**INTRODUCTION**

- **Low pressure on-board natural gas storage enables a true paradigm shift:**
  - Enables private natural gas fueling due to low compression requirements
  - Enables a low weight conformable tank
  - Enables more vehicle displacement options
  - Utilizes existing powertrains, making low pressure storage a “fueling option”
  - Lowers the cost of every gasoline gallon equivalent (GGE) of natural gas consumed
  - Opens the mass unserved light duty vehicle market
EMISSIONS BENEFITS - GENERAL

- NGV’s are clean relative to current technologies:
  
  - 75% reduction in carbon monoxide emissions*
  - 55% reduction in volatile organic compounds*
  - 50% reduction in nitrogen oxide emissions*
  - Up to 30% reduction in carbon dioxide emissions*

*Source: Southern California Gas Company; and the 2008 TIAx, LLC Report Well-To-Wheels (prepared for the California Energy Commission)
• ANGP selected Ingevity as our adsorbent manufacturer because of Ingevity’s global leadership in activated carbons for more than 100 years. Ingevity is the industry leader in adsorbent-based, on-board evaporative emissions control for gasoline fueled vehicles. Ingevity’s activated carbon media captures hydro-carbon emissions generated during fueling and engine shut down, then releases those gasoline vapors on engine start-up to be combusted and utilized, capturing and recovering over 3 million gallons of gasoline per day globally.

• Ingevity developed high performance activated carbon monoliths for ANGP, specifically focused on “working storage capacity” and commercial viability. All other adsorbent materials on the market, or in the laboratory, focus on “total storage capacity” which result in thermal properties that make them difficult to release stored gas, reducing the practical working storage capacity. These other adsorbents are also costly to produce (some more than 10 X the cost of Ingevity monoliths). The combination of reduced practical working storage capacity and high cost, results in commercially non-viable products. Automotive applications rely on working storage as the true measure of usable fuel capacity.

• Ingevity monoliths have superior thermal physics as compared to all other adsorbents on the market or in the laboratory. Ingevity monoliths have significantly lower heat generation when filling and significantly lower heat loss on release, than other currently available adsorbents. ANGP/Ingevity storage systems require NO additional on-board systems to release fuel from the adsorbent.
Activated carbon methane capacity

- Nuchar® Fuelsorb™ monolith
- Compressed natural gas

Methane capacity (V/V)

Pressure (psig)
GENERATION 1

• ANGP Generation 1 - Type I - Seamless ANG cylinders are being manufactured by Worthington Industries (On March 30, 2016, ANGP’s Generation 1 ANG cylinder was certified after passing all ANSI NGV2 tests)

• ANGP Generation 2 - Type IV – the union of the conformable tank and ANG technology – a collaboration among ANGP, United Technologies Research Center, Ingevity and A. Schulman (Early 2017)
Generation 1 Seamless Monolith-filled Aluminum Cylinders
• From order to delivery, ANGP’s manufacturing (Generation 2 Type IV Conformable Tank) process is diagramed as follows:
Generation 2

- Properties of Generation 2 is based on the multi-chambered Type IV conformable tank design developed by United Technologies Research Center and exclusively licensed to ANGP for low pressure automotive applications
- Generation 2 compared to Generation 1:
  - 40% less tank weight (not including adsorbent material)
  - 25% greater capacity per unit of vehicle displacement (greater conformity)
Conceptual Presentation Only – Actual placement and dimensions of the ANG module will vary
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• Average annual vehicle travel in the U.S. is 13,476 miles (U.S. Department of Transportation); and the average fuel consumption per light duty vehicle (LDV) in 2014 (U.S. Department of Transportation) was 527 gallons per vehicle.

• Various studies show that 75% of annual LDV mileage is used for the daily commute or in-town travel; on average 70 miles round trip; 5 GGE of natural gas on a bi-fuel Plug-in Hybrid Adsorbed Natural Gas Vehicle (PHANGV) would provide between 100 and 150 miles of range depending on the vehicle and the powertrain; allowing for the daily commute to operate on natural gas, replacing 395 gallons of gasoline, annually, with natural gas.
Based on the U.S. Energy Information Administration (EIA) research, natural gas usage data for 2014 is as follows:

- Total natural gas sold to residential customers = 5,082,314 million cubic feet
- Total number of residential customers = 67,227,762

| 2014 [EIA] Usage Residential (Million Cubic Feet) | 5,082,314 |
| 2014 Residential Customers [EIA]                  | 67,227,762 |
| Per Residential Customer (Cubic Feet)             | 75,598.44 |
| Per Residential Customer (MCF)                     | 76         |
| Per Residential Customer (BTU)                     | 75,598,441 |
| Therms per Residential Customer per Year           | 756        |
| GGE per Residential Customer per Year              | 663        |
| Typical Single NGV Consumption per Residential Customer per Year (GGE) | 395        |
| Potential Annual Product Usage Increase per Residential Customer | 60%        |

The opportunity for natural gas utilities is to increase natural gas consumption per residential customer, per year, by 60%
2016 Natural Gas Plug-in Hybrid Vehicle Awareness/Perception Study: Residential & Business; Dallas/Fort Worth, TX / September 2016
The Plugin Hybrid Adsorbed Natural Gas Vehicle (PHANGV) Concept was presented by Sparks Research, on the behalf of Atmos Energy to a statistical sample of consumers and businesses in the Dallas/Ft. Worth designated market area, as follows:

“Today we want your thoughts on a new hybrid vehicle concept that will utilize long-used technologies, and give drivers an option that was previously unavailable.

First, we’re going to cover some facets of this emerging technology that apply to your life/business. A “Plug-in” is a snap-in fuel connector or an electric plug device.

This new plug-in hybrid vehicle can be fueled at home and is NOT electric. Plus, there are public stations where you can refuel. This hybrid vehicle can also use gasoline making it truly a bi-fuel vehicle option.

The fuel for your commute to work can all be provided at home. You won’t have to worry about stopping at a convenience store, swiping a card, splash-back smells, wind, rain, etc. You would receive one bill per month for your fuel.”
• **Residential Findings (sample of 400 consumers)**
  • 40% of Surveyed Population are Very Interested in the Natural Gas hybrid concept
  • 74% (three out of four) are likely to seek information about the Natural Gas Plug-in vehicle concept:
    • 64% see the concept solving many problems rather than creating challenge
    • 58% would pay an additional $5,000 for the concept

• **Business Findings (sample of 103 businesses)**
  • 77% admit that, when assessing the needs of the company, believe the concept would be beneficial to the business
  • 58% would pay an additional $5,000 for the concept
**PHANGV vs. PHEV**

- A Chevy Volt class of PHEV costs an average of $0.0395 per mile for fuel (highway taxes excluded)
- A PHANGV (of equal class) costs an average of $0.0283 per mile for fuel (highway taxes excluded)
- The Chevrolet Volt utilizes a 390 lb. battery pack that provide 53 miles (advertised for the 2017 model using a 18.4 kWh battery pack) of range on electric operation (top speed on electric operation is 98 mph).
- An ANGP Generation 2 Type IV natural gas fuel module dimensions to fit a Chevy Volt class of sedan, would hold 5 GGE of natural gas with a maximum weight of 285 lbs. (including the natural gas); will have a range of 140 miles; and deliver the full performance of the vehicle’s internal combustion engine
- Current lithium ion battery costs are now targeting $300 per kWh; therefore the battery pack of the 2017 Chevy Volt will cost $5,520 for the battery pack alone ($300 X 18.4)
- **The full ANGP Generation 2 storage system is targeted to cost the OEM < $3,000**
ANGP’s LDV strategy is for bi-fuel operation (gasoline or natural gas); natural gas fueling at home or at a private depot. Bi-fuel operation mitigates fueling anxiety on extended driving beyond the daily commute or in-town travel.

Assuming that 75% of annual LDV mileage is used for the daily commute or in-town travel, 395 gallons of gasoline will be replaced with natural gas **yielding a reduction of CO\textsubscript{2} emissions by 1,868 lbs. per vehicle per year, or an 18.75% CO\textsubscript{2} reduction per vehicle per year!**

For every 250,000 bi-fuel natural gas passenger LDVs on the road in the U.S. (less than 0.1% of all registered vehicles), **467,087,500 lbs. (211,867 metric tons) of CO\textsubscript{2} reduction can be achieved!**

Frost & Sullivan Industry Analyst, Arpita Mukherjee is quoted, “Frost & Sullivan firmly believes that the on-board, low-pressure adsorbed natural gas (ANG) storage system developed by ANGP and its technology partners is an innovative, game-changing solution in the light duty vehicles’ (LDVs) fueling market. The significant economic benefits of ANGP’s low pressure natural gas storage system will certainly boost the global natural gas (NG) vehicles market while also strengthening the North American NG export industry.”
Low-pressure is the future of Natural Gas Vehicles!

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