

TECHNICAL WHITEPAPER

Conservation of Energy in Heavy-Duty Vehicle Systems

A first-principles framework for suspension damping energy recovery

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Redirecting an Existing Loss Stream

Heavy-duty vehicles dissipate the majority of their fuel energy through unavoidable loss mechanisms, including suspension damping — a continuous, designed-in energy sink that converts road-induced motion into heat. This paper establishes the thermodynamic foundation for redirecting a bounded fraction of that damping loss into usable electrical energy. Grounded entirely in first-principles energy conservation, it demonstrates that the Gravity system does not create energy or add propulsion load; it alters the destination of an existing loss stream.

In a modern Class 8 vehicle, approximately 35 to 40 percent of fuel energy reaches the wheels. The remaining 60 to 65 percent is lost before propulsion occurs — to engine inefficiency, exhaust and cooling heat, accessory loads, and friction. Once at the wheels, mechanical energy is continuously expended overcoming resistive forces, with suspension damping acting as a required and continuous energy sink.

Under a conservative, representative Class 8 long-haul duty cycle, the system recovers a modeled 3 percent of total fuel energy input — roughly 7 to 8 percent of the mechanical energy delivered to the wheels. At the modeled 10 kW net continuous over 2,000 annual operating hours, that is approximately 20,000 kWh per vehicle per year, achieved without increasing baseline damping forces, altering vehicle tuning, or imposing additional resistance on the drivetrain.

System Figures

Status	Figure	Basis
MEASURED	415 W peak	Operating vehicle under actual driving conditions, instrumented closed-course testing. Establishes that the full conversion chain functions on a moving vehicle.
MODELED	32 kW gross	

Status	Figure	Basis
		Mean gross hydraulic capture, Class 8 platform. Pratt Miller Engineering model on Peterbilt 589 road profile data. Technical figure; never presented as output.
MODELED	10 kW net	Continuous net electrical output after conversion losses. The commercial figure.
MODELED	20,000 kWh / vehicle / year	10 kW net across a 2,000-hour annual duty cycle — a conservative long-haul baseline.
UNMEASURED	Class 8 physical output	No full-scale test has been conducted. Closing this gap is the purpose of the funded demonstration program.

Gross and net are distinct quantities and are never combined. The measured prototype result establishes the conversion architecture; it is not a commercial output claim. Commercial-scale figures are modeled and are labeled as such throughout.

Section I — Conservation of Energy in Heavy-Duty Vehicles

Any credible discussion of energy recovery begins with the First Law of Thermodynamics: energy cannot be created or destroyed, only transformed. For a heavy-duty vehicle this principle strictly bounds how much energy can be recovered and dictates where it must originate. The Gravity system claims no exception to this law; it operates entirely within it.

Two purposes of wheel power

Mechanical power delivered to the wheels serves two purposes: increasing kinetic energy during acceleration, and replacing energy continuously dissipated to resistive processes in order to maintain speed. At steady highway speed, kinetic energy is nearly constant, so the engine is not maintaining motion so much as continuously replacing energy lost to resistance. Every one of those resistive processes is a candidate loss stream, and only one of them satisfies the conditions for practical recovery.

Dominant dissipation pathways

Loss Pathway	Mechanism	Recoverable On-Vehicle?
Aerodynamic drag	Energy transferred to surrounding air as turbulence and pressure; scales with speed squared.	No — dispersed into the air.
Rolling resistance	Tire deformation, road interaction, material hysteresis; scales with weight.	No — distributed across the tire-road interface.
Braking	Kinetic energy intentionally converted to heat for speed control; intermittent.	Partially — minor on steady highway.
Accessory and parasitic	Pumps, compressors, fans, and electrical generation draw engine power.	No — already consumed as work.

Loss Pathway	Mechanism	Recoverable On-Vehicle?
Suspension damping	Resistive force removes road-induced motion energy; converted to heat in the damper.	Yes — localized, continuous, required.

Section II — Why Suspension Damping Is Unique

Unlike aerodynamic drag or rolling resistance, which arise passively from motion, damping is intentionally engineered into the vehicle for stability, handling, and tire contact. Road irregularities introduce energy into the suspension; springs temporarily store it; and without damping the system would oscillate indefinitely. Dampers apply resistive force to remove that energy, and in conventional designs it converts almost entirely to heat in the damper fluid and structure.

The instantaneous mechanical power a damper removes is the product of damping force and suspension velocity. Because the damping force opposes motion, this power actively extracts energy from the suspension. That energy must go somewhere. In a standard shock absorber, all of it becomes heat. Heat generation is not a flaw in a conventional damper; it is the entire mechanism.

Three characteristics that make damping recoverable

- **Concentrated.** The loss occurs within a defined mechanical system — the damper — not dispersed across a surface or into the air.
- **Continuous.** It occurs whenever the vehicle moves over a real-world surface, even a well-maintained highway, across multiple axles.
- **Already paid for.** The fuel to overcome this loss has already been burned; the energy is being spent regardless of whether it is captured.

Suspension damping is not the largest loss in a Class 8 vehicle. Aerodynamic drag and engine inefficiency dominate total dissipation. But recoverability is determined by whether the loss is required, localized, and redirectable without increasing total vehicle losses, not by magnitude alone. Damping is the one major loss stream that satisfies all three conditions.

Section III — Redirection, Not Creation

Any system that recovers energy from vehicle operation must satisfy two non-negotiable conditions, both of which follow directly from conservation of energy.

Condition	Requirement
1 — Source	Recovered energy must come from an existing energy flow, traceable to fuel consumption or pack energy. It cannot appear from nowhere.
2 — No added load	Recovery must not increase total vehicle energy losses beyond baseline. If it does, the engine must supply additional fuel to compensate, and the net benefit is erased.

The failure mode of naive regenerative suspension

This distinction is where most theoretical regenerative suspension concepts fail. A system that recovers energy by increasing damping force beyond the baseline tuning envelope imposes

additional resistive work on the suspension. That additional work must be supplied by the engine through increased fuel consumption. In such a system, the recovered electricity is not reclaimed from an existing loss; it is manufactured by imposing a new fuel demand on the vehicle. The result is energy-negative or, at best, a wash.

How Gravity preserves baseline dynamics

The Gravity system avoids this failure mode by maintaining the original force-velocity behavior of the vehicle's suspension. Rather than increasing damping force, it replicates the baseline damping required for vehicle control. The total mechanical energy removed from suspension motion remains consistent with baseline requirements; the system alters only how that energy is dissipated — redirecting it to electrical generation instead of heat. Because baseline damping is preserved, recovery introduces no new loss.

Section IV — Mechanical-to-Electrical Energy Flow

Stage	Transformation	Domain
1 — Suspension motion	Road disturbance drives suspension articulation.	Mechanical input
2 — Hydraulic pressure	Controlled fluid flow and pressure generation.	Hydraulic
3 — Turbine element	Fluid flow converted to rotational mechanical energy.	Rotational
4 — Generation	Standard electromagnetic conversion to electricity.	Electrical output

Each stage is a familiar energy transformation; energy is neither created nor amplified, and each conversion incurs expected efficiency losses. The full chain has been physically validated on an operating prototype — 415 W peak under driving conditions — confirming that each transformation functions on a moving vehicle.

Why a load-bearing hydraulic architecture improves recovery

In a conventional suspension, passive springs support the vehicle's weight while separate dampers control motion by dissipating energy as heat. The Gravity system uses a load-bearing hydraulic architecture in which a greater portion of the vehicle's static weight is managed directly by the hydraulic system. When the suspension articulates under load, the working fluid is already under higher inherent pressure, and higher fluid pressure translates directly into more mechanical work performed by the fluid during suspension travel. That is not the generation of new energy; it is more efficient capture of the damping energy already being dissipated.

Section V — Recoverable Energy Under a Standard Duty Cycle

To quantify recoverable energy, this section uses a conservative, broadly representative Class 8 long-haul duty cycle. The intent is a defensible baseline that understates rather than overstates the opportunity.

Parameter	Value
Vehicle class	Class 8 tractor-trailer
Gross vehicle weight	Approximately 65,000 lb
Average cruise speed	Approximately 62 mph
Daily operation	Approximately 8 hours and 500 miles per day
Annual operation	Approximately 250 days — 2,000 operating hours, roughly 124,000 miles

Total fuel energy input

Diesel contains approximately 37 kWh of chemical energy per gallon on a lower-heating-value basis. At a midpoint efficiency of roughly 6.5 mpg, the modeled vehicle consumes approximately 76 gallons per day — about 2,820 kWh per day and 705,000 kWh per year of total fuel energy.

Electrical energy recovered — modeled

Independent Class 8 simulation establishes a modeled net continuous output of 10 kW when the vehicle is in motion, from 32 kW mean gross hydraulic capture reduced by hydraulic and electrical conversion losses. This is a time-averaged value, not a peak. Applied across the duty cycle: 80 kWh per day, 20,000 kWh per year, and approximately 3 percent of total fuel energy input — roughly 7 to 8 percent of the energy delivered to the wheels.

Section VI — Why 3 Percent Recovery Is Physically Sound

Recovering roughly 3 percent of total fuel energy does not imply capturing a dominant loss stream. It reflects redirecting a portion of damping losses already incurred. In operational units, at 62 mph and 10 kW average output, recovery resolves to approximately 0.16 kWh per mile, 10 kWh per driving hour, and 80 kWh per typical driving day — values that align with practical onboard storage and do not require oversized battery systems.

Thermal behavior as corroborating evidence

Conventional passive dampers dissipate all damping energy as heat, producing significant thermal buildup. Gravity systems exhibit measurably reduced thermal buildup during operation. Energy redirected into electricity is energy not appearing as heat. This corroborates, rather than independently proves, that the system redirects energy without adding parasitic resistance.

Annual scale and fleet implications — modeled

Scale	Annual Energy	Reference
Per vehicle	~20 MWh	Roughly two average homes for a year; about 540 gallons of diesel-equivalent energy
1,000 vehicles	~20 GWh	Comparable to a small power plant's annual output; roughly 1,800 homes

Scale	Annual Energy	Reference
10,000 vehicles	~200 GWh	Comparable to a mid-sized power station; roughly 18,000 homes

Section VII — Mass, Storage, and Where the Value Lives

Recovered electrical energy must be stored, consumed, or transferred. Added battery mass increases rolling resistance and inertial load. For highway operation the penalty from moderate mass increases is measurable but small per pound; as storage mass grows into the thousands of pounds, secondary effects eventually outweigh the value of the stored energy. Storage must therefore be sized deliberately, matched in hub-based operations to the energy recovered between facilities rather than to total daily generation.

The highest value of onboard storage is capability enablement, not energy resale. Stored energy can displace auxiliary-power-unit fuel, power onboard systems without idling, enable energy transfer at facilities without peak grid draw, and provide resilience during outages. In these roles, the value of the energy is set by what it enables rather than by its commodity price per kilowatt-hour.

Conclusion

Suspension damping is a constant, necessary energy dissipator in Class 8 vehicles, present regardless of road condition. Because the loss is required, localized, and already paid for in fuel, it presents a uniquely recoverable opportunity — one the Gravity system captures by redirecting an existing energy flow rather than imposing new resistance. Conservatively modeled, the system recovers approximately 3 percent of total fuel energy input, roughly 20,000 kWh per vehicle annually — modest in percentage, substantial in absolute terms, and drawn from a previously inaccessible source. The physics is established, the conversion chain is validated on operating hardware, and the recoverable energy is quantified under conservative assumptions. The remaining step is measuring it at Class 8 scale.

Gravity Driven Industries public edition. Figures stated by basis of evidence: measured on physical hardware, modeled in engineering simulation, or identified as not yet measured. Consistent with GDI System Figures — Current Reference v1.1, September 15, 2026.

v2.1 — public edition: internal-distribution marking removed; bench-top figure removed from System Figures; counterparty personnel names removed.