

Making our world more productive



Bulk specialty gas supply.

Debottlenecking the electronics material supply chain from material production to fab consumption.

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- The leading industrial gases and engineering company
- Formed in 2018 with the merger of Linde AG and Praxair, Inc – two world-class companies with nearly 140 years of shared history and successful achievements

One Linde

Uniting with a shared Vision, Mission and Strategic Direction, and demonstrating our Values and Behaviors in everything we do

2 million+
customers

Establishing a more diverse and balanced portfolio

100+

countries

Enabling strong, complementary positions in all key geographies and end markets

~80,000

employees

Achieving our full potential, individually and collectively

~\$15 millions

charitable giving and sponsorships in 2018

Supporting our communities through contributions and employee volunteerism

6,500+

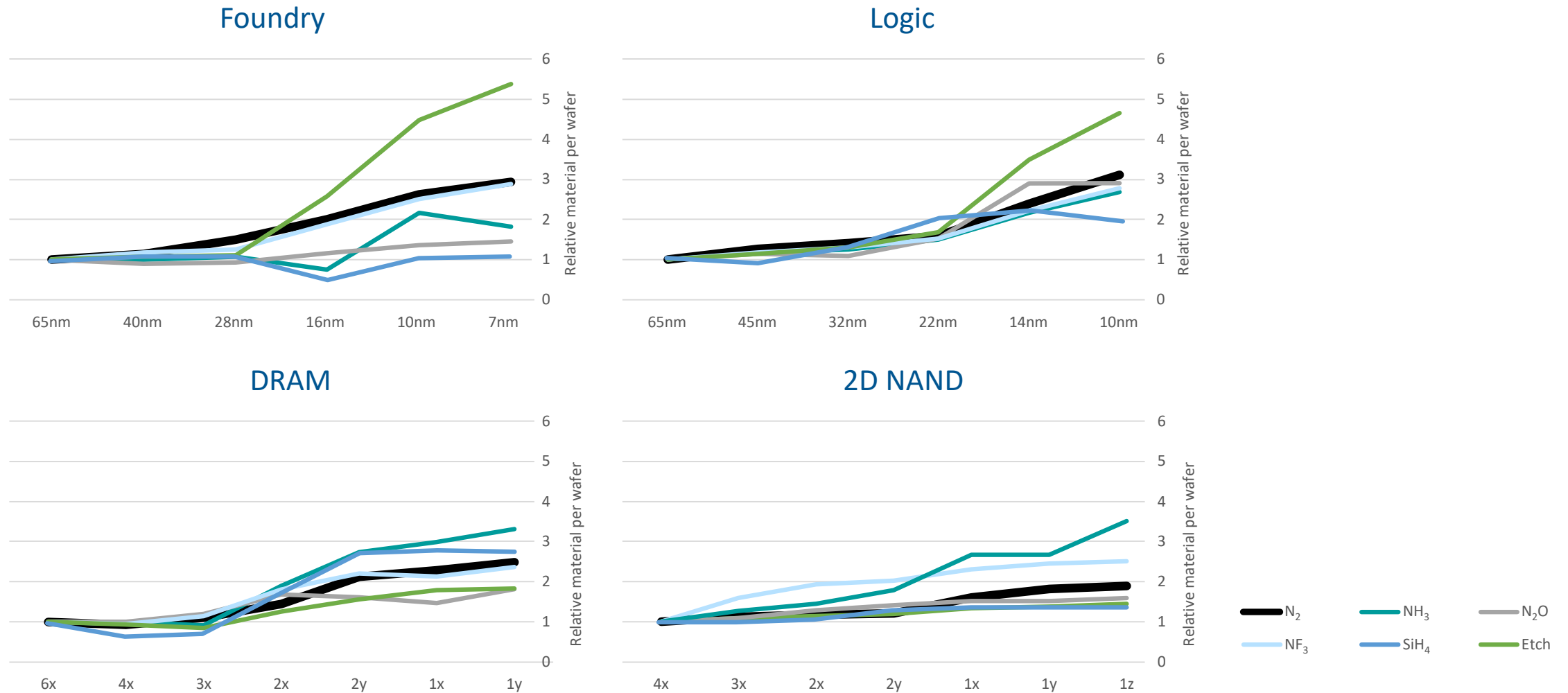
active patent assets worldwide

Leading with innovative products, solutions and technologies



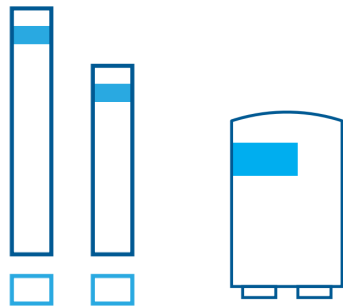
Material consumption increases with process complexity

Nitrogen and Electronic Material : relative volume vs nodes

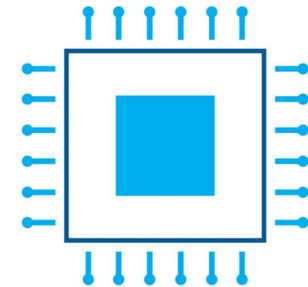
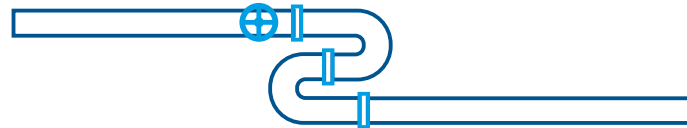


Source: IC Knowledge model

When bulk gas demand increases
We build a larger nitrogen generator and pipeline

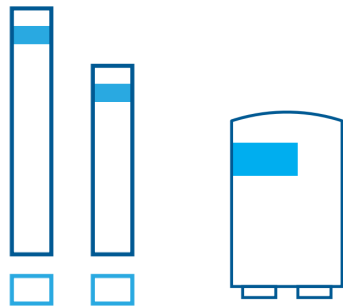


Nitrogen generator

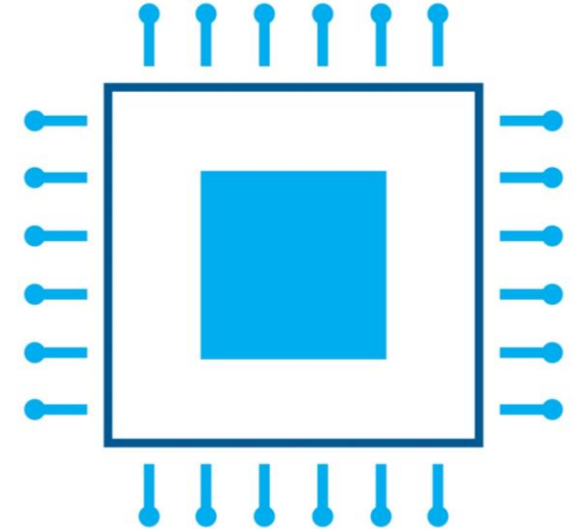
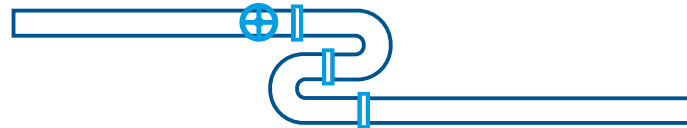


Fab

When bulk gas demand increases
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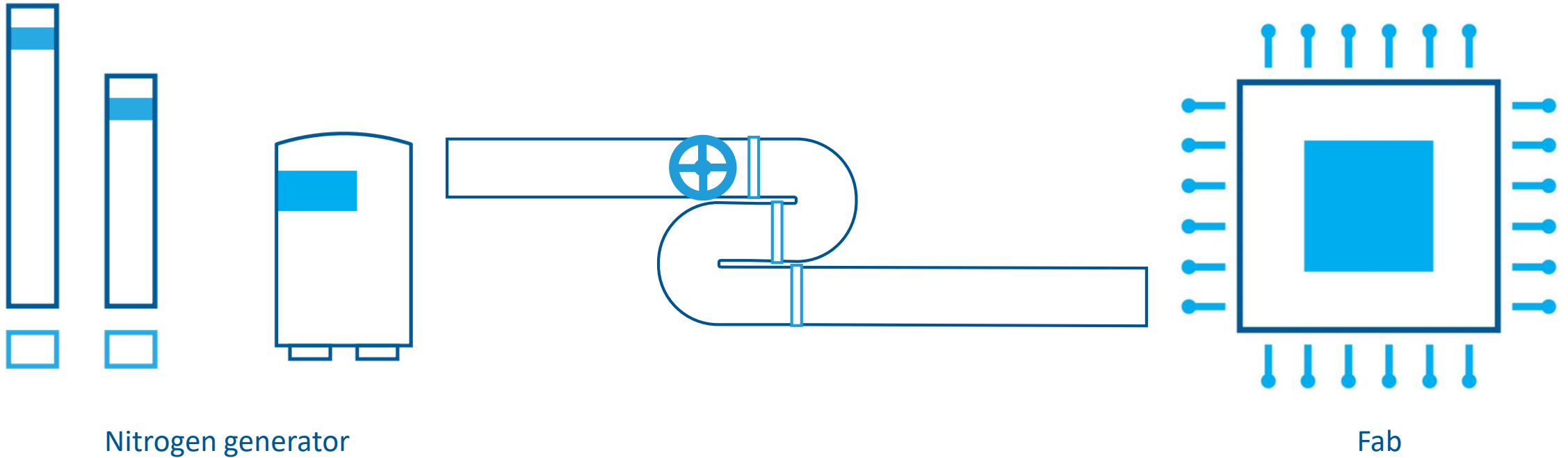


Nitrogen generator



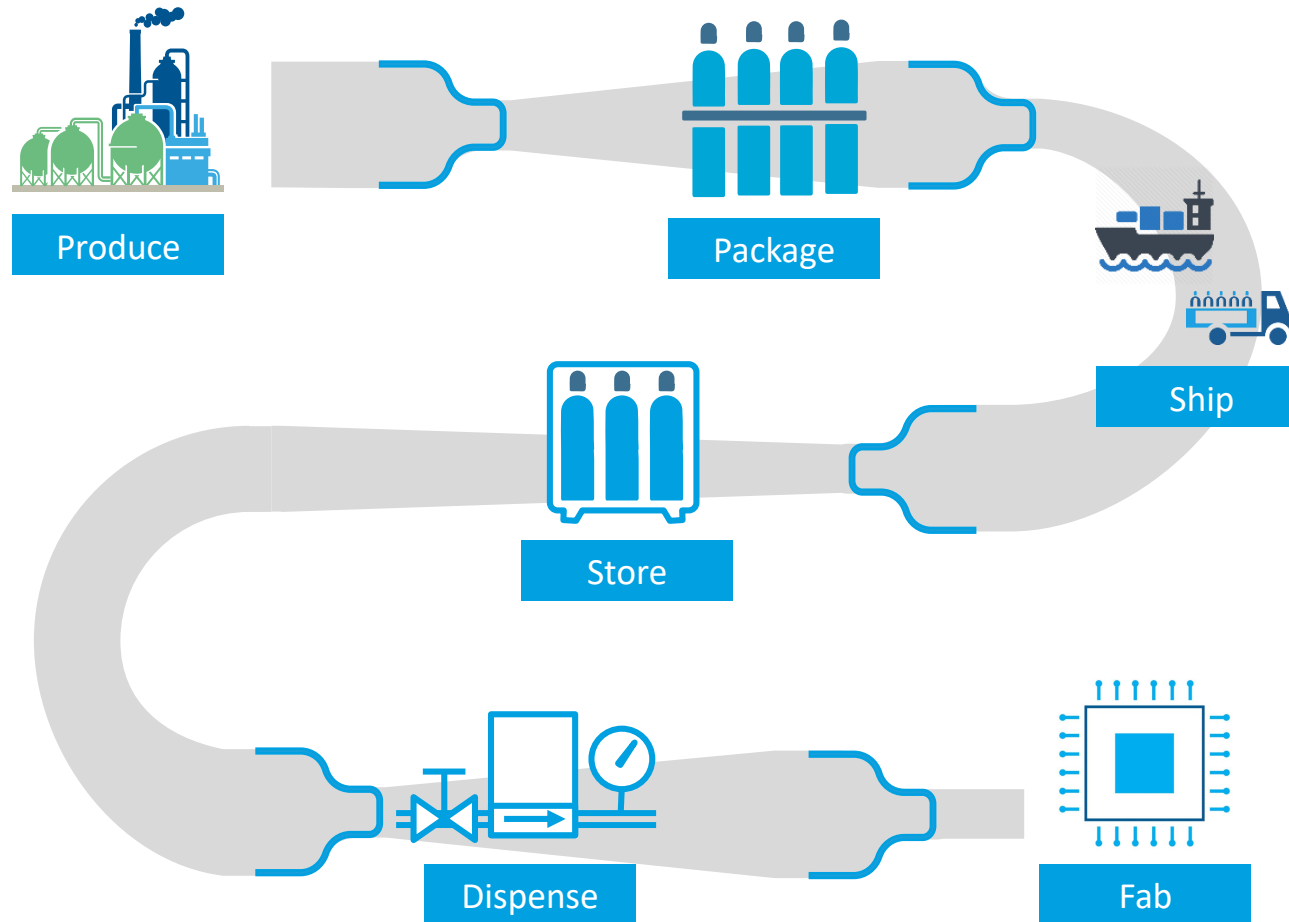
Fab

When bulk gas demand increases
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Electronic materials are not as simple

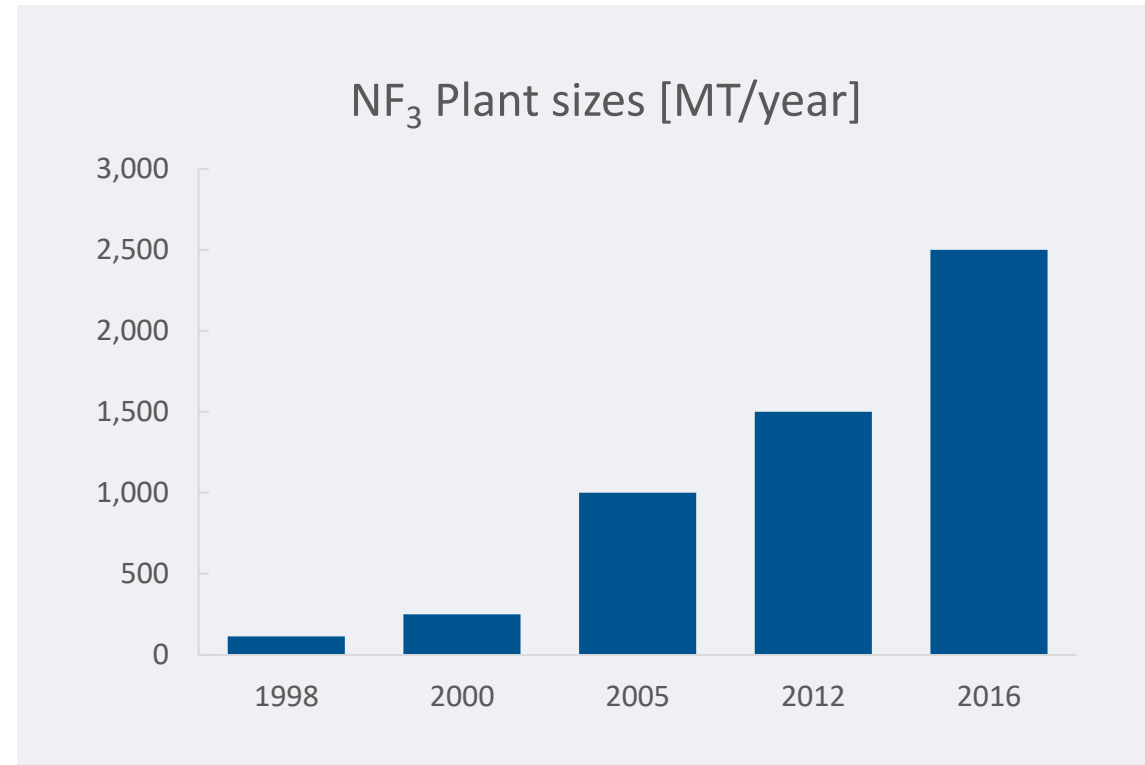
Need to debottleneck entire supply chain, sometimes over 1,000s of km



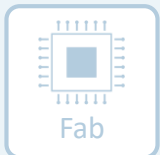
Whole supply chain is called
Bulk Special Gas Supply Chain(BSGS)

Electronic material production capacity scales with demand

But can be located 1,000s of kilometers from the fab



No NF₃ production in Taiwan, ASEAN, or Europe



Different packaging is required for different types of material



Ampoules

- Organometallic metal and silicon precursors
DOT4B, 8 or UN1A1, UN1H1

TDMAH
TDMAT
TDMAZ
TSA



Low vapor pressure

- Service pressure up to 500psig
DOT 4AA, 4BA, 4BW, 8AL, UN1A1, 3A

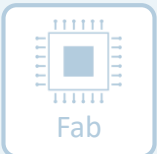
DCS
TCS
C₂H₂ (stabilized)
HCDS
C_xH_y
NH₃
Cl₂



High Pressure

- Service pressure up to 2900psig
DOT 3AA

NH ₃	Cl ₂
N ₂ O	CF ₄
NF ₃	C ₂ F ₆
SiH ₄	Kr
AsH ₃	CHF ₃
HBr	C ₄ F ₈
WF ₆	CO
CO ₂	C ₃ H ₆
PH ₃	Mixtures

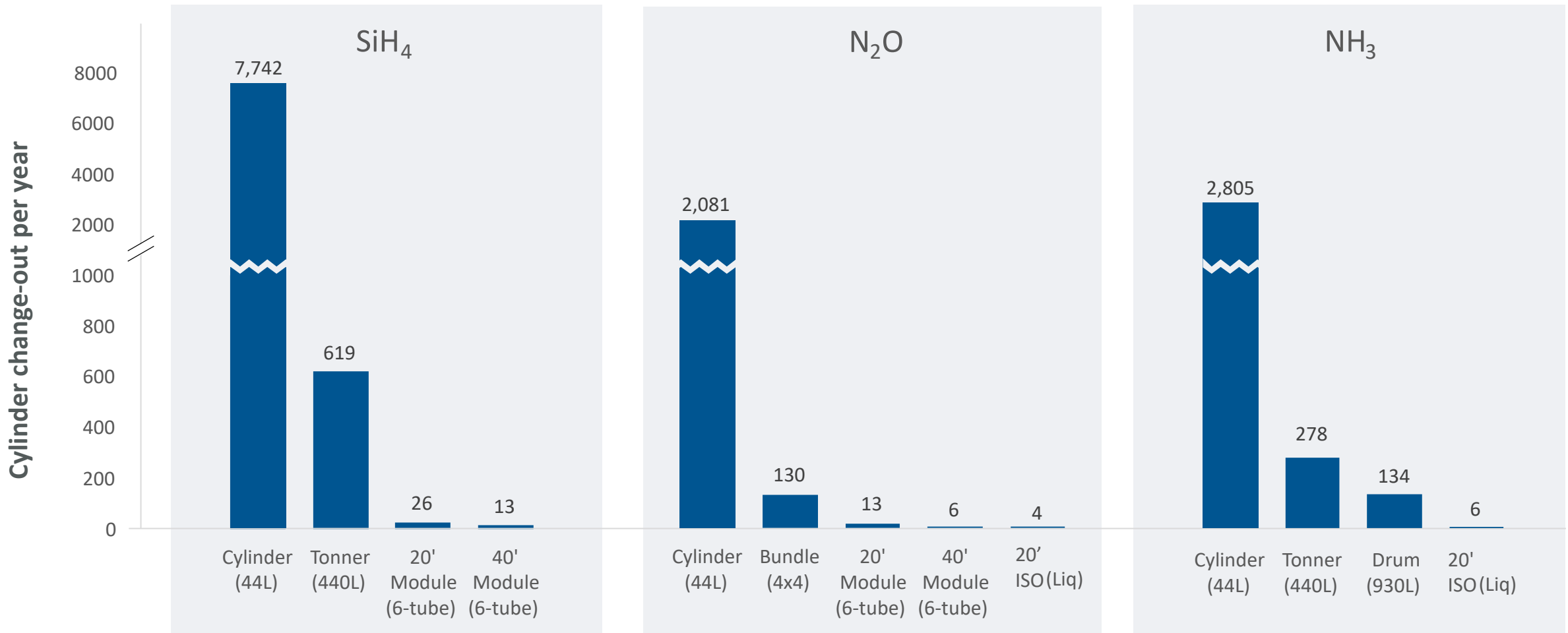


Bulk package impact – changeout frequency

Gen 8.5 TFT LCD Fab (~90k panels/month)



Package change frequency comparison



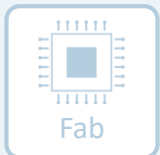
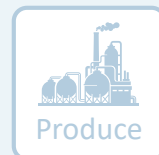
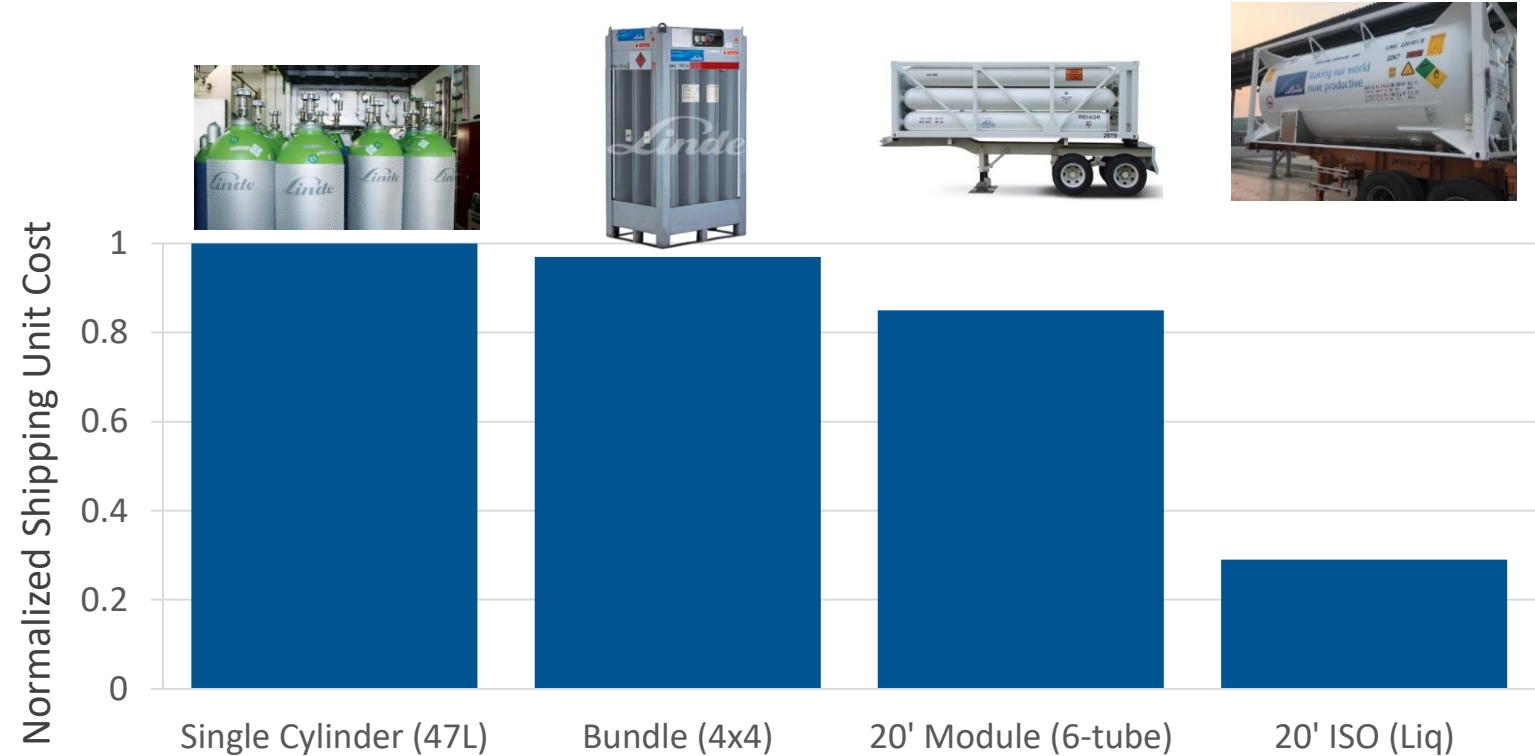
Shipping Cost Impact

Case study N₂O: 20' Container from Korea to Taiwan



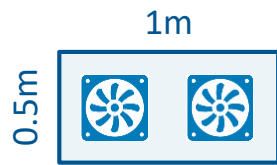
Relative shipping cost

- Unit Shipping Cost Saving
- Round trip basis
- Each shipping vessel assumed maximum loading

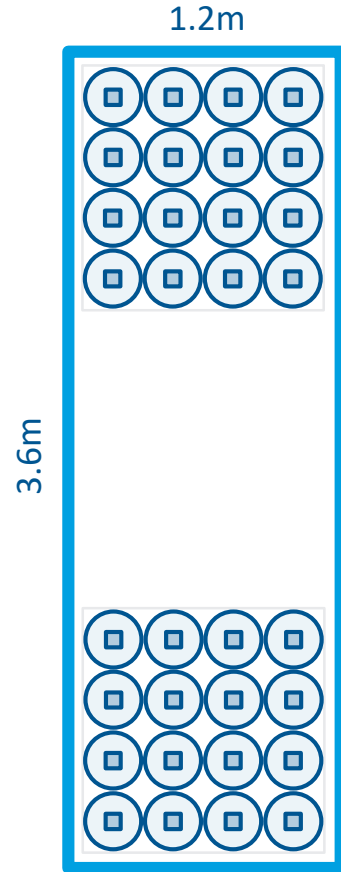


Package Footprint

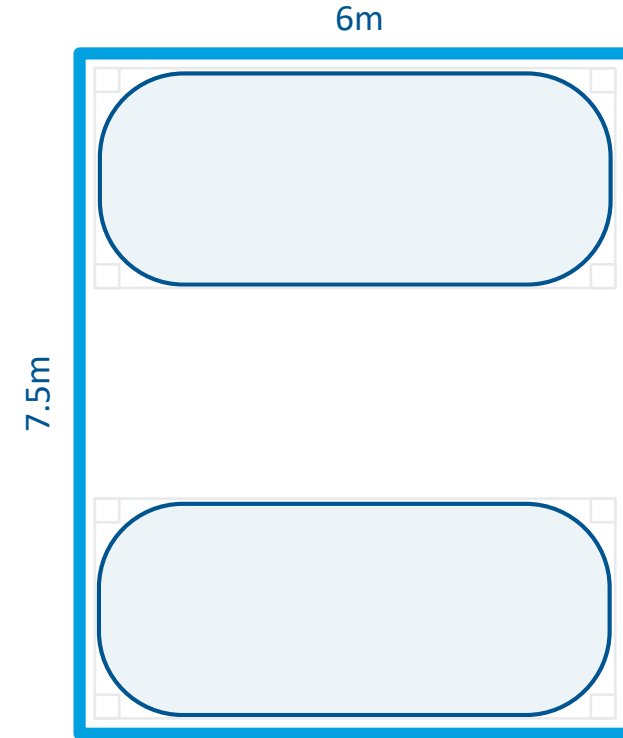
Area / mass samples – top view



Gas cabinet



Bundle



ISOtainer



Produce



Package



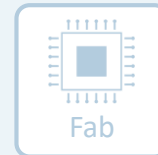
Ship



Store



Dispense



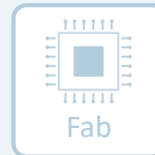
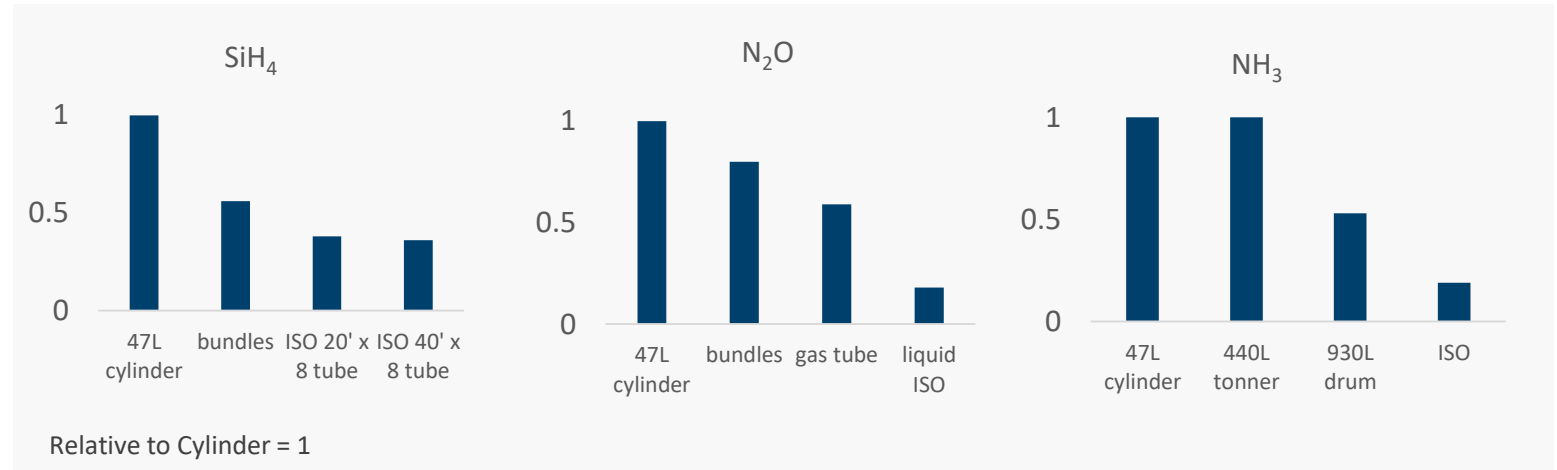
Fab

Package Footprint

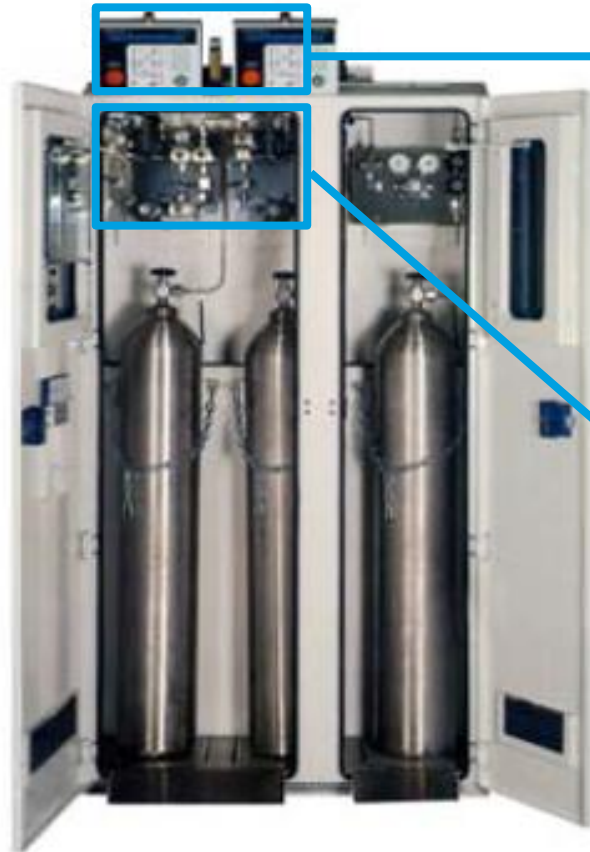
Relative area / mass - efficient use of space



- Scaling up the size of package generally reduces the footprint of gas storage in a fab
- Comparison to a single gas cabinet footprint, an ISO container can achieve the following area/mass improvement
 - 0.2 N₂O (20' liq ISO)
 - 0.36 NH₃ (20' ISO)
 - 0.2 SiH₄ (40' TT)
- Larger packages reduce total material footprint



Larger panels, temperature controls, flow control benefits



Programmable Logic Controller (PLC)

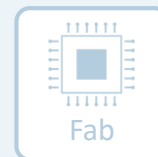
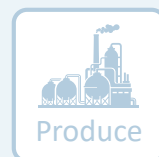
Provides fully automated control of the bulk system with maximum uptime.



BSGS Panel

Redundant plc, sensors and manifold

- increased automation
- failsafe operation
- lower maintenance = higher uptime



Key benefits



SAFETY

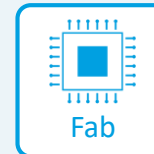
- Majority of systems are located outdoors of facilities and are treated as unmanned systems
- Human cylinder change frequencies minimized
- Traffic of cylinder movement within the facility reduced

QUALITY

- Reduced material variability
- Reduced contamination risks
- Reduced package defect probability

PERFORMANCE

- Higher material availability
- Increased automation +data
- Better fab footprint utilization

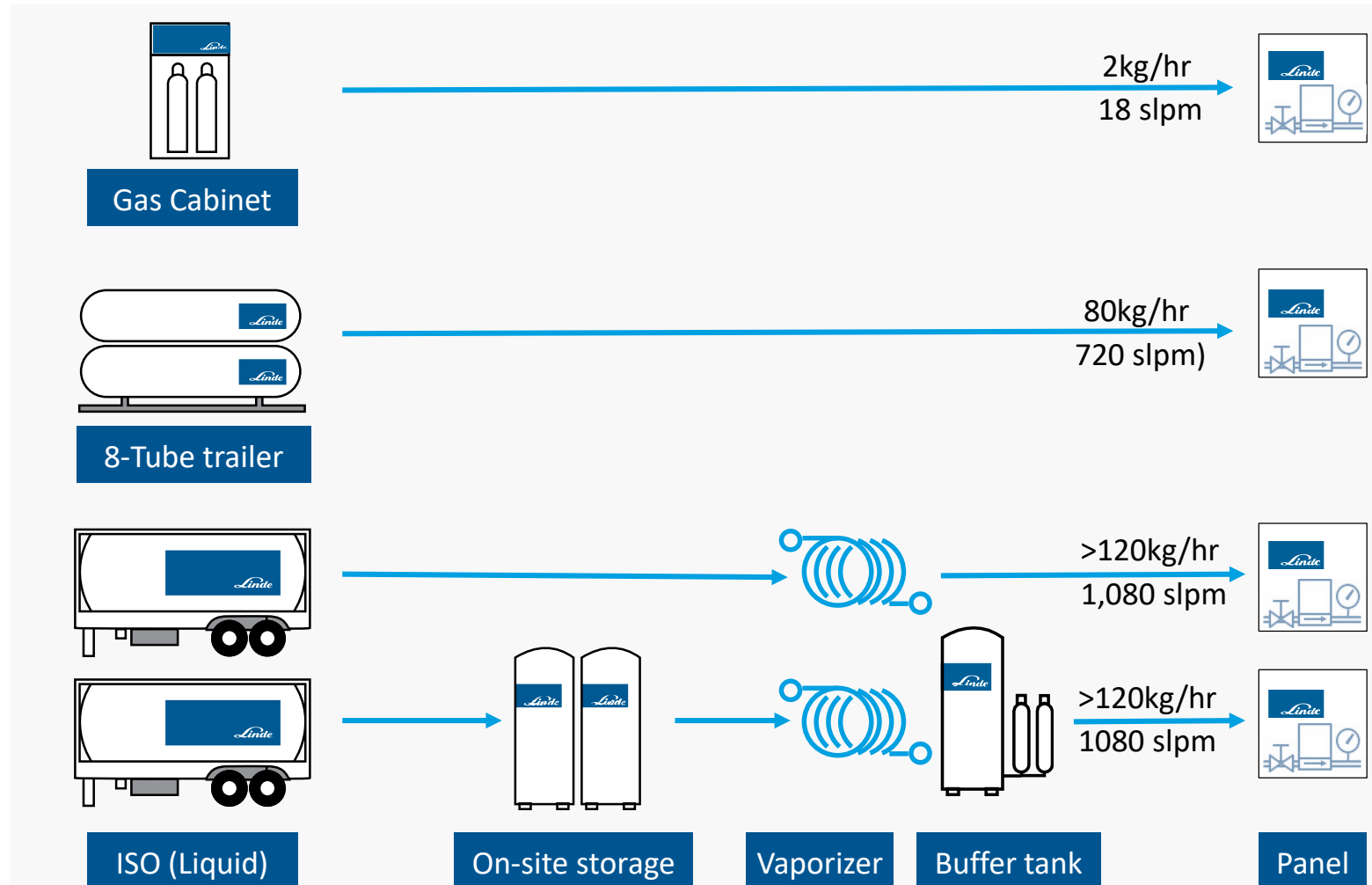


Case study : N₂O

Keeping pace with customer demand



- Customer demand increased, but area for material storage was limited
- Largest possible system, to-date, based on two 50MT on-site storage tanks
 - Max flow >120kg/hr
 - High purity liquid N₂O vaporization
 - Consideration of space availability and number of cylinder change-out

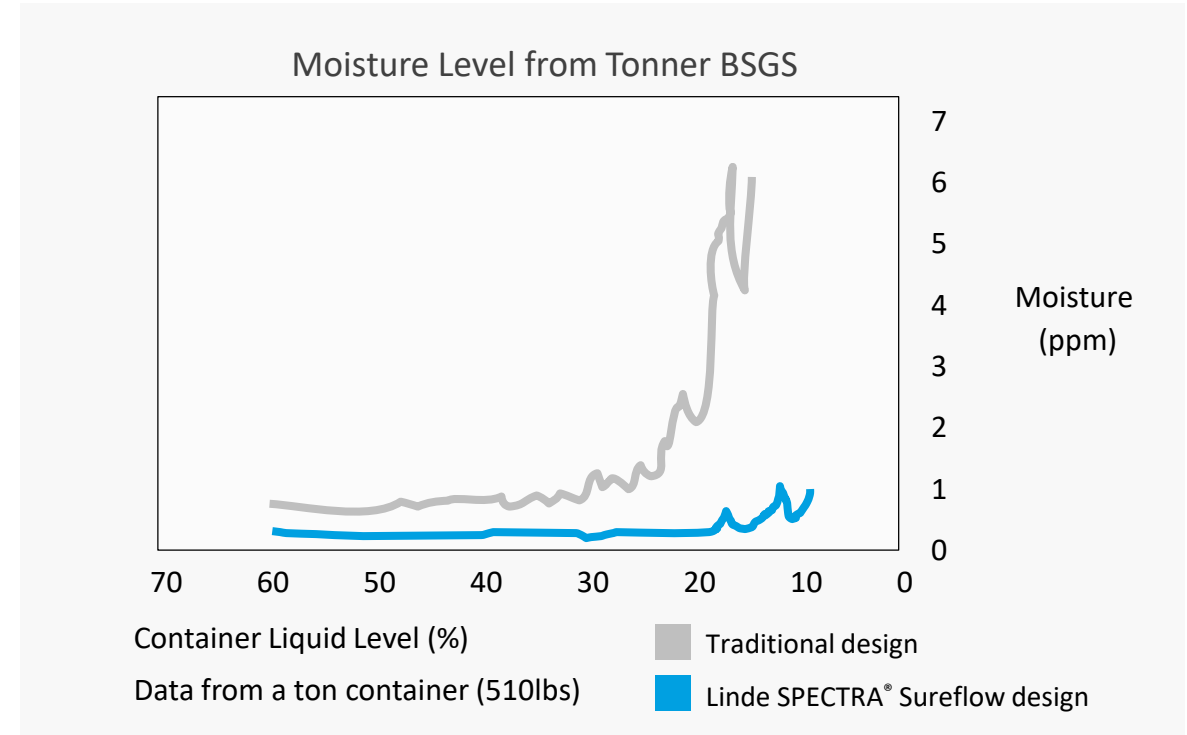


Case study : NH₃



Reduced levels of delivered moisture

- Vapor withdrawal BSGS: characterized by a gradual increasing H₂O concentration near cylinder end point.
- Heat transfer a strong function of heating blanket design.
- Linde Spectra Sureflow minimizes H₂O carryover at the tonner end-of-life.

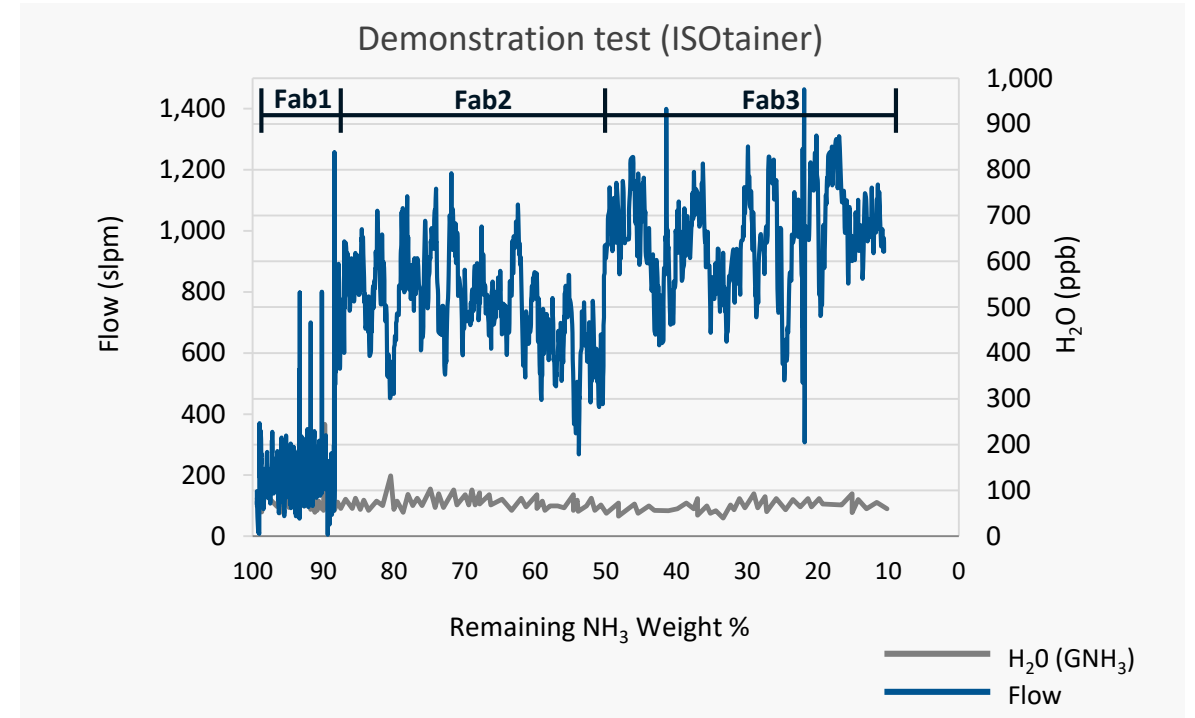


Case study : NH₃



Higher tolerance to variable flow

- Linde design maximized the heat transfer into liquid NH₃ at sustainable peak flow but minimizes H₂O carryover
 - H₂O unaffected by the surge of flowrates
 - H₂O remained low even near EOL (end of life)



Case study : High capacity packages

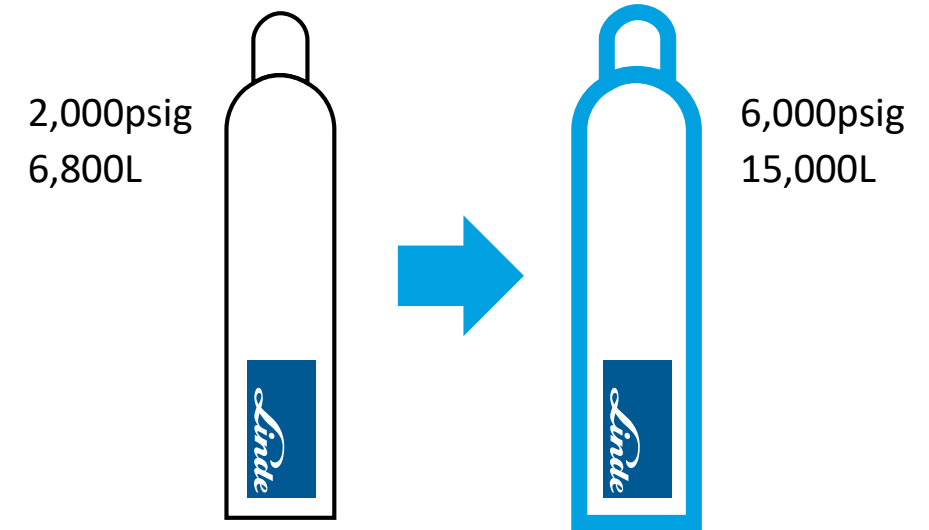


Challenges

- Increase the working pressure of cylinder and valve to sustain up to 6,000psig
- Maintain leak rate 10^{-8} mbar-L/s

Potential Benefits

- Higher fill capacity (potentially 2-3x)
- Improved cylinder utilization (up to 10% material saving)
- Plug-&-play drop-in replacement
- Improved footprint (area/mass)



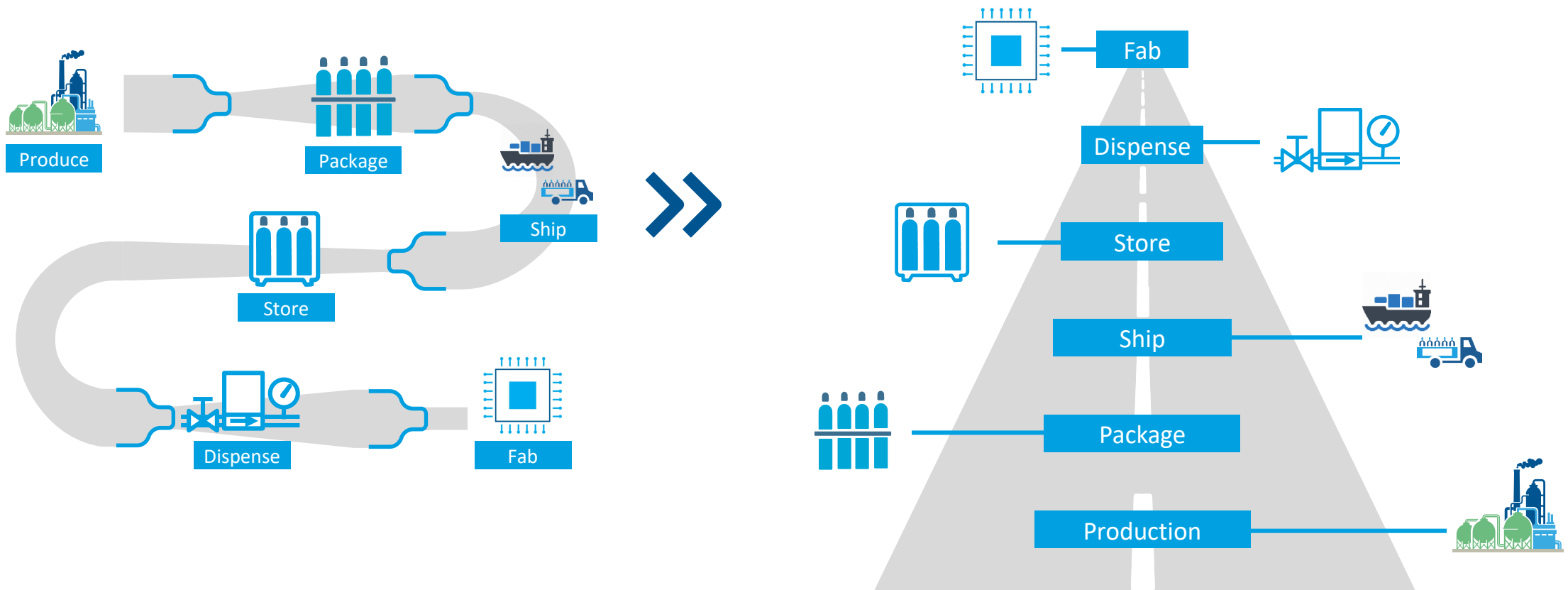
190K wspm DRAM Fab	2,100psig Fill	6,000psig Fill	
Fill density (L/cyl)	6,800	15,000	
Usage rate (cyl/mon)	218	94	
Cylinder utilization	92%	97%	
			Savings
Cylinder changeout	2,600	1,100	1,500
Heel loss (L/yr)	1,400,000	500,000	900,000

Debottlenecking in the fab
Wafers used to be carried by hand,
but now travel in automated wafer tracks



Conclusion

Linde's approach to BSGS – It is not just a larger package or panel, but the ability to debottleneck the entire supply chain



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Acknowledgement

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