

Energy in motion for a more resilient grid

Complete edition 3.0 · EN

This complete article brings together the introductory post, the technical generator explanation and the technology-and-cost charts. Read the concept, watch the one-minute video, then examine the assumptions and test plan.

The proposed permanent-magnet machine can convert externally supplied shaft power into electricity. With a suitable bidirectional drive and rotor design, it can also operate as part of a flywheel storage system. These are two operating modes with different energy boundaries.

How the generator works, step by step

1. Follow the energy

An external motor or turbine turns a rotor carrying NdFeB magnets. The changing magnetic field induces voltage in fixed copper stator windings on a laminated electrical-steel core. In Faraday's law, λ is the flux linkage of the winding. Drawing current produces opposing electromagnetic torque. At steady speed, the external drive supplies useful electrical output and all losses.

$$e = -d\lambda/dt \mid P_{\text{shaft}} = T_{\text{shaft}} \times \omega$$

T_{shaft} is shaft torque in N·m; ω is angular speed in rad/s. Magnets provide the field; the drive supplies the energy.

2. Control the electricity

Machine frequency follows the pole-pair count and rotor speed: p is pole pairs and n is rpm. Four poles at 1,500 rpm give 50 Hz before electronic conversion. A rectifier, DC link and inverter adapt the generated electricity to the load. Charging the flywheel requires a bidirectional motor drive; a passive rectifier alone cannot accelerate it electrically.

$$f = p \times n / 60$$

The converter, control system and connection requirements must be designed for the intended electrical service.

How the generator works, step by step

3. Store energy in motion

Charging speeds up the rotor; discharge slows it. J is rotational inertia, and $\omega_{\max}$ and $\omega_{\min}$ define the useful speed range. The expression below is the change in stored rotational energy. Delivered electrical energy is lower after conversion, waiting and auxiliary losses.

$$E_{\text{usable}} = \frac{1}{2}J(\omega_{\max}^2 - \omega_{\min}^2)$$

For a complete electrical storage cycle with matched starting and ending internal energy states, $E_{\text{in}} = E_{\text{out}} + E_{\text{loss}}$. Include charging, waiting, discharge and auxiliaries once. Shaft-to-AC generator efficiency and AC-to-AC storage efficiency measure different boundaries.

4. Ask what the vacuum saves

Vacuum reduces aerodynamic drag, while pumping consumes energy and reduced gas cooling complicates heat removal. Select pressure from measured total cycle losses. Check magnet temperature, demagnetization margin, insulation, rotor stress, magnet retention, balancing, critical speeds, overspeed protection and fragment containment. Copper, core, bearing and converter losses remain.

The useful comparison is the same delivered task in air and vacuum, including pump-down, standby, cooling and all auxiliary demand.

5. Measure before claiming a benefit

Measure shaft torque and speed, active electrical input and output, pressure, temperatures and every auxiliary load on a synchronized time base. Integrate energy across charging, waiting and discharge; state calibration, measurement uncertainty and starting/ending energy states. Publish repeatability, standby losses, lifetime and maintenance evidence.

The video is a conceptual animation, not a working prototype demonstration. The assumed 85% AC-to-AC efficiency and the price scenarios remain hypotheses to validate. A useful result must exceed measurement uncertainty and meet the defined service, mechanical and thermal requirements.

Complete companion: 2 guide pages, the 7-page illustrated article and 4 comparison charts. Component page labels are retained. Use the PDF bookmarks to navigate.

[Read the complete web edition and watch the video](#)

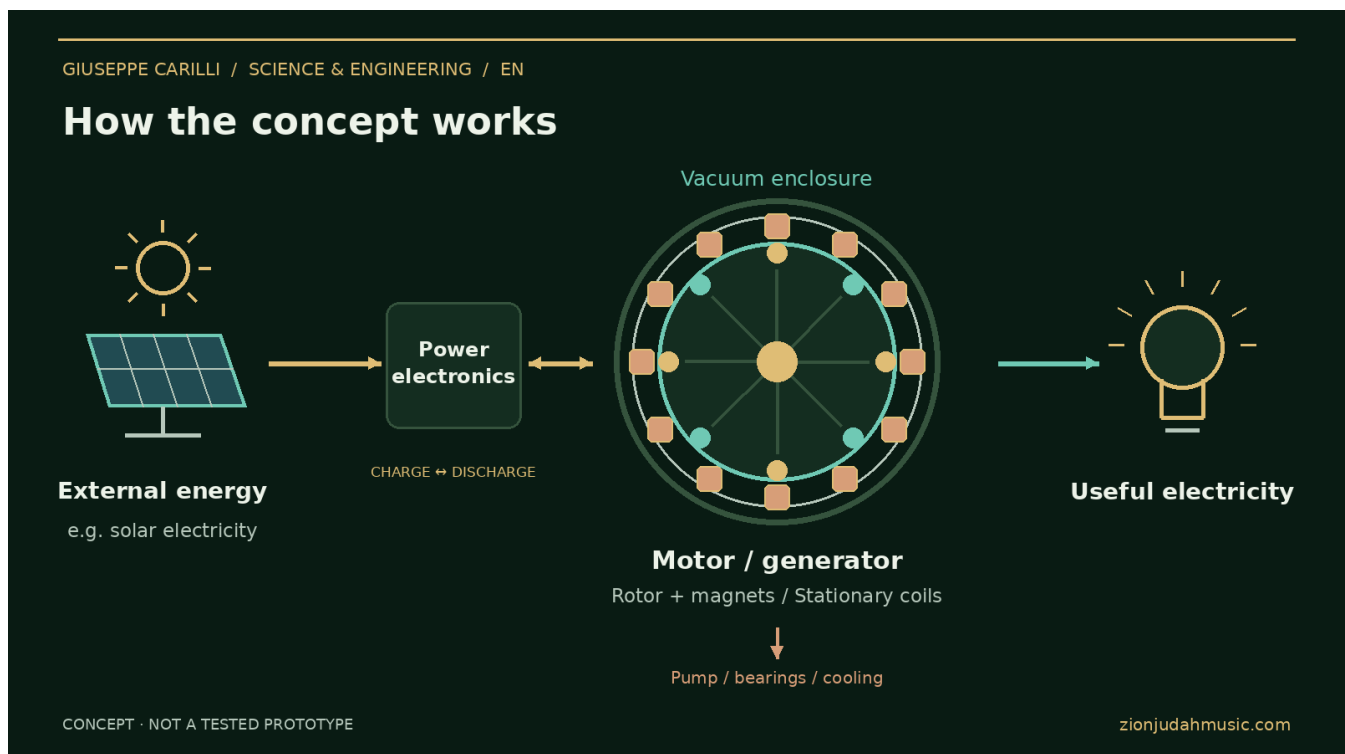
[Original technical paper](#)

SCIENCE & ENGINEERING · PUBLIC RESEARCH ARTICLE

Energy in motion for a more resilient grid

Giuseppe Carilli | 21 October 2026 | EN

Imagine a heavy wheel that acts like a rechargeable reserve. Electricity spins it faster. Later, the wheel slows down and the same machine returns some of that energy as electricity. This could help smooth short interruptions in solar generation or sudden changes in demand.



Conceptual illustration, not a construction drawing. In storage mode, electrical input accelerates the rotor; discharge slows it. In generator mode, an external shaft supplies mechanical energy. The two modes have different efficiency boundaries. [1]

The idea in one minute

- The energy comes from outside: for example, a solar plant or another mechanical source.
- The rotor stores energy as motion. Magnets help convert energy; they are not a fuel.
- Vacuum may reduce air drag. Its pump, cooling, bearings and controls still use energy.
- The goal is useful, affordable storage. The paper proposes a design and tests; performance and long-term cost remain to be measured.

What comes back out?

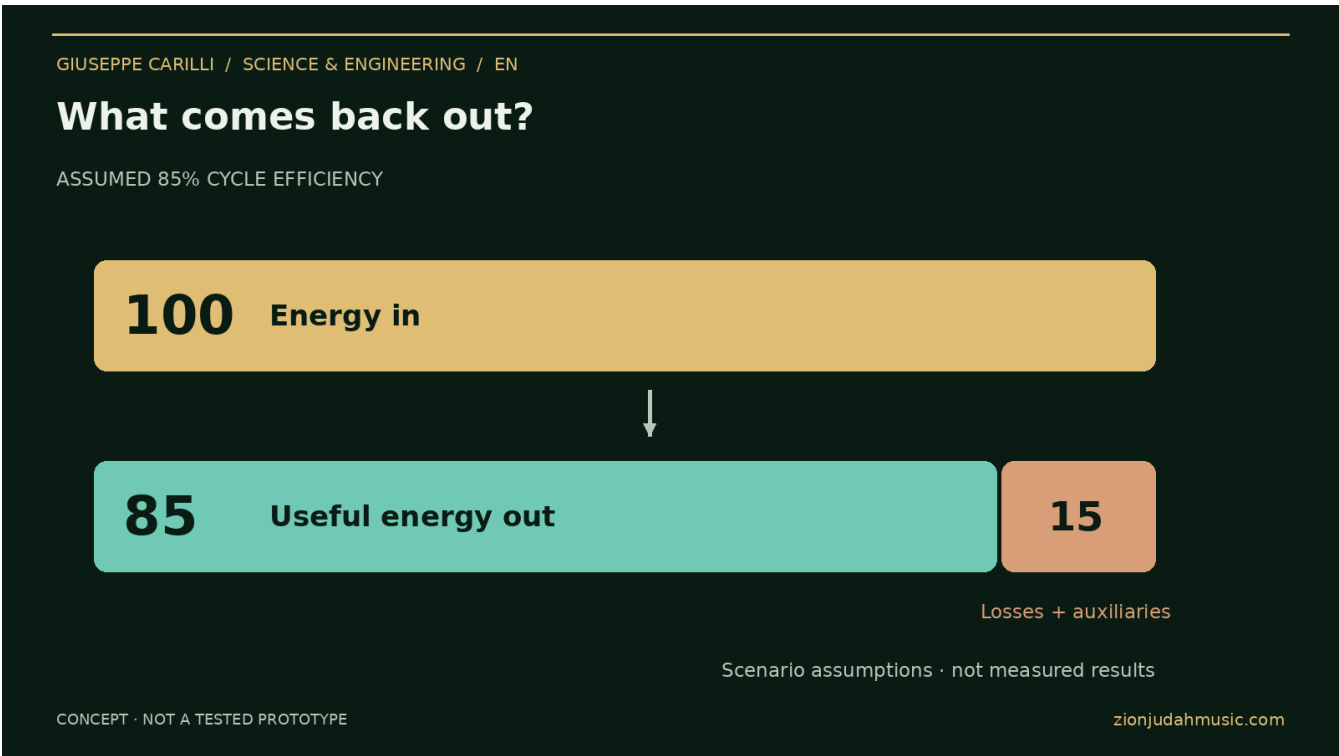


Illustration assuming 85% AC-to-AC cycle efficiency: 100 energy units in, 85 useful units out and 15 lost. Initial and final stored-energy states match; auxiliaries are counted once. These are scenario values, not prototype measurements.

Four useful words

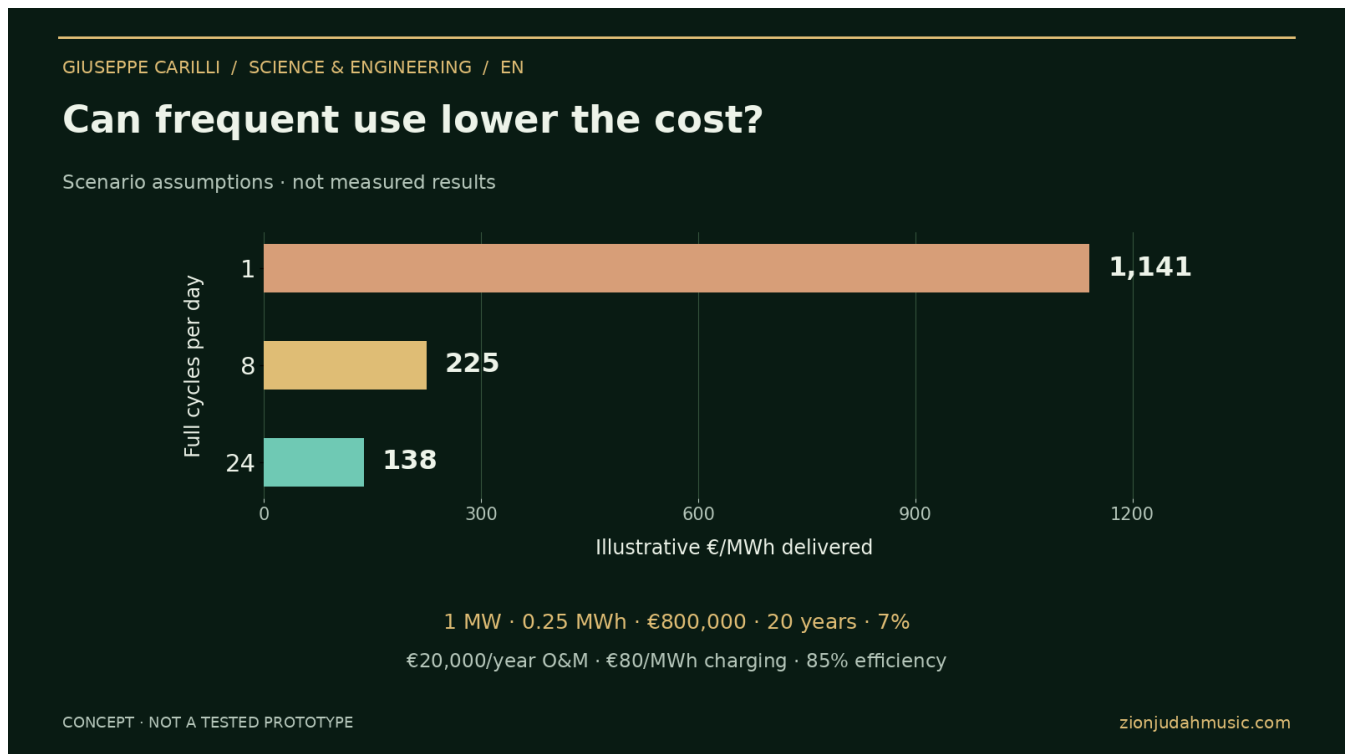
Word	Meaning
Power	How fast energy is delivered, measured in kW or MW.
Energy	How much can be delivered, measured in kWh or MWh.
Efficiency	The useful output divided by the input over a defined cycle.
Lifecycle cost	Equipment, charging, maintenance and other costs over the useful life.

Watch the short illustrated explainer · EN

Captioned conceptual animation. It shows energy storage and conversion, not a working prototype or measured performance. No narration.

Can frequent use lower the cost?

There is no demonstrated source of free electricity here. Sunlight can arrive without a fuel bill, but collection, equipment, charging losses and maintenance still cost money. Cleaner operation depends on the charging electricity and the full lifecycle. The cost example is a question to test, not a price promise.



Illustrative cost per delivered MWh, using the same hypothetical plant at different utilization levels. Rounded results: €1,141, €225 and €138/MWh. More use spreads fixed costs over more electricity, but requires sufficient charging time, demand and verified lifetime.

Illustrative scenario from the paper

1 MW output; 0.25 MWh delivered per full discharge (15 minutes); €800,000 installed capital; €20,000 annual routine maintenance; 20 years; 7% discount rate; €80/MWh charging-input cost; 85% assumed AC-to-AC cycle efficiency, including auxiliaries for the specified duty. These are modeling assumptions, not measured performance or a supplier offer. [1]

Calculated with unrounded values: capital recovery factor 0.0943929; annual fixed cost €95,514.34. $Q = 0.25 \times 365 \times c$. Indicative unit cost = $\text{€}95,514.34 / Q + \text{€}80 / 0.85$.

Inside the machine

The reference design places permanent magnets on the rotor and copper windings on a stationary stator. A rectifier, DC link and inverter adapt the electrical output to the load. Vacuum can reduce aerodynamic drag, but it complicates heat removal, sealing and service access. The optimum pressure is the one that improves the whole system, rather than simply the lowest achievable pressure. [1, 3]

Element	Engineering choice	Evidence to obtain
Magnets	NdFeB; consider SmCo or ferrite where appropriate.	Temperature, demagnetization margin and supply traceability.
Windings + core	Copper and insulated electrical-steel laminations.	Hot resistance, insulation and waveform-dependent core loss.
Rotor + enclosure	Qualified retention, balancing and fragment containment.	Stress, critical speeds, fatigue and fault response.
Bearings + vacuum	Bearings, seals, pump and emergency touchdown support as required.	Standby power, leakage and loss-of-control behavior.
Cooling + converters	Defined thermal paths and protected power electronics.	Hot-spot temperatures, conversion losses and usable AC output.

A small example makes the scale visible

An ideal thin ring of 10 kg and radius 0.20 m has $J = 0.40 \text{ kg}\cdot\text{m}^2$. At 3,000 rpm it contains about 5.48 Wh, equivalent to 19.7 seconds at 1 kW only if all its kinetic energy could be recovered without losses. A real machine retains a minimum operating speed, so less energy is available. This example is unrelated to the grid-scale cost scenario on the next page. [1; recalculated here]

$$E_{\text{rot}} = \frac{1}{2} J \omega^2 \quad E_{\text{usable}} = \frac{1}{2} J (\omega_{\text{max}}^2 - \omega_{\text{min}}^2)$$

J is rotational inertia; ω is angular speed in rad/s. Delivered electrical energy is lower after conversion, standby and auxiliary losses.

The cost of using it

A storage project must pay for the energy it receives and for the equipment that returns it. Compare alternatives at the same power, useful duration, response requirement, waiting time and annual duty. DOE's storage-cost methodology includes charging and replacement costs. Its assessment provides a framework, not a quotation or a validation of this machine. [4]

Full cycles/day	Delivered MWh/year	Modeled €/MWh
1	91.25	1,141
8	730	225
24	2,190	138

Calculated with unrounded values: capital recovery factor 0.0943929; annual fixed cost €95,514.34. $Q = 0.25 \times 365 \times c$. Indicative unit cost = €95,514.34 / Q + €80 / 0.85.

With these assumptions, falling below €150/MWh requires about 18.73 full cycles per day. At 24 cycles per day the model implies 175,200 full cycles over 20 years, before downtime. That duty, lifetime and charging schedule must be demonstrated. Doubling capital to €1.6 million raises the 24-cycle estimate to about €172/MWh. Grid connection, taxes, exceptional repairs and end-of-life costs remain outside this simplified case. Efficiency must be measured again for each waiting-time profile.

Use market comparisons carefully

IRENA reports global weighted-average generation costs for new 2025 projects of USD 33/MWh for onshore wind and USD 44/MWh for solar PV, in 2025 dollars. These describe generation, not the delivered cost of this storage system. EIA's AEO2026 estimates concern US resources entering service in 2031 under stated policy and financing assumptions. Neither is a local tariff, a guaranteed price or a single ranking of interchangeable services. [5, 6]

Does the vacuum save enough energy, over the real operating cycle, to justify its equipment, power demand and maintenance?

A useful result would be repeatable net savings compared with the same task in air, larger than measurement uncertainty, with acceptable temperatures, mechanical containment and total cost. Independent measurements are the next step.

What would count as evidence?

A credible next step is a contained laboratory demonstrator, evaluated by qualified engineers before a field pilot. Define the service and the pass/fail criteria before seeing the results. The supplied paper presents a design assessment and scenarios; it does not supply independent prototype measurements proving net savings or commercial viability. [1]

01 Define the boundary. Record every external electrical and mechanical input, useful output and auxiliary load. Include batteries, the DC bus and initial rotor energy.

02 Measure synchronized data. Log active power, shaft torque, speed, pressure and temperature together. State calibration, sampling, integration method and uncertainty.

03 Compare air and vacuum. Use matched load and speed trajectories. Measure pump-down and standby demand, and compare a conventional machine on the same useful task.

04 Close the cycle. Start and end at matched speed and other stored-energy states, or correct explicitly for their changes. Integrate energy over charging, waiting and discharge.

05 Publish a decision. Require a repeatable net benefit larger than measurement uncertainty, acceptable temperatures and containment, and a competitive lifecycle cost for the defined service.

For an electrical-only storage cycle at matched internal states: $E_{in} = E_{out} + E_{losses}$, with auxiliaries counted once. Report both AC-to-AC cycle efficiency and standby loss. Generator shaft-to-AC efficiency is a different boundary and must be identified separately.

From an Italian test bench to a worldwide discussion

A pilot near a variable industrial load or solar plant can make the service measurable. PVGIS can support solar-resource assessment where relevant; measured load data and local network requirements complete the picture. Grid connection and market access need current, jurisdiction-specific approval. [7]

Environmental comparison should include manufacturing, magnet sourcing, lifetime, repairs, containment and the electricity used for charging and auxiliaries. A flywheel has mechanical failure risks and ongoing losses. Batteries, supercapacitors and other storage options should be compared on the same service. More renewable generation and effective storage perform complementary roles.

I welcome critical review from researchers, engineers, students and anyone interested in resilient energy. The contribution I want to make is practical: a transparent hypothesis, reproducible measurements and a decision that others can check. Shared knowledge and care for Mother Earth belong together.

Sources, methods and edition notes

Selected primary sources supporting this article. The original paper contains a broader 25-item bibliography. Links were checked on 21 October 2026. External sources describe established principles or other projects; they do not endorse this proposed machine.

[1] Giuseppe Carilli · [Electromagnetic machine with a vacuum enclosed rotor](#)

Author-supplied technical paper · 22 pages · IT / EN / ES

[2] U.S. Department of Energy · [Grid-Scale Flywheel Energy Storage Plant](#)

Project fact sheet · October 2012

[3] NASA · [7.0 Thermal Control](#)

Small Spacecraft Technology State of the Art · 2026

[4] U.S. Department of Energy · [2022 Grid Energy Storage Technology Cost and Performance Assessment](#)

Storage methodology and lifecycle cost boundaries · 2022

[5] IRENA · [Renewable Power Generation Costs in 2025: Executive Summary](#)

2026 · 2025 USD · pp. 6-7

[6] U.S. Energy Information Administration · [Levelized Costs of New Generation Resources in AEO2026](#)

April 2026 · 2031 online year · pp. 2-3, 6 and 8

[7] European Commission, Joint Research Centre · [Photovoltaic Geographical Information System \(PVGIS\)](#)

Site-specific solar-resource tools

What this edition clarifies

- Adds the usable-energy relation between maximum and minimum speed, and separates the small-ring example from the hypothetical 1 MW scenario.
- Recomputes the financial example, identifies excluded costs and makes the high-cycle lifetime requirement explicit.
- Separates documented technology, design choices, assumed economics and evidence still required. It does not claim a new physical principle, a validated prototype, peer review or commercial readiness.

Captioned conceptual animation. It shows energy storage and conversion, not a working prototype or measured performance. No narration.

Equations and scenario results were recalculated from the paper's stated inputs. No experimental dataset was supplied or generated for this edition. This is an editorial companion article, not a replacement for the original technical paper.

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Different technologies, different jobs

Follow the energy source before comparing a cost per MWh.

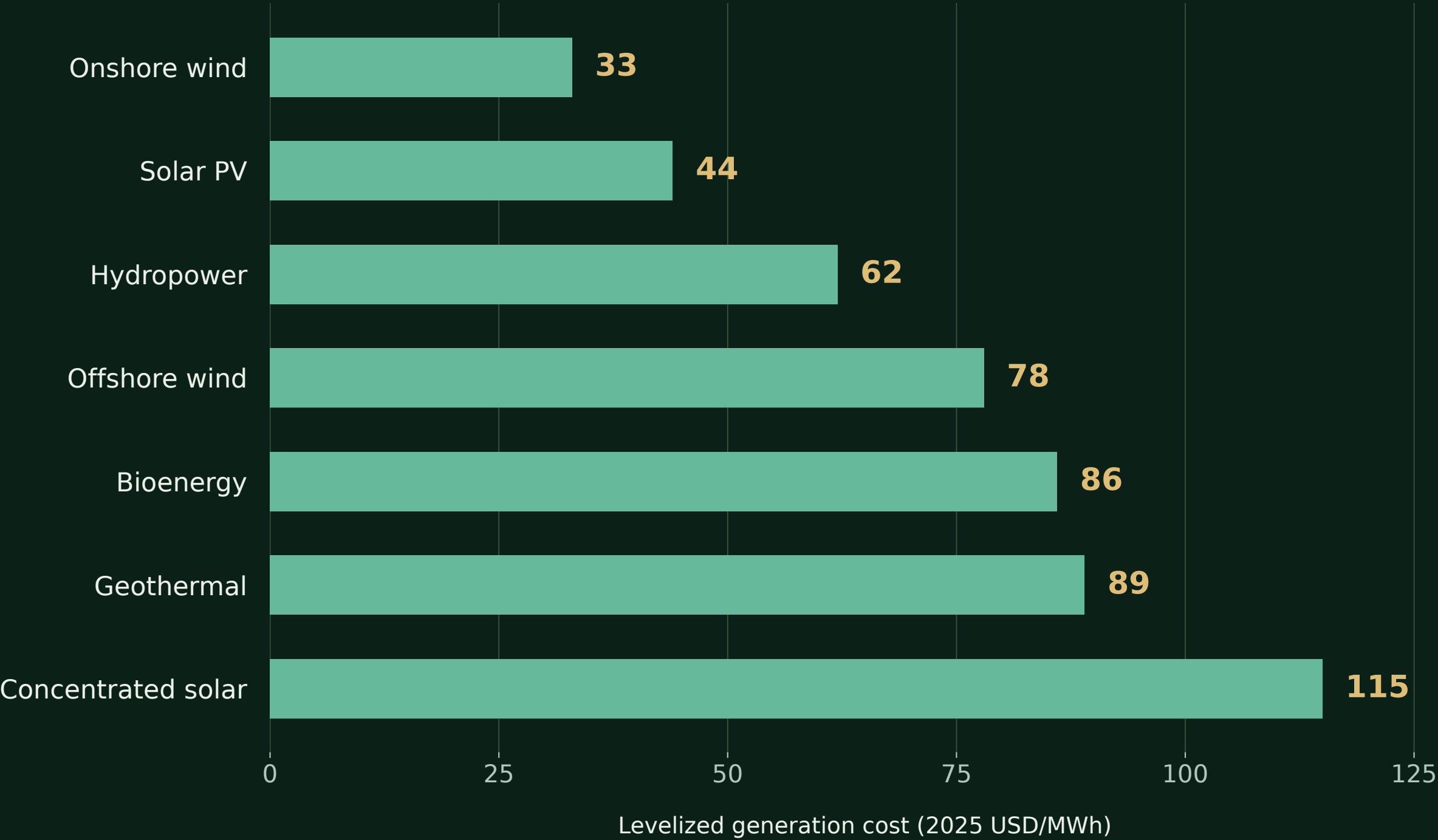
Technology	Energy entering the system	Job / main constraint
Solar PV	Sunlight	Generation / variable sunlight
Wind	Wind	Generation / variable wind
Hydropower	Flowing or stored water	Generation / site and water availability
Nuclear fission	Nuclear fuel	Generation / fuel, cooling and waste
PM generator	External shaft power	Conversion / input power and losses
Vacuum flywheel	Previously supplied electricity	Storage / standby losses and containment
Battery	Previously supplied electricity	Storage / ageing and thermal management
Pumped hydro	Previously supplied electricity	Storage / suitable sites and water

Established technology roles. The proposed rotor configuration still requires validation.

Basis: author technical paper; DOE energy-storage assessment; EIA AEO2026.

Renewable generation costs worldwide

New utility-scale projects commissioned in 2025 - capacity-weighted global LCOE

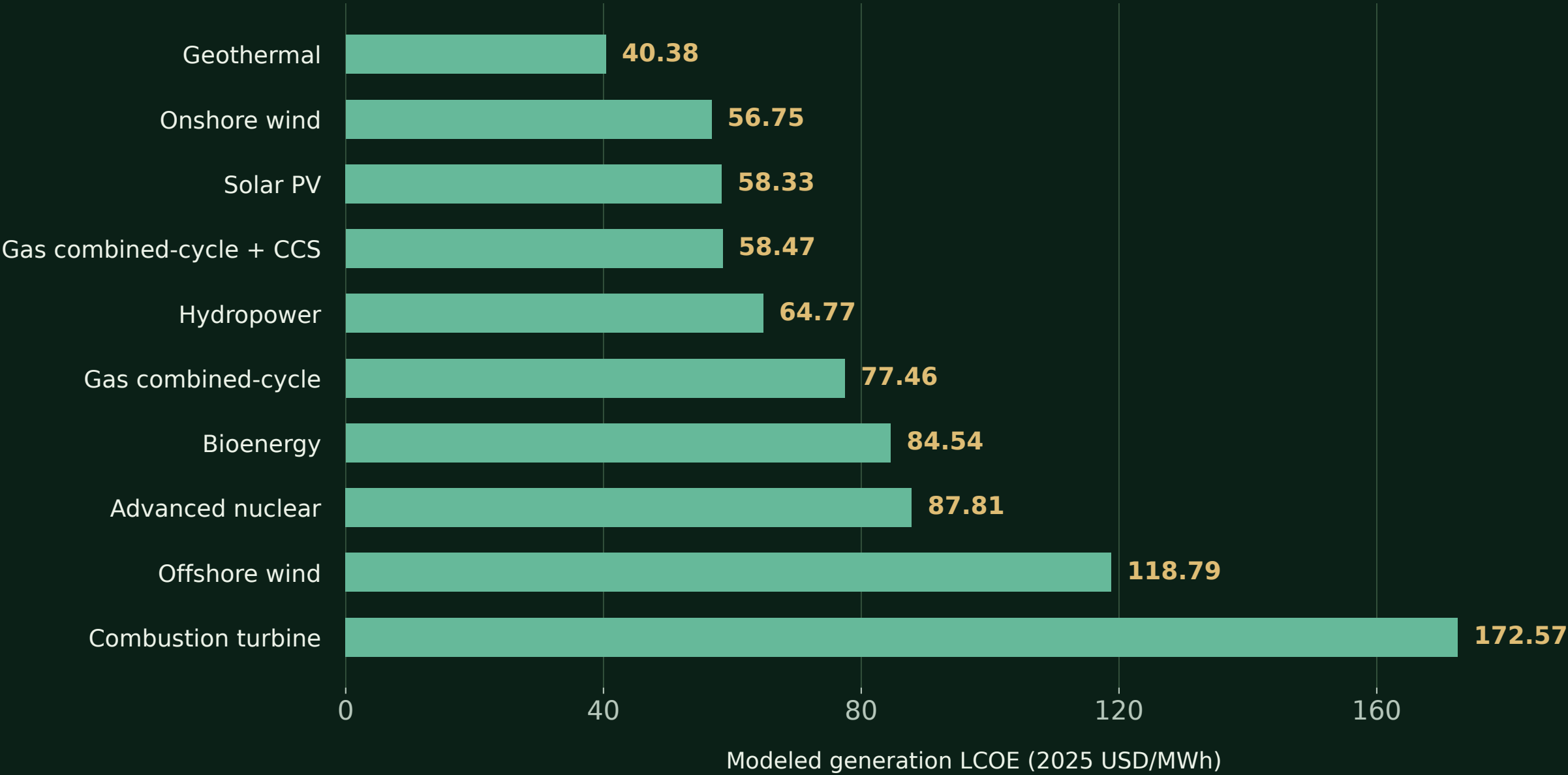


These are generation costs, not electricity tariffs or the cost of firm power at every hour.

Source: IRENA, Renewable Power Generation Costs in 2025, executive summary, pp. 3, 6-7.

A U.S. generation scenario for 2031

EIA AEO2026 Counterfactual Baseline - simple regional averages, credits included



PV + four-hour battery hybrid: 94.20 USD/MWh LCOE

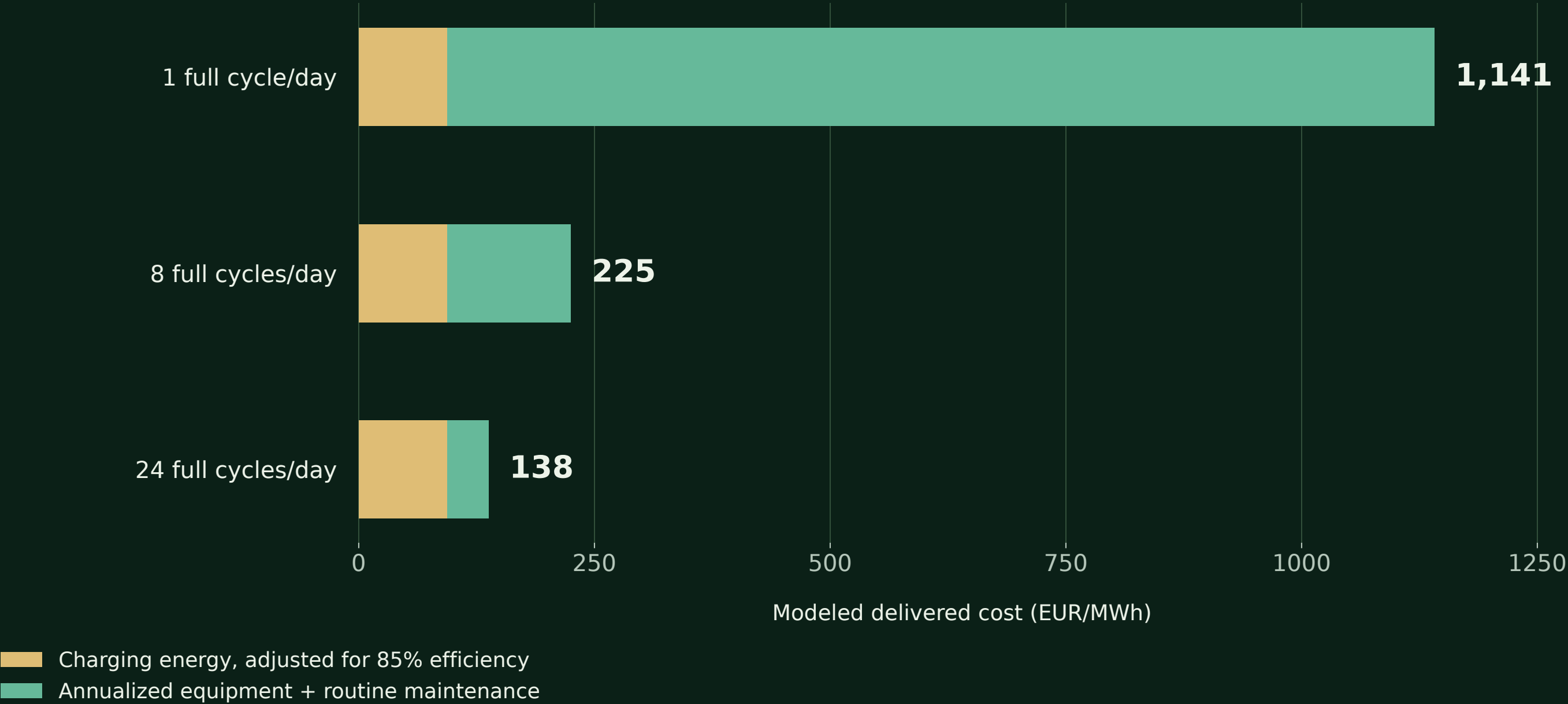
Standalone battery: 152.61 USD/MWh LCOS

Hybrid generation and battery storage have different service boundaries. LCOE alone does not measure grid value.

Source: EIA AEO2026 levelized-cost report, p. 8. Policy, location and assumed duty affect the result.

Why use changes the modeled storage cost

Same proposed 1 MW / 0.25 MWh system - assumptions, not measured performance



At 24 cycles/day: 175,200 cycles in 20 years before downtime. Lifetime and charging schedule must be demonstrated.

Author scenario: EUR 800k capital; EUR 20k/year maintenance; 20 years; 7%; charging EUR 80/MWh.