“Innovation in Composite CNG Cylinders”

JEC ASIA 2009
Automotive & Mass Transport Forum
Owens Corning Company Highlights

• Building Materials and Composites
• Founded 1938
• $6 Billion sales in 2008
• 16,500 employees in 30 countries
• Industry leader in all markets served
  – Glass fiber insulation, roofing & asphalt and composite solutions
• First company to trademark a color – Pink
• A Fortune 500 company for 55 consecutive years
• 2008 Fortune magazine most admired companies
• OCV™ Reinforcements, OCV™ Technical Fabrics, OCV™ Non-Woven Technologies
Agenda

Slide 4. **NGV Market Status & Trends**
Slide 5. **CNG Fuel – Key Drivers**
Slide 6. **Classification of Cylinders**
Slide 7. **CNG Cylinder Needs**
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Slide 14. **OCV XStrand® makes High-Performance Affordable for CNG Composite Cylinder**
Slide 15. **Safer, Lighter, Stronger, Affordable**
NGV Market Status & Trends

- 2020 forecasts a NGV population of 50 mill at 15% CAGR
- Asia & S. America are leading the growth
- Developing countries are leading the growth
  - Cheaper fuel & lower pollution
- In Asia, India & China have low NGV population & low penetration offering greater scope for growth
CNG Fuel – Key Drivers

- Rising Pollution & Environmental concerns
  - Natural gas is more environmentally friendly
    - Particle matter
    - Hydro Carbon
    - NOx
    - Carbon Monoxide (CO)

- Supply security
  - Crude Oil: 42 years consumption. Reserve in 61 countries (*)
  - Natural Gas: 58 years consumption. Reserve in 111 countries (*)

(*) Based on year 2007 proven reserves & consumption

- Lower price & more energy efficient

- Proven Technology in Transportation
  - Large scale since 1960
### Classification of CNG Cylinders

<table>
<thead>
<tr>
<th></th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Share (%)</td>
<td>93%</td>
<td>4%</td>
<td>&lt; 2%</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>Structure</td>
<td>Metal</td>
<td>Metal Liner reinforced with resin Impregnated continuous filament (hoop Wrap)</td>
<td>Metal Liner reinforced with resin Impregnated continuous filament (fully Wrap)</td>
<td>Resin impregnated continuous filament with a non-metallic liner</td>
</tr>
<tr>
<td>Most commonly used</td>
<td>CrMo steel</td>
<td>CrMo steel with Glass Fiber</td>
<td>Aluminium with HP Glass &amp;/or Carbon</td>
<td>HDPE liner with Carbon</td>
</tr>
<tr>
<td>Indicative cost - US$/litre</td>
<td>$3 to $5</td>
<td>$5 to $7</td>
<td>$9 to $14</td>
<td>$11 to $18</td>
</tr>
<tr>
<td>Indicative weight - Kg/litre</td>
<td>0.9~1.3</td>
<td>0.8~1.0</td>
<td>0.4~0.5</td>
<td>0.3~0.4</td>
</tr>
</tbody>
</table>

Sources: CompositeMarketReports.com
CompositeWorld.com

- Evident weight reduction (up to 75%) in adopting Type 3 & 4 but comes at a cost...
CNG Cylinder Needs

High specific strength, modulus, toughness

- High operating pressure > 200bar
  - Fuel density \( n = \frac{PV}{RT} \) > distance to re-fuel
- Low weight could lower fuel consumption allow for payload increase
- Impact resistance
- Bullet resistant per testing protocol
- Long life (Static and Cyclic fatigue resistance)
  - Determines design “Safety Factors”

<table>
<thead>
<tr>
<th>Cylinder Type</th>
<th>Fibre Reinforcement</th>
<th>Minimum Burst Ratio</th>
<th>Minimum Stress Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td></td>
<td>2.25</td>
<td>N/A</td>
</tr>
<tr>
<td>Type 2</td>
<td>Glass</td>
<td>2.50</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>Aramid</td>
<td>2.35</td>
<td>2.35</td>
</tr>
<tr>
<td></td>
<td>Carbon</td>
<td>2.35</td>
<td>2.35</td>
</tr>
<tr>
<td>Type 3</td>
<td>Glass</td>
<td>3.50</td>
<td>3.65</td>
</tr>
<tr>
<td></td>
<td>Aramid</td>
<td>3.00</td>
<td>3.10</td>
</tr>
<tr>
<td></td>
<td>Carbon</td>
<td>2.35</td>
<td>2.35</td>
</tr>
<tr>
<td>Type 4</td>
<td>Glass</td>
<td>3.65</td>
<td>3.65</td>
</tr>
<tr>
<td></td>
<td>Aramid</td>
<td>3.10</td>
<td>3.10</td>
</tr>
<tr>
<td></td>
<td>Carbon</td>
<td>2.35</td>
<td>2.35</td>
</tr>
</tbody>
</table>

Extracted from ISO 11439 Standard
Why Composites?

• **Weight Reduction**
  – Reduces fuel consumption
  – Reduces environmental footprint
  – Increases distance between refueling

• **Corrosion resistance**
  – Improves Safety
  – Increases Life
  – Reduces Maintenance

• **Design flexibility**
  – Improves Fuel System integration (Type 4 cylinder)
High Performance Reinforcements Product Line

WindStrand® Reinforcements
FliteStrand® Reinforcements
ShieldStrand® Reinforcements
XStrand® Reinforcements

Available as Single End Roving or Fabric

Fiber glass filament
Ref: Owens Corning

Roving

Fabric

Final Applications

Ref: Owens Corning
Innovation in Composite Cylinders

• High Performance Reinforcements
  – XStrand® is one of the latest innovative solution from Owens Corning for the manufacturing of Industrial, Sports & Recreation items at affordable cost & sustainable availability.

• Practical Benefits of XStrand® Reinforcements
  Compare to E-Glass:
  – Up to 30% increased strength
  – Up to 17% increased modulus
  – Up to 30% lower coefficient of linear thermal expansion
  – Up to 10x better fatigue properties
  – Superior corrosion resistance
  – Higher temperature resistance
## Reinforcements Properties Comparison

<table>
<thead>
<tr>
<th></th>
<th>E-Glass</th>
<th>OCV Advantex®</th>
<th>OCV XStrand®</th>
<th>AGY S2 Glass (*)</th>
<th>T700 Carbon Fiber (**)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pristine Fiber Tensile Strength (MPa)</td>
<td>3,448</td>
<td>3,751</td>
<td>4,605</td>
<td>4,590-4,830</td>
<td>4,900</td>
</tr>
<tr>
<td>Impregnated Fiber Tensile Strength (MPa)</td>
<td>2,137</td>
<td>2,413</td>
<td>3,448</td>
<td>3,660-4,280</td>
<td>NA</td>
</tr>
<tr>
<td>Modulus (GPa)</td>
<td>72</td>
<td>81</td>
<td>87</td>
<td>86-90</td>
<td>230</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>2.60</td>
<td>2.63</td>
<td>2.52</td>
<td>2.46-2.49</td>
<td>1.80</td>
</tr>
<tr>
<td>Specific Pristine Tensile Strength (m)</td>
<td>1.35*10^5</td>
<td>1.46*10^5</td>
<td>1.86*10^5</td>
<td>1.88<em>10^5– 2.00</em>10^5</td>
<td>NA</td>
</tr>
<tr>
<td>Specific Tensile Modulus (m)</td>
<td>2.82*10^6</td>
<td>3.14*10^6</td>
<td>3.52*10^6</td>
<td>3.52<em>10^6– 3.73</em>10^6</td>
<td>NA</td>
</tr>
</tbody>
</table>

(*) Source AGY Pub. LIT2004-341
(‡) Source TORAYCA.com /properties
Value Proposition – Case Study -

Type 4 – 190 liter CNG Cylinder -Case Study- (Material SA- Belgium)

- XStrand® reinforcement enables about 40% cost reduction versus Carbon/ Epoxy Type 4 solution (with obviously a weight penalty).
- XStrand® cylinder is half the weight of a typical steel tank.
Cost Structure of Type 4 CNG Cylinder – Case Study

- **Basis:** 190L, 200bar CNG cylinder
  - Direct Cost (fiber, resin, production)

**Graph:**
- **Carbon (*)**
  - Direct Relative cost: 100%
  - Safety factor: 2.35
- **XStrand® (**)**
  - Direct Relative cost: 60%
  - Safety factor: 3.65
- **E-glass (**)**
  - Direct Relative cost: 30%
  - Safety factor: 3.65

Source: Material SA - Belgium
OCV XStrand® makes High-Performance Affordable for CNG Composite Cylinder

• Affordable Lightweight Performance
  – High Strength, High Modulus glass fiber available in Large quantities
  – Allowing Comparable cost positioning to E-Glass reinforced CNG type 4 cylinder with weight Reduction
  – Substitution for S-Glass in CNG Type 3 & 4 CNG cylinder – at a lower cost position
  – Replace or Combine with carbon fiber in CNG type 3 & 4 – where Cost is a critical factor to increase Market Penetration

• Drivers for Substitution of Type 1 & 2 CNG Cylinder
  – Shortage of seamless steel tubes
  – Increase concerns for Environmental impact
  – Better Integration to fit Car design
  – Experience consolidation in Composite tanks manufacturing
  – Evolution to Higher Pressure systems to reduce Payload

• Opportunities
  – Market Penetration through the gain of Technology leadership
  – Full recognition of CNG Fuel system from Car manufacturers (new car design integrating CNG fuel system)
  – Reduction of Safety factors for High-Performance Glass Fiber
Safer, Lighter, Stronger, Affordable

Market Drivers -
- Improves Safety
- Reduces fuel consumption
- Reduces environmental footprint
- Reduces distance to refuel
- Available
- Affordable

The success of NGV mass development will pass through the development of Affordable High-Performance Materials & Technology to bring storage tanks beyond actual limits.
Thank you

More information:

www.owenscorning.com/composites/
www.ocvreinforcements.com/hp/