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
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, 26ft² footprint
- Heat Exchanger $55K, 21ft² 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
Joule-Thomson coefficient is negative when operating within the pressures and temperatures experienced at a hydrogen dispenser (\(\mu < 0\)).

- 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.”
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).

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

![Diagram](image_url)

- **N_SD chart**
  - **Piston expanders**
  - **Partial admission axial turbines**
  - **Full admission axial turbines**
  - **Operating regime where radial turbines have equivalent performance**

**Equations**

\[
N_S = D / S \]

\[
D_S = \sqrt{D / N} \]

\[
N = \text{rpm}
\]

\[
V_3 = \text{ft.}^3/\text{sec.}
\]

\[
H_{ad} = \text{ft., lb/lb}
\]

\[
D = \text{ft.}
\]

**Definitions**

- S/D = 0.25
- S/D = 0.5
- η = 0.2
- η = 0.4
- η = 0.6
- η = 0.8
- η denotes the efficiency related to total inlet pressure and static exhaust pressure

**Notes**

- The chart illustrates various types of turbines and their operating regimes.
- Specific conditions and parameters are used to classify different turbine models.
- Efficiency values are critical for performance evaluation.

---

*Source: NREL*
# Turboexpander Project Plan

## Turboexpander Alternative Fueling Concept Project Plan

<table>
<thead>
<tr>
<th>Task</th>
<th>Subtask</th>
<th>Proposed Scope</th>
<th>Future Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turboexpander Design/Fabrication</td>
<td>1) Device Specification</td>
<td>Q1 2 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) System Layout</td>
<td>Q2 3</td>
<td>Q5 1 2 3</td>
</tr>
<tr>
<td></td>
<td>3) Conceptual Design</td>
<td>Q3 1 2 3</td>
<td>Q6 1 2 3</td>
</tr>
<tr>
<td></td>
<td>4) Safety Analysis</td>
<td>Q4 1 2 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5) Hardware Design</td>
<td>Q5 1 2 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6) Design Review</td>
<td>Q6 1 2 3</td>
<td>Q7 1 2 3</td>
</tr>
<tr>
<td></td>
<td>7) Procurement/Fabrication*</td>
<td>Q7 1 2 3</td>
<td>Q8 1 2 3</td>
</tr>
<tr>
<td>Testing</td>
<td>8) Assembly and System Testing</td>
<td>Q1 2 3</td>
<td>Q5 1 2 3</td>
</tr>
<tr>
<td></td>
<td>9) Turboexpander Testing</td>
<td>Q2 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10) Data Compilation</td>
<td>Q3 1 2 3</td>
<td>Q6 1 2 3</td>
</tr>
<tr>
<td>Reporting</td>
<td>11) Milestone: Final Report</td>
<td>Q4 1 2 3</td>
<td>Q7 1 2 3</td>
</tr>
<tr>
<td>Future Work</td>
<td>Testing scope based on test results</td>
<td>Q5 1 2 3</td>
<td>Q8 1 2 3</td>
</tr>
</tbody>
</table>

* Lead time is dependent on turboexpander vendor selection
- 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
Future Work – Funding Opportunity Announcement

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

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

---

**ESIF – Energy Systems Integration Facility**

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

www.nrel.gov

Publication Number