Featured Article - Green Hydrogen

Turning Wastewater into Green Hydrogen: Engineering the Future of Clean Energy

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Water, Energy, and the Decarbonization Puzzle

The race toward **net-zero carbon emissions** is pushing nations and industries to look beyond conventional renewables like solar and wind. Enter **green hydrogen** — hailed as the "fuel of the future." It can decarbonize hard-to-abate sectors such as steel, cement, aviation, and shipping while also serving as a versatile energy carrier.

But behind the promise of hydrogen lies a hidden paradox: **water demand**

Producing just **1 kg of hydrogen** requires nearly **9 litres of ultrapure water.** Scaling up to gigawatt electrolyser parks could strain freshwater resources, particularly in water-stressed regions like India and the Middle East.

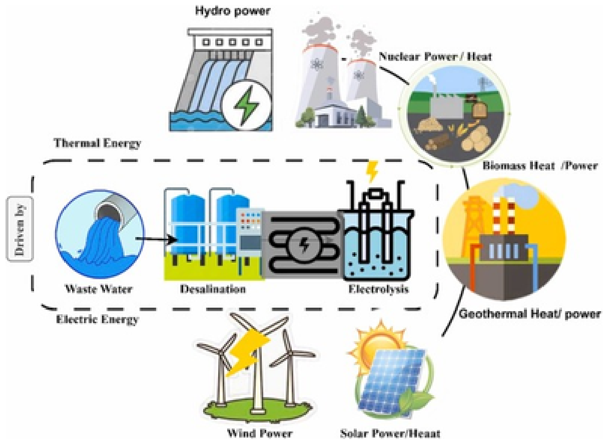
This article explores the **engineering pathways, technical calculations, and process integration** of turning wastewater into a reliable feedstock for electrolysers, unlocking a dual sustainability benefit: **wastewater reuse + green hydrogen generation.**

Wastewater as a Feedstock: From Pollutant to Hydrogen Carrier

Why Wastewater?

- **Availability:** Every city and industry produces it.
- **Circular economy:** Converts waste into value.
- **Decentralization potential:** Onsite hydrogen production at industrial parks, refineries, or solar manufacturing fabs.

However, electrolysers demand **extreme water purity:** conductivity ≤ 0.1 µS/cm, silica < 0.01 ppm, and TOC ≤ 50 ppb. This means wastewater must undergo **multi-stage purification.**



Technical Treatment Train for Electrolyser-Grade Water

1.Primary Treatment

- Screens, grit chambers, and oil separators remove coarse solids and floating contaminants.

2.Secondary (Biological) Treatment

- **Activated Sludge, MBR (Membrane Bioreactor), or MBBR (Moving Bed Biofilm Reactor)** break down dissolved organics.
- Dissolved BOD/COD reduced by 90–95%.

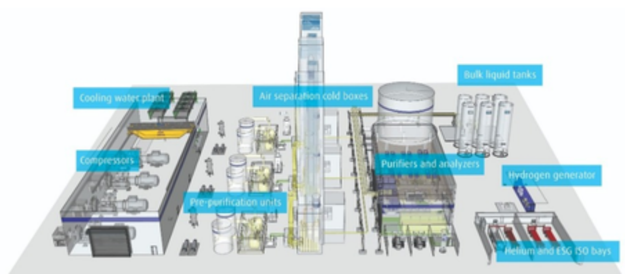
3.Tertiary Polishing

- Ultrafiltration (UF) or sand filters.
- UV disinfection or ozonation..

4.Advanced Purification

- Reverse Osmosis (RO): Removes salts, hardness, and most dissolved organics.
- Electrodeionization (EDI): Continuous ion removal without chemicals.
- UV Oxidation & Degassing: TOC destruction and dissolved gas removal.

At this stage, the water matches **semiconductor fab-grade DI water** — the exact requirement for PEM and alkaline electrolysers.



Electrolysis: Splitting Molecules, Not Atoms

The Science in Numbers

The core reaction:

$$2H_2O(l) \xrightarrow{\text{Electricity}} 2H_2(g) + O_2(g)$$

Reversible cell voltage (thermodynamic minimum):

$$E_{rev} = \frac{\Delta G}{nF} \approx 1.23\ V\ (25^{\circ}C)$$

Practical voltage (due to overpotentials): 1.8–2.2 V

Hydrogen production rate (moles/s):

$$\dot{n}_{H_2} = \frac{I}{2F}$$

Where:

- III = Current (A)
- FFF = Faraday constant (96485 C/mol)

Example: For a 10,000 A cell at 2 V:

$$\dot{n}_{H_2} = \frac{10,000}{2 \times 96485} = 0.0518\ mol/s$$

$$= 0.104\ g/s \approx 375\ g/h$$

Scaling up with stacks → multi-megawatt hydrogen output.

Electrolyser Technologies

1.Alkaline Electrolyser (AEL):

- Mature, cost-effective, tolerant to impurities.
- Uses KOH/NaOH electrolyte.
- Efficiency: 60–65%.

2.Proton Exchange Membrane (PEM):

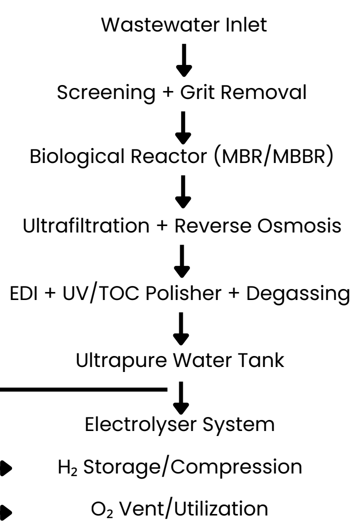
- Requires ultrapure water.
- High purity hydrogen (>99.99%).
- Fast response, suited for renewable integration.
- Efficiency: 65–75%.

3.Solid Oxide Electrolyser (SOEC):

- High-temp (700–900 °C).
- Can achieve >80% efficiency.
- Still in pilot phase.

For **wastewater-fed systems, PEM** (with rigorous polishing) or **Alkaline** (for robust operation) are most feasible.

P&ID Conceptual Layout



Energy & Mass Balance

Water Requirement

- 1 kg H_2 → 9 L ultrapure water + ~50 kWh electricity

Wastewater Utilization Example

- 1 MLD wastewater (1,000,000 L/day)
  - Assume 80% recovery after treatment → 800,000 L/day
  - Hydrogen potential:

$$\frac{800,000}{9} \approx 88,800\ kgH/day$$

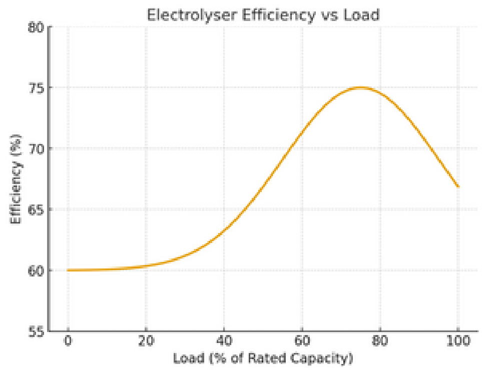
- Equivalent energy:

$$88,800 \times 33.3\ kWh/kg \approx 2,956\ MWh/day$$

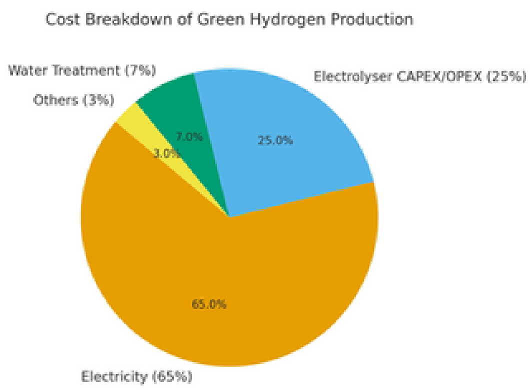
This equals **powering ~120,000 Indian homes daily.**

Performance Characteristics

- Efficiency vs Load Curve:
  - Peak efficiency (70–75%) at ~70–80% rated load.
  - Efficiency dips at both low (<30%) and full (100%) load.



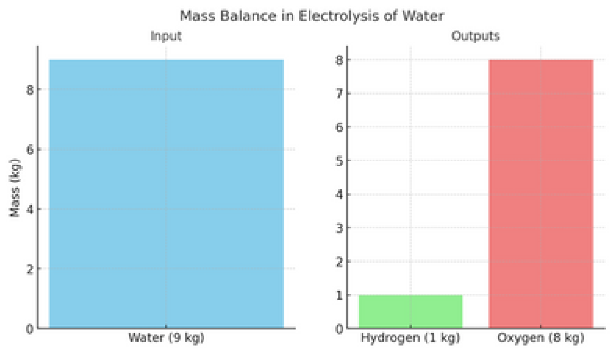
- Hydrogen Cost Breakdown (conceptual pie chart idea):
  - Electricity: 65–70%
  - Water treatment: 5–8%
  - Electrolyser CAPEX/OPEX: 20–25%



Beyond Hydrogen: The Bonus Oxygen

For every 1 kg of hydrogen produced, 8 kg of oxygen is released. Instead of venting, oxygen can be reused in:

- Wastewater plant aeration (reduces blower energy).
- Steel and glass industries.
- Medical/healthcare oxygen supply.



Sustainability Benefits

✅ Reduces freshwater demand in hydrogen plants
✅ Converts wastewater from liability to asset
✅ Enables distributed hydrogen hubs in cities and industrial clusters
✅Promotes zero-liquid discharge (ZLD) and circular economy models

Looking Ahead

In the coming decade, expect to see:

- **AI-driven quality monitoring** for wastewater-fed electrolysers.
- **Hybrid solar + wind + wastewater hydrogen hubs.**
- **Integration with green ammonia, methanol, and fuel-cell ecosystems.**
- Municipalities turning **sewage into hydrogen fueling stations.**

Conclusion

Green hydrogen is not just about splitting water — it's about **engineering smarter water-energy loops.** By treating wastewater into an electrolyser-ready feed, we unlock a sustainable pathway that addresses both **water scarcity** and **energy decarbonization.**

As cities, industries, and nations embrace this model, wastewater will no longer be a burden. Instead, it will power our fuel cells, ships, planes, and industries — turning yesterday's effluent into tomorrow's clean energy.

I strongly believe wastewater-fed electrolysers are not just a concept but the **next industrial revolution in energy and environment management.** The world must see wastewater not as a burden but as a fuel for the future.

"In every drop of treated wastewater, I see the spark of tomorrow's clean hydrogen economy."

— Sharath Chandra Maroju

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