Integrating domestic and international electronic material solutions

Anshul Sarda, Vice President, Electronic Special Gases, The Linde Group
March 2018
The Linde Group worldwide

- Operating in over 100 countries
- Revenue of 135 Billion RMB
- 60,000 employees
Linde Gases – Leading industrial gases company in APAC

Revenue split by product area

Revenue split by industry

— Strong position in major industrial clusters in Asia/Pacific
— Solid track record of revenue growth built on a diverse portfolio of leading customers
Company profile

Linde Electronics
- Leading in electronic gases
- Serving global top semiconductor, solar, display and LED customers
- Part of the Linde Group – an international industrial gas and engineering company

Linde LienHwa
- Leading in electronic gases
- Mainly serving top tier customers in Mainland China and Taiwan for over 30 years

Total electronic bulk and special gas solution provider with local expertise and global network adding value to customers’ business
Linde LienHwa - Serving all of Asia with broad portfolio

Linde LienHwa (LLH) is a 50:50 joint venture company within The Linde Group.

LLH TW Headquarters

Leading electronics specialty gases supplier in Mainland China and Taiwan since 1984.

LLH CN Headquarters

Over 1,600 employees, largest industrial gases manufacturer in Taiwan with production, warehousing, and trading capabilities.

Leading bulk Gas market share in Mainland China and Taiwan. Leading Electronic special gas market share.

ESG Material Center
Linde and the China semiconductor industry
Established wafer fabs
1988 – 2015
Announced wafer fabs

2015+
Linde global ESG supply network

>50+ sources globally
Why are gases important to semiconductors?
Where gases are used in the fab

1. Bulk tanks for liquid argon, carbon dioxide, nitrogen, and oxygen
2. On-site nitrogen
3. Gas distribution system within the fab
4. Electronic specialty gases (ESGs) and chemical supply
5. Gas management system
6. Gas purification system
7. On-line chemical analysis
8. Bulk ESGs plus helium and hydrogen
Material and gases in global electronics manufacturing

Relative semiconductor spend $B

- Capex: 67
- R&D: 55
- Materials: 44

Electronic gas market $5B

- 60% ESGs
- 40% Bulk

Bulk gases

- Nitrogen (N₂)
- Oxygen (O₂)
- Argon (Ar)
- Hydrogen (H₂)
- Helium (He)
- Carbon dioxide (CO₂)

Electronic special gas market $3B

- Top 10 ESGs

- N₂O, WF₆, PH₃
- SiH₄, C₂F₆, Laser (Ne, Ar, Xe, F₂)
- NH₃, NF₃, HCl, Si₂H₆

Capex R&D Materials

Bulk gases

60% ESGs

40% Bulk

2016 2021

Semi Display LED Solar

NH₃ NF₃ HCl Si₂H₆

Top 10 ESGs
Examples of key processes that use ESGs

**Deposition**

- **SiCl₂H₂ + NH₃**
- **Si₃N₄**
- **Si**

*Plasma / heat*

**Lithography**

- **Deep UV laser**
- **Mask**
- **Lens**
- **Wafer**

**Etching**

- **HBr + Cl₂ + O₂**
- **Fluorocarbons**: CₓHᵧF𝑧, CₓFₓ, CₓFₓ₂, CₓFₓ₃, CₓFₓ₄, CₓFₓ₅, CₓFₓ₆, CHF₃, CH₂F₂, CH₃F, CₓHFₙ
- **Sulfur hexafluoride**: SF₆
- **Halides**: HCl, Cl₂, HF, F₂, HBr, ClF₃, XeF₂
- **Oxygen**: O₂

**Nitrogen gases**: NH₃, N₂O
**Silicon gases**: SiH₄, Si₂H₆, TCS, HCDS, TMS
**Oxygen**: O₂
**Tungsten hexafluoride**: WF₆
**Germane**: GeH₄

**Laser gases**: 95+% Ne, with Ar, Kr, and F₂
**Carbon dioxide**: CO₂
**Hydrogen**: H₂
Examples of key processes that use ESGs

**Doping**
- **Hydrides**: AsH₃, BF₃, B₂H₆, PH₃, GeH₄, Ge₂H₆
- **Oxygen**: O₂
- **Hydrogen**: H₂
- **Argon**: Ar

**Annealing**
- Original Si surface
- Oxide
- Si substrate
- Si substrate
- Plasma / heat

**Chamber Cleaning**
- Plasma deposition
- Wafer
- Plasma cleaning
- Contaminated chamber
- Deposited film on sidewalls
- Chamber ready for next process

**Chamber Cleaning Chemicals**
- **Nitrogen trifluoride**: NF₃
- **Other fluoride gases**: CF₄, C₂F₆, C₆F₆, ClF₃, SF₆
- **Chloride gases**: HCl, Cl₂
- **Fluorine**: F₂
Gas supply model

- **On-site**
  - Gas production and purification plant
  - Pipeline
  - On-site supply
  - Pipeline

- **Bulk**
  - Transport of liquefied gas

- **Cylinder**
  - ESG filling sites
China semiconductor industry requirements
30 Years of mainland China semiconductor industry
Capacity growth and technology advancement

Cumulative MSI/year in China
MSI = millions of square inches of silicon

- **Domestic Only**
  - 1988: small fabs for domestic/military purposes
  - 1993: many generations behind leading-edge
  - 1998: larger but isolated fabs
  - 2003: foreign leading-edge + domestic-foreign JVs
  - 2008: several generations behind leading-edge

- **Domestic + Foreign**
  - 2013: mega fabs and clusters of investment
  - 2018: sustained government support for domestic leading-edge technology

- **Big Fund Era**
  - 2023: sustained growth and investment
  - 2025: future outlook
China semiconductor industry may be young...
But customers have same requirements

- Quality
- Secure supply
- Expertise
Between the variability of the raw material source...

Liaoning Fluorspar:
HF, NF₃, SF₆, CF₄, etc.

Guangxi Tungsten:
WF₆, WCl₅

Yunnan Germanium:
GeH₄, Ge₂H₆
...and the precision of manufacturing
Material suppliers like Linde are the quality gatekeepers
Managing supply chain determines quality

Measure at each step, prevent defects, continuous improvement

Raw materials → Receiving → Prep → Purification → Blending → Fill → QA/QC/Lab → Delivery → Final product quality

Traditional quality focus
Measurement systems analysis (MSA), Statistical process/Quality control (SPC/SQC)
Quality: Customers are driving tighter requirements

Customers
Expect Linde to meet purity specifications and control limits

Are even more concerned about unknown and uncontrolled impurities

Example
Specification: 50 ppm
Control limit: 20 ppm
Mean: 8 ppm
For bulk products, our customers see quality analysis in real time
Quality: local and consistent

Copy-exact procedures to produce consistent results

Suzhou Electronics Facility

Taichung Electronics Facility
Delivering quality requires control across the full supply chain

Material providers like Linde are the quality gatekeepers
China ESG supply chain
China ports

- Tianjin port
- Qingdao port
- Lianyungang
- Shanghai port
- Ningbo port

Hong Kong port

North China base
West China base
East China base
South China base

5,500 km
Importing electronic materials into China takes 10 – 50 days.
China raw material processor locations
Major supply disruptions can change how we do business

Tianjin Port Explosion: 2015
Major supply disruptions can happen for positive occasions

Beijing Olympics: 2008
Major supply disruptions can happen when just a few important people meet.
Long-term success for materials suppliers
Long-term success is integrating global expertise
Local partner. Global expertise.

Start with global expertise

- Know-how
- Production
- Logistics
- Quality
- Safety
Long-term success is integrating global expertise
Local partner. Global expertise.

Start with global expertise
- Know-how
- Production
- Logistics
- Quality
- Safety

Invest in domestic capability
- R&D
- Production
- Distribution
- People
Long-term success is integrating global expertise
Local partner. Global expertise.

Start with global expertise
- Know-how
- Production
- Logistics
- Quality
- Safety

Invest in domestic capability
- R&D
- Production
- Distribution
- People

Partner with local raw materials suppliers
- Implement quality standards
- Secure supply chain
electronicsinfo@linde.com