2014 North American Carbon Nanotubes Technology Innovation Award
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Background and Company Performance

Industry Challenges

Carbon nanotubes are an evolving technology that can be used to advance the physical properties of known materials. A carbon nanotube is essentially a nano-sized cylinder of carbon atoms (graphene) that possess unusual or superior properties, such as outstanding thermal conductivity, as well as mechanical or physical properties. These tiny particles—a nanometer is one-billionth the thickness of a human hair—can have around 10 to 15 times the tensile strength of stainless steel, and can be 5 times as thermally conductive as copper. This is why CNTs, as they are known, are incorporated into aerospace aluminum parts to structurally reinforce them, and incorporated into a polymer matrix to increase electrical and thermal conductivity much greater than traditional carbon black or metal powder fillers. CNTs are also being used in applications such as water filtration, sports equipment, body armor, auto body panels, rockets, and building materials.

Most CNTs are multi-walled carbon nanotubes (MWNTs), that is, they are single carbon nanotubes with 5 to 15 layers. Single-walled carbon nanotubes (SWNTs), which possess a single wall, have been less commercially used and are more expensive, but have great potential. SWNTs have an outer diameter (OD) of 1 to 3 nanometers compared to the 8 to 40 nanometer OD of MWCNTs.

The strong carbon-carbon bonds of SWNTs provide mechanical strength and Young's modulus of nearly 1,000 Gpa, which translates into 50 times higher than the modulus of steel. These particles' geometry can be slightly altered to tailor their mechanical, electrical, and thermally conductive properties to suit specific applications. Thus, SWNTs have great potential in the development of high performance composites, to control the assembly of molecular electronics, and to fabricate next generation, ultra-sensitive sensor devices.

Commercialization of SWNTs has lagged behind that of MWNTs due to the much higher costs of the SWNTs, which are 50 to 1000 times greater than that of MWNTs. This is caused by the greater difficulty in processing SWNTs, which comprise mixtures of carbon allotropes and inorganic particles that are not easily isolated. Thus, it is expensive to purify SWNTs for commercial use.

OCSiAl USA and its parent company OCSiAl LLC, based in Luxembourg, and sister firms in Russia, Germany, and Korea, have developed an industrial process to synthesize SWNTs that can be scaled up to eventually produce hundreds of thousands of tons of these nanoparticles, thereby potentially reducing production costs up to 100 times.
Technology Attributes and Future Business Value of OCSiAl

Industry Impact

OCSiAl's ability to produce SWNTs in commercial scale quantities for commercial application will drive the use of these nanoparticles, first in research, and then in high-end industrial and consumer applications, because it has simplified the multi-stage process typically used to make carbon nanotubes.

Best Practice Example: OCSiAl's Graphetron 1.0 processing plant in Novosibirsk, Russia, will scale up its production of SWNTs to 10 tons per year; this is nearly double the combined production capacity of major SWNT producers Unidym, Toray Industries, SouthWest Nanotechnologies, and KleanCarbon in 2010.

Product Impact

OCSiAl scientists have designed their TUBALL product to contain a minimum of 75% SWNTs, less than 15% of non-carbon impurities, with predominant non-carbon element being iron. Virtually all non-carbon species are encapsulated; provide highly crystalline nanotubes; and price close one-fiftieth analogue materials. These characteristics enable OCSiAl's SWNTs to be used as a universal additive, that is, simultaneously enhancing the strength and electric and thermal conductivity of most materials, such as polymer composites, rubbers, metals, and some others, upon the addition of as little as 0.001% to 0.1% by weight TUBALL. For example, significant improvement of cyclability of lithium ion batteries occurs at 0.02% weight carbon nanotube loading.

Best Practice Example: OCSiAl sought and received third-party validation of its SWNTs quality from Intertek, the London, United Kingdom-based multinational inspection, product testing, and certification company. In May 2014 Intertek confirmed the concentration of more than 75% SWNTs in a sample of the TUBALL product. Intertek's Certificate of Analysis concerning TUBALL (Certificate Number IWTN/COA/W663/001) supports the impact of OCSiAl's product.

Scalability

OCSiAl designed its process to synthesize SWNTs—protected by 2 Russian patents (2,157,060 and 2,47,8572), 2 United States patents (6,846,467 and 8,137,65), and various patents pending—to eliminate the multiple stages typically used to process carbon nanotubes. This will make it easier for the OCSiAl process to be used on a pilot scale first and, in time, to be scaled up to produce new generations of SWNTs with increasing levels of quality and functionality.

Best Practice Example: In November 2013 OCSiAl inaugurated its pilot industrial synthesis facility, named Graphetron 1.0, at the R&D center of OCSiAl in the Nanomodified Materials Center at the Technopark of Novosibirsk Akademgorodok. Graphetron 1.0 initially produce
up to 1 ton of SWNTs per year. In time, the production of the TUBALL SWNTs produced at Graphetron will be increased to 10 tons per year.

**Visionary Innovation**

OCSiAl’s synthesis process completely encapsulates the impurities of catalyst particles in its SWNTs. This addresses a common problem in SWNT production: the presence of catalyst particles that are considered impurities in carbon nanotubes. Furthermore, OCSiAl scientists will limit the content of the free metal particles in their TUBALL SWNTs to 1%. Making SWNTs with greater purity is a major goal of nanotechnology developers.

Best Practice Example: At the 10th International Nanotechnology Symposium Nanofair 2014 held in July in Dresden, Germany, OCSiAl presented research comparing the influence of different carbon additives—carbon nanofibers, carbon black, SWNTs, and MWNTs—on the resistance and service life of lithium-ion batteries that incorporate these additives in their cathode material. The best performance was achieved by the OCSiAl SWNTs, which showed reduced cell resistance to less than 25% of its original value with the adding of only 0.2% of the SWNTs in tests.

**Application Diversity**

OCSiAl USA’s single-walled attributes have high performance characteristics that enable their use as a universal additive in multiple applications. Its SWNT characteristics include: 100 times the strength of steel, thermal stability up to 1,000 degrees C, 1,000 times the length to diameter ratio, and possessing a surface area equivalent to 2 basketball courts in a single gram of material. New technology serves multiple products, multiple applications, and multiple user environments.

Best Practice Example: OCSiAl USA provides its TUBALL as an additive to slurries to make the electrodes in lithium-ion batteries last longer and has partnered with an unnamed but leading developer of rubber and tires to use the SWNTs for structural reinforcement in automobile tires. OCSiAl USA has successfully tested adding 0.05% of TUBALL to polypropylene to increase polypropylene’s modulus of tension by 50% and raise its temperature distortion point by 15%, desirable traits in automotive applications. OCSiAl is developing a technique to use its SWNTs as the conductive layer in a series of transparent conductive films that can be used as transparent electrodes in manufacturing touch screens, liquid crystal displays, and the cover electrodes for both solar cells and organic light-emitting diodes.

The most promising application of TUBALL is in lithium-ion, the most common portable electrochemical power source today due to their compactness, energy capacity, output power, and cycle life. When the TUBALL BATT suspension is added to the electrode slurry during the preparation of cathodes for Li-ion batteries with different cathode chemistry, it
substantially increases the cyclability of li-ion batteries as well as increasing their
discharge and charge power rate.

The improvements that TUBALL brings to lithium ion batteries were confirmed by
Fraunhofer IKTS in Germany, the largest ceramic research center in Europe. After
extensive testing, Fraunhofer IKTS found that adding the OCSiAl nanomodifier improved
li-ion performance more than 60%. In July 2014, at the International Nanotechnology
Symposium Nanofair held in Dresden, Germany, OCSiAl demonstrated the results of
comparison of different modifiers, such as carbon black, carbon nanofibers and multi-
walled carbon nanotubes, to enhance Li-Ion batteries. The tests showed that the addition
of only 0.2% TUBALL BATT could reduce cell resistance to less than one-quarter of its
initial value, the best performance of all the additives tested at the Nanofair.

Customer Acquisition

The company has formed dealership relations with nanotechnology firms based on their
partners' agreement to purchase quantities of OCSiAl's SWNTs to use in research and
products, thereby acquiring customers and marketing opportunities simultaneously. Best
Practice Example: At the NANO KOREA 2014 symposium in July 2014, OCSiAl announced
the signing of an agreement to supply 100 kilograms of its TUBALL product to Applied
Carbon Nano Technology Co., Ltd., of Pohang City, Korea. The latter company is a leading
Korean nanotechnology developer, and the quantity of the purchase is quite large by
single wall carbon nanotube production standards. OCSiAl maintains an office in Korea
that will use this sale for future penetration of Asian markets for its SWNTs.

One month later, in late August, 2014, OCSiAl announced that it had entered into a 100-
kilogram agreement with one of the key players in Chinese nanoindustry. Combined with
the previously described Korean contract, the SWNT manufacturer's portfolio of contracts
for 2015 now exceeds what was known as a market maximum and shows no sign of
slowing down.

Conclusion

Carbon nanotubes have taken material science to another level with their ability to change
the characteristics of known materials such as structural strength, permeability, electrical
conductivity, and thermal transport; improve the capabilities of known parts; or allow the
creation of totally new products. Single-walled carbon nanotubes in particular have strong
potential in advanced technologies including high performance composites, molecular
electronics, and ultra-sensitive sensor devices. The high purity and large scale production
of the OCSiAl TUBALL products is a potential game changer, earning OCSiAl the 2014
North American Technology Innovation Award in Carbon Nanotubes.
Significance of Technology Innovation

Ultimately, growth in any organization depends upon finding new ways to excite the market, and upon maintaining a long-term commitment to innovation. At its core, technology innovation or any other type of innovation can only be sustained with leadership in three key areas: understanding demand, nurturing the brand, differentiating from the competition. This three-fold approach to nurturing innovation is explored further below.

Understanding Technology Innovation

Technology innovation begins with a spark of creativity that is systematically pursued, developed, and commercialized. That spark can result from a successful partnership, a productive in-house innovation group, or the mind of a singular individual. Regardless of the source, the success of any new technology is ultimately determined by its innovativeness and its impact on the business as a whole.
Key Benchmarking Criteria
For the Technology Innovation Award, we evaluated two key factors—Technology Attributes and Future Business Value—according to the criteria identified below.

Technology Attributes
- Criterion 1: Industry Impact
- Criterion 2: Product Impact
- Criterion 3: Scalability
- Criterion 4: Visionary Innovation
- Criterion 5: Application Diversity

Future Business Value
- Criterion 1: Financial Performance
- Criterion 2: Customer Acquisition
- Criterion 3: Technology Licensing
- Criterion 4: Brand Loyalty
- Criterion 5: Human Capital

Best Practice Award Analysis for OCSiAl USA
Decision Support Scorecard
To support its evaluation of best practices across multiple business performance categories, Frost & Sullivan employs a customized Decision Support Scorecard. This tool allows our research and consulting teams to objectively analyze performance, according to the key benchmarking criteria listed in the previous section, and to assign ratings on that basis. The tool follows a 10-point scale that allows for nuances in performance evaluation; ratings guidelines are illustrated below.

RATINGS GUIDELINES

The Decision Support Scorecard is organized by Technology Attributes and Future Business Value (i.e., the overarching categories for all 10 benchmarking criteria; the definitions for each criteria are provided beneath the scorecard). The research team confirms the veracity of this weighted scorecard through sensitivity analysis, which confirms that small changes to the ratings for a specific criterion do not lead to a significant change in the overall relative rankings of the companies.
The results of this analysis are shown below. To remain unbiased and to protect the interests of all organizations reviewed, we have chosen to refer to the other key players in as Company2 and Company3.

**DECISION SUPPORTSCORECARDFORTECHNOLOGY INNOVATION AWARD (ILLUSTRATIVE)**

<table>
<thead>
<tr>
<th>Measurement of 1–10 (1 = poor; 10 = excellent)</th>
<th>Technology Attributes</th>
<th>Future Business Value</th>
<th>Average Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Innovation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCSIAI USA</td>
<td>9.5</td>
<td>9.2</td>
<td>9.3</td>
</tr>
<tr>
<td>Company 2</td>
<td>9.0</td>
<td>8.5</td>
<td>8.7</td>
</tr>
<tr>
<td>Company 3</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
</tr>
</tbody>
</table>

**Technology Attributes**

**Criterion 1: Industry Impact**
Requirement: Technology enables the pursuit of groundbreaking new ideas, contributing to the betterment of the entire industry

**Criterion 2: Product Impact**
Requirement: Specific technology helps enhance features and functionality of the entire product line for the company

**Criterion 3: Scalability**
Requirement: Technology is scalable, enabling new generations of products over time, with increasing levels of quality and functionality

**Criterion 4: Visionary Innovation**
Requirement: Specific new technology represents true innovation based on a deep understanding of future needs and applications

**Criterion 5: Application Diversity**
Requirement: New technology serves multiple products, multiple applications, and multiple user environments

**Future Business Value**

**Criterion 1: Financial Performance**
Requirement: High potential for strong financial performance in terms of revenues, operating margins and other relevant financial metrics

**Criterion 2: Customer Acquisition**
Requirement: Specific technology enables acquisition of new customers, even as it enhances value to current customers

**Criterion 3: Technology Licensing**
Requirement: New technology displays great potential to be licensed across many sectors and applications, thereby driving incremental revenue streams
Criterion 4: Brand Loyalty
Requirement: New technology enhances the company’s brand, creating and/or nurturing brand loyalty

Criterion 5: Human Capital
Requirement: Customer impact is enhanced through the leverage of specific technology, translating into positive impact on employee morale and retention

Decision Support Matrix
Once all companies have been evaluated according to the Decision Support Scorecard, analysts can then position the candidates on the matrix shown below, enabling them to visualize which companies are truly breakthrough and which ones are not yet operating at best-in-class levels.

DECISION SUPPORT MATRIX FOR TECHNOLOGY INNOVATION AWARD (ILLUSTRATIVE)
The Intersection between 360-Degree Research and Best Practices Awards

Research Methodology
Frost & Sullivan’s 360-degree research methodology represents the analytical rigor of our research process. It offers a 360-degree-view of industry challenges, trends, and issues by integrating all 7 of Frost & Sullivan's research methodologies. Too often, companies make important growth decisions based on a narrow understanding of their environment, leading to errors of both omission and commission. Successful growth strategies are founded on a thorough understanding of market, technical, economic, financial, customer, best practices, and demographic analyses. The integration of these research disciplines into the 360-degree research methodology provides an evaluation platform for benchmarking industry players and for identifying those performing at best-in-class levels.
Best Practices Recognition: 10 Steps to Researching, Identifying, and Recognizing Best Practices

Our awards team follows a 10-step process (illustrated below) to evaluate award candidates and assess their fit with our best practice criteria. The reputation and integrity of our awards process are based on close adherence to this process.

<table>
<thead>
<tr>
<th>STEP</th>
<th>OBJECTIVE</th>
<th>KEY ACTIVITIES</th>
<th>OUTPUT</th>
</tr>
</thead>
</table>
| 1 Monitor, target, and screen | Identify award recipient candidates from around the globe | • Conduct in-depth industry research  
• Identify emerging sectors  
• Scan multiple geographies | Pipeline of candidates who potentially meet all best-practice criteria |
| 2 Perform 360-degree research | Perform comprehensive, 360-degree research on all candidates in the pipeline | • Interview thought leaders and industry practitioners  
• Assess candidates’ fit with best-practice criteria  
• Rank all candidates | Matrix positioning all candidates’ performance relative to one another |
| 3 Invite thought leadership in best practices | Perform in-depth examination of all candidates | • Confirm best-practice criteria  
• Examine eligibility of all candidates  
• Identify any information gaps | Detailed profiles of all ranked candidates |
| 4 Initiate research director review | Conduct an unbiased evaluation of all candidate profiles | • Brainstorm ranking options  
• Invite multiple perspectives on candidates’ performance  
• Update candidate profiles | Final prioritization of all eligible candidates and companion best-practice positioning paper |
| 5 Assemble panel of industry experts | Present findings to an expert panel of industry thought leaders | • Share findings  
• Strengthen cases for candidate eligibility  
• Prioritize candidates | Refined list of prioritized award candidates |
| 6 Conduct global industry review | Build consensus on award candidates’ eligibility | • Hold global team meeting to review all candidates  
• Pressure-test fit with criteria  
• Confirm inclusion of all eligible candidates | Final list of eligible award candidates, representing success stories worldwide |
| 7 Perform quality check | Develop official award consideration materials | • Perform final performance benchmarking activities  
• Write nominations  
• Perform quality review | High-quality, accurate, and creative presentation of nominees’ successes |
| 8 Reconnect with panel of industry experts | Finalize the selection of the best-practice award recipient | • Review analysis with panel  
• Build consensus  
• Select winner | Decision on which company performs best against all best-practice criteria |
| 9 Communicate recognition | Inform award recipient of award recognition | • Present award to the CEO  
• Inspire the organization for continued success  
• Celebrate the recipient’s performance | Announcement of award and plan for how recipient can use the award to enhance the brand |
| 10 Take strategic action | Share award news with stakeholders and customers | • Coordinate media outreach  
• Design a marketing plan  
• Assess award’s role in future strategic planning | Widespread awareness of recipient’s award status among investors, media personnel, and employees |
About Frost & Sullivan

Frost & Sullivan, the Growth Partnership Company, enables clients to accelerate growth and achieve best in class positions in growth, innovation and leadership. The company's Growth Partnership Service provides the CEO and the CEO's Growth Team with disciplined research and best practice models to drive the generation, evaluation and implementation of powerful growth strategies. Frost & Sullivan leverages almost 50 years of experience in partnering with Global 1000 companies, emerging businesses and the investment community from 31 offices on six continents. To join our Growth Partnership, please visit http://www.frost.com.