Turbeon
POWER SYSTEMS

White Paper

Technology and project description

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Executive Summary

The global shift from fossil fuels to renewable energy is inevitable, driven by environmental, economic, and geopolitical factors. Leading companies across industries are aligning their strategies with this evolution, while transportation is rapidly moving toward electrification. As these sectors evolve, there is a growing demand for lightweight electric power sources capable of supporting demanding applications.

Batteries alone cannot meet this challenge. Energy-intensive applications require onboard energy storage densities that current battery technologies cannot provide. Fuel cells powered by hydrogen offer a viable alternative; however, adoption remains slow due to limited infrastructure, high hydrogen cost, and the excessive weight and volume of conventional fuel cell systems.

Turbeon is designed to bridge this gap and enable customers to begin the energy transition before hydrogen infrastructure is ready. The system is compact, lightweight, and capable of operating on either hydrogen or methanol. Methanol is currently the most practical fuel option because it is widely available, inexpensive, and easier to handle. In the future, the same platform can transition to hydrogen without requiring customers to adopt a new technology. Turbeon is therefore a solution designed for future systems, while remaining highly effective under today's market and infrastructure conditions.

Two key features differentiate Turbeon from existing fuel cell solutions: a compact built-in methanol reformer and a direct air-cooling architecture. The reformer provides fuel flexibility, allowing customers to use either hydrogen or methanol. Direct air cooling eliminates the need for heavy liquid-cooling components such as radiators, pumps, and coolant circuits. Together, these features significantly reduce system weight and complexity while improving economic viability.

These capabilities are enabled by the use of high-temperature PEM (**HT PEM**) fuel cells, which operate at higher temperatures than conventional low-temperature PEM systems. Turbeon also incorporates innovative design solutions at the cell, stack, and system levels, together with non-standard operating parameters and control algorithms, to achieve the required targets for weight, volume, and durability.

Turbeon is relevant to a broad range of markets, with the strongest value proposition in **aviation, heavy machinery, maritime and portable power generation**. Because the core technology is common across these applications, the final market focus can be refined in approximately 1.5 to 2 years, coinciding with the stage where product configuration becomes necessary and a strategic investor is expected to join.

The Turbeon team has been developing LT PEM and HT PEM fuel cell products since 2016, bringing deep technical expertise as well as a strong understanding of customer requirements. This background provides a clear view of technical challenges, the development path, and key risks involved in near-term commercialization.

Turbeon Power Systems is currently seeking financial investors for the first stage of the project, which focuses on building a stack prototype and validating the reformer design. Engagement with potential customers is also welcomed; such collaboration will help refine product configuration in exchange for early access to the Turbeon system for testing and evaluation.

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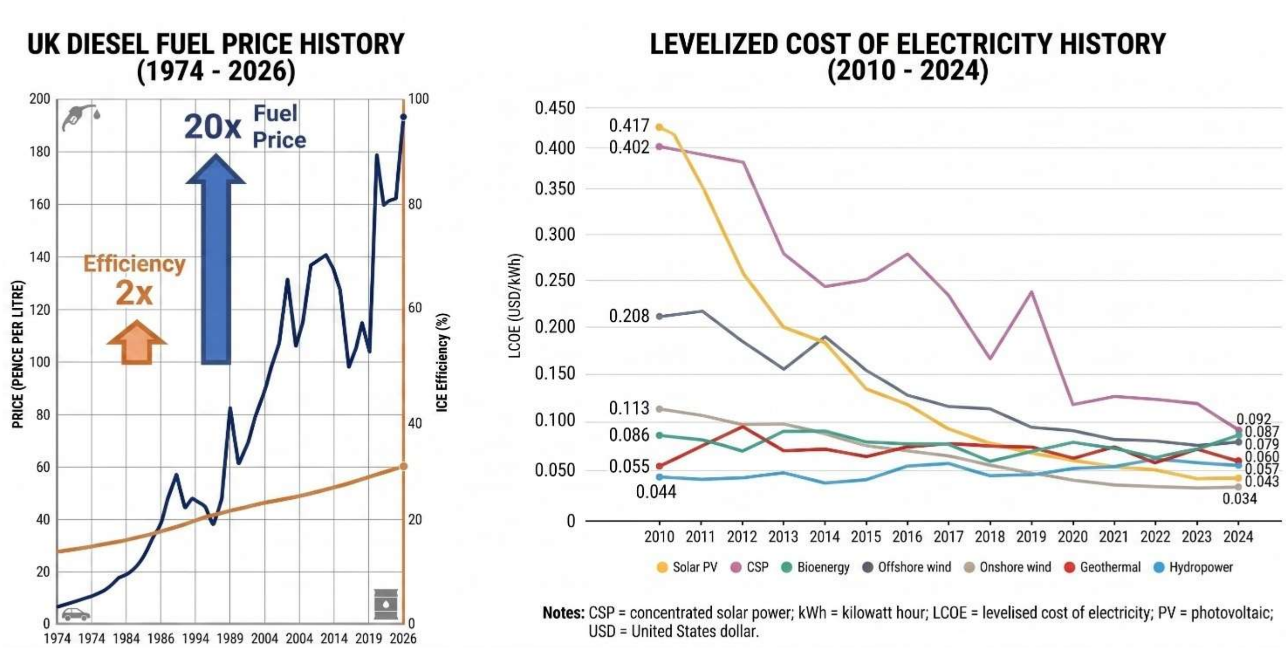
INTRODUCTION

The global energy transition from fossil fuels to renewables is accelerating, driven by the strategic mandates of market leaders in the transportation and mobile power sectors. This shift is propelled by a combination of powerful regulatory, economic, and geopolitical factors.

First, most developed nations have implemented stringent requirements for minimizing CO_2 and pollutant emissions from transport and power generation equipment. These regulations are reinforced by robust economic incentives for both manufacturers and end-users to adopt clean energy solutions.

Second, the economic landscape has shifted dramatically. While fossil fuel prices have been characterized by long-term volatility and growth over the last 50 years (Figure 1a), the Levelized Cost of Energy (LCOE) for renewables has declined rapidly over the past 15 years (Figure 1b). These tendencies decouple electricity costs from fossil fuel prices and are projected to eventually drive the cost of "green" hydrogen below that of traditional fuels.



a) b)

Figure 1. (a) UK Diesel fuel price and average ICE efficiency from 1974 to 2026, and (b) Levelized cost of renewables from 2010 to 2024[1,2,3]

Third, heavy reliance on fossil fuels introduces substantial risks related to political instability and global conflicts. In contrast, renewables and hydrogen offer a path toward strategic energy autonomy and operational resilience, making the energy transition a critical factor in economic security for industrial users.

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[1] https://commonslibrary.parliament.uk/research-briefings/sn04712/
[2] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_TEC_RPGC_in_2024_Summary_2025.pdf
[3] https://www.epa.gov/automotive-trends/explore-automotive-trends-data

In the search for zero-emission alternatives, two primary paths have emerged: Li-ion batteries and hydrogen fuel cells. While Li-ion batteries have become the standard for passenger cars and light mobility, they face fundamental physical limits in energy-intensive applications such as heavy-duty trucking, maritime, autonomous power generation, and aviation. The low gravimetric energy density of current battery technology remains a prohibitive factor, leading to excessive weight and cost. Consequently, hydrogen fuel cells are recognized as the mainstream technology capable of meeting the demands of high-power, long-range applications.

However, existing hydrogen solutions face significant hurdles regarding infrastructure requirements, thermal management, and overall operational efficiency - challenges that demand a new architectural approach to unlock the full potential of zero-emission flight and transport.

1. Problem Statement

While the potential for hydrogen is vast, the adoption of fuel cell technology remains significantly slower than that of Li-ion batteries. This disparity is driven by three fundamental barriers:

- **Delayed Hydrogen Infrastructure:** High capital expenditure and logistical complexity.
- **Prohibitive Hydrogen Costs:** A vast gap between production costs and end-user prices.
- **Physical Constraints:** The excessive weight and volume of current-generation fuel cell systems.

The Infrastructure Bottleneck

Hydrogen infrastructure is substantially more expensive to deploy than charging stations or liquid fuel networks. The storage, transportation, and refuelling of gaseous fuels require specialized high-pressure equipment, leading to slow regional development. Currently, while there are over 600,000 gasoline filling stations worldwide, the number of hydrogen refuelling stations (HRS) barely reaches a thousand[4]. At the current pace, it may take over a decade for hydrogen to become widely accessible, even in highly developed economies.

The Cost Barrier

The cost of renewable ("green") hydrogen remains a critical hurdle. Although the price of renewable electricity is falling, electrolysis and the subsequent compression, storage, and logistics remain expensive. To achieve commercial parity with fossil fuels, the hydrogen price needs to drop below **$4/kg**. However, current prices at refuelling stations exceed **$10/kg**[5,6], making the technology economically unviable for most commercial operators today.

Volumetric and Gravimetric Limitations

Even when compressed to 700 bars, hydrogen remains a bulky fuel. For example, the hydrogen tanks in a Toyota Mirai occupy 142 litres[7] - 2.5 times the volume of a typical gasoline tank for a similar vehicle

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[4] https://www.h2stations.org/statistics/
[5] https://atawey.com/en/hydrogen-prices-in-2026-cost-per-kg-refuelling-costs-comparisons-and-2030-outlook/
[6] https://www.letstalkleasing.co.uk/news/hydrogen-car-fuelling-costs
[7] https://media.toyota.co.uk/wp-content/uploads/sites/5/pdf/210426M-NG-Mirai-Tech-Spec.pdf

class - while being twice as heavy. This volumetric challenge is compounded by the "cooling penalty" of modern Low-Temperature PEM (LT PEM) fuel cells.

Modern fuel cell systems based on LT PEM operate at relatively low temperatures (60-80 °C). In high-power applications, especially in hot climates (>35 °C) they require massive liquid-cooling systems. The combined weight of the coolant, large-surface radiators, and pumps often exceeds the weight of the fuel cell stack itself. Consequently, the total specific power of a high-output LTPEM system typically plateaus at 0.7 kW/kg. This falls far short of the 1.5 kW/kg required for viable zero-emission aviation and heavy-duty transport.

Conclusion

Faced with these infrastructure, cost, and weight limitations, the energy transition for energy-intensive sectors - such as aviation, heavy machinery, maritime, and autonomous power generation - has effectively stalled. Since Li-ion batteries cannot bridge the energy-density gap for these applications, a fundamental shift in fuel cell architecture is required.

2. Solution

Turbeon is a fuel cell system designed to address the primary barriers to hydrogen technology adoption. The architecture incorporates a built-in methanol reformer to resolve fuel-supply challenges and utilizes direct air cooling at high operating temperatures to overcome the weight and volume constraints typical of conventional liquid-cooled systems.

The integrated reformer provides fuel flexibility, allowing operations to start with widely available, cost-effective liquid methanol while remaining fully compatible with a future transition to hydrogen as infrastructure matures. By eliminating liquid-cooling components such as radiators, coolants and pumps, the system's weight is reduced by more than 50% and its volume by approximately 1.5 times compared to legacy LTPEM solutions.

Following the "one core technology — several industry solutions" principle, the Turbeon platform is adapted into three distinct configurations (Figure 2):

- **Aviation:** An ultra-light, aerodynamically-shaped power system designed for eVTOLs and heavy cargo drones. The hydrogen-fueled version can deliver a specific power of up to 2.0 kW/kg, meeting the critical requirements for zero-emission flight.
- **Heavy Machinery & Maritime:** A highly-efficient, compact power plant with a built-in methanol reformer. This configuration is optimized for long-haul logistics and heavy industrial machinery - spanning the freight transport, maritime, rail, construction, mining, and agricultural sectors - where reducing weight and volume while achieving 1:1 operational parity with diesel engines is critical. By delivering high energy density alongside zero toxic exhaust and full CO_2 neutrality[8], it enables a seamless transition to sustainable operations in the most demanding industrial environments.

[8] In the case of methanol, complete carbon neutrality can be achieved by using "green" and "blue" fuels.

- **Ground Generator:** An all-in-one, fully autonomous all-weather power module. Designed for immediate operational readiness, it requires no complex integration and provides silent performance (<57 dB) in extreme ambient conditions ranging from -40°C to +55°C.

Figure 2. Turbeon's industry solutions

The key characteristics of Turbeon are presented in Table 1.

Table 1. Key characteristics of Turbeon

Parameter	Value
Housing	Compact capsule (Aviation/Machinery) or Standalone module (Ground)
Main components	Fuel cell stacks, Turbo-compressor, Fan, Catalytic chamber (ATO), Methanol Reformer (optional)
Power capacity	10 ÷ 350 kW – one module
Technology	Air-cooled closed cathode HT PEM fuel cell
Fuel type	Hydrogen of any grade or synthesis-gas containing up to 1.5% of CO*
Oxygen supply	e-Turbo-compressor: 2.0 ÷ 3.0 compression ratio, >80% power from turbine
Ambient conditions	-40°C to +55°C
Level of noise	<57 dB
Effective ceiling	>6 km
Modifications	H_2 / Methanol
Exhaust	No toxic exhaust: H_2O / H_2O (67%) + CO_2 (33%),
System efficiency	45% (avg.) for the H_2 modification and >42% for the modification on methanol

Fundamentally, Turbeon is a modular unit scalable from 10 kW to 350 kW, utilizing air-cooled, closed-cathode HTPEM technology. Its high operating temperature enables the tolerance of CO concentrations in syngas of up to 3% and allows for heat and water recovery to optimize the reforming process. While the aerodynamically shaped capsules for aviation and transport offer versatile internal or external installation options to suit specific vehicle architectures, the Ground Generator serves as a standalone, "plug-and-play" solution. This architecture ensures effective operation across a wide range of climates while remaining relatively insensitive to air pollution.

3. Innovations enabling Turbeon

The technological foundation of the Turbeon platform is High-Temperature Proton Exchange Membrane (HT PEM) technology, which possesses inherent physical and chemical advantages over standard low-temperature (LT PEM) systems. Unlike conventional fuel cells that rely on water for membrane hydration, HT PEM utilizes a **phosphoric acid electrolyte**. This fundamental difference enables operation at significantly higher temperatures (130–180°C) and provides a wide operating range, making the system inherently insensitive to humidity levels and ambient air contaminants. Furthermore, the phosphoric acid electrolyte does not freeze in arctic conditions or evaporate in extreme heat, ensuring high operational robustness in any climate.

Despite these technical strengths, HT PEM technology remains significantly undervalued in the commercial market. Adoption has been historically stalled by two primary factors:

- **Perceived Reliability Constraints:** The corrosive nature of the internal acidic environment and the potential mobility of the electrolyte led many industry players to view the technology as having a limited service life.
- **Engineering Barriers:** Previous development efforts failed to capitalize on the technology's potential due to the inability to design a solution that was both lightweight and efficient enough for high-power mobile applications. Consequently, competitors largely abandoned HT PEM in favour of bulky, liquid-cooled LT PEM systems.

The Turbeon platform resolves these historical trade-offs through a combination of advanced materials, specialized control algorithms, fuel cell design, and optimized architecture. By implementing proprietary start-stop protocols, high operating pressure, and corrosion-resistant bipolar plate designs, the system achieves a service life of **5,000 hours** with significant potential for further enhancement. Crucially, the Turbeon platform overcomes the weight penalty of traditional fuel cells through three key innovations:

- **Direct Air-Cooling Architecture.** Scaling air-cooling to the hundred-kilowatt range represents a fundamental engineering breakthrough, overcoming the historical "fan power trap" where the low thermal capacity of air required massive flow rates, leading to extreme internal stack resistance and prohibitive parasitic power consumption. Attempting to reduce this airflow creates sharp temperature gradients that degrade cell performance - a barrier that previously capped air-cooled output at approximately 5 kW. Turbeon resolved these constraints by implementing a unique fuel cell and system design to significantly reduce required air volumes while maintaining a precise, stable temperature differential across all cells. Through a proprietary bipolar plate design and centralized air-supply packaging, the system ensures even air distribution with **less than 5% power consumption for cooling to produced power**, enabling a specific power of **2.0 kW/kg** that was previously considered technologically impossible for fuel cell systems.

- **Integrated Lightweight Methanol Reformer.** While traditional methanol reformers are bulky and slow, the Turbeon system integrates a high-efficiency reformer utilizing advanced catalyst technology and high-pressure operation. By utilizing waste heat from the fuel cell stacks (high-exergy thermal recovery) to pre-condition the methanol-water mixture, the system reduces methanol consumption by **20%**. This integration provides full fuel flexibility without the volume and weight penalties of legacy equipment.
- **Advanced MEA and Acid Management.** The performance and longevity of the system are secured by a proprietary Membrane-electrode assembly (MEA) design. By combining modern PBI membranes with an improved catalyst-layer structure on a paper-based electrode, the MEA achieves superior phosphoric acid management. This design is **three times less expensive** than commercially available MEAs and delivers a power density of **0.6 W/cm^2**, with a clear technical roadmap to reach **1.0 W/cm^2** in the medium term.

Summary

The synergy of innovative bipolar plate, stack, and system designs ensures a compact, low-weight architecture through direct air-cooling. The integrated methanol reformer further minimizes operational expenses by enabling the use of inexpensive fuel without traditional weight or complexity penalties. Combined with a minimalist balance of plant (BoP), MEA advancements are projected to achieve a capital cost of **750 $/kW** for the hydrogen version and **1,100 $/kW** for the methanol variant in mass production. In total, seven specific innovations in architecture, component design, and materials transform the Turbeon platform into a lightweight, dual-fuel, and commercially viable power solution for multiple industrial segments.

4. Case Study

Case #1: Heavy Cargo Drone

The case of a cargo drone with a three-hour flight range is considered below. Four energy systems based on Li-ion batteries, hydrogen LT PEM fuel cells, and both Hydrogen and Methanol versions of the Turbeon system are compared in Table 2. The analysis assumes a peak power demand during takeoff and landing is 150 kW, with an average power consumption of 90 kW over the three-hour flight.

Table 2. Comparison of Turbeon system with Li-ion and LTPEM systems for heavy cargo drones

Parameter	Li-ion[9]	LT PEM + H_2[10]	Turbeon: H_2	Turbeon: methanol
Energy capacity of the system	300 kWh of charge	20 kg of hydrogen	20 kg of hydrogen	180 kg of methanol (65% aq.)
Total volume of tanks (350 Bar for H_2)	n/a	830 l	830 l	200 l
Time for refuelling/recharging	2 hours	15 minutes	15 minutes	5 minutes
Weight of the power generation system	n/a	215 kg	100 kg	230 kg
OPEX (EU average)	$40/hour	$160/hour	$120/hour[11]	$40/hour
Ambient temperature	-10°C ÷+40°C	-15°C ÷+35°C	-40°C ÷+55°C	-40°C ÷+55°C
Total weight of the system	**2 000 kg**	**440 kg**	**320 kg**	**410 kg**
Total volume of the system	**0.8 m^3**	**1.1 m^3**	**1.0 m^3**	**0.65 m^3**

The data clearly illustrates that the **2,000 kg Li-ion configuration is a non-viable solution** for a three-hour mission. This "battery weight penalty" effectively consumes the aircraft's entire lift capacity, leaving virtually no margin for payload or structural mass. In contrast, the Turbeon system enables the same mission with 80–85% less weight, transforming the drone from a technological demonstrator into a profitable commercial asset.

- **Payload Maximization:** Turbeon (H_2) offers a **120 kg advantage** over conventional LT PEM systems. For a cargo drone, this mass reduction translates directly into increased revenue per flight hour.
- **Volumetric Efficiency:** For space-constrained airframes, the Methanol version is the optimal choice, occupying only **0.65 m^3** - nearly 40% more compact than hydrogen storage solutions.
- **Operational Economics:** The Methanol configuration provides a massive 4x reduction in fuel costs, reaching $40/hour versus $160/hour for hydrogen, thanks to the use of cost-effective industrial methanol and existing liquid fuel logistics.
- **Environmental Robustness:** While Li-ion and LT PEM systems suffer from severe performance drops in extreme weather, Turbeon's high-temperature architecture ensures consistent power from **-40°C to +55°C**.

Case #2: Heavy-Duty Truck

This case study evaluates the integration of the Turbeon methanol system into a heavy-duty electric powertrain, using the Volvo FH Electric[12] as a baseline. The analysis compares pure battery-electric

[9] https://www.iea.org/reports/global-ev-outlook-2024
[10] https://www.researchgate.net/publication/403128677_Optimising_Fuel_Cell_Systems_for_Aviation
[11] Turbeon can operate on low-grade hydrogen which is cheaper than "green" hydrogen
[12] https://www.volvotrucks.com/en-en/trucks/electric/volvo-fh-electric.html

vehicle (BEV) architecture with a Turbeon-battery hybrid configuration optimized for long-haul logistics. Power consumption data is derived from Volvo's 2022 official field test results[13].

Table 3. Comparison of a hybrid Turbeon system with a Li-ion powertrain for Volvo FH Electric truck.

Parameter	Pure battery powertrain	Turbeon-battery hybrid
Max power output	540 kW	540 kW
Battery pack capacity	540 kWh	135 kWh
Turbeon power capacity (max continuous power)	n/a	160 kW
Fuel (methanol 65% aq.) tanks volume[14]	n/a	1.5 m^3
Weight of the battery pack	~3600 kg	~900 kg
Weight of Turbeon including reformer and full tank	n/a	1700 kg
Electricity/Fuel consumption per 100km	110 kWh	83 l
Time for refuelling/recharging (full tank/battery)	1.5 hours	<15 minutes
Total powertrain weight with the full tank	**~3.6 tons**	**~2.6 tons**
Effective range on one tank	**470 km**	**1 800 km**

The transition to a Turbeon-powered hybrid architecture provides four decisive advantages for logistics operations:

- **Payload Capacity Optimization:** The replacement of 2.7 tons of low-density batteries with a high-efficiency methanol system results in a 1,000 kg increase in payload capacity. For long-haul transport, this extra ton significantly improves the profit margin per kilometer.
- **Infrastructure Resilience:** While pure BEV fleets require specialized 350 kW high-power charging stations - which remain non-standard and expensive to deploy - the Turbeon system utilizes liquid methanol. This fuel can be distributed through existing liquid fuel infrastructure with minor modifications, allowing for rapid refueling in under 15 minutes.
- **Extended Mission Range:** An effective range of 1,800 km allows a single vehicle to complete transcontinental routes without intermediate refueling. This capability drastically reduces the required fleet size to maintain consistent delivery volumes across major logistics corridors.
- **Enhanced Utilization Rate:** A 6x reduction in "refueling vs. recharging" downtime ensures maximum vehicle uptime. The ability to refuel quickly enables a continuous operational cycle, which is a critical requirement for Tier-1 logistics providers.

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[13] https://www.volvotrucks.com/en-en/news-stories/press-releases/2022/jan/volvos-heavy-duty-electric-truck-is-put-to-the-test-excels-in-both-range-and-energy-efficiency.html

[14] Total volume of tanks is taken from Volvo FH diesel truck specification

Case #3: Ground Power Generator

This case study analyzes a 60-kW power generator designed for construction sites and remote industrial locations. The operational requirement is to provide continuous power for an 8-hour shift at an average load of 40 kW. In such scenarios, pure battery systems are commercially unviable due to excessive weight and the lack of recharging infrastructure, while hydrogen storage is hindered by logistical complexity. Consequently, the Turbeon methanol system is compared directly against a high-specification silent diesel generator.

Table 4. Comparison of a methanol-fueled Turbeon system with a diesel generator.

Parameter	Diesel Generator (Silent execution)	Methanol-fuelled Turbeon
Nominal power capacity	60 kW	60 kW
Average power consumption	40 kW	40 kW
Average system efficiency	33%	42%
Fuel (65% methanol) tanks volume	120 l	270 l
Dry system weight	1 370 kg	200 kg
Noise level@7 meters	62-67 dB	<57 dB
Toxic emissions	Soot, NO_x	No
Electricity cost[15]	0.6 $/kWh	0.4 $/kWh
Ambient temperature	-25°C ÷+45°C	-40°C ÷+55°C
Fuelled system weight	**1 450 kg**	**410 kg**
Total system volume	**4.1 m³**	**0.55 m³**

The Turbeon ground power module demonstrates four critical advantages over legacy diesel technology:

- **Unmatched Portability:** With a dry weight of only **200 kg** and a volume of **0.55 m³**, the system provides a 7-fold reduction in mass and volume compared to diesel alternatives. This compactness allows for deployment via standard light utility vehicles without the need for heavy lifting equipment, significantly increasing site mobility.
- **Urban and Silent Operation:** Producing a noise level of **<57 dB**, the system is twice as quiet as "silent" diesel units. Combined with zero toxic emissions (no NOx or soot), this performance enables 24/7 operation in noise-sensitive urban environments and at public events where strict air quality standards apply.
- **Logistical Resilience:** Unlike diesel, which requires specialized additives and storage protocols in sub-zero conditions, methanol remains stable and effective in extreme arctic environments. Furthermore, Turbeon's high-temperature architecture avoids the thermal derating common in diesel engines operating above +35°C.

[15] Calculated for EU.

- **Operational Cost Reduction:** Based on current energy prices, the Turbeon system delivers electricity at approximately two-third the cost of a diesel generator. This higher efficiency (42% vs 33%) and lower cost of fuel results in substantial long-term OPEX savings for fleet operators.

5. Market Opportunities

The global shift toward Net-Zero operations is creating an unprecedented demand for high-energy-density, eco-friendly power sources. Turbeon is strategically positioned at the intersection of several massive industrial shifts: the electrification of regional flight, the decarbonization of heavy-duty logistics and maritime, and the transition to silent, clean mobile energy.

Turbeon targets high-growth segments where traditional batteries and low-temperature fuel cells (LT PEM) fail to meet operational demands. The Serviceable Addressable Market (SAM) is projected to grow from $65.5 billion in 2030 to $95.3 billion by 2035, representing a weighted portfolio CAGR of 7.8% (Table 5).

Table 5. Turbeon's addressable markets.

Serviceable Available Market	Segment	2030	2035	CAGR 2030-2035
Aviation	Long-range eVTOL (>150 km), Heavy Cargo Drones (>25 kg payload)	$2.4B	$10.4B	34%
Heavy Machinery & Maritime	Long-Haul/Heavy, Inland & Coastal Vessels, Port Logistics	$53.6B	$71.2B	5.8%
Ground Generation	Eco-friendly, low noise portable generators	$9.5B	$13.7B	7.6%
TOTAL	**Turbeon Energy Systems**	**$65.5B**	**$95.3B**	**7.8%**

Target: 10% Market share through licensing

Aviation: eVTOL and Heavy Cargo Drones

The Advanced Air Mobility (AAM) sector is transitioning from experimental flight to full-scale commercialization. Turbeon addresses the urgent demand for power systems that support regional logistics and urban mobility.

- **Market Dynamics.** The combined Total Addressable Market (TAM) for eVTOL and Heavy Drones is projected to reach $97.3 [16][17] billion by 2035, driven by the certification of major eVTOL platforms and the rising demand for autonomous middle-mile and long-range logistics.
- **The Turbeon Edge.** Turbeon's Serviceable Addressable Market (SAM) focuses on high-performance missions: Regional eVTOL (range >150 km) and heavy drones (payload >25 kg).

[16] https://www.cervicornconsulting.com/evtol-aircraft-market
[17] https://www.insightaceanalytic.com/report/cargo-drones-market/1722

These segments account for approximately 33% of the total market, where battery weight and low turnaround efficiency make electric-only solutions unviable, and legacy LTPEM systems suffer from excessive weight and "cooling drag."

Turbeon targets the Power System share, estimated at 30–35% of the total aircraft acquisition cost. By delivering high specific power (>1.5 kW/kg) and superior thermal management, Turbeon provides the essential technology required for commercially profitable regional aviation.

Heavy Machinery & Maritime: Heavy-Duty Trucks, Off-Highway Machinery, Marine Vessels, and Locomotives

The heavy-duty transport, industrial machinery, and maritime sectors represent some of the most challenging areas for global decarbonization. Turbeon provides a drop-in replacement for diesel engines in applications where battery weight, limited range, and charging downtime are commercially prohibitive. By utilizing liquid methanol as a high-density hydrogen carrier, Turbeon overcomes the critical infrastructure and logistical barriers associated with traditional LT PEM systems, enabling rapid refueling, extended range, and high uptime in demanding industrial and marine environments.

- **Market Dynamics.** The global market for heavy-duty and marine engines is projected to reach approximately $181.3[18][19][20] billion by 2035. Growth is driven by stringent environmental mandates (EPA Tier 4, Euro Stage V, IMO regulations) and corporate Net-Zero commitments in the "hard-to-abate" industrial sectors.
- **The Turbeon Edge.** Turbeon's SAM is derived by focusing on specific high-torque, long-endurance niches within the engine industry where HTPEM technology offers a decisive advantage:
  - Heavy-Duty Trucks: Targeting the long-haul Class 8 engine segment, which accounts for ~32% of the total market.
  - Maritime & Inland Waterways: Focusing on inland and coastal vessels, tugboats, and port logistics, where liquid methanol utilizes existing infrastructure and avoids complex hydrogen storage.
  - Off-Highway Machinery: Focusing on the high-power (>400 HP) segment (representing ~40% of the market), where battery integration causes significant payload capacity reduction.
  - Locomotives: Targeting the Freight and Shunting segment, representing ~54% of global diesel engine demand.

By leveraging liquid methanol logistics, this solution bypasses the critical constraints of slow battery charging and the complex infrastructure requirements of traditional hydrogen refueling. This allows for seamless operation in sectors like long-haul freight, maritime transport, deep-pit mining, and the 54% of global rail lines that remain non-electrified, providing the 24/7 uptime required for industrial

[18] https://www.futuremarketinsights.com/reports/heavy-duty-engine-market
[19] https://www.futuremarketinsights.com/reports/off-highway-vehicle-engines-market
[20] https://www.researchandmarkets.com/reports/6015454/diesel-locomotive-engines-market-global

workflows. Turbeon provides the same continuous operating time as legacy diesel systems while offering significantly lower system weight and zero toxic emissions. Consequently, Turbeon unlocks a Serviceable Addressable Market in this sector projected to reach $71.2 billion by 2035, maintaining a stable and defensible growth profile.

Ground Generation

The mobile power generation market is undergoing a mandatory shift toward cleaner alternatives due to urban noise ordinances and strict emission restrictions in "Zero-Emission Zones." The implementation of HT PEM technology ensures a lightweight and compact design, facilitating reliable performance across a wide operating temperature range from -40°C to +50°C. This provides a robust, silent, and energy-dense power source for off-grid and urban environments.

- **Market Dynamics.** The global market for portable and mobile generator sets is projected to reach approximately $25.3 [21][22] billion by 2035. Growth is driven by regulatory pressure to eliminate diesel emissions and the rising demand for high-reliability, silent power in the entertainment, healthcare, and public utility sectors.
- **The Turbeon Edge.** Turbeon's SAM focuses on the 10–200 kW power range, representing approximately 70% of the total mobile power market. Within this segment, the SAM is derived from two high-value niches:
  - Construction & Industrial: Targeting the "Clean & Silent" niche (estimated at 40% of the segment). These systems offer significantly lower weight and a compact footprint, facilitating easy deployment. High operational robustness and low OPEX, driven by cost-effective industrial methanol, provide a superior alternative to both diesel and battery-based units.
  - Events, Emergency & Public Utilities: Focusing on mission-critical applications (film sets, disaster relief, mobile clinics) where clean and silent operation is a prerequisite (representing 80% of the niche due to a lack of viable alternatives).

By leveraging liquid methanol logistics, this solution provides robust operation in environments requiring extreme resilience and silent performance (<57 dB). Turbeon provides the same continuous operating time as specialty diesel generators while offering a compact footprint and zero toxic emissions. Consequently, Turbeon unlocks a SAM in this sector projected to reach $13.7 billion by 2035, capturing the transition to emission-free stationary and mobile power generation.

Summary

Turbeon is strategically positioned to capitalize on a multi-billion-dollar market shift. By focusing on the intersection of high-power requirements and logistical independence, Turbeon unlocks segments previously stalled by technological limitations. The ability to offer a scalable, modular power plant that outperforms both batteries and legacy fuel cells ensures that Turbeon's SAM remains high-margin and defensible as global decarbonization accelerates.

[21] https://www.researchnester.com/reports/construction-generator-sets-market/5951
[22] https://www.businessresearchinsights.com/market-reports/emergency-power-generators-market-105587

6. Market Implementation Strategy

Turbeon follows a de-risked, phased approach to move from core technology validation to global industrial scale. Our roadmap is designed to build significant intellectual property (IP) value while securing early market traction through strategic partnerships (see Figure 3).

- **Phase 1: Validation & IP Moat (Years 1-2)**
  The primary focus is the development of 4 kW and 10 kW stack and system prototypes, including an integrated methanol reformer. This stage aims to confirm all technical parameters in rigorous laboratory conditions. Turbeon will secure its competitive advantage by submitting 7+ patent applications and establishing a dedicated assembly and testing laboratory. Revenue generation begins through Joint Development Agreements (JDA) and Non-Recurring Engineering (NRE) fees from early-stage strategic partners.

- **Phase 2: Market Entry & Field Trials (Year 3)**
  This phase focuses on real-world validation and brand recognition. Turbeon will introduce a commercial-ready 20 kW power system, marking the critical transition from TRL 5 to TRL 7. The focus shifts to accumulating "field" test-hours and confirming "live" performance and reliability. Generation of the first B2B revenue through trial sales will occur while continuing to adapt the system for various market applications (Aviation, Ground Power, and Heavy Machinery) alongside our partners.
  By deploying high-power system test rigs Turbeon will be prepared to scale up the system up to 350 kW power.

- **Phase 3: Global Scaling & Licensing (Year 4+)**
  As the technology matures into a modular system scalable up to 350 kW, Turbeon will transition to its primary long-term business model: intellectual property licensing. By partnering with Tier-1 OEMs and key strategic players across various sectors, Turbeon will license its proprietary HT PEM architecture for mass-market integration. This strategy allows Turbeon to become the global industry standard for clean power in aviation, heavy machinery, and ground power, while securing high-margin, recurring royalty streams from every unit manufactured and deployed by our partners.

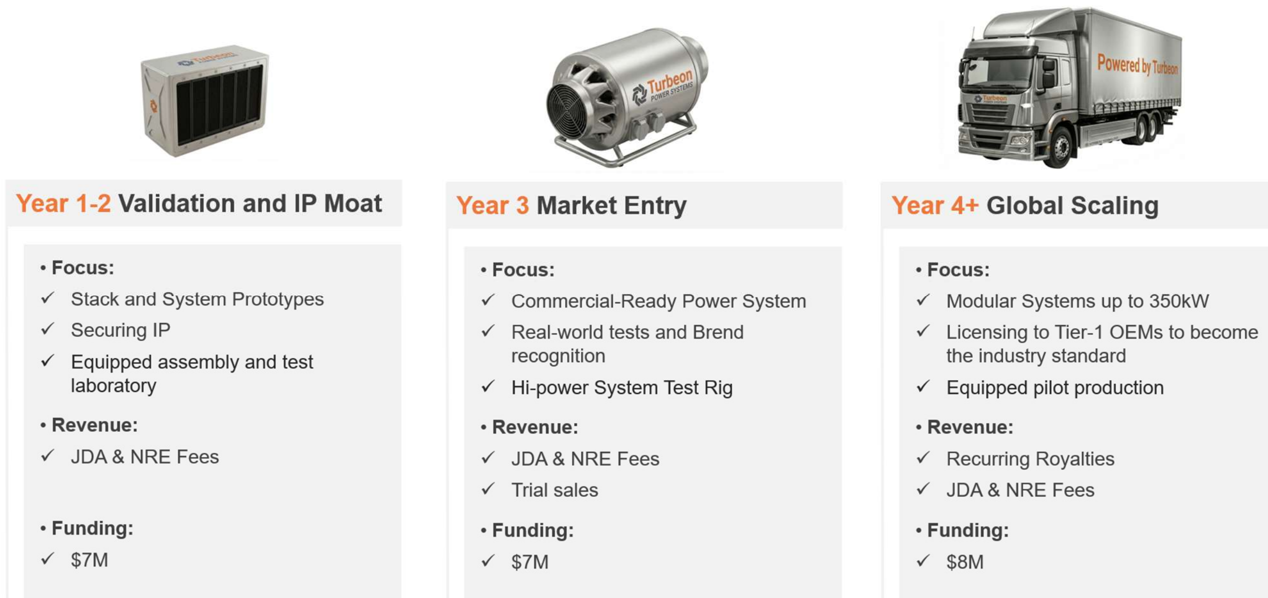

Figure 3. *Phased Commercialization Roadmap*

7. Leadership Team

Turbeon is led by two world-class experts - scientists, engineers, and tech leaders who have been at the forefront of hydrogen fuel cell innovation for nearly two decades. The leadership team brings a combined 50+ years of industrial experience in R&D, material science, design, and the creation of high-growth deep-tech companies (see Figure 4).

The team's expertise is rooted in some of the most influential organizations in the hydrogen and aerospace sectors, including ZeroAvia, HyPoint, and BMPower. This leadership group has a proven track record of transitioning complex fuel cell concepts into aviation-grade power systems.

Core Leadership:

- **Sergei Panov, PhD, Co-Founder, CEO & CTO (Product Development)**
  A technical visionary with 25+ years of industrial experience, including over a decade focused on fuel cell (FC) systems. Sergei previously served as the Head of HTPEM Product Development at ZeroAvia, Co-founder and CTO of HyPoint, CEO and CTO of BMPower. His expertise lies in navigating the full product lifecycle, from initial concept to industrial-scale integration.
- **Sergei Shubenkov, Co-Founder, R&D Director (Product Innovation)**
  A theoretical physicist (MIPT) and the architect of the Turbo-Air-Cooled FC concept. With 17+ years in the FC industry, Sergei has served as the Head of Innovation at ZeroAvia, Co-founder and R&D Director at HyPoint, Director of Technical Support at BMPower. He is responsible for the unique high-exergy thermal recovery direct air-cooled architecture that gives Turbeon its competitive edge.

A Proven Track Record

The credibility of the Turbeon leadership team is evidenced by their pivotal role in the development and scaling of HyPoint, which was acquired by ZeroAvia at a $100M valuation. This successful exit demonstrates the team's ability to not only innovate but to create significant market value and achieve strategic milestones in the high-stakes aerospace industry.

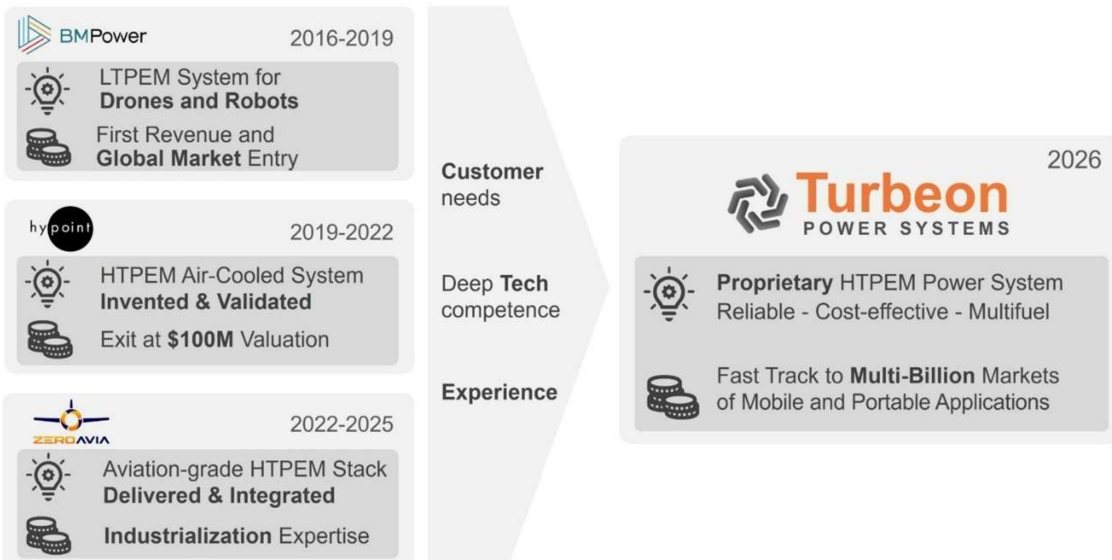

Figure 4. *Team History*

SUMMARY

Turbeon is a lightweight, dual-fuel HT PEM fuel cell platform engineered to overcome the critical barriers - infrastructure, cost, and weight - that have historically stalled the hydrogen transition in aviation, heavy-duty transport, maritime and mobile power generation.

By integrating a built-in methanol reformer with a high-temperature, direct air-cooled architecture, Turbeon offers a unique value proposition: it allows customers to utilize widely available, cost-effective liquid methanol today, while remaining fully compatible with a future transition to pure hydrogen without changing the power platform.

The technical and commercial foundation of Turbeon includes:

- **Proprietary Innovations**: Seven distinct innovations at the cell, stack, and system levels that eliminate heavy liquid-cooling components and reduce system weight by **more than 50%**.
- **Economic Advantage**: A significant reduction in both CAPEX (through advanced, lower-cost MEA design) and OPEX (through high-exergy heat recovery and methanol flexibility).
- **Market Scalability:** A modular design scalable from **10 kW to 350 kW**, addressing a Serviceable Addressable Market (SAM) projected to reach **$95.3 billion by 2035**.

Ultimately, Turbeon serves as the essential technological bridge. It provides a practical, high-performance solution for the immediate needs of today's infrastructure while ensuring long-term relevance and sustainability in the global hydrogen economy.

CONTACT INFORMATION

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