



Smarter and More Resilient Supply for Sustainability

On-site Generation of Ultra High Pure Ammonium Hydroxide
with Reduced Environmental Impact

Karl Urquhart
Nov 2022



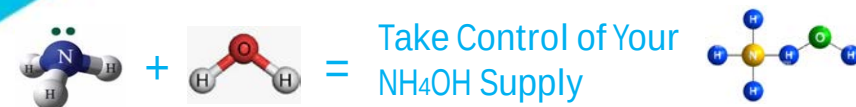
SEMICON® EUROPA

Nov 15-18, 2022 | MESSE
MÜNCHEN | Co-located with
electronica





Exyte At a Glance



Exyte Group at a Glance

Global Leader in Design, Engineering & Construction

History of 100+ years

Strategic focus on high-tech facilities



Specialized expertise in **controlled and regulated environments**



Serving clients with the most **technically demanding requirements**



Full spectrum of services from consulting & design to managing **turnkey solutions**.



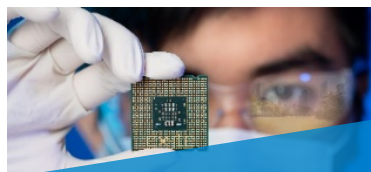
A global company with a local presence, operating in 20+ countries



Sales Revenue of **€4.9 billion** and Order Intake of **over €8 billion** (2021)



More than **7,400 highly experienced and motivated** employees (2021)



Advanced Technology Facilities (ATF)

- Semiconductor
- Batteries
- Flat Panel Display
- Photovoltaics



Biopharma & Life Sciences (BLS)

- Pharmaceuticals & Biotechnology
- Food & Nutrition
- Consumer Care
- Specialty Chemicals



Data Center (DTC)

- Cloud Computing
- Co-Location
- High Performance Computing
- Enterprise

Consulting
& Planning

Engineering
& Design

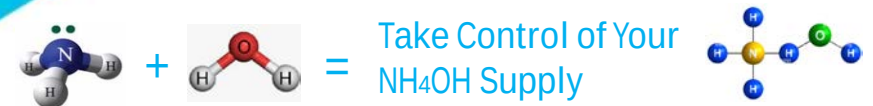
Project
& Construction
Management

Equipment
& Services

Commissioning,
Qualification
& Validation



Supply Challenges



Supply Challenges

Full / tight capacity for materials across different segments

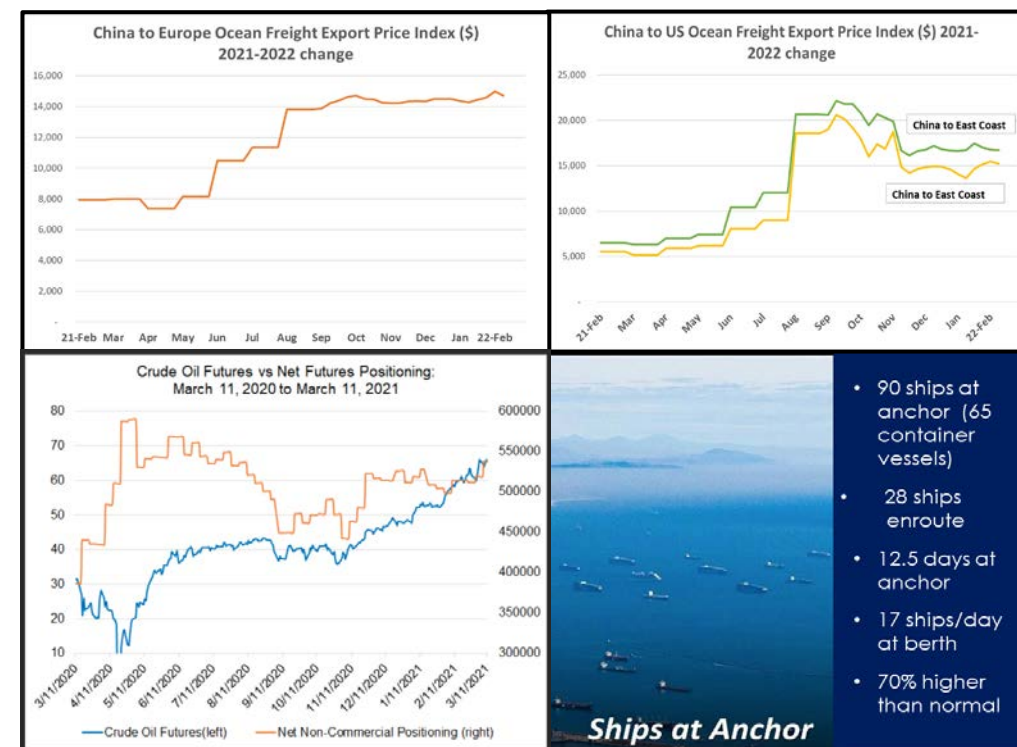
➤ Increasing material lead times & supply constraints:

- Some customers are on allocation basis.
- Transportation delays: congested seaports, shortage of trucks/ truckers, fewer flights.
- Labor shortage.

➤ Increasing costs - Freight cost continue to hold at high levels:

- Average oil price in 2022 is forecasted to be ~50% higher than 2021.
- Average rates per mile for dry van freight will continually rise.
- Reefer or specialized cargo, such as dangerous goods, will be higher.
- Average per mile / meter rates have increased ~14% from December 2021.
- Short-term easing of increasing rates is not anticipated.

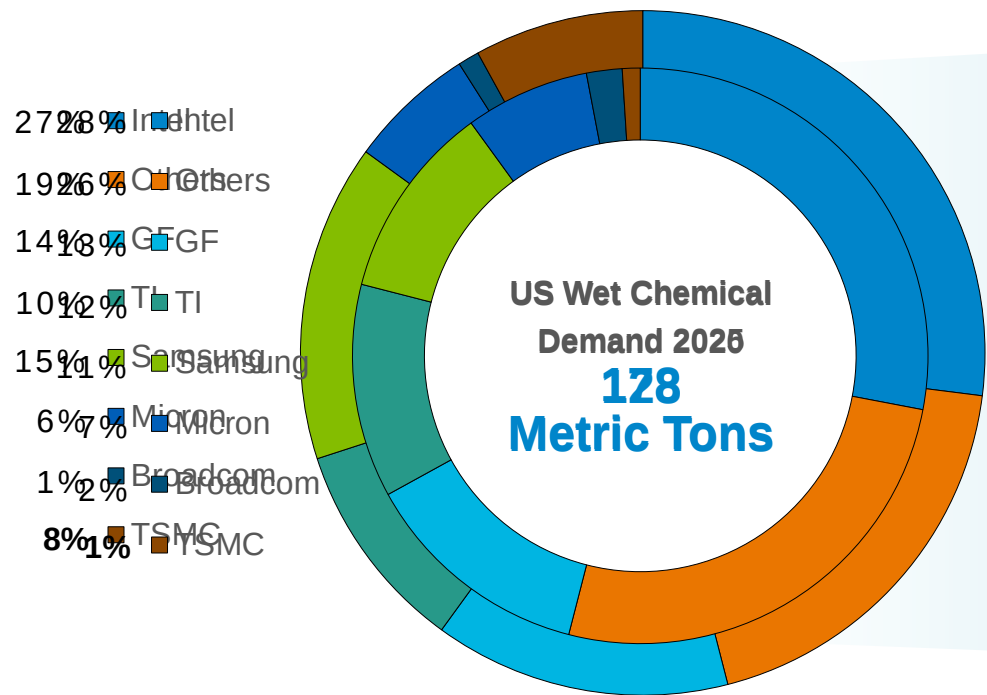
➤ Material in short supply such as wafers, wet chemicals, specialty gases must increase capacity: > 2 years to complete expansion.



Source: Port of Los Angeles | Techcet and CMC Members

Supply Challenges

Chemical demand continue to surge

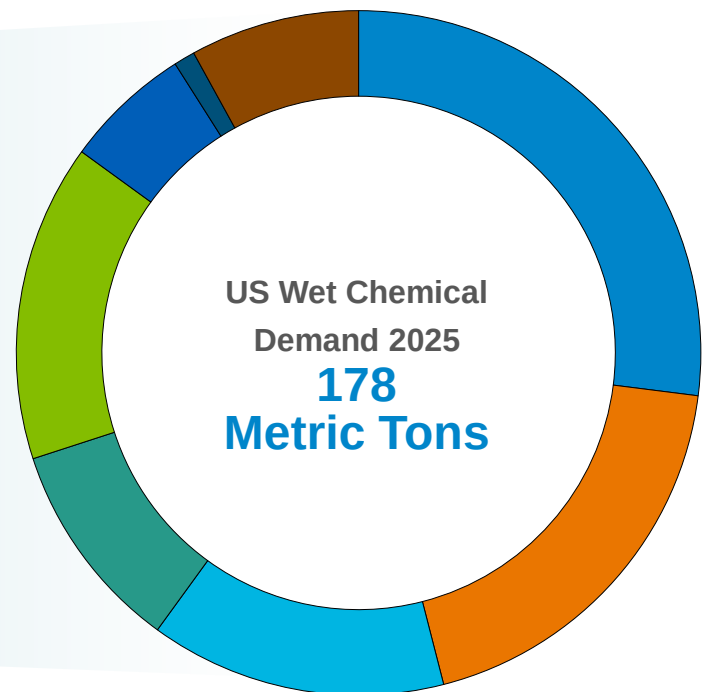
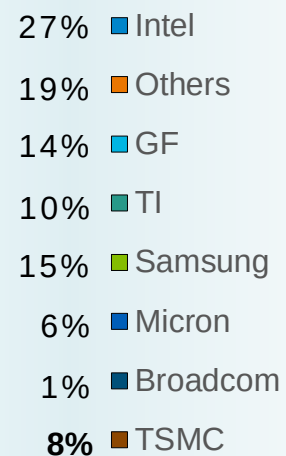
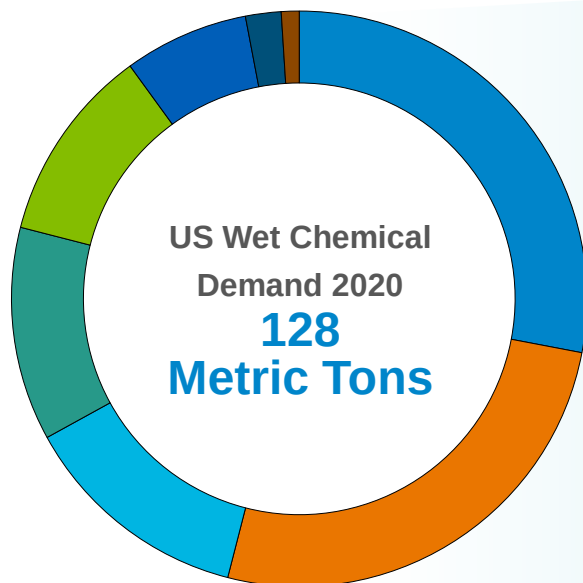
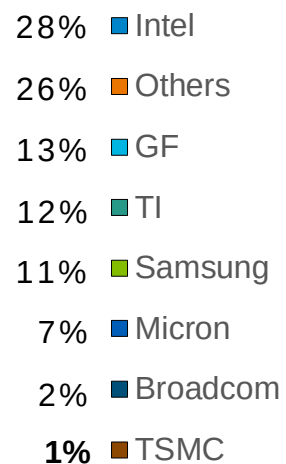


Demand to rise >40% from leading chip makers from 2020-2025

Source: Techcet

Supply Challenges

Chemical demand continue to surge



Demand to rise >40% from leading chip makers from 2020-2025

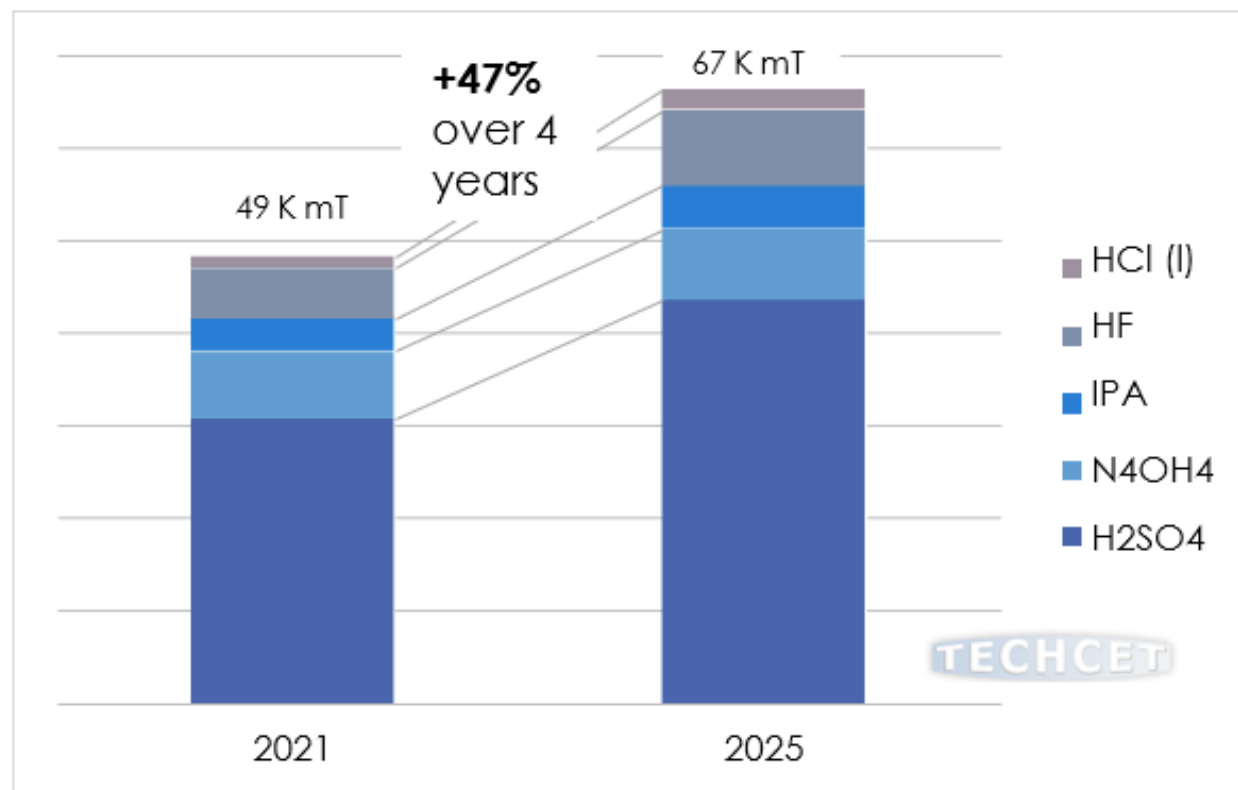
Source: Techcet

Supply Challenges

Chemical demand continue to surge

Example:

- Supply chains of HCl(g) , HCl(l) , H_2SO_4 , NH_4OH , IPA, HF in Europe.
- Surveyed CMC Fabs & other chemicals demand projections to 2025:
 - 47% (2021-2025)
 - 20% (2016-2020)
- Mostly high purity material imports are from Asia

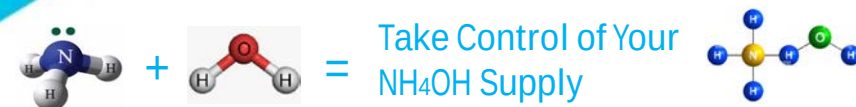


Impact of expansions on European chemical demand

Source: Techcet

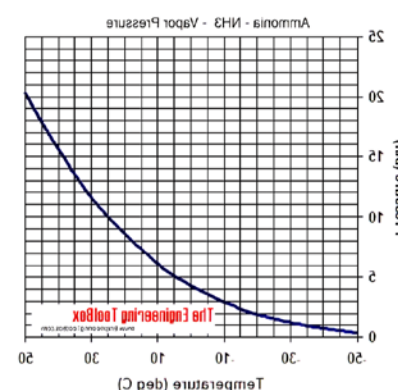
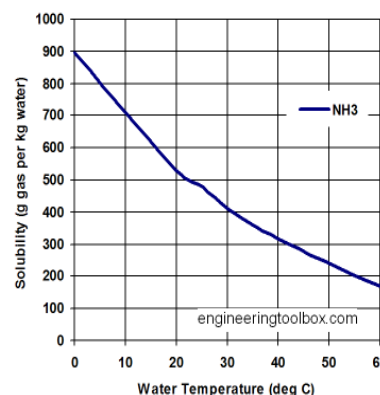
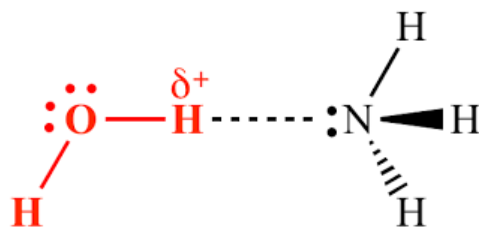


Ammonium Hydroxide (NH₄OH) in Semiconductor Manufacturing



NH₄OH in Semiconductor Manufacturing

- High-purity water, acids, bases, and solvents are essential to the cleaning and etching of microelectronic devices.
- NH₄OH is widely used in **volumes far out-reaching the practical methods of logistics** for the suppliers and factories.
- The semiconductor fabrication **requires strict control of all sources of assay and contamination**; contamination accounts for estimated 50% of yield losses.
- Contamination can enter into the chemistries through:
 - Manufacturing processes,
 - Packaging, shipping or means of delivery to the factories.
- 29% w/w NH₄OH used in semiconductor - 29% w/w NH₃ gas dissolved in 71% H₂O:
 - Solubility and vapor pressure, both temperature dependent, are associated factors to assay stability.
 - Keeping NH₃ dissolved from source to final location is crucial.



Source: Techcet

NH₄OH Supply vs Demand USA

NH₄OH US Market Landscape Overview

- Primary drivers of growth will be expansions of leading-edge chip manufacturers.
- Volume demand; 47% growth, 7% CAGR.
- ~11% of demand currently by imports.

Highest Growth Segments (2020-2025) include:

- i14nm/N10: +13% CAGR .
- DRAM: +6% CAGR.

19% (or ~8 MKg) projected shortfall for NH₄OH:

- IC grade by ~12%.
- UHP grade by -32%.

<10% of the US IC industry's NH₄OH demand is fed by imports.

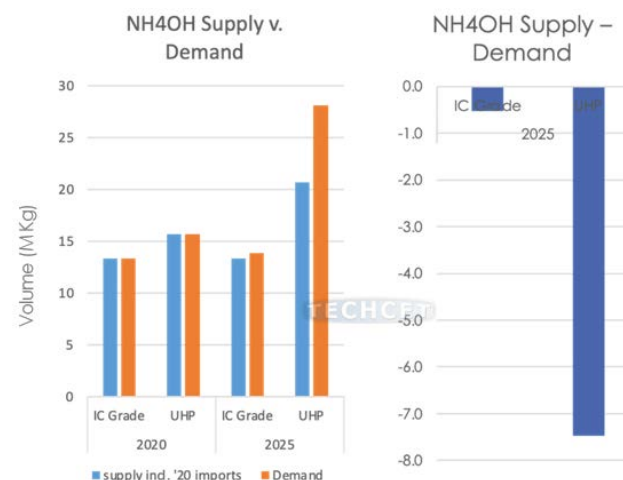
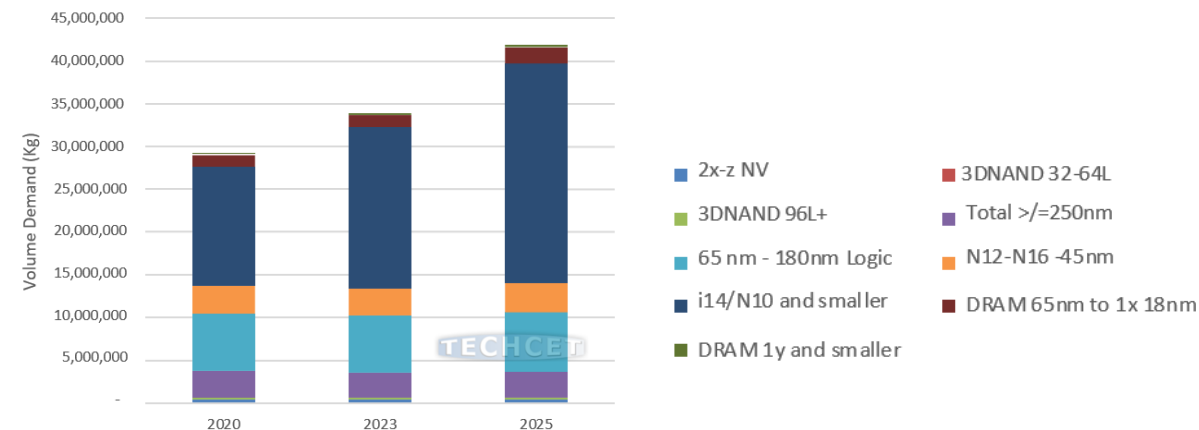


Chart on left shows material that is supplied to US Chip fabrication market which includes US produced and imports.

Source: Techcet

NH₄OH

Ammonia, NH₃, raw material

NH₃ is widely used in many markets ie. Agriculture:

- Capacity and utilization reflect near 230 million-tons at 82%
- While spare capacity near 43 tons per year

Varying Grades of Anhydrous NH₃:

- Premium Grade - “Metallurgical” **P-Grade**, 99.995% purity
- Refrigeration Grade - “**R-Grade**”, 99.98% purity
- Commercial / Agricultural Grade - “**C / Ag-Grade**”, 99.5% purity
(Major world consumption):
 - Large scale transportation networks – shipping, rail and pipelines
- New Fuel Grades are in development by some companies

Target – Blended NH₄OH quality MUST be consistent regardless of the Incoming NH₃ Grade used



Source: ammoniaenergy.org/wp-content/uploads/2020/12/Oliver-Hatfield.pdf

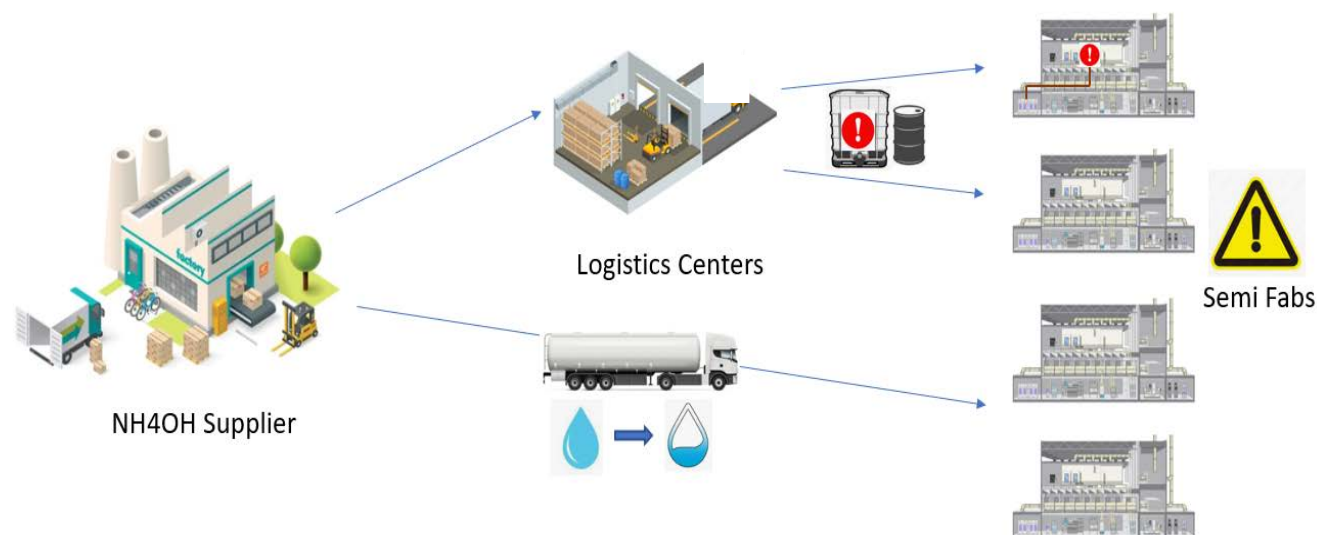
NH₄OH

Traditional manufacturing process

Traditionally, NH₄OH is Produced off-site and delivered to chip makers:

- In intermediate vessels and containers (isotainers, totes, drums and bottles).
- These ultimately are connected to the factories' chemical distribution networks
 - piped to the individual tools manufacturing the devices.

Each part of the process **from its origin to the final connection** is **potential contamination entry point**.



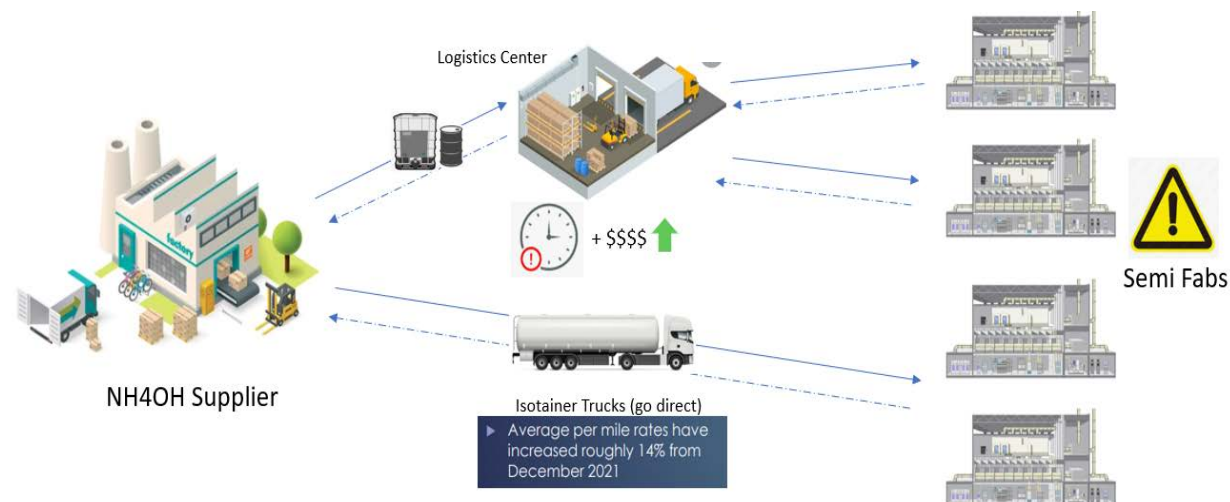
Minimize Contamination Risk

NH₄OH

Traditional manufacturing process

Intermediary Vessels have to be ordered and stored to keep up with usage:

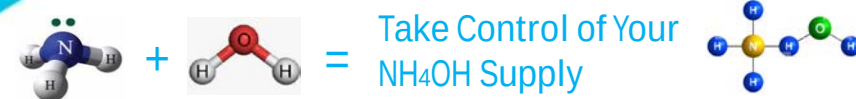
- Ever-increasing volume **increases transportation, warehousing or staging areas**. Example: 29% w/w NH₄OH requirement of 20,000 liters a day would result logistical supply below:
 - 100 individual drums (200 liter each = 25 pallets of four drums) or
 - 18 individual totes (1,136 liters each) or
 - 1 liquid Iso-tanker truck (20,000 liter)
- Many sites having **on-site quantity limitations**.
- Leads to increased **chances of developing quality issues** in assay and purity of the supply sources.
- Long lead time to order – approx. a year to add 1 new ISO
- **Urgent supply can increase cost**; 2x to 4x depending on distance between supplier and customer.
- **High cost** tied directly to the unit price of purchased NH₄OH.



Protect Against Supply Chain Disruptions



Integrated NH_4OH On-site Generation Technology



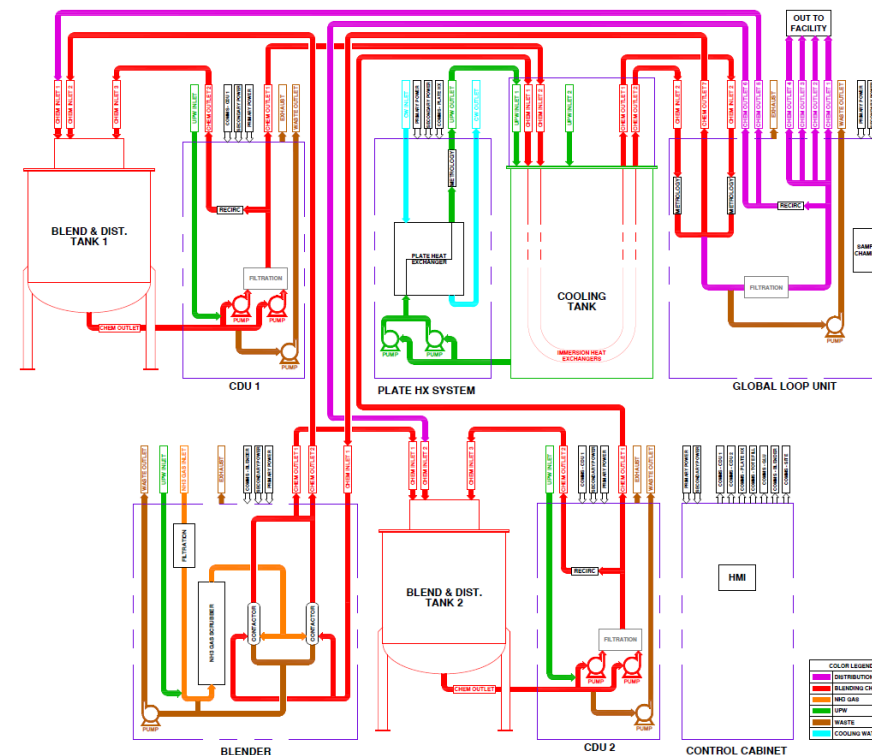
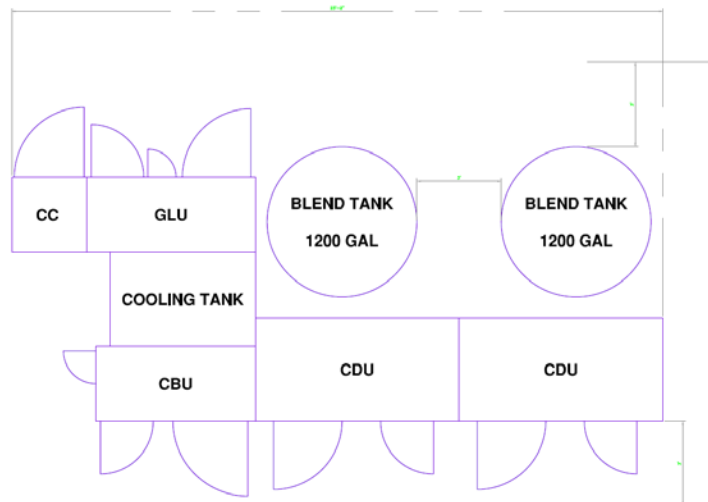
Integrated NH_4OH On-site Generation Technology

Significant improvement to the overall supply

Reduce Logistical Issues by using factory's own UHP H_2O supply.

On-site purifier allows the use of low grade NH_3 gas source while still producing NH_4OH of the highest tier quality in assay stability and purity.

Closed loop process integrated with existing chemical distribution network or as stand-alone unit — provides the least amount of risk in assay stability, loss, purity or contamination.



Block diagram of Exyte system

2 modes of operation:

- **Single batch**
(operator response required)
Allows the sampling and verification analytically before going on-line
- **Continuous batch**
(no operator response required)
Capable to fill totes or drums, as required

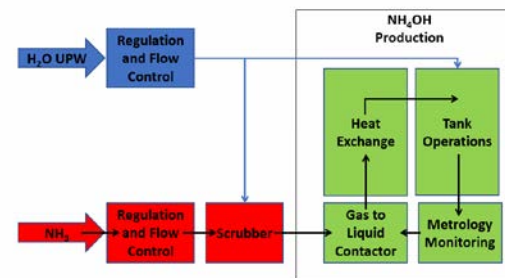
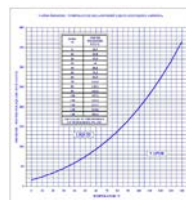
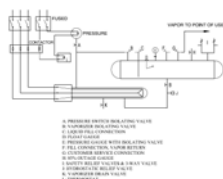
Integrated NH_4OH On-site Generation Technology

Process flow within semiconductor fab site

Fab gas yard



Incoming liquid anhydrous NH_3 is heated to produce the gas pressure and flow required,



- Blending process tank is filled with a defined volume of UHP H_2O , circulated to lower temperature.
- Incoming gas is sent through a wet scrubber, prior to being injected into the circulation flow of UHP H_2O , via a gas to liquid contactor.
- 2 metrology sets continuously measure and endpoint the NH_4OH concentration.

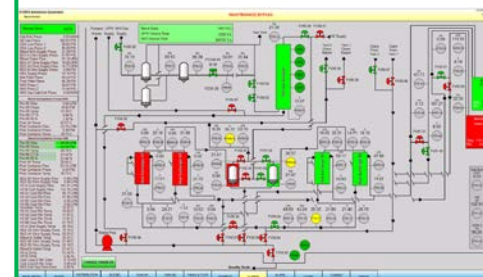
Into the fab



Incoming Liquid Anhydrous NH_3 Gas in ISO Tank.



Incoming liquid anhydrous NH_3 gas is piped to the blending equipment.



Injection of NH_3 stops when target assay is achieved

- Content of the process tank is either transferred to a bulk storage tank or flowed directly into the fab, subject to configuration..
- Tank is released for use and another batch is made in the next available tank.

Integrated NH_4OH On-site Generation Technology

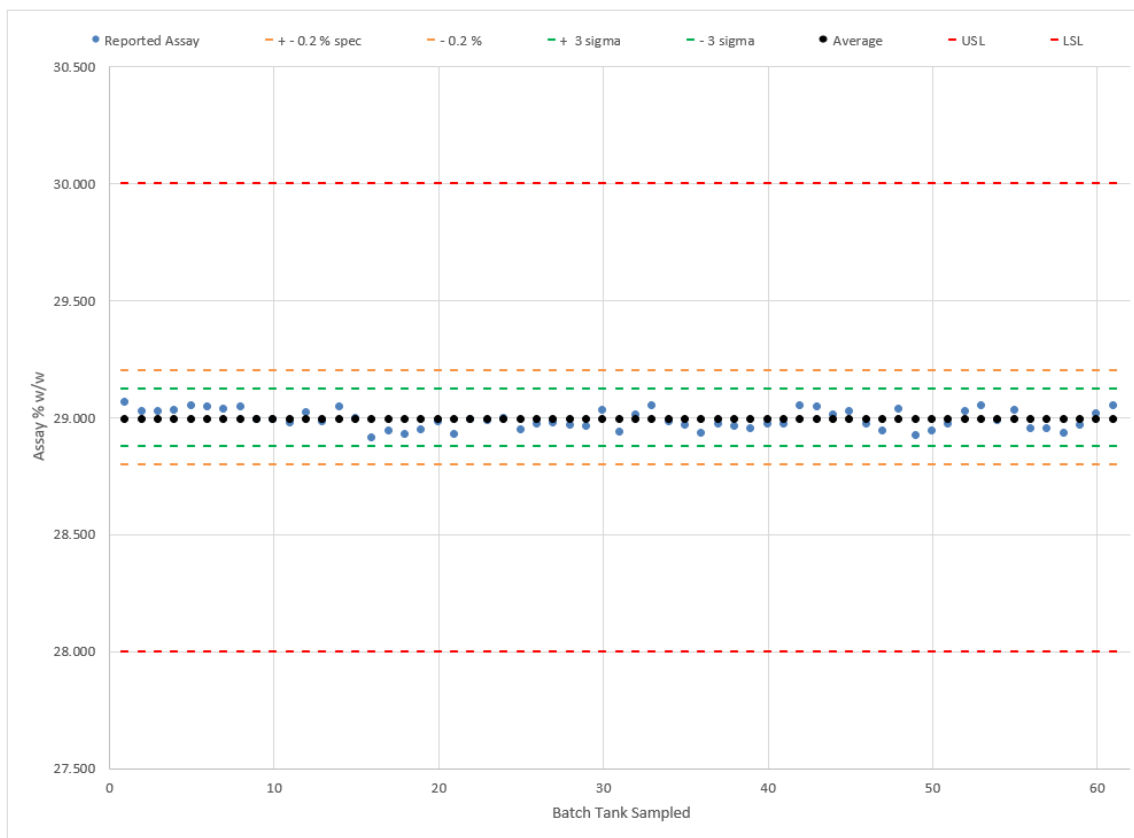
Process and quality control management system

The technology **offers different metrology principles** tied to density and ionic values

Mass-balanced based process. Metrologies verify the volumes, ensuring the mass balance is maintained.

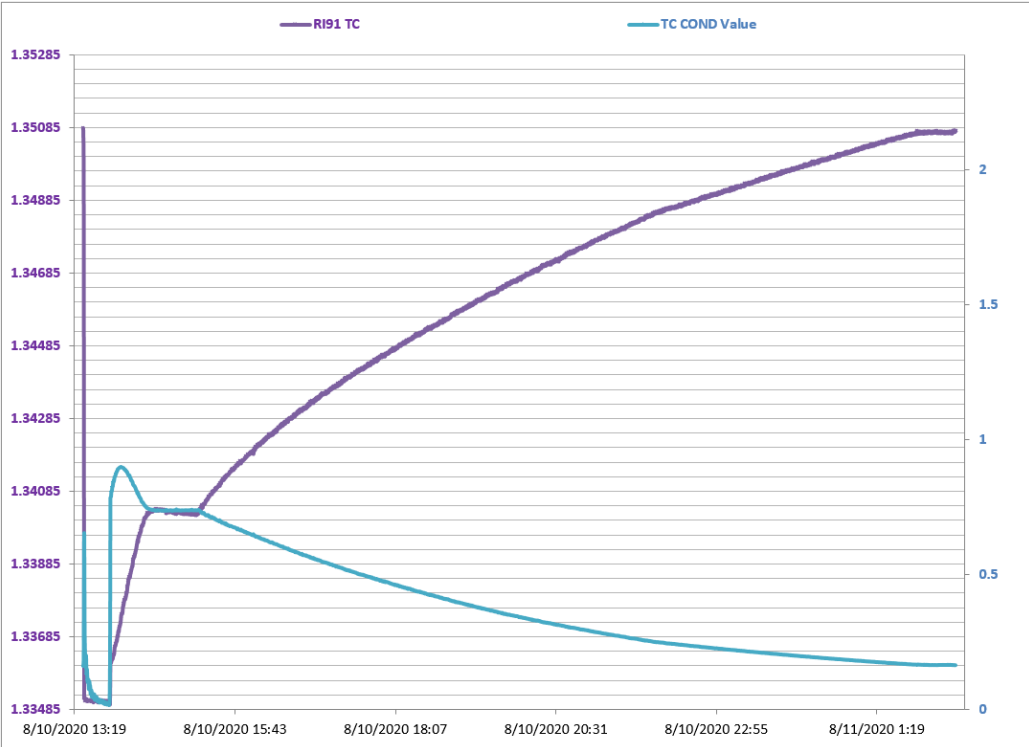
All process chemical components are continuously tracked and recorded.

Batch number generation for traceability once assay concentration is achieved - Includes the amount of UHP H_2O , and NH_3 used to achieve the concentration with all process data attached to the batch.

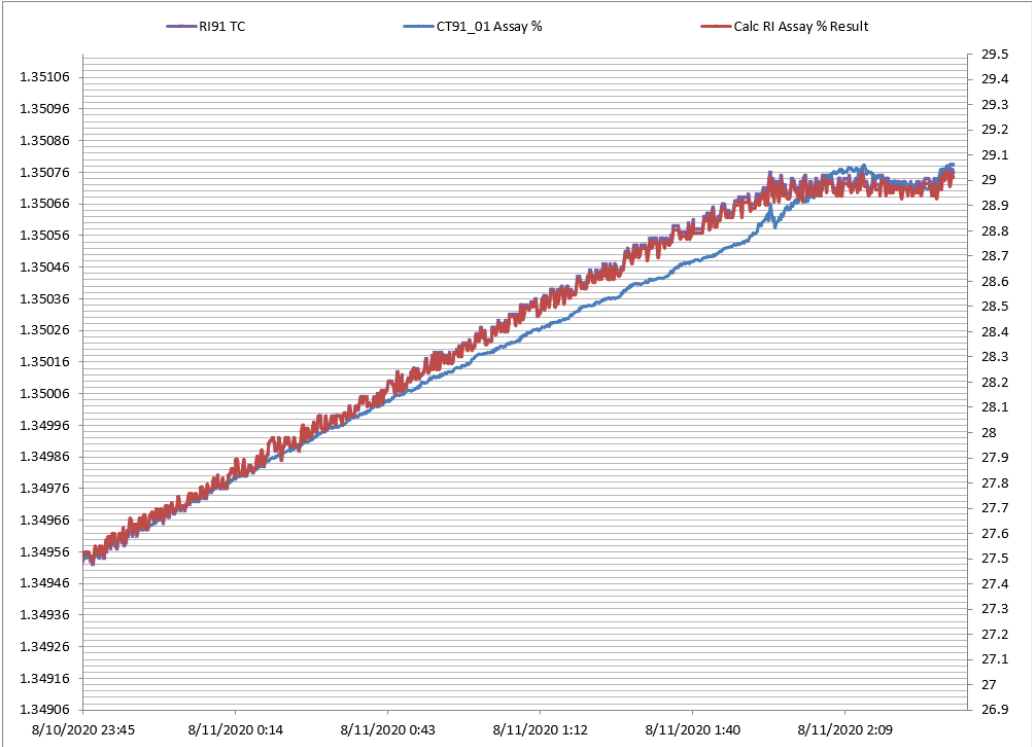


Integrated NH₄OH On-site Generation Technology

Process and quality control management system



Metrology signatures of a batch



Concentration end-pointing of the batch

Integrated NH₄OH On-site Generation Technology

Product quality assurance

Typical reported values are shown.

Variations or excursions are typically a result of sampling error - from the bottle or exposure to air during sampling process.

Closed loop sealed environment where product is produced ensures highest purity.

Elements such as Na, Ca, and K shows up due to any contamination from the environment.

Particles are dependent upon method setup.

Typical values under 100 @ 0.1 and under 500 @ 0.05.

In reality, the actual post filter at 80 counts @ 0.02.

Chemical:	Ammonium Hydroxide (NH ₄ OH)	P-Grade	R-Grade	CI/Ag-Grade		
Data Type:	Typical Yearly Running Averages	NH ₃	NH ₃	NH ₃		
System Type	Fusion NH ₄ OH Generation System					
Customer		Customer #1	Customer #2	Customer #3		
Analysis-Bep	Min.	Result Ave Value	Result Ave Value	Result Ave Value	Max.	Units
Ammonium Hydroxide (NH ₃ w/w)	28.00	29.125	29.017	28.988	30.00	%
Aluminum		0.01	<0.01	0.001	0.1	ppb
Antimony		<0.01	<0.01	<0.004	0.1	ppb
Arsenic		<0.01	<0.01	<0.006	0.1	ppb
Barium		<0.01	<0.01	<0.003	0.1	ppb
Beryllium		<0.01	<0.01	<0.005	0.1	ppb
Bismuth		<0.01	<0.01	<0.006	0.1	ppb
Boron		0.01	<0.01	0.001	0.1	ppb
Bromide		N/A	<2	<2		
Cadmium		<0.01	<0.01	<0.002	0.1	ppb
Calcium		<0.01	<0.01	0.003	0.1	ppb
Chloride		<2.0	<5	<5	100	ppb
Chromium		<0.01	<0.01	<0.004	0.1	ppb
Cobalt		<0.01	<0.01	<0.004	0.1	ppb
Copper		<0.01	<0.01	<0.010	0.1	ppb
Gallium		<0.01	<0.01	<0.004	0.1	ppb
Germanium		<0.01	<0.01	<0.004	0.1	ppb
Gold		<0.01	<0.01	<0.010	0.1	ppb
Indium		<0.01	<0.01	<0.010	0.1	ppb
Iron		<0.05	<0.05	<0.010	0.1	ppb
Lanthanum		<0.01	<0.01	<0.006	0.1	ppb
Lead		<0.01	<0.01	<0.003	0.1	ppb
Lithium		<0.01	<0.01	<0.004	0.1	ppb
Magnesium		<0.01	0.01	<0.007	0.1	ppb
Manganese		<0.01	<0.01	<0.003	0.1	ppb
Molybdenum		<0.01	<0.01	<0.004	0.1	ppb
Nickel		<0.01	<0.01	<0.010	0.1	ppb
Niobium		<0.01	<0.01	<0.006	0.1	ppb
Nitrate		<10.0	<4	<4		ppb
Nitrite		N/A	<5	<5		ppb
Palladium		<0.01	<0.01	<0.015	0.1	ppb
Phosphate		<10.0	<2	<2	50	ppb
Platinum		<0.01	<0.01	<0.010	0.1	ppb
Potassium		<0.01	<0.01	<0.004	0.1	ppb
Silver		<0.01	<0.01	<0.002	0.1	ppb
Sodium		<0.01	<0.01	0.003	0.1	ppb
Strontium		<0.01	<0.01	<0.002	0.1	ppb
Sulfate		<10.0	11	<10	100	ppb
Tantalum		<0.01	<0.01	<0.018	0.1	ppb
Thallium		<0.01	<0.01	<0.008	0.1	ppb
Tin		<0.01	<0.01	<0.006	0.1	ppb
Titanium		<0.01	<0.01	<0.008	0.1	ppb
Tungsten		<0.01	<0.01	<0.006	0.1	ppb
Vanadium		<0.01	<0.01	<0.003	0.1	ppb
Zinc		<0.01	<0.01	<0.010	0.1	ppb
Zirconium		<0.01	<0.01	<0.010	0.1	ppb
Particle Count (0.2)		137	202.3	104.1	1000	Ct/mL
Particle Count (0.5)		17.6	21.13	10.5	200	Ct/mL
Color		<5.0	<5.0	<5.0		
Appearance		P	P	P	P	P

Integrated NH₄OH On-site Generation Technology

Product quality assurance

Typical reported values are shown.

Variations or excursions are typically a result of sampling error - from the bottle or exposure to air during sampling process.

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Typical values under 100 @ 0.1 and under 500 @ 0.05.

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Analysis by ICP-MS (Evaporation)

		Sample #	080822-29%NH ₄ OH-XXXFAB-NH ₄ OH Gen Tank 1, Sample XXXFAB-01	
Control Limits	Specification	Parameter	Results	STDV
		% NH ₄ OH	29.073	0.242

Analysis by titration

All data in units of ppb

Blue font indicates data at or below detection limits

NH ₄ OH Specifications		Sample #:		080822-29%NH ₄ OH-XXXFAB-NH ₄ OH Gen Tank 1, Sample XXXFAB-01			
Control Limits	Specification	Element		Results	Recovery	MDL	Half Delta
0.050	0.100	Aluminum	Al	0.001	98%	0.001	
0.050	0.100	Antimony	Sb	0.001	95%	0.001	
0.050	0.100	Arsenic	As	0.001	93%	0.001	
0.050	0.100	Barium	Ba	0.001	102%	0.001	
		Beryllium	Be	0.001	94%	0.001	
		Bismuth	Bi	0.001	99%	0.001	
0.050	0.100	Boron	B	0.011	128%	0.003	
		Cadmium	Cd	0.001	96%	0.001	
0.080	0.100	Calcium	Ca	0.005	101%	0.004	
0.050	0.100	Chromium	Cr	0.001	100%	0.001	
0.050	0.100	Cobalt	Co	0.001	95%	0.001	
0.050	0.100	Copper	Cu	0.001	98%	0.001	
		Gallium	Ga	0.001	100%	0.001	
		Germanium	Ge	0.001	96%	0.001	
		Gold	Au	0.001	84%	0.001	
0.080	0.100	Iron	Fe	0.001	97%	0.001	
0.050	0.100	Lead	Pb	0.001	102%	0.001	
0.050	0.100	Lithium	Li	0.001	98%	0.001	
0.050	0.100	Magnesium	Mg	0.001	96%	0.001	
0.050	0.100	Manganese	Mn	0.001	99%	0.001	
		Molybdenum	Mo	0.001	102%	0.001	
0.100	0.100	Nickel	Ni	0.002	95%	0.002	
		Niobium	Nb	0.001	102%	0.001	
0.050	0.100	Platinum	Pt	0.001	99%	0.001	
0.080	0.100	Potassium	K	0.003	94%	0.001	
		Silver	Ag	0.001	105%	0.001	
0.050	0.100	Sodium	Na	0.003	89%	0.001	
		Strontium	Sr	0.001	101%	0.001	
0.050	0.100	Tantalum	Ta	0.001	59%	0.001	
		Thallium	Tl	0.001	103%	0.001	
0.050	0.100	Tin	Sn	0.001	101%	0.001	
0.050	0.100	Titanium	Ti	0.002	96%	0.002	
0.050	0.100	Tungsten	W	0.001	102%	0.001	
0.050	0.100	Vanadium	V	0.001	99%	0.001	
0.050	0.100	Zinc	Zn	0.001	78%	0.001	
		Zirconium	Zr	0.001	77%	0.001	

Integrated NH₄OH On-site Generation Technology

Cost savings

Technology allows best practice for material supply, enabling fabs to keep pace with supply and demand more efficiently. Example data below demonstrates cost savings:

NH4OH CONTRIBUTION Break Down	Use		Use		Use		Cost USD \$
29% NH4OH gallons per month	36,500.00	gal/mo	138,167.10	liter/mo	273,969.00	lb/mo	
SG	0.90						
Total mass/gal	7.51	lb/gal	3.40	kg			
29% NH4OH Cost per gallon							\$1.16
29% NH4OH Cost per liter							\$0.31
NH3 Assay	29.00%	percent					
NH3 portion	2.18	lb/gal	0.99	kg			\$1.13
NH3 consumed	79,451.01	lb/mo	36,038.37	kg/mo	79,451.01	lb/mo	\$41,314.53
NH3 price per lbs	0.52	\$ USD					
DIW Assay	71%	percent					
DIW portion	5.33	lb/gal	2.42	kg			\$0.03
DIW consumed	194,517.99	lb/mo	88,231.88	kg/mo	194,517.99	lb/mo	\$972.59
UPW price per lbs	0.0050	\$ USD					
Anhydrous NH3 Required	15,427.38	gal/mo	58,398.81	liters			
Anhydrous NH3 Required	3,550.41	gal/week	13,439.73	liters			
Anhydrous NH3 Required	507.20	gal/day	1,919.96	liters			
DIW Required	23,323.50	gal/mo	88,288.78	liters			
DIW Required	5,367.60	gal/week	20,318.51	liters			
DIW Required	766.80	gal/day	2,902.64	liters			



Integrated NH_4OH On-site Generation Technology

Environmental & safety benefits

Energy & safety risks reduction:

- Reduce shipment by 71% - No transport of UHP H_2O component in NH_4OH (only liquified NH_3 needs to be transported)
 - Assuming 14K L/ day usage → eliminate ~500 iso container trips between the fab and the chemical supplier location.
- Reduced logistics leads to reduction in overall operational safety risks on-/off-site
- Reduce the fleet of stainless steel iso tankers.
- Reduce plastic containers needed in the case of non-isotainer supply lines
 - Assuming 14K L/ day usage → eliminate 6,400 (200L) drums or 1,300 (1000L) totes every 3 years will be saved.

Emissions and waste reduction:

- No NH_3 is lost to head space of shipping containers or environment
- The closed loop structure of the tank vent design reduces scrubbed exhaust flow associated to NH_3
 - H_2O isolation boxes installed between the tank and the exhaust flow path to scrub and remove any NH_3 for the exhaust flow stream. Thereby, keeping the NH_3 in the products being supplied to the fab tools.
- The system is configurable to allow <20L of NH_4OH waste per year in scrubber column volume. Allowing captured scrub impurities to be sent to a fab industrial waste flow
 - Normal supply chain generates more waste at the chemical factory when empty vessels are received and refilled.

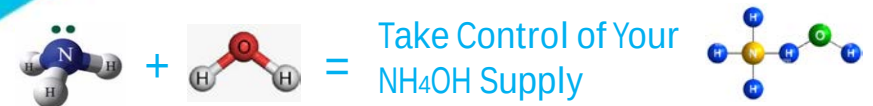


Integrated NH_4OH On-site Generation Technology





Key Takeaways



Key Takeaways

On-site NH_4OH generation technology by Exyte

- **Mitigate supply chain challenges – removing** substantial amount of transportation, intermediate vessels, packaging and storage in the operations.



- Reduction in logistics leads to **reduction in the overall operational safety risks on/off-site**
- **A closed loop process technology** capable to be integrated with the fab's site distribution channels.
- Ensure **highest and consistent quality** in assay and purity, while using lower NH_3 raw material grades.
 - Process results exceed levels of SEMI C21-0618 specification for NH_4OH
 - Production batch performance monitoring and traceability
- A commercial model that provides **cost savings, desired quality and more environmentally friendly**, enabling a **more sustainable semiconductor industry**.

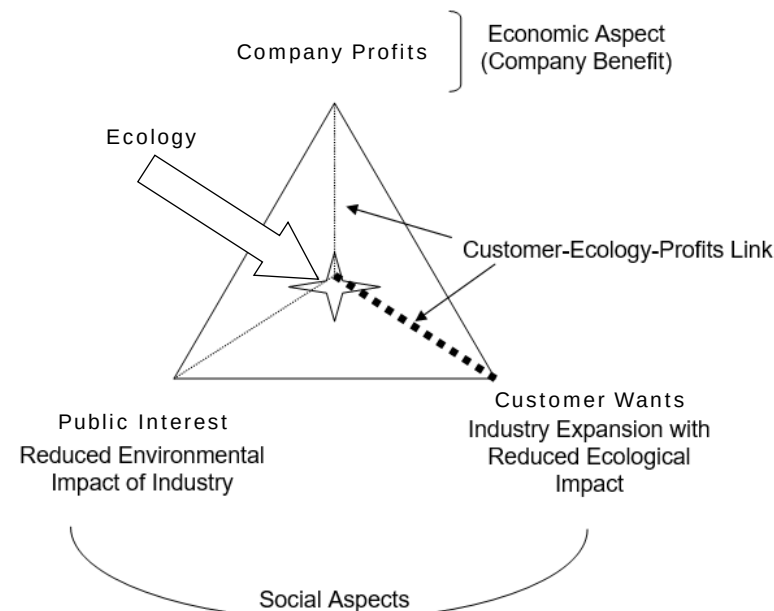
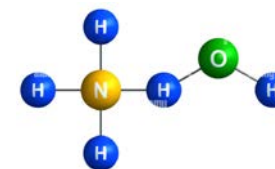


Figure: Pyramid Commercial Model – adopted from Parasuraman 2000 and modified to reflect Kotler 2003 triangle of balance in societal marketing



Smart and More Resilient Supply System for Sustainability



Thank You

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