Physics, Ecology, Mathematics and Engineering of the Negawatt Economy: A Formal Architecture for Verified Energy Conservation

Author:
Nigel Grier
Negawatt Economy Research Collaborative, Australia

Ecological Engineer and Founder, Grier & Associates
Juris Doctor Candidate, University of Canberra

Email: nigel@grier.sg

ORCID: https://orcid.org/0009-0008-2043-1533

Mastodon Social handle: @nigelgrier

Preprint status statement:
This manuscript is a **non-peer-reviewed preprint submitted to EarthArXiv**. It has not yet been submitted for peer review in any journal. Feedback and critique are welcome to inform further development and future publication.

Physics, Ecology, Mathematics and Engineering of the Negawatt Economy

A Formal Architecture for Verified Energy Conservation

Nigel Grier
Negawatt Economy Research Collaborative, Australia

Ecological Engineer; Founder, Grier & Associates; Juris Doctor Candidate, University of Canberra

ORCID: 0009-0008-2043-1533
Correspondence: nigel@grier.sg

Preprint: not peer reviewed

Version 3.1, 26 September 2026

Abstract

The contribution is a formal issuance architecture for verified energy conservation. The Negawatt (NWT) is the registry denomination of that conservation: one NWT equals one megawatt-hour (1 MWh) accepted under Proof of Conservation. In this paper, energy conservation means measured and verified avoided energy use relative to an adjusted baseline; it does not mean the First-Law conservation-of-energy principle. Kilowatt-hours remain the operational unit of practice; one thousand verified kilowatt-hours constitute one NWT.

The architecture is situated in four registers: classical thermodynamics and information physics; systems ecology; a classified set of accounting equations; and a measurement, reporting, and verification (MRV) chain specified at the level of principle. The Negentropy Yield is the continuous expression of verified energy conservation. Its period-total form, formalised in this paper and consistent with the Protocol, is the same quantity implemented for issuance. Analytic overlays (the boundary-dependent Negawatt Multiplier, its lifecycle special case, carbon class, and ecological scores) may describe upstream or contextual consequences. They do not rescale the minted MWh. One NWT is denominationally equivalent to any other NWT; it is not thereby economically, carbon-, or locationally equivalent.

Established physics (the First and Second Laws, Carnot's bound, exergy destruction, Schrödinger's discussion of negative entropy, Landauer's bound, Prigogine's dissipative structures) and established ecology (Lindeman, Lotka, Odum, Holling, Lovelock/Daisyworld) are lineage, not new laws. Deep Solar Time is introduced as a proposed construct; the Deep Time Solar Equation is a prospective formalism, not an issuance equation. Proof of Conservation is an evidence chain, not a claim that blockchain is physically necessary. The paper does not invent saved-energy certificates or primary-energy factors. It integrates verified claim-period conservation into a non-rescalable registry denomination. It does not claim operational or jurisprudential closure.

Keywords

negawatt; verified conservation; negentropy; exergy; emergy; measurement and verification; Proof of Conservation; primary energy factor; systems ecology; Negatrope

---

1.0 Introduction

The transition from a combustion-based civilisation to a post-combustion economy is a change in how value is defined, not only a change in how energy is supplied. For two centuries industrial progress was measured by generation and material throughput. Growth was treated as synonymous with combustion. As the planetary consequences of that paradigm have become measurable, the defining metric of the next era is not how much energy is produced but what is conserved.

The Negawatt Economy is a proposed system for valuing conservation as a lawful and measurable yield. It is grounded in the physics of order and dissipation: living and technical systems maintain structure by channelling energy and exporting entropy. This paper sets out the technical foundation of that system. It draws on classical thermodynamics, systems ecology, and applied engineering to formalise conservation as a quantifiable quantity. It extends the lineage of efficiency and systems thinking into an architecture that can be measured, recorded, and, under a declared protocol, issued as a registry denomination.

The Negawatt (NWT) is the registry denomination of verified energy conservation. One NWT equals one megawatt-hour of verified energy conservation accepted under Proof of Conservation. In this paper, energy conservation means measured and verified avoided energy use relative to an adjusted baseline; it does not refer to the thermodynamic conservation-of-energy principle. Each NWT corresponds to evidentiary restraint: energy not consumed relative to a declared baseline, upstream energy supply not required for that increment, and, where marginal supply is combustion-based, corresponding combustion avoided. Energy performance is reported in kilowatt-hours (kWh). Every 1,000 kWh of accepted conservation constitutes one NWT. NWT may subsequently function institutionally as a unit of account for verified conservation, but that economic role is distinct from its physical registry denomination and is INTERPRETIVE.

The purpose of this paper is to describe the physics, mathematics, and engineering that underpin that denomination. It follows a foundational scholarly sequence: *Conservation is Coherence: Introducing the Negawatt Philosophy of Lawful Design*,[1] *The Negatrope: A Legal Doctrine for Verified Conservation in the Post-Combustion Economy*,[2] and *The Negawatt Protocol*, Public Version 1.0,[3] within the wider Ten Layers Architecture of the Negawatt Economy. Those publications span multiple layers; they are not a one-to-one map of Layers 1–3. This is the first publication of the equations. The paper does not invent new laws of nature. It proposes instruments by which established laws can be expressed in human systems of measurement and record.

The term "negawatt" itself is not original to this project. Amory Lovins coined it in 1989, building on the energy-efficiency argument developed in earlier work, including his 1976 article 'Energy Strategy: The Road Not Taken?'. [4,5] Energy-savings certificates, white certificates, and efficiency-obligation schemes already record conservation, often in megawatt-hours or in deemed lifetime units.[6] Primary-energy factors already convert a final-energy saving into an upstream equivalent without redefining the saving.[7] This paper does not invent those ingredients. It asks a stricter architectural question: under what physical, mathematical, ecological, and engineering conditions can verified energy conservation be represented as a reproducible registry denomination without conflating physical quantity with contextual value?

1.1 Context: the post-combustion economy

Combustion powered industry and underwrote a century of material prosperity. Fossil-fuel combustion transfers geologically stored carbon to the atmosphere and accelerates material and energetic dissipation across coupled human and ecological systems. The same physical laws that describe the degradation of order describe its preservation.

The post-combustion economy, as used here, reinterprets energy not only as a commodity to be consumed but as a structured potential to be conserved. Order in an open system is maintained only through organised flow and restraint. Conservation, in that frame, is not omission. It is an act that preserves usable energy and organised structure relative to a counterfactual in which the energy would have been degraded. The Negawatt Economy gives that act a measurable form: continuous measurement, verification, and registry, with kWh as the unit of practice and MWh as the unit of issuance.

This is a proposed institutional reading of thermodynamics, not a new thermodynamic law. The First and Second Laws are not amended. What changes is the accountancy of restraint.

1.2 Links to prior papers

Conservation is Coherence: Introducing the Negawatt Philosophy of Lawful Design framed conservation as an act of intelligence within the biosphere: restraint as participation in the maintenance of order, not as abstention.[1] *The Negatrope: A Legal Doctrine for Verified Conservation in the Post-Combustion Economy* translated that claim into a jurisprudential proposal: the conditions under which conservation might be recognised as a verifiable, registrable act capable of supporting a digital record.[2] That philosophy paper named the Three Gaps that those works address. *The Negawatt Protocol*, Public Version 1.0 (19 July 2025), is the operational specification for measurement, validation, issuance, transfer, and retirement.[3]

This paper is the scientific and engineering member of that sequence. It does not replace the Protocol, and it does not enact the Negatrope doctrine as positive law. It supplies the physical and mathematical architecture that the Protocol and the doctrine presuppose. It is not Layer 4 or Layer 7 of the Ten Layers Architecture; those layers name functions of the Economy, not publication numbers.

Quantified energy-savings instruments already exist. France's certificats d'économies d'énergie (CEE) are an important institutional antecedent: one CEE equals one kilowatt-hour *cumac* of final-energy savings, that is, cumulative discounted lifetime savings.[6] The scheme includes standardised operations and specific operations calculated case by case. Specific operations may rely on project-specific engineering and measurement evidence, but "measured operations" is not presented here as a separate formal scheme category. Similar obligation and certificate schemes exist elsewhere. The novelty claimed here is architectural, not the invention of a saved-energy unit. NWT is a registry denomination of verified energy conservation for a declared claim period, accepted under Proof of Conservation, fixed at 1 NWT = 1 MWh, with overlays forbidden to rescale issuance.

Question	White certificates (CEE)	Emergy	Rebound
What is counted	Cumulative discounted final-energy savings	Solar energy of one kind embodied in a product	Increased service that eats a technical saving
Unit in that literature	1 CEE = 1 kWh cumac [6]	A historical account, not a facility kilowatt-hour [19] [20]	Where quantified, an energy deduction, not a second NWT
Relation to 1 NWT	An antecedent for recording savings. Not a claim-period verified megawatt-hour under Proof of Conservation	Lineage for upstream history. Not used to mint	Enters the deduction term. Does not mint

European primary-energy practice makes the same *kind* of split this paper requires. Commission Delegated Regulation (EU) 2023/807 provides that, for savings in kWh electricity, Member States may apply a default coefficient of 1.9, or a justified national coefficient.[7] Conceptually, $E_{\text{primary,equiv}} = E_{\text{saving}} \times \text{PEF}$. The PEF is not mathematically identical to $M_{\text{Neg}}(B)$. It shows that a regulator can convert a final-energy saving into an upstream equivalent without redefining the saving. That is the Negawatt firewall: the multiplier does not mint extra NWT.

Comparable institutional precedents exist outside Europe. The Republic of Korea certifies building energy performance as annual primary energy per unit floor area, converting delivered energy through official primary-energy conversion coefficients under the Building Energy Efficiency Certification scheme.[8] Japan's Building Energy Efficiency Act likewise evaluates buildings using primary-energy consumption, applying official conversion coefficients for electricity specified by ministerial notice.[9] New Zealand's national energy balances distinguish total primary energy supply, consumer (final) energy, and transformation losses.[10] Singapore publishes generation input and gross electricity output from which a fleet-average generation conversion factor can be calculated (Section 4.2),[11] while its building Energy Use Intensity remains a delivered-electricity metric (annual electricity divided by gross floor area).[12] China maintains a national standard for determining organisational energy savings.[13] Australia's official energy statistics distinguish primary energy from total final energy consumption, but this paper does not treat Australia as possessing a general national electricity primary-energy factor analogous to the European default coefficient.[14] These frameworks differ in purpose, boundary, and legal function from $M_{\text{Neg}}(B)$ and LNM. They nevertheless demonstrate that associating delivered or final-energy quantities with upstream energy requirements, transformation losses, or primary-energy equivalents is established practice across multiple jurisdictions. Such conversion does not, by itself, redefine the underlying delivered-energy quantity.

1.3 The Three Gaps

Ecologists have often studied ecosystems with people held at the margin; economists have often studied human systems with ecology held at the margin. The two disciplines that most directly concern energy, materials, and value have evolved apart. One speaks in trophic webs, productivity, and resilience; the other in capital, markets, and growth. Each can be internally coherent while jointly describing an incomplete world.

Conservation is Coherence termed the resulting divisions the Three Gaps: epistemological, ontological, and institutional. The epistemological gap is a gap of knowledge and measurement. Economics quantifies transactions without a required energy or entropy account; ecology measures flows without a required price. Odum's systems ecology treated economies and ecosystems as energy hierarchies governed by the same physical constraints, yet institutions continue to administer them as separate domains. The ontological gap is a gap in what is treated as real: human activity as figure and nature as ground, or the reverse. The institutional gap is the administrative separation of economic, environmental, and scientific instruments, each optimising its own indicators while the biosphere integrates the residue.

Nicholas Georgescu-Roegen treated the economic process as constrained by a finite terrestrial stock and by the solar flow, and as degrading useful energy in use.[42] That constraint is accepted here. An NWT is not his unit. It is not an entropy, and it does not measure a march toward a heat death.

Those three gaps are named once here. Later sections do not re-explain them. Section 6.3 states only how the architecture of this paper is intended to bear on each.

1.4 Scope, structure, and how propositions are classified

The paper proceeds from physics to ecology to mathematics to engineering to legal characterisation:

- Section 2 traces thermodynamics, negentropy, exergy, and emergy.
- Section 3 treats ecosystem energetics as one thermodynamic lens on living systems (INTERPRETIVE; not a reduction of ecology).
- Section 4 presents the Negawatt equations and classifies each.
- Section 5 specifies the engineering and MRV architecture at the level of principle.
- Section 6 relates that architecture to the Negatrope proposal without converting the paper into legal advice.

Every substantive scientific or mathematical proposition is treated as one of:

- **ESTABLISHED**: a recognised law, equation, standard, or well-supported finding;
- **DERIVED**: a relationship obtained from established principles with explicit assumptions, units, and boundary;
- **PROPOSED**: an original Negawatt construct;
- **INTERPRETIVE**: a philosophical, ecological, legal, or systems reading of established or derived relations;
- **UNRESOLVED**: a proposition that cannot yet be made technically defensible without an author decision, a better derivation, or better evidence.

Editorial polish does not alter a proposition's classification.

The research question this paper answers is: under what physical, mathematical, ecological, and engineering conditions can verified energy conservation be represented as a reproducible registry denomination without conflating physical quantity with contextual value?

2.0 Physics

Physics supplies the first principles from which the Negawatt Economy is derived. Energy cannot be created or destroyed; it changes form. Each real transformation makes a portion of energy unavailable for further work. The persistence of life, and of technical civilisation, depends on the capacity to maintain local order in an environment that, left to itself, tends toward dissipation.

In *What Is Life?* Erwin Schrödinger described living systems as maintaining their structure by "feeding on negative entropy": importing order and exporting disorder.[15] From photosynthesis to industry, structure emerges when energy is channelled and disorder is displaced, not when the Second Law is suspended. Conservation, in this paper, is proposed as a lawful act of coherence in that sense: the preservation of usable energy within a declared system, relative to a baseline, under measurement.

This section does not yet introduce Negawatt instruments. It states the physical lineage.

2.1 Energy and the laws of thermodynamics

The First Law states that energy is conserved through transformation.[16] It fixes the quantity of energy in a closed account and says nothing about quality. The Second Law introduces quality and direction. In every real process some portion of energy becomes unavailable for work as entropy increases. Usable energy degrades into dispersed heat.[17] That principle gives time an arrow in macroscopic physics: systems move from organised potential toward disorder unless energy is structured through them and entropy is exported.

The contrast is the central physical fact of the project. Total energy is conserved; the capacity to perform work is not. Organisms, ecosystems, and machines maintain local order by exporting entropy. That process does not violate the Second Law. It expresses it. Conservation of *energy* (First Law) is not conservation of *work potential*. The measured issuance quantity is First-Law energy at the declared boundary. Any reading of that quantity as conserved work potential or deferred dissipation is INTERPRETIVE and would require a restated integrand and a declared reference environment.

Conservation so understood is a thermodynamic *act* in an open system, not a moral overlay on physics. Whether it should also be a juridical act is a separate question, taken up in Section 6.

2.2 Negentropy

If entropy describes the drift toward disorder, negentropy names the local emergence of order within that drift. Schrödinger's formulation was biological and physical, not economic.[15] Negentropy is not a violation of the Second Law. Life delays dissipation through organisation. Each organism is an open system that maintains internal order by exporting entropy. The biosphere, fuelled by solar input, is the largest such system we know.

The same description applies, analogically, to technical systems. A building, a plant, or a grid maintains organised function by drawing on energy and information. The greater the organised function, the more energy is ordinarily required to sustain it. The Negawatt proposal inverts the usual economic reading of that fact. It seeks coherence not only through increased throughput but through verified restraint: the same service, or a declared service, at lower dissipation.

The name "Negentropy Yield" in Section 4 is therefore authorial framing. Schrödinger himself later called "negative entropy" an awkward expression and noted that, writing for physicists, the argument would more properly turn on free energy.[15] He did not define Negentropy Yield. The operational quantity in this paper is energy (kWh or MWh). It is not thermodynamic entropy (J/K) and not exergy unless the integrand is restated.

2.3 Energy, exergy, and emergy

Energy measures quantity. Exergy and emergy, in different traditions, measure quality and history.

Exergy is the portion of energy available to do useful work relative to a defined environment.[18] A joule of high-temperature steam and a joule of waste heat are equal in First-Law quantity and unequal in work potential. Exergy falls as energy becomes more disordered. Each irreversible transformation consumes potential. In that sense exergy measures the distance between stored potential and dissipated heat.

Emergy, as developed by Howard T Odum, extends quality through time.[19] It is the embodied energy of one kind (often solar) required to generate a product or service of another kind. A litre of petrol, on that account, embodies a long solar and geological history. Transformity is the ratio of emergy to available energy, and is used to describe hierarchy: more organised systems are described as requiring higher-quality inputs.[20] Forests, rivers, and cities are treated as layers in an energetic hierarchy, not as incommensurable domains.

These concepts are ESTABLISHED within their own literatures. Emergy accounting is contested outside the systems-ecology community; this paper uses it as lineage, not as a meter protocol. Georgescu-Roegen's constraint sits beside exergy, not inside the meter.[42] Exergy is work potential relative to an environment. Emergy is a history. Neither is issued. The issued quantity is First-Law energy avoided at a declared boundary. A registry is not an escape from the Second Law. The Negawatt interpretation is INTERPRETIVE: conserved energy at the point of use preserves not only a kilowatt-hour but the upstream chain that would have been degraded to supply it. That interpretation is only as good as the declared boundary of the chain.

2.4 Origin equations

Carnot. The modern study of conversion begins with Sadi Carnot's ideal heat engine:[21]

$$\eta_{\text{Carnot}} = 1 - \frac{T_c}{T_h} \tag{1}$$

Status: ESTABLISHED. T_h and T_c are the hot-source and cold-sink temperatures in kelvin. The equation states a maximum conversion efficiency for a reversible heat engine between two thermal reservoirs, not a typical plant efficiency and not a general law of order and disorder. That work depends on a *temperature* gradient is Carnot's result. Quality-of-energy language is a further INTERPRETIVE reading.

Exergy destruction. The Gouy–Stodola relation expresses the useful-work potential destroyed by irreversibility:[22]

$$\dot{X}_{\text{dest}} = T_0\, \dot{S}_{\text{gen}} \tag{2}$$

Status: ESTABLISHED. The left-hand side is the rate of exergy destruction; T_0 is the reference-environment temperature; and the entropy-generation rate is the remaining factor. Every joule of exergy destroyed is useful-work potential that cannot be recovered at that environment. First-Law energy is conserved; exergy is not. Exergy analysis maps irreversibility. The Negawatt project does not replace this equation; it asks, in a different unit system, for the conserved-energy counterpart of avoided degradation.

Transformity. Odum's ratio,

$$\tau = \frac{\text{Emergy input}}{\text{available energy of product}} \tag{3}$$

Status: ESTABLISHED within emergy accounting. It is not a facility-meter quantity and is not used for issuance.

The Negawatt equations in Section 4 inherit this lineage. They do not supersede it.

2.5 Experimental and conceptual proof points

Carnot as analogy. Carnot's engine showed that conversion pays a tribute to entropy. In Negawatt language, conservation is proposed as the inverse *operation* of combustion in an accounting sense: where an engine consumes a gradient to produce work, verified restraint preserves a gradient that would otherwise have been consumed. That is INTERPRETIVE. It is not a claim that conservation is a heat engine run backwards.

Maxwell's Demon and Landauer. Maxwell's sorting demon appeared to defy the Second Law by separating fast and slow molecules without cost.[23] The paradox is resolved once information is treated as physical. Landauer showed that logically irreversible operations, including bit erasure, have a minimum heat dissipation of order $kT \ln 2$ per bit.[24] Intelligence can create local order, but not for free. The Negawatt Economy, if it works, is an information system inserted into an energy system: measurement and verification applied to restraint. It is a "demon" only in that metaphorical sense. It does not sort molecules, and it does not evade dissipation. It records avoided dissipation at the scale of kilowatt-hours.

Prigogine. Ilya Prigogine showed that in far-from-equilibrium systems, energy flow above a threshold can produce organised patterns (dissipative structures) that maintain themselves by dissipating energy.[25] The biosphere is such a system. Verified conservation in human systems is proposed as a designed feedback that reduces unnecessary dissipation while maintaining service. That analogy is INTERPRETIVE. Continuous commissioning is not a Bénard cell.

2.6 Transition to ecology

The laws of thermodynamics, and the experiments that revealed them, show that order is lawful but conditional. From dissipative structures the bridge to ecology is direct. The biosphere is the most complex self-organising negentropic system known. It converts high-quality solar energy into chemical bonds, biological structure, and, over evolutionary time, information. Ecosystem energetics provides one legitimate thermodynamic lens on living systems. That reading is INTERPRETIVE. It does not reduce population dynamics, community assembly, evolutionary history, information, or ecological organisation to energy alone. The Negawatt Economy extends the *energetic* part of that lens, as a design thesis, into human energy systems: verified conservation as a measurable act of organised restraint at the civilisation–biosphere interface.

3.0 Ecology

If physics provides the laws, ecology shows their living expression. The biosphere captures diffuse solar energy, structures it into biomass, and is shaped by feedback across soils, waters, atmosphere, and biota. Leaving a forest standing conserves living structure. Restoring a grassland reconstructs a successional system. Avoiding a facility increment of energy use is a counterfactual in a technical system. They are not one ecological process. They may be *read* together as restraint of dissipation and preservation of organised systems; that reading is INTERPRETIVE and does not move the NWT meter.

Lovelock proposed that the biosphere functions as a planetary-scale system of feedback and regulation.[26] That hypothesis is a scientific research programme, not a legal axiom. It is used here as ecological context for conservation, not as proof that a conserved megawatt-hour in a building "is" Gaia.

3.1 Ecology as applied physics

Every organism and ecosystem is a system of energy transformation, constrained by the same limits that govern engines. Energy moves through trophic pathways (from sunlight to plant, plant to herbivore, and through detritus) with loss at each conversion.

Raymond Lindeman expressed ecosystem function as quantitative energy flow.[27] Production at one trophic level is a fraction of production at the level below:

$$P_{n+1} = \lambda P_n \tag{4}$$

Status: ESTABLISHED as a trophic-dynamic relation; $\lambda \approx 0.1$ *is a classical empirical rule, not a universal constant.* Later work shows substantial variation by ecosystem type, commonly of order 5–20 per cent. Lindeman's result is that most captured energy is dissipated as metabolic heat at each step. The biosphere is a cascade of diminishing power, not a cycle of perfect reuse.

Alfred Lotka proposed, as a conjecture rather than a settled law, that systems tend toward configurations that maximise useful power intake, transformation, and use, the maximum-power principle.[28] Survival, on that conjecture, favours a balance between power and endurance rather than efficiency at any cost. The principle remains contested within ecology. Odum later represented ecosystems as networks of storage, transformation, and feedback, linking trophic dynamics to thermodynamic accounting through emergy and transformity.

The Negawatt reading of this lineage is INTERPRETIVE. Where Lotka described the pursuit of power, verified conservation is proposed as a human analogue of restraint that keeps service inside a lower-dissipation envelope. That analogue is a design claim. It is not a deduction from Lotka's mathematics.

3.2 Empirical lineage: Holling, Lovelock, Daisyworld

Crawford Holling's resilience is the capacity of a system to absorb disturbance and reorganise without losing defining structure and function, including by moving between domains of attraction; he distinguished that ecological resilience from engineering resilience as return-time to a fixed equilibrium.[29] In energy language, resilience is the capacity to maintain organised function under changing load, an INTERPRETIVE translation, not Holling's own equation, and not a collapse of resilience into efficiency.

Lovelock's Gaia hypothesis proposed that life participates in regulating climate and chemistry through feedback. Watson and Lovelock's Daisyworld model showed, in a numerical parable, that black and white daisies of differing albedo can regulate planetary temperature without central control.[30] Daisyworld is a proof of concept for feedback, not an empirical model of Earth's biota, and not a valuation formula for Negawatts.

This lineage (Lindeman, Odum, Holling, Lovelock, Daisyworld) is the empirical and theoretical backbone of the ecological half of the paper. It shows that life persists through organised energy flow. The Negawatt equations do not replace it. They attempt to place human conservation on the same side of the ledger as organised flow, rather than treating conservation as an economic residual.

3.3 Transition to the formulations

Ecology shows that structure arises from patterned flow and patterned restraint. The next section translates that principle into human measurement. The translation is where originality is claimed, and where classification becomes obligatory.

4.0 Negawatt Economy equations

Physics defines the limits of transformation. Ecology shows how life organises within those limits. Mathematics, in this paper, is the bridge to measurement. The purpose of the following equations is not to add laws of nature. It is to express conservation inside systems of record.

Two layers must be kept distinct throughout.

1. **Issuance quantity.** What is minted as NWT is verified energy conservation, in MWh, against a declared adjusted baseline. The Negentropy Yield integral is the continuous form of that quantity. The period-total formalisation in this paper is the same quantity implemented for a claim. One NWT is one accepted megawatt-hour.
2. **Analytic overlays.** Multipliers, a temporal reading of lifecycle amplification, Deep Solar Time, and coherence metadata interpret, scale, or label that quantity. They must not redefine it.

One NWT is denominationally equivalent to any other NWT because each represents one accepted MWh of verified energy conservation. This does not mean that all NWTs have identical economic, carbon, ecological, temporal, or locational value. Time, location, electricity mix, carbon intensity, persistence, ecological context, confidence, additionality, and system conditions may differ. Those attributes belong in metadata, separate analytical overlays, or later valuation systems. They do not change $1\,\text{NWT} = 1\,\text{MWh}$. Physical denomination and contextual value are distinct. That distinction is part of the contribution of this paper.

4.1 The Negentropy Yield Equation

The Negentropy Yield is the continuous expression of verified energy conservation. It is proposed Negawatt terminology for an energy quantity, not Schrödinger's quantity and not a new thermodynamic state variable. It integrates adjusted-baseline avoided power over the claim period and then applies period deductions:

$$\mathcal{N}_{\text{yield}}(\Delta t) = \max\left[0,\ \int_{\Delta t} \left(P_{\text{baseline,adj}}(t) - P_{\text{actual}}(t)\right) \mathbb{1}_{\text{eligible}}(t)\, dt - E_{\text{deductions}}(\Delta t)\right] \tag{5}$$

Status: ESTABLISHED in form as an avoided-energy M&V integral; PROPOSED in Negawatt naming, formal packaging, and integration into Proof of Conservation. Physical quantity: energy. Operational units: kWh or MWh; SI unit: joule (J). Not thermodynamic entropy (J/K). Not exergy unless the integrand is restated.

Here $P_{\text{baseline,adj}}(t)$ is instantaneous counterfactual power on the declared boundary, adjusted to the conditions at t (weather, occupancy, production, and other approved independent variables); $P_{\text{actual}}(t)$ is metered power; $\mathbb{1}_{\text{eligible}}(t)$ is 1 when the claim is eligible at t and 0 otherwise; and $E_{\text{deductions}}(\Delta t)$ is a claim-period energy scalar for rebound where quantified, load shifting not already captured, and unresolved data gaps subject to Protocol rules. The result has the units of energy (kWh or MWh). Eligibility is predeclared, reconstructable from the M&V plan, and frozen for the claim. It is applied symmetrically: an ineligible interval drops both baseline and actual. It is not used retrospectively to delete poor-performance intervals. Weather, occupancy, and production belong in $P_{\text{baseline,adj}}$. Additionality is an eligibility, attribution, or policy test, not an arbitrary metered-energy subtraction.

The name "Negentropy Yield" is authorial language for restraint. The physical quantity is energy. The SI unit is the joule; operational units are kWh or MWh. The equation does not measure Schrödinger negentropy (which would involve entropy units) and does not measure avoided exergy destruction unless the integrand is restated in exergy.

Define the period totals on the same eligible domain:

$$E_{\text{baseline,adj}} = \int_{\Delta t} P_{\text{baseline,adj}}(t)\, \mathbb{1}_{\text{eligible}}(t)\, dt$$

$$E_{\text{actual}} = \int_{\Delta t} P_{\text{actual}}(t)\, \mathbb{1}_{\text{eligible}}(t)\, dt$$

This paper formalises that quantity as a period total, consistent with the Protocol's issuance architecture. Energy totals are taken from integrating watt-hour registers. One-minute telemetry, required by the public Protocol as the evidentiary basis for issuance, is for replay, short-cycle visibility, gap forensics, and anti-gaming; it does not itself establish statistical accuracy of the counterfactual.

$$E_{\text{verified}}(\Delta t) = \max\left(0,\ E_{\text{baseline,adj}} - E_{\text{actual}} - E_{\text{deductions}}\right) \tag{5a}$$

Status: PROPOSED operational formalisation consistent with the Negawatt Protocol; period-total implementation of Equation (5).

Equations (5) and (5a) are the same map only where: (i) the same eligible domain is used; (ii) baseline and actual use the same eligibility mask; (iii) deductions are the same claim-period scalar; (iv) the floor is applied once to the claim-period total. In general $\max(0, \sum_i x_i) \neq \sum_i \max(0, x_i)$. Negative eligible performance within Δt offsets positive eligible performance before the floor. Negative performance remains in the audit record even when issuance is zero. Issued energy therefore depends on how Δt is cut; admissible claim-period length relative to the operating cycle is a Protocol control. One NWT is minted for each accepted megawatt-hour of E_{verified}. Continuous one-minute data are the public Protocol's evidentiary default, not a claim that finer sampling eliminates baseline-model uncertainty.[3]

The mint identity is equation (11): $1\,\text{NWT} = 1\,\text{MWh}$.

Illustrative period total. Suppose a declared 24-hour claim on a single eligible domain yields $E_{\text{baseline,adj}} = 12.4\,\text{MWh}$, $E_{\text{actual}} = 10.1\,\text{MWh}$, and $E_{\text{deductions}} = 0.2\,\text{MWh}$ for quantified rebound. The gross difference is $12.4 - 10.1 = 2.3\,\text{MWh}$. After the deduction, $E_{\text{verified}} = 2.1$ MWh of verified energy conservation. Registry treatment of the sub-MWh remainder, including fractional issuance or accumulation prior to issuance, is governed by the Protocol. An ineligible maintenance interval, if predeclared, is masked on both series and contributes to neither total. If that same gross difference were instead partitioned into two shorter claims whose eligible residuals were $+2.6$ and -0.3 MWh before the same deduction, the parts sum to 2.3 MWh, not to 2.1. Flooring each part at zero before summing would not reproduce the single-period floor of the 2.1 MWh total. The numbers are pedagogical. Admissible claim-period length is a Protocol control, not a result of this paper.

4.2 Negawatt Multiplier

The Negawatt Multiplier is a reciprocal-efficiency factor on a declared energy boundary B. That boundary names both ends: the input stream and the output stream.

$$M_{\text{Neg}}(B) = \frac{E_{\text{input}}(B)}{E_{\text{output}}(B)} = \frac{1}{\eta(B)} \tag{6}$$

Status: DERIVED as a first-law identity on a declared boundary; PROPOSED as a Negawatt overlay. Does not mint.

The NWT-relevant case is the member of this family whose **output** is the declared NWT measurement boundary. In that case $E_{\text{output}}(B)$ is the energy at which E_{verified} is measured, and $M_{\text{Neg}}(B)$ maps a conserved unit at the meter onto avoided input on B. Downstream end-use or device efficiency is not included in that default: those losses sit after E_{verified} and including them would count the same decrement twice. A primary-to-service analysis, whose output is useful service rather than metered energy, is a different declared B. It is not the NWT-relevant multiplier.

The Lifecycle Negawatt Multiplier in Section 4.3 is the NWT-relevant case whose input is the full upstream chain.

If, and only if, $\eta(B) = 0.10$ on the same B, 1 MWh of output on B corresponds to 10 MWh of input on B. That numerical example is an illustration of the algebra. It is not a universal constant of grids.

When B is the NWT-relevant case, the corresponding avoided-input quantity is

$$E_{\text{eff}} = E_{\text{verified}} \times M_{\text{Neg}}(B) \tag{7}$$

Status: DERIVED given (5a) and (6), and only where $E_{\text{output}}(B)$ is the NWT measurement boundary. Not NWT.

There is no universal Negawatt multiplier. The multiplier is a property of the declared boundary B, the energy chain within it, and the relevant vintage. Average conversion, marginal generation, marginal emissions, and long-run capacity consequence are different questions. Issuance of NWT does not depend on choosing a marginal grid model. Any overlay offered as a system consequence must declare which interpretation is used. Where system efficiency varies materially through time, a later application may define $M_{\text{Neg}}(B, t)$; that is not a new core numbered equation here.

Worked boundary example: generation. $B_{\text{generation}}$ takes generation energy input as E_{input} and gross plant electrical output as E_{output}. In Singapore, Energy Market Authority statistics for 2024 report 10,533 ktoe of energy input to electricity generation and 5,126 ktoe of gross electricity output, a generation efficiency of approximately 49 per cent.[11] Thus $M_{\text{Neg}}(B_{\text{generation}}) \approx 2.1$. That figure is a fleet-average for the year. Average and marginal conversion factors are not interchangeable. The example is not LNM, and it is not the NWT-relevant multiplier unless the NWT is itself measured at the plant busbar.

Worked boundary example: useful service (RMI). Lovins and Lovins record that about five to seven units of fuel are required to deliver one unit of energy to a conventional car's wheels.[31] That is a fuel-to-wheels useful-service boundary: fuel input through drivetrain to wheels. It is not a universal Negawatt multiplier, not a default LNM, and not evidence that every NWT avoids five to seven MWh upstream. It shows that a wider declared useful-service boundary can generate substantially larger reciprocal-efficiency factors than a meter-boundary LNM. The paper's default LNM ends at the NWT measurement boundary and excludes that downstream service stage.

4.3 Lifecycle Negawatt Multiplier

The Lifecycle Negawatt Multiplier is not a different mathematical family. It is equation (6) evaluated on $B_{\text{lifecycle}}$, whose output is the NWT measurement boundary:

$$\text{LNM} = M_{\text{Neg}}(B_{\text{lifecycle}}) = \frac{E_{\text{input}}(B_{\text{lifecycle}})}{E_{\text{output}}(B_{\text{lifecycle}})} = \frac{1}{\eta_{\text{lifecycle}}} \tag{8}$$

Status: DERIVED in form as $M_{\text{Neg}}(B_{\text{lifecycle}})$; PROPOSED as a Negawatt construct. Does not mint. LNM is not multiplied with a second M_{Neg}.

Where applicable, $B_{\text{lifecycle}}$ includes resource extraction, processing, transport, fuel preparation, conversion or generation, transmission and distribution, and delivery to the NWT measurement boundary. $E_{\text{output}}(B_{\text{lifecycle}})$ is energy at that NWT boundary. It does not include downstream appliance, motor, lighting, HVAC-terminal, or other useful-service efficiency when E_{verified} is already measured energy at the facility boundary. A primary-to-service study is a separate analysis with a different declared endpoint.

A lifecycle efficiency is a meaningful scalar only for a named lifecycle chain to the NWT measurement boundary. It is not a property of "the" energy system. Contrasting upstream chains include, as illustrations only and without assigned numerical values: domestic gas extraction → processing → combined-cycle generation → transmission and distribution → facility meter; imported LNG → liquefaction → shipping → regasification → generation → transmission and distribution → facility meter; coal extraction → preparation → rail → steam generation → transmission and distribution → facility meter.

No generic LNM headline number is offered. Smil's historical account documents conversion efficiencies that rose (on his figures, overall conversion of order 15 per cent around 1800 and mean conversion of order 40–50 per cent in affluent systems by 2000).[32] Cullen and Allwood estimate global conversion relative to theoretical device limits of order 11 per cent; that reciprocal is about 9, and the denominator is a distance to a theoretical limit, not a First-Law efficiency on $B_{\text{lifecycle}}$.[33] A generation-only boundary is ordinary $M_{\text{Neg}}(B_{\text{generation}})$, not LNM. European default primary-energy coefficients for electricity savings (1.9, or a justified national coefficient) illustrate the same *kind* of split as $E_{\text{verified}} \times M_{\text{Neg}}(B)$: an upstream factor applied to a final-energy saving without redefining the saving.[7] CCC does not enter LNM.

LNM also admits a temporal reading. Conservation of 1 MWh at the measurement boundary avoids LNM megawatt-hours of primary throughput **on** $B_{\text{lifecycle}}$. That is avoided future primary throughput, avoided future entropy generation associated with that chain, and, where marginal supply is combustion-based, avoided combustion, not the destruction of entropy already produced, and not a rewriting of the past.[34] Relative to building new supply, verified conservation can reduce throughput in the claim period itself. That operational advantage is not a physical rate through time, and it is not a numbered equation distinct from (8).

4.4 Deep Solar Time and the Deep Time Solar Equation

This section introduces **Deep Solar Time (DST)** as a proposed construct for representing the deep temporal inheritance of solar energy embodied in biospheric structure. The **Deep Time Solar Equation** is presented as a prospective mathematical formalism intended to express that construct. The ingredients (solar flux, photosynthesis, biospheric energetics, evolution, succession, geological time) have established literatures. To the author's knowledge, Deep Solar Time is introduced here as a named construct. The named synthesis and proposed formalism are the author's contribution; the underlying scientific ingredients are not claimed as novel. Deep Solar Time may inform ecological interpretation, value, narrative, time, biospheric coherence, and later overlays. It is not reduced to a single layer of the Ten Layers Architecture.

All life on Earth is the memory of sunlight. That proposition is INTERPRETIVE. The statement is intentionally interpretive rather than universal biophysical literalism. Most biospheric productivity is ultimately solar-driven, while chemosynthetic ecosystems demonstrate that biological energy capture is not exclusively dependent on contemporary solar flux. Deep Solar Time therefore describes the dominant planetary energetic inheritance rather than asserting that every biological pathway is directly solar-powered. It is not a claim that biodiversity is stored joules, that genetic information is energy-equivalent, or that species loss can be measured as erased solar joules.

The Deep Time Solar Equation is written:

$$\phi_{\odot} = \int_{t_0}^{t_n} S_{\odot}(t) \cdot \varepsilon_{\text{biosphere}}(t)\, dt \qquad \text{(DST-1)}$$

Status: PROPOSED / UNRESOLVED: NOT AN ISSUANCE EQUATION.

$S_{\odot}(t)$ is described here as incident solar flux. A time-integral of flux has the dimensions of energy per area, not total Earth-system energy, unless a declared spatial integration (an area term) is supplied. A future operational form must distinguish total incident solar power from areal solar flux. $\varepsilon_{\text{biosphere}}(t)$ is not an operational time series over geological time. Present biospheric structure contains a deep temporal inheritance of solar transformation; that inheritance is not yet a calorimeter reading. DST-1 is not used in Proof of Conservation, does not mint NWT, and is not asserted as an operational geophysical measure. It is intended to inform subsequent work on Biospheric Coherence.

4.5 Coherence Contribution Coefficient

If E_{verified} quantifies what is conserved in energy terms, and $\phi_\odot$ is the proposed Deep Solar Time term, the Coherence Contribution Coefficient is a proposed weighting of conservation by ecological context:

$$\mathrm{CCC} = \sum_{i=1}^{n} \omega_i \cdot \frac{\mathcal{N}_{\mathrm{yield},i}}{\phi_{\odot,i}} \tag{CCC-1}$$

Status: PROPOSED / UNRESOLVED: NOT AN ISSUANCE EQUATION.

ω_i are author- or policy-specified weights. They are not empirical constants of the biosphere. Planetary-boundary research may constrain the *idea* of such weights; it does not supply their values.[35] Without a normalisation convention, CCC is not guaranteed dimensionless, is not guaranteed comparable across sites, and is not a "coefficient" in the ordinary sense. Multiplication of CCC by MWh would corrupt the denomination of NWT.

CCC-1 inherits every unresolved question in DST-1 wherever it uses $\phi_\odot$. Ecological validation of weights remains future work. CCC does not mint NWT, does not create extra NWT, does not redefine a MWh, and does not imply present validated biodiversity pricing. It may function eventually as metadata, a non-issuance score, or a separately designed instrument. ECV is not introduced.

4.6 Summary of equations

The displayed forms appear in the numbered equations above. The tables below record status and issuance role only, so that the mathematics is not forced into a narrow cell.

Established physical and ecological relations

ID	Name	Status	Issuance
(1)	Carnot efficiency	ESTABLISHED	No
(2)	Exergy destruction (Gouy–Stodola)	ESTABLISHED	No
(3)	Transformity	ESTABLISHED (emergy)	No
(4)	Lindeman transfer	ESTABLISHED (empirical λ)	No

Operational Negawatt architecture

ID	Name	Status	Issuance
(5)	Negentropy Yield	ESTABLISHED M&V form; PROPOSED name/packaging	Yes (continuous form)
(5a)	Period total	PROPOSED operational formalisation of (5); consistent with Protocol	Yes (input)
(6)	Negawatt Multiplier	DERIVED identity; PROPOSED overlay; does not mint	No
(7)	Effective input	DERIVED only where output of B is the NWT boundary	No
(8)	Lifecycle multiplier	Special case of (6); does not mint	No
(11)	Denomination $1\,\mathrm{NWT} = 1\,\mathrm{MWh}$	Protocol invariant	Yes (identity)

Prospective / unresolved ecological formalisms (not in the operational sequence)

ID	Name	Status	Issuance
DST-1	Deep Time Solar Equation	PROPOSED / UNRESOLVED — NOT AN ISSUANCE EQUATION	No
CCC-1	Coherence Contribution Coefficient	PROPOSED / UNRESOLVED — NOT AN ISSUANCE EQUATION	No

Identifiers (9) and (10) are unused so that DST-1 and CCC-1 are not read as the next operational equations after (8).

The physical lineage is Schrödinger, Carnot, and exergy analysis. The ecological lineage is Odum, Lindeman, and Lovelock. The legal lineage is the author's Negatrope proposal. The operational lineage is the Protocol. Those lineages are not the same kind of authority.

5.0 Engineering implementation

Engineering is where the preceding equations become infrastructure. The function of this section is to show how conservation is observed, recorded, and made available as evidence, without reproducing the Protocol. Where a rule is an issuance rule, the Protocol governs.

Engineering here is technical and evidentiary.[36] The same discipline that would be required of a metered generator is required of metered restraint. The engineered system is the mechanism that can prove that conservation occurred, inside a declared boundary, during a declared interval. Physics defines order; mathematics expresses a claim; engineering either preserves an audit trail or it does not.

5.1 Measurement integrity and continuous commissioning

Every NWT must correspond to verifiable data that support a real reduction against a declared baseline. Estimation without a measurement boundary is not Proof of Conservation.

Meters and sampling. Instruments must be of stated class, installed on the correct boundary, and read at an interval sufficient to reconstruct the claim. The public Protocol requires one-minute streamed data as the evidentiary basis for issuance.[3] The current implementation specification uses that cadence for replay, short-cycle visibility, anomaly detection, gap forensics, anti-gaming, and provenance. One-minute sampling does not itself establish statistical accuracy of the savings claim and does not eliminate baseline-model uncertainty. Baseline-model uncertainty is typically the larger term for adjusted-baseline claims. Finer sampling is admissible; coarser sampling is a Protocol exception, not a default. Exact gap-fill algorithms and metering-class tables belong in the Protocol.

Calibration, drift, and missing data. Sensors drift. Gaps occur. A claim period with unaddressed gaps, unlogged substitutions, or out-of-calibration instruments is not issuance-grade. Gap rules, substitution, and failure handling are specified in the Protocol.[3]

Commissioning and continuous commissioning. Static commissioning establishes that the system as built can perform. Continuous commissioning keeps that performance inside a declared envelope for the life of the claim. It is aligned in spirit with ISO 50001 energy-management cycles and with the commissioning tradition in building services.[37] It is not a substitute for a baseline.

Baseline and counterfactual. Avoided energy is not observed. It is constructed. The IPMVP states the comparison as reporting-period use versus the baseline, adjusted to reporting-period conditions.[38] ASHRAE Guideline 14-2023 and ISO 50015 supply technical content for that comparison.[39] [40] A valid baseline must represent a normal operating cycle. The baseline-model version is frozen at registration: model form, independent-variable set, and coefficients or approved fitting state. Reporting-period baseline values may change through approved independent-variable adjustments. Silent retrospective refitting to inflate savings is not permitted. Baselines are expressed in SI performance units. Numerical model-adequacy thresholds belong in the Protocol. The Protocol's cooling metric is kW/RT, not COP or EER, for issuance decisions.

Weather, occupancy, and operational change. Weather-normalisation, occupancy adjustment, and production adjustment are ordinary M&V. They are how a counterfactual is prevented from crediting a mild week or an empty building as conservation.

Persistence, rebound, and load shifting. Persistence is whether the reduction continues. Rebound is increased service that eats the technical saving. Load shifting is displacement in time or location that can look like a reduction inside a narrow boundary. Validators must treat these as deductions or as out-of-scope, not as optional narrative. They enter $E_{\text{deductions}}$ in equations (5) and (5a), not the eligibility flag.

Uncertainty. Measured savings have uncertainty. ASHRAE Guideline 14 treats uncertainty as part of a savings claim. This paper does not invent a numeric uncertainty threshold; the Protocol governs claim-grade uncertainty.[3]

Continuous observation can make a facility self-correcting: a designed analogue of a dissipative structure, not an instance of one. Measurement is a structural condition of the Negawatt Economy, not a clerical step after design.

5.2 Proof of Conservation and the registry

Proof of Conservation (PoC) is the evidentiary standard for issuance. It is not a consensus algorithm. It is a claim, with exhibits, that a quantified reduction has occurred relative to a valid baseline and that additionality, permanence, and non-duplication tests have been met.

A PoC record, at minimum, binds three things:

1. **Measurement record**: the time series, boundary, and adjustments that support E_{verified};
2. **Validation**: an accredited validator's confirmation that the record meets the Protocol;
3. **Registry entry**: a unique identifier linking the accepted MWh to a registered project, claim period, and attributed account.

That chain is evidence architecture. Cryptographic signatures and trusted timestamps are ordinary tools for provenance. A distributed ledger is a possible registry implementation; it is not thermodynamically required, and it is not sufficient. Consensus among validators is an institutional fact, not a substitute for meters.

The Protocol treats an NWT as a digital record of 1 MWh of verified avoided use. It states that an NWT is not an emissions offset, an energy right, or a speculative future performance. Issuance, transfer, and retirement are registry operations designed to prevent double counting by unique identifiers and status (active, retired, cancelled). Carbon-indexed classification, where used, is contextual metadata and does not change the MWh identity.

This paper does not claim that a registry entry is “immutable” in a metaphysical sense, “admissible” in every court, or “legally recognised” as a property right by existing positive law. Those are questions of forum, statute, and contract. What the architecture can claim is narrower: a replayable measurement, a named validator, a unique record, and a rule against double counting inside the Protocol.[41]

5.3 Boundaries

Lawful measurement requires boundaries. Three are necessary; they are not the same object.

Temporal. Conservation is verified inside the interval from t0 to tn, the limits of the claim and of the integral in (5). Claim-period duration relative to the operating cycle is a Protocol control. This paper states the flooring principle; it does not prescribe window length. Time-stamping prevents duplication across claims and permits adjustment for conditions that vary in time.

Physical and geographic. The physical boundary is an energy-balance envelope, identical in baseline and reporting periods: facility, process, feeder, or network as declared. On-site generation, storage, imports, exports, and nested meters must be declared. A fall in grid import caused solely by new on-site generation is not automatically conservation of the underlying service load. Export is not energy conservation. A joule accepted on one registered envelope cannot be accepted on another. Detailed aggregation algorithms belong in the Protocol. Geographic context (grid zone, bioregion) may inform CCC weights or carbon classification. Context must not move the meter. A conserved megawatt-hour in a biodiversity hotspot is still one megawatt-hour.

Juridical. The juridical boundary names the persons and the law under which the claim is made: the custodial operator of the physical system, the governing law of the verification, and the account to which the registry attributes the NWT. Attribution is a Protocol and contractual fact. Whether it amounts to “ownership” or “title” in a given jurisdiction is a question of that jurisdiction’s law (Section 6).

These three must be reconcilable before issuance. Temporal limits are those of equation (5) and of its period total (5a).

5.4 Deployment models

Deployment has three interlocking pathways: the digitisation of facilities, the establishment of validator networks, and the integration of environmental and ecological metadata. Together they put physics on a meter, integrity in an independent function, and ecology in a label, not in the mint.

Digitised facilities. Commercial buildings, industrial plants, microgrids, and municipal networks are equipped with metering and control capable of one-minute capture. Those streams feed digital MRV. Historical data establish reference conditions. The difference between adjusted baseline and actual, once validated, is the evidentiary basis of PoC. Digitised facilities are instrumented plant.

Validators. Validators are independent custodians of evidentiary integrity. Operating under accreditation, they test accuracy, completeness, additionality, and provenance. Three functions are necessary:

- **Verification**: that the time series reflects genuine conservation rather than statistical artefact, load shifting, or a temporary behavioural spike;
- **Attribution**: that juridical boundaries, system ownership, and reporting periods are correctly assigned;
- **Recommendation**: a validation report recommending issuance or rejection.

Local validators can handle facility data. Regional review can reconcile aggregates. That hierarchy is an institutional convenience. It is not a thermodynamic necessity, and this paper does not posit a class of "higher-order validators" with metasystemic powers beyond ordinary aggregation and double-count checks. Where the Protocol defines subnets, those rules govern.[3]

Ecological metadata. Energy and ecology are coupled in the world. They must not be fused in the registry denomination. Remote sensing (for example NDVI or land-cover change), biodiversity inventories, and ecosystem-service models may be linked as metadata. They may feed CCC as metadata or as a non-issuance score. They must not "adjust the lawful value" of an NWT. One MWh remains one NWT; the label may record that the MWh was conserved in a named bioregion.

5.5 Scaling

Scaling is the problem of keeping measurement, validation, and attribution consistent as the number of sites grows. Three tiers are conceptually useful and only partly technically necessary.

Local verification is technically necessary. Without site-level integrity there is nothing to scale.

Network integration is technically necessary to the extent that double counting, overlapping boundaries, and inter-jurisdictional claims exist. Spatiotemporal identifiers that bind each accepted MWh to time, location, and account are an engineering response to that problem. They do not create "a distributed network of truth" in any sense stronger than a well-designed registry.

Systemic aggregation is a reporting and governance function: summing accepted conservation, analysing coverage, informing policy. It is not a third physics. Claims that planetary-scale "systemic coherence" emerges automatically from more nodes are INTERPRETIVE. A larger network can equally propagate a bad baseline.

5.6 Operational issuance

This subsection states how the operational equations (5)–(8) and (11) meet the Protocol. DST-1 and CCC-1 are not issuance equations.

Issuance is executed as a period total. Equation (5a) is the period-total implementation of equation (5).

1. A project is registered with a declared physical, temporal, and juridical boundary and a baseline methodology.
2. One-minute streamed data are captured and retained, as required by the public Protocol for issuance evidence; coarser sampling, if any, is a Protocol exception.
3. For each claim period, E_{verified} is computed from equation (5a).
4. A validator tests the computation, the deductions, and the eligibility rules.
5. The registry issues NWT in accordance with the Protocol denomination of 1 NWT = 1 MWh

(equation (11)). Treatment of sub-MWh quantities, including fractional issuance or accumulation prior to issuance, is governed by the Protocol.[3]
6. Multipliers, LNM, and CCC may be stored as analytics or metadata. They do not alter the minted amount.
7. Transfer and retirement change account and status, not history.

Project design documents, validator accreditation, dispute rules, and revocation are specified in the Protocol.[3]

5.7 Inefficient grids and the negentropic paradox

Inefficient energy systems, high-loss chains, and high-carbon grids are related and not identical. A diesel island grid can be inefficient and carbon-intensive. A hydro system with long, lossy lines can be high-loss and low-carbon. Primary-energy multipliers follow η, not carbon intensity. Carbon classification, in the Protocol, is a separate label.

The so-called negentropic paradox is, in its defensible form, a restatement of equation (6): as $\eta(B)$ falls, $M_{\mathrm{Neg}}(B)$ rises. Conserving a kilowatt-hour on a high-loss chain avoids more primary throughput than conserving the same kilowatt-hour on a high-efficiency chain, **on that boundary**. The relationship is linear in $1/\eta(B)$, not exponential. Georgescu-Roegen's constraint does not turn that larger multiplier into a larger NWT.[42] The multiplier remains an overlay. The unit remains the verified megawatt-hour.

The ethical reading (that high-loss, often poorer, systems should not be last in line for MRV) is INTERPRETIVE and political. It does not follow from the Second Law. It can still be a reason to deploy measurement first where loss and harm coincide: coal basins, diesel towns, extractive plant. Opportunity is not a thermodynamic field. It is a planning choice.

Entropy is not eliminated by better accountancy. Proof of Conservation makes a measured loss manageable; it does not convert dissipation into order.

6.0 Integration and legal characterisation

Law is how a polity recognises, protects, and records claims. Having set out physics, ecology, mathematics, and engineering, this section relates them to the Negatrope proposal. It is not legal advice. It distinguishes five things that must not be fused.

1. **Existing positive law**: statutes, cases, and regulations as they stand in a named jurisdiction. This paper states almost none, because almost none yet name a Negawatt.
2. **Proposed Negatrope doctrine**: the author's jurisprudential framework, in which verified conservation is argued to be capable of recognition as lawful structure.
3. **Contractual architecture**: what parties can create by agreement: baselines, validator appointments, registry rules, transfer restrictions.
4. **Evidence architecture**: what can be shown: telemetry, signatures, timestamps, validator reports, replayable calculations.
5. **Digital-asset architecture**: what a registry can issue or transfer *inside its rules*, subject always to property, securities, tax, and payments law in the relevant forum.

An NWT, in the Protocol's own terms, is a digital record of 1 MWh of verified avoided use.[3] It does not, by that fact, constitute an offset, an energy right, or a recognised property title. Whether a court would receive a PoC bundle as evidence is a question of that court's rules. Whether a registry credit is a "lawful digital asset," "owned," or "title" depends on the law that governs the registry and the parties. Cross-jurisdiction "recognition" is a hope of harmonised standards, not a present legal result.

The Negawatt Economy can still function as a proposed infrastructure of order: a bridge *offered* between physical measurement and legal proof. Offering is not enactment.

6.1 Negatrope: conservation as proposed lawful structure

The Negatrope Legal Doctrine proposes that conservation, when verified, is not the absence of action but the presence of structure, and that law in the Anthropocene should be able to recognise that structure. Each accepted NWT is, on that proposal, the operational expression of the doctrine: physical evidence of restraint, recorded.

Traditional private law is more at ease with what is built, extracted, or performed. The doctrine asks it to become at ease with what is not consumed, provided the non-consumption is evidenced. That is a jurisprudential claim. It is not a description of current law. Proof of Conservation can supply a factual substrate, measurement, validation, registry. The doctrine would supply a rule of recognition. Until a jurisdiction adopts such a rule, or parties contract to treat registry credits in a defined way, the record is evidence and contract, not "an act in law" in the strong sense.

Interoperability of registries, similarly, is a standards programme. It "mirrors the conservation of energy" only as a metaphor.

6.2 Custody, attribution, and transfer

Custody of evidence. The chain begins at the meter. Data are attested by a validator and written to a registry with a time-stamp and identifier. That is a chain of evidentiary custody. It supports provenance. It does not, by itself, create title.

Attribution. Attribution names who is credited in the registry: typically the operator or owner of the bounded system, or a transferee under contract. "Proximate agency" is a useful contractual principle. It is not a universal rule of property. Secondary interests (financiers, aggregators, landlords) belong in contract. Registry metadata should record them if they exist. "Legal parentage" is a metaphor.

Transfer. If the Protocol and the governing contract allow, registry credits may be transferred or retired by authenticated instruction, without duplicating the underlying measurement event. That is digital-asset architecture. It is "the lawful assignment of restraint" only inside those rules. Subdivision without reference to the measurement event is a double-count risk and should be forbidden by the Protocol even if a jurisdiction's general law is silent.

Standing, enforceability, and remedies for false claims are institutional design questions (accreditation, revocation, dispute resolution). The Protocol sketches a Swiss-foundation DAO as one such design. Other designs are possible. None of them is implied by Carnot's equation.

6.3 Bearing on the Three Gaps

The Three Gaps were defined in Section 1.3. This subsection states only the operational bearing.

Epistemological. MRV supplies a shared measurement: energy restraint against a baseline, with a validator, reported operationally in kilowatt-hours (SI unit: joule). Economics and ecology can both read a kilowatt-hour. They will still disagree about price and meaning. The Negawatt does not abolish that disagreement. It narrows the factual predicate.

Ontological. The proposal is that maintained order is as real as produced goods. That is the author's ontology. A registry cannot legislate ontology. It can only refuse to treat conservation as a blank.

Institutional. Embedding PoC in commercial and regulatory instruments would connect engineering data to claims those institutions already know how to process, disclosure, procurement, finance. That is a programme of adoption. It is not already "a continuous legal fabric."

Coherence as governance remains a thesis: that a civilisation in better equilibrium with its biosphere would align what it knows, what it treats as real, and what it enforces. The NWT is offered as a unit in which that alignment could be practised. It is not itself the equilibrium.

Postscript: sequence and architecture

The Negawatt Economy has one numbered architecture, the Ten Layers: (1) Philosophy; (2) Legal Doctrine; (3) Protocol; (4) Operating System; (5) Infrastructure; (6) Economic Logic; (7) Measurement Architecture; (8) Governance System; (9) Narrative and Semiotics; (10) Cultural and Temporal Layer. Those layers are functions of the Economy. They are not a map of publications.

Three papers already form a foundational scholarly sequence spanning multiple layers: *Conservation is Coherence: Introducing the Negawatt Philosophy of Lawful Design*; *The Negatrope: A Legal Doctrine for Verified Conservation in the Post-Combustion Economy*; and *The Negawatt Protocol*, Public Version 1.0. This is the first publication of the equations. It is not Layer 4 and not Layer 7. It advances measurement architecture, ecological interpretation, and the fenced introduction of Deep Solar Time.

Subsequent work includes Biospheric Coherence, further development of Deep Solar Time, empirical Proof of Conservation implementation, Protocol development, and economic and governance design. The architecture is not complete. Every accepted NWT remains one megawatt-hour of verified energy conservation, energy not used, on a baseline, in a boundary, with a name attached. The memory of sunlight is a horizon, not a mint rule.

Declarations

Funding

No external funding was received for this research.

Competing interests

The author is the originator of the Negawatt Economy framework and has associated commercial and intellectual interests in its development. These interests are disclosed for transparency.

Data and materials availability

No new empirical dataset was generated for this study. Sources and standards relied upon are identified in the reference list.

Author contributions

Nigel Grier: conceptualisation, methodology, formal analysis, investigation, writing (original draft), and writing (review and editing).

Generative AI assistance

Generative AI tools were used for research, organisation, editorial review, and document formatting. All substantive claims, equations, interpretations, source selections, and final wording were reviewed and approved by the author, who takes full responsibility for the content.

Preprint statement

This manuscript is a non-peer-reviewed preprint prepared for submission to EarthArXiv.

References

[1] N. Grier, Conservation is Coherence: Introducing the Negawatt Philosophy of Lawful Design, EarthArXiv preprint (2025). https://doi.org/10.31223/X52F28

[2] N. Grier, The Negatrope: A Legal Doctrine for Verified Conservation in the Post-Combustion Economy, SSRN (18 June 2025). https://ssrn.com/abstract=5309430

[3] Negawatt DAO, The Negawatt Protocol, Public Version 1.0 (19 July 2025). Section 4.8.1 requires 1-minute interval streamed data as the evidentiary basis for issuance.

[4] A. B. Lovins, Energy Strategy: The Road Not Taken?, Foreign Affairs 55 (1) (1976) 65.

[5] A. B. Lovins, The Negawatt Revolution, keynote address to the Green Energy Conference, Montreal (1989).

[6] Ministère de la Transition écologique (France), Dispositif des Certificats d'économies d'énergie. 1 CEE = 1 kWh cumac of final energy; standardised operations and specific operations calculated case by case. https://www.ecologie.gouv.fr/politiques-publiques/dispositif-certificats-deconomies-denergie

[7] Commission Delegated Regulation (EU) 2023/807 of 15 December 2022 on revising the primary energy factor for electricity in application of Directive 2012/27/EU, OJ L 101, 14.4.2023, p. 16.

[8] Korea Energy Agency, Building Energy Efficiency Certification System. Certification grades are defined by annual primary energy consumption per unit floor area (kWh m^{-2} $year^{-1}$). https://www.energy.or.kr/front/conts/105002002002000.do

[9] Ministry of Land, Infrastructure, Transport and Tourism (Japan), materials of the Subcommittee on Building Energy Consumption Performance Standards, confirming that building energy performance is calculated from delivered energy converted to primary energy using conversion coefficients specified by ministerial notice. https://www.mlit.go.jp/policy/shingikai/content/001583726.pdf

[10] Ministry of Business, Innovation and Employment (New Zealand), Energy in New Zealand 2026. Distinguishes total primary energy supply, consumer (final) energy, and energy transformation. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/energy-in-new-zealand

[11] Energy Market Authority of Singapore, Singapore Energy Statistics, Chapter 2, Energy Transformation (2024 figures: 10,533 ktoe generation input; 5,126 ktoe gross electricity output; generation efficiency $\approx$ 48.7%).

[12] Building and Construction Authority (Singapore), Building Energy Benchmarking. Energy Use Intensity is annual electricity consumption (kWh) divided by gross floor area (m^2). https://www1.bca.gov.sg/sustainability/legislation-on-environmental-sustainability-for-buildings/existing-buildings/building-energy-benchmarking-report/

[13] State Administration for Market Regulation and Standardization Administration of China, GB/T 13234-2018, Determination of energy savings in organizations (published 17 September 2018; implemented 1 April 2019; current; NEQ ISO 50047:2016). National Standard Information Public Service Platform: https://std.samr.gov.cn/gb/search/gbDetailedCNF?id=7643B2F250F7267CE05397BE0A0AAF6A.

[14] Department of Climate Change, Energy, the Environment and Water (Australia), Australian Energy Update 2026 / Australian Energy Statistics. Distinguishes primary energy and total final energy consumption. https://www.energy.gov.au/publications/australian-energy-update-2026

[15] E. Schrödinger, What Is Life? The Physical Aspect of the Living Cell, Cambridge University Press, Cambridge, 1944.

[16] R. Clausius, Ueber die bewegende Kraft der Wärme und die Gesetze, welche sich daraus für die Wärmelehre selbst ableiten lassen, Annalen der Physik und Chemie 79 (1850) 368.

[17] L. Boltzmann, Lectures on Gas Theory, trans. S. G. Brush, University of California Press, Berkeley, 1964 (first published 1896).

[18] Z. Rant, Exergie, ein neues Wort für "technische Arbeitsfähigkeit", Forschung auf dem Gebiete des Ingenieurwesens 22 (1956) 36.

[19] H. T. Odum, Environment, Power, and Society, Wiley-Interscience, New York, 1971.

[20] H. T. Odum, E. C. Odum, Energy Basis for Man and Nature, McGraw-Hill, New York, 1976.

[21] S. Carnot, Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance, Bachelier, Paris, 1824.

[22] A. Bejan, Advanced Engineering Thermodynamics, Wiley, New York, 1997, chs 2–3.

[23] J. C. Maxwell, Theory of Heat, Longmans, Green, London, 1871.

[24] R. Landauer, Irreversibility and Heat Generation in the Computing Process, IBM Journal of Research and Development 5 (3) (1961) 183. See also R. Landauer, Information is Physical, Physics Today 44 (5) (1991) 23.

[25] G. Nicolis, I. Prigogine, Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations, Wiley, New York, 1977.

[26] J. E. Lovelock, Gaia: A New Look at Life on Earth, Oxford University Press, Oxford, 1979.

[27] R. L. Lindeman, The Trophic-Dynamic Aspect of Ecology, Ecology 23 (4) (1942) 399. https://doi.org/10.2307/1930126

[28] A. J. Lotka, Elements of Physical Biology, Williams & Wilkins, Baltimore, 1925. See also A. J. Lotka, Contribution to the Energetics of Evolution, Proceedings of the National Academy of Sciences 8 (6) (1922) 147.

[29] C. S. Holling, Resilience and Stability of Ecological Systems, Annual Review of Ecology and Systematics 4 (1973) 1.

[30] A. J. Watson, J. E. Lovelock, Biological Homeostasis of the Global Environment: The Parable of Daisyworld, Tellus B 35 (4) (1983) 284.

[31] A. B. Lovins, L. H. Lovins, Reinventing the Wheels, The Atlantic Monthly (January 1995).

[32] V. Smil, Energy and Civilization: A History, MIT Press, Cambridge, MA, 2017.

[33] J. M. Cullen, J. M. Allwood, Theoretical Efficiency Limits for Energy Conversion Devices, Energy 35 (5) (2010) 2059. https://doi.org/10.1016/j.energy.2010.01.024. See also J. M. Cullen, J. M. Allwood, The Efficient Use of Energy: Tracing the Global Flow of Energy from Fuel to Service, Energy Policy 38 (1) (2010) 75.

[34] I. Prigogine, From Being to Becoming: Time and Complexity in the Physical Sciences, W. H. Freeman, San Francisco, 1980.

[35] J. Rockström et al., A Safe Operating Space for Humanity, Nature 461 (2009) 472. https://doi.org/10.1038/461472a

[36] W. B. Arthur, The Nature of Technology: What It Is and How It Evolves, Free Press, New York, 2009.

[37] International Organization for Standardization, ISO 50001:2018, Energy management systems: Requirements with guidance for use.

[38] Efficiency Valuation Organization, International Performance Measurement and Verification Protocol: Core Concepts 2022, EVO 10000-1:2022.

[39] ASHRAE, Guideline 14-2023: Measurement of Energy, Demand, and Water Savings, ASHRAE, 2023.

[40] International Organization for Standardization, ISO 50015:2014, Energy management systems (Measurement and verification of energy performance of organizations) General principles and guidance.

[41] International Organization for Standardization, ISO 14064-3:2019, Greenhouse gases: Part 3: Specification with guidance for the verification and validation of greenhouse gas statements.

[42] N. Georgescu-Roegen, The Entropy Law and the Economic Process, Harvard University Press, Cambridge, MA, 1971.