The Technologically Transformational Automotive Electronics Market and the Implications for Material Supply

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A problem has been detected and Windows has been shut down to prevent damage to your computer.

PFN_LIST_CORRUPT

If this is the first time you’ve seen this Stop error screen, restart your computer. If this screen appears again, follow these steps:

Check to make sure any new hardware or software is properly installed. If this is a new installation, ask your hardware or software manufacturer for any Windows updates you might need.

If problems continue, disable or remove any newly installed hardware or software. Disable BIOS memory options such as caching or shadowing. If you need to use Safe Mode to remove or disable components, restart your computer, press F8 to select Advanced Startup Options, and then select Safe Mode.

Technical information:
*** STOP: 0x0000004e (0x00000099, 0x00900009, 0x00000900, 0x00000900)

Beginning dump of physical memory
Physical memory dump complete.
Contact your system administrator or technical support group for further assistance.
Driven by innovation and growing regulation

Automobile industry co-locating with semiconductor industry to accelerate innovation

In Europe, countries challenging the internal combustion engine

- Technology company
- Automotive company
Electronics ubiquitous on cars

- Parental controls
- Engine control
- Airbag deployment
- Adaptive front lighting
- Adaptive cruise control
- Automatic braking
- Electronic throttle control
- Electric power steering
- Instrument cluster
- Driver alertness monitoring
- Windshield wiper control
- Head-up display
- Idle stop / start
- Electronic valve timing
- Cylinder de-activation
- OBDII
- Event data recorder
- Interior lighting
- Auto-dimming mirror
- Active cabin noise suppression
- Accident recorder
- Voice / data communications
- Cabin environment controls
- DSRC
- Entertainment system
- Battery management
- Digital turn signals
- Navigation system
- Lane correction
- Electronic toll collection
- Active exhaust noise suppression
- Active suspension
- Hill-hold control
- Security system
- Regenerative braking
- Antilock braking
- Parking system
- Electronic valve timing
- Electronic throttle control
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Electronics ubiquitous on cars

Safety Negligible

- Parental controls
- Instrument cluster
- Interior lighting
- Voice / data communications
- Entertainment system
- Electronic toll collection
- Auto-dimming mirror
- Active cabin noise suppression
- Cabin environment controls
- Battery management
- Navigation system
- Head-up display
- Idle stop / start
- Electronic valve timing
- Cylinder de-activation
- Active vibration control
- Remote keyless entry
- Seat position control
- Regenerative braking
Electronics ubiquitous on cars

Safety Enhancement

- Night vision
- Windshield wiper control
- Adaptive front lighting
- Driver alertness monitoring
- Event data recorder
- Accident recorder
- OBDII
- Lane departure warning
- Tire pressure monitoring
- Lane correction
- Security system
- Digital turn signals
- Active suspension
- Hill-hold control
- Parking system
Electronics ubiquitous on cars

Safety Critical

- Engine control
- Airbag deployment
- Automatic braking
- Electric power steering
- Electronic throttle control
- Blindspot detection
- Transmission control
- Electronic stability control
Now becoming computers on wheels

**Autonomous Vehicles**

- **Cameras**: ~20–40 MB per second
- **Radar**: ~10–100 KB per second
- **Sonar**: ~10–100 KB per second
- **GPS**: ~50 KB per second
- **Lidar**: ~10–70 MB per second

4,000 GB per day...each day

Source for data: Intel
Planes rely on chips for safety – achieved by redundancy

Jets manufactured per year: < 2000
Base price: $270 million

Passenger vehicles manufactured per year: 100 million
Base price: $27,000
A fast growing market

Market representing around $35B in 2016
Growing much faster than the total IC market

<table>
<thead>
<tr>
<th>Segment</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive</td>
<td>14.1%</td>
</tr>
<tr>
<td>Ind/Med</td>
<td>9.1%</td>
</tr>
<tr>
<td>Total ICs</td>
<td>6.4%</td>
</tr>
<tr>
<td>Computer</td>
<td>5.7%</td>
</tr>
<tr>
<td>Comm</td>
<td>5.5%</td>
</tr>
<tr>
<td>Gov/Mil</td>
<td>4.2%</td>
</tr>
<tr>
<td>Consumer</td>
<td>4.0%</td>
</tr>
</tbody>
</table>
Automobile application will grow all areas of semiconductor design and fabrication.

If all cars have the same level of intensity of i3, this represents 600k wspm capacity requirement.

**Example of semiconductor content in a BMW i3 (based on silicon area)**

- CMOS 53%
- Memory 14%
- Power 18%
- Analog 9%
- MEMS 3%
- CIS 3%

*Source: Applied Materials, TechInsights*

Note: This car has no autonomous driving capability.
Requirements for cars are higher than for phones

<table>
<thead>
<tr>
<th></th>
<th>Consumer</th>
<th>Industrial</th>
<th>Automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation time</td>
<td>2 to 5 years</td>
<td>5 to 10 years</td>
<td>Up to 15 years</td>
</tr>
<tr>
<td>Supply</td>
<td>Average 1 year</td>
<td>2 to 5 years</td>
<td>Up to 30 years</td>
</tr>
<tr>
<td>Temperature</td>
<td>0 to 40°C</td>
<td>-10 to 70°C</td>
<td>-40 to 160°C</td>
</tr>
<tr>
<td>Humidity</td>
<td>Low</td>
<td>Environment</td>
<td>0% to 100%</td>
</tr>
<tr>
<td>Tolerated failure rate</td>
<td>&lt;10%</td>
<td>&lt;&lt;1%</td>
<td>Target: 0% failure</td>
</tr>
</tbody>
</table>

**Increased requirements**
- Lifetime
- Supply
- Operating conditions

**Lead to**
- “Zero defect” policy
- Traceability

**Requirements for cars are higher than for phones**

**Operating conditions**
- Environment
  - Consumer: <1%°
  - Industrial: <<1%°
  - Automotive: Target: 0% failure

**Temperature**
- Consumer: 0 to 40°C
- Industrial: -10 to 70°C
- Automotive: -40 to 160°C

**Humidity**
- Consumer: Low
- Industrial: Environment
- Automotive: 0% to 100%
Quality:
Between raw materials and the cleanroom
Mass market safety only achievable with quality across the full supply chain

Material providers like Linde are the quality gatekeepers
Between the variability of the raw material source...

Fluorspar mine: HF, NF₃, SF₆, CF₄, etc.
Between the variability of the raw material source...

Tungsten mine: $WF_6$
Between the variability of the raw material source...

Germanium mine: \( \text{GeH}_4, \text{Ge}_2\text{H}_6 \)
...and the precision of manufacturing
...and the precision of manufacturing
Material suppliers like Linde are the quality gatekeepers
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
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)
Production plant for Electronic Specialty Gases: Cylinder preparation
Production plant for Electronic Specialty Gases: Cylinder filling
Production plant for Electronic Specialty Gases: Blending
Production plant for Electronic Specialty Gases: Analysis
Supply chain:
Ensuring business continuity
Supply interruptions can be caused by natural disasters

Fukushima Earthquake and Tsunami: 2011
Supply interruptions can be caused by human events

Tianjin Port Explosion: 2015
Global EM supply network

Linde global suppliers network: multiple sourcing HCl
Global EM supply network

Linde global suppliers network: multiple sourcing $\text{N}_2\text{O}$
Global EM supply network

Linde global suppliers network: multiple sourcing NH₃
Global EM supply network

Linde global suppliers network: multiple sourcing He
Global EM supply network

Linde global suppliers network: distributed portfolio

N. America
- BCl₃
- B₂H₆
- Cl₂
- DCS
- Halocarbons
- HBr
- Laser gas
- NH₃
- Si₂H₆
- WF₆

Europe
- He
- Ne
- Xe
- TCS
- NF₃
- SiH₄
- WF₆
- Halocarbons
- BCl₃
- HCl
- GeH₄
- HF
- He
- SiH₄
- TCS
- N₂O
- Dopants
- Si₂H₆

Asia
- Cl₂
- DCS
- F₂ Mix
- Halocarbons
- HBr
- HCl
- NF₃
- NH₃
- SF₄
- Si₂H₆
- CHF₃
- F₂
- GeH₄
- HCDS
- He
- N₂O
- POCl₃
- SiH₄
- TCS

>50+ sources globally
Material supply by trading

Multiple sources – same product
example: HCl

Sourcing

- Access to 4/7 Global suppliers representing 67% of HCl capacity
- Distribute prime source to the respective region, as well as introduce new source for BCP

Assets

- Variety of fleet
  - ISO tube
  - Drum, Y Tonner, Cylinder
- Capability in ISO tube service
- Periodic testing, maintenance, and upgrading of assets in line with global standards

Quality

- Proven track record of bulk HCl supply to semiconductors customers across the world for several decades
- Multiple sources – same final product
Conclusion:
Quality and supply chain work together
Quality: Holistic, collaborative approach

We achieve electronics industry quality standards with close collaboration throughout the supply chain.

**Raw materials**
- Qualify products
- Manage supplier performance
- Manage deviations from specification
- Ensure process changes

**Linde**
- Align with EICC
- Manage deviations from specification
- Establish & certify QMS
- Manage process changes
- Control production quality
- Perform incoming material QC
- Ensure business continuity

**Customer**
- Check & develop required capability
- Understand customer requirements
- Manage deviations from specification
- Manage process changes

**Key Points**
- Linde aligns with EICC to ensure business continuity.
- Quality management involves managing deviations from specification, ensuring process changes, and controlling production quality.
- Collaborative approach between raw materials, Linde, and customers.

**Quality: Holistic, Collaborative Approach**
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- 14-17 NOV 2017 MUNICH GERMANY
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