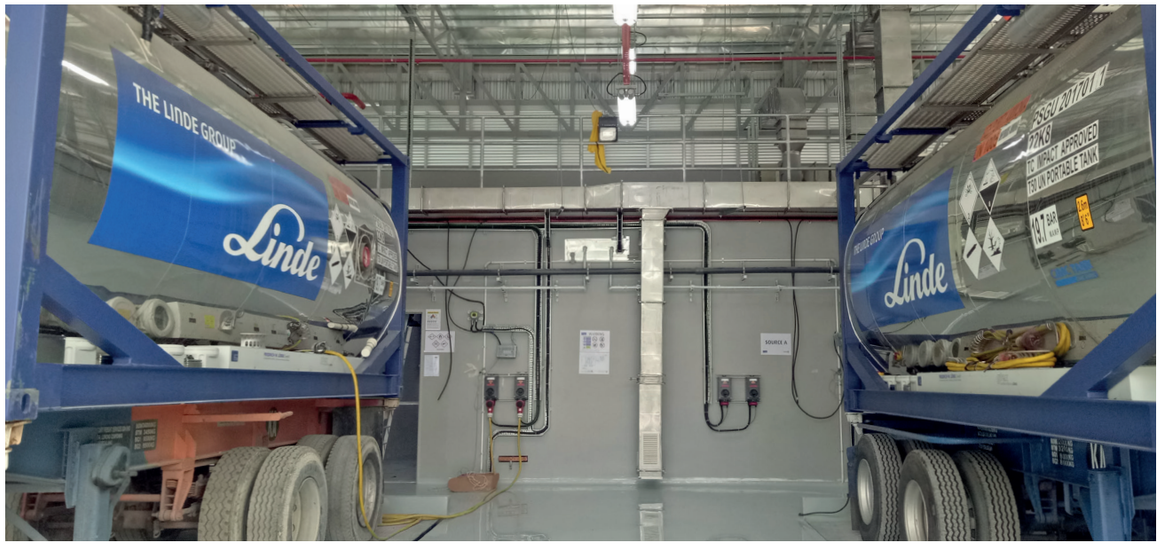


Ammonia: A feedstock providing the platform for electronics

By Aidan Lee, Global Product Manager, Linde Electronics

While ammonia is manufactured on a massive scale to help feed the world, it is increasingly used in important reactions in the electronics industry. In this article, we discuss the applications driving the increased consumption, and look at how the large supply of the raw feedstock affects the market for the highly purified material needed for making electronic devices.

Applications

Semiconductor chips can be extremely complex, sometimes taking more than 1,000 different steps to make nano-scale, three-dimensional structures. But these devices are often built upon simple chemicals and materials.

Ammonia is a good example. When reacted directly with silane or other silicon reactants, silicon nitride is deposited as a thin-film.

$$4\ NH_3 + 3\ SiH_4 \rightarrow Si_3N_4 + 12\ H_2$$

This reaction is driven either by heating the surface on which the silicon nitride will be deposited, or by reacting the chemicals in a plasma discharge. The resulting silicon nitride thin film is a workhorse.

Typical ammonia use by application sector

Typical Fab	Ammonia Requirement
Display	120 tons / year
Semiconductor	120 tons / year
LED	1,500 tons / year
Solar	80 tons / year

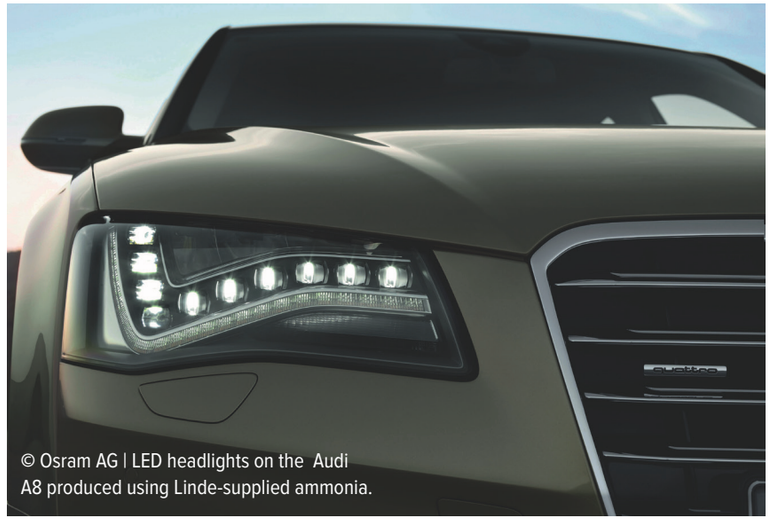
- **Display:** To make a flat panel display screen, each individual pixel is controlled by its own pair of transistors. Silicon nitride is used as an electrical insulator in these transistors, like the plastic insulator wrapped around a wire. The latest 4k television screens have over 8 million of these pixel – transistor pairs.
- **Semiconductor:** While much more complex, semiconductor chips use the same types of simple transistor pairs found in display screens, and can contain upwards of 8 billion of these tiny circuits per chip. Silicon nitride is used not only as an electrical insulator, but also as a chemical barrier. In this role, the nitride formed with silicon – as well as more exotic elements like tungsten and tantalum – separates two more reactive thin films which might degrade under high currents or voltages.
- **Solar:** Silicon nitride fills a dual role in the manufacture of silicon-based solar cells. In addition to being used as an electrical insulator, the material also serves as an anti-reflective coating, ensuring that sunlight reaches the photovoltaic layers inside of the cells instead of bouncing off the surface.
- **LED:** Working nearly in the reverse function of solar cells, LEDs (light-emitting devices) turn electrical current into visible light. The fundamental material which generates the light is gallium nitride, which is also formed by reacting ammonia with another gas, trimethyl gallium. This reaction is very inefficient, and in high-volume production, it takes approximately 1,000 ammonia molecules on average to make one reaction with the gallium precursor.

Supply

Ammonia is the highest volume chemical gas by weight used in electronics, with the exception of nitrogen, which is usually produced on-site. Even though annual electronics demand is growing nearly 10% per year, electronics demand is still less than 0.02% of total global production.

Most of this demand is in the four countries of China, Japan, South Korea and Taiwan, which dominate all of the electronic application sectors cited above. Because of the low feedstock and production costs, it is the packaging, distribution, and dispense which dominate the cost to supply this material.

- **Feedstock:** Nearly 90% of the 175 million metric tons of ammonia is used for the production of fertilizer. Coupled with the fact that it is made by the direct reaction of nitrogen and hydrogen from natural gas, large quantities of industrial grade ammonia can be locally sourced in almost all geographies.
- **Purification:** Electronics grade ammonia is highly purified, with a minimum purity of 99.9999%. Moisture and oxygen are the key impurities which need to be removed, along with other atmospheric contaminants. The purification process is a combination of absorption and distillation. At the customer site, it is common for additional point-of-use purifiers to be used on the manufacturing tools.
- **Packaging:** Ammonia can be supplied in cylinders, however the high-volume demand at manufacturing locations dictates that larger packages are used such as drums and horizontal containers that can hold up to 500kg, and ISO containers that can carry more than 10 tons each. In all packages, ammonia is shipped as a liquefied gas with head pressure of around 10 bar.
- **Distribution:** Because the production costs are low, and the feedstock is universally available, most electronic grade ammonia is produced within a few hundred kilometers of the point of consumption in East Asia.
- **Dispense:** While shipping as a liquid ensures the most cost-effective transportation costs, the high consumption rate means that special dispense systems must be used in order to rapidly and safely vaporize the ammonia while maintaining the high level of material purity.


© Osram AG | LED headlights on the Audi A8 produced using Linde-supplied ammonia.

> "Electronics grade ammonia is highly purified, with a minimum purity of 99.9999%"

Summary

Used from the inception of the commercial electronics industry over 50 years ago, electronics grade ammonia demand has grown with the volume and complexity of the market sector. Just as importantly, shrinking semiconductor device sizes and new applications like LEDs continue to drive purity specifications to ever lower levels.

Interestingly, the invention of ammonia compression was the founding event for the Linde Group 138 years ago. Today, Linde is the leading designer and provider of the nitrogen and hydrogen plants used to feed modern ammonia synthesis plants. In the electronics sector, Linde operates ammonia purification plants in China, Germany, South Korea, Taiwan and the US to provide the highest grade material locally to its largest customers. And Linde has provided the highest-flow ISO distribution system, yielding up to 3,000 standard liters per minute of ultra-high purity ammonia. SGR