Turboexpander: Alternative Fueling Concept for Fuel Cell Electric Vehicle Fast Fill – Proof of Concept Testing

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June 14, 2018

DOE Hydrogen and Fuel Cells Program
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID # h2039

Overview

Timeline and Budget

- Project start date: 06/01/18
- Project end date: 06/01/19
- Total project budget: $250K
  - CRADA Call Tasks
    - DOE/Honda $25K each
  - AOP Tasks
    - DOE/Toyota $100K each
  - Total DOE funds spent*: $0

* As of 3/31/18

Barriers

- Cost of dispensed hydrogen
- Parasitic power requirements for -40°C precooling
- Footprint for chiller and heat exchanger at hydrogen station

Partners

- Toyota
- Honda
- FOA Proposal
  - Sandia
  - Creare
  - Anglo American

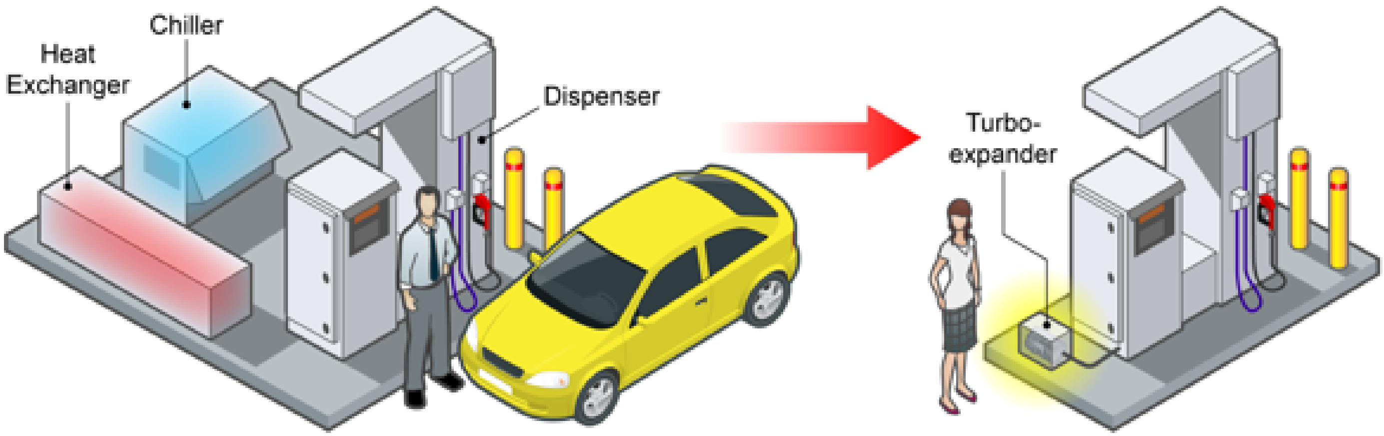
Relevance: Project Objectives

To provide turboexpander proof of concept test data that can be used as a basis for full prototype design and system analysis. The turboexpander is designed to replace the Joule-Thomson valve currently used to control SAE J2601 pressure ramp rates.

1. System Analysis: Complete system thermodynamic sizing and performance analysis. System analysis will optimize expander operation over transient flow conditions.
2. Design/Build: Fabricate hydrogen turboexpander hardware capable of conducting proof of concept testing. Testing will utilize NREL's hydrogen demonstration station and gravimetric test apparatus.
3. Validation Testing: Perform turboexpander testing utilizing NREL's Hydrogen Infrastructure Testing and Research Facility (HITRF) capability.
4. Final Reporting

Relevance: Problem Statement

Problem Statement: Station precooling is energy intensive and prone to high cost of installation and operation



Current Technology

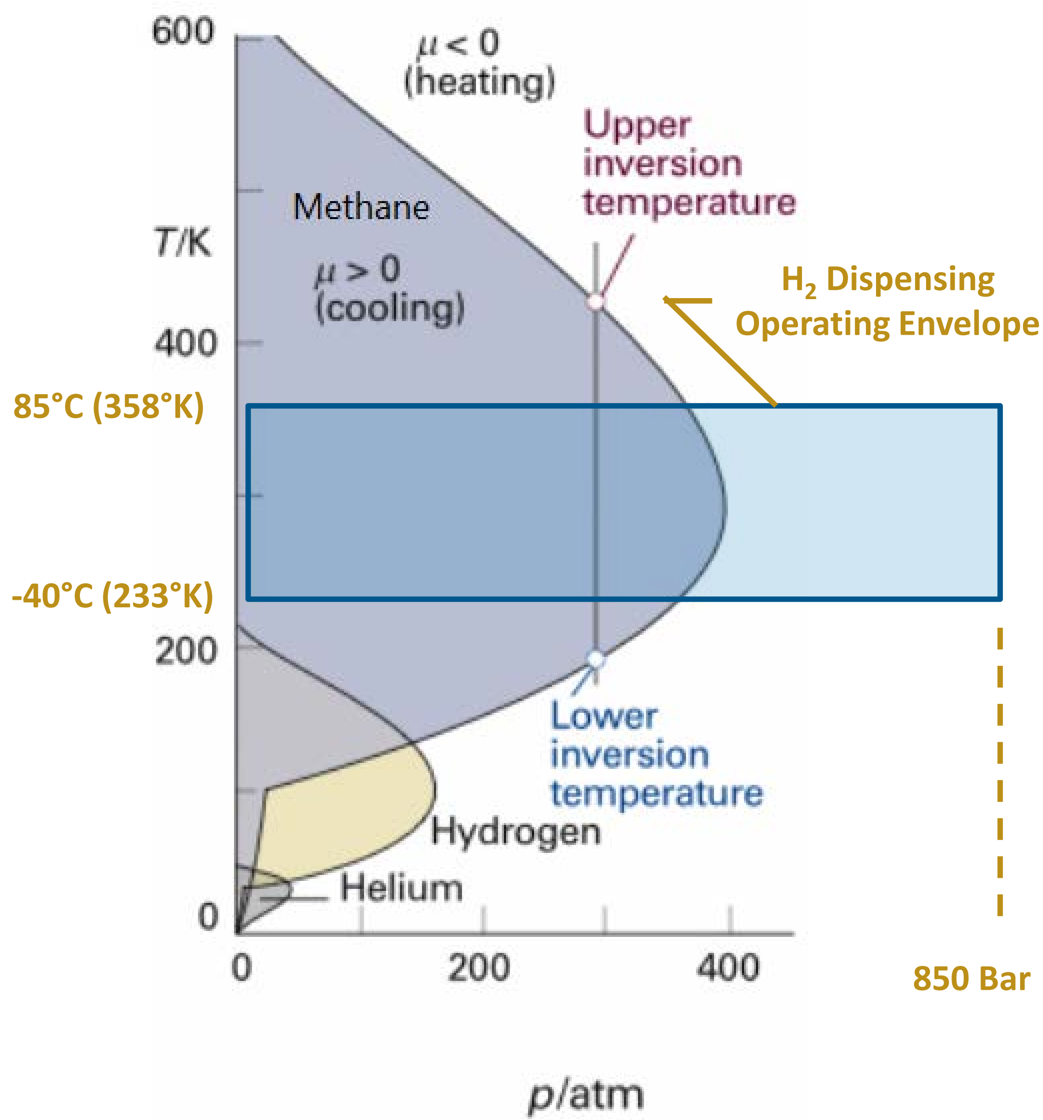
- NREL station: -40°C precooling system
- Control valve regulates pressure drop but induces Joule Thomson heating
- Chiller 12KW, $130K, 26ft^2 footprint
- Heat Exchanger $55K, 21ft^2 footprint
- Heat Transfer Fluid $7K

Turboexpander Benefits

- Save capital & operating cost
- Minimize footprint/weight
- Improve station reliability
- Recycle percentage of pressure energy
- On demand chill down capability

Relevance: Joule Thomson Expansion

- Joule-Thomson coefficient is negative when operating within the pressures and temperatures experienced at a hydrogen dispenser (μ<0)
- Negative Joule-Thomson coefficient will result in heating of the hydrogen across an isenthalpic expansion (control valve)
- Joule-Thomson effect definition (Encyclopedia Britannica): *"The change in temperature that accompanies expansion of a gas without production of work or transfer of heat."*



Temperature Rise Effects – CNG Compression Heating

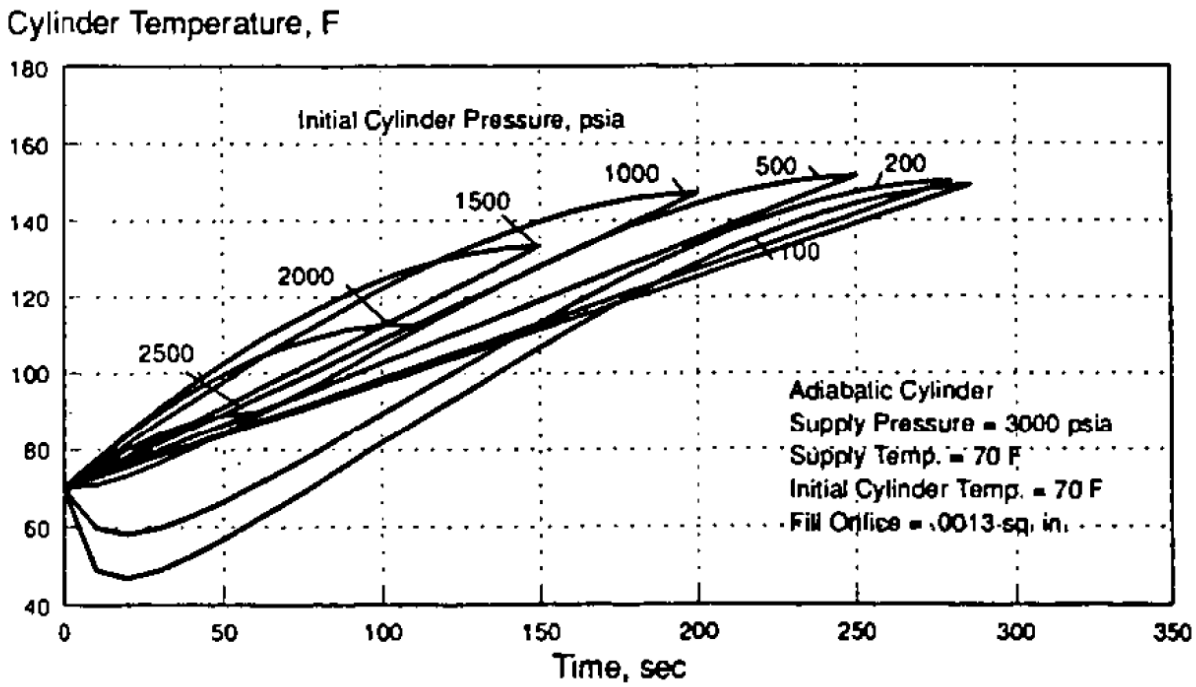
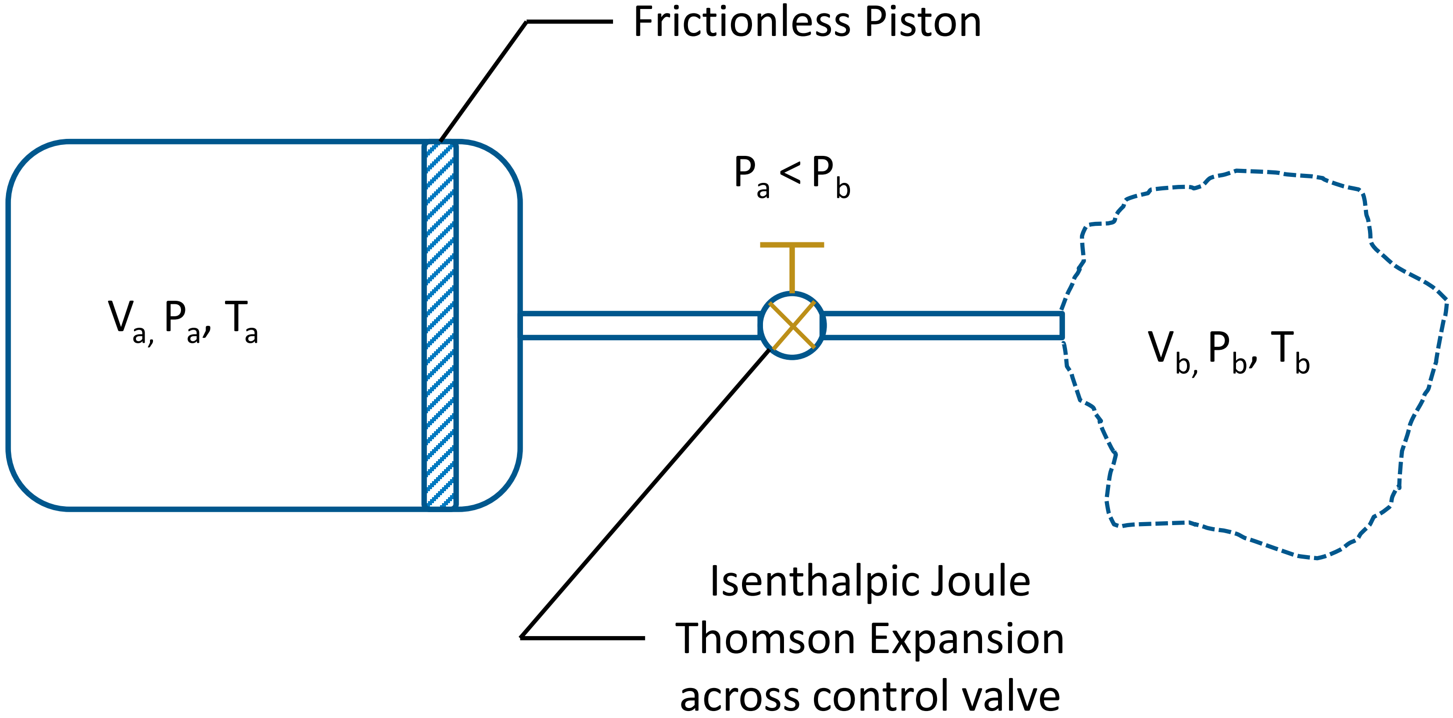


Fig. 4 Temperature in a 10"x50" Aluminum cylinder during a 3000 psia charge

CNG fast fill fueling shows a temperature rise under most conditions even though methane has a positive Joule-Thomson coefficient (i.e., it cools as it expands through the control valve)

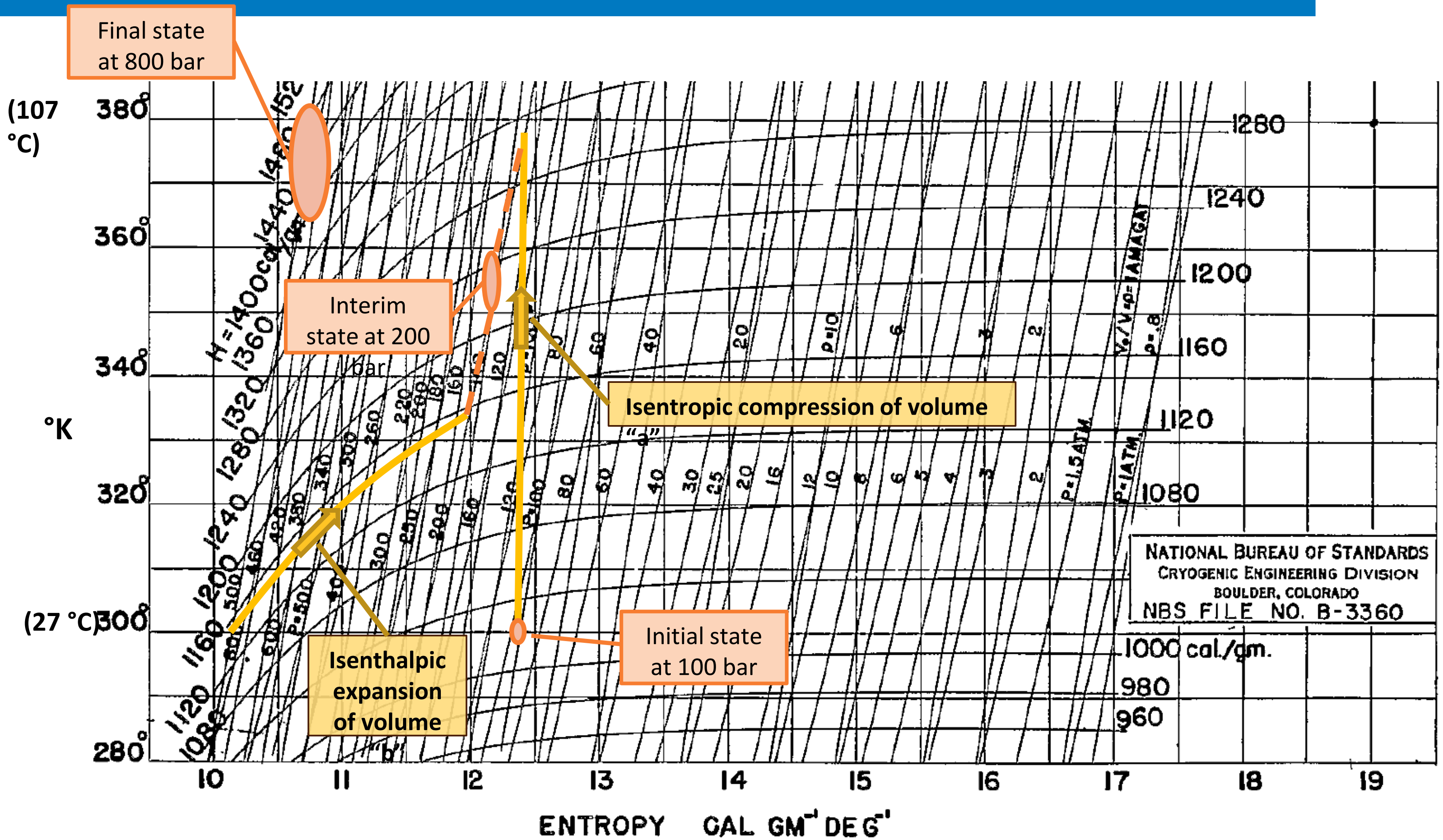
Source: *"Modeling the Fast Fill Process in Natural Gas Vehicle Storage Cylinders", K. Kountz, Institute of Gas Technology, 1994*

Isentropic Compression and Isenthalpic Expansion



Gas in the cylinder is assumed to be undergoing isentropic compression, while the gas entering the cylinder is undergoing an isenthalpic expansion

Hydrogen T-S Diagram



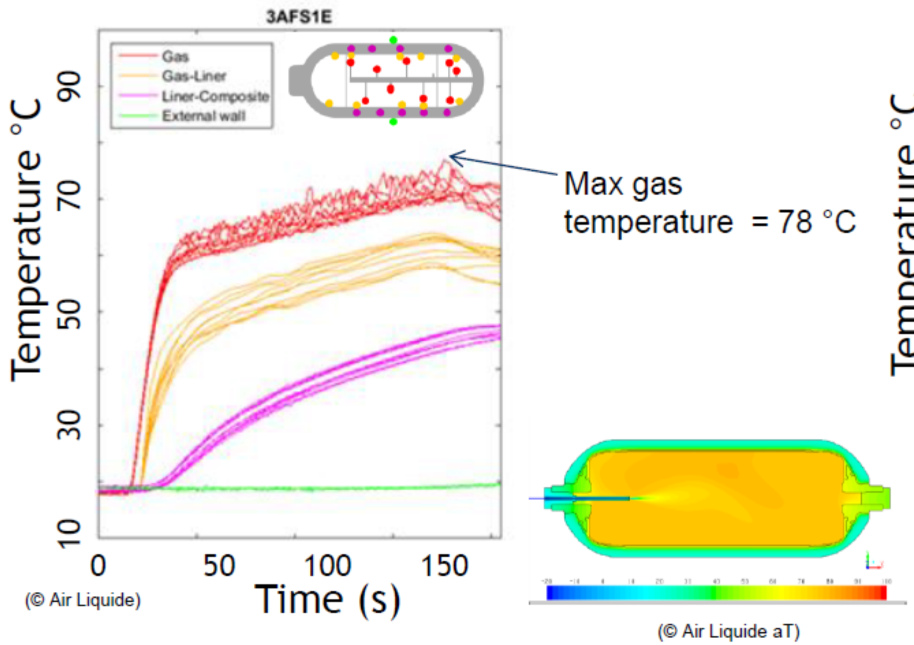
Heating of volume a and b are depicted on a T-S diagram; volumes will mix in the cylinder resulting in temperature which is "average" of the two volumes (mixing rate will depend on turbulent velocity)

Source: *"Selected Cryogenic Data Notebook, Section III Properties of Hydrogen", Jensen et. al., BNL 10200-R, Revised August 1980*

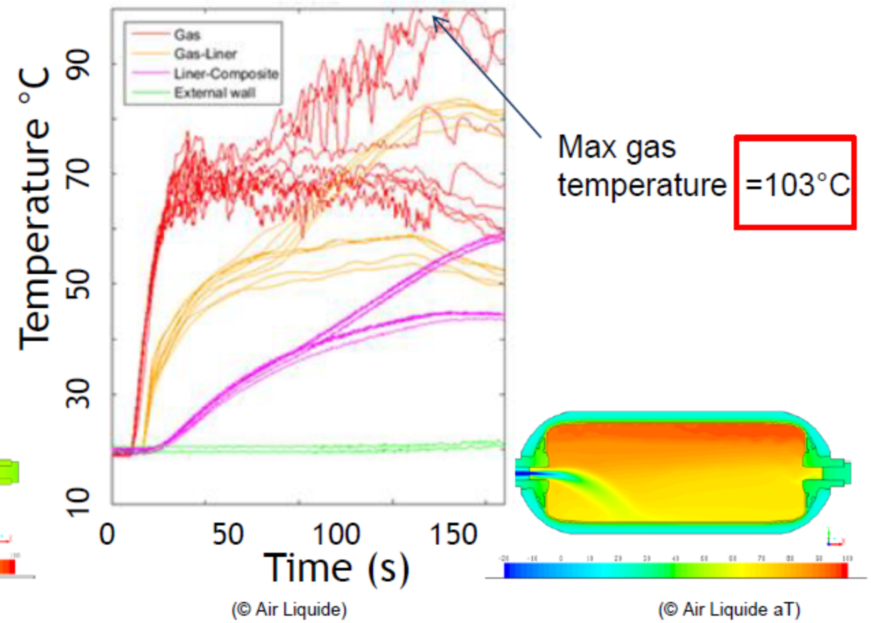
HyTransfer Fill Temperature Summary

- Horizontally filled tanks with H2 with a one-hole axial injector
- Type IV 36 l : 3 minute filling with Tinlet = -20°C

Injector with 3 mm internal diameter



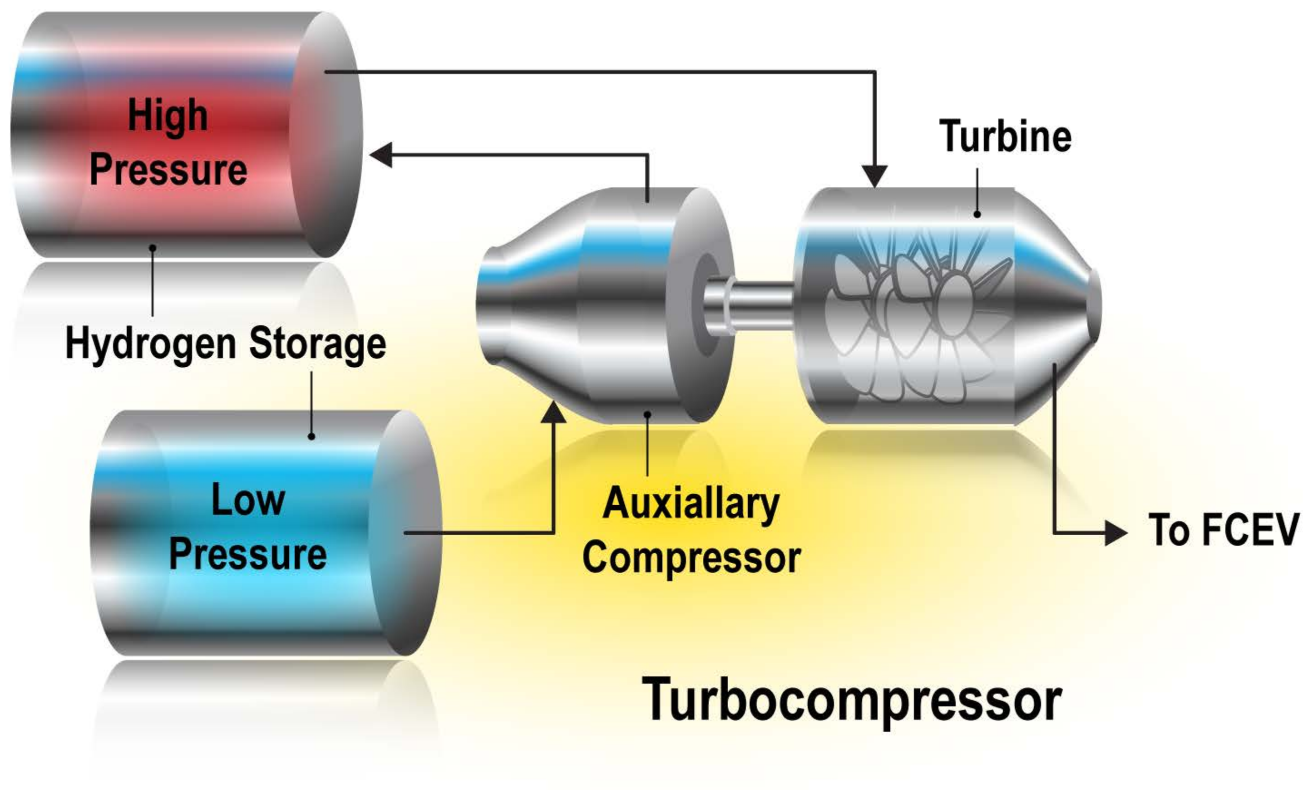
Injector with 10 mm internal diameter



Ref :(Bourgeois, Brachmann et al., 2016)

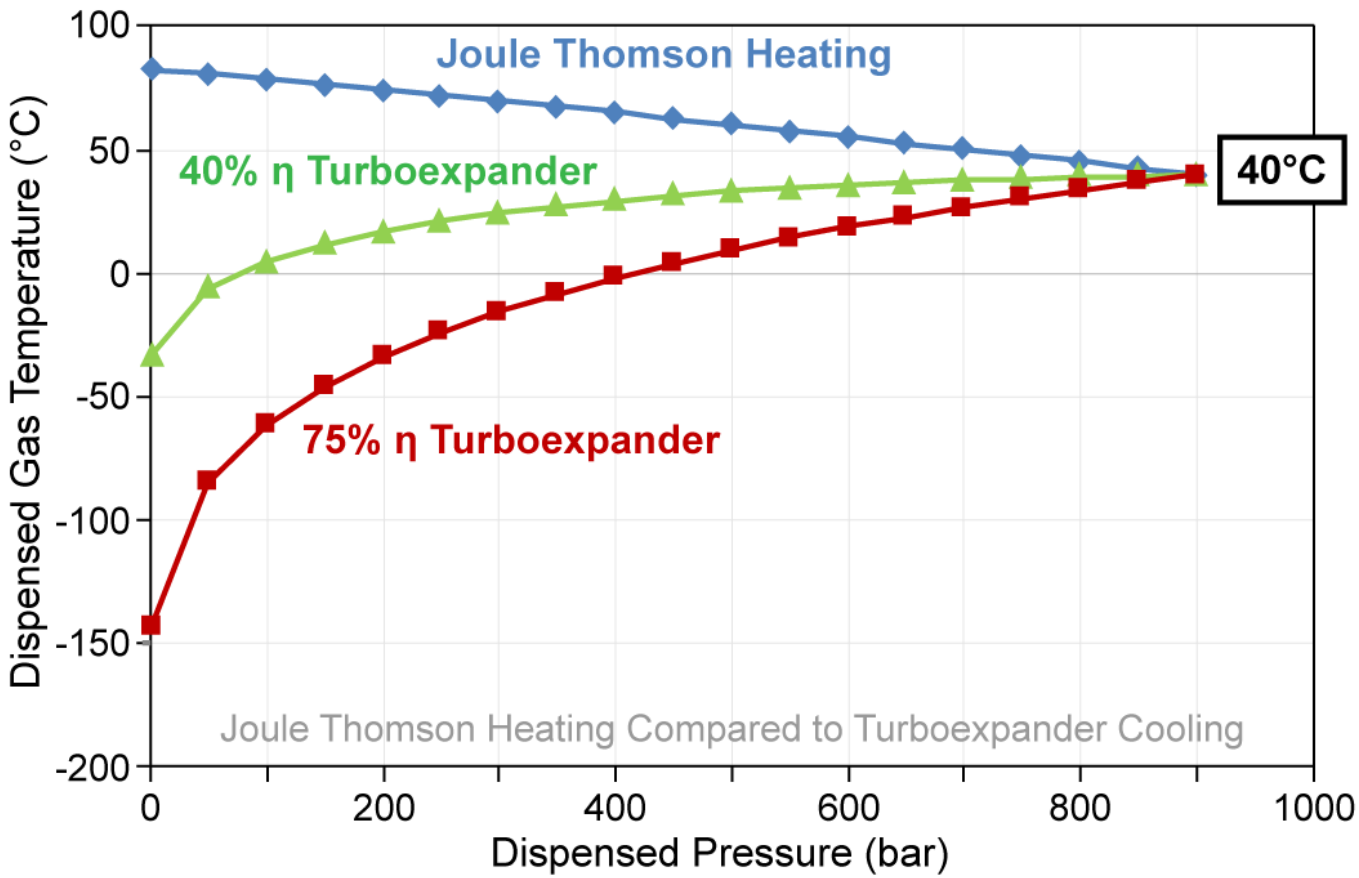
Initially, gas in the cylinder heats rapidly due to 1) high ΔP across throttling valve and 2) high ΔT of isentropic compression in cylinder

Turboexpander Concept



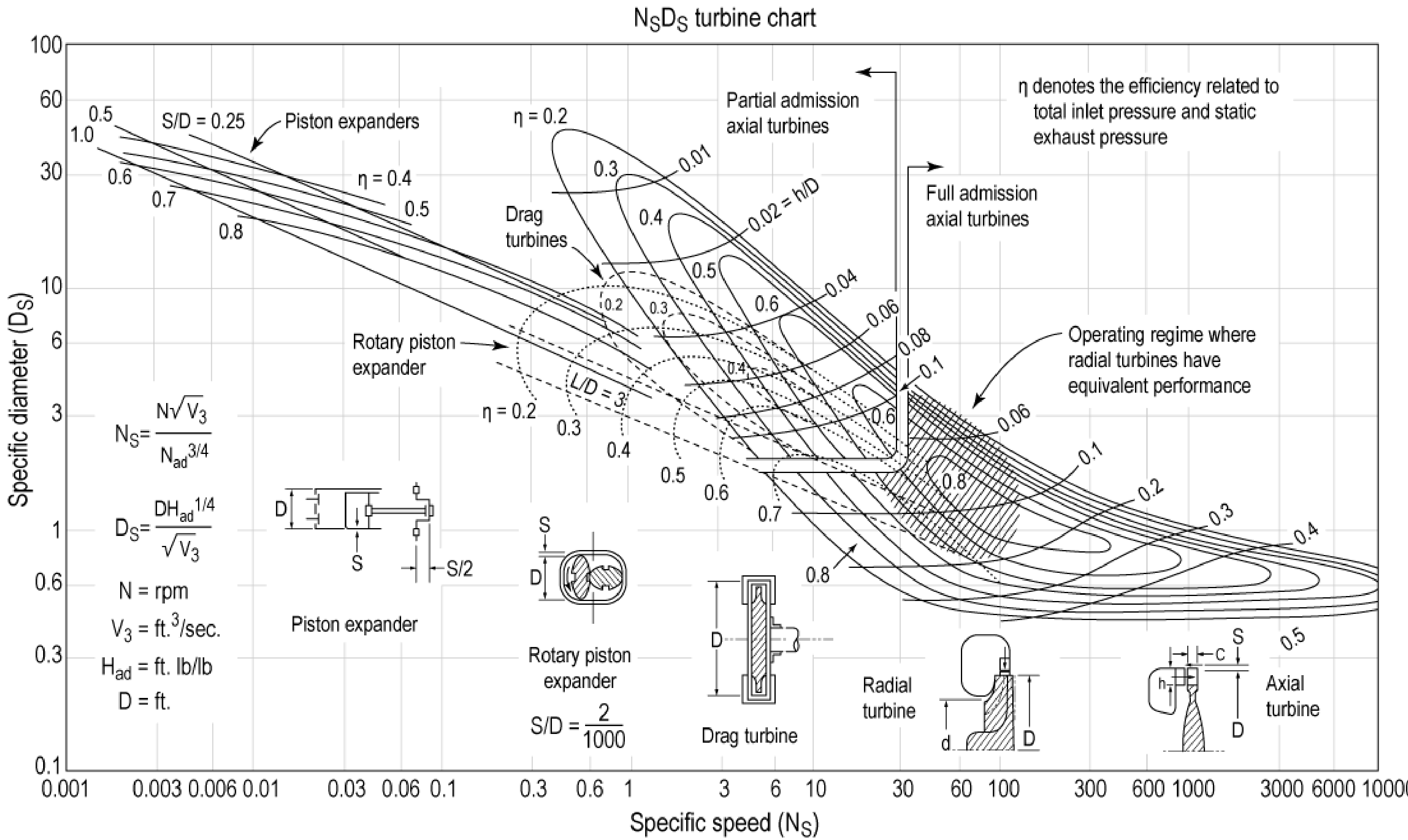
Turbine energy can be recovered by coupling to an auxiliary compressor, which may show system level improvements over an electric generator power recovery concept

Turboexpander Concept

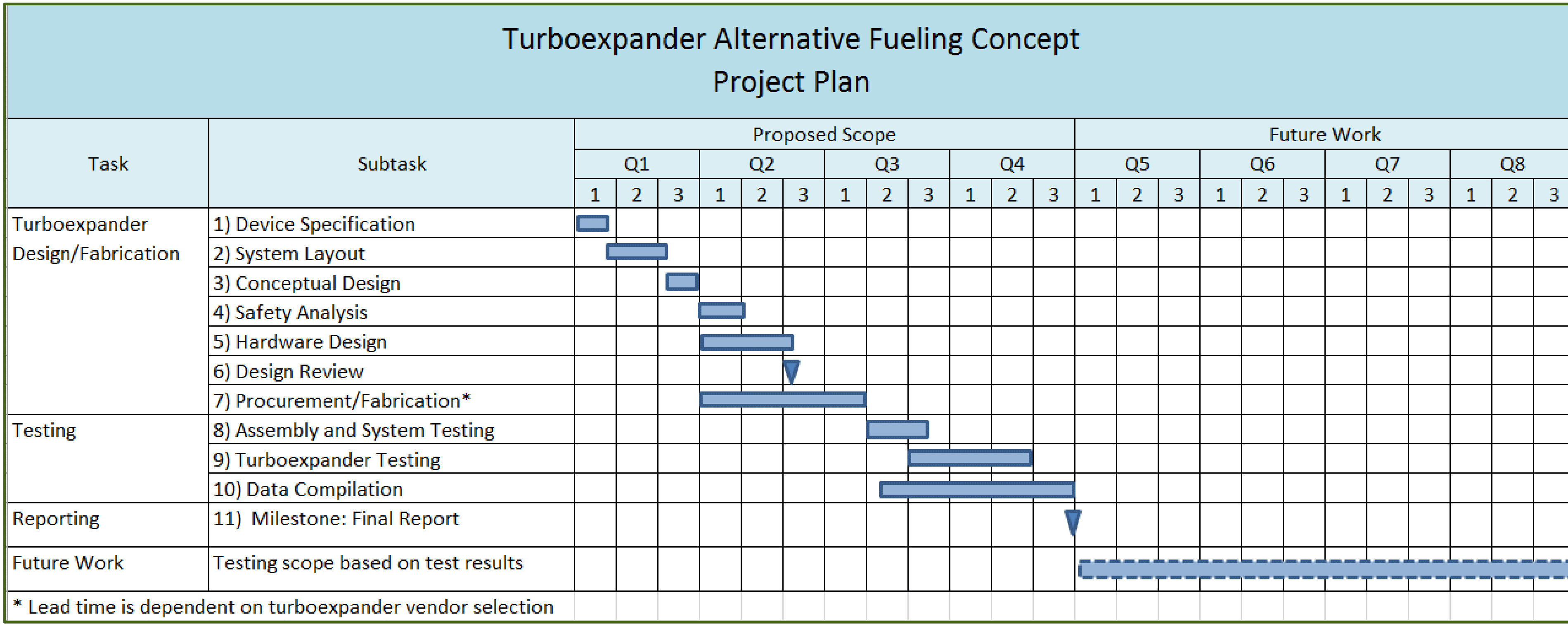


40% efficient turbine is capable of achieving -40°C precooled temperatures at worst case 40°C ambient temperature conditions

TurboexpanderConcept



Turboexpander Project Plan



Intellectual Property: Patent Application

- Hitachi has abandoned its patent application
- Hitachi is working on a concept with NEDO and plans to publish within one year
- Hitachi conceptual design shows a back to back turbine with 75% efficiency, suggesting radial inflow turbines in series

(19) **United States**
(12) **Patent Application Publication**
YOSHIDA et al.

(10) **Pub. No.: US 2016/0281928 A1**
(43) **Pub. Date: Sep. 29, 2016**

(54) **HYDROGEN PRECOOLING SYSTEM**

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(21) Appl. No.: **15/042,587**

(22) Filed: **Feb. 12, 2016**

(30) **Foreign Application Priority Data**

Mar. 23, 2015 (JP) 2015-059323

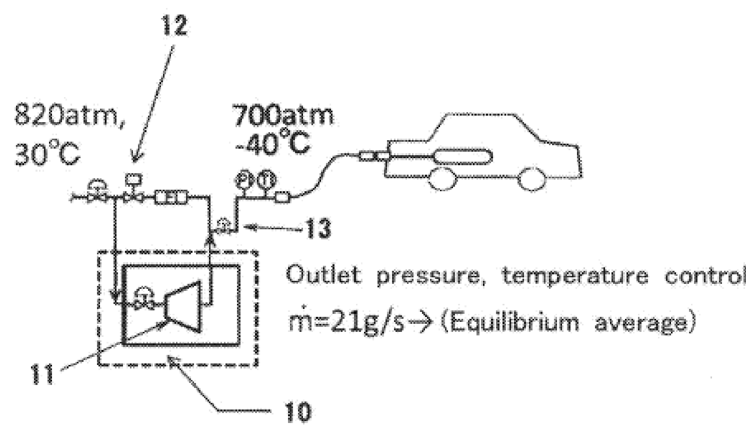
Publication Classification

(51) **Int. Cl.**
F17C 5/06 (2006.01)

(52) **U.S. Cl.**
CPC ***F17C 5/06*** (2013.01); *F17C 2221/012* (2013.01); *F17C 2223/0123* (2013.01); *F17C 2225/0123* (2013.01); *F17C 2270/0168* (2013.01); *F17C 2270/0184* (2013.01); *F17C 2227/0358* (2013.01); *F17C 2227/0362* (2013.01)

(57) **ABSTRACT**

[Purpose]
[Problem] To present a precooling system for lowering the temperature of hydrogen gas at a final filling unit of a hydrogen of a hydrogen station simple in construction, small in the load of maintenance and management tasks, and capable of lowering the running cost including the cost of consumption power source.
[Solving Means] To precool hydrogen gas by lowering the temperature of hydrogen gas by an expander **11** in a process of expanding and compressing the hydrogen gas, and by making use of its cold heat energy.



Future Work – Funding Opportunity Announcement

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

FY18 Hydrogen and Fuel Cell R&D FOA	
FOA: DE-FOA-0001874	
Concept Paper	
Project Title:	Direct Cooling of Hydrogen to Decrease Energy Consumption in Hydrogen Vehicle Fueling Infrastructure

- A concept paper has been submitted to DE-FOA-0001874 for $1.5M to advance the turboexpander concept from proof of concept phase (current project) to prototype component and system level validation
- 20% industry cost share is required
- Technical partners include Sandia and Creare
- If the concept paper is selected NREL will pull together funding team

Summary

Turboexpander Advantages	Turboexpander Challenges
Reduce station footprint by eliminating chiller and heat exchanger	Development time/cost required for system design and development
Provide on-demand cooling that matches the hydrogen fill cycle	Expander maintenance and operation cost to maintain high reliability
Consistent back to back fills without a theoretical limit to number of fills	Higher complexity of expander design compared to chiller and heat exchanger
Recover compression energy improving overall efficiency of station operation	Limited number of suppliers in the market of high pressure expanders
Potential ability to improve J2601 protocol with faster fills and higher state of charge (lower precooling temperatures are possible)	Development time and cost for creating new J2601 protocol will require validation testing to meet SAE Fuel Cell Interface Committee needs

ESIF – Energy Systems Integration Facility

NREL laboratory facility provides laboratory space R&D testing of high pressure hydrogen component and system.

Thank You

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Publication Number

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