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, 0x000000900, 0x000000900)

Beginning dump of physical memory
Physical memory dump complete.
Contact your system administrator or technical support group for further assistance.
Safety Critical: Driving Quality and Supply Chain Requirements for Automotive Electronics

Dr. Anish Tolia, VP of Global Marketing, Linde Electronics
September 20, 2017
Safety Critical
Driven by innovation and growing regulation

Automobile industry co-locating with semiconductor industry to accelerate innovation

In Europe, countries sunsetting the internal combustion engine
# Electronics Ubiquitous on Cars

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parental controls</td>
<td>Instrument cluster</td>
</tr>
<tr>
<td>Engine control</td>
<td>Driver alertness monitoring</td>
</tr>
<tr>
<td>Airbag deployment</td>
<td>Windshield wiper control</td>
</tr>
<tr>
<td>Adaptive front lighting</td>
<td>Auto-dimming mirror</td>
</tr>
<tr>
<td>Adaptive cruise control</td>
<td>Accident recorder</td>
</tr>
<tr>
<td>Automatic braking</td>
<td>Event data recorder</td>
</tr>
<tr>
<td>Electric power steering</td>
<td>Interior lighting</td>
</tr>
<tr>
<td>Cylinder de-activation</td>
<td>Voice / data communications</td>
</tr>
<tr>
<td>Electronic valve timing</td>
<td>DSRC</td>
</tr>
<tr>
<td>Electronic throttle control</td>
<td>Lane correction</td>
</tr>
<tr>
<td>Idle stop / start</td>
<td>Electronic toll collection</td>
</tr>
<tr>
<td>Active vibration control</td>
<td>Battery management</td>
</tr>
<tr>
<td>OBDII</td>
<td>Digital turn signals</td>
</tr>
<tr>
<td>Blindspot detection</td>
<td>Navigation system</td>
</tr>
<tr>
<td>Transmission control</td>
<td>Hill-hold control</td>
</tr>
<tr>
<td>Remote keyless entry</td>
<td>Regenerative braking</td>
</tr>
<tr>
<td>Cylinder de-activation</td>
<td>Anti-lock braking</td>
</tr>
<tr>
<td>Idle stop / start</td>
<td>Electronic stability control</td>
</tr>
<tr>
<td>Electronic throttle control</td>
<td>Parking system</td>
</tr>
<tr>
<td>Electronic throttle control</td>
<td></td>
</tr>
</tbody>
</table>
Electronics ubiquitous on cars

Safety Negligible

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

Safety Enhancement

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

- **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

<table>
<thead>
<tr>
<th>Jets manufactured per year</th>
<th>Base price</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2000</td>
<td>$270 million</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Passenger vehicles manufactured per year</th>
<th>Base price</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 million</td>
<td>$27,000</td>
</tr>
</tbody>
</table>
A fast growing market

Market representing around $35B in 2016

Growing much faster than the total IC market

<table>
<thead>
<tr>
<th>Market</th>
<th>Growth Rate</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.

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

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

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

Note: This car has no autonomous driving capability.

Source: Applied Materials, TechInsights
Requirements for cars are higher than for phones

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

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

<table>
<thead>
<tr>
<th></th>
<th>Consumer</th>
<th>Industrial</th>
<th>Automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation time</strong></td>
<td>2 to 5 years</td>
<td>5 to 10 years</td>
<td>Up to 15 years</td>
</tr>
<tr>
<td><strong>Supply</strong></td>
<td>Average 1 year</td>
<td>2 to 5 years</td>
<td>Up to 30 years</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>0 to 40°C</td>
<td>–10 to 70°C</td>
<td>–40 to 160°C</td>
</tr>
<tr>
<td><strong>Humidity</strong></td>
<td>Low</td>
<td>Environment</td>
<td>0% to 100%</td>
</tr>
<tr>
<td><strong>Tolerated failure rate</strong></td>
<td>&lt;10%</td>
<td>&lt;&lt;1%</td>
<td>Target: 0% failure</td>
</tr>
</tbody>
</table>
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, NF$_3$, SF$_6$, CF$_4$, etc.
Between the variability of the raw material source...

Tungsten mine: WF₆, WCl₅
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

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

Beijing Olympics: 2008
Supply interruptions can be caused by human events

G20 Summit: 2016
Supply interruptions can be caused by human events

Tianjin Port Explosion: 2015
And they can happen close to home

Loma Prieta Earthquake: 1989
And they can happen close to home

Hurricane Harvey: 2017
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 $\text{NH}_3$
Global EM supply network

Linde global suppliers network: multiple sourcing SiH₄
Global EM supply network

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

Linde global suppliers network: distributed portfolio

N. America
- BCL$_3$
- B$_2$H$_6$
- Cl$_2$
- DCS
- Halocarbons
- HBr
- Laser gas
- NH$_3$
- Si$_2$H$_6$
- WF$_6$

Europe
- Dopants
- He
- N$_2$O
- TCS
- HCl
- HF
- NH$_3$
- Xe

Asia
- Cl$_2$
- DCS
- F$_2$ Mix
- Halocarbons
- HBr
- HI
- NF$_3$
- NH$_3$
- SF$_6$
- Si$_2$H$_6$

>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

Global Capacity 2017 (>17.5 Ktons)
Material supply by manufacture

Multiple local plants – same process example: N₂O

**Manufacture**
- High volume product – must be made close to source for cost
- Manufacture in 4 countries to be close to customer
- Same process in each location

**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 N₂O supply to semiconductors customers across the world for several decades
- Multiple local plants – 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.