the Energy to Lead

# GTI Advanced Energy Systems

## Infrastructure Basics
## for an Emerging Hydrogen Fuel Alternative

## AIChE South Texas Section

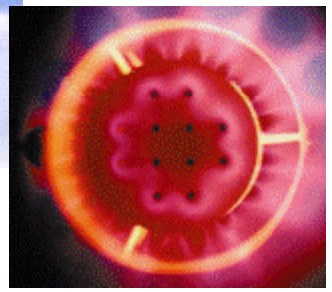
**Brian Weeks**

**3-4-10**

# Discussion for Today

- Who is GTI
- Why Hydrogen and Fuel Cell Vehicles
- Hydrogen Infrastructure Basics
- Hydrogen Safety

# Gas Technology Institute



**Solving Important Energy Challenges via:**

- > Contract Research
- > Program Management
- > Technical Services
- > Education and Training

**> Over 1,000 patents**
**> Nearly 500 products commercialized**



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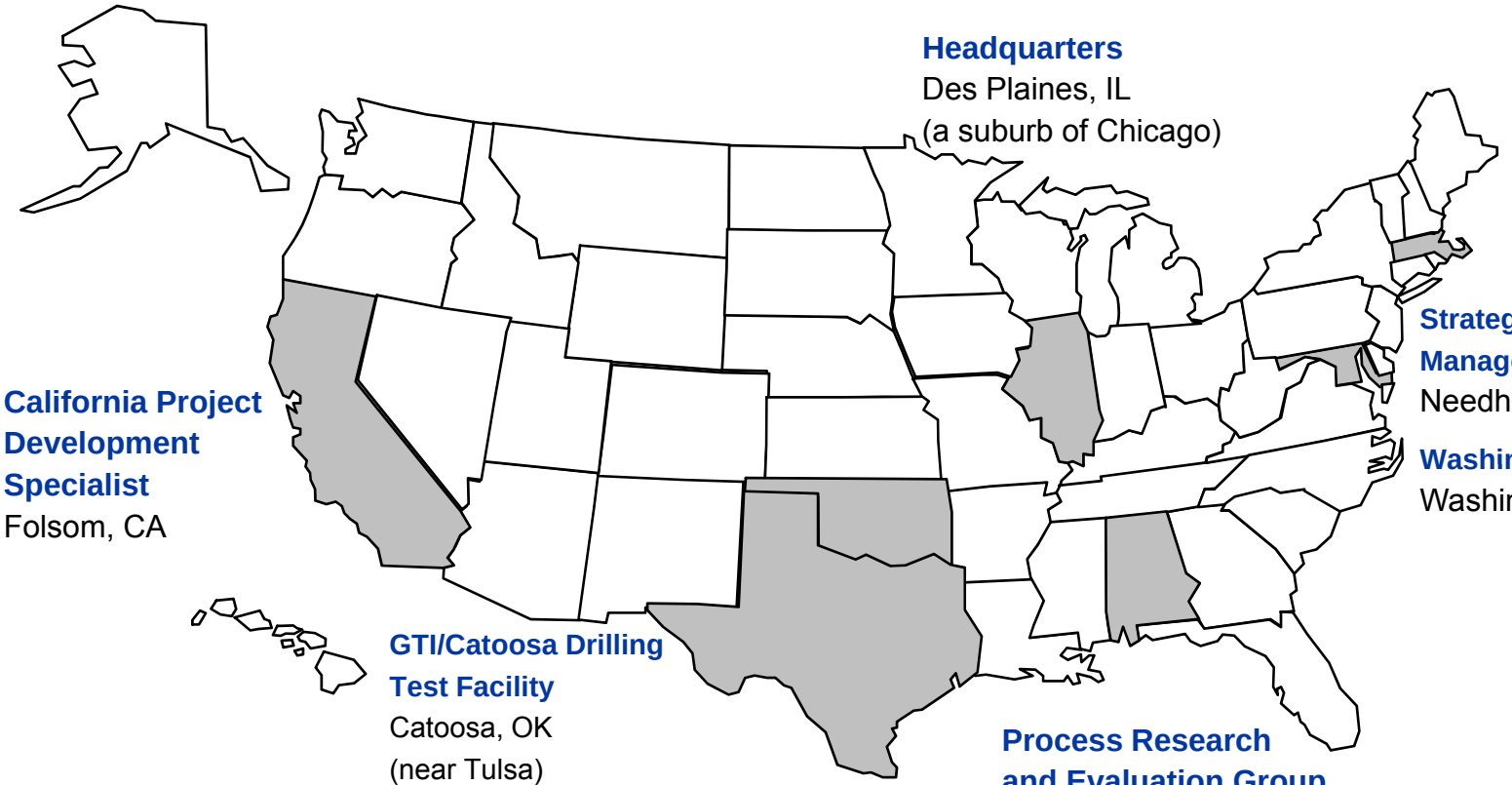
# GTI Locations



**Headquarters**
Des Plaines, IL
(a suburb of Chicago)

**California Project Development Specialist**
Folsom, CA

**Strategic Account Management**
Needham, MA (NGA)

**Washington Operations**
Washington, DC

**GTI/Catoosa Drilling Test Facility**
Catoosa, OK
(near Tulsa)

**Regional Office**
Houston, TX

**Process Research and Evaluation Group**
Birmingham, AL

# Why Hydrogen?

- Recognition that the cost of fuel includes social costs
- There are clear private sector benefits to adopting hydrogen and fuel cell technology
- International Auto and Energy Companies are investing big bucks
- $120 oil
- Government is on board



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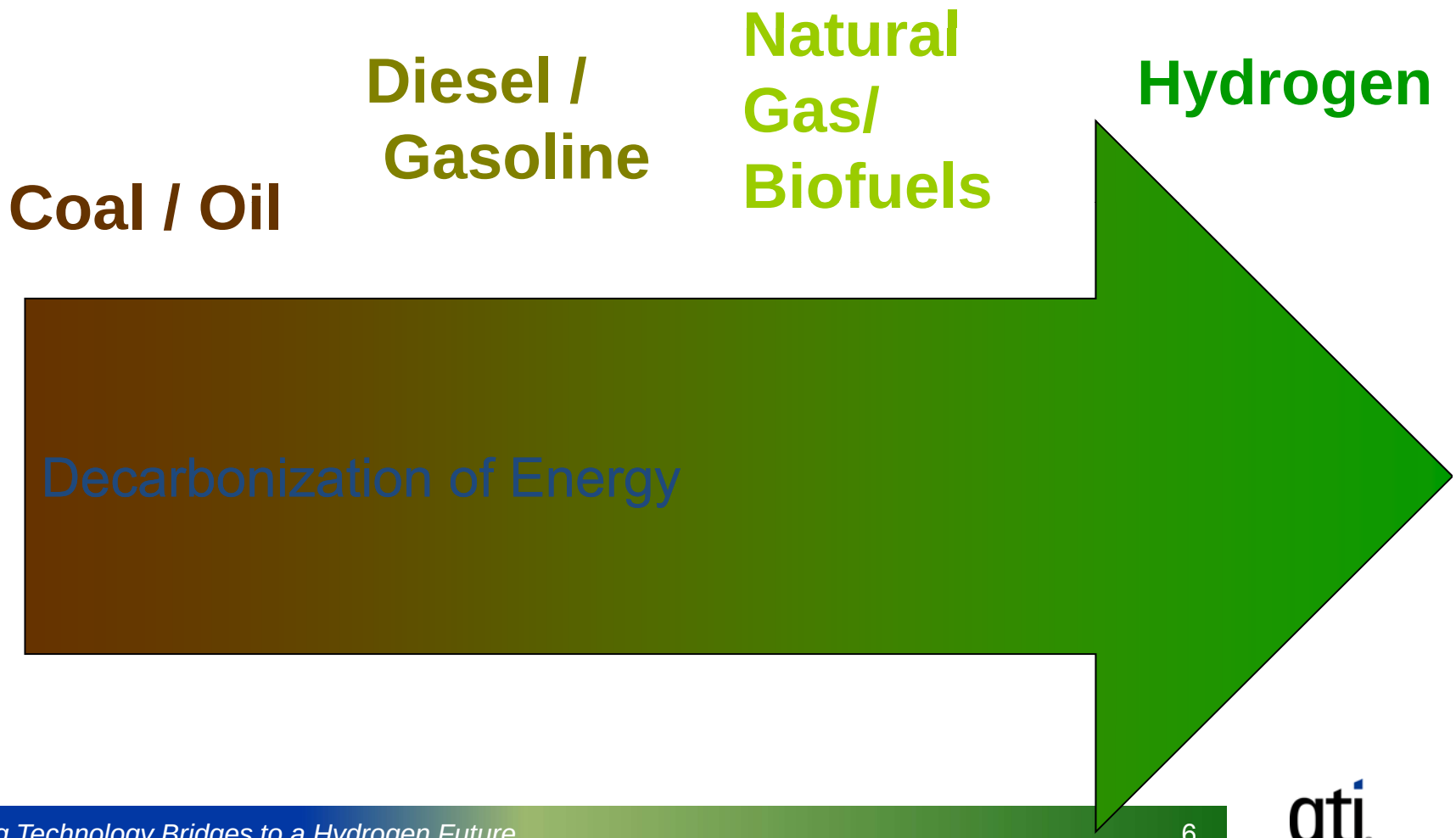
# Evolution of the Fuels Industry

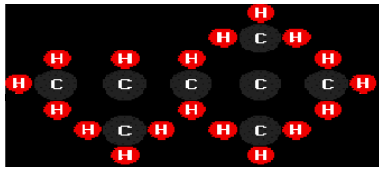


# Carbon Content of Transportation Fuels

## Today's Fuels

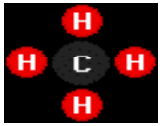
**Diesel C16H34**

**Gasoline C8H18**

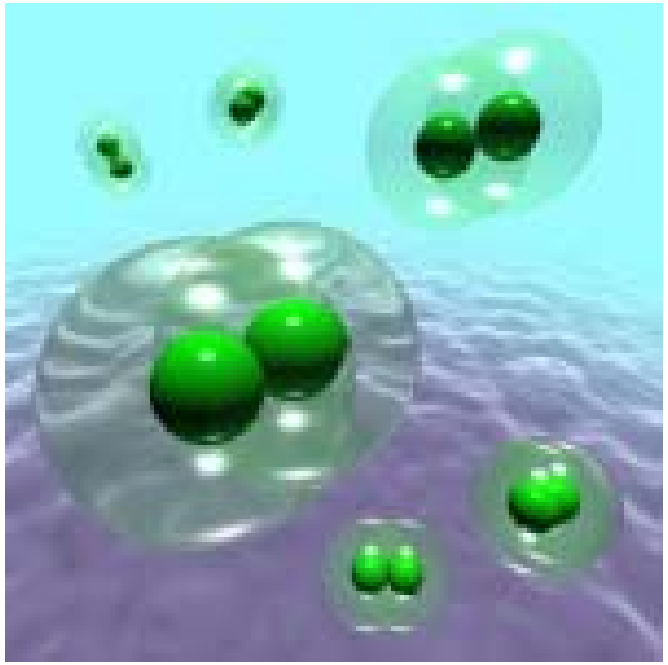


**Propane C3H8**

**Natural Gas CH4**



**Hydrogen**





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# Hydrogen Facts

- 1 kg of Hydrogen (2.2 lbs) = 113,500 btu's = 1 gal of gasoline (6 lbs)
- At $6 natural gas, hydrogen costs $1- $2 / gge to make
- Hydrogen is highly flammable, but less explosive than natural gas or gasoline.
- Most of the cost of Hydrogen comes from storage and transportation (60% - 90% of delivered cost)
- Compressed hydrogen is stored on vehicles at slightly higher pressures than NGV's



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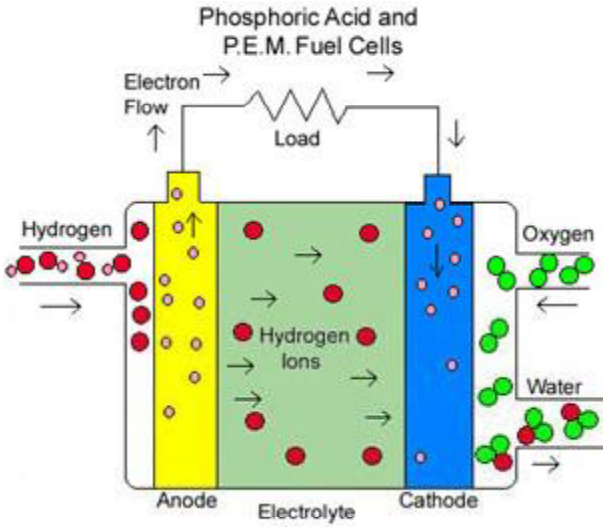
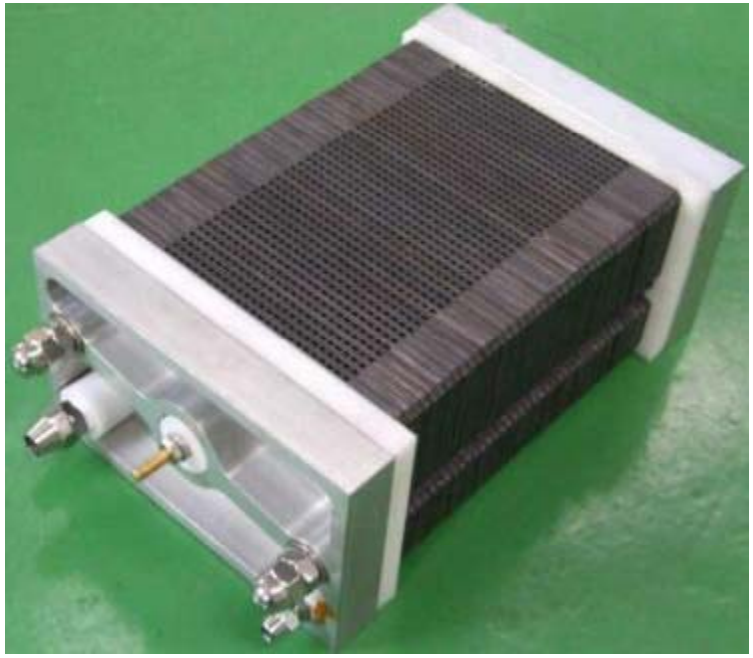
# Hydrogen Facts Continued

- 95% of hydrogen produced worldwide comes from Natural Gas.
- There a 8.7 million NGV's on the road worldwide (only 250K in the U.S.) so compressed gas vehicles are common in most of the developed world.
- Growth of hydrogen as a fuel can lead to economic development for Texas.

# What is a Fuel Cell?



# Fuel Cell Types

| Fuel Cell Type | Time to Market | Temp (°C) | Applications |
|---|---|---|---|
| Alkaline | Present | 70-90 | Space Shuttle |
| Phosphoric Acid | Present | 150-210 | Power, 250kW+ |
| **Proton Exchange** | **Present** | **70-90** | **Mobile** |
| **Solid Oxide** | **Emerging** | **800-1000** | **Power, 1 kW – 1 MW** |
| Molten Carbonate | Present | 550--650 | Power, 250 kW+ |

# Why Fuel Cell Vehicles?

| Performance Feature | Conventional Vehicle | Fuel Cell Vehicle |
|---|---|---|
| Emissions | | ✓ |
| Performance and Efficiency | | ✓ |
| Versatility | | ✓ |
| Range and Convenience | ✓ | |
| Cost | ✓ | |



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# Comparing Performance of Conventional and Hydrogen Buses

| Drive / Emissions | Nox (g/mi) | PM (g/mi) | CO2 (g/mi) | Fuel Consmpt | Emissions Reduction |
|---|---|---|---|---|---|
| **Conventional Diesel** | 30 | 0.24 | 2200 | 4 mpg | Poor |
| **Conventional CNG** | 15 | .02 | 2500 | 3.3 mpgde | Better |
| **Hydrogen CNG (HCNG)** | 7-8 | 0 | 2300 | 3.3 mpgde | Very Good |
| **Hybrid Diesel** | 13-16 | .03 | 1700 | 5 - 6.5 mpg | Good |
| **Hybrid CNG** | 2 | .01 | 2000 | 3.9 mpgde | Very Good |
| **Hybrid Gasoline** | 0.5 | 0 | 2100 | 3.4 – 6 mpgde | Very Good |
| **Hybrid Hydrogen ICE** | 0.5 | 0 | Nil | 7 mpgde | Excellent |
| **Hybrid Drive Fuel Cell** | 0 | 0 | 0 | 8 – 11 mpgde | Excellent |

# Fuel Cell Vehicles




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# Fuel Cell Cars – Here Today




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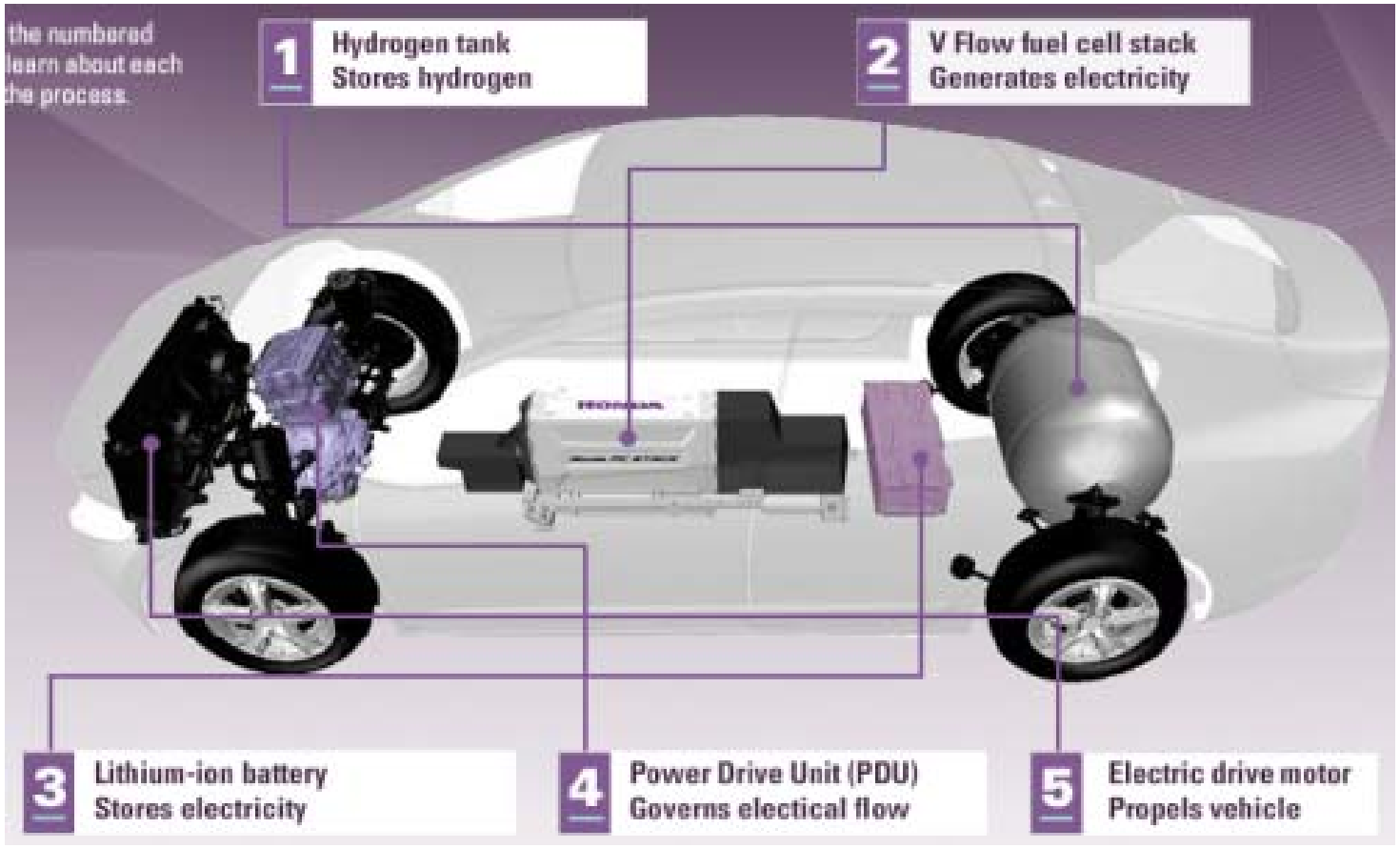
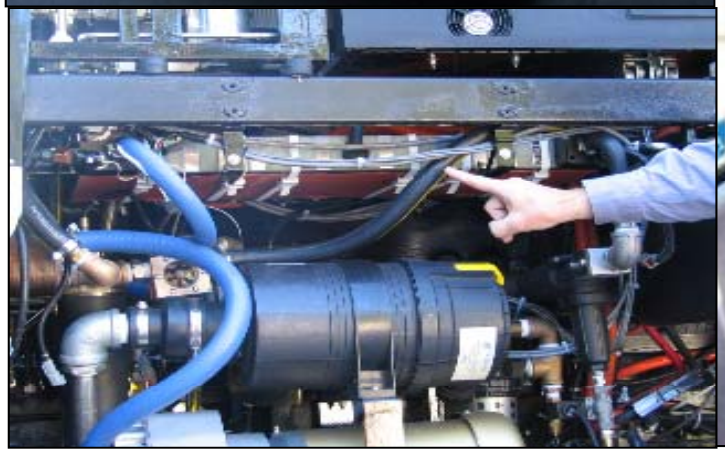
# Fuel Cell PowerTrain



# A Fuel Cell Bus for Texas



# Recently Completed a Nine Month Test Program

- Ebus 22’ Shuttle Bus
  - Two hydrogen tanks
  - 60 kWh NiCD Batteries
  - 19.1 kW Ballard Fuel Cell Stack
  - 40 mile range on batteries alone
  - 180 to 200 mile range with fuel cell and batteries
  - Has regenerative braking for improved fuel economy

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# Proterra Bus to Arrive in Austin in 2011

35’ Transit Bus
Fuel Cell / Battery Hybrid Bus
Ground-up design
Regenerative Braking
Up to 10 mpg equivalent

# Industrial Truck Market is a Near-term Commercial Application

**Value Drivers:**

- Lower cost than electric batteries
- Increased productivity
- Better performance
- Frees up warehouse space

**Observations:**

- Focus is on battery replacement (not outdoor forklifts)
- Infrastructure not as much of an issue
- Government is big supporter
- Three projects in Texas



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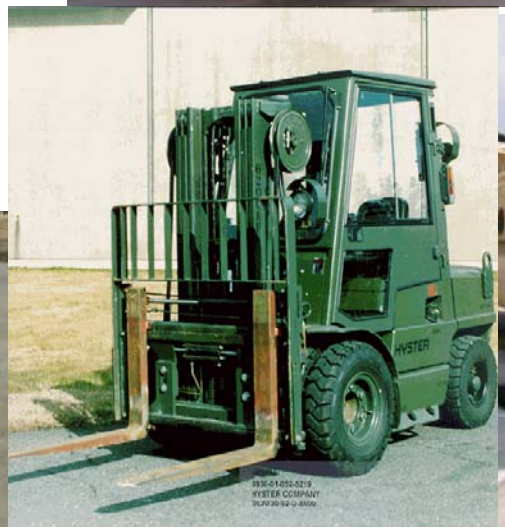
# DOD Facilities with Hydrogen Vehicle Demonstrations

Selfridge ANGB
Hickam AFB
Robins AFB
Grand Forks AFB
Ft. Belvoir
Ft. Lewis
San Joaquin Distribution Ctr



# Hydrogen Infrastructure

- One of the biggest obstacles for fuel cell vehicles is lack of a national supply infrastructure
- Fewer than 100 stations in North America
- Most stations are on the coasts (CA, NY, SC, FL, WA, BC)



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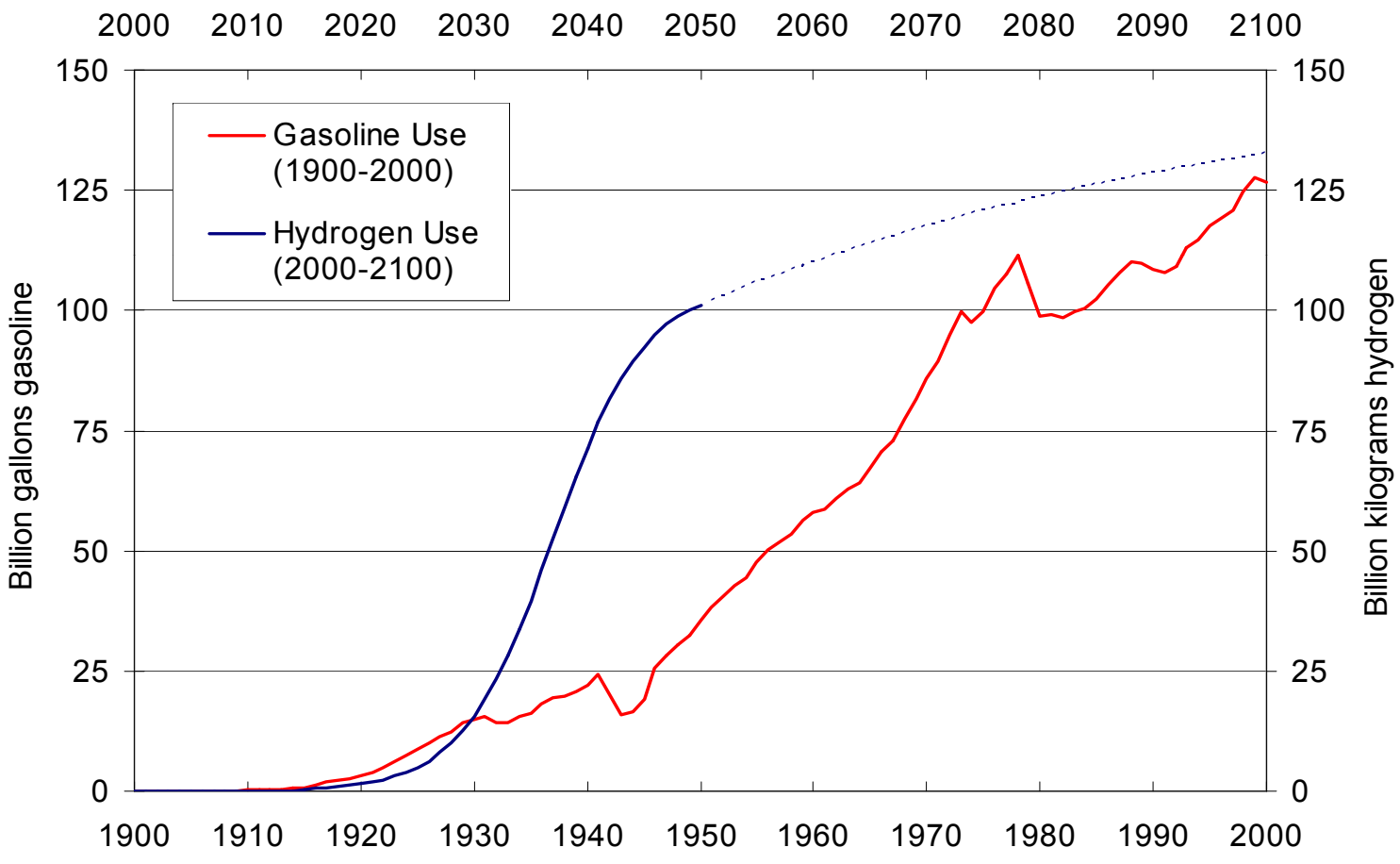
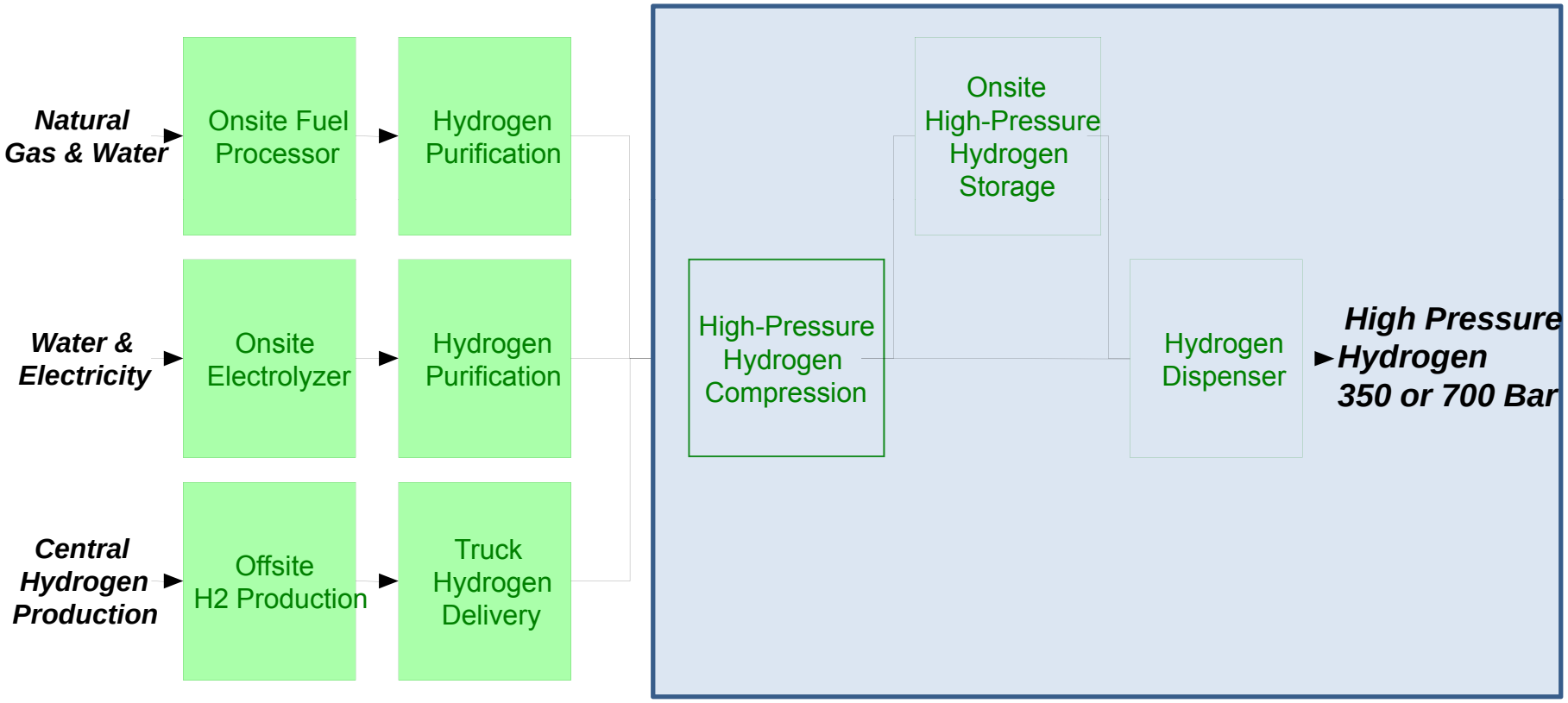
# Hydrogen Infrastructure
# Building an Industry Takes Years




Comparison of Gasoline's market growth with that projected for Hydrogen (NAS 2004 Study)

# Basic Hydrogen Station Flow Process



# Hydrogen Supply

Reformer
- Low variable cost
- high capital cost
- high efficiency
- low emissions


Hydrogen Tube Trailer
- readily available
- High variable cost
- low efficiency
- high emissions

Electrolyzer
- High capital cost
- Med variable cost
- Med efficiency
- Med emissions



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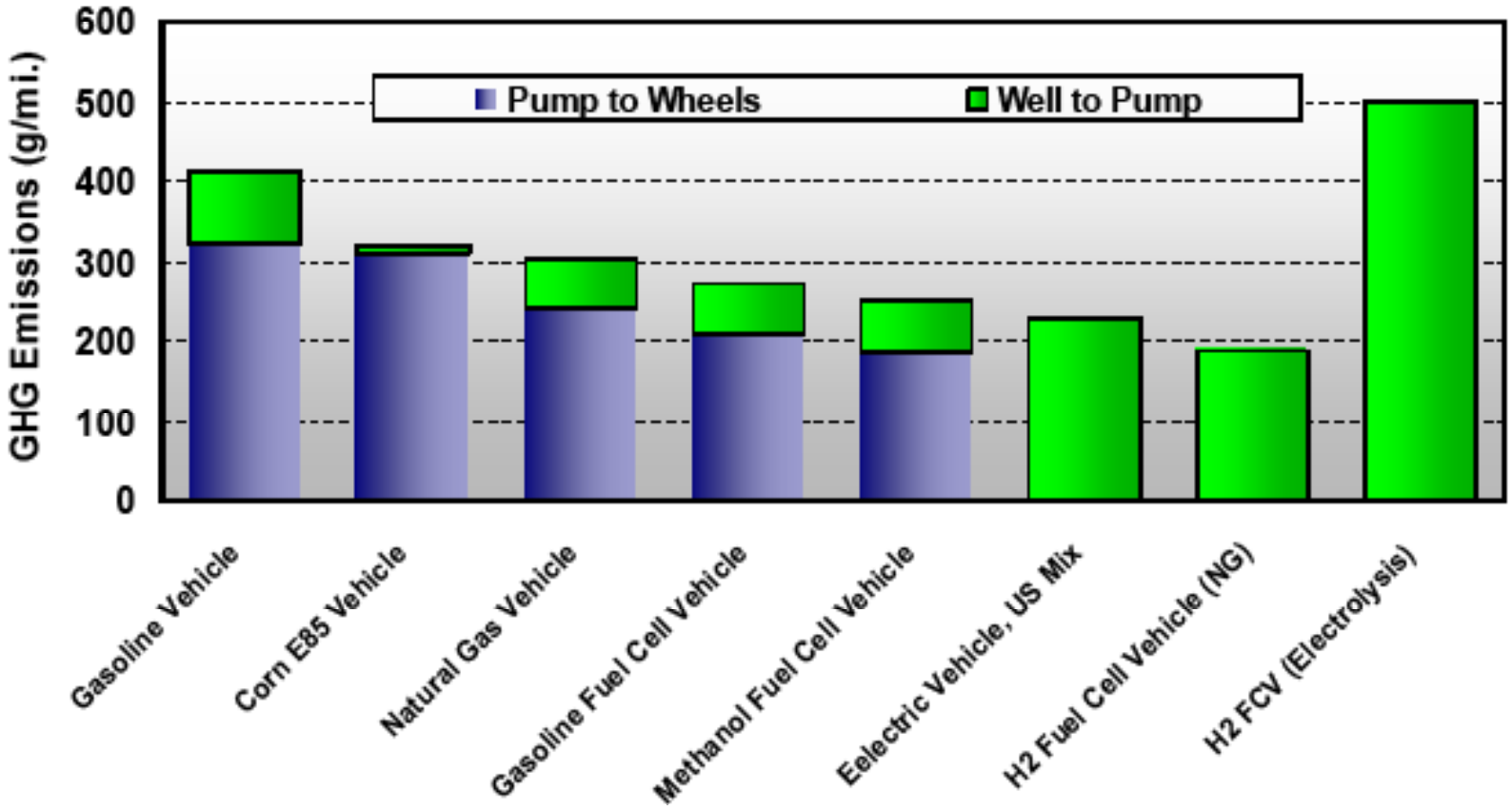
# Well to Wheels GHG Emissions
# Comparison of Vehicle/Fuel Combinations




Argonne National Lab, Transportation Technology R&D Center

# Fueling Station Technology of a Decade Ago

# Existing Hydrogen Station Prototypes




# 4 Case Study Examples

- Electrolysis – SMUD
- Delivered Hydrogen – Columbia, SC
- On-site Steam Methane Reformation – Austin, Tx
- On-site Waste Water Digester Gas – Ft. Lewis, Wa

# Hydrogen Fueling Station Examples

## SMUD's Solar-Powered Station - Sacramento

**High Cost – Low Capacity – Zero Emissions – big "WOW" factor**



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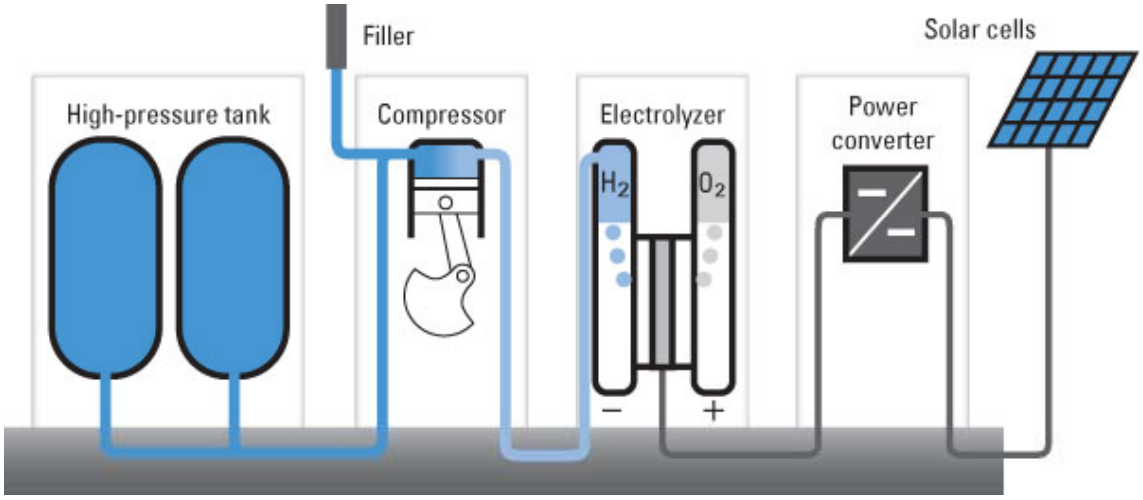
# Electrolysis based stations offer on-site generation options for small fleets

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# Hydrogen Fueling Station Examples

## GTI's Hydrogen Station in South Carolina


**Low cost – small footprint –big "practicality" factor**

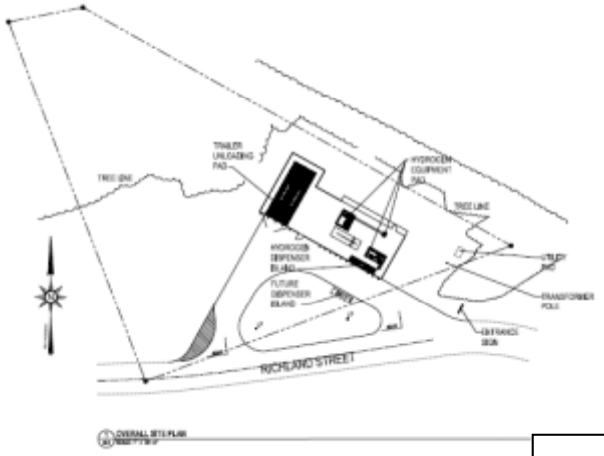
# Two GTI Station Examples

## Columbia Station

**Columbia, SC**

**Station Capacity: 120 – 130 kg/day**

**Tube Trailer Delivery**



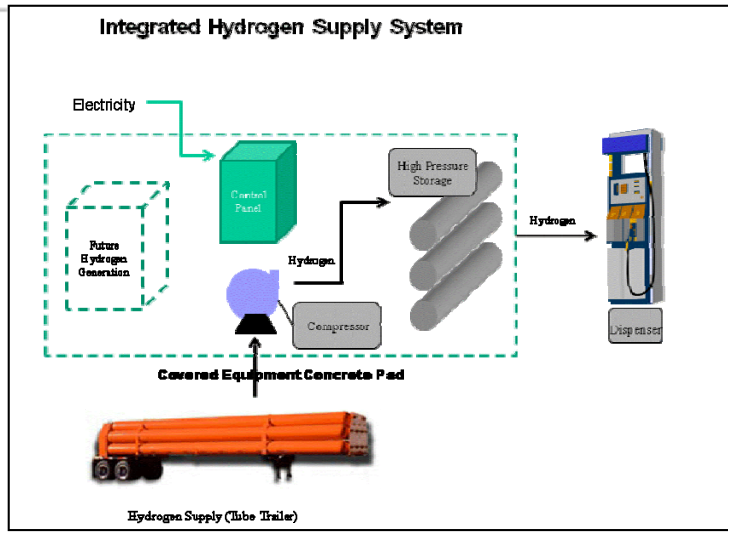

**CSD Installed Cost: $825k**

**Hydrogen Cost: $14 per kg**

**Site Eng/Prep: $200K**

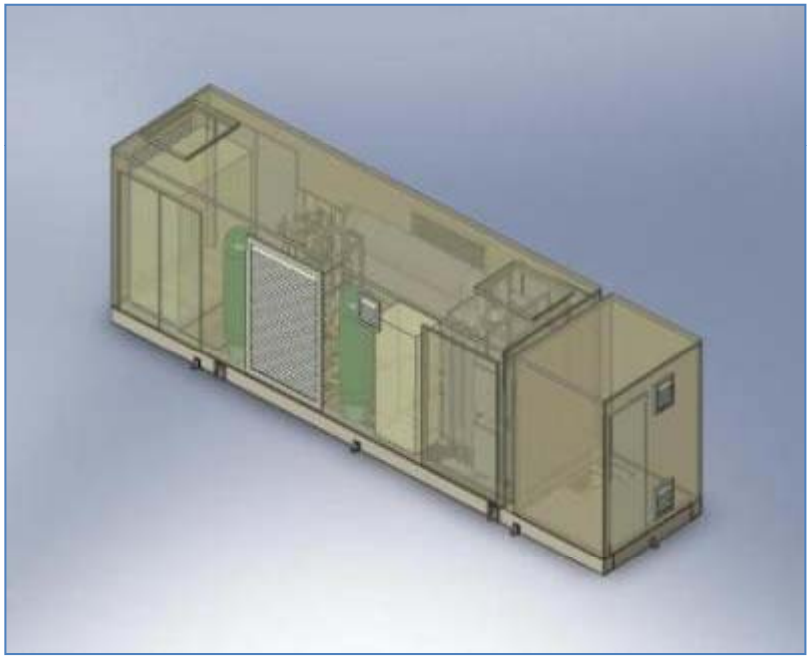
**Contract to Commissioning:**

**10 months**




"Conventional" delivered hydrogen station design

# Austin Hydrogen Fueling Station
# Integrated SMR On-site $H_2$ Generation





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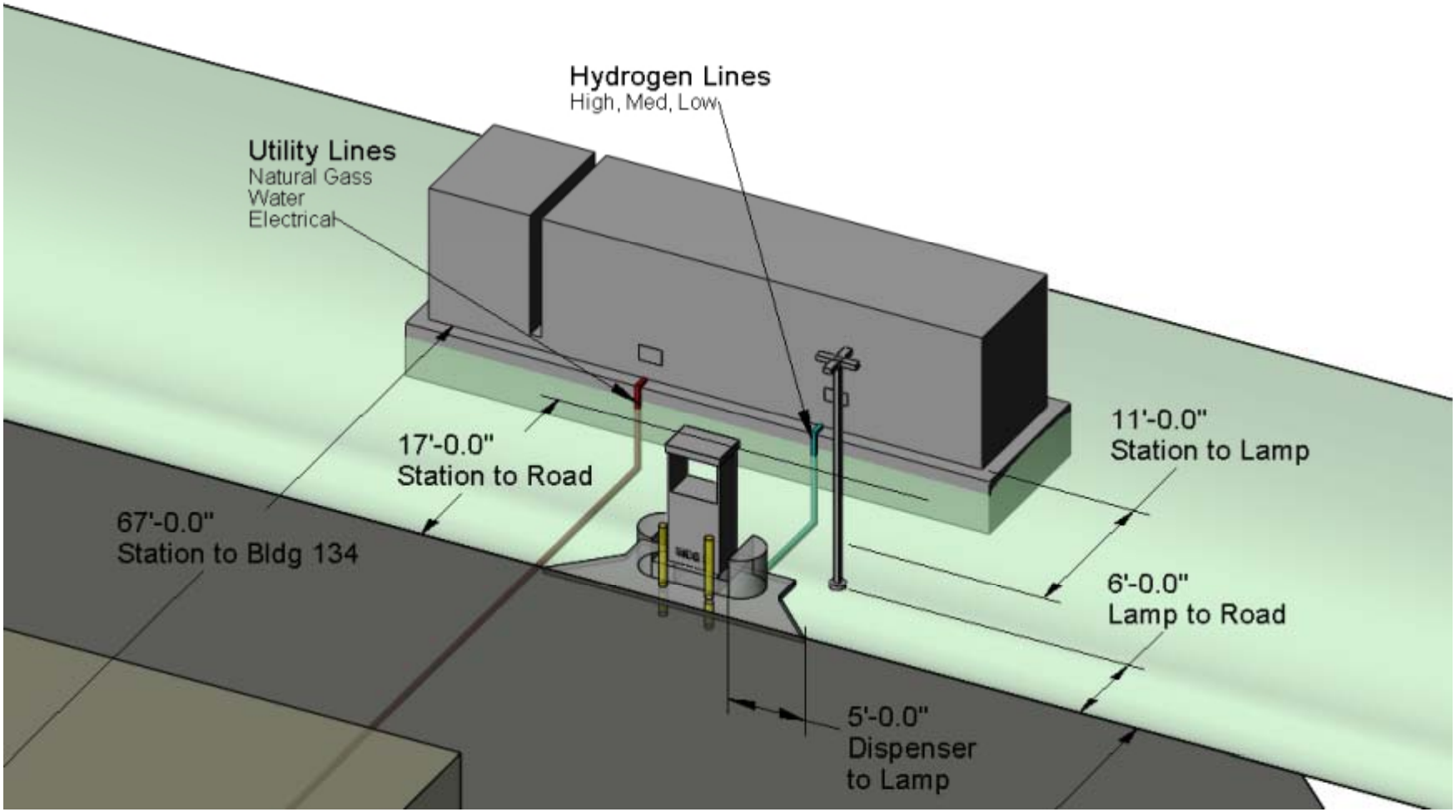
# Installation layout of Pre-fab Hydrogen Station



# Skid-mounted Hydrogen Fueling Station

**Pictorial Journey from Factory to Station site.**

# Fueling station arrives at University of Texas

Pad site ready for installation

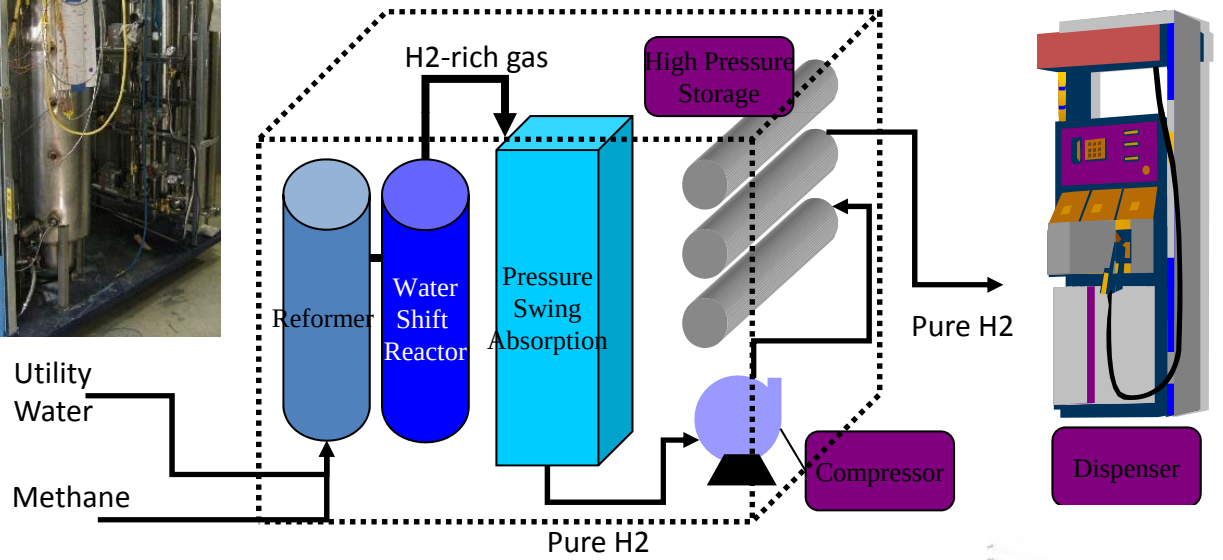
Station being lowered into place (operation took about 30 minutes).

## Final connections being made – dispenser and hydrogen supply lines

# Austin Hydrogen Station and Fuel Cell Bus

# GTI Integrated Hydrogen Supply System

## Flow Process Diagram




**Integrated Hydrogen Supply System**

United States Department of Energy
Cooperative Agreement DE-FC04-02AL67607
August 2007



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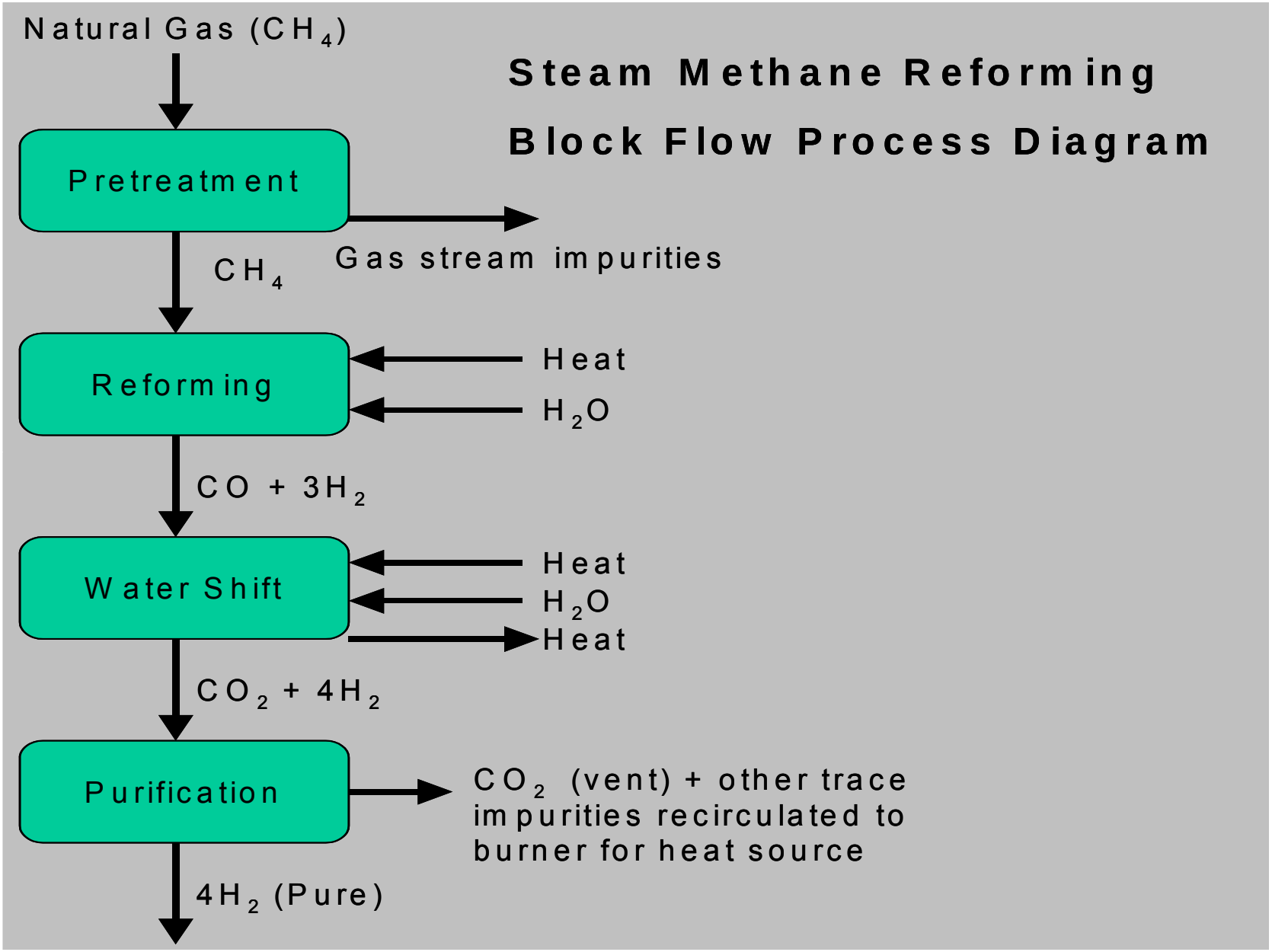
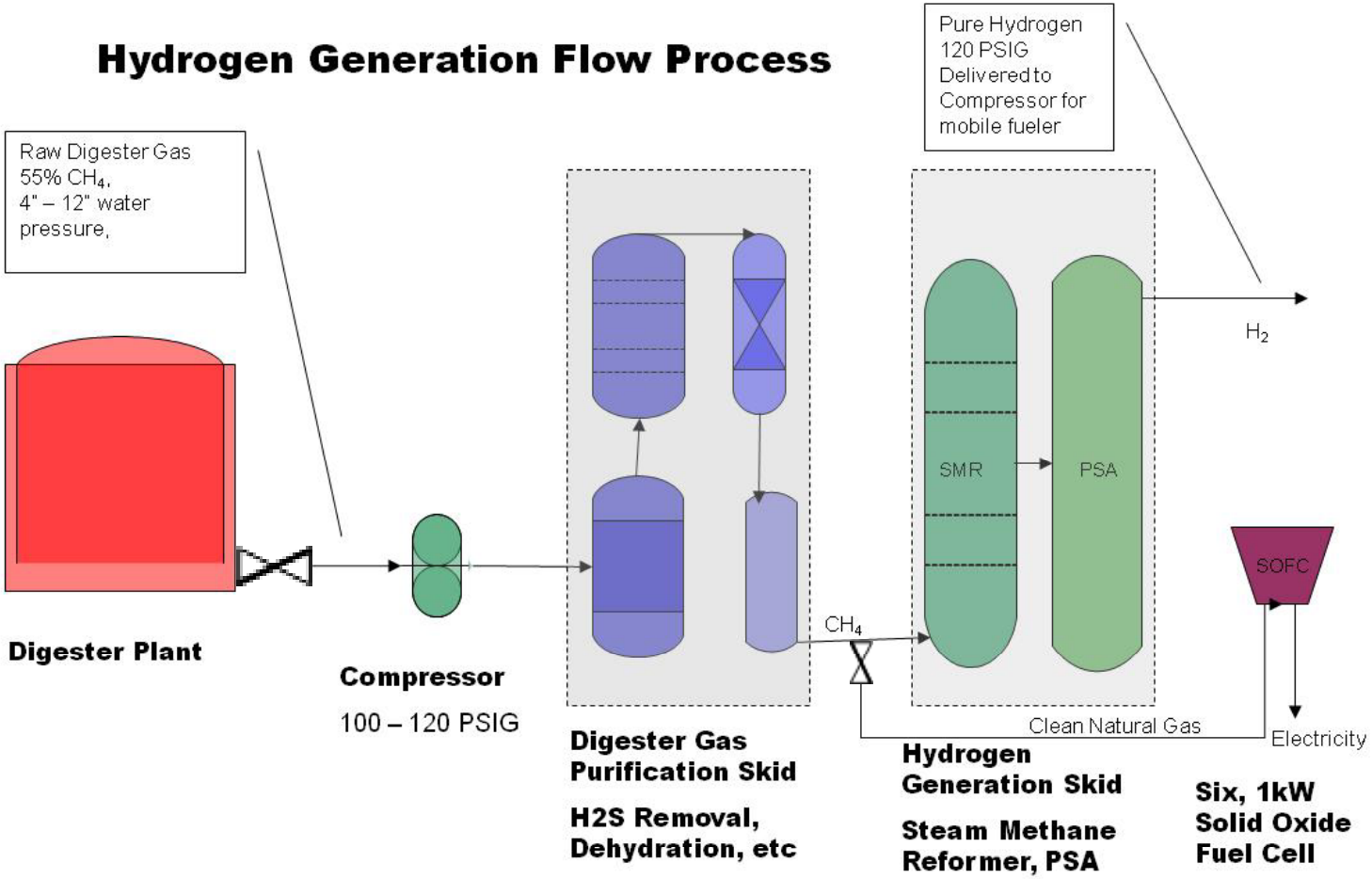
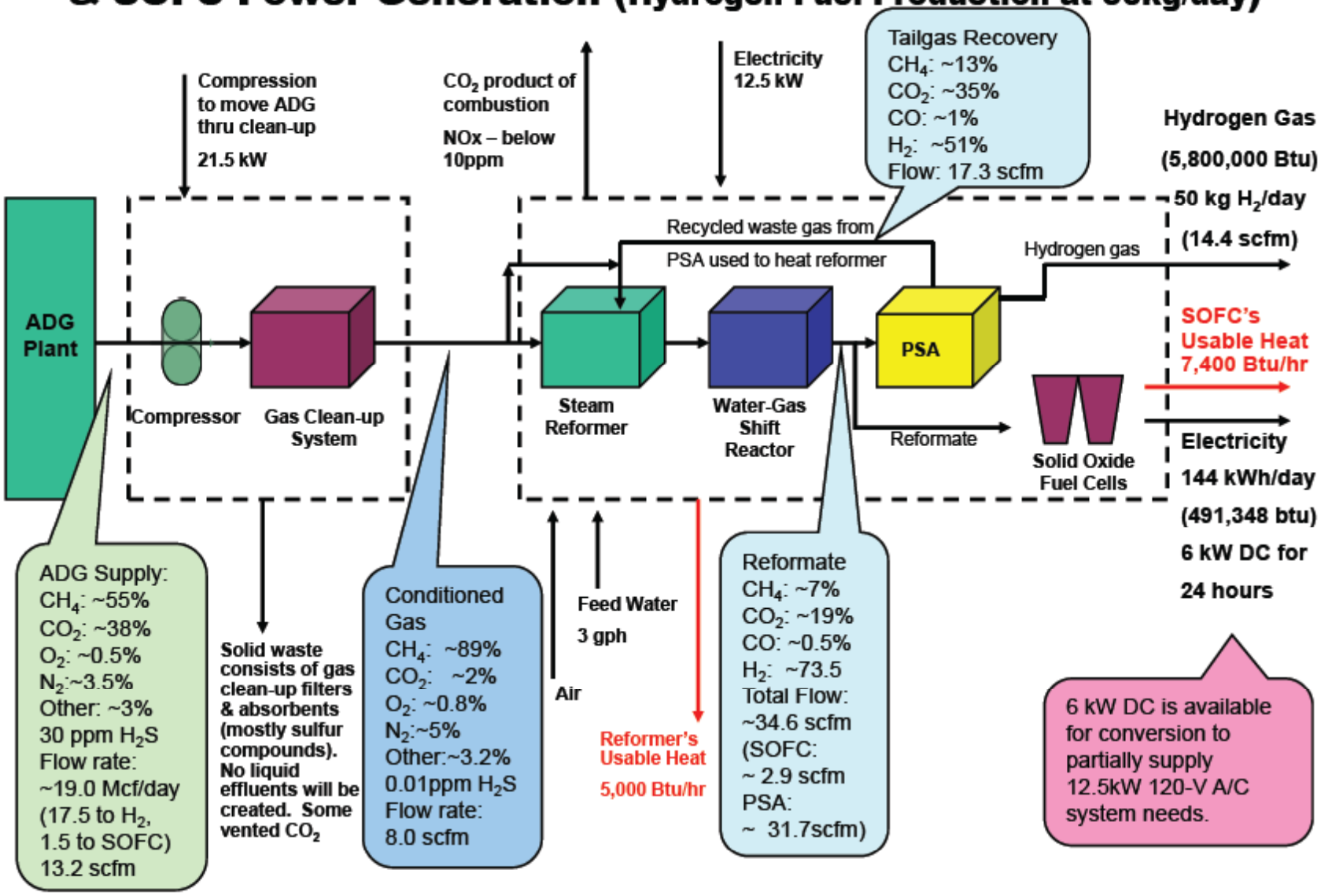

Natural Gas ($CH_4$)
Steam Methane Reforming
Block Flow Process Diagram
Pretreatment
Gas stream impurities
$CH_4$
Reforming
Heat
$H_2O$
$CO + 3H_2$
Water Shift
Heat
$H_2O$
Heat
$CO_2 + 4H_2$
Purification
$CO_2$ (vent) + other trace impurities recirculated to burner for heat source
$4H_2$ (Pure)

# Ft. Lewis WWDG Hydrogen Generation Process Flow Diagram

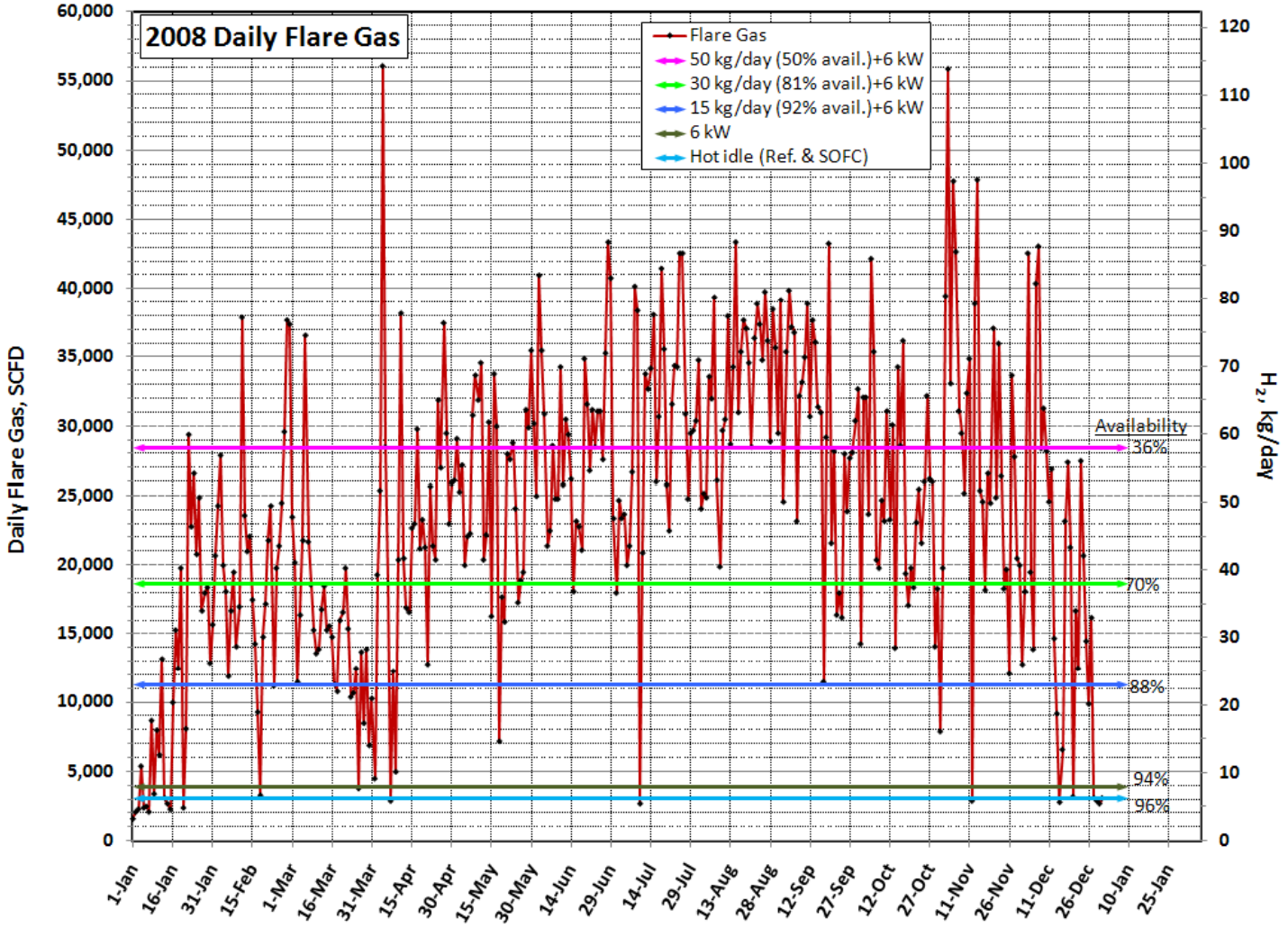


# Process Flow Diagram for On-site Hydrogen Supply System & SOFC Power Generation (Hydrogen Fuel Production at 50kg/day)



# BioGas Sources Present Process Controls Challenges

## Daily Digester Gas Production Rates (2008)



# Natural gas infrastructure can reduce hydrogen infrastructure costs

- 2% of North American natural gas production can fuel 10 million hydrogen cars!
- Converting natural gas to hydrogen on-site has the fewest emissions of any commercial method.
- Hydrogen from natural gas is the least expensive option for hydrogen today
- Hydrogen from natural gas yields CO2 reductions greater than 50% and almost no other emissions.
- Renewable hydrogen processes are technically feasible, but expensive



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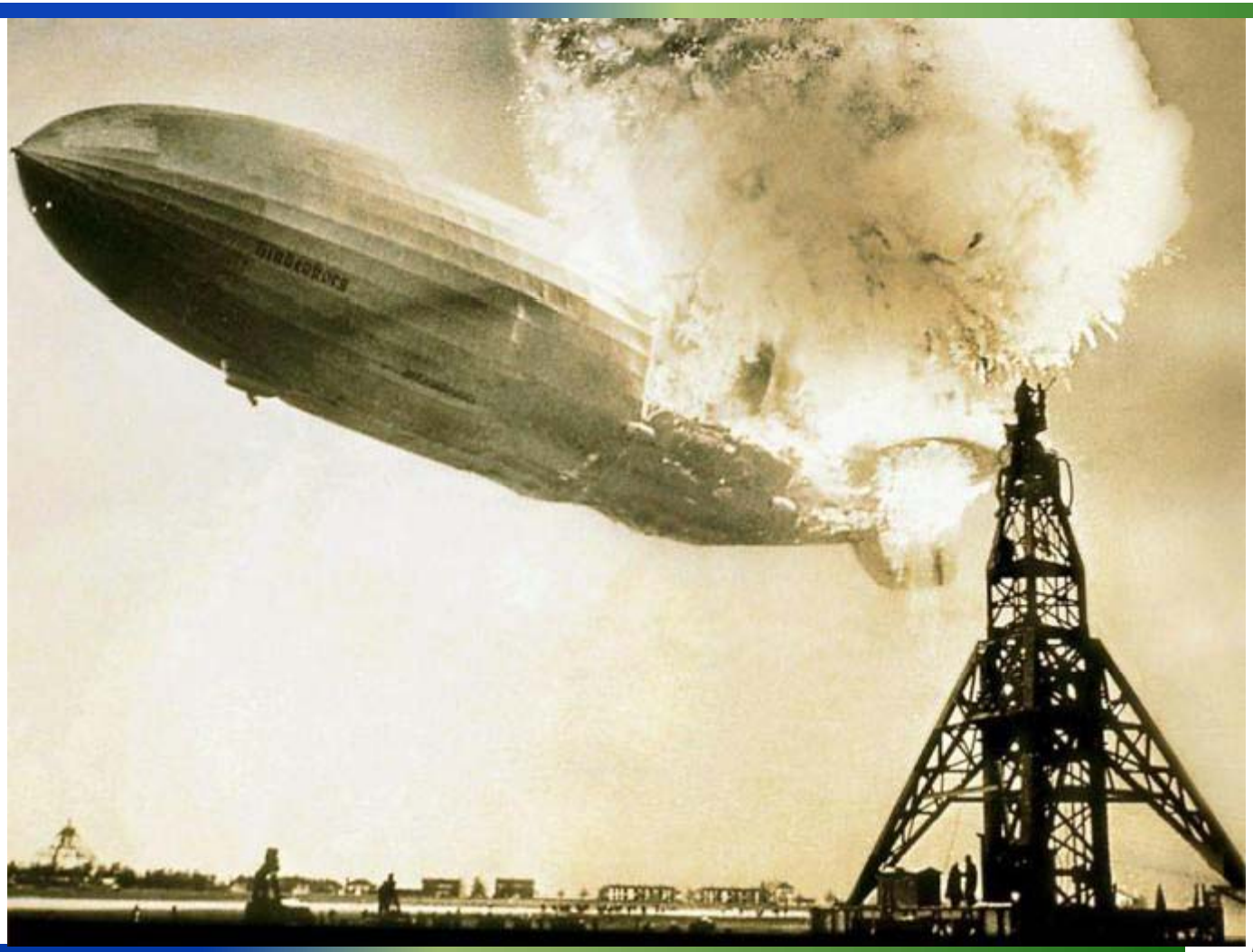
# Hydrogen Safety



# Cars on Fire!
# Hydrogen and Gasoline

Photo 1 - Time: 0 min, 0 sec - Hydrogen powered vehicle on the left. Gasoline powered vehicle on the right.



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# Cars on Fire!
# Hydrogen and Gasoline

Photo 2 - Time 0 min, 3 seconds - Ignition of both fuels occur.
Hydrogen flow rate 2100 SCFM. Gasoline flow rate 680 cc/min.



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# Cars on Fire!
# Hydrogen and Gasoline

Photo 3 - Time: 1 min, 0 sec - Hydrogen flow is subsiding, view of gasoline vehicle begins to enlarge



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# Cars on Fire!
# Hydrogen and Gasoline

Photo 4 - Time: 1 min, 30 sec - Hydrogen flow almost finished. View of gasoline powered vehicle has been expanded to nearly full screen



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# Cars on Fire!
# Hydrogen and Gasoline

Photo 6 - Time: 2 min, 20 sec - Deflagration in the interior, following frame shows flames exiting around edges of trunk lid.



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# Cars on Fire!
# Hydrogen and Gasoline

Photo 7 - Time: 2 min, 40 sec - Frame prior to driver's side rear tire rupture.

# Cars on Fire!
# Hydrogen and Gasoline

Photo 8 - Time: 2 min, 40 sec - Driver's side rear tire rupture sends debris out the passenger side of the vehicle.

# Summary

- Hydrogen is Safe
- Hydrogen is a domestic fuel
- Hydrogen is clean
- Hydrogen is efficient
- Hydrogen is a high value fuel
- Hydrogen is here now
- A forward-looking energy portfolio will include Hydrogen

# GTI Upcoming Events/Partnering Opportunities

- **Global Unconventional Gas 2010**
  **Unlocking Your Potential**
  **When:** June 15-17, 2010
  **Where:** Amsterdam, Netherlands
- ARPA – E Proposal on BioFuel Production (See Brian Weeks in GTI Houston office)
- Gas Processing Technology Opportunity (will be at GPA conference in Austin (March 21-24th)

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Creating technology solutions with impact across the energy spectrum

*Thank you for being interested in hydrogen and clean energy!*

*For more information:*

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