the reference pressure. In the case of Table 7, a reference pressure of 20 bar has been used; however, by choosing a reference pressure of 100 bar, the volume would be reduced by 100/20, that is, 5 times less volume for 100 bar than for 20 bar, which provides the opportunity to significantly reduce the total volume of the installation.

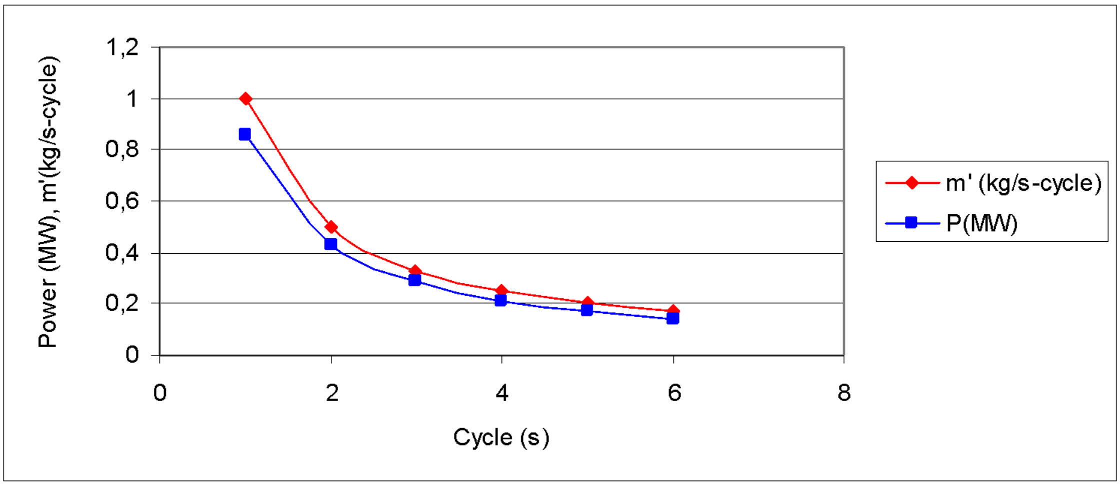

Figure 9. Power (MW) as a function of mass flow rate and cycle time (s) for a given reference pressure of 60 bar and v_{tot} (m^3)=1.45

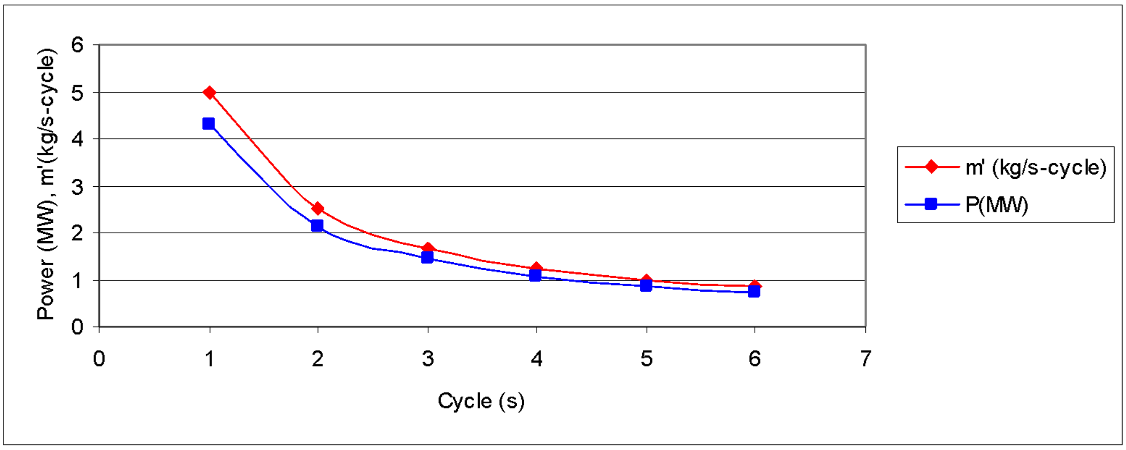

Figure 10. Power (MW) as a function of mass flow rate and cycle time (s) for a given reference pressure of 60 bar and v_{tot} (m^3)=7.05

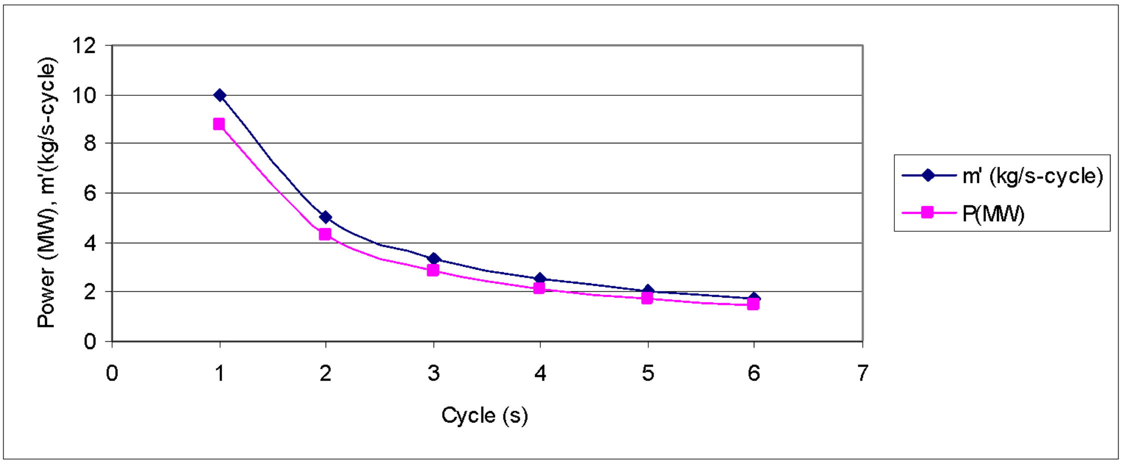

Figure 11. Power (MW) as a function of mass flow rate and cycle time (s) for a given reference pressure of 60 bar and v_{tot} (m^3) = 238

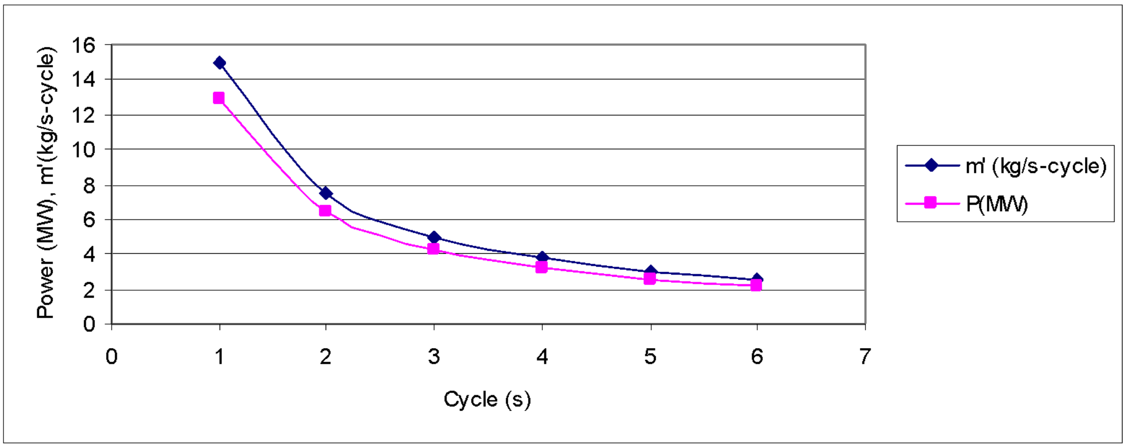

Figure 12. Power (MW) as a function of mass flow rate and cycle time (s) for a given reference pressure of 60 bar and v_{tot} (m^3) = 14.15

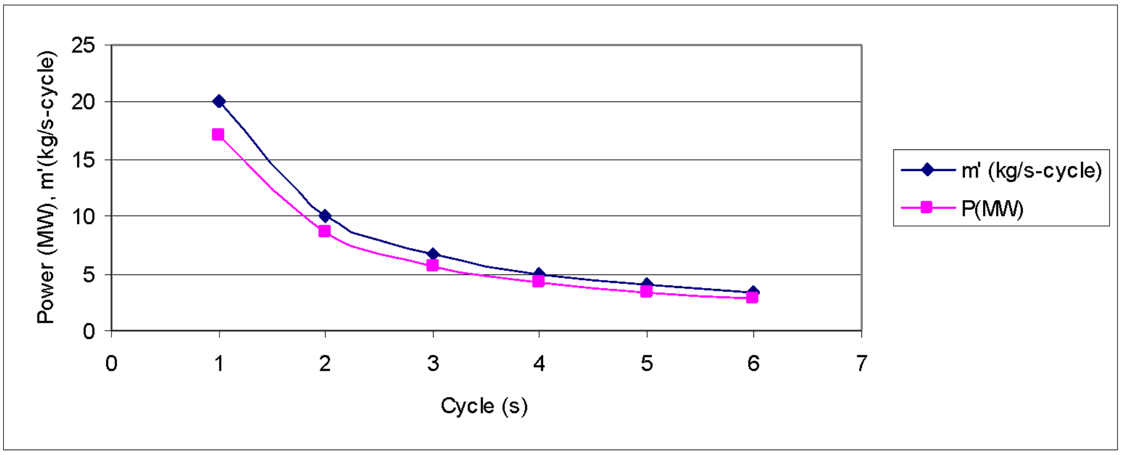

Figure 13. Power (MW) as a function of mass flow rate and cycle time (s) for a given reference pressure of 60 bar and v_{tot} (m^3) = 21.22

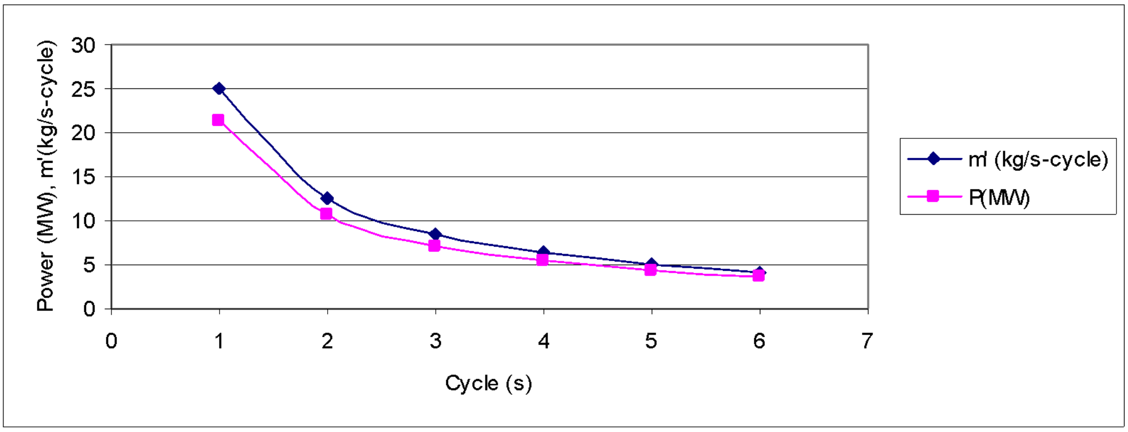

Figure 14. Power (MW) as a function of mass flow rate and cycle time (s) for a given reference pressure of 60 bar and v_{tot} (m^3)=35.37

Finally, once the dimensions have been estimated, based on the total volume of the SSPM, we have the minimum information required to implement a prototype capable of providing rigorous evidence on the behavior of the plant.

4. Electric railway traction systems

Electric railway traction involves the use of electrical power to propel railway vehicles, converting electrical energy into mechanical movement using motors. Actually modern systems are highly efficient, with electric locomotives converting up to 90% of their energy into motion, while providing high starting torque. The proposed systems do not require either overhead catenaries cables or a third rail to supply power, as the power is generated internally.

4.1 Key Electrification Systems

1 Alternating Current (AC) Systems**:** Preferred for high-speed and long-distance lines (15 kV or 25 kV at 50/60 Hz or 16.7 Hz). These systems allow higher voltages, requiring fewer substations and lighter overhead wires.

4.2 Key Technologies and Components [1]

1 Traction Motors: Modern systems almost exclusively use three-phase AC motors (induction or permanent magnet synchronous) for higher efficiency, durability, and reduced maintenance compared to older DC motors.[1],[23], [24].

2 Power Converters (IGBTs/Thyristors): Modern power electronics, such as Insulated Gate Bipolar Transistors (IGBTs), allow precise vector control of motor speed and torque, leading to efficient energy conversion and smooth acceleration.

3 Regenerative Braking: Modern trains act as generators during braking, converting kinetic energy back into electricity that can be returned to the storing system (battery).

4 Control Systems: Microprocessor-based controls manage power distribution and wheel-rail interaction to prevent wheel slip and ensure optimal efficiency.

4.3 Traction Configurations

Traction configuration depends on the type of electric train. In modern rail technology, there are two main configurations:

1 train with concentrated traction (locomotives) and

2 trains with distributed traction (Electric Multiple Units or EMUs).

Concentrated Traction (Locomotive + Cars): Only the power cars (locomotives) have the electric motors. The passenger cars are towed and do not have their own traction.

Distributed Traction (EMU/AVE): Many cars (not necessarily all, but a large number) have electric motors and traction equipment underneath them.

Details below:

1 Distributed Traction Trains (EMUs - Electric Multiple Units)

These are common in commuter trains, subways, and some modern high-speed trains.

Distributed Motors: The electric motors are distributed throughout several cars of the train.

Advantages: They offer faster acceleration, better regenerative braking (energy saving), and greater grip on inclines.

Examples: Most subways and commuter trains (like the Civia in Spain) use this configuration.

2 Concentrated Traction Trains (Locomotive)

These are common in freight trains and some long-distance passenger trains.

Power cars: One or two special cars at the front (or front and rear) contain high-powered electric motors that move the entire train.

Tracked cars: The passenger cars do not have motors.

In summary: On subways and commuter trains, traction is distributed throughout almost the entire train (EMU). On long-distance trains with locomotives, traction is only at the front ends.

Figure 15 Illustrate a simplified architecture for a self-sustaining power supply system based on one independent SSPM to assist an electric traction system (ETS) that can be installed in one train traction car, while Figure 16. Illustrate a simplified architecture for a self-sustaining power supply system based on two independent SSPMs to assist two ETSs that can be installed in two train traction cars. Figure 17 illustrates a simplified electric scheme for a self-sustaining power supply system based on two independent SSPMs to assist two electric traction system (ETS) that can be installed in two independent train traction cars.

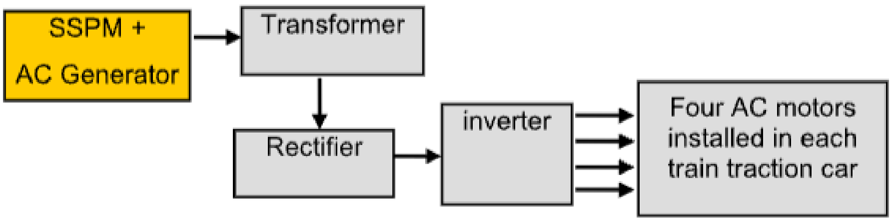

Figure 15. Illustration of a simplified architecture for a self-sustaining power supply system based on a SSPM to assist an electric traction system (ETS) that can be installed in a train traction car.

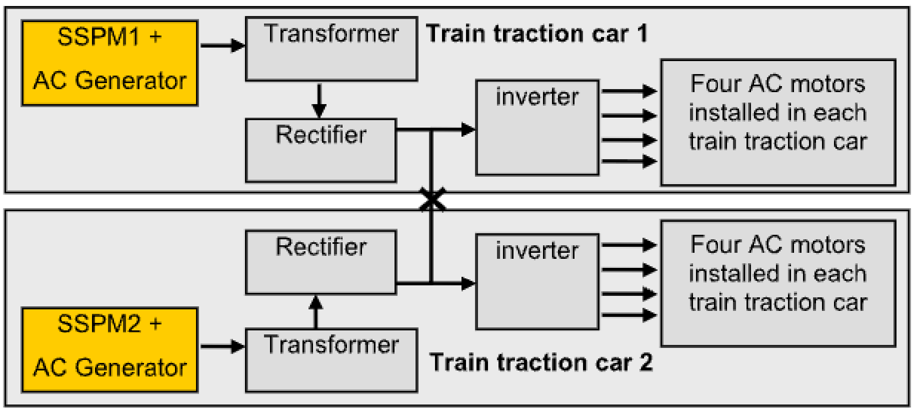

Figure 16. Illustration of a simplified architecture for a self-sustaining power supply system based on two independent SSPMs to assist an electric traction system (ETS) that can be installed in TWO train traction cars.

The architecture shown in Fig 15 doesn´t include redundancy in all critical elements: generators, transformers, motors, electrical accumulators and essential services (not shown); however, the architecture included in Fig. 16 depicts a double-redundant prototype model

Benefits include:

1 Energy Efficiency: Since it does not use fossil or nuclear fuels, the concept of thermal efficiency is irrelevant; rather, the concept of "self-sufficiency index" should be used [22]. The resulting installation is highly

efficient because an Energy Management System (EMS) optimizes load distribution to meet total demand according to (the "power plant" concept).

2 Emissions: Not combustion. Zero emissions of both CO2 and NOx because it does not use combustion engines.

3 Reduced Maintenance: Engines based on SSPMs are shared among the propulsion systems and can be shut down when not needed, reducing wear and tear.

4 Noise Reduction: It eliminates the mechanical transmission from the engines to the propellers, reducing radiated noise.

5 High Availability: The system can be designed to offer high redundancy and reliability. For example, a pair of constantly charged batteries that allow for the startup maneuver of an SSPM unit.

Finally, in Fig. 17 a simplified scheme of an electric train traction system is included, depicting the architecture of a self-sustaining energy-assisted ETS adapted to feed two train traction cars.

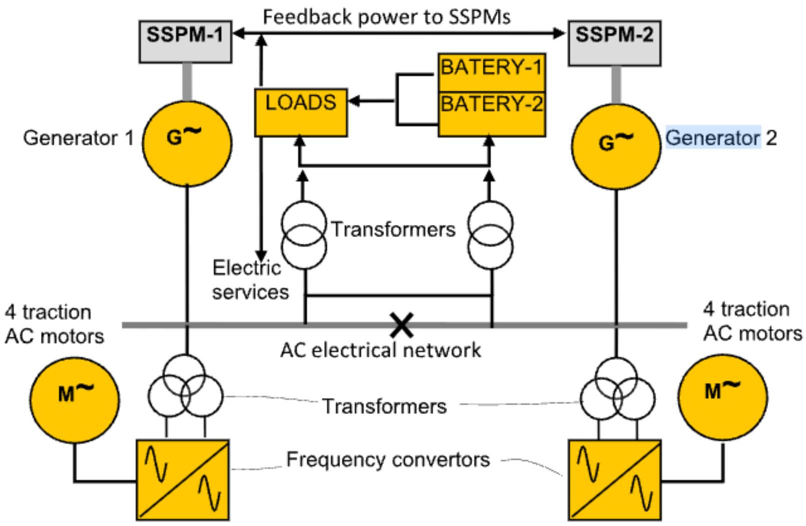

Figure 17. Illustration of a simplified architecture of a self-sustaining energy-assisted ETS adapted to feed two train traction cars.

Summarizing, the fundamental reasons justifying its global deployment include:

1 The infrastructure required for electric traction via catenaries or rail is not needed.

2 The copper used for overhead lines is not required.

3 Significant contributions to the zero-emission goal.

4 Unlimited autonomies.

5 Analysis of results: Accepting Contraction Work as Output

The reader should understand that the author defines the contraction work (5–1) as a useful output, not an input. This analysis is conducted strictly within the framework proposed by the article itself, applying logical and thermodynamic consistency according to our own equations and assumptions. Below, I present an analysis that accepts the article's model without questioning it in terms of misalignments with fundamental principles, verifying whether the results are indeed derived from that model.

5.1 What is claimed in the article (Restated Clearly)

The sVsVs cycle consists of:

Process 1–2	Isentropic compression (feed pump)	**Work in** (w_{i12})
Process 2–3	Isochoric heat addition	**Heat in** (q_{i23})
Process 3–4	Isentropic expansion	**Work out** (w_{o34})
Process 4–5	Isochoric heat extraction (cooling)	**Heat out** (q_{o45})

Process 5–1 Isentropic contraction **Work out** (w_{o51})

Net work equation (Eq. 11):

$$\mathbf{w_n = w_{o34} + w_{o51} - w_{i12}}$$

Thermal efficiency (Eq. 12):

$$\boldsymbol{\eta_{th} = w_n / q_{i23}}$$

The authors explicitly state that although every Power Unit defy Carnot efficiency because of the contribution of the contraction work, individually these sVsVs cycles are aligned with the First and Second Laws of thermodynamics, which means that obey Kelvin-Planck and Clausius statements shown in section 2.3.8.

5.2 Checking Internal Consistency of the Results (According to article Model)

From **Table 3** (results for 8 PUs), take PU1 as an example:

Quantity q_{i23} (heat in) Value (kJ/kg) 220.56

Quantity w_{o34} (expansion out) Value (kJ/kg) 104.65

Quantity w_{o51} (contraction out) Value (kJ/kg) 75.69

Quantity w_{i12} (pump work in) Value (kJ/kg) 40.44

The net work (Eq. 11):

wn = 104.65 + 75.69 − 40.44 = **139.90 kJ/kg ✓** (matches Table 3)

The thermal efficiency (Eq. 12):

η_{th} = 139.90 / 220.56 = **63.4% ✓** (matches Table 3)

So far, **internally consistent** with author own definitions.

5.3 The Critical Question: Where does contraction work (w_{o51}) come from physically?

In the paper it is stated (Process 5–1):

"Thermal energy in the form of enthalpy is converted into mechanical work by contraction."

But in **standard** thermodynamics, when a gas contracts **volume decreases** and does work ***on the surroundings***, while its internal energy ***decreases*.**

However, as shown in Fig.2 (a) by a T-s diagram, the paper claims instead:

"Vacuum induced by cooling during process 4–5 is responsible for the ***increase in temperature, pressure and consequently internal energy*** *during process 5–1 and the* ***performance of output useful work*** *during process 5–1.*

This is the core inconsistency even within my own framework: However has been experimentally proved considering vacuum as a pressure lower than a reference pressure.

Process 4–5 is isochoric cooling (heat extracted, temperature drops, pressure drops). That creates a low-pressure state.

Process 5–1 is contraction (volume decreases). For a gas to contract ***and* do work *out***, the external pressure must be *lower* than the gas pressure. But after cooling, the gas pressure is already low (see Table 2: PU1, point 5 pressure = 56.58 bar, point 1 pressure = 60 bar). Going from 56.58 bar to 60 bar while decreasing volume requires **work input**, not output.

It appears to treat contraction as if the gas is ***pulling*** (in fact consists of a pulling force) on the turbine blades due to vacuum, but that would mean the gas pressure is ***below*** reference pressure.

The author's model concludes that the work resulting from the contraction (w_{o51}) is mathematically included, but the physical mechanism is not justified because it cannot be explained by conventional reasoning. No energy balance shows where the energy for this work plus the increase in internal energy comes from, **except by violating the conservation of energy**.

Why is the existence of useful work produced by contraction irrefutable?

To meet the requirements to convert heat to work by expansion and contraction simultaneously doing output useful work, only two thermo mechanical actuator structures are available: reciprocating motion-based actuators such as cylinders and, rotating-based actuators such as gas turbines

a) Reciprocating Double-Acting Actuating Cylinders: where when a cylinder chamber operates with positive pressure does work by expansion, while the complementary cylinder chamber operates with negative pressure gives rise to contraction work since the cylinder piston is the physical separation between both cylinder chambers.

b) Gas turbines operating by means of thermo-baric pulses: Consists of a gas turbine that operates on the basis of simultaneous positive and negative baro-thermal pulses. Both types of pulses are due to positive and negative pressures relative to the reference pressure, achieved by simultaneously heating and cooling the respective working fluid reservoirs corresponding to the high and low temperatures sides in contact respectively with turbine inlet and outlet sides.

Both defined thermo-mechanical actuators are characterized each one by two actuation chambers:

a). Expansion chamber capable of converting heat into useful work output by expansion subject to a condition. The necessary and sufficient condition to perform output useful work by expansion of the thermal working fluid is $P_{exp} > P_{ref}$. Such pressure difference produces a push force by expansion.

b) Contraction chamber capable of converting heat into useful work output by contraction subject to a condition. The necessary and sufficient condition to perform output useful work by contraction of the thermal working fluid is: $P_{ref} > P_{cont}$. Such pressure difference produces a pull force by contraction.

Both expansion and contraction forces operate simultaneously in the same direction, resulting in a net increase in net forces that contribute to the increase.net work and consequently in thermal efficiency.

While the role (expansion and contraction) of each chamber of the actuator cylinders changes in each sVsVs cycle, in the case of turbines the high-temperature side always corresponds to expansion while the low-temperature side always corresponds to contraction

5.4 Testing the Cascade Self-Sufficiency Claim

The SSPM cascades 8 PUs. The feedback heat to PU1 is: qi_feedback_PU1 = 345.10 kJ/kg (from Table 3, bottom)

The total net work of the SSPM (after feedback) is: 857.90 kJ/kg

So the system claims to produce **857.90 kJ/kg of useful work** while only consuming **345.10 kJ/kg of feedback heat** to PU1. That is an energy ratio of **2.48 : 1** (output work / input heat).

Even if we accept that w_{o51} is valid output, the **First Law for the entire cascade** requires:

Total energy in = Total energy out

Energy in:

5.4.1 Feedback heat to PU1: 345.10 kJ/kg

5.4.2 (No other external heat or work)

Energy out:

5.4.3 Net work from all PUs: 857.90 kJ/kg

5.5.4.4 Heat rejected to environment (not recovered): ∑qo45 – ∑q_rec = 1650.85 – 1337.19 = 313.66 kJ/kg

Sum out = 857.90 + 313.66 = **1171.56 kJ/kg**

That is ***3.4 times*** the energy input of 345.10 kJ/kg.

This is a **direct violation of the First Law of Thermodynamics** (FLT) (energy conservation) unless:

5.4.5 There is an unaccounted external energy source, **which is not the case**, or

5.4.6 The "feedback heat" is not the only input (but the paper claims self-sufficiency with no external supply), **which is not the case**.

Consequently, a flagrant violation of the FLT exists

5.5 Carnot Violation – Quantitative Check

For PU1 operating between:

5.5.1 T_3 (hot) = 750 K

5.5.2 T_1 (cold) = 700 K (not 350 K, because each PU has a small ΔT)

Carnot efficiency limit:

$\eta_{-carnot}$ = 1 – (700 / 750) = **6.7%**

Their reported η_{th} for PU1 = **63.4%**, which is **9.5 times higher** than Carnot for that temperature span.

The author acknowledges this and claim the cycle "does not obey Carnot constraints." But Carnot's theorem is not a constraint — it is a logical consequence of the Second Law. Violating Carnot means violating the Second Law, i.e., creating a perpetual motion machine of the second kind with the ability of support certain resistances due to loads.

Summarizing, the modeling and analysis procedures applied along the article are rigorously and correctly formulated. And the challenge posed by this article alone should prompt a review of the fundamental principles of thermodynamics. At a minimum, these principles should be subjected to consistent testing that aligns with the results of experimental observations obtained in prototype tests that have not yet been validated at the level of commercial production.

Refutation of the analysis based on conventional thermodynamic considerations:

Refutation of the analysis based on conventional thermodynamic considerations:

The vacuum induced by cooling during process 4-5, as shown in Figure 2, is responsible for:

-- The increase in internal energy during process 5-1

-- The performance of useful work during process 5-1.

- Something impossible in conventional thermodynamics: performing useful work while increasing internal energy during process 5-1.

These results have been experimentally validated using a double-acting actuator: double-acting actuator cylinder with closed processes.

While in conventional thermodynamics the equilibrium qi - qo = wo is absolutely indisputable, it cannot be fulfilled when the useful work obtained from the vacuum induced by cooling is responsible for performing useful work.

This contradicts the law of conservation of energy: the First Law of Thermodynamics (FLT), Carnot's statement, and the Second Law of Thermodynamics (SLT

These results have been experimentally validated using a double-acting actuator: a double-acting actuator cylinder with closed processes.

Therefore, these findings are absolutely disruptive, changing fundamental concepts of thermodynamics and physics regarding the conservation of energy.

6. Conclusion of the Analysis

Even when accepting the paper's my own definition of contraction work as a useful output:

Findings

Internal mathematical consistency: Yes, Eqs. 11–12 is followed correctly

Physical mechanism for w_{o51}: Proof of concept by means of a reciprocating double-acting cylinder; contradicts pressure-volume work direction

First Law for entire cascade: Violated (output energy > input energy by factor of **3.4**)

Second Law / Carnot: Violated (efficiency >> Carnot for given temperatures)

Self-sufficiency claim: Without experimental evidence, It can only be verified through prototyping, as it requires experimental evidence through a prototype developed at commercial level.

Therefore, I am aware that the academic analysis of the results does not demonstrate the existence of a valid self-sufficient power machine. The numerical results are internally consistent with the paper's own equations, but those equations do not represent a physically possible energy conversion process. I must acknowledge that according to conventional thermodynamics, the claimed net positive output of 857.9 kJ/kg-cycle after feedback is thermodynamically impossible without

1 an external energy source or

2 a fundamental revision of energy conservation principles.

Consequently, I believe that an extension of the fundamental principles should be urgently proposed to harmonize the results obtained with those presented in the article. I acknowledge the imperative need for firm and irrefutable evidence through experimental validation via prototyping procedures. The patents inherent to this technology are free available internationally. Anyone wishing to experiment is free to do so without impediment from patent rights.

Final Note:

In the references section, there is a blatant abuse due to the author's repetition exceeding 95%. Unfortunately, this could not have been otherwise because there is not a single publication in the entire academic world on these contributions: making useful mechanical work by contraction at zero cost, cascading power units, and recovering rejected cooling heat in a cascaded upwards to achieve energy self-sufficiency. The fact that a scientific contribution lacks citations from authors of recognized prestige neither diminishes nor adds anything to the scientific value of the contribution that is the subject of this article and the others previously published on energy self-sufficiency.

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