BIOGAS:
AN ECO-FRIENDLY SOURCE OF ENERGY

Biogas is growing in importance as an eco-friendly source of energy. It can be naturally produced from the decomposition of organic waste through a biochemical process, such as anaerobic digestion, or through thermo-chemical means such as landfills. As more uses for biogas are found, gas purity is a critical consideration. Biogas purity is essential for the protection of downstream equipment such as engines, membranes and fuel cells. Biogas purity standards are also being set for emerging applications such as renewable natural gas generation and vehicle fuel.

Damaging and Unwanted Impurities in Biogas

<table>
<thead>
<tr>
<th>Impurity</th>
<th>What is it?</th>
<th>Why remove it?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Sulfide (H₂S)</td>
<td>A hazardous chemical compound present in biogas derived from agriculture, wastewater treatment, and landfills</td>
<td>Carries a foul odor, poisonous, corrosive, and flammable</td>
</tr>
<tr>
<td>Siloxanes</td>
<td>Man-made organic compounds often found in landfills and wastewater treatment facilities</td>
<td>Cause significant damage, destruction, and reduced efficiency to engines, turbines, fuel cells, and catalysts</td>
</tr>
<tr>
<td>Volatile Organic Compounds (VOCs)</td>
<td>Organic chemical compounds often found in biogas derived from agriculture, landfills, and wastewater treatment facilities</td>
<td>Cause significant damage to membranes and contributes to SOx and NOx emissions</td>
</tr>
</tbody>
</table>

HYDROGEN SULFIDE REMOVAL

Hydrogen sulfide (H₂S) is typically present in biogas, although concentrations vary based on feedstock. Waste streams that are high in proteins containing sulfur-based amino acids (methionine and cysteine) can significantly influence biogas H₂S levels. The H₂S contained in biogas causes odors, equipment corrosion and sulfur emissions when the gas is burned, and is dangerous for human and animal health.
If the biogas is to be used in internal combustion engines, turbines or fuel cells, the removal of \( \text{H}_2\text{S} \) from the biogas is recommended to protect the equipment. Purifying biogas and concentrating the methane also require the removal of carbon dioxide, water and other contaminants before it can be called biomethane and used interchangeably with natural gas.

Our family of DARCO\textsuperscript{\textregistered} BG high performance granular activated carbons were developed specifically for removing \( \text{H}_2\text{S} \) from biogas streams. Produced by a proprietary high temperature steam activated process which doesn't use any impregnate, the risk of bed fires due to exothermic reactions is greatly reduced.

DARCO BG activated carbons are a high performance, cost-effective solution for \( \text{H}_2\text{S} \) removal and offer many benefits:
- Lower cost of \( \text{H}_2\text{S} \) removed
- Longer bed life
- Less disposal costs
- Chemistry that is not conducive to brickling
- Low dust emission during handling
- Easy to load and remove

In the figure below, the bar graph on the left shows the \( \text{H}_2\text{S} \) loading capacity of each competitive product. NORIT DARCO BG 1 activated carbon provides two times the loading capacity compared to caustic activated carbon and iron oxide media. The bar graph on the right shows the average $/lb. cost of removing \( \text{H}_2\text{S} \) for each product. Based on its much higher removal capacity, this graph illustrates how much more cost effective NORIT DARCO BG 1 activated carbon is to use.

For cost effective removal of \( \text{H}_2\text{S} \) in biogas environments that require very low pressure drop, we recommend NORIT ROZ3 activated carbon. NORIT ROZ3 activated carbon has also been designed for environments exhibiting low relative humidity less than 80%.

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Our product portfolio Biogas – \( \text{H}_2\text{S} \) removal

<table>
<thead>
<tr>
<th>Product</th>
<th>( \text{H}_2\text{S} ) loading %</th>
<th>Pressure drop</th>
<th>Performance at &lt; 60% relative humidity</th>
<th>Cost/kg of ( \text{H}_2\text{S} ) removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>DARCO\textsuperscript{\textregistered} BG 1 activated carbon</td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
</tr>
<tr>
<td>DARCO BGH activated carbon</td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
</tr>
<tr>
<td>NORIT\textsuperscript{\textregistered} ROZ 3 activated carbon</td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
</tr>
<tr>
<td>NORIT\textsuperscript{\textregistered} ROZ 4W activated carbon</td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
<td><img src="index.png" alt="Rating" /></td>
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</table>
SILOXANE REMOVAL

Siloxanes are a group of man-made organic compounds used to produce personal hygiene, health care and industrial products. This class of impurities presents a significant challenge along with volatile organic compounds (VOC) to operational efficiencies and costs in biogas production. Widespread use of siloxanes has contributed to significant amounts of impurities found in wastewater and landfills. Even at levels of 0.5 PPM in raw biogas, siloxanes can cause significant damage to and reduced efficiency of engines, turbines, boilers, fuel cells and catalysts. Siloxane damage leads to higher costs and can seriously impact biogas upgrading.

NORIT SILPURE activated carbon uses proprietary technology to preferentially adsorb siloxanes over high BTU volatile organic compounds commonly found in biogas. This process increases loading capacity and gas purity is improved, resulting in lower maintenance costs, less frequent material change-outs, and increased gas processing capability.

NORIT SILPURE activated carbon's surface chemistry:
- Removes 15 times more siloxanes in the field vs. traditional activated carbon
- Enables capture of both large molecular weight siloxanes and difficult to remove small molecular weight siloxanes
- Improves gas purity
- Increases loading capacity resulting in lower maintenance costs
- Increases service life 5 times over traditional activated carbon

Field trial results from Suez's Packington Landfill in the United Kingdom

On an equal weight basis, NORIT SILPURE activated carbon has been shown to remove 15 times more siloxanes in the field

<table>
<thead>
<tr>
<th>Kilograms of siloxanes adsorbed per metric ton of activated carbon</th>
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</thead>
<tbody>
<tr>
<td>NORIT SILPURE activated carbon</td>
</tr>
<tr>
<td>4 mm traditional activated carbon</td>
</tr>
</tbody>
</table>

This data represent siloxane and H2S adsorption in actual field test conditions at Suez's Packington Landfill in the United Kingdom. Siloxane removal under lab conditions should be considered carefully, as labs may not accurately mimic real biogas conditions due to the large number of competing compounds present in the gas stream, including siloxanes, VOCs, H2S and other sulfur species. The physical adsorption of siloxanes becomes significantly more difficult in the field due to competitive adsorption dynamics, which is why we designed NORIT SILPURE activated carbon to have a specific affinity for the removal of siloxanes.
VOLATILE ORGANIC COMPOUND REMOVAL

Biogas derived from landfill gas (LFG) and from agriculture and wastewater treatment facilities is usually heavily contaminated with volatile organic compounds (VOCs). As the market for biogas continues to shift from power generation to renewable natural gas (i.e. biomethane), the removal of halogenated VOCs has become extremely important to biogas upgrading systems and the effective operation of the system’s gas permeation membranes. Membrane processes are one of the most effective means for removing carbon dioxide (CO₂) to upgrade biogas and VOCs often contain essential oils (e.g. terpenes) that are harmful to the membranes themselves. In addition, these oils, at very low concentrations, give off a very strong odor. This strong odor can mask the effects of the odorants added to the upgraded gas as a safety requirement.

To prevent this, the VOCs in biogas are removed through the use of activated carbon. Our NORIT RB4 activated carbon has been optimized for highly efficient VOC adsorption to help biogas upgrading systems operate with the most precision. The removal of VOCs offers significant benefits which include:

- Membrane performance improvement
- Improved gas quality
- Greater operational efficiency
- Reduced operational costs
- Reduced downtime
- Increased volume of gas processed

Our biogas product portfolio – siloxane/VOC removal

<table>
<thead>
<tr>
<th>Product</th>
<th>Application</th>
<th>Siloxane loading</th>
<th>VOC loading</th>
<th>Pressure drop</th>
<th>Reduction in operational costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORIT SILPURE activated carbon</td>
<td>Engine site</td>
<td>☺</td>
<td>☆</td>
<td>○</td>
<td>☺</td>
</tr>
<tr>
<td>NORIT RB 4 / RB 4W activated carbon</td>
<td>Biomethane</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
<td>☆</td>
</tr>
<tr>
<td>NRS CARBON EA 3-4*)</td>
<td>Biomethane</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
</tr>
</tbody>
</table>

*) NRS CARBON EA 3-4 is a reactivated product and is available based on customer location

* For optimal removal efficiency of H₂S, siloxanes, and VOCs in a single filter, we recommend a layered media approach. Please contact your local application engineer for support.

We supply a diverse portfolio of activated carbon grades to purify the biogas from undesirable compounds like H₂S, siloxanes and VOCs. Our activated carbon products are specifically designed for the removal of these challenging impurities, making us an ideal partner for biogas producers who require a lower cost of impurity removal and improved profitability.
APPLICATION SUPPORT

Ongoing technical support is always close at hand at Cabot. Our application knowledge and expertise is always available to address your purification needs. We look forward to becoming your activated carbon partner.

If you have any questions or would like to obtain the following information, contact your nearest Cabot office:

1. An analysis of your activated carbon needs
2. Technical bulletins
3. Test information
4. Norit standard test methods (NSTM)
5. Specific application information
6. General information on activated carbon
7. Product information
8. Samples for testing

PARTNERING WITH US

We are the world's oldest and most experienced producer of activated carbon. Our history of innovation allows us to provide the right solution to meet each customer's application needs and ensuring better performance than "off the shelf" products. Our products are manufactured in ISO certified facilities and backed by a global network of sales, technical service and customer support professionals.

AHEAD OF THE CURVE ON PURIFICATION

Building on our 100-year history of innovation in manufacturing and product development, Cabot Norit Activated Carbon is the world's most experienced and one of the largest producers of activated carbon serving customers in more than 100 countries with manufacturing facilities in seven countries. Our products are used to efficiently and cost-effectively remove pollutants, contaminants and other impurities from water, air, food and beverages, pharmaceutical products and other liquids and gases. We have developed more than 150 different grades of activated carbon – produced from a variety of raw materials – that provide our customers with precise solutions for their specific application needs. Additionally, we offer a full range of activated carbon services including rental systems, carbon reactivation, bulk delivery and change-out, carbon evaluation and direct technical support.

Our sales, technical service and customer service teams are prepared to serve customers around the world. Contact us at cabotcorp.com/activatedcarboncontact

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