To:
From: Jamie Conway

Date: 13/06/2025

Vila Qatuan Pressure Battery:

A MODULAR PATHWAY TO SCALABLE OFF-GRID ENERGY

Author: Jme Conway
Project: Qatuan | Structural Intelligence Series | June 2025

Abstract

This document outlines the conceptual foundation, technical evolution, and practical implementation of a modular pressure battery system designed for Vila Qatuan — a regenerative prototype site in central Brazil. Through iterative testing and adaptation, we transitioned from gravity-based energy storage and solar pumping into a pressure-driven system built from local and recycled materials. Drawing inspiration from Tesla and Westinghouse's piston-based generator logic, this system replaces steam with wind and sun, storing mechanical energy in air and water pressure tanks. It offers a viable alternative to chemical batteries, particularly in hot, rural environments. The result is a cost-effective, scalable, maintainable solution that combines ancient mechanical insight with modern off-grid realities.

Table of Contents

1. Introduction: The Search for a Reliable Off-Grid Energy System

Summary: This section outlines the founding question that led to the pressure battery concept: how to power an off-grid regenerative site without relying on fragile or short-lifespan chemical batteries. It introduces the intention behind the project — combining resilience, appropriateness, and scalability into a replicable energy system. It also compares the pressure battery to an alternative: PV-powered hydrogen generation, noting pressure batteries are simpler, safer, more cost-effective, and far more appropriate for early-stage or rural implementation.

Our investigation began with a simple question: **How do we power Vila Qatuan sustainably, without relying on short-lived batteries or industrial-scale infrastructure?**

Initial Experiment: Gravity Battery with 1T Concrete Block

We tested a gravity battery by lifting a **1-tonne concrete block** to a height of **6 meters**, storing approximately:

$$E = mgh = 1000 \times 9.81 \times 6 = 58,860 \text{ J} = 16.35 \text{ Wh}$$

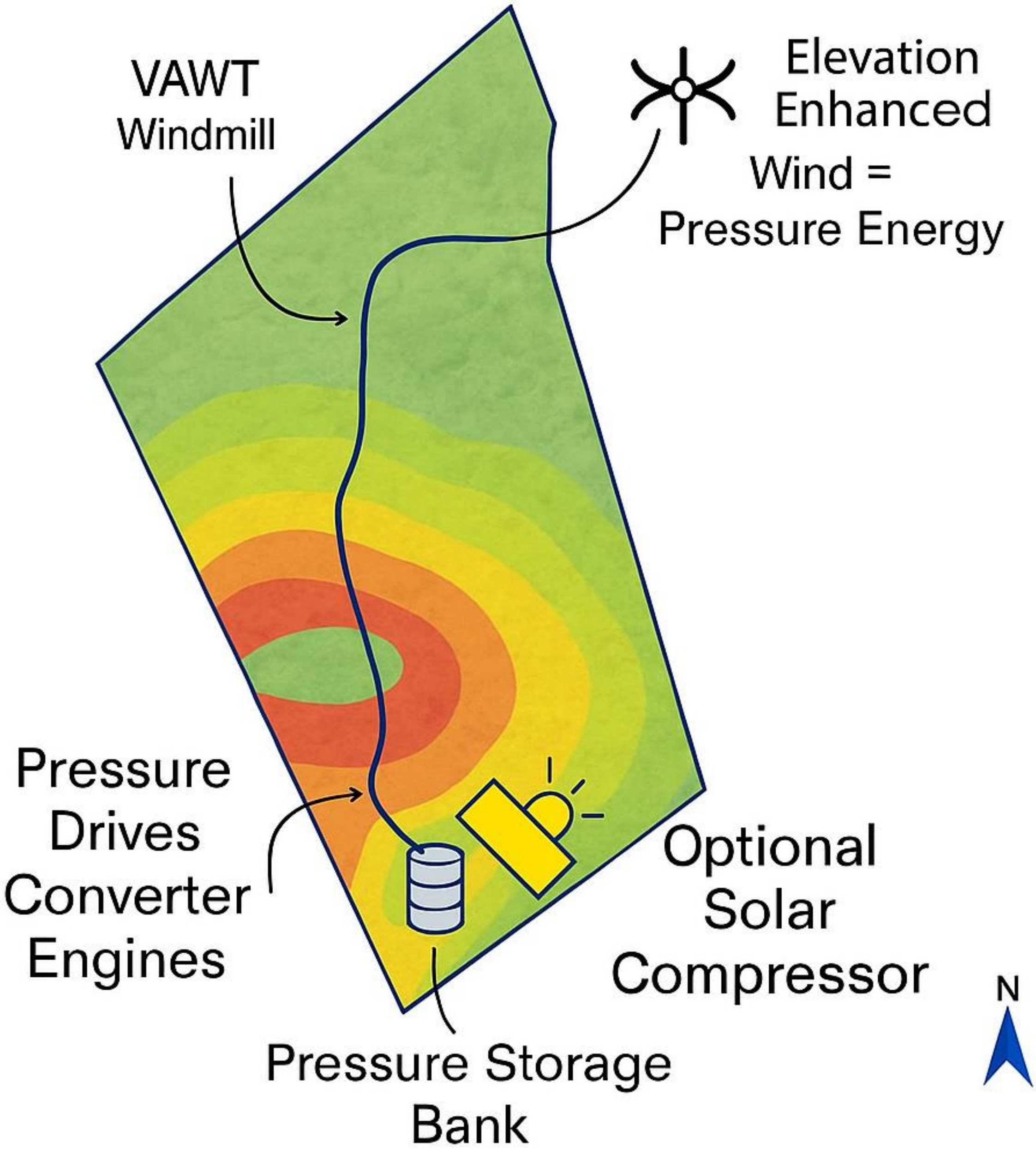
Despite its poetic simplicity, the energy return was underwhelming. For every tonne lifted, we could power a lightbulb for about 16 minutes.

Exploring Alternatives: Hydrogen vs Pressure

We also evaluated the potential of **PV-powered hydrogen electrolysis**. While hydrogen offers high energy density and long-term storage potential, it comes with high costs, lower conversion efficiency (~25–40%), technical complexity, and explosive risks. Pressure batteries, on the other hand, offer:

- Higher round-trip efficiency (~65–75%)
- Local materials and simpler builds
- No chemical hazards or catalysts
- Cheaper cost per usable kWh

Thus, while hydrogen might serve a future role for seasonal or vehicular applications, the pressure battery was clearly the more pragmatic and scalable choice for powering the VQ site today.



2. Transition: The 200W PV Water Pump & Terrain Advantage

Summary: We shift from abstract mechanical gravity storage to a real-world working solution using a PV-powered water pump and our topographical advantage. The experiment seeded the idea of distributed hydro storage using terrain, and set the groundwork for pressure-based systems. While the original concept depended on elevation for energy storage, the pressure battery model has since replaced this, making use of compressed air and water in ground-level tanks. The terrain remains relevant now for system layout and infrastructure placement, not gravitational potential.

We pivoted to solar: a 200W PV-powered pump drawing water from a lower source and sending it 25 meters up the hill to a tank. The elevation gave us an energy potential:

$$E = \rho g h V = 1000 \times 9.81 \times 25 \times 0.1 = 24,525 \text{ J} = 6.8 \text{ Wh per 100L}$$

This inspired a new idea at the time: using wind energy to pump water uphill, mimicking a modular hydroelectric system. While elegant in theory, it proved spatially and technically inefficient at our scale. As our thinking matured, we abandoned elevation-based energy storage in favour of compressed pressure systems using repurposed LPG tanks — more scalable, controllable, and terrain-independent.

However, the existence of the original elevated water tank is now an asset. With a working pressure battery system, we can eventually retrofit the technology to operate as a pressurised water elevation system as well. This could provide gravity-fed water for swimming pools or agriculture — and be driven entirely by wind and sun. If successful, this would transform the entire site into a living demonstration of hybrid off-grid water and energy infrastructure.

3. Evolution: From Steam Engines to Pressure Batteries

Summary: This chapter traces the reappropriation of Tesla and Westinghouse's steam-piston flywheel systems into a regenerative, modern pressure-storage energy concept. We replace combustion with wind and sunlight, and steam with air and water pressure. The result is a modern hybrid that borrows the resilience of classical mechanics and adapts it for rural sustainability.

We examined the legacy of Tesla and Westinghouse's steam engine generator sets. Their brilliance was in using pistons, pressure, and flywheels to govern output — a cyclical, analogue rhythm that could smooth chaotic input and deliver stable energy. These machines were never "dumb." They were designed to think kinetically.

We adapted their architecture for our own context:

- Instead of steam, we use compressed air or water.
- Instead of burning fuel, we use windmill-driven flywheels and PV-powered compressors.
- Instead of housing everything in a large, centralised generator room, we break it into modular, scalable cells.
- Instead of chemical degradation, we rely on mechanical regulation — pressure, flow, valve, piston, repeat.

We also replace expensive and fragile systems like lithium batteries and fuel cells with repurposed parts: LPG cylinders, automotive jacks, old alternators. This is not regression. It's **mechanical maturity** — tech that knows how to breathe, not burn.

From this redesign emerged the **PV-VAWT Pressure Battery System** — a modular infrastructure that's not only appropriate for hot climates, but teachable, buildable, and scalable using widely available materials.

4. System Description: How It Works

Summary: This section explains the architecture of the pressure battery system — how energy is harvested, stored, and released. It describes the major components and the flow of energy from wind and sunlight to mechanical and electrical outputs.

The system is built around **three main stages**: **input**, **storage**, and **release**.

Energy Input:

- **VAWT Windmills** (Vertical Axis Wind Turbines) are mounted in locations that optimise wind exposure. Their output drives a **mechanical flywheel** using a shaft and bearing system.
- **Photovoltaic Panels** (PV) also feed into the system during daylight hours, powering an electric **compressor** that contributes to the pressure reservoir.
- Both inputs contribute to building **mechanical or pneumatic pressure** within sealed storage tanks.

Storage:

- Recycled **88L LPG cylinders** are used as modular pressure vessels.
- These tanks store **compressed air or water**, pressurised to **5 bar** (or more depending on scaling needs).
- The storage is **entirely mechanical**, meaning it avoids battery degradation, thermal damage, or chemical breakdown.
- Storage can also be hybridised — air over water — allowing dual-phase compression and hydraulic support.

Release:

- The stored pressure is channelled through a **manual or automated valve** into a **piston assembly** or **turbine head**.
- This motion is transferred to an **alternator or generator**, producing electricity.
- Alternatively, the kinetic force can be used directly for **mechanical tasks** (e.g., pumping, milling, irrigation).

This creates a system that **absorbs intermittent energy** (from wind and solar) and releases it as **stable, paced output** — without relying on chemical storage, rare earths, or fragile electronics.

It's scalable. It's modular. It can be taught, built, repaired, and seen working with the naked eye.

Generator Integration Strategy

To convert stored mechanical pressure into usable electricity, the system connects to a generator via a Tesla turbine or piston assembly. After testing, the following generator types are best suited for performance and affordability:

Recommended Options:

- Brushless DC (BLDC) Motor – 24 V, 1500–3000 RPM
  - Efficient, compact, ideal for low to mid-output
- Automotive Alternator – 12 V
  - Durable, easy to source, decent output with flywheel smoothing
- Permanent Magnet Synchronous Generator (PMSG)
  - Best for high-efficiency and scaling beyond 500 W

These should be belt-coupled to the turbine/flywheel assembly to maintain ideal RPM and reduce stall risk.

Design Notes:

- Tesla turbines excel at RPM, not torque — always buffer with a flywheel
- Use a voltage regulator to stabilize output for real-world loads
- Direct mechanical drive (e.g., water pumps) remains a viable non-electric backup

5. Pressure Battery Maths

Summary: Provides the formal pressure storage calculations using the adiabatic compression formula. Demonstrates the limitations and benefits of low-pressure mechanical storage and the energy available per tank, making clear the system's requirements to meet daily energy goals.

We use compressed air as our energy storage medium. To determine how much usable energy can be stored per tank, we apply the adiabatic compression formula:

$$E = \frac{PV}{\gamma - 1}\left[1 - \left(\frac{P_0}{P}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

Where:

- PPP = tank pressure (Pa)
- P0P_0P0 = atmospheric pressure (Pa)
- VVV = volume of the tank (m^3)
- γ\gammaγ = adiabatic index (1.4 for air)

For 5 LPG tanks:

- Volume per tank = 88L = 0.088 m^3
- Total volume = 0.44 m^3
- Pressure = 5 bar = 500,000 Pa
- Atmospheric pressure = 101,325 Pa
- γ=1.4\gamma = 1.4γ=1.4

$$E = \frac{500,000 \times 0.44}{0.4}\left(1 - \left(\frac{101,325}{500,000}\right)^{0.2857}\right)$$

$$E \approx 201,000\,\mathrm{J} \approx 56\,\mathrm{Wh}\,(\mathrm{total})$$

Assuming 70% energy recovery efficiency:

$$\text{Usable energy} \approx 39\ \mathrm{Wh}$$

To reach larger goals:

- **1.5 kWh/day** requires ~35–40 tanks
- **5 kWh/day** requires ~90–100 tanks or higher pressure
- **15–20 kWh/day** could be achieved via a combination of pressure tanks, mechanical flywheel storage, and phased input/output control systems

This modular architecture allows us to **scale energy storage precisely**, using widely available or repurposed vessels.

Remembering the Role of the Flywheel

The flywheel in our system plays a subtle but vital role — it's effectively **doing the job gravity was meant to do**, but more efficiently. Whereas our earlier gravity battery lifted weight vertically, the flywheel stores energy through rotation. It's compact, scalable, and ideal for buffering energy from intermittent inputs like wind or solar.

In many ways, it is *gravity reimagined* — and for modern users unfamiliar with mechanical logic, it's the one piece that quietly carries the intelligence of the whole system.

Yes, some might laugh at the idea of solving 21st-century energy problems with wheels and tanks. But lithium doesn't last, and trust in corporate batteries won't get us through the night. The flywheel might.

6. Gravity Battery vs Pressure Battery

Summary: This chapter compares the original gravity battery concept with the evolved pressure battery system. It evaluates each based on energy density, scalability, durability, modularity, and appropriateness for off-grid use. The conclusion is clear: pressure batteries outperform gravity systems in almost every respect for real-world, modular applications at the village scale.

During our early experiments, the idea of lifting weight to store energy was intuitive and charming. But the numbers didn't lie. Lifting a 1-tonne block to 6 meters only gave us **~16 Wh** of usable energy — barely enough to charge a phone, let alone run a lab.

We needed something modular, scalable, and more energy-dense. Enter the pressure battery: instead of converting energy into height, we compress it into pressure — using air or water — and store it in tanks that can be stacked, swapped, or buried as needed.

Comparative Evaluation

Feature	Gravity Battery	Pressure Battery
Energy Density	Very low	Low to medium
Material Needs	Heavy construction	Lightweight tanks
Modularity	Poor	Excellent
Scalability	Requires height, cranes	Just add more tanks
Lifespan	High	High
Maintenance	Mechanical checks	Valve and piston checks
Visual Impact	Large structures	Can be discreet or buried
Educational Value	High	Even higher — hissing, spinning, pumping

The pressure battery approach retains the *soul* of the gravity battery — it's still mechanical, visible, and tactile — but it eliminates most of the spatial and structural drawbacks.

It also allows for smoother integration with flywheels and PV systems, enabling real-time energy pacing and hybrid designs. It's adaptable. Approachable. Scalable.

And in this phase of the project — it's what gives us the best chance at off-grid autonomy that can actually grow.

7. Thermo-Hydraulic Storage (Extension)

Summary: This chapter introduces the potential of using solar thermal energy in tandem with hydraulic storage methods. By heating water during the day and using that stored heat to drive pistons or preheat pressure tanks, the system can extend its functionality beyond electricity — creating low-pressure steam, hot water for domestic use, or long-duration kinetic energy storage.

While compressed air and flywheels are excellent for mechanical and electrical energy storage, they don't capture the **thermal potential** offered by sun-rich climates like Cavalcante.

By integrating **thermo-hydraulic storage**, we introduce a new layer of utility to the system — one that responds not just to motion and pressure, but to **temperature gradients**.

Key Concepts:

- **Solar thermal collectors** heat water stored in insulated tanks during the day.
- This hot water can serve two purposes:
  - **Domestic and agricultural use** (showers, sinks, sanitation, irrigation)
  - **Thermal engine input**, such as a low-pressure **Stirling engine** or steam piston.
- Heated water also reduces the energy needed to compress water into pressure tanks — acting as a **thermal assist**.

Why This Matters:

- No batteries are required.
- No complex electronics.
- It introduces a **third axis of energy buffering** — alongside pressure and rotation.
- It works extremely well in tandem with the **existing elevated water tank**, preheating the water before release for thermal-mechanical gains.

This extension doesn't replace the core pressure battery logic — it **enhances it**, letting heat and water join wind and sun as contributors to resilience.

In the future, a complete regenerative hub at Vila Qatuan might include:

- Wind-driven compression
- PV-powered backup
- Flywheel pacing
- Thermally assisted steam or piston generators

Each system speaks the same language: **motion, pressure, rhythm** — not lithium.

8. Cost Breakdown: Prototype Build (1–2 kWh/day system)

Summary: This chapter provides a detailed, itemised cost analysis of the pressure battery prototype system. It outlines how a basic wind- and PV-driven compressed air setup can be built for around **R$1,500–1,700**, using mostly off-the-shelf and recycled components. This makes it one of the most affordable regenerative storage systems possible at the community scale.

The following cost breakdown reflects our current design for a **hybrid wind–PV pressure battery prototype**, aimed at achieving **1–2 kWh/day** of usable energy.

Component	Function	Estimated Cost (R$)
VAWT Windmill (1.5kW rated)	Mechanical energy input	800
Flywheel + Axle (scrap steel)	Energy buffering + rotational inertia	150
Hydraulic Piston (car jack type)	Converts pressure into motion	100
1 x LPG Tank (88L, reused)	Pressure vessel for air/water	80
Compressor Crank Linkage	PV/VAWT-driven compression mechanism	60
Pressure Hose + Fittings	Transfers and seals compressed fluid	60
Manual Valve + Safety Relief	Control and pressure protection	25
Output Alternator + Controller	Generates usable electricity	150
Frame + Mounts	Mounting structure (wood/metal)	80
Wiring + Paint + Fixings	Connective parts, weatherproofing	60
Total Estimate		**R$1,565**

Notes:

- Optional additions include a second tank (R$80), or higher-efficiency alternator, which can raise the total to ~R$1,700–1,800.
- Using existing materials or community donations can bring the actual cost well below this mark.
- This build supports daily operation, observable performance, and iterative upgrades — making it a perfect educational and demonstrative unit.

It is, in short, an accessible system with a proof-of-function that's visible, modular, and reliable — and ready to be scaled.

Optional PV Add-On (1.1 kW System)

To boost pressure generation reliability, a 1.1 kW solar PV array (2 × 550W panels) can be added for daytime compression. Based on pricing from the TON SOLAR proposal, this system is cost-effective and compatible with rooftop mounting over the main cabin.

This allows pressure tanks to be topped up consistently through the day, extending overnight output without chemical batteries.

Estimated PV System Cost (Installed)

Component	Cost (R$)
2 × 550W Solar Panels	~2,800
Inverter (micro or small)	~500–900
Structure & Wiring	~300–500
Installation Labor	~200–400
Total Estimate	**R$3,600–4,200**

9. Modular Scaling Strategy

Summary: This chapter outlines how the pressure battery system can be scaled incrementally — from a single prototype to a full-site, 15–20 kWh/day regenerative energy grid. It emphasises modular replication, material reuse, and low-tech scalability, allowing local communities to expand power systems according to need and capacity.

The beauty of the pressure battery system lies in its **scalability**. Unlike lithium batteries or diesel generators that require large, capital-intensive deployments, this system can grow **organically**, one module at a time.

Each modular unit consists of:

- A small **VAWT or PV input**
- 1–5 **pressure tanks**
- A **compression mechanism** (manual, solar, or mechanical)
- A **release piston/turbine** feeding a local electrical or mechanical output

By duplicating and networking these modules, the system can meet expanding energy needs with resilience and flexibility.

Phased Growth Plan

Phase	Output/day	System Configuration	Use Case
Prototype	1–2 kWh	1 VAWT, 1 PV input, 5 tanks, piston & alternator	Basic demonstration, lighting, USB charging
Phase 1	5 kWh	2–3 VAWTs, 10 tanks, PV compressor	Small workshop, fridge, tools, irrigation
Phase 2	10 kWh	+10 PV panels, 20–30 tanks, hybrid release unit	Cabin + Community kitchen + daytime tools
Phase 3	15–20 kWh	20+ tanks, larger turbine or piston, flywheel hub	Full site backup, refrigeration, AC systems

Scalability Features:

- Tanks are modular and swappable
- Inputs can be PV, wind, or thermal
- Outputs can be electrical or mechanical
- Flywheels improve pacing and night coverage
- All components are field-maintainable

This approach allows Vila Qatuan to grow its energy capacity **organically** and without dependence on high-cost imports or short-life technologies. It creates a **living energy system** — one that evolves with the community it supports.

10. Why This Matters

Summary: This chapter frames the broader significance of the pressure battery system — not just as a technical solution, but as a cultural and ecological intervention. It challenges conventional energy narratives, restores mechanical literacy, and opens the door to energy sovereignty for rural and regenerative communities.

This system is more than a clever workaround. It's a **quiet revolution**.

By choosing compressed air, water pressure, flywheels, and sunlight, we are deliberately stepping away from extractive supply chains and toward **regenerative autonomy**. We are building systems with **no secrets** — no black boxes, no invisible software updates, no lithium mines, no planned obsolescence.

We're also bringing back something that modernity forgot: **mechanical intelligence**.

The pressure battery isn't smarter than a lithium cell — but it's more *appropriate*. It uses friction, compression, inertia, and release — all concepts a curious child can see, hear, and grasp. That visibility is power. That teachability is legacy.

In hot environments where battery banks fail and replacement parts are slow or unaffordable, this system offers:

- **Durability**
- **Modularity**
- **Repairability**
- **Zero dependency on chemical imports**

It creates a foundation for energy resilience that can evolve over time — one that can scale to villages, serve disaster relief efforts, run agroforestry irrigation, or drive small-scale industry. It can plug into modern circuits or operate entirely off-grid.

This matters not because it's perfect — but because it's *possible*.

And possibility is what we're really trying to restore.

11. Next Steps

Summary: This chapter lays out the immediate actions to be taken in building, testing, and documenting the pressure battery prototype. It includes a timeline, key milestones, and suggestions for future documentation, replication, and community engagement.

Now that the system has been mapped, costed, and aligned with the realities of Vila Qatuan, it's time to move from theory to application.

Immediate Actions:

- **Procure key components** (VAWT, flywheel material, piston, tanks, valves)
- **Assemble the prototype rig** on-site using the existing cleared terrain
- **Integrate PV and wind compression paths**
- **Test pressure retention**, piston output, and alternator coupling
- **Record all data and design refinements** for open replication

Suggested Timeline:

Week	Goal
1	Materials acquisition + site prep
2–3	Build flywheel and mount turbine
4	Install tanks, compressors, and linkages
5	Begin pressure testing and energy output trials
6–8	Optimize release flow + document version 1 prototype

Then:

- Expand to 5–10 tanks for full-day storage trial
- Explore PV + wind hybridisation for seasonal smoothing
- Create bilingual zine/manual for community and school use
- Build mobile or educational version for festivals, schools, and eco events

This system, once prototyped, becomes more than just an engineering solution. It becomes a **teaching tool**, a **demonstration of sovereignty**, and a **replicable pattern** for anyone with tools, time, and a reason to unplug from industrial fragility.

Let's build the first. Let's show that it works. And then — let's hand the plans to anyone who needs them.