



The 23rd International Asset
Facility and Maintenance
Management Conference

Slope Energy Storage Systems (SESS) in deserts

ready-to-deploy & easy to run and maintain
solutions for a feasible energy transition



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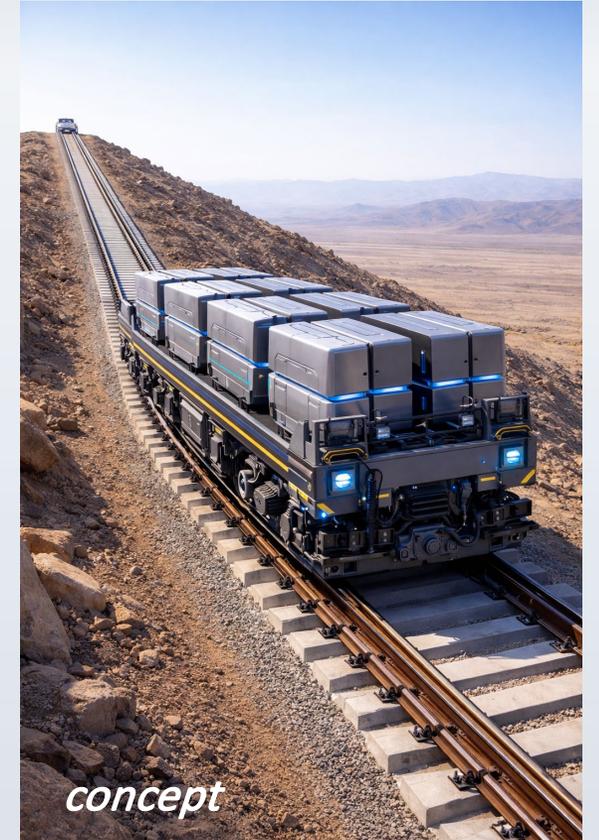
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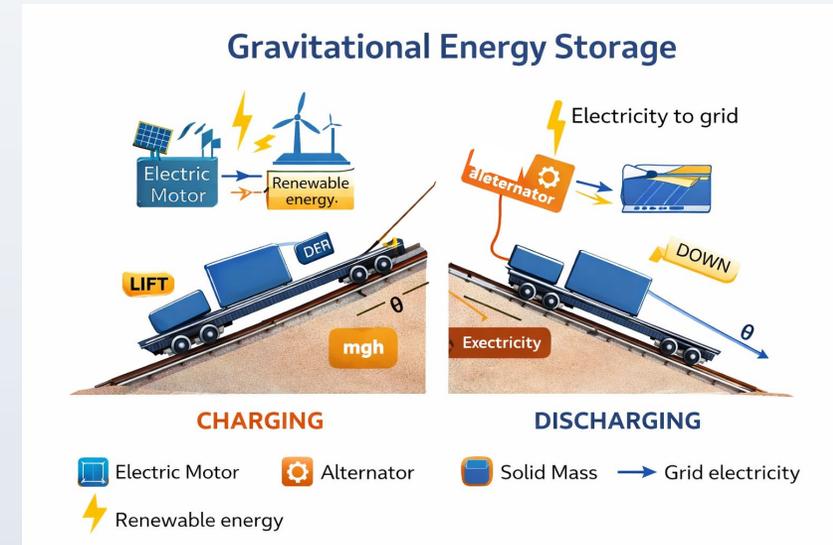
Slope Energy Storage Systems (SESS)

- **What it is:** a gravitational energy storage technology that stores and releases energy by moving large masses on rail along inclined slopes. Not an original concept: today the goal is to build *cost-competitive*, *easy-to-run* and *easy-to-maintain* systems.
- **Working principle:** surplus renewable energy is used to move **Special Railway Vehicles (SRV)** loaded with heavy masses uphill; electricity is recovered during the downhill run through onboard alternators and mechanical systems.
- **Main components:** Special Railway Vehicles (SRVs), heavy-mass materials, inclined rail tracks, onboard alternators and mechanical & electrical control systems.
- **Application areas:** particularly suitable for **large-scale renewable energy plants** in **arid regions**, where renewable energy production (mainly photovoltaic) needs to be stored.
- **Key advantages:** ready-to-deploy solution that is easy to operate and maintain, robust and scalable. No pollution. **No dangerous ending-life waste** to be recycled. **Job opportunities for low-qualified staff.**
- **Ideal geographical context:** vast and arid unpopulated areas, where renewable energy production must be matched with efficient and reliable energy storage capacity.



SESS: the principle

- Concept: gravitational energy storage stores electricity by lifting solid masses along inclined planes, **converting electrical energy into gravitational potential energy**.
- Operation: excess renewable energy (solar/wind) powers motors to lift heavy masses; when energy is needed, the masses descend and drive generators via mechanical systems
- Key characteristic: **power output** is proportional to the **speed** of the moving mass.
- **Energy example**: a 200-ton load (10×2×2 m ferrite block) on a 5% slope over a 10 km track can deliver ~200 kWh, assuming 80% alternator efficiency and 90% mechanical efficiency.
- Bidirectional use: renewable energy can lift the mass (charging), and stored energy is released on demand to the grid (discharging).
- **Technology readiness**: relies on standard, proven components (wheelsets, bearings, brakes, traction motors/alternators).
- Advantages: easy to implement, reliable, low maintenance, scalable, and cost-effective for large-scale energy storage.



Main challenges for SESS

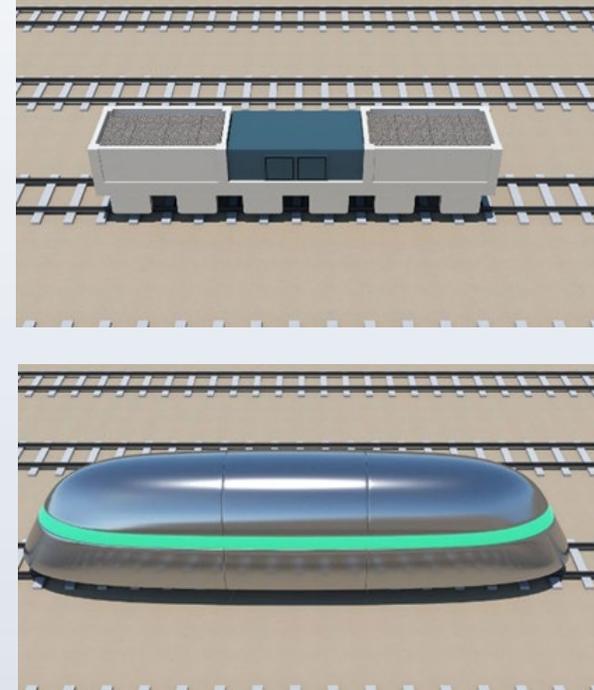
- Low energy density: requires large masses and elevation → suitable for **grid-scale** systems only
- Site & environmental constraints → **need adequate slope and unobstructed terrain**. Desert conditions: temperature extremes, sand storms, unstable soils
- Mechanical wear. Rail: fatigue, thermal stress, abrasion. Bearings & couplings: high loads, dust, corrosion. Efficiency losses ($\approx 5\text{--}15\%$). Rolling resistance, friction, aerodynamic drag
- Use of **proven railway technology**: standard wagons, rails, bearings, brakes, motors/alternators, rack-and-pinion systems, cable-hauled traction systems, etc.
- Predictive & preventive maintenance: dedicated diagnostic vehicles, continuous monitoring of tracks, wheelsets, bearings, power lines
- **Advanced control & safety systems**: electromagnetic & emergency mechanical braking, variable-speed operation, real-time sensors, fail-safe logic
- Grid-ready & resilient design: redundancy (components, controls, communications), fast response, power modulation, grid synchronization



SESS Special Railway Vehicles (SRV)



- **Special Railway Vehicles (SRV)**: purpose-designed rail wagons used as mobile energy storage units, loaded with heavy material to maximize stored gravitational potential energy
- **Charging phase** (*uphill* operation): electricity from renewable sources (photovoltaic and wind) powers the traction systems. SRVs are transported uphill, converting electrical energy into gravitational potential energy
- **Discharging phase** (*downhill* operation): during descent, SRVs move under controlled conditions. Regenerative braking systems convert kinetic energy into electrical energy. Power output is proportional to descent speed, which is actively regulated
- **Grid interface and buffering**: electrical energy is routed through buffer storage units. Chemical storage systems (e.g. advanced battery banks) smooth power fluctuations and ensure grid stability. Buffers compensate for speed variations and short-term interruptions
- Rolling stock design is determined by wagon mass, track gradient, and wheel–rail adhesion limits: for moderate slopes, **conventional adhesion-based** railway systems are sufficient; for steep gradients exceeding adhesion limits, alternative solutions are required, such as **rack-and-pinion** systems, **cable-hauled** traction systems
- **Control and automation managed by advanced AI-based control systems**: optimization of charging and discharging schedules, prediction of renewable availability, alignment of operations with grid demand. Wagon movements are coordinated to minimize mechanical stress and maximize efficiency
- Strong compatibility with intermittent renewable energy sources. Flexible, scalable, and sustainable solution for grid stabilization



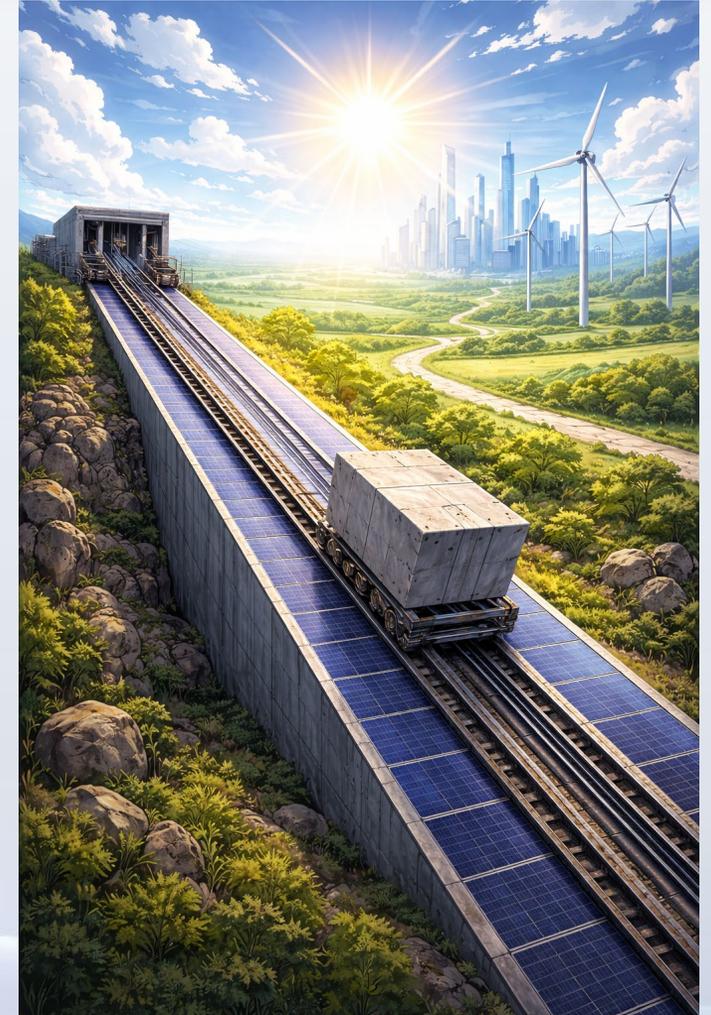
SESS design constraints

- Integrated architecture. SESS is built around **three core domains**: **SRV structure, power electronics, control & safety systems**
- **Mature supply chain**: SRV manufacturers, infrastructure builders, and technology providers are already identified, guaranteeing industrial readiness and strong alignment from early design stages
- **Robust SRV design for very high payloads** (e.g. ferrite), high-efficiency mechanics, low-loss bearings, precise rail alignment and optimized gear ratios to minimize rolling resistance and enable efficient energy generation across different speeds and gradients
- Mechanical-to-electrical conversion
- Advanced power electronics
- Control and safety systems
- **AI-driven grid interaction**: an intelligent management platform optimizes charging/discharging decisions based on grid demand, prices, and flexibility needs, positioning SESS as both an energy storage and grid-balancing solution



SESS implementation issues

- **Comprehensive site analysis:** evaluation of topographical and geological conditions, regulatory, social, and cultural factors, terrain suitability
- Engineering and system design choices
- **Integration with local energy users:** synergies with nearby facilities such as desalination plants, cement factories, refineries, irrigation systems, wastewater treatment, and waste management plants
- Manpower strategy (inclusive for high-medium-low qualified staff)
- Capital availability
- Infrastructure accessibility
- **Critical success factors:** mechanical simplicity, ease of operation and maintenance, use of moderately skilled labor, local job creation, strong social acceptance



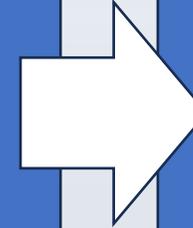
Tailoring

- terrain suitability
- environmental risks
- geological conditions
- grid interface requirements and availability (DSO–TSO)
- regulatory aspects
- construction constraints
- patent compliance for components (if applicable)
- social, and cultural factors
- synergies with nearby energy users
- dialogue with local communities
- pilot system business plan



Piloting

- pilot system design and deployment
- technical and operational validation
- performance assessment
- replicable and scalable solutions
- communication
- raising awareness
- business models
- business plan



Full scale

- implementation of the SESS system at the desired scale
- grid integration and commissioning
- operational start-up and optimization

Authors



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THANK YOU!

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