MOVE Program Overview

B. PROGRAM OVERVIEW

This program seeks to fund the development of transformational technologies that reduce the barriers to mass adoption of natural gas use in vehicles. Of particular interest are technologies that enable at-home refueling and low-cost, high energy density on-board storage for natural gas vehicles.

1. BACKGROUND

Massive increases in the U.S. natural gas reserves over the past decade present an unprecedented opportunity for advancing the economic, national, and environmental security of the nation. Spurred by technological advances in shale gas production, increased natural gas reserves have led to a decoupling of domestic natural gas with global petroleum prices, and historically low natural gas prices relative to petroleum, as shown in Figure 2.

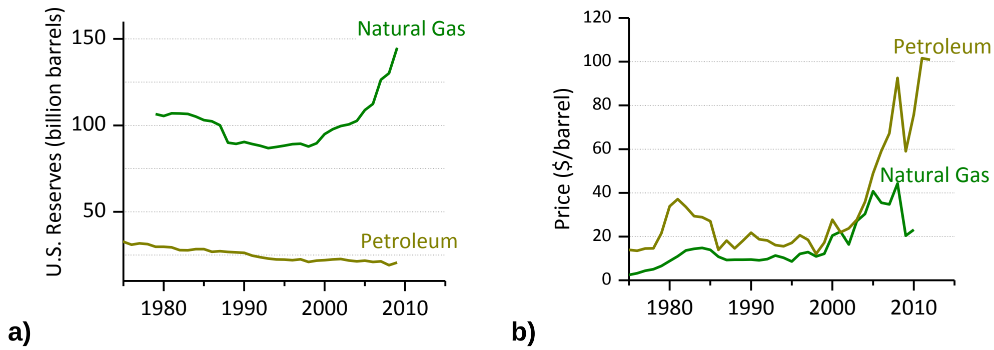

Figure 2. a) Estimated U.S. natural gas and petroleum reserves and b) average annual natural gas wellhead and crude oil spot prices in barrels of oil equivalent.[1]

The U.S. could achieve both increased independence from imported oil and a reduced national trade deficit through the prudent adoption of domestic natural gas in the transportation sector. The transportation sector is the single greatest cause of U.S. dependence on imported oil. In 2010, 94% of U.S. transportation energy came from petroleum, nearly half of which came from foreign sources.[2] In terms of economic impact, petroleum represented nearly 41% of the $646 billion U.S. trade deficit in 2010, Figure 3.

[1] U.S. Energy Information Administration, 2012. http://www.eia.gov/.
[2] U.S. Energy Information Administration. *Annual Energy Review 2010*. 19 Oct 2011.

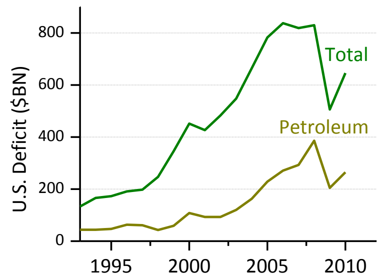

Figure 3. Annual U.S. trade deficit from petroleum and total.[3]

Natural gas vehicles also have potentially considerable environmental benefits. Natural gas contains less carbon per unit of energy than any other fossil fuel, producing lower carbon dioxide (CO_2) emissions per vehicle mile traveled. Argonne National Laboratory estimated that on average natural gas vehicles emit 270 g_{CO2}/mi compared to 450 g_{CO2}/mi for conventional gasoline vehicles on a well-to-wheels basis, or about 40% less greenhouse gas emissions.[4]

There are over 13 million natural gas vehicles on the road worldwide and only 120,000 in the United States.[5] Natural gas vehicles have the highest deployment in regions of the world where governments have artificially altered market conditions to favor natural gas. For example, in most of Europe, compressed natural gas is about $4.00/GGE (gasoline gallon equivalent) less expensive than gasoline due to high gasoline taxes.[6,7] By contrast, natural gas vehicles in the U.S. must compete with gasoline and diesel vehicles based on commodity market prices. As a consequence, the U.S. currently has limited deployment of natural gas vehicles and in only small, specific market sectors. These include buses and fleet vehicles, in addition to some heavy-duty trucking applications, such as refuse trucks that benefit from both high fuel use and predictable daily routes.

In terms of refueling infrastructure, the United States has five times fewer natural gas refueling stations per natural gas vehicle than nations with wide-spread adoption of natural gas vehicles.[8] However, a change appears to be on the horizon for heavy-duty, long-haul natural gas trucks as the private sector is beginning to finance CNG and LNG refueling stations along major highway corridors without the use of public funds.[9] By contrast, light-duty natural gas vehicles will still have to compete with a well-established gasoline refueling infrastructure that numbers over 118,000 stations nationwide.[10] Furthermore, the current cost of a natural gas refueling station is about $1.6M[11], compared to about $100k for gasoline.[12] At these costs, a natural gas infrastructure that is equivalent to gasoline could cost over $100 billion and take decades to complete.[13]

With over half of U.S. homes (65 million) with natural gas service, the natural gas light-duty vehicle infrastructure problem could be overcome with at-home natural gas refueling.[14,15] At-home refueling is further compelled by the U.S. average $2.00/GGE price advantage of residential natural gas over gasoline pump prices, as shown in Figure 4. The Honda Phill system is one attempt at introducing at-home refueling for natural gas vehicles, however it is too expensive at about $5,000 installed and has achieved little market penetration.[16,17]

[3] U.S. Census Bureau. Foreign Trade Statistics, 2011. http://www.census.gov/foreign-trade/index.html
[4] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, *Transportation Energy Data Book: Edition 30-2011*, p 11-11.
[5] Quantum presentation, Neel Sirosh, ARPA-E Workshop, Houston, TX. 26 Jan 2012.
[6] CNG Prices, www.CNG Prices.com. 31 Jan 2012.
[7] AAIreland. http://www.aaireland.ie. 31 Jan 2012.
[8] Quantum presentation, Neel Sirosh, ARPA-E Workshop, Houston, TX. 26 Jan 2012.
[9] Clean Energy Fuels. http://www.cleanenergyfuels.com/, 31 Jan 2012.
[10] U.S. Census Bureau. Industry Statistics Sampler, NAICS 4471, 2007.
[11] Whyatt, GA. Issues Affecting Adoption of Natural Gas Fuel in Light- and Heavy-Duty Vehicles. PNNL-19745. Sept 2010, pg 5.6.
[12] NREL. Cost of Adding E85 Fueling Capability to Existing Gasoline Stations, NREL/FS-540-42390, March 2008.
[13] Whyatt, GA. Issues Affecting Adoption of Natural Gas Fuel in Light- and Heavy-Duty Vehicles. PNNL-19745. Sept 2010.
[14] U.S. Energy Information Administration. Natural Gas Consumption by End Use. 31 Jan 1011.
[15] U.S. Census Bureau. State & County QuickFacts, Households, 2006-2010.
[16] Impco Automotive. Refuelling Appliances. http://www.impcoautomotive.com/index.php?pagename=fuelmaker. 12 Feb 2012.

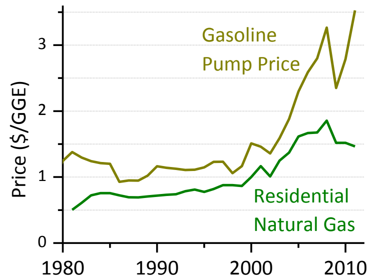

Figure 4. U.S. average natural gas and gasoline prices on an energy equivalent basis.[18,19]

Despite the current natural gas price advantage over gasoline, significant technological and economic barriers limit natural gas use in transportation (natural gas represents only 2% of U.S. transportation energy).[20] At a fundamental level, these challenges arise from the low volumetric energy density of natural gas—less than 30% of gasoline when compressed to 250 bar (CNG, 3600 psi), see Figure 5. Ultimately, the low volumetric energy density of natural gas limits the driving range of vehicles and makes cost effective storage solutions a significant challenge.

Figure 5. Energy density of fuels, where the volumetric energy density of CNG is calculated for cylinder Type I and Type IV tanks assuming a cylindrical useful volume $V_{cylinder}$ within a nominal square cuboid volume V_{cuboid} $[(\pi/4)V_{cuboid} = V_{cylinder}]$.

	Energy Density	
	(MJ/L)	(MJ/kg)
Diesel	37.3	46.2
Gasoline	34.2	46.4
LNG (-162 °C)	22.2	50.0
CNG (250 bar)	9.2	50.0
CNG + Type I	7.4	5.9
CNG + Type IV	7.4	15.6

Most natural gas vehicles today employ only basic technologies—90% of vehicles still use Type I tanks (low cost steel tanks)[21] and engines simply use modified gasoline and diesel engines. Type IV light-weight carbon fiber composites tanks have gained popularity in the U.S. and are installed in the natural gas-powered Honda Civic GX. While Type IV tanks have superior specific energy densities to steel tanks, they cost about four times more—primarily due to the cost of carbon fiber.[22] Both Type I and Type IV tanks are bulky, which is a major drawback for light-duty vehicles in which space is a premium. A key attribute that would advance natural gas-powered light duty vehicles is a conformable tank that can be shaped to efficiently fit within a vehicle with minimal loss of trunk space or effective volumetric energy density.

[17] Auto Observer. BRC FuelMaker Again Selling Phill Home CNG Fuel Station. http://www.autoobserver.com/2011/03/brc-fuelmaker-again-selling-phill-home-cng-fuel-station.html. 7 Mar 2011.
[18] U.S. Energy Information Administration. Annual Energy Review, 2011.
[19] U.S. Energy Information Administration. Natural Gas Prices. http://www.eia.gov/dnav/ng/hist/n3010us3m.htm. 12 Feb 2012.
[20] U.S. Energy Information Administration. *Annual Energy Review 2010*. 19 Oct 2011.
[21] Quantum presentation, Neel Sirosh, ARPA-E Workshop, Houston, TX. 26 Jan 2012.
[22] Based on ARPA-E internal analysis.

Even at attractive residential natural gas prices relative to gasoline, current technologies are unable to meet the stringent price and performance metrics required for the adoption of light-duty natural gas vehicles with home refueling. A light-duty natural gas vehicle that averages 12,500 miles per year at an average fuel efficiency of 25 mpg with home refueling station can cost no more than $4,200 more than an equivalent gasoline-powered vehicle in order to achieve a 5 year payback, see Figure 6. It should be noted, however that many vehicles travel much more than this and have lower fuel efficiencies, in which case the payback period would considerably shorter than 5 years. However, this program targets the more aggressive goal of reducing the cost of adoption for the average use case. In this case, if the balance of system (engine modifications, fuel delivery and exhaust system) and installation are excluded, then natural gas at-home refueling and on-board vehicle storage must together cost less than $2,000—requiring a radical departure from existing technologies, see Figure 7.

Figure 6. Estimated present value of adopting a natural gas vehicle assuming a five year payback at the current $2.00/GGE price advantage of natural gas over gasoline.

Parameter	Symbol	Calculation	Value	Units
Payback	t		5	y
Mileage	m		12,500	mi/y
Fuel efficiency	e		25	mi/GGE
Refuel rate	r		52	refuel/y
Price NG	P_{NG}		1.50	$/GGE
Price gasoline	$P_{gasoline}$		3.50	$/GGE
Price difference	ΔP	$= P_{gasoline}-P_{NG}$	2.00	$/GGE
Payment number	N	$= r \cdot t$	260	refuels
Payment amount	pmt	$= \Delta P \cdot m \cdot e^{-1} r^{-1}$	19.23	$/refuel
Interest rate (7%APR)	R	$= 7\% \cdot N^{-1}$	0.135	%/refuel
Present value	PV	$= pmt \cdot R^{-1} \cdot (1+R)^{-N} \cdot ((1+R)^{N}-1)$	4,220	$

Figure 7. Current and needed differential cost for the adoption of light-duty natural gas vehicles with at-home refueling.[23]

Component	Current	Needed
At-home refueling	$4,000	$ 500
On-board storage	$3,500	$1,500
Balance of system	$3,500	$1,000
Installation	$1,500	$1,000
Total	$12,500	$4,000

[23] Numbers based upon internal ARPA-E research.

D. PROGRAM OBJECTIVES

Consistent with ARPA-E's mission, this funding opportunity announcement (FOA) seeks to foster novel approaches in natural gas storage and at-home refueling for light-duty vehicles.

The primary objective of this program is to fund the development of systems-level solutions that could enable natural gas vehicles with on-board storage and at-home refueling with a five-year payback or upfront cost differential of $2,000, which excludes the balance of system and installation costs.

The secondary objective of this program is to fund the development of critical components to achieve the overarching systems-level goal. Specific aims include technological advancements in the area of (1) new sorbent materials for low-pressure storage of natural gas and (2) new high-strength, low-cost materials and manufacturing processes for conformable tanks[24] capable of high-pressure (250 bar) natural gas storage. Low-pressure approaches inherently reduce the burden (cost) on home refueling; however for high-pressure approaches this program also seeks (3) innovative low-cost, high-performance compressor technology.

A specific natural gas storage and compression pressure is not prescribed, except that the system should not exceed 250 bar (3,600 psi). Instead, this program establishes an overall system energy density requirement that should meet or exceed CNG (250 bar).

Successful applications for natural gas storage and at-home refueling for light-duty applications should demonstrate technological advancements in natural gas storage and at-home refueling that could yield a combined system cost that leads to a 5 year payback period.

E. TECHNICAL CATEGORIES OF INTEREST

This program is focused on supporting natural gas vehicle on-board storage and at-home refueling technology research and development projects that are able to address the Primary Technical Targets and Secondary Technical Targets described in Section I.F of the FOA.

ARPA-E will accept applications that have a well-justified, realistic potential to meet or exceed all of the Primary Technical Targets in one of the following categories by the end of the project period:

- **CATEGORY 1: Systems for On-Board Storage and At-Home Refueling**
- **CATEGORY 2: Sorbent Materials for Low Pressure Storage**
- **CATEGORY 3: New Tank Materials and Manufacturing Methods for High Pressure Storage**
- **CATEGORY 4: Compressor Technology for At-Home Refueling**

Favorable consideration will be given to applicants if they can meet or exceed at least one of the Secondary Technical Targets.

ARPA-E has interest in system-level solutions and component-level solutions. Of particular interest are applications that envision systems that incorporate the following key components that are considered to be enabling for natural gas storage in light-duty vehicles with at-home natural gas refueling.
Key components include:

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[24] Defined here as a tank with outer tank volume divided by the enclosing rectangular cuboid volume.

1) Engineered sorbents materials from molecule to tank that are capable of energy densities that meet or exceed CNG (250 bar) that corresponds to 9.2 MJ/L, but at lower pressures (less than 35 bar);
2) Innovative processes for manufacturing sorbent materials with improved cost, yield, and performance;
3) Creative integration of sorbent materials in gas tanks to improve packing density, increase rates of tank filling, enhance thermal integration, and maximize fuel delivery to the vehicle engine;
4) Conformable materials, manufacturing methods, and unique geometries able to withstand pressures up to 250 bar, without dramatically increasing system weight or cost;
5) New manufacturing processing of tank materials that offer dramatic performance or cost improvements and can be seamlessly integrated into a system-level solution; and
6) Inventive low-cost approaches to gas compression at small scales with the capability of compressing from atmospheric pressure up to the desired tank pressure at rates greater than 33.4 kW (2 scfm or 1 GGE/h).

Enabling work on any key component listed above is of interest; however, proposals that show a clear path to an integrated natural gas vehicle storage and refueling system solution are preferred. For applications envisioning component development, a conceptual system design should be presented that features the required performance metrics of the proposed component device.

It is expected that interested applicants will develop natural gas storage systems for at-home refueling of light duty vehicles by one of the following approaches:

1) Engineering new sorbent material and conformable tanks for low-pressure natural gas storage;
2) Developing new high-strength materials, manufacturing processes, and geometries for conformable high-pressure natural gas storage tanks; or
3) Developing high-performance, low-cost compressor technology.

The ideal Project Team will be comprised of materials, mechanical, chemical, automotive, and process engineers/scientists. It is important that the Project Team have expertise in every aspect of the system and good understanding of material properties, tank design, and fabrication. Project Teams should demonstrate and articulate a strong understanding of the practical use-case for the proposed light-duty vehicle application, including both commercial and operational merits and limitations.

F. TECHNICAL PERFORMANCE TARGETS

1. CATEGORY 1: Systems for On-Board Storage and At-Home Refueling

The final deliverable for this program area is a fully functional 10 GGE on-board storage tank with 2 scfm at-home refueling station for natural gas that meets all the primary technical targets, as listed below.

PRIMARY TECHNICAL TARGETS

ID	Category	Value (Units)
1.1.1	Cost of storage tank and at-home refueling	< $2,000
1.1.2	Volumetric energy density (fuel)	> 9.2 MJ/L
1.1.3	Gravimetric energy density (fuel + tank)	> 12 MJ/kg
1.1.4	Specific delivery rates	> 2.6 kW/L (0.2 kg/h-L)
1.1.5	Conformability factor	> 90%
1.1.6	Lifetime	100 cycles

1.1.7	Parasitic load of at-home refueling station	< 5% (1.8 kWh/GGE)

METRIC DESCRIPTIONS – PRIMARY TECHNICAL TARGETS

1.1.1. To attain a 5 year payback for a natural gas vehicle, a total cost of less than $2,000 is required for on-board storage and at-home refueling; this excludes balance of system and installation costs.

Applicants should submit a bill of materials to justify cost targets. Additional justification for approaches that will reduce manufacturing costs should be elaborated. A credible path to reach this metric is required.

1.1.2. The system-level volumetric energy density should be equal to or exceed 9.2 MJ/L (CNG at 250 bar).

Applicants should provide a well-justified description of how they will achieve this volumetric energy density.

1.1.3. The system-level gravimetric energy density should be twice that of a Type I CNG tank at 250 bar with fuel or 12 MJ/kg.

Applicants should provide a well-justified description of how they will achieve this gravimetric energy density and the contributions to this by system components.

1.1.4. The fuel delivery system will need to supply a methane flow rate of 2.6 kW/L over the entire range of tank pressures to achieve an engine power of 150 hp, assuming a 30% engine efficiency and 10 GGE tank size. The specific discharge rate must be measured at 20% tank capacity over 30 s.

Applicants should provide a well-justified description of how they will achieve this gas delivery rate.

1.1.5. The conformability factor is defined here as the outer tank volume divided by the enclosing rectangular cuboid volume and simply gives the packing efficiency of a tank within a box. In light duty vehicles, space is a premium and therefore tanks that can be "formed" to fit within tight spaces are of significant interest.

Applicants should provide a well-justified description of how they will achieve the conformability factor, including (1) tank geometry and/or topology including, if applicable, how inter-tank connections will be made, (2) tank materials and their properties, i.e. tensile strength, and (3) tank material manufacturing processes, as well as explain any technological gaps and how they will be overcome.

1.1.6. During this program, the applicant should demonstrate a lifetime of greater than 100 cycles with more than 80% of initial capacity. The longer term goal is 1,000 cycles, which corresponds to the U.S. average passenger vehicle that refuels 50 times per year and lasts 20 years. However, given the short duration of ARPA-E projects (< 3 years), the time required to test 1,000 cycles is impractical.

Applicants should provide a well-justified description of how they will achieve the target lifetimes of each of the system components.

1.1.7. A low parasitic load ensures home refueling savings are greater than the cost of operating the compressor. A parasitic load of 5% is equivalent to 1.7 kWh/GGE with a thermodynamic limit for isothermal compression of 0.5 kWh/GGE.

Applicants should provide a well-justified description of how they will achieve (1) this energy efficiency, including losses at each compression and cooling stage and (2) any technological approaches that will significantly reduce parasitic loss.

2. CATEGORY 2: Sorbent Materials for Low Pressure Storage

The final deliverable for this program area is a fully functional 6 L tank with sorbent and thermal management system that meets all primary technical targets and as many secondary technical targets as technically feasible, as listed below.

PRIMARY TECHNICAL TARGETS

ID	Category	Value (Units)
2.1.1	Volumetric energy density	> 12.5 MJ/L (sorbent) > 9.2 MJ/L (inner tank)
2.1.2	Gravimetric energy density	> 0.5 $g_{CH4}/g_{sorbent}$ (sorbent) > 0.4 g_{CH4}/g (inner tank)
2.1.3	Cost of sorbent (credible route to)	< $10/kg

METRIC DESCRIPTIONS – PRIMARY TECHNICAL TARGETS

2.1.1. Engine inlet pressure must be greater than 70 psig. For a system energy density equivalent to CNG (9.2 MJ/L) or greater, the sorbent-level volumetric energy density must exceed 12.5 MJ/L and 9.2 MJ/L after packing losses (25%).

Applicants should provide a well-justified description of how they will (1) achieve the volumetric energy density at the sorbent level, (2) employ packing strategies to achieve this, (3) maximize system pressure, and (4) mitigate methane losses from inaccessible methane stored below 70 psig.

2.1.2. The increased weight of sorbents (compared to a bare tank) should not exceed the reduction in tank weight. To achieve this, the packed sorbent must exceed 0.4 g_{CH4}/g at the inner tank level. Since additives may be blended with the sorbent to achieve the inner tank targets, sorbents gravimetric energy density must exceed 0.5 $g_{CH4}/g_{sorbent}$.

Applicants should provide a well-justified description of how they will (1) achieve a gravimetric energy density at the sorbent level, (2) employ packing strategies to achieve this, and (3) integrated other materials into the sorbent system, if applicable.

2.1.3. A manufactured sorbent cost of $10/kg will lead to a materials cost of $500 when accounting for metric 2.1.2 using a 10 GGE vehicle tank. This will enable a packed sorbent cost to the consumer of $1,000.

Applicants should (1) submit a bill of materials for the sorbents and (2) indicate if the chemical ingredients are commercially available. Approaches that could reduce manufacturing costs should be elaborated.

SECONDARY TECHNICAL TARGETS

ID	Category	Value (Units)
2.2.1	Specific desorption rates	> 2.6 kW/L (0.2 kg/h-L)
2.2.2	Lifetime	100 cycles
2.2.3	Desorption temperature	< 85 °C
2.2.4	Temperature tolerance	-40 °C to 85 °C
2.2.5	Impurity tolerance	Pipeline quality natural gas (C_2H_6,C_3H_8,CO_2,H_2O,S)
2.2.6	Safety requirements	Tolerant of abusive conditions and physical damage without catastrophic failure

METRIC DESCRIPTIONS – SECONDARY TECHNICAL TARGETS

2.2.1. Sorbent systems will need to supply a methane flow rate of 2.6 kW/L over the entire range of tank pressures to achieve an engine power of 150 hp, assuming a 30% engine efficiency and 10 GGE tank size. The specific discharge rate must be measured at 20% tank capacity over 30 s.

Applicants should provide a well-justified description of their target desorption rates, and what packing and thermal management strategies will be employed to achieve this bulk desorption rate at the tank scale.

2.2.2. During this program, the applicant should demonstrate a lifetime of greater than 100 cycles with more than 80% of initial capacity. The longer term goal is 1,000 cycles, which corresponds to the U.S. average passenger vehicle that refuels 50 times per year and lasts 20 years. However, given the short duration of ARPA-E projects (< 3 years), the time required to test 1,000 cycles is impractical.

Applicants should provide a detailed description of (1) sorbent lifetimes, (2) deactivation rates/processes, and (3) plans to deal with compaction.

2.2.3. The methane desorption temperature should not exceed the maximum temperature that existing pressure vessels are designed to tolerate (e.g.; Type IV carbon fiber CNG tanks).

Applicants should provide a well-justified description of how they will achieve methane desorption temperatures and plans to integrate thermal management into the system.

2.2.4. The sorbent temperature tolerance should match that of the overall tank. In addition to matching environmental conditions, the low-end temperature is reached at initial stages of refueling from a CNG station, and the high-end temperature is targeted for methane desorption.

Applicants should provide a well-justified description of thermal management strategies to accommodate heat transfer in and out of the sorbent/tank system.

2.2.5. The sorbent system must tolerate U.S. pipeline quality natural gas: < 5 mol% C_2H_6; < 1 mol% C_3H_8; < 1 mol% CO_2; < 100 ppm H_2O; and < 20 ppm sulfur-based compounds.

Applicants should provide a well-justified plan to accommodate contaminants and describe how this plan will impact the system level metrics, namely energy density and cost.

2.2.6. Applicants should provide a well-justified description of how they will achieve the safe operation of their sorbent system with respect to toxicity and stability. A credible plan to accommodate toxic/dangerous sorbents or additives should be given.

3. CATEGORY 3: New Tank Materials and Manufacturing Methods for High Pressure Storage

The final deliverable for this program area is a fully functional 10 GGE (140 L) compressed natural gas tank meeting all primary technical targets and as many secondary technical targets as technically feasible, as listed below.

PRIMARY TECHNICAL TARGETS

ID	Category	Value (Units)
3.1.1	Conformability factor	> 90 %
3.1.2	Gravimetric energy density (fuel+tank)	> 12 MJ/kg
3.1.3	Cost of tank	< $1500 (tank) < $750 (materials)

METRIC DESCRIPTIONS – PRIMARY TECHNICAL TARGETS

3.1.1. The conformability factor is defined here as the outer tank volume divided by the enclosing rectangular cuboid volume and simply gives the packing efficiency of a tank within a box. In light duty vehicles, space is a premium and therefore tanks that can be “formed” to fit within tight spaces are of significant interest.

Applicants should provide a well-justified description of how they will achieve the conformability factor, including (1) tank geometry and/or topology including, if applicable, how inter-tank connections will be made, (2) tank materials and their properties, i.e. tensile strength, and (3) tank material manufacturing processes, as well as explain any technological gaps and how they will be overcome.

3.1.2. The gravimetric energy density should be calculated by taking the total fuel energy divided by the mass of the fuel and tank up to the final interface seal. If many small tanks are interconnected, all connectors up to the final single interface seal should be included in the tank mass.

Applicants should provide a well-justified description of how they will (1) achieve the gravimetric energy density of the natural gas plus the tank(s) and interconnections if applicable, with a list of materials, dimensions, and weights; and (2) employ manufacturing strategies to achieve this, as well as address any technological barriers and how they will be overcome.

3.1.3. Complete 10 GGE tanks (140 L) must cost less than $1,500 at high manufacturing volumes with materials comprising less than half of this (< $750).

Applicants should (1) submit a bill of materials for a 10 GGE tank and, if applicable, (2) justify any approaches that will significantly reduce manufacturing costs.

SECONDARY TECHNICAL TARGETS

ID	Category	Value (Units)
3.2.1	Temperature range	-40 °C to 85 °C
3.2.2	Lifetime	100 cycles
3.2.3	Safety requirements	Tolerant of abusive operating conditions and physical damage without catastrophic failure

METRIC DESCRIPTIONS – SECONDARY TECHNICAL TARGETS

3.2.1. Vehicles typically experience temperatures ranging from -40 °C to 85 °C.

Applicants should provide a well-justified description of how the materials will be robust at temperatures from -40 °C to 85 °C and maintain suitable performance.

3.2.2. During this program, the applicant should demonstrate a lifetime of greater than 100 cycles with more than 80% of initial capacity. The longer term goal is 1,000 cycles, which corresponds to the U.S. average passenger vehicle that refuels 50 times per year and lasts 20 years. However, given the short duration of ARPA-E projects (< 3 years), the time required to test 1,000 cycles is impractical.

Applicants should provide a well-justified plan for testing and validation.

3.2.3. Applicants should provide a well-justified description of how their tanks will tolerate abusive operating conditions and physical abuse including chemical exposure, impact and drop testing, and be designed to fail by venting rather than bursting.

4. CATEGORY 4: Compressor Technology for At-Home Refueling

The final deliverable for this program area is a fully functional 2 scfm compressor meeting all primary technical targets and as many secondary technical targets as technically feasible, as listed below.

PRIMARY TECHNICAL TARGETS

ID	Category	Value (Units)
4.1.1	Flow rate	> 33.4 kW (2 scfm or 1 GGE/h)
4.1.2	Cost	< $500 (system) < $250 (materials)
4.1.3	Operating lifetime	1,000 h
4.1.4	Parasitic load	< 5% (1.7 kWh/GGE)

METRIC DESCRIPTIONS – PRIMARY TECHNICAL TARGETS

4.1.1. The compressor inlet and outlet pressures will be atmospheric and 250 bar (3,600 psig), respectively at ambient temperatures. For an ideal gas, this corresponds to a total compression ratio (CR) of 250:1; however, natural gas has a compressibility factor of 87%[25] giving a CR = 215:1. The 2 scfm natural gas flow rate corresponds to 1 GGE/h, enabling overnight refueling.

Applicant should provide a well-justified description of (1) the compressor stage types, sizes, and compression ratios, and cooling strategies and (2) the compressor integration and manufacturing processes, paying particular attention to explain technological gaps and how they will be overcome.

4.1.2. Compressor materials are assumed to cost half of the total compressor cost or $250.

Applicants should provide a well-justified description of (1) a bill of materials for a 2 scfm compressor and, if applicable, (2) any technological approaches that will significantly reduce manufacturing cost.

4.1.3. Ninety percent of Americans commute less than 70 miles per day[26]. At fuel economy of 25 mpg, filling rate of 1 GGE/h, and 250 commuting days per year a compressor must operate almost 750 h per year and 20 years of operation corresponds to 15,000 h of operation. For this program area, compressors are expected to demonstrate 1,000 h of continuous operation without service, which is practical given the short duration (<3 years) or ARPA-E projects.

Applicants should provide a well-justified description of (1) how the compressor design will enable lifetimes > 15,000 h and (2) the testing procedure and plan to demonstrate 1,000 h of continuous operation during the project.

4.1.4. A low parasitic load ensures home refueling savings are greater than the cost of operating the compressor. A parasitic load of 5% is equivalent to 1.7 kWh/GGE with a thermodynamic limit for isothermal compression of 0.5 kWh/GGE.

Applicants should provide a well-justified description of how they will achieve (1) this energy efficiency, including losses at each compression and cooling stage and (2) any technological approaches that will significantly reduce parasitic loss.

SECONDARY TECHNICAL TARGETS

ID	**Category**	**Value (Units)**
4.2.1	Weight	≤ 22 kg (50 lb)
4.2.2	Temperature range	-40 °C to 85 °C
4.2.3	Safety requirements	Tolerant of physical damage without catastrophic failure

METRIC DESCRIPTIONS – SECONDARY TECHNICAL TARGETS

4.2.1. For low cost installation, an at-home refueling station should be installable by a single unaccompanied technician, requiring a weight of less than 50 lb.

Applicants should (1) submit a list of the estimated weight of materials for an optimized 2 scfm prototype compressor, and (2) justify any technological approaches that will significantly reduce final weight.

4.2.2. Applicants should provide a well-justified description of how the compressor materials will sustain operation at temperatures from -40 °C to 85 °C.

4.2.3. Applicants should provide a well-justified description of how their at-home refueling station will tolerate abusive conditions.

[25] RH Perry and D Green. Perry's Chemical Engineer's Handbook. 6th ed. pg 3-116.
[26] US Department of Transportation, Bureau of Transportation Statistics, Omnibus Household Survey, 2003, http://www.bts.gov/publications/omnistats/volume_03_issue_04/pdf/entire.pdf, accessed 2-11-2012.

G. APPLICATIONS SPECIFICALLY NOT OF INTEREST

The following types of applications will be deemed nonresponsive and will not be reviewed or considered (see Section III.C.2 of the FOA):

- Applications that fall outside the "Technical Performance Targets" specified in Section I.F of the FOA, including but not limited to:
  - Renewable natural gas (biogas) production or supply infrastructure;
  - Liquefied natural gas (LNG) infrastructure or LNG vehicle technologies; [27]
  - Supply infrastructure or refueling stations for light-duty natural gas vehicles; and
  - Improvements to engines for light-duty natural gas vehicles.
- Applications that were already submitted to pending ARPA-E FOAs.
- Applications that are not scientifically distinct from applications submitted to pending ARPA-E FOAs.
- Applications for basic research aimed at discovery and fundamental knowledge generation.
- Applications for large-scale demonstration projects of existing technologies.
- Applications for proposed technologies that represent incremental improvements to existing technologies.
- Applications for proposed technologies that are not based on sound scientific principles.
- Applications for proposed technologies that are not transformational, as described in Section I.A of the FOA. Transformational, as illustrated in Figure 1 above, is the promise of high payoff in some sector of the energy economy.
- Applications for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress (see Figure 1 above).

[27] Unless a compelling case can be made that such an approach can meet all the primary technical targets listed Section I.F and also adequately address operating costs of liquefaction and tank evaporation.