Adsorbed Natural Gas

A promising new alternative fuel solution for low-pressure natural gas storage in the large light duty fleet vehicle market

Sustainable Fleet Technology Conference
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Large, light–duty fleet vehicles are limited by today’s alternative fuel solutions

Alternative fuels focused on small LDVs (sedans) and medium/heavy duty vehicles…

…yet >60% of U.S. vehicle sales are large LDVs

**U.S. new LDV sales by size***

~17M vehicles/year

- Small LDV Sedans ~40%
- Large LDV Pickups Vans SUVs ~60%

*Source: IHS; small LDVs defined as sedans; large LDVs defined as pickups, vans, SUVs and crossovers

** Alliance of Automobile Manufacturers (2017)**

Example vehicles

- Hybrid Electric Vehicles (HEVs + PHEVs) 83% of all EVs**
- Battery Electric Vehicles (BEVs) 17% of all EVs**
- Compressed Natural Gas (CNG) Vehicles (NGVs)

- **Top 3 selling LDVs were pickup trucks**
- **6 of the top 10 selling vehicles were large LDVs**

(source: Car and Driver – 2017 U.S. Sales)
Electrics are economically challenged in large, light-duty fleet vehicles

<table>
<thead>
<tr>
<th>Hybrid EV type:</th>
<th>Chevy Volt Hybrid EV</th>
<th>Workhorse W-15 REEV</th>
<th>PHANGV™ ANG Bi-Fuel Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery weight</td>
<td>404 lbs</td>
<td>1,080 lbs</td>
<td>300 lbs</td>
</tr>
<tr>
<td>Battery cost</td>
<td>$3,680 (@$200/kWh)</td>
<td>$12,000 (@$200/kWh)</td>
<td>$2,000</td>
</tr>
<tr>
<td>Battery Range</td>
<td>53 miles</td>
<td>80 miles</td>
<td>80 miles</td>
</tr>
<tr>
<td>Battery cost per range mile</td>
<td>$69</td>
<td>$150</td>
<td>$25</td>
</tr>
</tbody>
</table>

> 2x sedan

< 20% electric

Private fueling is critical to natural gas vehicle adoption

PHANGV™ ("Plug-in Hybrid Adsorbed Natural Gas Vehicle) is a registered trademark of ANGP Inc.

* Specifications for Chevrolet Volt PHEV sedan

** Specifications for Workhorse W-15 EV pick-up truck (gasoline ICE "range extender")
Convenient, single vehicle electric chargers are reasonably low cost for daily PHEV mileage needs. Why not CNG fueling appliances for NGVs?

- Comprehensive 8-year ongoing study of over 30 CNG fueling appliance designs from over 20 appliance manufacturers
- Total 10-year costs of the <$5K initial cost appliances indicated:
  - Maintenance costs were #1 (highest)
  - Electricity costs were #2
  - Initial cost was #3

- But … what if the fill pressure was below 1,000 psig?

A valuable, low-pressure natural gas technology platform

Ingevity’s deep automotive experience in adsorbed fuel storage technology

Ingevity is the global leader in gasoline vapor (mixed hydrocarbon gas) “catch-and-release” applications for life-of-vehicle automotive emissions control.

Commercial, patent-pending Nuchar® FuelSorb™ activated carbon monoliths enable low-pressure (<1,000 psi) onboard natural gas fuel storage paired with gasoline (Ford QVM certified 2018 ANG bi-fuel F-150; calibration work to be completed in October 2018).

Low-pressure ANG fuel storage enables safe, reliable, convenient, and economical private refueling (GTI study to be completed in January 2019).

Delivered to fleet vehicles and individual consumers:
- Range
- Convenience
- Value
ANG’s Value Proposition

**Range**
A “hybrid” bi-fuel vehicle can service ~75% of daily usage miles with natural gas

**Convenience**
Private refueling leverages the existing natural gas pipeline infrastructure available in over 68 million U.S. homes and over 5 million U.S. businesses

**Value**
Fuel savings for natural gas users range from $1.00 to $1.50 per gasoline gallon equivalent (GGE) compared to gasoline*

ANG has more than twice the capacity of compressed natural gas at 900 psi

Value delivered across wide range of key stakeholders

- **Natural Gas Producer**
  - Increased natural gas demand

- **Natural Gas Utility**
  - Higher per-meter capacity utilization

- **Automotive OEM**
  - Alternative fuel option using a single powertrain where PHEVs are economically challenged

- **Fleet Vehicle Owner**
  - Sustainable fuel savings

*Assumes $2.50/gal average gasoline price and $1.00 – $1.50/GGE natural gas cost (US EIA; Ingevity estimate)