Project H
A Complete Spaceport Hydrogen Solution

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Engineering and Technology
Background

- In the 1950's and 1960's, NASA and USAF requirements pushed the development of large scale liquid hydrogen technology.
- Since the completion of LC 39, cryogenic technology has progressed, in many cases by two generations:
  - Refrigeration systems
  - Transfer lines and disconnects
  - Compressors and valves
  - Controls and instrumentation
- Spaceport hydrogen operations are different from every other industrial gas customer, and industry is not optimized to meet our needs:
  - Very large scales
  - Very unsteady demand and high peak demand
  - Strict delivery requirements
- Hydrogen has a reputation as a difficult and expensive fuel choice, but a necessary evil due to performance benefits.
- KSC/CCAFS needs to upgrade its hydrogen infrastructure, optimized for unique spaceport applications and designed for minimal operations costs.
Project H Goals

• Goal is to increase the efficiency of hydrogen operations to >80%
  - Current KSC practice is approximately 55%
  - Defined by mass launched/mass purchased

• Targeted hydrogen losses
  - Storage tank boil off
  - Chill down losses
  - Tanker venting recovery
  - Line drain and purge
  - Tank venting

• Local hydrogen production and liquefaction capability
  - Sized for KSC needs but allowed to sell offsite
  - Can stimulate local economy

• Propellant conditioning and densification
  - Bulk temperature to 16 K
  - Thermal energy storage for launch, load balancing

• Reduction in helium use
• Reducing in spaceport carbon footprint

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Project H Elements

- Ultimate goal is a complete KSC/CCAFS hydrogen system optimized for spaceport operational demands
- Economic and energy efficiency for minimal life cycle costs
- Consists of 4 elements
  - **Local hydrogen production system**
    - Tie into existing natural gas pipeline and electrical grid
    - Capitalize on latest plant designs
  - **Hydrogen compression and gaseous distribution system**
    - Advanced compressors and hydrogen pipeline feeding LC 39 A and B, LC 40, LC 41, LC 37, and LC 36
    - Addition of vehicle refueling station for fleet applications (existing)
  - **Integrated refrigeration and storage system**
    - Provides for liquefaction, conditioning, and zero loss storage and transfer
    - Hybrid cycle uses closed helium refrigerators with open cycle hydrogen expansion
  - **High efficiency transfer lines**
    - Vapor shielded for 10x reduction in heat leak
    - Integrates vent cycle back to liquefier

- All components and subsystems are commercially available
- Major development challenge is engineering and integration, not technology development

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Project H Phasing

- Although the subsystem technology is mature, at the system level operations will be very different, and there will be a learning curve associated with use.

- To mitigate this risk, Phase 1 will build a smaller scale demonstration system (0.5 MMSCFD) to prove operations and efficiency:
  - Exact sizing to be determined via trade study
  - Can utilize some existing equipment for minimal cost
  - Method of maintaining critical skills

- Upon successful completion, Phase II will build a full scale spaceport system:
  - Allows for time to determine future Spaceport demands
  - Will need CCAFS and commercial buy in

- Phase I system has multiple continued uses:
  - Can be used to shave peak loads from full scale Spaceport system
  - Can be used as a hydrogen center of excellence for energy research and education
  - Can be used by a commercial supplier for hydrogen industries, even if Phase II isn't funded
  - Can be sent to Launch Complex 36, 40, or 41, West Palm Beach or SSC for incorporation into their operational system
  - Can serve as densified propellant testbed
Local Hydrogen Production

- No current hydrogen production within 400 miles of KSC
  - Currently come from New Orleans (700 miles)
  - Gap in national hydrogen production map
- Steam methane reformation (SMR) is currently the preferred method
  - Experience base allows for cost estimates with engineering certainty
  - Cost ($M) = 5.384 * Capacity (TPD)\(^{0.6045}\)
- Can take advantage of recent plant technologies for energy efficiency and economics
- Existing natural gas line sized for eventual hydrogen production at KSC
- KSC demands smaller than typical plants being built
  - Sizing fits within DoE goals for distributed scale production
  - Possible future partnership with DoE
- Other potential partners include Pratt and Whitney/Rocketdyne
  - Developed compact reformer process
  - Pilot scale plant in testing
  - One step reaction with simplified carbon capture
  - 30-40% lower capital cost compared to SMR

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Hydrogen Compression and Distribution

- Hydrogen compression is a mature technology but there are efficiencies to be gained over current oil lubricated piston compressors.
- Linde has recently developed ionic liquid hydrogen compressors that can be used.
- Spaceport scale distribution can use gaseous pipelines between the central production facility and various launch pads for liquefaction.
- Gaseous hydrogen pipelines are a mature technology with hundreds of miles of pipe in Europe and North America.
  - Cost models are known with engineering certainty.
  - Cost ($) = 200,000 * length (miles) * diameter (in).
- Gaseous distribution system capabilities.
  - Can be used for high pressure GH2 fleet refueling.
  - Gas source eliminates need for vaporizer, increases effective tank capacity.
  - Serves as compression source for hybrid liquefier cycle.
Integrated Refrigeration and Storage System

- Many past studies and projects have used active refrigeration with storage tanks
  - Early work focused on reliquefier concepts
    - Open cycle liquefiers using the ullage gas as the working fluid
  - Later NASA work used close cycle refrigerators for zero boil off applications
    - Coldhead condensers in ullage space
    - Pumps with forced liquid convection to cold heat exchanger
- Recent KSC demonstrations have proved IRAS concepts for LH2 and LOX on small scale (<100 gallons)
  - Uses close cycle refrigeration with heat exchange in liquid region of tank, will depend on natural convection
  - Hydrogen system has demonstrated liquefaction, zero boil off, and hydrogen densification
- Advantages
  - Less active systems
  - Ability to control liquid temperature
    - Allows for greater thermal storage
    - Allows for propellant conditioning and densification
    - Final stage of a single pass open cycle liquefier
- Liquefaction accomplished by a hybrid system, part open cycle liquefier and part closed cycle refrigerator.

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High Efficiency Transfer Lines

- Current operational techniques lose approximately 20,000 gallons during chilldown
  - Brute force approach using only latent heat
  - Vapor is route to flare stack and burned
- In the event of scrub, lines are purged with GHe and warmed back up
  - Similar loss profile the next attempt
- Current Line Heat Leaks (1” LN2 pipe)
  - Bare Pipe (190 W/m): Foam (20 W/m) Vacuum Jacket (0.4 W/m)
- Targeted Heat Leak Values
  - Vapor Shielded Lines 0.04 W/m
  - Reduces LC39 transfer line heat leak from 1000 W to 100 W, within range of refrigeration system
- High efficiency transfer lines, based on similar helium lines for national laboratory systems, can be developed for spaceport hydrogen applications
- Lines are custom designed for individual applications
- Cost models are well known
- LH2 HETF application has unbalanced flow, extended no flow durations, higher temperatures than LHe
Economic Justification

- Several studies over the past 40 years have shown economic payback of hydrogen ZBO system at LC-39
- A new economic model is being developed to incorporate Project H elements
- Payback period depends on LH2 cost, electric cost, storage volume, refrigeration efficiency, hydrogen recovery modes, and capital costs
- Payback period varies from 5 years to 12 years compared to current system
- Only considers hydrogen and electrical cost, does not include labor savings
- More detailed models are currently being developed, including peak and average demand estimates
Estimates shown are for average demand only, peak demand calculations and load balancing is in work.

**Demand Model**

### Current State of the Art

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### Proposed Hydrogen System

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Reduced Hydrogen Production
Environmental Benefits

- Hydrogen production and liquefaction is a very energy intensive operation
- Reduction in hydrogen losses will have environmental benefits
- Preliminary environmental impact estimates have been done to quantify the carbon savings associated with this proposed system
- Savings come from reduced production demands, reduced liquefaction energy demands, and transportation savings.
- Does not account for increased production efficiency or carbon capture technology during production

- CO2 savings equate to eliminating the carbon footprint of 2100 people or eliminating 2800 cars from the road.

<table>
<thead>
<tr>
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<th>Annual LH2 Production (millions of gallons)</th>
<th>GH2 Production Energy Required (MWh)</th>
<th>Liquefaction Energy Required (MWh)</th>
<th>Total Energy Required (MWh)</th>
<th>CO2 Emitted (millions of lbs)</th>
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Conclusions

• Current Kennedy Space Center practice results in half the hydrogen purchased being lost
  - Leads to large economic losses
• KSC needs are different than other industrial gas customers
• The industrial gas companies are optimized for other customers needs
• KSC should modernize its liquid hydrogen systems, taking into account cryogenic advances made in the past 50 years, to optimize life cycle costs for the unique KSC application

• Project H ideas for local hydrogen production, gaseous distribution, integrated refrigeration and storage, and high efficiency transfer lines should be investigated further