Sustainable Mobility and Transportation Fuels

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Today's Talk

- Who is GTI
- Some Thoughts on Sustainability
- Natural Gas Supply and Vehicle Applications
- Hydrogen for FCV's
- Sustainability, NatGas, and Hydrogen

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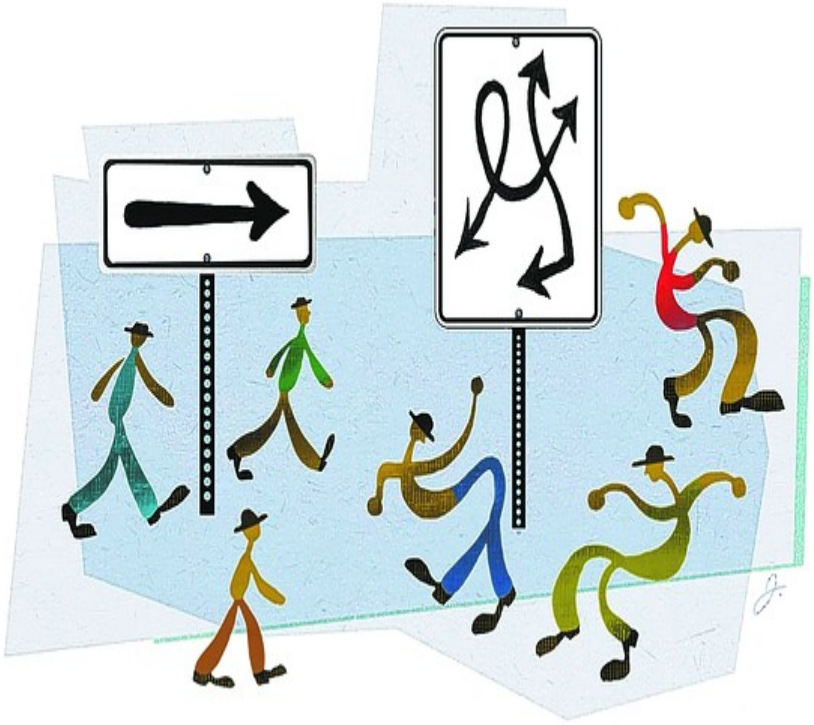
Company Overview

- Independent, not-for-profit established by the natural gas industry
- Headquarters in Des Plaines, IL
- GTI tackles tough energy challenges turning raw technology into practical solutions
- Downhole to the burner tip including energy conversion technologies
- Applied collaborative research, development, & demonstration

RESEARCH & DEVELOPMENT | PROGRAM MANAGEMENT | TECHNICAL/ ANALYTICAL | CONSULTING | TRAINING

How to Achieve Energy Sustainability



Energy Sustainability may be achieved either by changing human behavior or by technology…
Which do you choose?

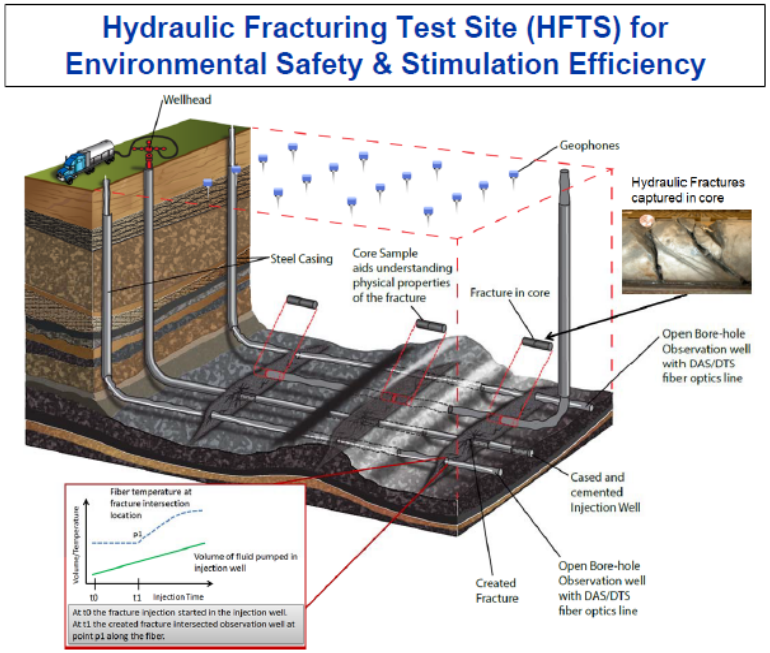
What exactly IS Sustainable Transportation?

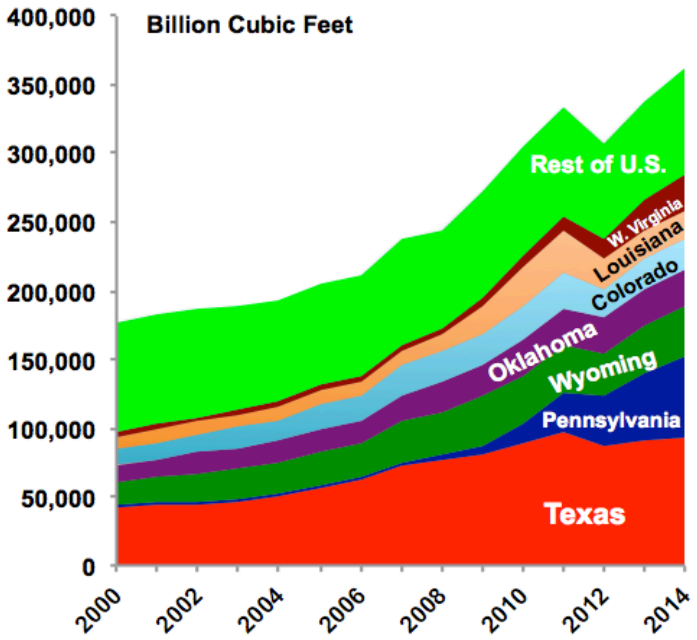
- Fuel?
  - Oil
  - Electricity (Source: Coal, NatGas, Nuclear, Wind, Hydro, Solar)
  - Natural Gas
  - BioGas
  - Hydrogen
- Vehicle Platform?
  - ICE
  - Hybrid
  - Fuel Cell
  - Battery

What are the right questions?

- Are vehicle emissions a disqualifier for sustainable transportation?
- How about a renewable fuel, but with emissions?
- How about zero emissions, but not a renewable fuel?
- What is the price for sustainability?
  - Societal
  - Economic
  - Who Pays?
- Are any of our existing commercial transportation options really 100% “sustainable”?

Natural Gas, a plentiful, but sustainable resource?





In 2000, Texas and Pennsylvania held a combined 24% of U.S. proven gas reserves. They now hold 43%.

Since 2008 alone, thanks to the Marcellus shale play, West Virginia has increased its share of U.S. gas reserves from 1% to 7%.

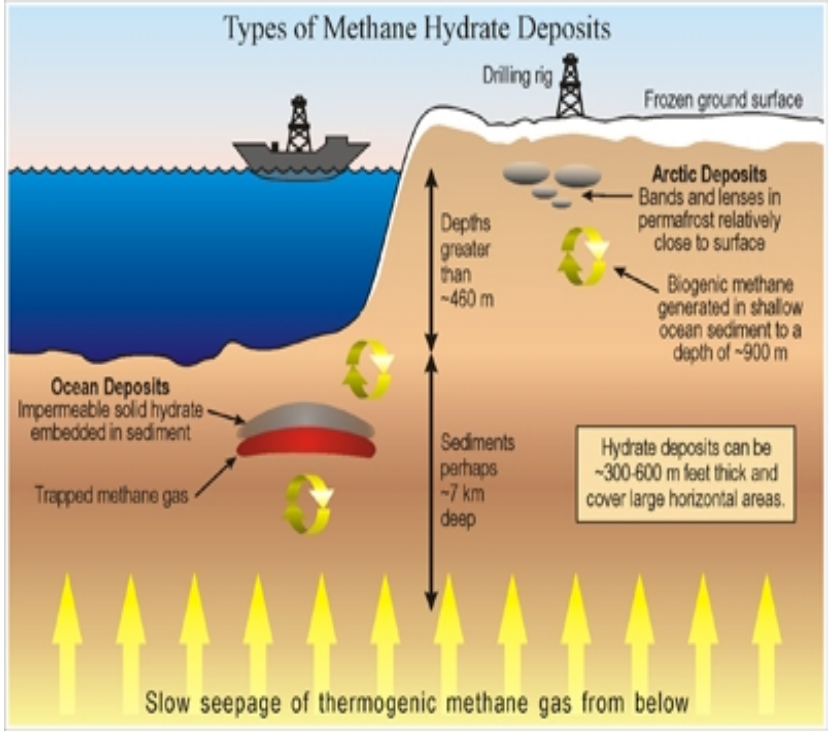
GTI's HFTS Project is enabling higher recovery at lower per unit cost & impact

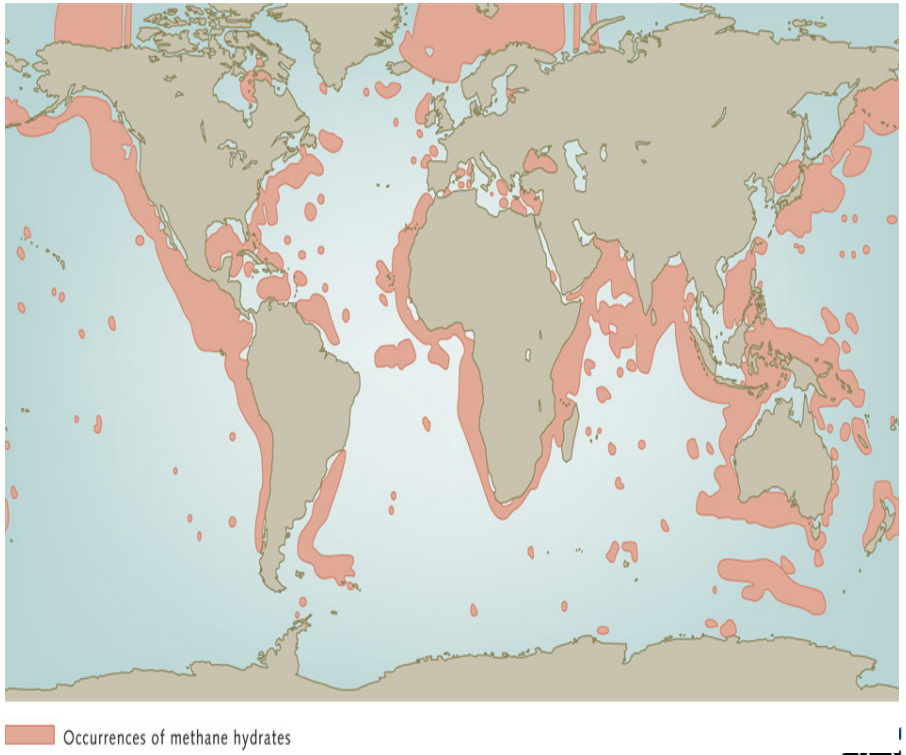
US Proven Natural Gas Reserves – continual upward revisions

Source: EIA 2015 Energy Outlook

Natural Gas, a plentiful, but sustainable resource?

Gas Hydrates represent 2X – 10X conventional reserves
Not economically viable – but remember what we said about technology?





Transportation Sector and Natural Gas Vectors

- Broadly defined, natural gas has a big footprint in U.S. transportation sector
  - Around 1.3 Tcf/year (over 2 Tcf with pipeline use added in*)
  - Indirect and direct uses
- **Indirect uses**
  - **Petroleum refining (0.8 Quads)**
  - **Ethanol production (0.5 Quads)**
  - Other new indirect vectors (e.g., GTL, electric vehicles, etc)
- **Direct uses**
  - **NGVs (CNG, LNG)**: significant upside

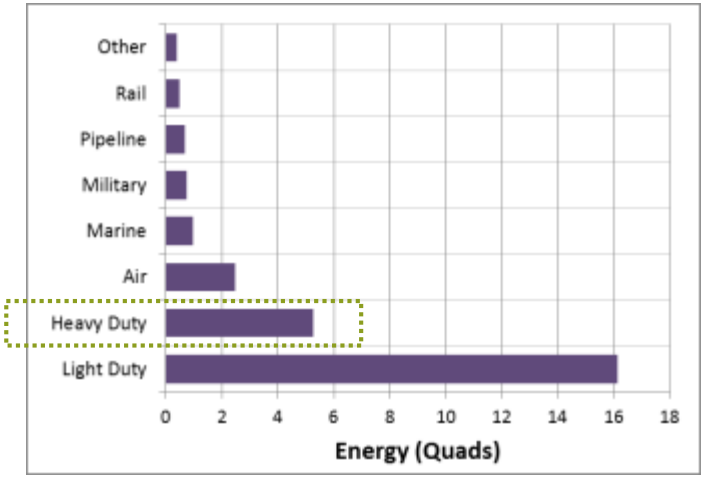
* Natural gas pipelines are part of multi-modal transportation sector (about 0.67 Quads)

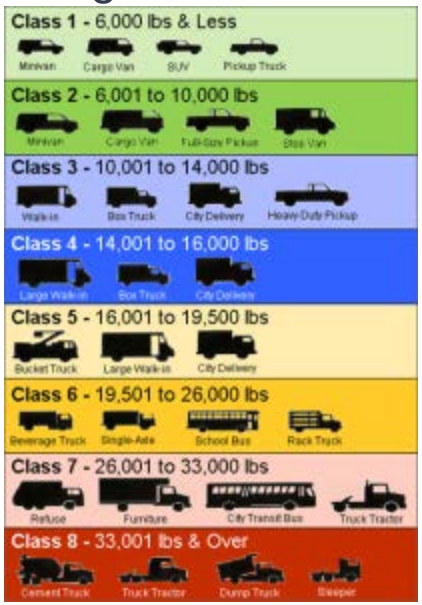
Heavy-Duty Vehicles Represent Key Target Market

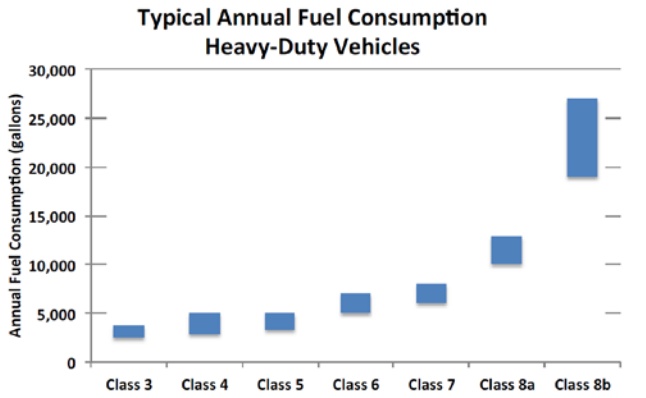
- Over 1.2 Tcf market scenario, with long-term core around freight vehicles
- High-fuel-use fleets see good payback periods today
  - Over 5-10K gallons/year (as high as 20-25K gallons/year)

Vehicle Class	Fuel Displaced (Million Gasoline Gallon Equivalent)	Natural Gas Demand (Bcf)
Freight Trucks	8,913	1,096
Refuse Trucks	579	71
Transit Buses	557	68
School Buses	432	53

High fuel displacement scenario
Source: NGV America







Range of Annual Fuel Use By Heavy Duty Vehicle Class

Hydrogen Supply

Multiple Options… Is any one the "best" for all applications?

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

Hydrogen Tube Trailer
or LH2 Delivery
- readily available
- High variable cost
- low efficiency
- high emissions

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

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
- 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
- Fuel cells and EVs are about on par with each other from an emissions point of view
- Vehicle OEM's are highly motivated to get out from under emissions regulations. Hydrogen balances zero-emissions with performance demanded by consumers.
- Hydrogen-fueled FCV's double the efficiency of ICE vehicles

Sustainability, Hydrogen, Natural Gas

Renewable Natural Gas to Hydrogen…

Sources of biogas for renewable hydrogen…

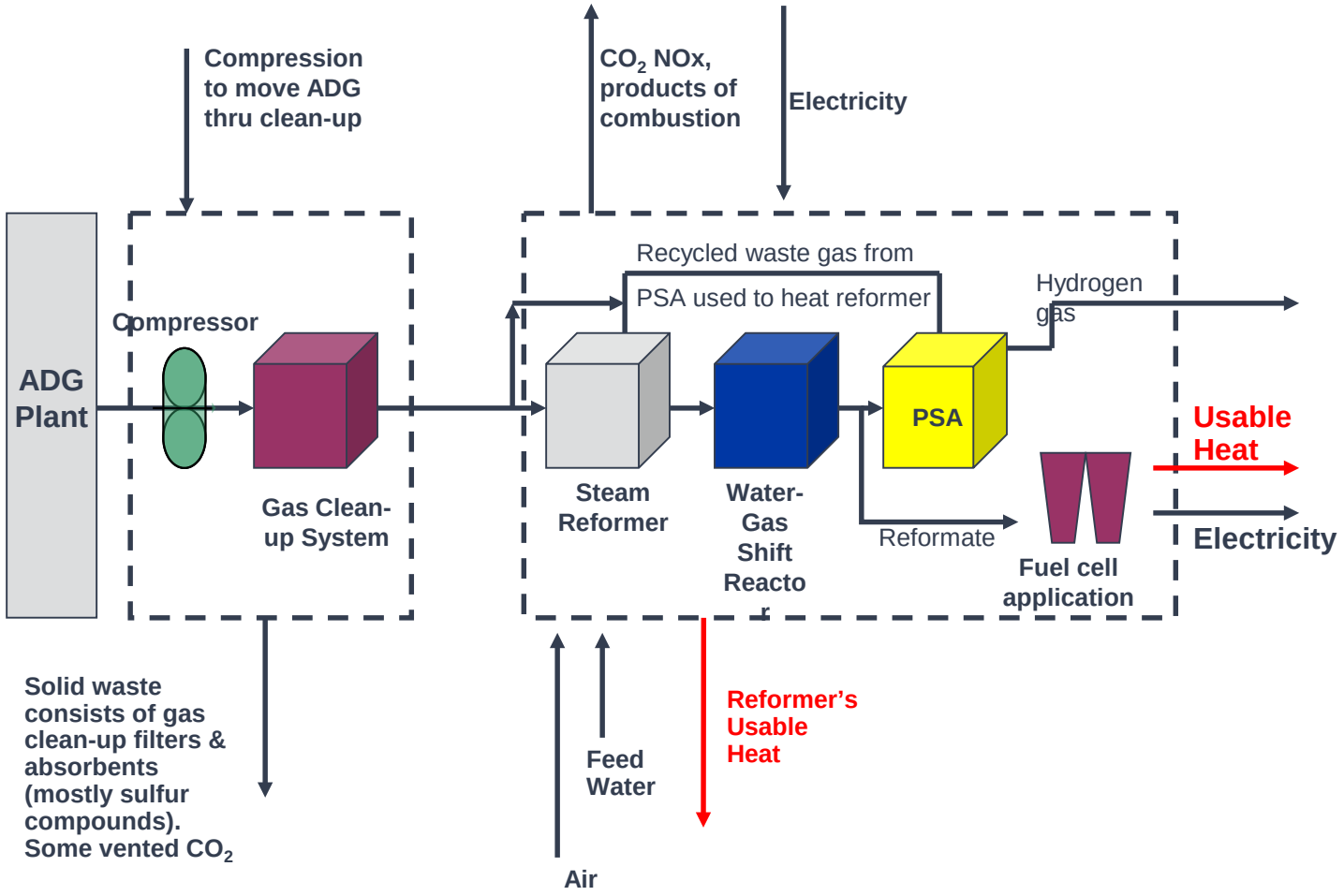
- Produced from digesters
  - Animal manure (dairy cows, swine)
  - Waste water treatment facilities
- Generated from Landfills
- Digestion of food processing waste streams
- Produced from thermal chemical processes like gasification utilizing renewable feed-stocks including forest residues and agricultural wastes.

The methane (CH4) component of each of these biogas feedstocks is the primary source for renewable hydrogen generation

Technology facilitates Biogas to Renewable Hydrogen for Vehicles

- Hydrogen generation system from biogas will consist of three key components
  - Biogas cleanup system (H_2S, CO_2, H_2O, etc removal) to yield biomethane
  - Biomethane reformation system (Typically steam-methane reformation — 75-80% efficient)
  - Hydrogen purification (remaining impurities removed including CO, CO_2,CH_4)
- Hydrogen compression, high pressure storage, and dispensing
- Periodic Hydrogen purity checks

Illustrative Process Flow Diagram for On-site H_2 Supply System & Fuel Cell Power Generation From Aerobic Digester Gas Plant



Summary

- Technology has pushed the resource base limits of conventional energy sources continually outward.
- Determining which fuel and vehicle platform is “better” is a complex process built on shifting assumptions.
- There will likely be a clear fuel and vehicle platform “fit” for certain applications.
- Continual improvement in technology across multiple pathways and across the entire life cycle is important in the “road” toward sustainability.
- It’s doubtful that any fuel/vehicle platform combo today meets everyone’s strict definition of “sustainable”…

  …or maybe they all do….

Turning Raw Technology into Practical Solutions

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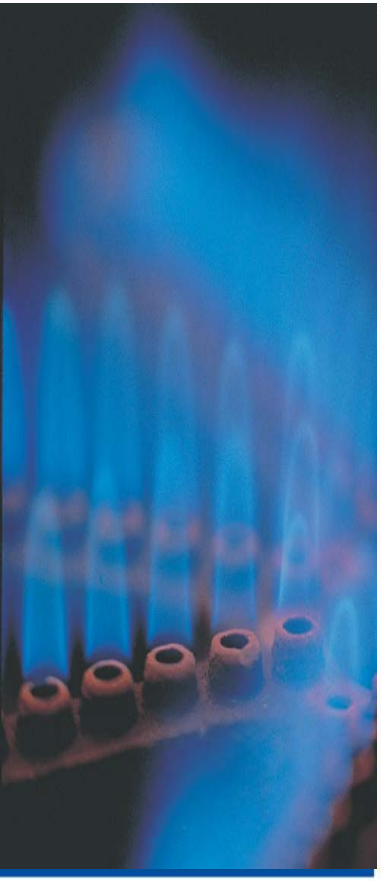


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