the Energy to Lead

Development of a Cost-Effective Free-Piston Linear Motor Compressor for Home Refueling

> **Jason Stair**
Engineer, End Use Solutions
Gas Technology Institute

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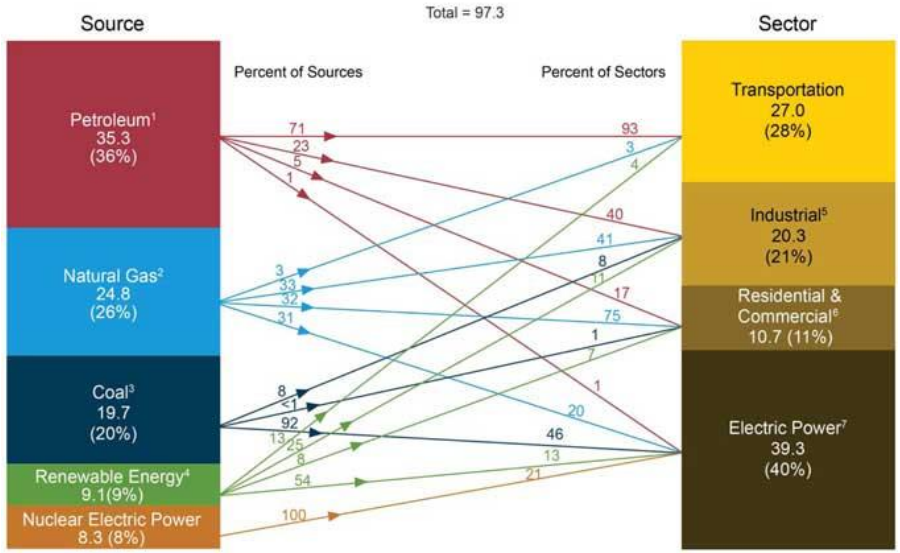
NGV Potential

- ~27 Quadrillion BTUs used for transportation
- Natural gas–3% of total
  - 94% is pipeline
  - 6% is vehicles
  - <0.2% of total transportation energy is consumed by NGVs
- Light-duty vehicles
  - 58.6% of total transportation energy consumption
  - 72% of on road energy consumption
- Low-cost home refueler could open gateway to light-duty market

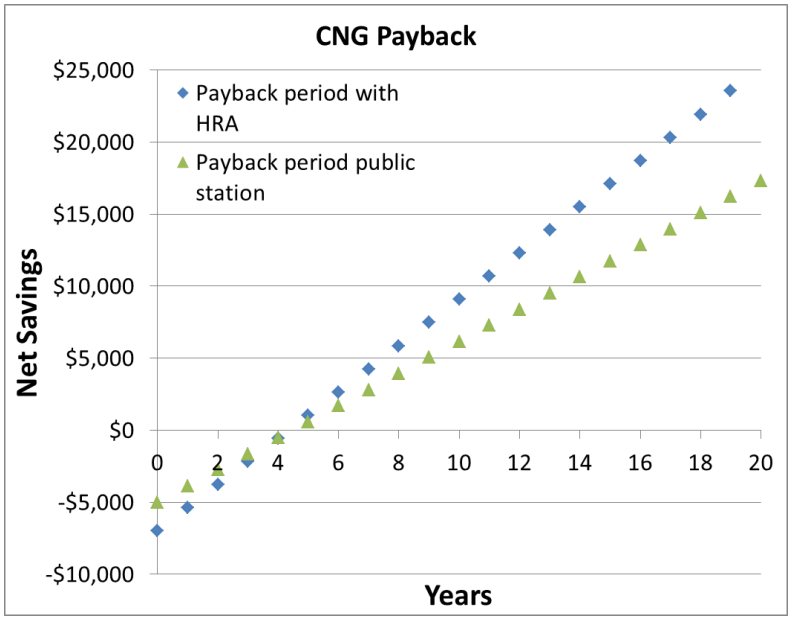
Primary Energy by Source and Sector (Quad Btu)



http://www.eia.gov/totalenergy/data/annual/pecss_diagram.cfm
https://www.ngvamerica.org/media-center/presskit/
http://cta.ornl.gov/data/chapter2.shtml

Economics

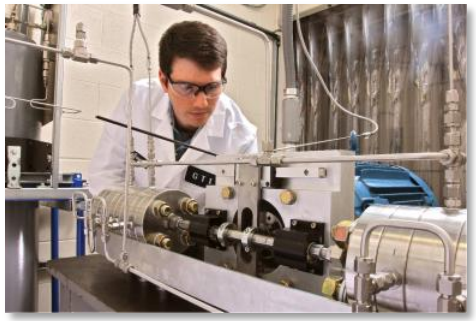
- **Gasoline**
  - $3.51/gallon → National Average
- **Natural gas**
  - Public Stations: $2.11/GGE → National Average
  - Home: $1.50/GGE
    - Based on typical residential gas and electric rates
    - Can decrease as total monthly gas consumption increases
- **NGV Cost**
  - $5000 - $10,000 premium for a light-duty vehicle
- **HRA**
  - ~$2,000 targeted installed price
- **Payback**
  - Based on 25 MPG @ 20K miles/year (800 gallons/year)
  - Payback period is slightly reduced for HRA, but long-term savings is increased
  - Added convenience of filling at home



http://www.cng now.com/average-cng-prices/pages/default.aspx
http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm

Project Team

> Funded by Advanced Research Projects Agency-Energy (ARPA-E) under the Methane Opportunities for Vehicular Energy (MOVE) Program



Compressor Design

> Stage geometry and valve design
> Compressor fabrication
> High-pressure testing

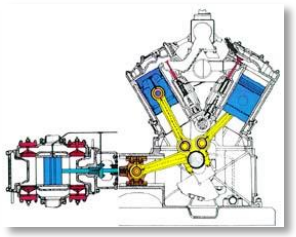
Linear Motor Design

> Motor topology trade study
> Motor controls development
> Motor fabrication and assembly

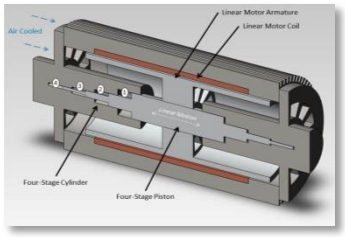
Seal/Coating Development

> Seal and coating bench testing
> Target 15,000 hour life

Technology



Reciprocating Compressor



Free Piston Linear Motor Compressor (FPLMC)

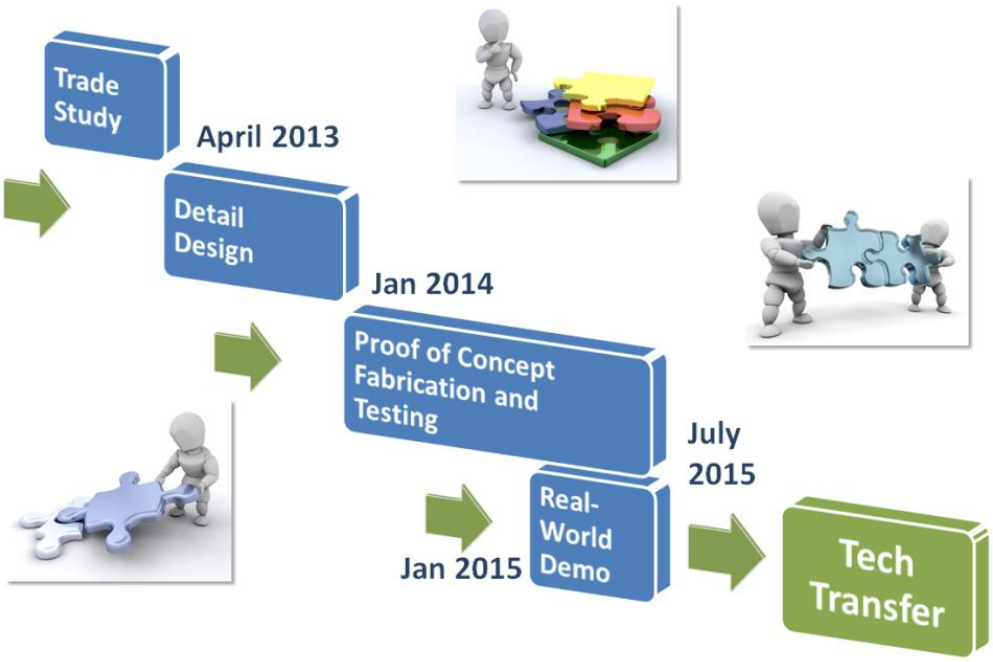
Metric	Current State of Art	FPLMC
Price	~$4,000	$1000-$1500
Energy	1.7 kWh/GGE	<1.7 kWh/GGE
Flow Rate	1 SCFM (0.5 GGE/hr)	≥2 SCFM (1 GGE/hr)
Fill Pressure	250 bar (3600 psi)	250 bar (3600 psi)
Life	<5,000 hrs	15,000 hrs
Weight	150 lbs	100 lbs

- **Integrated linear motor and compressor**
  - No rotary to linear motion conversion → Compact package
- **Multi-stage dual-acting free piston**
  - Single moving part → Reduced part count and cost
- **Near frictionless coatings**
  - Ultra low friction → Increased seal life and reduced maintenance

Project Timeline

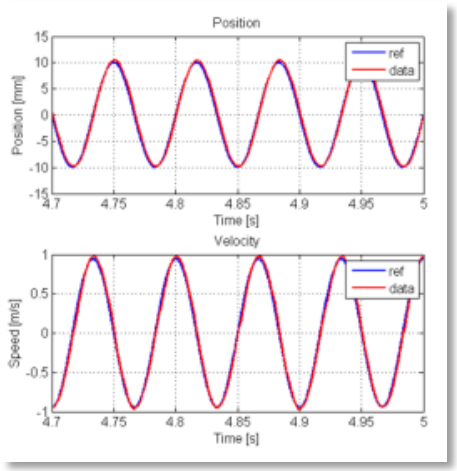
> **Schedule**

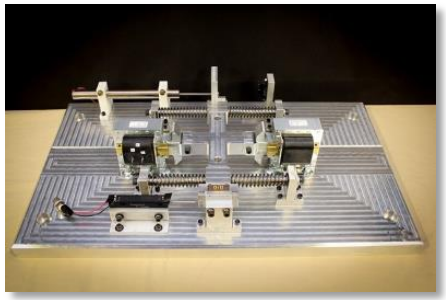
- 24-month into 36-month project
- Trade study and detail design are complete
- Individual component testing is complete
- Currently fabricating components for full-scale test

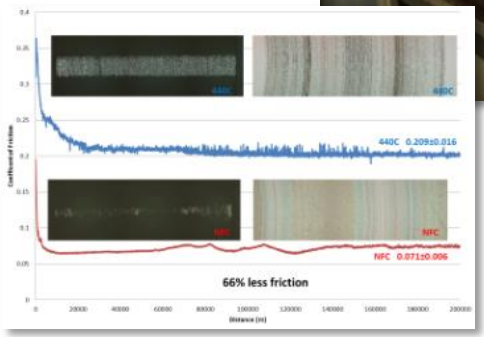


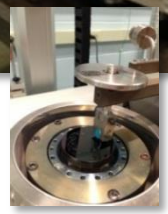
Progress and Highlights

- **Compressor Design**
  - Stage geometry optimized using dynamic models
  - Valve design, fabrication and testing complete
- **Linear Motor Design**
  - Trade study completed, balance cost/performance
  - Controls system demonstrated
- **Seal/Coating Development**
  - Identified materials and coatings that lead to low friction and wear in natural gas environment
  - Demonstrated over 3,500 hours at full pressure accelerated testing, test ongoing



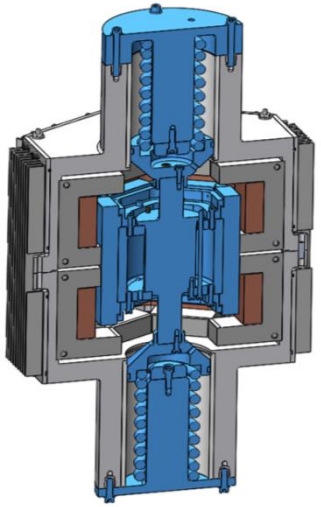


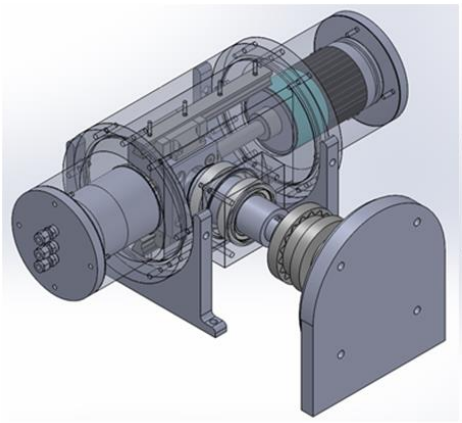


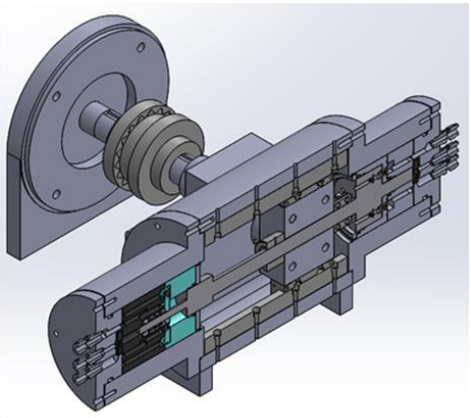


Full-Scale Fabrication and Testing

- Fabrication expected to be complete by **October 2014**
- The linear motor will be tested, and the controls refined, using springs that simulate the compressor stages
- The compressor will be independently tested using a more traditional reciprocator in order to validate gas compression performance

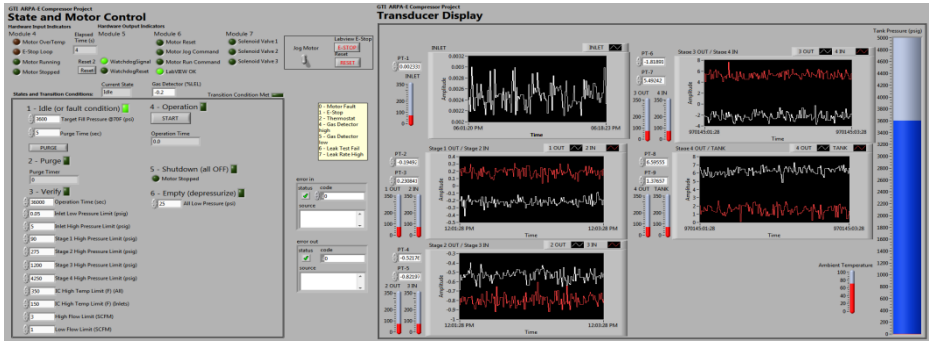






Full-Scale System Testing

- The linear motor and compressor will be assembled into the final unit for testing using natural gas
- The compressor will be extensively tested in a controlled environment for over 1,000 hours to prove system operation and durability



Environmental and Real-World Testing

- A second unit will be tested in an environmental chamber to simulate operation under extreme temperature conditions at -40 to 120F (-40 to 50C)
- Finally, a real NGV will be filled using the FPLMC

Future Work

- **Durability Testing**
  - Continue testing the FPLMC and components to ensure the target life can be met
  - Improve the design of components that fail prematurely
- **Design, Fabricate and Test Beta Unit**
  - Refine the design and incorporate improvements from testing
  - Develop incorporated controls for stand alone unit
  - Conduct lab and field tests of beta unit
- **Commercialization**
  - Move patent filings to issuance
  - Formalize licensing strategy
  - Identify commercialization partner
- **Related Work**
  - Model and develop a large scale FPLMC for commercial station applications
  - Model and develop a high pressure booster compressor to improve fill time and storage utilization
  - Model and develop an inline booster compressor for pipeline distribution applications

Connect With Us

Contact:
Jason Stair

847-768-0935
Jason.Stair@gastechnology.org

Gas Technology Institute

1700 S Mount Prospect Rd,
Des Plaines, IL 60018, USA

www.gastechnology.org