
# Hydrogen Loss Mitigation with Active Refrigeration

## GenH2 Overview

# WHY LH2?

## Advantages of LH2

- *Safety*
  - *LH2 stored at only 1-10 bar*
  - *GH2 stored at 300 to 1000 bar*
- *Value and Control*
  - *Purity – liquefaction is inherently a purification process*
  - *Cryogenic distillation ensures the purity required of fuel cell systems*
- *Transport LH2 (1) to GH2 (10) ratio*
  - *Latest published results indicate a transport capacity of approximately 4500 kg of LH2 per truck (US DOE)*
  - *A 40-ton truck carrying compressed hydrogen can deliver only 450 kilograms*
- *Increased energy storage capacity with dramatically less footprint and weight*

# CHALLENGES WITH LIQUID HYDROGEN

- Normal Evaporation Rate (NER)
  - Liquid hydrogen storage generally loses 1% per day due to heat leak into the tank.
- Compression
  - Saturated liquid is being pumped
  - Causes cavitation
  - Gas blow-by on piston rings
  - Significantly more losses due to the gaseous hydrogen being directed back to the storage tank.
- Filling and dispensing losses
  - 18,000gal tank @ 25% full contains 350kg of gaseous hydrogen in the ullage space.
  - The gaseous hydrogen is displaced and vented while filling the tank with liquid.
- Super-saturated liquid
  - Vapor eruption occurs when the liquid is disturbed which releases heat and causes pressure to build and tank to vent.

# Existing Liquid Hydrogen Method

13 to 20% Transfer Loss
(Tanker transfer to tank)

1% (min.) Storage Loss
Daily

10% Transfer Loss from Tank to
Dispensing Interface


## Operational Losses 16-31%

- **Also: hydrogen recovery and recondensation from vehicle tank filling processes and blowdowns**

# Cost Benefit Analysis based on Transit Buses

18K-gallon (4800kg) LH2 tank is usually refilled when level reaches 25%, Tank is full at 90% with 10% ullage space for boil off which leaves 3600kg of usable Hydrogen.

- 15 transit buses using 30kg per day will require 450kg per day to support the buses: Tank fill once a week.
- 30 transit buses using 30kg per day will require 900kg per day to support the buses: Tank fill twice a week.
- 45 transit buses using 30kg per day will require 1350kg per day to support the fleet: Tank fill three times a week.
- From 45 to 60 buses, a fill every day is needed

Transit agencies should understand that as the fleet grows, the losses greatly increase. From the analysis, three tank fills a week will result in $1,248,000 losses per year. (Based on 25% loss, at $10 per kg)

# Cost-Benefit Analysis cont...

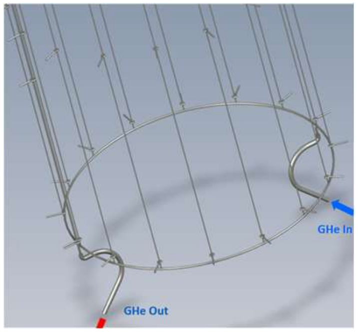
| | | | | | | |
|---|---|---|---|---|---|---|
| | | Transfer Loss Assumption | 25% | | | |
| | | Transfers Per Week | | | | |
| | | 1 | 2 | 3 | 4 | 5 |
| kg/transfer | 3,200 | 800 | 1600 | 2400 | 3200 | 4000 |
| | | Transfers Per Year | | | | |
| | | 1 | 2 | 3 | 4 | 5 |
| kg/transfer | 3,200 | 41,600 | 83,200 | 124,800 | 166,400 | 208,000 |
| | | | | | Price/kg | $10.00 |
| | | Annual $ Saved/Year | | | | |
| | | Transfers Per Year | | | | |
| | | 52 | 104 | 156 | 208 | 260 |
| kg/transfer | 3,200 | $ 416,000 | $ 832,000 | $ 1,248,000 | $ 1,664,000 | $ 2,080,000 |

GEN H2 DISCOVER HYDROGEN

# Typical venting loss illustration

# CRYOGENIC CONTROLLED STORAGE

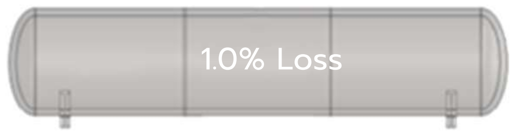
- Next generation Liquid Hydrogen Storage
- New technology controlled refrigerated storage inspired by NASA Integrated Refrigeration and Storage (IRaS) system and utilizes active helium refrigeration
- Enables complete control over the state of the cryogenic fluid, including ullage pressure control
- LH2 densification allows for effective zero-loss transfer of hydrogen for vehicle tank filling or off-take from a tanker
- Subcooled Liquid enables increased performance of pumps, increased reliability of system, less maintenance
- Capability for both Zero-loss transfer and Zero-boiloff

# *Existing Liquid Hydrogen Method*

13 to 20% Transfer Loss
(Tanker transfer to tank)


1% Storage Loss Daily
(NER)




LH2 Storage

2-10% Transfer Loss to Dispensing Interface

**Operational Losses 16-31%**

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# *GenH2 Liquid Hydrogen Value Chain*

Zero Loss*


* Time dependent

0% Daily Storage Loss with active refrigeration (NER)

Active refrigeration system

0% Transfer Loss to Dispensing Interface

**Zero or Reduced Loss Transfer & Zero Tank Boiloff**

# Cryogenic Controlled Storage Using Active Refrigeration

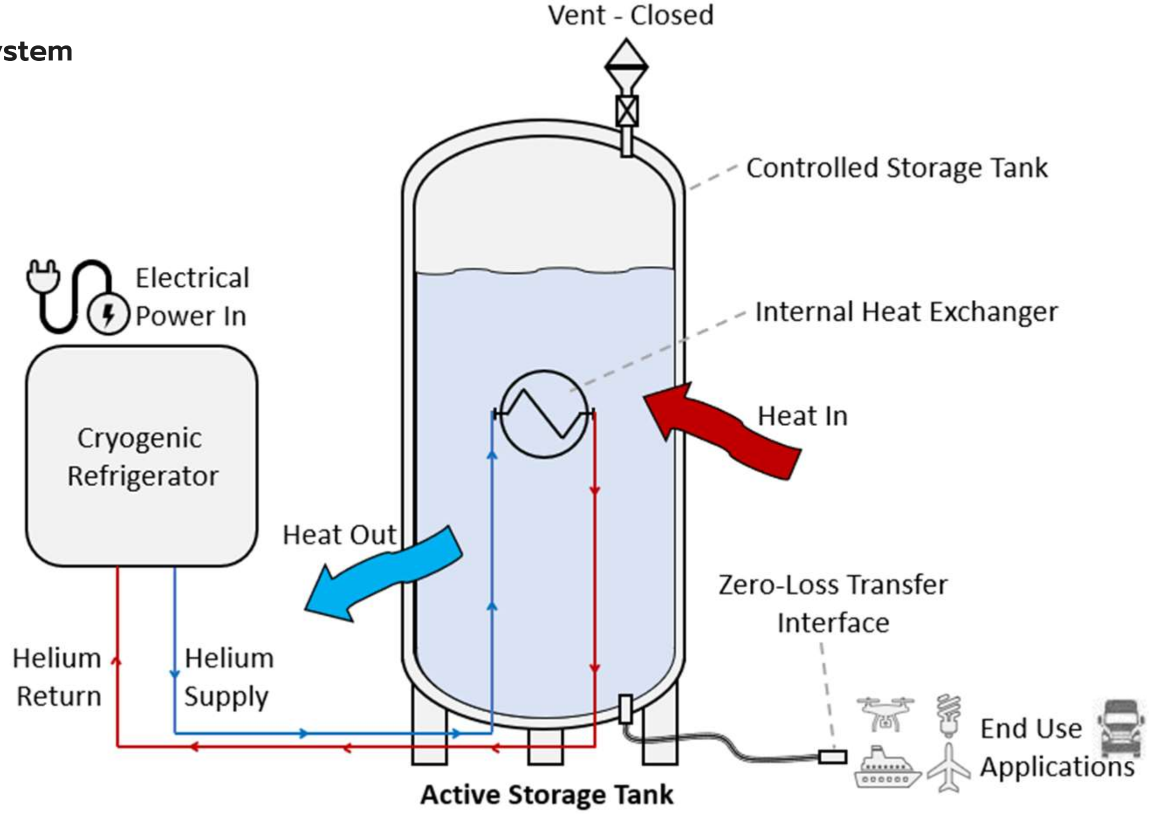
## LH2 CONTROLLED STORAGE, WITHOUT LIQUEFIER

**RS – Series Refrigeration System**

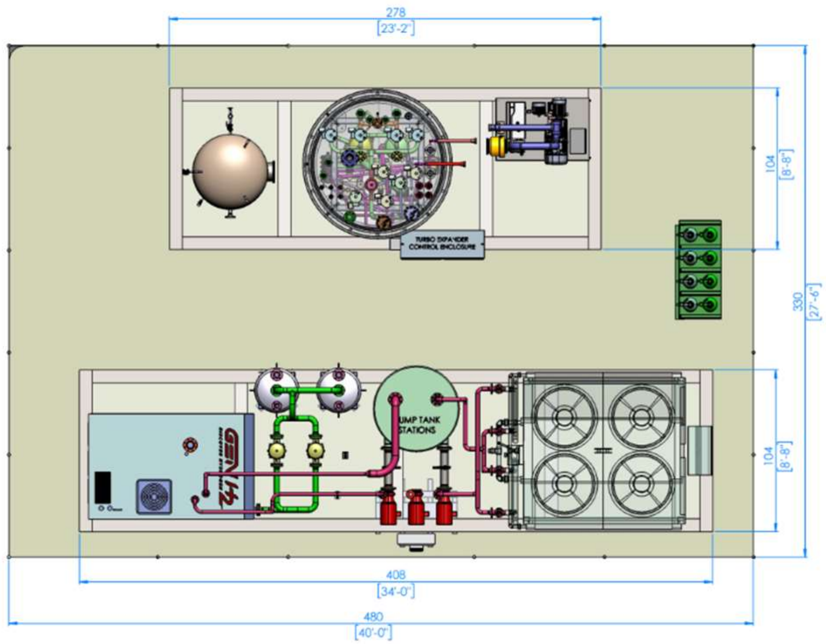
**Example:**

**RS1500**

**RS3000**



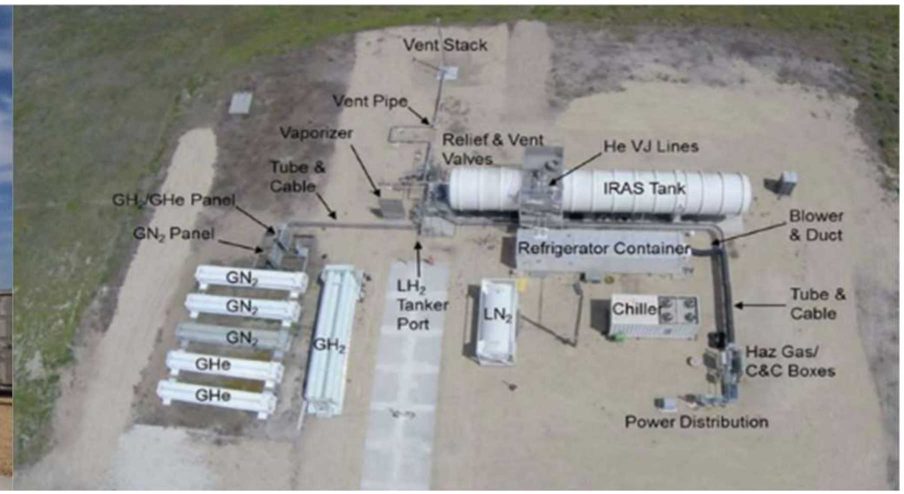
# Helium Refrigeration System




- 1200 Watts of cold power @ 20kelvin
- Compact design
- Ease of maintenance
- Reliability very high due to turbo expansion gas bearings

# Example - Integrated Refrigeration and Storage (IRaS) Demonstration Site

Photos are from Cryogenics Test Laboratory at NASA Kennedy Space Center, Florida. Head & Senior Principal Investigator, James E Fesmire




**Now put into service for rocket engine testing at NASA Marshall Space Flight Center, Huntsville., AL**

# Controlled Refrigerated Transfer to address the Transfer-Loss Challenge

## *Three Operational Conditions of $LH_2$*

**NBP** (1 atm) — 20.3K

| **EXTRACOOLED**<br>*New method of $LH_2$ transfer*<br>T ↓ | **TEMPORARILY SUBCOOLED**<br>*Old method of $LH_2$ transfer*<br>T ↑ |
|---|---|
| • Higher density<br>• Zero-loss transfer capability in some cases<br>• Safer and faster<br>• Constant process with on/off capability ($LH_2$ on demand) | • Substantial losses by venting after transfer (temporary)<br>• Finite operational process<br>• Long wait times between runs for liquid to re-equilibrate at NBP (Normal Boiling Point)<br>• Constant heat gain (pressure increase) |
| Active / Refrigerated Storage | Passive Storage |
| Controlled Storage / Transfer | No Control |
| Flow Like Water | Flow Like Boiling Water |
| Steady Process | Transient Process |

# IRaS Results - Tanker Offloading

- Storage without NASA IRaS
  - Based on NASA Space Shuttle STS Program data, approximately one half of the LH2 was lost including an average of 13% due to tanker transport and offload processes.
  - Heat ingress causes ullage pressure buildup which leads to venting and tank blow-down losses
  - Extensive losses normally occur by conventional methods such as tanker transfer which requires tank blow-downs to relieve ullage pressures.

- Storage with NASA IRaS
  - Heat from transport and line cool down is removed by an RS-series refrigerator, allowing zero-loss offload.
  - Zero-loss tanker offloads were achieved for fill levels of 0-33%, 33-67%, and 67-100%

- **Conclusion – controlled storage enables zero-loss tanker offload**