ELECTROLYZER TECHNOLOGY

ISOTHERMAL ELECTROLYSIS.

>92% SYSTEM EFFICIENCY.

Pulsed waveform architecture eliminates waste heat. No platinum. No iridium. No membranes. Industrial-grade hydrogen production at unprecedented efficiency using commodity materials.

>92%	8×	<30°C	0
SYSTEM EFFICIENCY	LESS HEAT LOSS	OPERATING TEMP	RARE EARTH METALS

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Non-Confidential

EXECUTIVE SUMMARY

Tobe Energy has developed a fundamentally different approach to water electrolysis that achieves >92% electrical efficiency while eliminating the exotic materials, complex thermal management, and degradation mechanisms that constrain conventional electrolyzer technologies.

94.7%	~75%	1,000+	80k+
ELECTRICAL EFFICIENCY (LHV)	CAPEX REDUCTION	HOURS TESTED	EST. STACK LIFE (HRS)

KEY DIFFERENTIATORS

ATTRIBUTE	CONVENTIONAL ELECTROLYZERS	TOBE APPROACH
Operating Temperature	60–80°C (PEM), 70–90°C (Alkaline)	**Near ambient (<30°C)**
Critical Materials	Platinum, Iridium, Nafion membranes	**304 SS, commodity components**
Electrolyte	Concentrated KOH (25-40%)	**Dilute solution (pure water compatible)**
Primary Failure Mode	Membrane degradation, catalyst poisoning	**Standard industrial wear items**
Thermal Management	Active cooling required	**Minimal (isothermal operation)**

THE CORE INSIGHT

Conventional electrolysis generates significant waste heat because it operates continuously at voltages well above thermodynamic minimum. Tobe's pulsed approach works at lower effective overpotentials, converting electrical energy to chemical energy with minimal thermal loss.

THE PROBLEM

Green hydrogen remains expensive primarily because electrolysis is inefficient. Electricity accounts for 60-80% of levelized hydrogen cost, yet conventional electrolyzers convert only 60-75% of input energy to hydrogen.

WHY CONVENTIONAL SYSTEMS ARE STUCK

PEM Electrolyzers

Achieve good current density but require platinum-group metals and expensive proton-exchange membranes. Membrane degradation limits lifetime. Iridium scarcity constrains scale-up—global production cannot support terawatt-scale deployment.

Alkaline Electrolyzers

Avoid PGMs but require concentrated caustic electrolyte (25-40% KOH), creating safety, handling, and corrosion challenges. Limited turndown capability makes them poorly suited for variable renewable power.

THE THERMAL PENALTY

Both technologies operate at elevated temperatures (60-90°C) and generate substantial waste heat. This isn't incidental—it's fundamental to how they work.

Conventional Approach

- Continuous DC operation at 1.8–2.2V
- High overpotentials → waste heat
- Active cooling infrastructure required
- 65-75% system efficiency typical
- Balance of plant adds cost and failure modes

Tobe Approach

- Pulsed waveform operation
- Lower effective overpotentials
- Near-isothermal operation
- >92% system efficiency demonstrated
- Simplified system architecture

THE SCALE CHALLENGE

Meeting global decarbonization targets requires electrolyzer capacity measured in terawatts. Current PGM-dependent technologies face fundamental material constraints. A new approach using commodity materials isn't just cost-competitive—it's necessary for scale.

WHAT TOBE IS

Tobe is a category-level rethink of water electrolysis. Rather than incremental improvements to PEM or alkaline systems, we've developed a fundamentally different electrochemical architecture that eliminates the constraints those technologies accept as given.

CORE ARCHITECTURE

SUBSYSTEM	FUNCTION	KEY INNOVATION
Power Electronics	Converts input to controlled pulse waveforms	Proprietary pulse patterns for electrochemical kinetics
Electrolysis Module	Houses electrode stacks and manages electrolyte	Membrane-free design using 304 SS construction
Gas Handling	Separates, dries, and pressurizes H_2 and O_2	Simplified separation (no membrane → cleaner streams)

WHAT MAKES IT DIFFERENT

No Membranes ZERO PROTON-EXCHANGE MEMBRANE	**No Caustic** WORKS WITH DILUTE OR PURE WATER	**No PGMs** ZERO PLATINUM OR IRIDIUM	**Near Ambient** OPERATES <30°C, NO ACTIVE COOLING

WHERE IT FITS

- **Behind-the-meter installations** — Industrial facilities with variable renewable generation
- **Hydrogen hubs** — Centralized production serving multiple offtakers
- **Data center backup power** — Converting excess renewable capacity to stored hydrogen
- **Distributed production** — Small-scale on-site generation for fleet fueling or industrial processes

PERFORMANCE

We report efficiency using clear definitions to enable direct comparison. All figures represent measured system performance, not theoretical or stack-only values.

LHV VS HHV BASIS

Hydrogen's lower heating value (LHV) is 33.33 kWh/kg. The higher heating value (HHV) is 39.41 kWh/kg. We report LHV efficiency as the industry standard for combustion and fuel cell applications.

MEASURED PERFORMANCE

PARAMETER	VALUE	NOTES
Electrical Efficiency (LHV)	94.7%	Stack performance at nominal operating point
System Efficiency	~42.23 kWh/kg H_2	Including power electronics and gas handling
Turndown Range	10–100%	Maintains efficiency across operating range
Response Time	<1 second	Grid-following capability for renewable integration
Startup Time	Immediate	No warm-up period required
Operating Pressure	Up to 350 psig	Reduces downstream compression
Operating Temperature	<30°C	Near-ambient, minimal thermal management
Ambient Range	-30°C to +50°C	Outdoor installation without climate control
H_2 Purity	>99%	Higher purity available with standard PSA

WHY THIS MATTERS

At typical industrial electricity rates ($0.04–0.06/kWh), improving efficiency from 70% to 94% reduces the electricity cost component of hydrogen from ~$2.38/kg to ~$1.77/kg. Over the lifetime of a facility producing 1,000 kg/day, this represents millions in savings.

RELIABILITY

Tobe's architecture eliminates the primary failure modes that limit conventional electrolyzer lifetime. Nothing in the stack gets "used up" during operation.

FAILURE MODES ELIMINATED

CONVENTIONAL FAILURE MODE	ROOT CAUSE	TOBE APPROACH
Membrane Degradation	Chemical attack, mechanical stress	**No membrane in system**
Catalyst Poisoning	Contamination of PGM catalysts	**No catalysts required**
Thermal Cycling Fatigue	Expansion/contraction from temp swings	**Isothermal operation**
Caustic Corrosion	Concentrated KOH attacks materials	**Dilute/neutral electrolyte**
Electrode Degradation	Corrosion at high temperature	**Low-temp with corrosion-resistant 304 SS**

LIFETIME PROJECTION

80,000+	Standard	Field	Minimal
ESTIMATED STACK HOURS	WEAR ITEMS ONLY	SERVICEABLE DESIGN	SCHEDULED MAINTENANCE

DESIGN PHILOSOPHY

- **Commodity materials** — 304 stainless steel uses globally available supply chains
- **Modular architecture** — Individual cells serviceable without system shutdown
- **No single points of failure** — Redundant sensing and control throughout
- **Industrial standards** — Components selected for proven reliability

SCALING APPROACH

Tobe systems scale through modular multiplication of proven cell designs. This maintains performance while reducing manufacturing risk and enabling flexible deployment.

PRODUCT LINE

MODEL	CAPACITY	H_2 OUTPUT	FOOTPRINT	TARGET APPLICATION
Tobe-25	25 kW	~12 kg/day	Compact skid	Distributed, pilot, R&D
Tobe-250	250 kW	~120 kg/day	20' container	Commercial, fleet fueling
Tobe-2500	2.5 MW	~1,200 kg/day	Multi-container	Industrial, hub-scale

MANUFACTURING PHILOSOPHY

Current State

Prototype systems built using standard fabrication. No specialized equipment or exotic materials required. Current cost includes NRE and low-volume inefficiencies.

Prototype cost: ~$446/kW

Production Projection

At MW-scale volumes, cost converges toward commodity manufacturing. Primary drivers are power electronics and structural steel—well-understood supply chains.

Projected at scale: ~$177/kW

CAPEX ADVANTAGE

Conventional PEM electrolyzers cost $700–1,200/kW at scale. Alkaline systems range $500–800/kW. Tobe's projected $177/kW represents ~75% reduction from PEM and ~65% from alkaline.

SUPPLY CHAIN CONSIDERATIONS

- **No PGM dependency** — Eliminates platinum/iridium price volatility and supply constraints
- **No membrane supply chain** — Removes Nafion sourcing as bottleneck
- **Standard industrial components** — Leverages global 304 SS and power electronics base

VALIDATION STATUS

Tobe has completed extensive prototype testing under DOE SBIR grant funding, with independent measurement of key performance parameters across multiple operating conditions.

TESTING SUMMARY

TEST CAMPAIGN	SYSTEM	DURATION	CONDITIONS	KEY RESULTS
Phase 1	6 kW	500+ hrs	Low TDS water	**94.2% efficiency confirmed**
Phase 2	6 kW	300+ hrs	High TDS water	**Consistent, no degradation**
Phase 3	15 kW	200+ hrs	Variable load	**Full turndown validated**

MEASUREMENT METHODOLOGY

- **Power measurement:** INA260 precision power sensors (±1% accuracy)
- **Flow measurement:** FS1015 mass flow transmitters with NIST-traceable calibration
- **Purity verification:** KE-25 electrochemical O_2 sensors for cross-gas detection
- **Safety monitoring:** TGS821 hydrogen leak detection throughout facility

WHAT REMAINS

Validated

- Core efficiency claims (94.7% electrical)
- Turndown capability (10-100%)
- Water quality tolerance
- Response time and startup behavior
- Gas purity at output

In Progress

- Extended duration testing (8,760 hrs target)
- Full environmental range (-30°C to +50°C)
- Pressure cycling endurance
- Production unit cost validation
- Third-party certification pathway

NEXT STEPS

Tobe is advancing from prototype validation to pilot deployment, with a clear pathway to commercial production for qualified early adopters.

DEVELOPMENT ROADMAP

PHASE	TIMELINE	MILESTONE
Prototype Validation	**Complete**	Core performance demonstrated at 6-15 kW scale
Pilot Unit Build	Q1-Q2 2026	25 kW integrated system for field deployment
Pilot Deployment	Q3 2026	Installation at partner site with operational data
Commercial Unit	2027	250 kW containerized system for early commercial sales

ENGAGEMENT OPPORTUNITIES

Pilot Partners
HOST SITES FOR FIELD VALIDATION

Strategic Partners
INTEGRATION INTO LARGER SYSTEMS

Investors
SERIES A FOR COMMERCIAL SCALE-UP

Technical Review
DETAILED DILIGENCE FOR QUALIFIED PARTIES

CONTACT

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Request: Technical specs, pilot scoping call, or diligence materials

Disclaimer: This document contains forward-looking statements regarding projected performance, costs, and timelines. Actual results may vary. Performance figures represent laboratory measurements under controlled conditions; field performance may differ. Cost projections assume production volumes not yet achieved.