Critical Challenges in Materials Supply to Advanced Semiconductor Manufacturing Fabs

Dr. Anish Tolia, Head of Global Marketing, Linde Electronics
May 22, 2015

Key factors in gas supply.

New materials, processes, and adaptable supply chain to meet evolving market needs

Scale	Quality	Supply chain	Sustainability
Larger fabs and smaller devices mean more gases	Changing needs due to complex technology	Complex global supply chain management	Reduce environmental impact

Key factors in gas supply.

New materials, processes, and adaptable supply chain to meet evolving market needs

Scale	Quality	Supply chain	Sustainability
Larger fabs and smaller devices mean more gases	Changing needs due to complex technology	Complex global supply chain management	Reduce environmental impact

Scale. Drivers for increased consumption.

THE LINDE GROUP
Linde

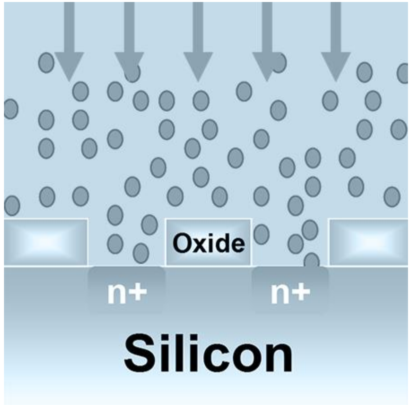
Rapid deployment of very large fabs

- Typical logic foundry now 80,000 WSPM
- Typical memory fab now exceeding 120,000 WSPM
- Fabs concentrated in clusters (science parks)

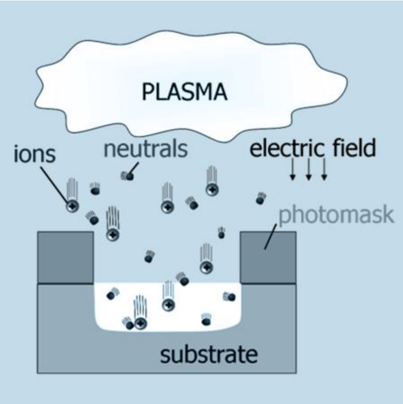
Solid State TECHNOLOGY The ConFab

THE LINDE GROUP
Linde

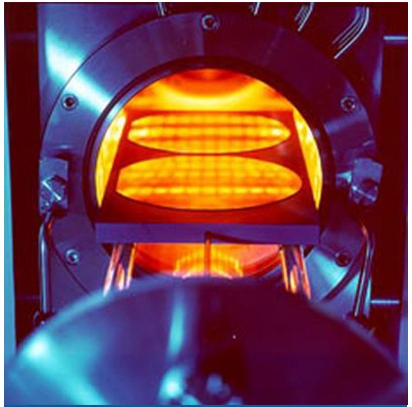
Scale. Several hundred process steps and hundreds of gases and chemicals.



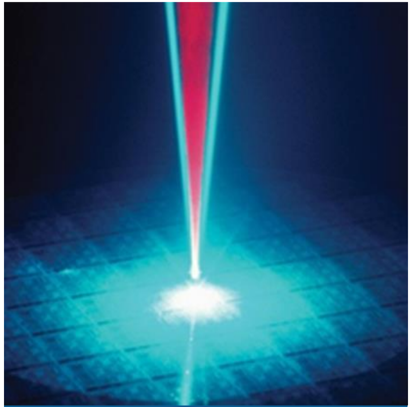
Doping / thermal



Etch / clean



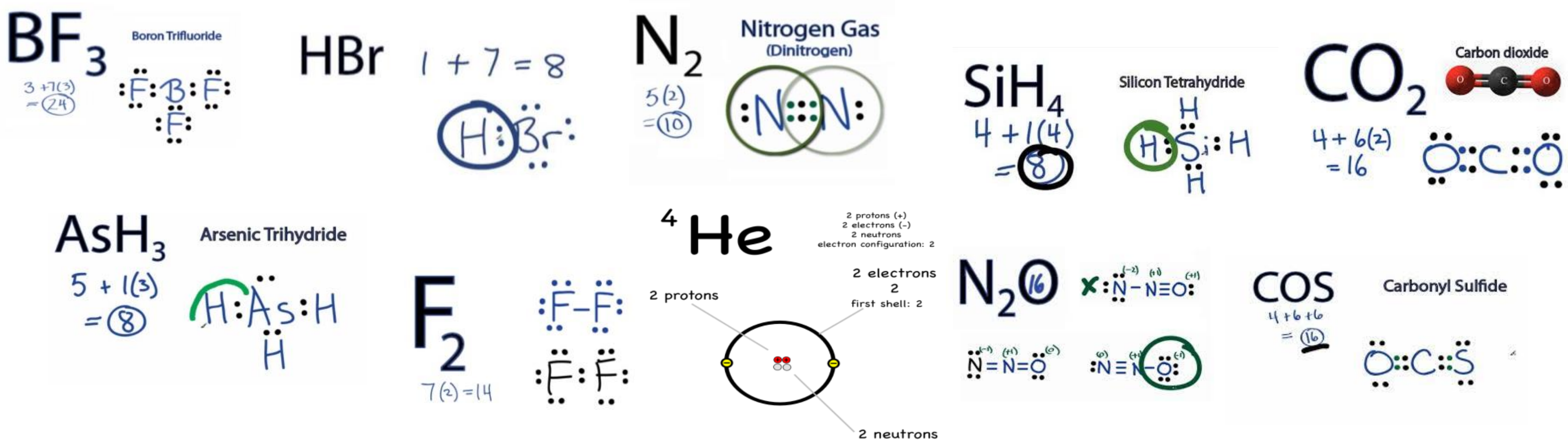
Deposition



Litho / patterning

Solid State TECHNOLOGY
The ConFab

Scale. Several hundred process steps and hundreds of gases and chemicals.

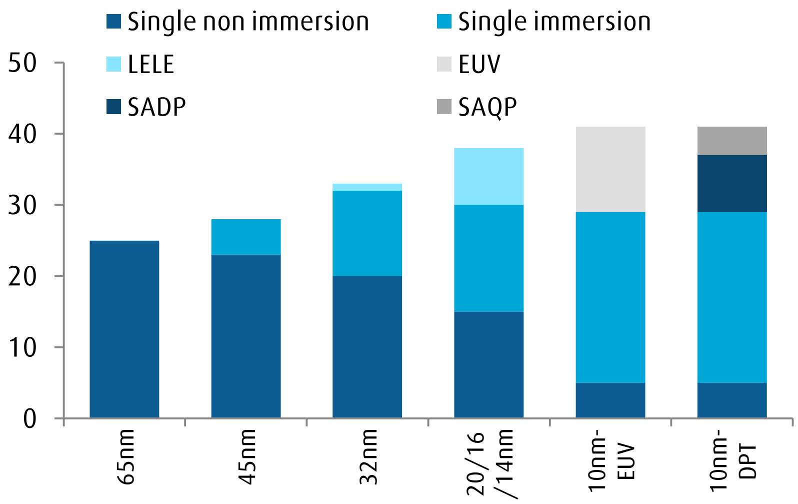


Scale. Drivers for increased consumption.

Multi-patterning

- Move from single-patterning to multi-patterning because of small devices
- Small feature size requiring better optical resolution and move to EUV lithography
- Increased transistor processing (epitaxy, etch, ALD) driving new and increased materials

Number of layers by node

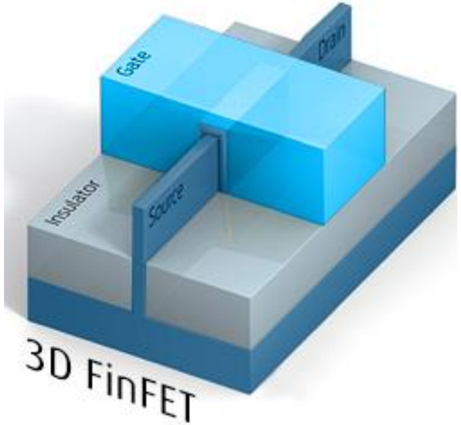


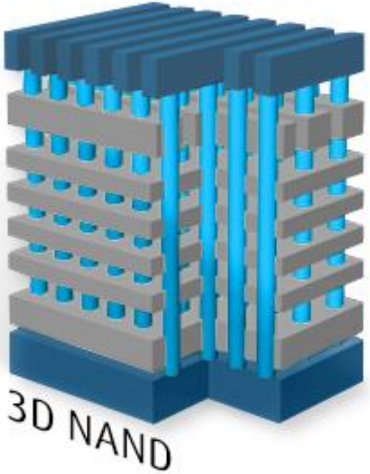
Graph source: Credit Suisse

Scale. Drivers for increased consumption.

Move to more complex 3D devices

- 3D FinFET
  - Increased epitaxy steps
  - Increased ALD
- 3D NAND
  - Complex etch
  - Increased deposition

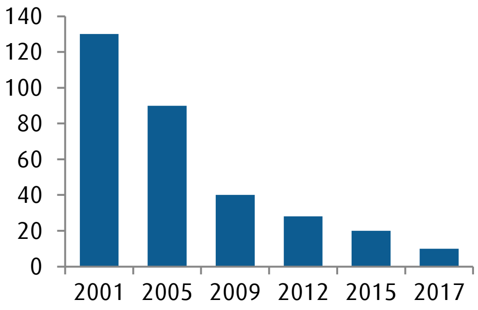




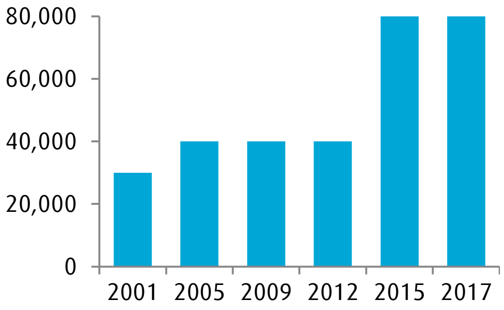
Scale. Increased use of nitrogen.

- Increasing fab capacity drives more consumption
- Advanced technology nodes use more N_2 due to more tools driven by multi-patterning
- Need for on-site generators with increased capacity as gas need increases

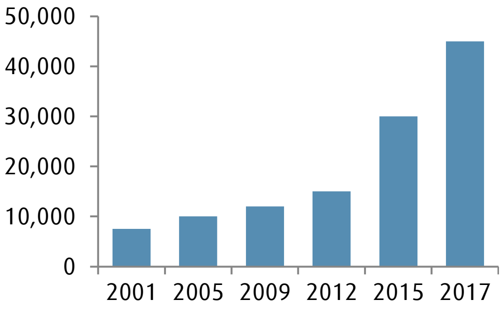
Process node (nm)



Typical fab size (WSPM)



N_2 consumption(Nm^3/h)



Scale. Increased use of hydrogen.

Compressed gaseous hydrogen (CGH_2)

Economical transport for short to medium distances

Liquid hydrogen (LH_2)

Economical transport for medium to long distances

(only in U.S. and Europe)

On-site production

Production through steam reforming or electrolysis

No hydrogen transport costs

Key factors in gas supply.

New materials, processes, and adaptable supply chain to meet evolving market needs

Scale
Larger fabs and smaller devices mean more gases

Quality
Changing needs due to complex technology

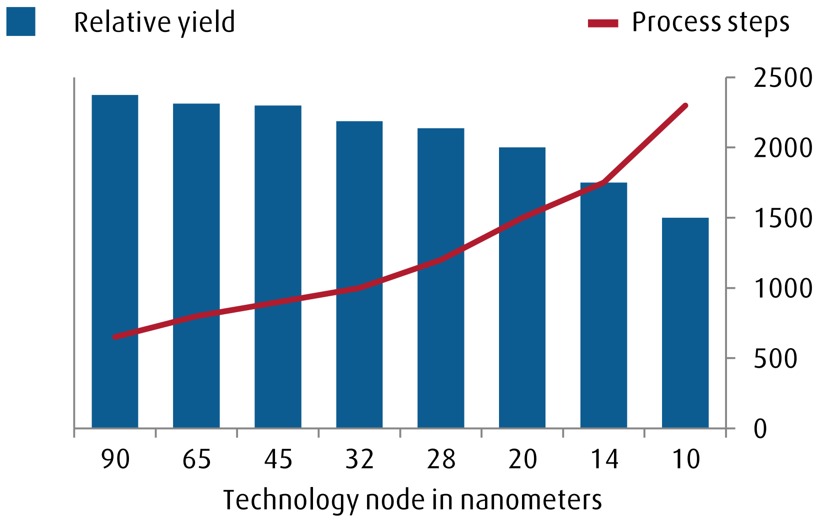
Supply chain
Complex global supply chain management

Sustainability
Reduce environmental impact

Quality. Drivers.

- Complexity of processes and reduced yield with each added process
- Risk from higher investments and operational costs
- Engineers not knowing how a specific impurity might impact performance: the challenge of the unknown

Semi manufacturing yields and steps



Graph source: Entegris

Quality. Increasingly important for chip manufacturers at leading technology nodes.

- A modern high-volume semiconductor fab hugely amplifies value and cannot afford any process excursions
- Stringent focus on controlling variation in all inputs to the chip fabrication process

Starting wafer

Typical cost = $120

Fab CAPEX now >$7B

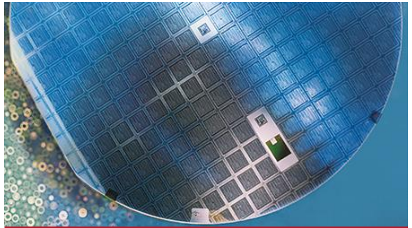
40K to 80K wafer starts per month

Fabrication

Advanced logic:
process steps > 600

Cycle time 6 to 10 weeks

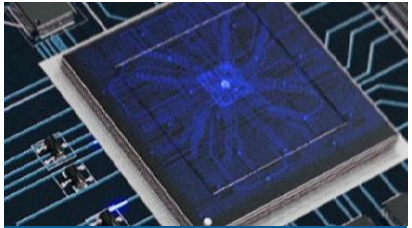
Processing cost = ~$1,000 - $5,000



Finished wafer

Cost per processed wafer = $1,000 - $5,000

"Value" up to $20K - $40K (based on ASP of the chips)



IC chip

Average selling price ~$1 to > $2000

Quality. Need for holistic system.

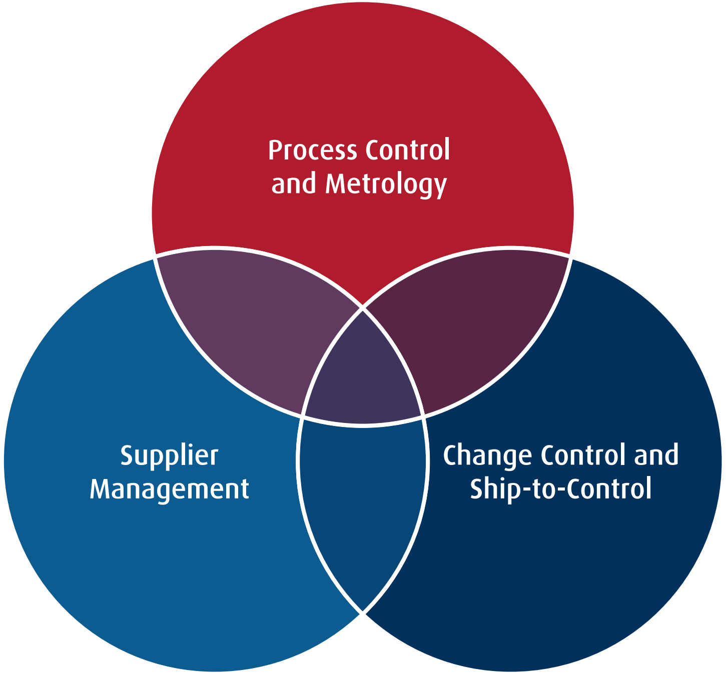
Challenges in meeting demands

- Increase in complexity of monitoring and ensuring process stability across the entire supply chain
- An increasing demand for people such as materials scientists, chemists, and process engineers

Quality. Need for holistic system.

Challenges in meeting demands

- Increase in complexity of monitoring and ensuring process stability across the entire supply chain
- An increasing demand for people such as materials scientists, chemists, and process engineers



Quality. Need for holistic system.

Measurement systems

Gas distribution systems

Receiving → Prep → Purification → Fill → QA/QC/Lab → Delivery

Final product quality

Traditional quality focus

Measurement systems analysis (MSA), Statistical process/Quality control (SPC/SQC)

Quality. Reduce variability, tighten control limits.

IC technology step changes drive electronic materials purity and analytical requirements

15 to 20 years ago →	Within the last 10 years →	Recent / Present →	Near future
High-purity EMs	High-purity EMs Tight consistency	High-purity EMs Tighter consistency Use of overall process control system	High-purity EMs Tighter consistency Wide use of overall process control system Fingerprinting

Quality. Reduce variability, tighten control limits.

A need for process stability across the entire supply chain

- Rigorous measurement, enabled with fingerprinting and metrology
- Gas purity and consistency/reliability
- Business continuity planning
- Process/statistical quality control

Key factors in gas supply.

New materials, processes, and adaptable supply chain to meet evolving market needs

Scale
Larger fabs and smaller devices mean more gases

Quality
Changing needs due to complex technology

Supply chain
Complex global supply chain management

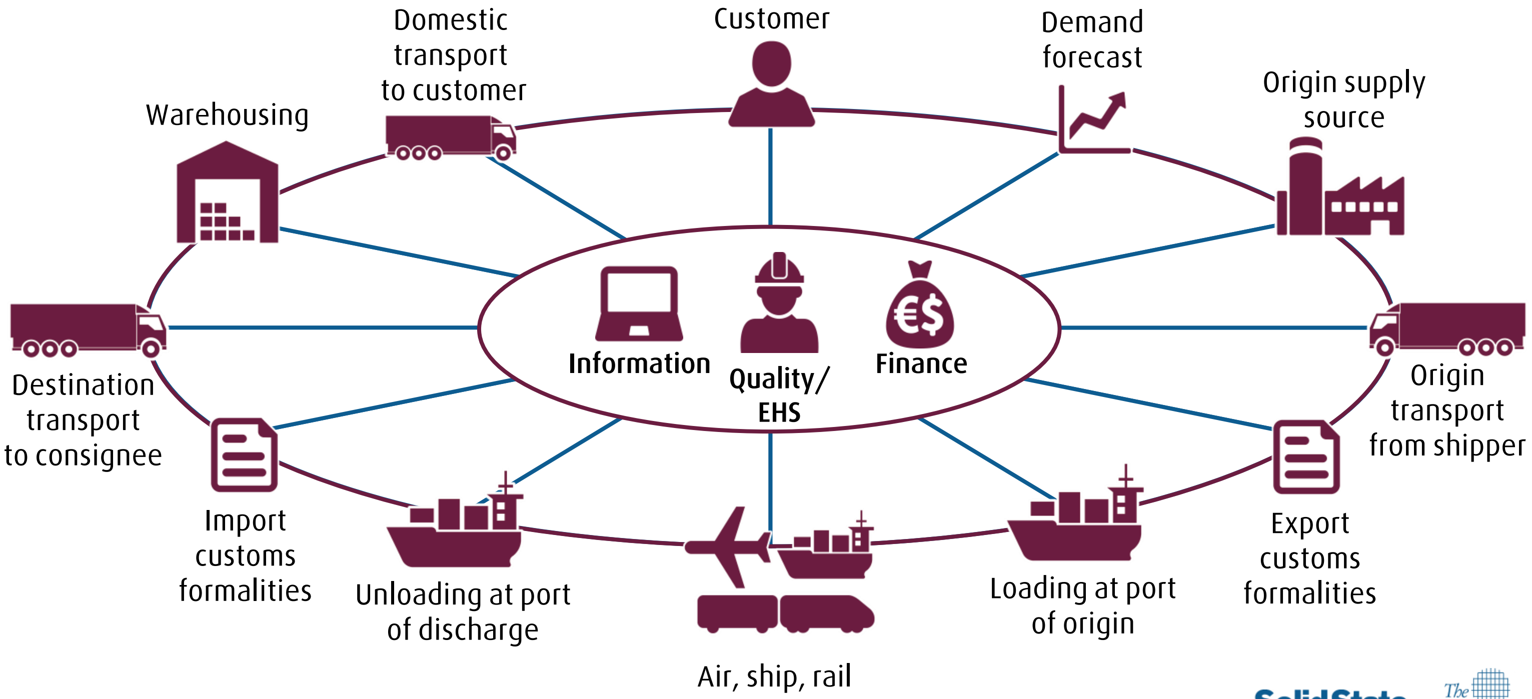
Sustainability
Reduce environmental impact

Supply chain. Global supply chain comes with challenges.

- Capacity planning
  - Usage volumes for specialty gases
  - Visibility into ramp demand of materials for new technologies
- Limited raw materials suppliers
- Security of supply and move to local and regional suppliers
- Natural disasters and shortages
- Transportation labor strikes
- Change in government regulations

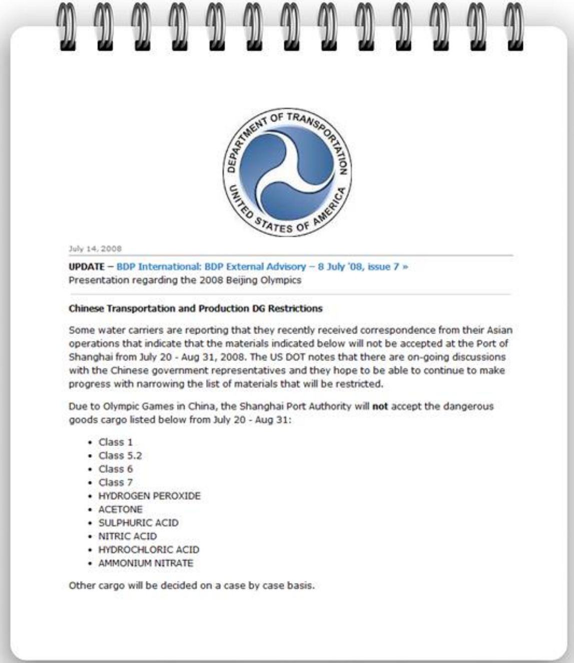
Japan earthquake and tsunami devastation – Source: LA Times

Supply chain. Interlinked, comprehensive, customer-focused.



Supply chain. China and the 2008 Olympics.

- Chinese government block of hazardous materials into multiple ports during the 2008 Olympics
- Materials had to be trucked in and added two months extra delivery time
- Required a lot of advanced planning



July 14, 2008

UPDATE – BDP International: BDP External Advisory – 8 July '08, issue 7 »
Presentation regarding the 2008 Beijing Olympics

Chinese Transportation and Production DG Restrictions

Some water carriers are reporting that they recently received correspondence from their Asian operations that indicate that the materials indicated below will not be accepted at the Port of Shanghai from July 20 - Aug 31, 2008. The US DOT notes that there are on-going discussions with the Chinese government representatives and they hope to be able to continue to make progress with narrowing the list of materials that will be restricted.

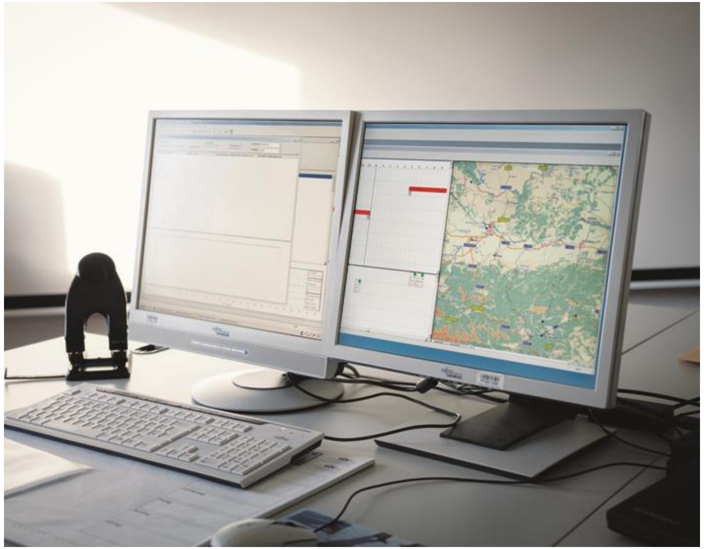
Due to Olympic Games in China, the Shanghai Port Authority will **not** accept the dangerous goods cargo listed below from July 20 - Aug 31:

- Class 1
- Class 5.2
- Class 6
- Class 7
- HYDROGEN PEROXIDE
- ACETONE
- SULPHURIC ACID
- NITRIC ACID
- HYDROCHLORIC ACID
- AMMONIUM NITRATE

Other cargo will be decided on a case by case basis.

Supply chain. Business Continuity Planning.

- Conduct Business Continuity Planning (BCP) with alert nodes in proactive processes
- Identify potential supply gaps by plotting product-source mapping
- Create raw materials, manufacturing, transportation, and labor shortage contingency plans
- Develop supply gap mitigation and implementation plans



Supply chain. Business Continuity Planning.

- Assess where and how to invest to diversify supply chain on multiple continents
- Do procurement forecasting and planning with customers and suppliers to meet demands
- Acquire two sources for raw materials and have customers qualify both sources
- Establish footprint closer to customer with on-site and local supply plants
- Coach suppliers on Statistical Quality Control (SQC), Statistical Process Control (SPC), and customer requirements to show things they do can help customers avert disaster at multiple points in the supply chain

THE LINDE GROUP Linde

Solid State TECHNOLOGY The ConFab

Key factors in gas supply.

New materials, processes, and adaptable supply chain to meet evolving market needs

Scale	Quality	Supply chain	Sustainability
Larger fabs and smaller devices mean more gases	Changing needs due to complex technology	Complex global supply chain management	Reduce environmental impact

Sustainability. Big fabs, big use of resources.

Water

10 cubic meters used per wafer at 14 nm node x 80,000 wafers per month x 12 months =

9,600,000 cubic meters of water used per year (enough for 39,506 people in U.S.)

Electricity

1220 kilowatt per hour used per wafer at 14 nm node x 80,000 wafers per month x 12 months =

1,152,000,000 kilowatt – hours or

1,152,000 megawatt – hours electricity used per year (enough for 94,846 people) in U.S.)

Natural gas

61 cubic meters used per wafer at 14 nm node x 80,000 wafers per month x 12 months =

58,560,000 cubic meters of natural gas used per year (enough for 26,899 people in U.S.)

Greenhouse gases

8 greenhouse gases used, which if unabated, are the equivalent of 4.2 tons of CO_2 per wafer. After 90% abatement at 14 nm node x 80,000 wafers per month x 12 months =

400,000 tons CO_2 equivalents used per year

Sustainability. Big fabs, big carbon footprint.

Annual carbon footprint including electricity, natural gas, and chemicals of just one 80,000 wafers per month capacity fab =

1,300,000 tons

Sustainability. Drivers.

- Increasing environmental focus and concerns
- Heightened environmental regulations
- Use of large volumes of rare and high value gases
- Pressure to reduce operating costs

SPECTRA® nitrogen plant (world’s best energy efficiency)

Sustainability. Material recovery solutions.

On-site, closed-loop recovery

- Materials recovered on site, purified, and are available for re-use in the manufacturing process

On-site, open-loop recovery

- Materials recovered on site and are available for use in other applications

Off-site recovery

- High-cost materials recovered, shipped off site, and purified at an external facility for re-use

Helium
recovered on-site and returned to customer

Argon
recovered on-site and returned to customer

Xenon
recovered and processed off-site

Sulfur hexafluoride
recovered on-site and returned to customer

Sulfuric acid
recovered on-site and sold to industrial users

Sustainability. Fluorine.

Fluorine technology to reduce emissions by tens of million tons of CO_2 equivalent per year

Global warming potential of greenhouse gases
(100 year GWP kg CO_2 eq)

F_2	NF_3	SF_6
0	17,200	22,800

Sustainability. Fluorine.

THE LINDE GROUP
Linde

Fluorine technology to reduce emissions by tens of million tons of CO_2 equivalent per year

Case example: Major memory fab

- Using on-site fluorine plants as a safer and more cost-effective alternative to cylinder fluorine for cleaning Chemical Vapor Deposition (CVD) chambers in its manufacturing process
- Using fluorine to replace other fluorinated cleaning gases such as nitrogen trifluoride (NF_3) following tests that demonstrated reductions in cleaning time of up to 40% and a 35% decrease in the mass of gas used

Solid State TECHNOLOGY The ConFab

Implications for manufacturers.

Proactively plan up front

Partner with suppliers who

- Commit to your needs
- Value and implement process control and measurement
- Provide security and diversity of supply

Do longer term planning to include

- Building of on-site gas production and recovery
- CAPEX investments

www.linde-gas.com/electronics

electronicsinfo@linde.com