

# **Indefinite Off-Grid Power via HHO Fuel Cells**

Closed-loop hydrogen generation, storage, and recombination for sustained off-grid energy

Lateralus Language



Stack pressure: 10-30 bar (matched to storage)

Key design consideration: the electrolyzer must handle variable input power (solar curves). Alkaline electrolyzers tolerate 20-100% of rated power; minimum power threshold prevents electrolyte contamination.

## 4. Gas Storage and Safety

Hydrogen storage at 200-350 bar in steel or composite cylinders is the practical choice at this scale. Safety requirements are stringent:

- **Separation:** H2 and O2 tanks must be stored separately and in ventilated enclosures. Mixed HHO gas is explosive at 4-75% H2 in air concentration.
- **Grounding:** all metallic surfaces must be bonded and grounded to prevent static discharge ignition.
- **Leak detection:** catalytic H2 sensors (not electrochemical) with automatic shutoff valves on any detected leak.
- **Pressure relief:** certified PRV on each tank, sized for worst-case thermal expansion (fire exposure scenario).
- **Purge lines:** inert gas (N2) purge capability for maintenance and emergency procedures.

## 5. Fuel Cell Selection and Sizing

For recombination, a PEM fuel cell stack is preferred over an H2 combustion generator for grid-quality AC output:

PEM fuel cell (preferred):

Electrical efficiency: 50-60% (DC output)  
 Output quality: DC → inverter → AC  
 Noise: near-silent  
 Maintenance: membrane replacement every 5-10 years  
 Water output: 0.9 kg/kWh (recaptured)

H2 combustion generator (alternative):

Electrical efficiency: 25-35%  
 Output quality: AC direct (but requires governor)  
 Noise: loud (combustion)  
 Maintenance: engine overhaul every 2000-5000 hours

The PEM fuel cell is the better choice for sustained off-grid use despite higher upfront cost. The combustion generator is suitable as backup for fault conditions.

## 6. Water Management

Water quality is critical: the electrolyzer requires deionized water (< 1  $\mu\text{S}/\text{cm}$  conductivity) and the fuel cell produces slightly acidic water (from membrane operation). The closed loop water management:

Fuel cell water output

- Condensate collection tank
- Deionization column (mixed-bed resin)
- Conductivity sensor (reject if > 1  $\mu\text{S}/\text{cm}$ )
- Electrolyzer feed tank
- (electrolyzer refill as needed)

The deionization resin requires periodic regeneration or replacement (approximately annually at 10 kW continuous operation). Total water in the loop: approximately 200-500 liters for a 10 kW / 500 kWh system.

## 7. System Integration and Control

The system controller manages energy dispatch between three modes:

- **Surplus mode:** solar/wind exceeds load. Excess power routed to electrolyzer. Electrolysis rate proportional to surplus.
- **Balance mode:** solar/wind matches load. Electrolyzer and fuel cell both idle. Battery buffer (small, for transients) absorbs variation.
- **Deficit mode:** solar/wind insufficient. Fuel cell activates to supplement. H2 consumption rate proportional to deficit.

The control algorithm is implemented as a Lateralus pipeline: sensor readings flow through the pipeline and emerge as actuator commands for the electrolyzer power controller and fuel cell load regulator.

## 8. Practical Economics

At current (2026) component prices, the HHO closed-loop system is economically competitive with battery storage only for storage durations exceeding approximately 3 days:

10 kW system, 500 kWh storage:

Li-ion battery system:	~\$75,000 (15-year life, 2 replacement cycles)
HHO closed-loop system:	~\$120,000 (25+ year life, no major replacement)
Break-even duration:	>72 hours storage requirement

For seasonal storage (months), HHO is the only practical option – no battery chemistry can economically store energy across seasons.

The primary use case is remote locations with extreme seasonal variation: high northern latitudes, isolated islands, and research stations where resupply is expensive and infrequent.

Lateralus is an open-source, zero-dependency programming language. Project home: <https://lateralus.dev>. Source: [github.com/bad-antics/lateralus-lang](https://github.com/bad-antics/lateralus-lang). Released under CC BY 4.0.