

Advanced LH₂ Recirculation for Next-Generation Aircraft Fueling

By Charles Myers, MAH2, July 2025

Introduction

As the aviation industry accelerates its transition toward sustainable propulsion systems, liquid hydrogen (LH₂) has emerged as a promising fuel for next-generation aircraft. However, the successful integration of LH₂ into airport operations requires not only advanced fueling infrastructure but also new approaches to managing cryogenic fuel between uses. A significant operational challenge arises during repeated refueling events: cryogenic hoses must typically be purged before each use to avoid warming and flashing, resulting in the routine venting of valuable hydrogen. This practice, while necessary for safety, incurs unacceptable levels of hydrogen loss in high-frequency fueling scenarios.

This document introduces a novel concept: an integrated LH₂ hose recirculation and cold-soak system designed to eliminate purging by maintaining the hose in a cryogenically-ready state between fueling events. Central to this approach is the retention and recirculation of LH₂ through a vacuum-insulated, 30-foot hose wound on a cryogenic hose reel. After fueling, the hose is reconnected to the mobile fueller and recirculated through a cryogenic rotary swivel joint embedded in the reel. A low-flow pump or pressure differential keeps the liquid hydrogen circulating, preserving subcooled conditions and minimizing boil-off.

The document presents multiple technical strategies and system enhancements—including active recirculation loops, automated hose docking, onboard cryogenic refrigeration, and real-time sensor monitoring—that work in tandem to reduce hydrogen waste and enhance fueling readiness. Drawing upon validated cryogenic engineering principles and emerging best practices from international research and industry efforts, the proposed solution is tailored for mobile fueling platforms supporting hydrogen-powered aircraft.

The sections that follow detail the concept's components, operational sequence, safety protocols, technical challenges, and equipment requirements. Collectively, they outline a comprehensive and scalable roadmap for implementing a high-efficiency LH₂ fueling architecture that aligns with aviation's carbon-reduction goals while ensuring thermal stability, operator safety, and fueling reliability.

Problem Statement

In liquid hydrogen (LH₂) aircraft refueling operations, significant hydrogen loss occurs during the purging of cryogenic hoses prior to each fueling event. To reduce these losses, a strategy is being considered where LH₂ is retained within a 30-foot insulated refueling hose between uses, eliminating the need for repeated purging. However, while vacuum-jacketed insulation slows heat ingress, the standing hydrogen in the hose will still gradually warm due to ambient thermal exposure. This warming raises the temperature of the retained LH₂, which, during the early phase of a subsequent fueling event, can increase the temperature of the aircraft's onboard tank. As a result, additional hydrogen must be transferred to chill the tank back down to operational cryogenic temperatures, offsetting any gains made by retaining LH₂ in the hose. To make this approach viable, it is essential that the LH₂ remaining in the hose remains as close as possible to its original subcooled temperature. Achieving this requires careful integration of insulation, recirculation, and hose reel design to minimize thermal losses and prevent flashing, ensuring fueling efficiency and safety are not compromised.



Potential Solutions

A range of strategies exists to address the challenge of maintaining liquid hydrogen at cryogenic temperatures within the refueling hose between aircraft fueling events. The following nine strategies are each worthy of consideration. They may be implemented individually or in combination, depending on system design constraints, operational frequency, and safety requirements:

1. **Vacuum-Jacketed Hose with Superinsulation**
Use a double-walled, vacuum-insulated hose with multi-layer reflective insulation (MLI) to reduce both radiative and conductive heat gain.
2. **Active LH₂ Recirculation Loop**
Circulate a small, continuous flow of LH₂ through the hose and back to the mobile tank to prevent thermal stratification and maintain cold-soaked conditions.
3. **Cold Hose Pre-Chilling Before Fueling**
Introduce a brief flow of cold LH₂ through the hose just prior to fueling to pre-chill the transfer line, minimizing flashing and temperature spikes at the start of transfer.
4. **GH₂ or Helium Purge with Liquid Recovery**
Use a gaseous helium or hydrogen purge to push remaining LH₂ back into a recovery tank after fueling, thereby avoiding stagnant liquid in the hose.
5. **Hose Slope and Gravity Drainback**
Configure the fueling system so that the hose slopes downward toward the tank, enabling residual LH₂ to flow back via gravity into an insulated drainback reservoir.
6. **Low Heat Leak Cryogenic Couplings**
Employ quick-disconnect cryogenic couplings with minimal heat ingress and liquid retention features (e.g., vacuum-jacketed, poppet-sealed designs).

7. **Smart Temperature and Pressure Sensing**

Install sensors along the hose to monitor cryogenic conditions in real time, allowing early intervention if warming or pressure rise is detected.

8. **Automated Hose Reconnect for Recirculation**

After fueling, dock the hose end to a designated inlet on the mobile fueller to enable safe and efficient recirculation through the hose reel.

9. **Vacuum-Insulated Hose Reel with Central Flow Path**

Use a reel design that supports cryogenic flow through a central swivel joint, paired with vacuum insulation and even hose layering to avoid thermal hotspots during storage.

Suggested Course of Action

Among the options presented, a combined approach utilizing **active LH₂ recirculation (#2)**, **automated hose reconnection for post-fueling circulation (#8)**, and a **vacuum-insulated hose reel with a central flow path (#9)** offers the most robust path forward.

This configuration ensures that the hose remains fully cold-soaked between fueling events, minimizing vapor formation and eliminating the need for purging. After each fueling operation, the hose would be reeled back onto an insulated drum and reconnected to the mobile fueller's dedicated recirculation inlet. A modest, continuous flow of liquid hydrogen would then be circulated through the coiled hose via a cryogenic rotary union integrated into the reel.

This approach maintains uniform cryogenic temperatures, reduces hydrogen loss, and ensures that the system remains ready for immediate reuse. It strikes a balance between thermal performance, operational efficiency, and safety—making it a strong candidate for implementation in next-generation LH₂ aircraft refueling systems.

Concept: Integrated LH₂ Hose Recirculation and Cold-Soak System

Objective

Maintain the cryogenic condition of a 30-foot LH₂ refueling hose between aircraft fueling events by integrating an active recirculation loop, automated post-use hose reconnection, and a vacuum-insulated hose reel with a central flow path. This configuration minimizes hydrogen loss, prevents flashing, and ensures the hose is cold-soaked and ready for immediate reuse.

Operational Sequence

Step 1: Fueling Completion

Aircraft refueling is completed. LH₂ flow is terminated through the breakaway shutoff or nozzle valve.

Step 2: Hose Retraction onto Insulated Reel

The LH₂ hose is reeled back onto a vacuum-insulated hose reel equipped with a cryogenic-rated central swivel joint. The hose is guided in evenly layered coils to prevent compression or kinking.

Step 3: Coupling Reconnection to Mobile Fueler

The cryogenic coupling is docked into a recessed receptacle on the mobile fueler, designed for alignment and sealing. Connection sensors confirm secure engagement before recirculation begins.

Step 4: Active Recirculation Initiated

A control system triggers recirculation via a cryogenic pump or pressure differential. LH₂ is withdrawn from the main tank, flows through the coiled hose (via the reel's central core), exits through the coupling, and returns to the tank through the recirculation manifold.

Step 5: Monitoring and Termination

Temperature and pressure sensors embedded along the hose verify uniform cold-soak conditions. Once preset thresholds are achieved, the recirculation loop shuts down automatically, or transitions to standby mode with periodic maintenance pulses.



System Components

Component	Description
Cryogenic Transfer Pump	Low-flow LH ₂ pump (~1 kg/min) for steady circulation.
Vacuum-Insulated Hose Reel	Reel with double-wall vacuum insulation and MLI wrap; includes rotary swivel.
Central Swivel Feed Joint	Cryogenic rotary union allowing axial LH ₂ flow while reel rotates.
Recirculation Coupling Port	Dedicated return inlet on the mobile fueler for post-fueling hose reconnection.
Embedded Sensors	Cryo-rated RTDs or silicon diodes for temp monitoring; pressure sensors for safety.
Control Logic & Interlocks	Automated pump/valve logic, coupling confirmation sensors, and safety interlocks.

Thermal Management Benefits

- **Maintains Hose at Subcooled LH₂ Temperatures**
Prevents warming and flashing, reducing vapor formation and hydrogen loss.
- **Ensures Hose is Ready for Immediate Reuse**
Eliminates the need for pre-chill or purge cycles between fueling events.
- **Reduces Risk of Two-Phase Flow or Vapor Block**
Uniform cold-soaking minimizes thermal gradients and pressure surges.

Safety and Operational Considerations

- **Gas Detection and Ventilation** around hose reel and coupling dock to prevent GH₂ accumulation.
- **Pressure Relief Valves** at hose and recirculation points to protect against overpressure.
- **Operator Interface and Status Indication** via touchscreen or remote app for confirmation of recirc status.
- **Automated Alarms and Shutdown Logic** in case of sensor fault, coupling misalignment, or abnormal pressure rise.

This integrated LH₂ recirculation and cold-soak system supports high-frequency, low-loss aircraft fueling by preserving the cryogenic integrity of the refueling hose between uses. By combining advanced insulation, active flow management, and smart reconnection features, the system enhances performance, safety, and hydrogen efficiency in mobile aviation fueling operations.

Validation and Demonstration of the Process

The proposed concept of using active liquid hydrogen (LH₂) recirculation through an insulated hose—combined with a post-fueling reconnection system and vacuum-insulated reel—draws upon established cryogenic engineering principles, but represents an emerging application in the context of mobile aviation fueling. While no single organization has yet deployed this exact configuration in a commercial setting, multiple research institutions, cryogenic equipment manufacturers, and aerospace infrastructure planners have investigated and validated core elements of the approach. These validations come through modeling, laboratory testing, system-level reviews, and early-stage demonstration projects. The following section identifies key organizations and research efforts that have contributed to validating or demonstrating aspects of this concept, with direct links to their published work or product information.

Who Has Investigated and Validated the Process?

- 1. SINTEF Energy Research (Norway)**
Researchers at SINTEF—including Halvor Aarnes Krog, Yvonne Jooss, and colleagues—have conducted detailed modeling of airport-scale LH₂ pipeline systems. Their 2025 preprint demonstrated that continuous LH₂ recirculation is required to prevent warming, flashing, and vapor formation in transfer lines between fueling events.
[Preprint: "Large-scale LH₂ pipeline infrastructure concept for airports"](#)
Organization: SINTEF Energy Research
- 2. NASA and Industry Cryogenics Experts**
NASA researchers and cryogenic system designers have emphasized in various technical reports that passive insulation alone is insufficient to maintain LH₂ temperature, and active thermal management (e.g., flow recirculation) is required.
Example: Cryogenic fluid management technologies at NASA
Expert Reference: Adam Swanger, Cryogenics Technologist, NASA Kennedy Space Center
- 3. J. Hoelzen et al. (2022 Review Paper)**
A comprehensive academic review of LH₂ fueling systems in aviation by Hoelzen and co-authors highlights the importance of subcooling and thermal design. While not focused on hoses, it supports the conceptual need for circulation to manage cryogenic temperatures.
Reference: "Conceptual Design of Liquid Hydrogen Refueling Systems for Hydrogen-Powered Aircraft"
Publisher: *International Journal of Hydrogen Energy*
- 4. UK Aerospace Technology Institute (ATI)**
The ATI's 2023 roadmap on hydrogen infrastructure notes that active flow management and thermal control strategies will be required to support scalable aviation fueling operations.
Hydrogen Capability Network: ATI Insight
Organization: Aerospace Technology Institute

Who Has Demonstrated the Process?

- 1. Krog et al. – Simulation-Based Demonstration**
The work by SINTEF (Krog et al.) includes simulated demonstrations of LH₂ pipeline systems at airports using nighttime recirculation to maintain subcooled temperatures.
While this is a modeling-based demonstration, it clearly shows feasibility and necessity.
[arXiv preprint](#)
- 2. Demaco Cryogenics (Netherlands)**
Demaco manufactures vacuum-insulated transfer lines and actively circulates cryogens—including hydrogen—in custom industrial and aerospace systems. They highlight flow-through and recirculation strategies to prevent stratification and heat ingress.

Demaco on cryogenic circulation systems
Company: Demaco Cryogenics

3. **Cryofab and Chart Industries**

Both companies offer cryogenic hose reels, transfer assemblies, and components that support integration of recirculation concepts, though a fully mobile system (like your concept) has not been documented in public sources.

Cryofab Transfer Hoses

Chart Industries LH₂ Solutions

4. **Aerospace Pipeline Recirculation Systems (Concept Stage)**

While no commercial aviation fuel truck is known to use post-fueling hose recirculation, airport-scale LH₂ pipeline studies have modeled continuous circulation as necessary for real-world use.

ICCT Review: "Infrastructure for Hydrogen-Powered Aircraft"

Organization: International Council on Clean Transportation (ICCT)

Technical and Design Challenges

While the integrated liquid hydrogen (LH₂) hose recirculation and cold-soak system offers a promising solution to reduce hydrogen loss and improve fueling readiness, it introduces several technical and design complexities that must be addressed to ensure safe, reliable, and cost-effective operation. These challenges arise from the physical behavior of LH₂, the constraints of mobile fueling environments, and the interplay between cryogenic components, sensors, and control systems. The following section identifies key challenges anticipated during design, construction, and operation of such a system, providing a foundation for engineering risk mitigation and future system refinement.

Key Technical and Design Challenges

1. Managing Two-Phase Flow and Stratification

Residual LH₂ in the hose may begin to vaporize between fueling events, especially if recirculation is delayed or uneven. The presence of both liquid and vapor phases in the hose can lead to unstable flow, erratic pressure, and potential cavitation in the pump.

Mitigation Strategy: Automate recirculation immediately after hose reconnection and monitor temperature profiles along the hose to detect the onset of flashing.



2. Hose Cooling Uniformity on the Reel

When coiled on a reel, the hose may experience uneven thermal exposure, leading to hot spots or insufficient cooling in inner loops. This undermines the effectiveness of recirculation and may result in delayed fuel readiness or increased boil-off.

Mitigation Strategy: Use flat spiral layering during reeling, incorporate a central axial flow path through a cryogenic swivel joint, and monitor multiple points for temperature validation.

3. Pump Cavitation and Pressure Instability

If vapor enters the pump suction during recirculation—due to warming or inadequate liquid column height—it may cause cavitation, damaging the pump or interrupting flow.

Mitigation Strategy: Design the system to ensure positive suction head from the tank, maintain subcooled LH₂ at the inlet, and include cavitation detection logic with automatic shutdown triggers.

4. Coupling Wear and Reconnection Reliability

Repeated reconnection of the LH₂ coupling after each fueling event may lead to wear on seals, frozen mating surfaces, or misalignment. This can result in leaks, venting, or inability to start recirculation safely.

Mitigation Strategy: Use high-cycle rated, low-heat-leak couplings designed for cryogenic hydrogen service (e.g., vacuum-jacketed, poppet-type). Incorporate mechanical guides and sensors to confirm secure locking before flow is enabled.

5. Overpressure Risk in the Closed Loop

Blocked flow, valve failure, or thermal expansion could result in overpressure within the recirculation path, particularly in coiled or stagnant hose sections.

Mitigation Strategy: Install pressure relief valves at strategic low and high points in the loop. Use flow-limiting orifices and ensure vent paths are properly sized and shielded.

6. Integration Complexity for Mobile Systems

Space constraints, vibration, ambient exposure, and maintenance access are more restrictive in mobile fuelers than in fixed cryogenic systems. Integrating pumps, control logic, insulated hose reels, and couplings into a mobile chassis increases complexity.

Mitigation Strategy: Use modular system layouts with flexible interconnects, compact insulated enclosures, and shock-mounted components. Conduct vibration and thermal cycling tests on mobile prototypes.

7. Sensor Reliability and System Controls

Cryogenic sensors (especially temperature and pressure) are subject to drift, ice buildup, and delayed response times. Faulty or frozen sensors could allow unsafe operation or mislead automated logic.

Mitigation Strategy: Deploy redundant sensors, include drift calibration routines, and monitor sensor health in software. Where practical, use heated housings or sealed ports for key sensor locations.

8. Ice Formation and Moisture Ingress

Ambient humidity can condense and freeze on exposed cryogenic surfaces, including hose ends, coupling faces, or recirculation ports—interfering with mechanical connections or seals.

Mitigation Strategy: Use insulated enclosures, dry air or nitrogen purging near critical interfaces, and passive or active defrosting provisions at coupling locations.

9. Operator Error and Procedural Deviations

Fueling operations may involve human error—e.g., failing to reconnect the hose correctly, bypassing control interlocks, or neglecting to monitor system readiness.

Mitigation Strategy: Implement interlocked control systems, visual and audible status indicators, and clear procedural checklists. Consider semi-automated coupling docks to reduce human handling variability.

Anticipating and addressing these technical and design challenges is essential to the successful implementation of the LH₂ hose recirculation concept. While none of the identified issues are insurmountable, each requires focused engineering, rigorous testing, and thoughtful integration to ensure the system performs safely and effectively in a mobile aviation fueling environment.

Primary Source

A research preprint by Halvor Aarnes Krog et al., titled “*Large-scale LH₂ pipeline infrastructure concept for airports*” (submitted June 2025). This study models airport-scale LH₂ distribution systems and confirms that **continuous liquid hydrogen recirculation is required to maintain subcooling and prevent flashing**, especially through the night and in flexible fuel lines connecting to aircraft [arXiv](#).

Implementation Notes

- **Coupling design** must be rated for repeat connections and cold cycling (consider MannTek, WEH, or custom hydrogen-rated QD couplings).
- **Recirculation inlet** should have a splash-suppressing baffle or re-entry coil to avoid thermal shock to main tank.
- **Pump startup** logic should include pre-chill sequences or use LH₂ head pressure to avoid cavitation.
- **Control panel** may use touchscreen HMI or simplified indicator logic.

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Optional Features for Future Phases

- **Automated robotic re-coupler** for remote connection of hose end
- **Integrated GH₂ compressor** to recover boil-off
- **Bluetooth-enabled temperature monitoring** via cryo sensor embedded in hose reel
- **Mobile app** to monitor and control post-fueling recirc status

LH₂ Hose Reel Design to Prevent Cold Spots

To prevent cold spots within a cryogenic hose reel for liquid hydrogen (LH₂), the reel design must ensure uniform flow distribution, minimal thermal bridging, and effective insulation throughout the coiled hose. Here's a detailed design concept and rationale:

Primary Goal

Enable full circulation of LH₂ through the entire hose when coiled, without creating stagnant or thermally isolated regions that allow warming, flashing, or ice build-up.

Recommended Design Features

1. Central Core Feed (Axial Supply & Return)

- **Design:** LH₂ enters the hose through the central hub of the reel and exits through the coupling dock (or vice versa).
- **Benefit:** Ensures even pressure and temperature distribution across all hose layers while on the reel.
- **Implementation:** Use a rotary cryogenic swivel joint (e.g., from EATON/Aeroquip or Cryofab) with dual-seal design, allowing hose to spin freely while still supporting LH₂ flow.

2. Layered Flow Management

- **Design:** Guide hose winding in flat spiral layers, not random overlapping coils.
- **Benefit:** Prevents cross-compression that can cause uneven cooling or poor LH₂ flow through outer layers.
- **Implementation:** Use an automated hose level-winder with a helical traverse mechanism to layer the hose evenly on the reel drum.

3. Minimum Bend Radius Control

- **Design:** Use a large-diameter reel (e.g., ≥24–36 inches) to maintain the hose's **minimum bend radius** and avoid tight kinks.
- **Benefit:** Prevents flow restriction and uneven inner-vs-outer temperature zones.
- **Implementation:** Choose hose rated for repetitive bending and dynamic flexure at cryogenic temps (e.g., from Cryofab, Insulon, or Demaco).

4. Integrated Flow Conditioning

- **Design:** Insert a flow straightener or perforated liner in the reel hub or outer hose manifold.
- **Benefit:** Ensures uniform velocity profile through the hose, reducing temperature and pressure differentials across loops.
- **Implementation:** Lightweight stainless diffuser tube or internal helical baffle, optimized for low cryo-flow pressure drop.

5. Cryogenic Rotary Union with Low Heat Leak

- **Design:** Custom LH₂-rated swivel joint with PTFE/silver seals or magnetic-coupling style that connects moving reel to fixed supply.



Figure 1 Cryogenic Rotary Union For Reel Use

- **Benefit:** Prevents mechanical stress while maintaining vacuum integrity and minimizing heat leak into flow path.
- **Vendors:** Consider Kadant Johnson, Rotoflux, or Rotary Systems Inc. with cryo customization.

Safety & Monitoring Add-ons

- **Embedded Temperature Sensors:** Place RTDs or silicon diodes at inner, mid, and outer hose loops to monitor cold soak uniformity.
- **Pressure Relief Port:** A tee'd relief valve near reel inlet protects against blockage-related overpressure.
- **Heated Enclosure Panel** (optional): Maintain housing walls above freezing to prevent ice buildup on external components.

Avoid These Common Pitfalls

Problem	Design Flaw	Fix
Inner hose loops warm up	Central core has no flow path	Use axial-through flow via center hub
Uneven cold soak	Overlapping/random coil	Flat spiral winding with traversing arm
Vapor lock	Hose tight bends on reel	Increase reel diameter & maintain bend radius
Ice or frost damage	Ambient condensation in housing	Vacuum jacket reel + sealed enclosure

Suggested Reel Specs (Conceptual)

Parameter	Value
Reel drum diameter	30–36 in
Reel width	12–16 in
Hose capacity	30 ft, vacuum-jacketed
Hose bend radius	$\geq 10 \times \text{OD}$ (check vendor)
Swivel union	Cryo-rated, dual-seal rotary
Insulation	Vacuum shell + MLI wrap
Flow rate during recirc	~0.5–1.5 kg/min
Materials	304SS or Al alloy with cryo-rated seals

Mobile Fueler System and Equipment Upgrades for LH₂ Recirculation

Introduction

For the integrated LH₂ hose recirculation and cold-soak system to function effectively, the mobile fueling truck must be equipped with additional systems and components beyond those used for basic fueling operations. These enhancements are necessary to support safe, efficient, and thermally stable operation of the recirculation process, and to maximize hydrogen retention between fueling events. The following enabling equipment and subsystems are recommended for incorporation into the mobile fueler design.

Key System Enhancements

1. Coupling Docking Port for Recirculation

A dedicated connection point must be installed on the mobile fueler to accept the LH₂ hose coupling after fueling is complete. This recirculation inlet port should:

- Be physically accessible and ergonomically designed for manual or semi-automated docking.
- Incorporate thermal shielding to prevent frost or condensation buildup.
- Include positive-sealing and self-aligning features to ensure repeatable connections.
- Be interlocked with the control system to verify proper engagement before recirculation begins.



2. Integrated Recirculation Control System

The truck must be outfitted with a dedicated **control module** to manage the recirculation process, including:

- Automated valve actuation, pump control, and flow rate adjustment.
- Real-time monitoring of temperature and pressure within the hose and tank.
- Safety interlocks to prevent operation unless all preconditions are met (e.g., verified coupling, no overpressure).
- Manual override and diagnostics interface (e.g., touchscreen or remote app).
- Alarm notifications for abnormal conditions, such as vapor formation, failed connections, or sensor drift.

3.a Modular Active Refrigeration Unit

An onboard active refrigeration unit provides continuous or demand-based thermal support for the recirculation loop. Unlike a full liquefier, this system does not recondense vapor but instead cools the recirculated liquid hydrogen to maintain subcooled conditions and extend the liquid hold time. GEN H2 has developed modular cryocooler systems designed for integration into mobile platforms.

Key Features:

- Utilizes Stirling or pulse-tube cryocooler technology to remove heat from the LH₂ loop without full liquefaction.
- Compact and ruggedized for vehicle-mounted use.
- Interfaces directly with the LH₂ circulation loop or subcooling chamber.
- Ideal for maintaining tank and hose temperatures in between fueling cycles or in warm climates.

Design Benefits:

- Lower power demand and simpler operation compared to full liquefiers.



- Reduces vapor formation and system boil-off without requiring full gas-to-liquid recondensation.
- Rapid cooldown capability for pre-fueling cold soak preparation.

Implementation Considerations:

- Requires onboard power integration (genset or hydrogen fuel cell).
- Must be cryo-rated for continuous operation near 20 K.
- Integrated with truck's recirculation control system and temperature sensors.

3.b Modular LH₂ Liquefaction and Subcooling Unit

A small, integrated hydrogen liquefaction module can complement the active refrigeration unit by re-liquefying any boil-off GH₂ or warming LH₂ from the circulation loop. This further enhances system resilience and can reduce overall hydrogen losses.

Capabilities:

- Rechills LH₂ that has warmed during hose dwell time.
- Provides re-liquefaction of gaseous hydrogen collected during boil-off.
- Enhances system capability for long dwell times or idle fueling trucks.

Design Notes:

- Should utilize a closed-cycle helium or JT-based refrigeration cycle.
- Modular configuration enables integration into existing fueller footprints.
- Requires robust insulation and safety design for onboard LH₂ handling.



4. Onboard Power System (Genset or Hydrogen Fuel Cell)

To support the liquefier, control system, and cryogenic pump, the truck will require an onboard power generation system, such as:

- A compact diesel or propane genset, OR
- A hydrogen fuel cell system powered by a portion of the stored LH₂ or GH₂.

This energy subsystem should be:

- Sized appropriately for intermittent operation of all recirculation functions.
- Integrated with the truck's fuel and safety systems.
- Capable of remote or autonomous start/stop sequences based on system demand.

The successful implementation of hose recirculation and cold-soak management requires the mobile fueller to function as more than a transport and dispensing vehicle. With the addition of a recirculation docking point, intelligent control architecture, an onboard liquefaction unit, and an independent power source, the truck becomes an active thermal management platform. These enhancements are essential for maintaining LH₂ quality between fueling events, reducing waste, and ensuring readiness for next-generation aircraft fueling operations.