Principles and Mechanics of Hydrokinetic Power Systems

A Civil and Water Resources Engineering Perspective

Hamidreza Khalaj Zahraei   Muhammet Yağcıoğlu

Izmir Institute of Technology
Civil Engineering Department

January 5, 2026

Principles and Mechanics of Hydrokinetic Power Systems

A Civil and Water Resources Engineering Perspective

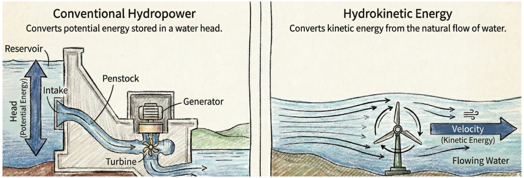


Figure: Working Principle

Introduction to Hydrokinetic Energy (HECS)

- HECS generates electricity from the **kinetic energy** of flowing water.
- It avoids large dams and reservoirs, so civil works are smaller and faster.
- The approach is often called **zero-head** or **in-stream** power.

HECS aligns well with sustainable water management and low-impact energy planning.

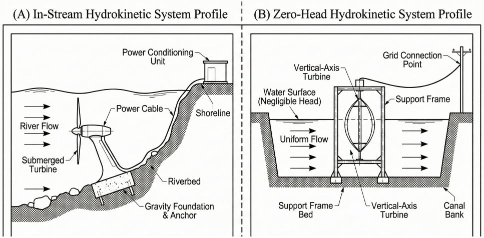
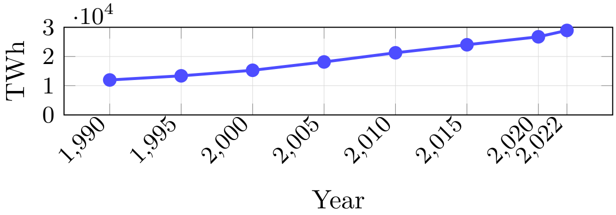


Figure: Tidal and in-strea energy turbine concept (Wikimedia Commons).

Why Humanity Needs HECS: Energy Demand and Decarbonization

- Global electricity generation keeps rising with electrification and growth.
- Grids need firm, low-carbon power that complements solar and wind variability.
- HECS can supply steady power in river and tidal corridors close to loads.



Source: Our World in Data (Ember), 2024.

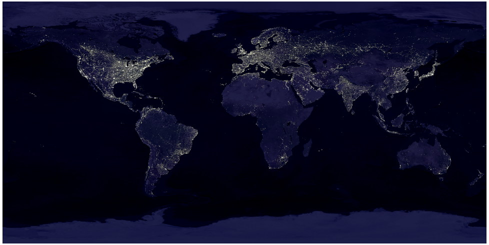


Figure: Global night lights as proxy for demand (Wikimedia Commons).

Water–Energy–Climate Nexus

- Climate variability intensifies droughts and alters river hydrology.
- Water resources must serve energy, ecosystems, and communities together.
- HECS provides low-impact generation without major storage loss or diversion.

Civil engineers must balance energy extraction with resilience, equity, and long-term water security.

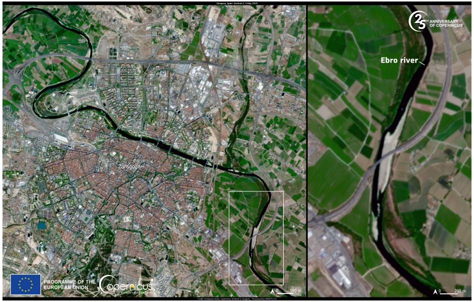


Figure: Drought-exposed riverbed (Wikimedia Commons).

Kinetic vs Potential Energy: The Core Distinction

- **Conventional hydropower** uses potential energy from head.
- **Hydrokinetic power** uses kinetic energy in free-flowing water.
- Minimal flow modification improves ecological compatibility and navigation.

This distinction reduces land take and resettlement impacts often tied to large dams.

Figure: Hydropower dam infrastructure (Wikimedia Commons).

Hydrokinetic Applications and Benefits

- Works in rivers, tidal straits, and coastal channels with steady flow.
- Modular devices allow phased deployment and easier maintenance.
- Low visual impact and smaller civil works improve permitting.
- Predictable tides help grid planning and reliability.

Civil engineers align energy output with navigation, ecology, and local demand.

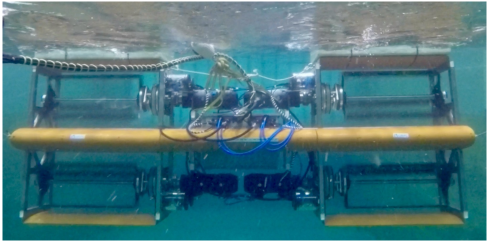


Figure: In-stream turbine deployment (Wikimedia Commons).

Major Operational Projects by Country

Country	Project	Type	MW
Scotland (UK)	MeyGen	Tidal stream	6.0
Scotland (UK)	Orbital O2	Floating tidal stream	2.0
N. Ireland (UK)	SeaGen	Tidal stream	1.2
South Korea	Uldolmok	Tidal current	1.0

Sources: Wikipedia (MeyGen; Orbital Marine Power; SeaGen; Uldolmok).

Figure: Tidal energy turbine concept (Wikimedia Commons).

Project Highlights and Lessons

- **MeyGen (Scotland):** Largest tidal stream array in operation.
- **Orbital O2 (Scotland):** Largest single tidal turbine platform.
- **SeaGen (N. Ireland):** Early full-scale commercial prototype.
- **Uldolmok (South Korea):** National demonstration of tidal current power.

These projects show that scale, durability, and permitting define success.

Figure: Tidal turbine deployment (Wikimedia Commons).

Working Principle: Flow to Electricity

- **Rotor rotation:** Moving water creates torque on the blades.
- **Mechanical transfer:** Shafts and gear stages transmit torque.
- **Electromagnetism:** Rotating magnets induce current in the stator.
- **Delivery:** Power electronics and transformers condition output.

The conversion chain is compact but demands robust sealing and corrosion control.

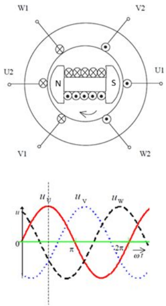


Figure: Synchronous generator schematic (Wikimedia Commons).

Site Selection and Resource Assessment

- Consistent flow and adequate depth are the first screening criteria.
- Bed material and scour risk define foundation strategy.
- Proximity to loads and grid access drives project viability.
- Environmental constraints shape layout and monitoring plans.

Continuous field measurements are essential before civil design begins.

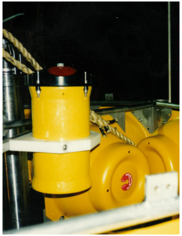
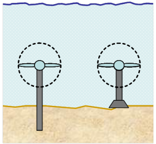


Figure: ADCP flow measurement (Wikimedia Commons).

Civil and Environmental Design

- Foundations must resist drag, turbulence, and debris; scour analysis is critical.
- Bed conditions drive gravity, pile, or anchor systems while preserving navigation.
- Fish passage and habitat continuity guide layout, permitting, and monitoring.
- Low visual impact improves public acceptance and long-term access.

Civil design integrates structure, hydraulics, and ecology.

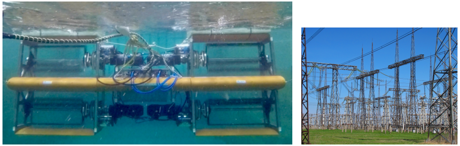


Figures: Bottom-mounted concept and fish ladder (Wikimedia Commons).

Construction and Grid Integration

- Modular components enable rapid installation and retrieval.
- Construction windows depend on flow, tides, and navigation schedules.
- Subsea or riverbed cables connect turbines to shore substations.
- Power electronics and transformers condition voltage for the grid.

Access planning and utility coordination drive cost and schedule.



Figures: In-stream deployment and substation infrastructure (Wikimedia Commons).

Reliability Challenges and Mitigation

- **Biofouling:** Managed with coatings and cleaning schedules.
- **Cavitation:** Reduced by optimized blade geometry and control.
- **Corrosion:** Addressed with materials selection and cathodic protection.

Durability planning lowers lifecycle costs and improves project bankability.

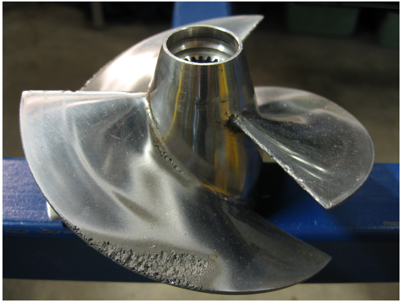


Figure: Cavitation damage on propeller (Wikimedia Commons).

Conclusion and Global Outlook

- HECS offers a sustainable option where large dams are not feasible.
- Success depends on site-specific engineering and clear regulation.
- Well-characterized sites can scale from pilots to dependable arrays.

Analogy: A dam is a heavy battery; a hydrokinetic turbine is a fan in the flow, harvesting energy without stopping it.

References: Our World in Data. (2024). Electricity generation – TWh (Ember). https://ourworldindata.org/grapher/electricity-generation
Wikipedia contributors. (n.d.). MeyGen. https://en.wikipedia.org/wiki/MeyGen
Wikipedia contributors. (n.d.). Orbital Marine Power. https://en.wikipedia.org/wiki/Orbital_Marine_Power
Wikipedia contributors. (n.d.). SeaGen. https://en.wikipedia.org/wiki/SeaGen
Wikipedia contributors. (n.d.). Uldolmok Tidal Power Station. https://en.wikipedia.org/wiki/Uldolmok_Tidal_Power_Station

Figure: Tidal turbine deployment (Wikimedia Commons).