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FlowCosmologyv2.2–Cross –
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1 Introduction

Energy moves. Everything that exists is defined by that motion. From the expansion of galaxies to the metabolism of a single cell, order emerges wherever energy flows through matter. When that flow stops, structure collapses.

1. Introduction — The Logic of Flow

Energy-Flow Cosmology (EFC) is presented not as a final physical theory, but as a generative framework. Its purpose is to identify patterns and constraints that recur across natural and artificial systems — from spacetime geometry to metabolic organization. The framework is built to inspire and structure testable hypotheses about energy flow and entropy, not to replace established models.

Conventional cosmology treats energy as something contained inside spacetime. Energy-Flow Cosmology (EFC) reverses the logic: spacetime and structure arise from continuous flow. Entropy measures how freely energy can move — how close a system is to equilibrium. In this picture, low-entropy regions behave like the smooth space of general relativity; high-entropy regions act more like quantum turbulence. Between them lies the zone of resonance where stars, ecosystems, and cognition form.

EFC started as a cosmological framework, but its logic extends far beyond physics. Every complex system — planetary, biological, social, or digital — obeys the same thermodynamic grammar. That universality makes EFC a bridge between the sciences of matter and the sciences of life.

The approach builds on decades of research into non-equilibrium thermodynamics, most notably the work of Ilya Prigogine on dissipative structures and Hermann Haken on synergetics. It also connects to Eric Chaisson at Harvard, whose studies of energy rate density showed that the complexity of galaxies, life, and civilization can all be measured by how fast energy moves through them. EFC combines these traditions into one analytic frame.

2. Theoretical Foundations — Energy and Entropy as Universal Variables

2.1 Non-equilibrium physics

Prigogine demonstrated that systems far from equilibrium can self-organize by exporting entropy. Instead of decaying into disorder, they form ordered patterns that accelerate energy dissipation. Convection cells, hurricanes, and living cells all follow this principle. EFC generalizes it to the scale of the universe itself: the cosmos is a non-equilibrium system continuously redistributing energy from high-density zones toward equilibrium.

The same reasoning holds for social and technological networks. Energy gradients create flows; flows create feedbacks; feedbacks create structure. Collapse happens when feedbacks can no longer channel the energy efficiently — a failure visible in both galaxies and economies.

2.2 Complexity as flow efficiency

Chaisson's work quantified complexity in terms of energy rate density — how much energy passes through a system per unit of mass or function. Stars operate at one level, plants and animals at another, industrial societies higher still. EFC adopts energy rate density not as a monotonic measure of progress, but as a dynamic window of stability. Complexity can only exist within an optimal range of energy throughput: too little flow leads to equilibrium (death), too much destroys structure (chaos). This adaptive window principle defines the conditions under which systems can sustain ordered complexity.

Institutions such as the Santa Fe Institute and MIT's Non-Equilibrium Systems Group now study how this scaling applies across biology, economics, and computation. EFC aligns with that research by treating flow and entropy as the common denominators of complexity.

2.3 Continuity across scales

EFC rejects hard boundaries between disciplines. The same feedback logic that shapes a star's magnetic field also appears in urban power grids and neural networks. Where physics describes gradients of pressure or curvature, sociology describes gradients of opportunity or inequality — both are expressions of energetic imbalance. By tracking how systems maintain or lose stability as flows intensify, one can compare phenomena as different as hurricanes, markets, or brains using the same language.

2.4 A relational universe

Instead of viewing the universe as a collection of objects, EFC views it as a set of relationships maintained by flow. Order and disorder are not opposites but stages of transformation. Energy is never lost; it only changes form. Entropy is not destruction but redistribution. This perspective unites cosmology with ecology, information theory, and systems science in a single thermodynamic continuum.

EFC's approach diverges from prior entropic-gravity theories. Whereas Jacobson (1995) and Verlinde (2011) derive Einstein's equations as thermodynamic relations within spacetime, and Bianconi (2025) treats gravity as a function of quantum relative entropy,

EFC defines energy flow itself as the generative substrate of geometry. Entropy here is not derivative but constitutive — it creates curvature rather than describing it. This distinction situates EFC as a complementary, rather than competing, framework to current entropic-gravity research.

3. Applied Domains — Thermodynamics Across Scales

3.1 Climate and Planetary Energy Balance

Civilization itself is a thermodynamic structure. Cities, industries, and infrastructures transform concentrated energy into motion, heat, and information. Anthropogenic heat flux (AHF) is negligible on a global scale but significant regionally. In dense urban areas,

AHF acts as a local entropy amplifier, contributing to the urban heat island effect and microclimatic instability. From an EFC standpoint, this represents a local failure of entropy management, not a planetary forcing mechanism. The relevant thermodynamic insight is therefore regional optimization of waste-heat dissipation, not global radiative imbalance.

Practical uses of this perspective include:

Mapping regional energy-rate densities to identify heat-stress zones.

Designing cities and data centers to minimize local entropy build-up.

Evaluating renewable technologies not just by carbon offset, but by net entropy reduction per joule.

In this sense, climate policy becomes applied thermodynamics—steering civilization’s energy metabolism within the planet’s dissipative limits.

3.2 Artificial Intelligence and Machine Systems

Artificial intelligence systems are the newest high-energy ecosystems on the planet. Every neural model, from consumer chatbots to autonomous vehicles, represents a dense concentration of electrical flow. Data centers already consume more power than some nations; they also produce comparable thermal waste. Researchers like Geoffrey West and Jürgen Schmidhuber have explored how scaling laws and computational thermodynamics define the limits of efficiency in complex systems. EFC provides a way to interpret these limits physically: AI networks are dissipative structures that convert energy into information. When their energy throughput exceeds their capacity to reorganize—when training outpaces learning—they drift toward instability, memory saturation, or systemic collapse.

This aligns with ongoing work in energy-efficient computation and thermodynamic computing, positioning EFC as a conceptual bridge rather than a new discipline. Its contribution is to frame algorithmic stability and hardware scaling in the same energetic language used for natural systems.

Key applications include:

Measuring energy-to-information ratios during large-scale training.

Optimizing hardware layout for entropy dissipation rather than raw compute.

Monitoring the “thermal signature” of algorithmic processes to prevent runaway energy loops.

The same principles governing stellar stability or metabolic efficiency apply here. EFC thus bridges astrophysics and machine learning: both are energy-flow systems seeking dynamic equilibrium.

3.3 Economic and Societal Systems

Economic growth has always been an energy story. From the agricultural to the digital era, progress tracks rising energy-rate density. Work by Robert

Ayres and Benjamin Warr and Charles A. S. Hall demonstrates that GDP and energy throughput are inseparable. When energy availability declines or becomes inefficiently distributed, social structures strain or collapse—a point also made by Joseph Tainter in his analysis of civilizational decline.

EFC translates these historical patterns into physical language. Societies, like stars, must shed entropy to remain stable. As complexity increases, so does energetic cost. At high enough flow densities, marginal gains diminish and system stress rises—seen in financial crises, infrastructure failures, or political polarization.

Practical implications include:

Using energy-throughput metrics to gauge systemic vulnerability.

Reframing productivity as the efficiency of entropy conversion, not raw output.

Recognizing that sustainability hinges on maintaining stable energetic gradients between production and consumption.

Economies that manage energy symmetrically—recycling waste, decentralizing supply, stabilizing demand—approach thermodynamic balance. Those that overshoot face entropy shocks that no policy rhetoric can mask.

3.4 Biological and Medical Systems

Life exists by resisting equilibrium. Every organism maintains internal order by exporting entropy to its surroundings. This insight, introduced by Erwin Schrödinger in *What is Life?*, and expanded by Lynn Margulis and Eric Schneider James Kay, lies at the center of biological thermodynamics.

EFC extends it by viewing organisms as local flow nodes in a universal energy network. Cells, organs, and ecosystems are nested dissipative systems. Health corresponds to coherent flow; disease to entropic blockage.

In oncology, researchers increasingly describe tumors as metabolic disorders—regions where energy flow becomes autonomous and self-reinforcing. In neuroscience, the Free Energy Principle proposed by Karl Friston interprets cognition as predictive entropy minimization. Both align with the EFC premise: intelligence and life are energy systems seeking dynamic balance between order and uncertainty.

Potential medical applications include:

Energy-flow mapping of tissues to detect early metabolic stress.

Therapies that restore coherence in cellular energy transfer rather than merely target chemical pathways.

Viewing regeneration and healing as re-establishment of optimal flow rather than reversal of damage.

Biology, under this lens, becomes applied cosmology—micro-scale expressions of the same thermodynamic logic shaping galaxies.

3.5 Cognitive Analogy (not Identity)

Biological Systems

Information is not separate from energy; it is one of its forms. Every act of thought or computation consumes energy and changes entropy. The link between cognition and thermodynamics has been formalized by Claude Shannon

and later by Karl Friston, whose work connects perception and learning to free-energy minimization. In psychology and neuroscience, this principle explains how systems maintain coherent internal models of their environment.

Cognitive Analogy

EFC unifies these perspectives: the mind is an energy-flow structure that interprets and reorganizes entropy. Consciousness may be understood as the resonance of ordered energy flow within a complex biological medium. When viewed alongside developments in computational neuroscience and systems theory, this interpretation dissolves traditional boundaries between physics and phenomenology.

This analogy does not claim physical identity between neural processes and thermodynamic equations; it illustrates how predictive systems stabilize flow through informational resonance.

4. Cross-Domain Synthesis — Toward a Unified Thermodynamic Logic

Across all domains, a single pattern repeats: energy flows through a structure, the structure self-organizes to manage the flow, and entropy measures how effectively it does so. Whether in plasma physics, machine intelligence, or social organization, systems thrive by keeping energy throughput within their adaptive window.

Researchers at the Santa Fe Institute describe this as complexity by constraint — order arising from the regulation of flow. EFC offers a physical vocabulary for that phenomenon. It treats emergence not as an abstract property but as the observable outcome of energy seeking the most efficient pathways through matter and information.

This logic reveals deep analogies:

SystemOptimal Flow RangeBreakdown ModeStarStable nuclear flowCollapse
(supernova)EcosystemModerate energy recyclingExtinction or stagnationEconomyBalanced production-consumptionInflation, inequalityBrain/AIEfficient energy-information exchangeOverfitting, decoherence

Different languages, same physics. By analysing these flows, EFC builds a shared map where cosmologists, ecologists, economists, and engineers can compare system stability in common units of energy and entropy rather than metaphor.

5. Methodological Outlook — From Theory to Measurement

Over the next decade, several practical directions could translate EFC from concept to instrumentation:

Global Energy-Entropy Atlas – Integrate satellite thermal data, energy-consumption maps, and social-economic indicators into a single open dataset.
– Institutions like NASA GISS and the World Resources Institute are already assembling compatible layers. – EFC adds a unifying index: total entropy production per region.

Thermodynamic AI Metrics – Partner with research centers such as Deep-Mind Science or OpenAI Research to track the energy cost of learning. – Standardize “energy-per-token” or “entropy-per-decision” as benchmarks for sustainable computation.

Economic Flow Modeling – Apply EFC analytics to macro-models using data from the International Energy Agency and IMF Data. – Identify energetic tipping points preceding recessions or technological leaps.

Bioenergetic Diagnostics – Use imaging and metabolic data from the NIH Human BioMolecular Atlas to build flow-maps of healthy versus pathological tissue. – Cross-reference entropy indicators with disease progression.

Education and Systems Design – Introduce thermodynamic thinking into design schools and policy programs, emphasizing feedback, flow, and limits instead of linear growth. – Institutions like the Stockholm Resilience Centre already promote similar systems-based approaches.

Through these efforts, EFC can evolve from theoretical synthesis into a practical analytic language linking energy policy, AI engineering, and biological research.

6. The Five-to-Ten-Year Outlook

2025–2030 — Empirical grounding

Expect quantitative work comparing entropy production across technological and natural systems. EFC’s primary objective during this phase is to quantify entropy production in real systems, allowing direct comparison with established cosmological and ecological models.

Early adopters will likely come from climate modeling, network science, and computational neuroscience.

Data fusion from satellites, sensors, and open-energy ledgers will allow the first planetary energy-flow baselines.

2030–2035 — Cross-disciplinary integration

The idea of “energy economics” will merge with “information thermodynamics.”

AI models will include thermodynamic constraints to reduce energy waste.

Health sciences will use bioenergetic signatures for early diagnostics.

2035 onward — Predictive systems ecology

The most advanced research may treat the biosphere, human society, and digital infrastructure as one coupled flow system.

By then, the distinction between “cosmological” and “social” modeling may disappear; both will operate within shared thermodynamic simulations.

The long-term scientific significance of EFC will not rest on terminology but on its ability to predict and prevent system failure — from overheating data centers to collapsing ecosystems.

6.1 Entropic Halo Temperature Hypothesis

EFC predicts that galactic halos represent low-entropy convergence zones rather than dark-matter particle fields. If correct, these regions should display distinct thermal asymmetries detectable in X-ray or radio spectra. Observational programs using instruments like JWST, Euclid, and Athena X-ray Observatory can test for these profiles. Confirmation would empirically distinguish EFC’s entropic geometry from CDM’s particle-based halo

7. Discussion — Limits and Responsibilities

EFC operates as an open scientific framework: its role is not to claim final answers but to map energy-entropy relationships across disciplines. Its success

should be measured by the quality and testability of the hypotheses it generates, not by theoretical closure. By reframing complexity as a dynamic negotiation between flow and form, EFC offers a pragmatic foundation for integrative science.

Critics will rightly demand falsifiable predictions. That is why the next phase must prioritize measurable outcomes: entropy budgets, energy-efficiency gradients, and comparative stability metrics. Only through such data can the framework mature from theory to science.

8. Conclusion — The Continuum of Flow

Energy-Flow Cosmology reframes existence as a continuous negotiation between order and dissipation. The same rules that sculpt the cosmos also govern machines, economies, and minds. By adopting flow and entropy as universal coordinates, researchers gain a single vocabulary for stability, adaptation, and collapse.

In the coming decade, this thermodynamic perspective may become a foundation for integrative science — a meeting point where astrophysics, ecology, and artificial intelligence describe the same reality in compatible terms. Not a grand theory of everything, but a practical grammar for everything that moves.

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