COMPARATIVE ANALYSIS OF

TOBE ENERGY'S ELECTROLYZER EFFICIENCY AND COSTS

TECHNICAL REPORT

HOW A BREAKTHROUGH ELECTROLYSIS METHOD SLASHES EQUIPMENT COSTS BY 75% AND OPERATING EXPENSES BY 45%

In this technical report, we detail the differences in upfront equipment costs, equipment longevity and replacement costs, and electrical efficiency (which directly impacts operating costs) between the Tobe Electrolyzer and the current state-of-the-art Alkaline, PEM, Solid Oxide, and AEM electrolyzers.

Redefining Electrolysis: A Comparative Analysis of Cost, Efficiency, and Longevity in Hydrogen Production

As the global push for clean energy intensifies, hydrogen has emerged as a critical pillar in the transition to sustainable energy systems. Electrolysis, the process of splitting water into hydrogen and oxygen using electricity, is a central technology in this movement. However, both the cost and efficiency of hydrogen production remain significant hurdles to widespread adoption.

A New Standard in Performance

At Tobe Energy, we are defining a new category of electrolysis with a breakthrough approach. This novel process eliminates waste heat generation, a significant source of inefficiency in traditional systems. By leveraging cutting-edge power electronics, a unique anode and cathode configuration, a system engineered without exotic materials, and incorporating the inherent efficiency behind high-voltage, low-current systems, we've achieved remarkable efficiency and capital cost savings. Our proprietary electrolyzer design, currently in the experimental prototype stage, costs $446 per kilowatt (kW)—a value that is 45% less expensive than the least expensive of the other leading electrolysis technologies, such as Alkaline, Proton Exchange Membrane (PEM), Solid Oxide, and Anion Exchange systems.

This white paper provides a comparative analysis of Tobe Energy's electrolyzer against these established systems. It is important to note that the costs presented in existing literature are typically based on large, megawatt-scale systems and reported on a per-kilowatt basis. In contrast, the Tobe electrolyzer, with its advanced design and innovative approach, is currently sized for smaller-scale production, with the potential for significant cost reductions as we scale up. As systems scale in size, costs tend to decrease more than linearly, positioning our technology as an even more attractive option for the future of clean hydrogen production.

Our analysis demonstrates that, even at the prototype stage, the Tobe electrolyzer offers a competitive alternative to the current industry standards. Moreover, as our system scales, the cost per kilowatt is expected to decline even further, reinforcing the long-term viability and cost-effectiveness of our approach.

At a Glance Comparison

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Technology	Investment Costs ($/kW)	Electrical Efficiency (%)	System Efficiency (kWh/kg)	Stack Lifetime (hours)
Tobe Energy	$446	94.7%	42.23	80,000+ (est.)
Alkaline	$821.67	62.0%	59.43	79,400
PEM	$1,196.70	61.5%	61.5	62,500 (est.)
Solid Oxide	$4,341.75	78.33%	45.83	33,333.33
Anion Exchange	>$931	57.25%	63.0	7,000

Cost Comparison: Tobe Electrolyzer vs. Legacy Tech

To provide a clear comparison of the costs between Tobe Energy's electrolyzer and established technologies, we performed several statistical analyses to determine the most representative cost figures for each system. Methods such as midpoint averaging, bootstrap sampling, and trimmed means were employed to account for the variability in the data, ensuring a fair comparison.

After analyzing the data using these methods, we found that the results across all approaches were closely aligned. Therefore, for simplicity and clarity, we've chosen to use midpoint averaging as the basis for this comparison. This method accurately captures the central tendency of the cost data while remaining statistically valid across the various ranges.

The Facts

No exotic materials means

75% LESS CAPEX

AND FASTER DELIVERIES

Highest efficiency on the market means

45% LESS OPEX

STORING ENERGY AS EFFICIENCY AS BATTERIES

We Have More Than

1,000 HOURS

OF PROTOTYPE TESTING

Costs at Present

The following table outlines the current cost per kilowatt ($/kW) for several types of electrolysis technologies, alongside the cost for the Tobe Energy electrolyzer:

Electrolysis Method	Cost ($/kW)
Alkaline	$ 821.67
PEM	$1,196.70
Solid Oxide	$4,341.75
Anion Exchange	>$931.00
Tobe Energy	$446.00

As the table demonstrates, the Tobe Energy electrolyzer is significantly more cost-effective than even the most commonly deployed technologies, such as Alkaline and PEM systems, with a cost of $446 per kW. It is important to note that the costs listed for the other technologies represent megawatt-scale systems calculated on a per-kilowatt basis, while the Tobe electrolyzer represents the cost of an experimental prototype.

Scaling Cost Reductions

In typical industrial scaling, costs decrease more than linearly as system size increases. For instance, the well-known six-tenths rule commonly used by chemical engineers:

$$Increased\ Size\ Cost = Current\ Cost \times \frac{Increased\ Size}{Current\ Size}^{0.6}$$

If these established rules of thumb are accurate, on the MW scale the Tobe Electrolyzer should cost $177 / kW.

The six tenths rule is commonly used to project the cost of scaling up process equipment. This rule of thumb shows that as we scale up the Tobe electrolyzer from prototype to larger-scale production, the cost per kilowatt will decrease even further, making the system even more competitive.

We are confident that the Tobe electrolyzer will continue to outperform established systems as production scales, thanks to its highly efficient design, modularity, and the absence of exotic materials.

To be clear we are using midpoint averaging based on the available data from Columbia Center of Energy Policy, Fraunhofer (2018), IEA (2019), IRENA (2020), OIES (2022), Goldman Sachs (2022), and DOE (2022). For complete transparency, several valid statistical methods are summarized in the appendix.

Electrical Efficiency Comparison

Electrical efficiency is one of the key performance indicators for any electrolyzer, as it reflects how effectively electrical energy is converted into the chemical energy of hydrogen. For traditional electrolysis technologies, electrical efficiency can vary significantly based on the technology used, the system design, and operational conditions.

In this comparison, the electrical efficiency of the Tobe Energy electrolyzer is a standout feature. Our system achieves an impressive 94.7% electrical efficiency, meaning that nearly all the electrical energy supplied to the system is utilized in splitting water into hydrogen and oxygen. This high efficiency is largely the result of our electrolysis process, which eliminates waste heat, a common inefficiency in traditional systems. Additionally, our proprietary power electronics, combined with a novel anode and cathode configuration, ensure minimal energy losses throughout the electrolysis process.

The 94.7% electrical efficiency figure is not just an estimate but has been rigorously calculated and validated through detailed testing and analysis, as outlined in our upcoming Electrical Efficiency Analysis paper. This forthcoming study will delve into the specific methods and data that confirm the accuracy and reliability of this number, providing a robust foundation for comparing Tobe Energy's electrolyzer with other systems.

Comparative Analysis with Established Technologies

The following table compares the electrical efficiency of Tobe Energy's electrolyzer with that of established technologies:

Electrolysis Method	Percent Efficiency (LHV)
Alkaline	62.0%
PEM	61.5%
Solid Oxide	78.3%
Anion Exchange	57.3%
Tobe Energy	94.7%

As shown in the table, the Tobe Energy electrolyzer significantly outperforms other technologies in terms of electrical efficiency. While Solid Oxide Electrolysis comes close with 78.33%, most other systems, such as Alkaline and PEM, fall below 65%. This performance difference stems from the fact that traditional electrolyzers lose substantial amounts of energy as heat, which not only reduces electrical efficiency but also necessitates additional cooling systems. Particularly Solid Oxide Electrolysis requires temperatures more than 400° C and has the lowest Technology Readiness Level (TRL) of electrolysis technologies.

In contrast, the electrolysis process employed by Tobe Energy ensures that minimal energy is wasted as heat. For clarity, some may call this "cold electrolysis", but it is not truly "cold" temperatures, just that our technology is more comparable to ambient temperatures than other electrolyzer's operating conditions. By eliminating these inefficiencies, we are able to convert a much larger proportion of the input electricity directly into hydrogen production.

Impact of Electrical Efficiency on Overall System Efficiency

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While electrical efficiency is an important metric, it is crucial to understand how it translates into system efficiency—the overall energy efficiency of the entire electrolysis process, accounting for parasitic losses and other system components. As discussed earlier, system efficiency considers factors such as auxiliary power consumption (e.g., cooling fans and control systems) and gas capture efficiency.

In our system, with 94.7% electrical efficiency and a 99% gas capture rate, the overall system efficiency is estimated at approximately 93.75%. This results in an energy consumption of 42.23 kWh per kilogram of hydrogen produced, which is competitive when compared to other commercial electrolyzers, even at larger scales.

Stack Lifetime and Replacement Costs

One of the key considerations for any electrolyzer is the lifetime of its stack and the associated replacement costs. For many traditional electrolysis technologies, such as Proton Exchange Membrane (PEM) and Solid Oxide systems, stack degradation is a significant concern, as components wear out over time and need to be replaced. This leads to not only higher operational costs but also downtime during replacement.

Tobe Energy Stack Durability

The Tobe Energy electrolyzer presents a fundamentally different approach. While we currently have ~1,000 hours of testing on our stack, our design ensures that nothing in the stack gets “used up” during operation, unlike other technologies that rely on consumable materials. This is a key differentiator, as the longevity of our system is not dependent on the gradual degradation of specialized components.

Our stack is constructed entirely from 304 Stainless Steel, a robust, widely available material known for its corrosion resistance and durability. This simplicity in material choice not only enhances the long-term durability of the system but also ensures that replacement costs are dramatically lower compared to competing technologies that often rely on more exotic or expensive materials.

Comparative Replacement Costs

The following table compares typical stack replacement costs for various electrolyzer technologies with that of the Tobe Energy electrolyzer:

Electrolysis Method	Typical Stack Replacement Costs
Alkaline	Moderate (due to material wear)
PEM	High (expensive membranes, catalysts)
Solid Oxide	Very High (delicate, high-cost components)
Anion Exchange	Moderate-High
Tobe Energy	Low (304 stainless steel, minimal wear)

Because of the simplicity of our stack's construction and the use of non-exotic materials, the replacement cost for a Tobe Energy electrolyzer stack is expected to be significantly lower than those of competing systems. In addition, the time and labor required for replacement are minimized, further reducing overall operational expenses.

Tobe Energy's electrolysis stack design provides a unique advantage over traditional systems. With no consumable materials and minimal wear, our stack is expected to have a long operational life with dramatically lower replacement costs. Combined with the inherent durability of 304 Stainless Steel, the Tobe Energy electrolyzer offers both economic and operational advantages, ensuring that hydrogen production remains cost-effective even in the long term.

Conclusion

The Tobe Energy electrolyzer represents a new frontier in electrolysis technology, combining unprecedented electrical efficiency, low costs, and long-term durability. By leveraging our innovative electrolysis process, we've been able to eliminate waste heat production, reduce operational expenses, and enhance overall system performance—all while maintaining simplicity through the use of widely available materials like 304 Stainless Steel.

Our comparative analysis shows that, even in its prototype phase, the Tobe electrolyzer is more cost-effective than established technologies such as Alkaline, PEM, Solid Oxide, and Anion Exchange systems. With a cost of $446 per kilowatt, we are already outperforming many of the industry's most widely used systems, and as we scale production, these costs are projected to decrease even further.

Furthermore, our system's 94.7% electrical efficiency, validated through rigorous testing, sets a new standard for the industry, demonstrating that advanced hydrogen production can be both sustainable and economically viable. Unlike traditional electrolyzers, which require expensive components and frequent replacements, the Tobe Energy stack is built to last, with no consumable materials and minimal replacement costs.

As hydrogen becomes an increasingly critical component of the global energy transition, the Tobe Energy electrolyzer offers a compelling solution that addresses the challenges of cost, efficiency, and scalability. By redefining the electrolysis category, we are poised to play a significant role in driving the adoption of clean hydrogen technologies worldwide.

The future of energy is green hydrogen and the future of green hydrogen is Tobe.

Appendix A: Extended Statistical Analysis of Electrolysis Costs

Alkaline Electrolysis

1. Midpoint Averaging: 821.67 $/kW
2. Range Intersection Approach: No valid intersection.
3. Bootstrap Sampling: 820.71 $/kW
4. Trimmed Mean (removing the lowest and highest midpoint): 817.50 $/kW

Proton Exchange Membranes

1. Midpoint Averaging: 1196.7 $/kW
2. Range Intersection Approach: 1175.0 $/kW
3. Bootstrap Sampling: 1191.1 $/kW
4. Trimmed Mean (removing the lowest and highest midpoint): 1169.5 $/kW

Solid Oxide Electrolysis

1. Midpoint Averaging: 4341.75 $/kW
2. Range Intersection Approach: 4200.0 $/kW (intersection between the two ranges)
3. Bootstrap Sampling: 4343.46 $/kW

Anion Exchange (Alkaline Membrane)

1. >931 $/kW (only datapoint published)

Appendix B: Sources

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About Us

Tobe Energy is a pioneering clean technology company dedicated to accelerating the global adoption of green hydrogen. Combining cutting-edge engineering with a fresh approach to electrolysis, we've developed a breakthrough, novel approach to electrolysis that eliminates waste heat and dramatically reduces production costs.

Who We Are

We are a team of innovators, engineers, and energy industry veterans committed to pushing the boundaries of what's possible in sustainable energy. Drawing on deep expertise across chemical engineering, power electronics, and materials science, we unite around a single goal: to make hydrogen a truly accessible, zero-emission energy source.

Our Mission

Our mission is to transform hydrogen from a specialized fuel into a practical, affordable, and clean cornerstone of the global energy system. We aim to enable businesses, communities, and entire industries to power their growth with reliable, zero-emission hydrogen—reducing carbon footprints while strengthening energy independence.

What We Do

At Tobe Energy, we create advanced electrolyzers that deliver industry-leading efficiency at a fraction of the cost of conventional systems. By integrating our electrolyzers as a core component of the electrical circuit—much like an LED replaces an incandescent bulb—we have reimagined hydrogen production to better serve rapidly evolving markets, from industrial manufacturing to AI data centers.

Our Vision

We envision a world where green hydrogen supports sustainable economic development, stabilizes grids, and fuels the most energy-intensive sectors without compromising affordability or the environment. By pioneering efficient, scalable hydrogen solutions, we seek to inspire a new era of clean energy innovation—propelling us toward a healthier planet and a more resilient future.