FRAUNHOFER CHILE:
A DRIVER FOR INNOVATION IN CHILE

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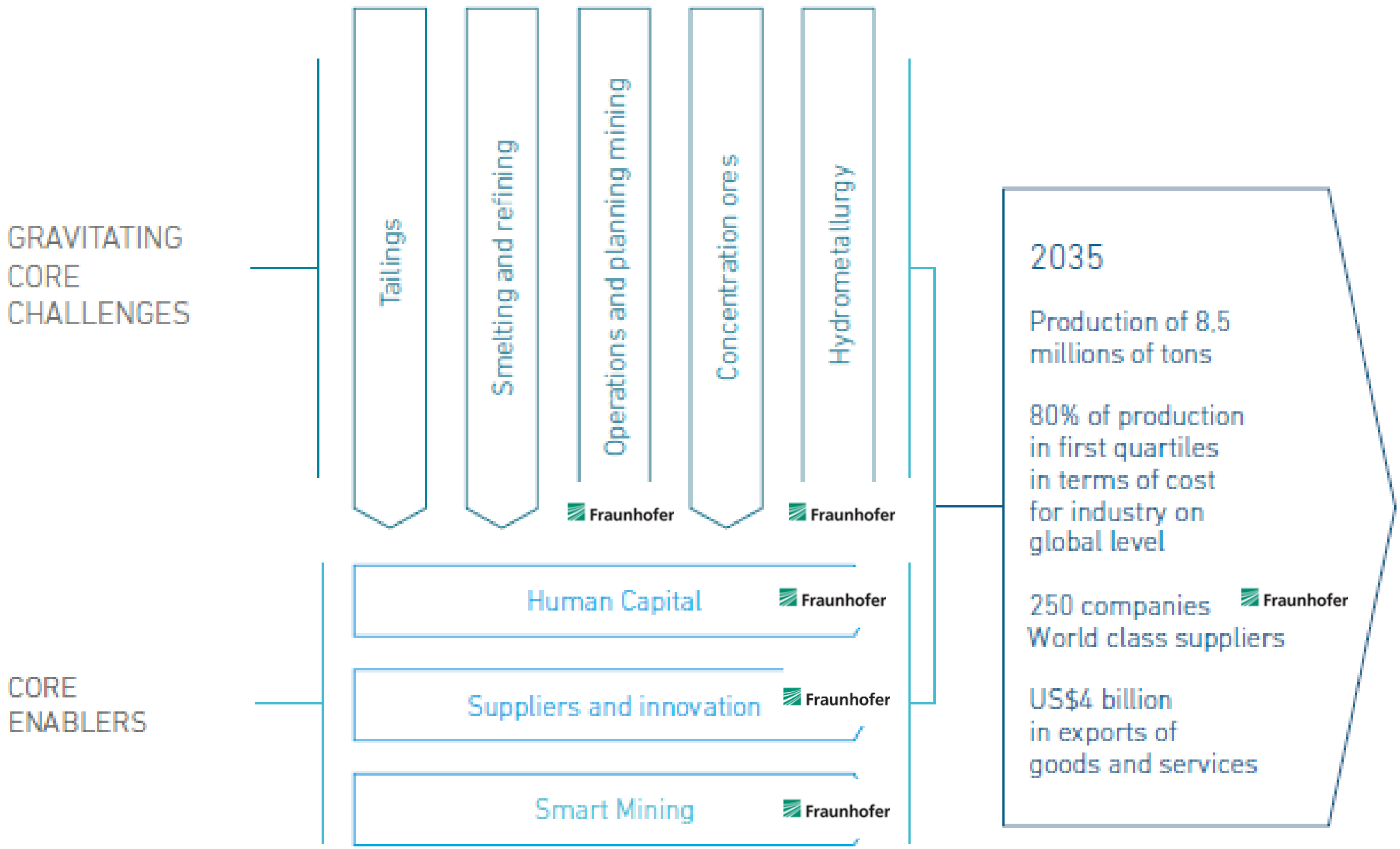
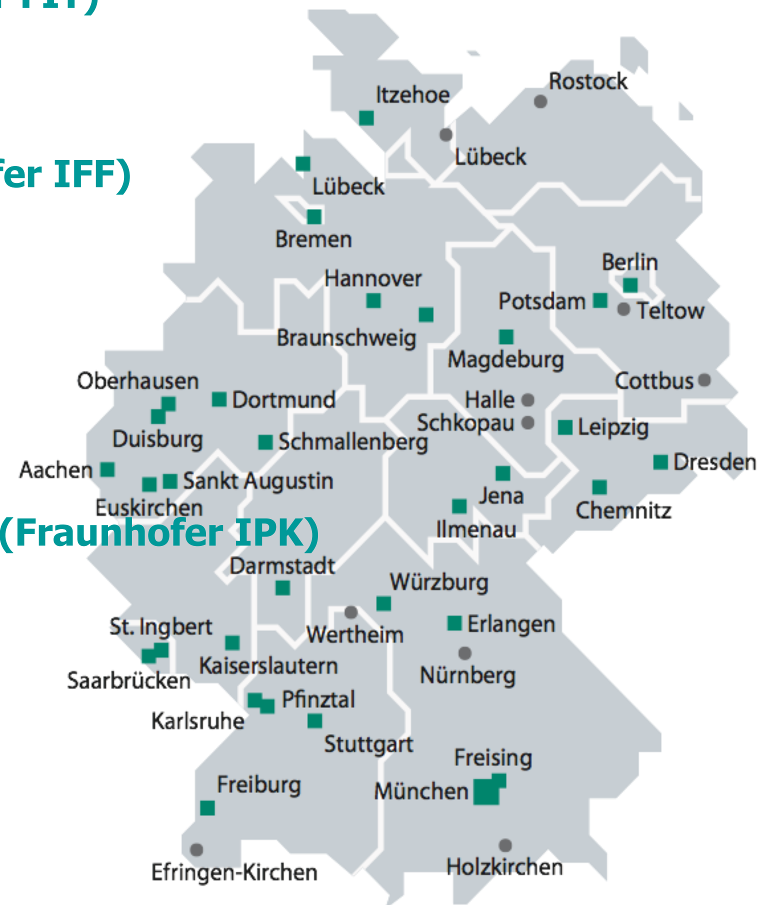
Carlos Saffie Vega
Business Development Manager
Fraunhofer Chile Research - Center for Systems Biotechnology

Present and Future Challanges of Chilean Mining Industry



Fraunhofer Gesselschaft & Mining Industry

- Institute for Applied Information Technology **(Fraunhofer FIT)**
- Institue for Chemical Technology **(Fraunhofer ICT)**
- Institute for Factory Operation and Automation **(Frunhofer IFF)**
- Institute for Intergrated Circuit **(Fraunhofer ISS)**
- Institute for Laser Technology **(Fraunhofer ILT)**
- Institute for Material Flow and Logistic **(Fraunhofer IML)**
- Institute for Production Systems and Design Technology **(Fraunhofer IPK)**
- Institute for Supply Chain Services **(Fraunhofer SCS)**



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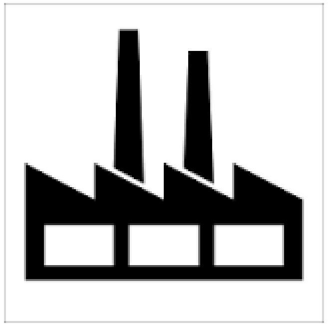
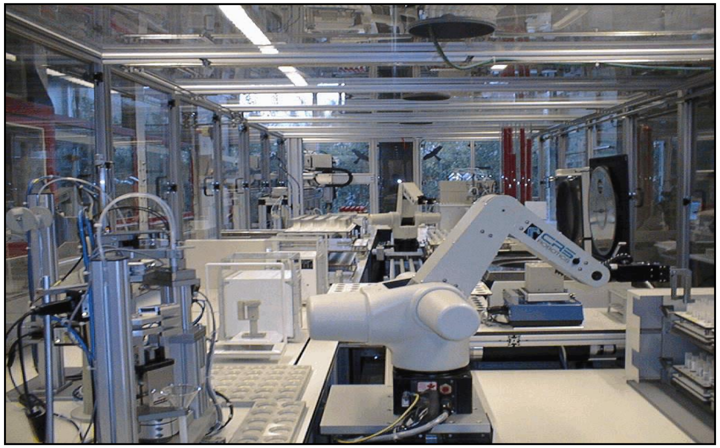
Fraunhofer Chile – Center for Systems Biotechnology: Technology Platforms

COMPUTING DATA ANALYSIS

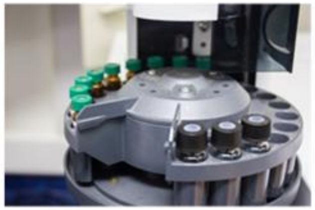
MOLECULAR MODELLING

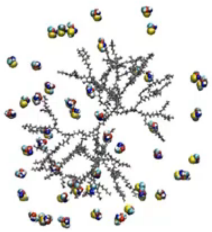


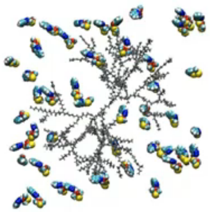
NANOPARTICLES & BIOPOLYMER SYNTHESIS



APPLIED GENETICS







NANOTECHNOLOGY – MINING INDUSTRIAL PROCESSES

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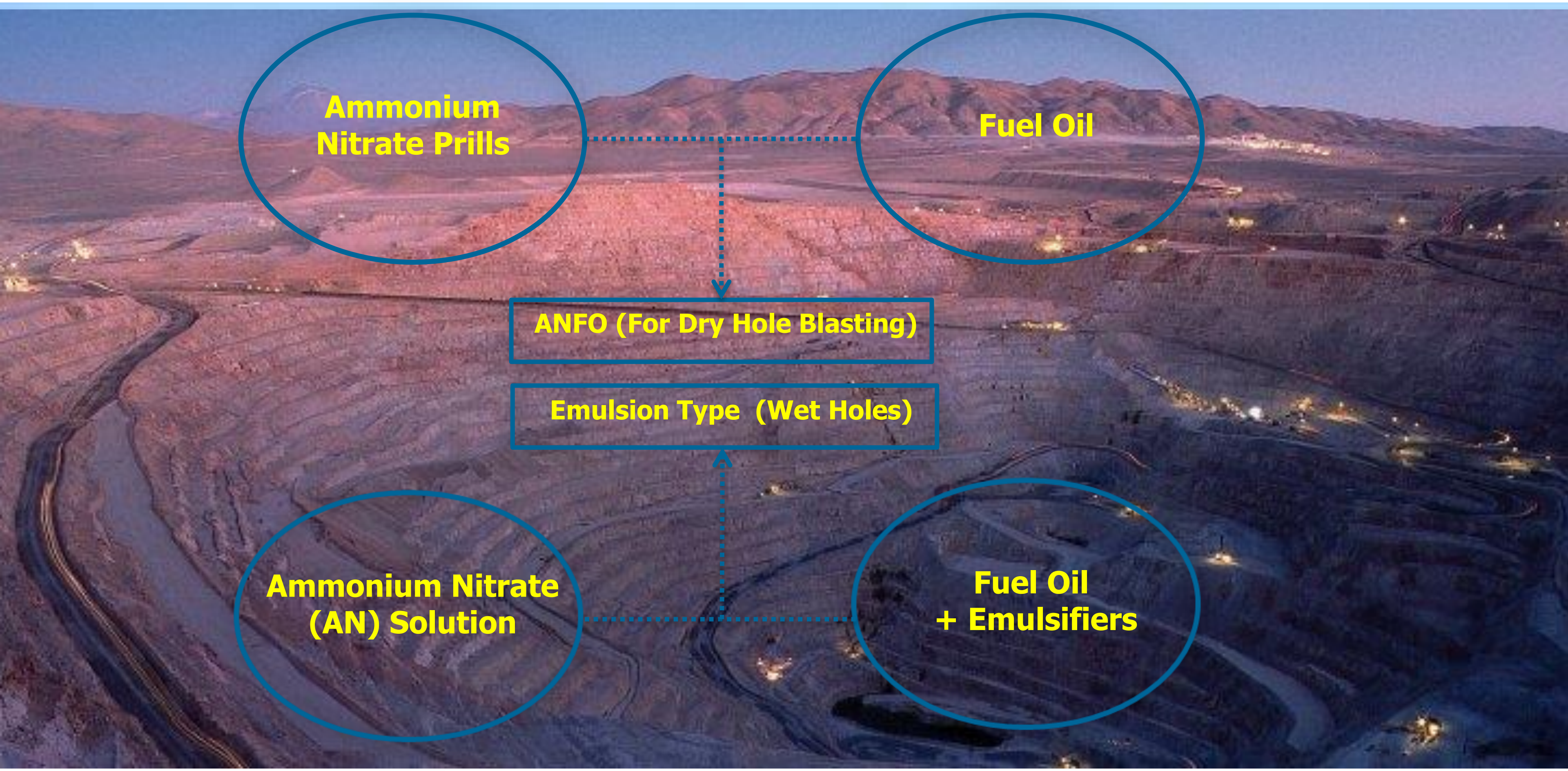
Open Pit Mining Operations Requires World Class Suppliers

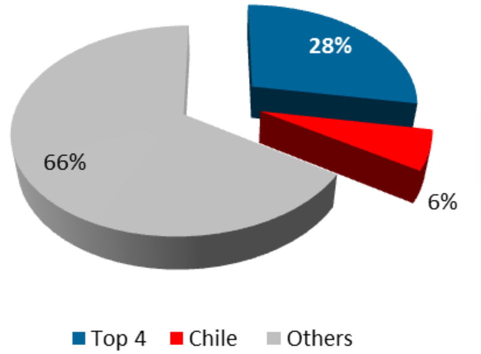


Explosives are a key material used to break a piece of earth into grounded rocks for further treatment processes.

* Minera Escondida -BHP Billiton. Antofagasta

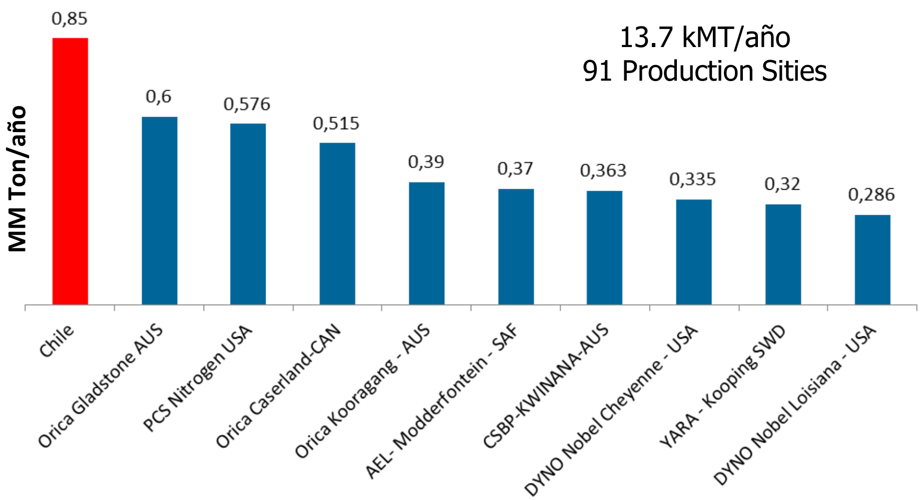
Ammonium Nitrate Derived Explosives Industry Overview

- Ammonium Nitrate main producers countries includes United States; Canada, Australia; South Africa and Chile.
- Chile is one of the top producer of Ammonium Nitrate derived explosives, especifically Ammonium Nitrate Fuel Oil (ANFO) (6% worldwide production)
- National and LatinAmerican Mining Industry has a strong dependence of explosives for open pit operation and underground mining exploration. 80% of explosives comes from ANFO.



Explosives

ANFO



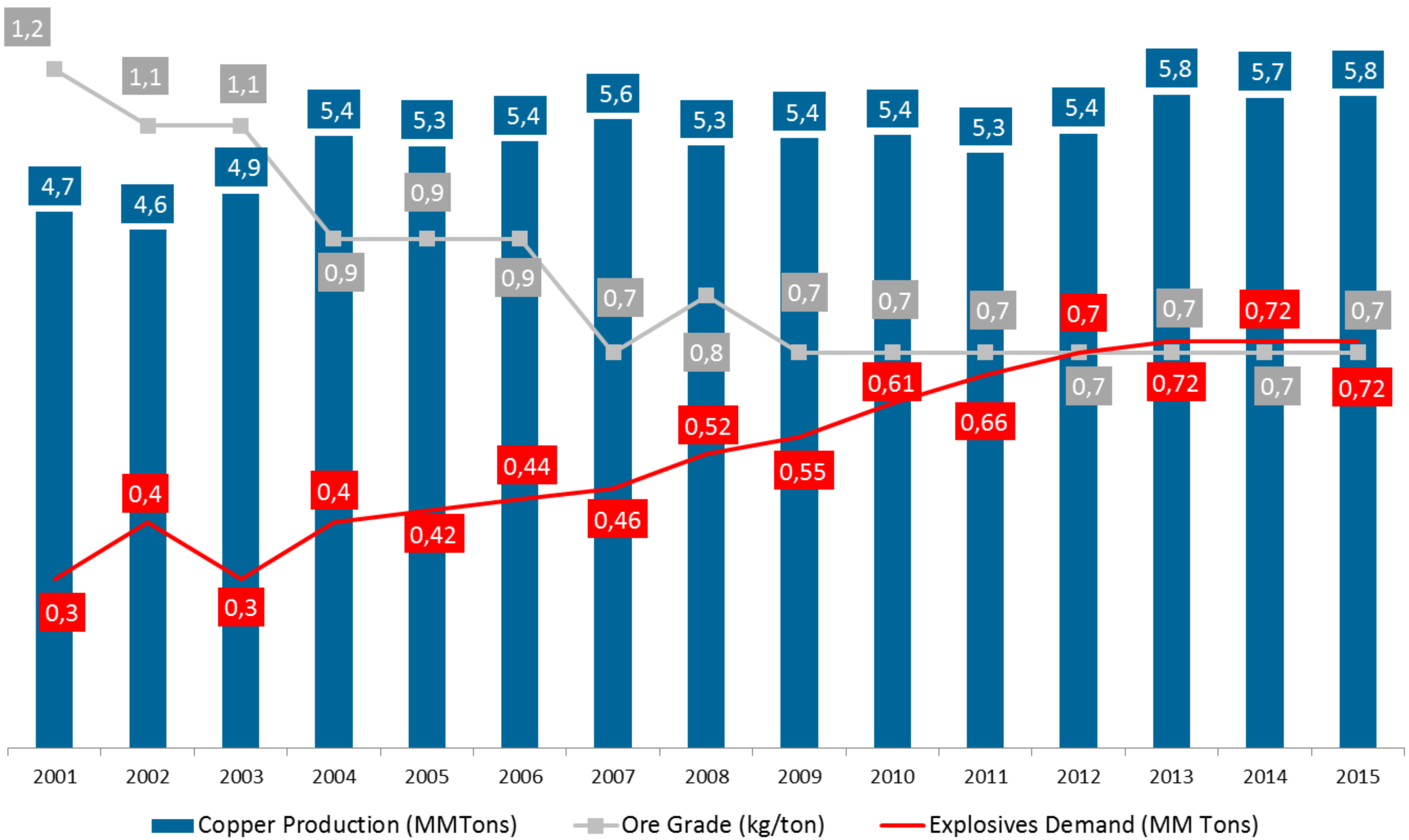
Offer vs Demand (MMT)*

*LatinAmerica Market Forecast

*Frost & Sullivan and Industry Data

Ammonium Nitrate Derived Explosives – Chilean Mining Overview

The Ammonium Nitrate derived explosives demand is expected to increase in upcoming years due to new mining operations and decrease in ore grades from currents copper mines



* Own Elaboration based con Cochilco and Industry Data

Ammonium Nitrate Production Process

Step1
- Ammonia and raw materials maritimal transport and storage

Step 2
- Raw Material Management (Regasification & Storage)

Step 3
- Nitric Acid Generation (Industrial Ostwald Process)

Step 4
- Ammonium Nitrate Production (Product Formulation)

Ammonium Nitrate Production Process

- Step1 — Ammonia and raw materials maritimal transport and storage
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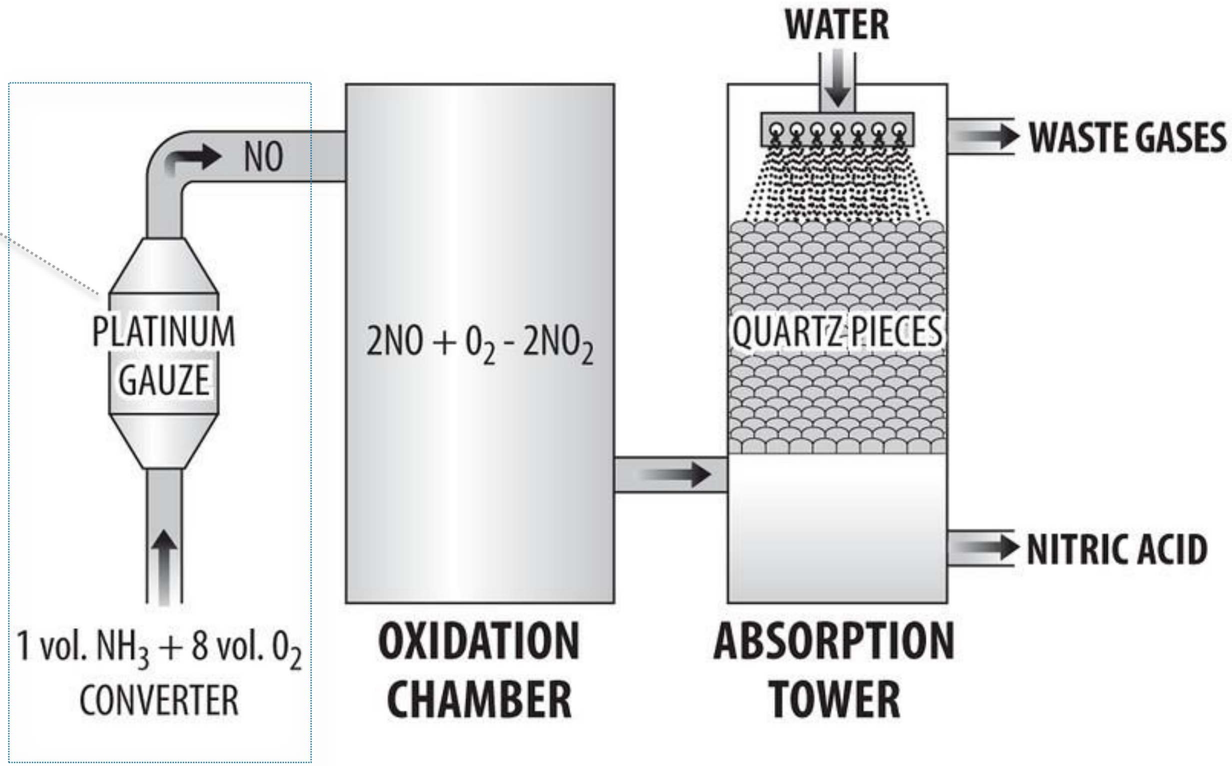
- Step 3 — Nitric Acid Generation (Industrial Ostwald Process)
- Step 4 — Ammonium Nitrate Production (Product Formulation)

The Ostwald Process of Creating Nitric Acid

Wilheim Ostwald (Nobel Prize 1909) , German

900ºC
9 bar



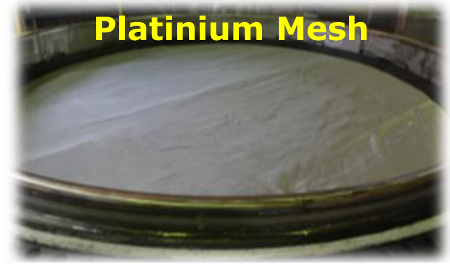
Characteristics :

- ✓16 to 25 woven mesh
- ✓Mesh Diameter- 3290mm
- ✓ Wire Diámeter 0.076mm
- ✓Totel Weight ≈ 82 kg.
- ✓ Catalyst Load is 2.12 kg/(Ton_{HNO3}/h).
- ✓≥90% Pt
- ✓Around US$2.5 MM/mesh

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad \Delta H_{298} = -226\, {}^{kJ}/_{mol}$$

* Chemical Engineer Handbook 2011

The Ostwald Process of Creating Nitric Acid

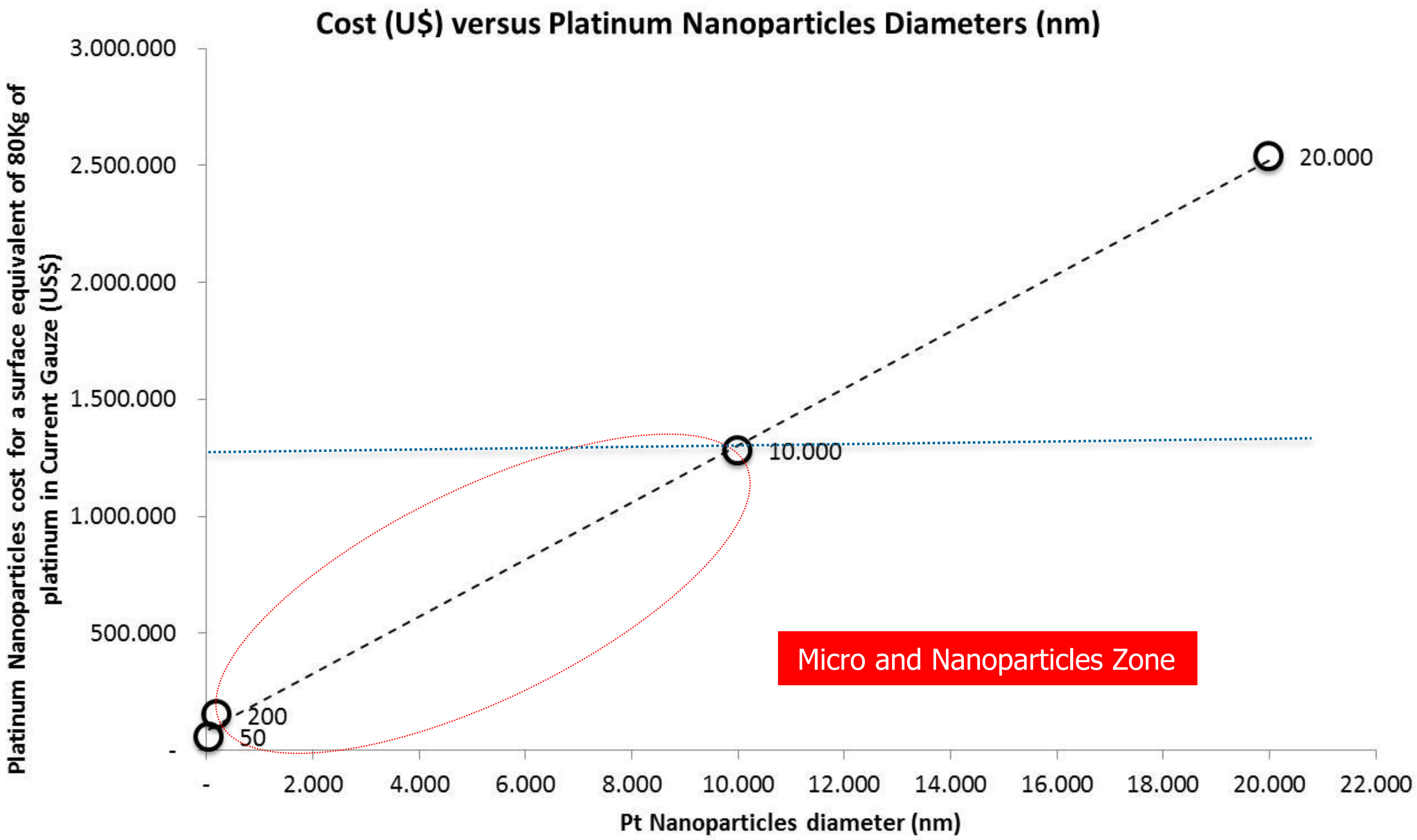


Operational “Pains”:

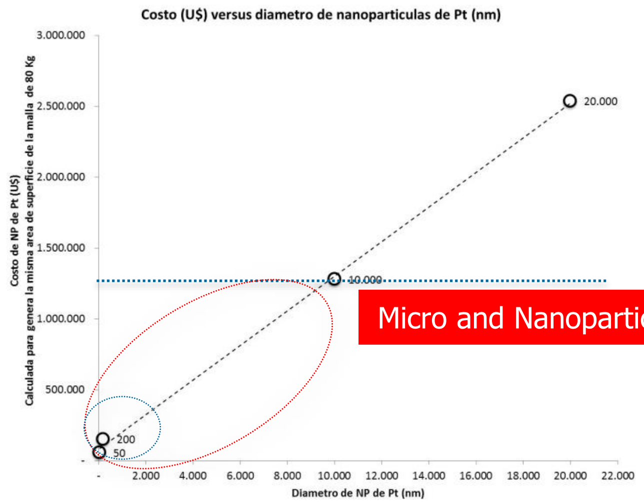
- High Cost of single catalytic gauze (from 10 up to 25 individual mesh) , 80kg of Platinum per mesh (90% p/p); high platinum losses (≥ 15%) during production phases due to extreme operational conditions
- Cost associated to Plant downtimes required for gauze reeplacement (Average 3 per year, one week each one)
- Generation of greenhouse gases as secondary reactions due to decrease in catalytyc effiiency. (Ammonia convertion rate below 93% promote secondary reactions).

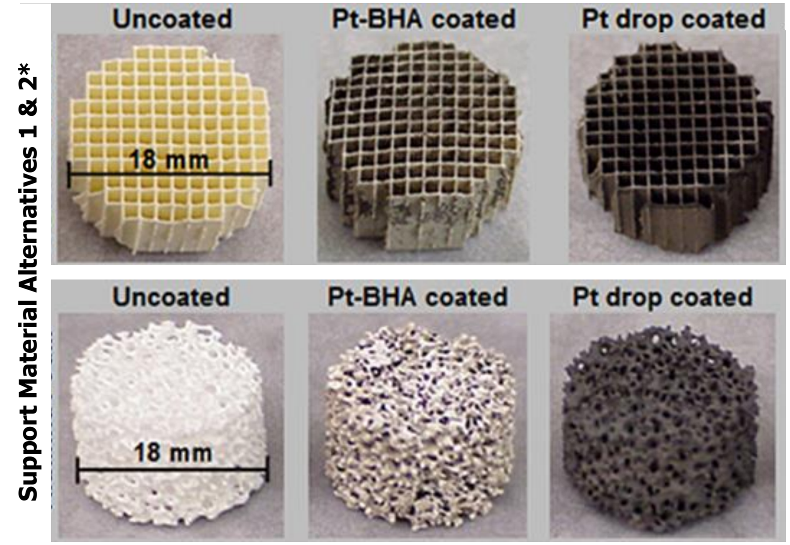
Platinum Nanoparticles as Opportunity for Process Improvement

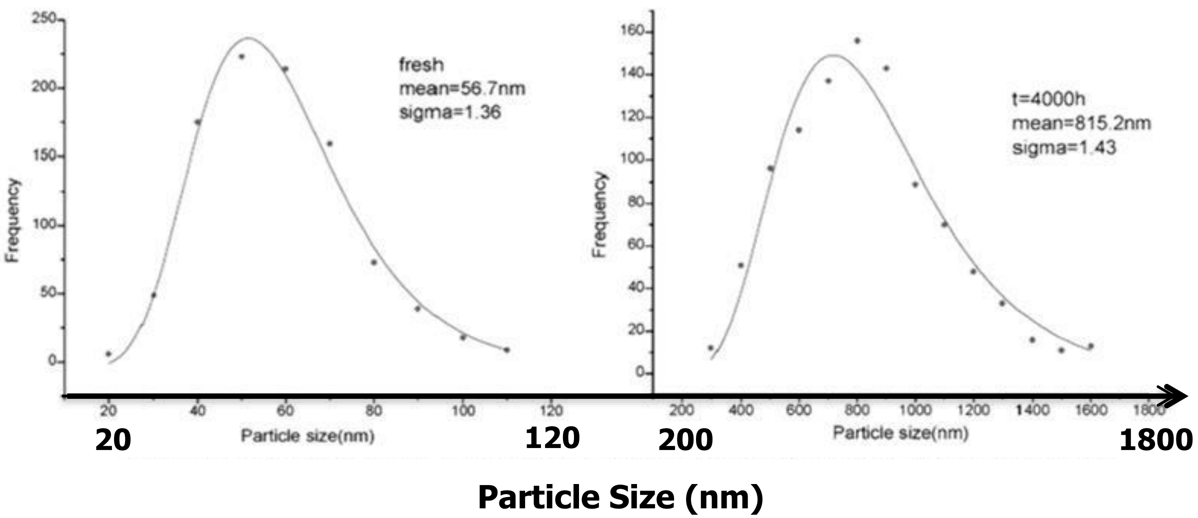
- Scientists from Fraunhofer Chile and UNAB in a joint effort with Fraunhofer Institute for Silicate Research (Fraunhofer ISC) propose an alternative for improve the performance and productivity of catalytic effect during Ammonic convertion process.



Platinum Nanoparticles as Opportunity for Process Improvement







80% Less Platinum per Mesh!!!

*Veser et al; Chemical Engineering Journal; 2014

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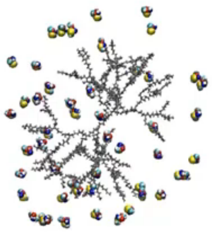
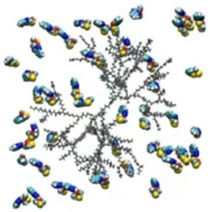
Universidad Andrés Bello

Fraunhofer ISC

Concluding Remarks

- Average Nitric Acid operational expenditures savings stimated in US$7.5MM per plant per year.
- Full technology development option throught strong collaboration between Chilean and German scientists plus access to client industrial facilities.
- Diversification of local suppliers products for international Mining Industry
- Future Commercial Opportunities from I.P applied to differents industrial sectors (i.e Pharmaceutical & Automotive Industry).
- Results from Industrial test by the end of FY2017





NANOTECHNOLOGY – MINING INDUSTRIAL PROCESSES

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Fraunhofer Chile – Center for Systems Biotechnology

QUÍMICA ANALÍTICA Y SINTÉTICA

MALDI Toff- MS

ION TRAP – MS

Q-Tof Micro

Analizador Elemental

EXTRACCIÓN DE COMPUESTOS DE VALOR

Carbonización Hidrotermal

Generación de Biogás

Extracción Supercrítica

Encapsulación Emulsificación

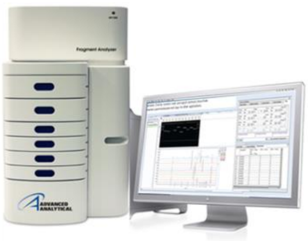
BIOLOGÍA MOLECULAR

Hamilton Liquid Handler

Sample Handler

Secuenciador MiSeq Ilumina

Fragment Analyzer



Ammonium Nitrate Production Facilities : Prillex

Layout Enaex´s Explosives Production Process

The production process could be divided in 5 phases:

Raw Materials Management

Nitric Acid Production

Ammonium Nitrate Production (prill and Solution)

Explosives Production

Ammonium Nitrate Transport and Storage

Planta Prillex América, Mejillones

4 Plantas Ácido Nítrico

- Planta 1: 130 ton/día
- ~~Planta2: 100 ton/día~~
- Planta 3: 925 ton/día
- Planta 4: 925 ton/día

Total: 1980 ton/día — 700,000 ton/año

3 Plantas Nitrato de Amonio

- Planta 1: 270 ton/día
- Planta 3: 1,060 ton/día
- Planta 4: 1,060 ton/día

Total: 2,390 ton/día — 820,000 ton/año

2 Plantas de Emulsiones

19,000 ton/mes — 100,000 ton/año

Capacidad de Almacenamiento Prillex® AN

- En Planta: 5,000 ton
- Externo: 44,000 ton

3 Est. Alm. Amoníaco

Capacidad Total 30,000 ton, (10,000 ton c/u)

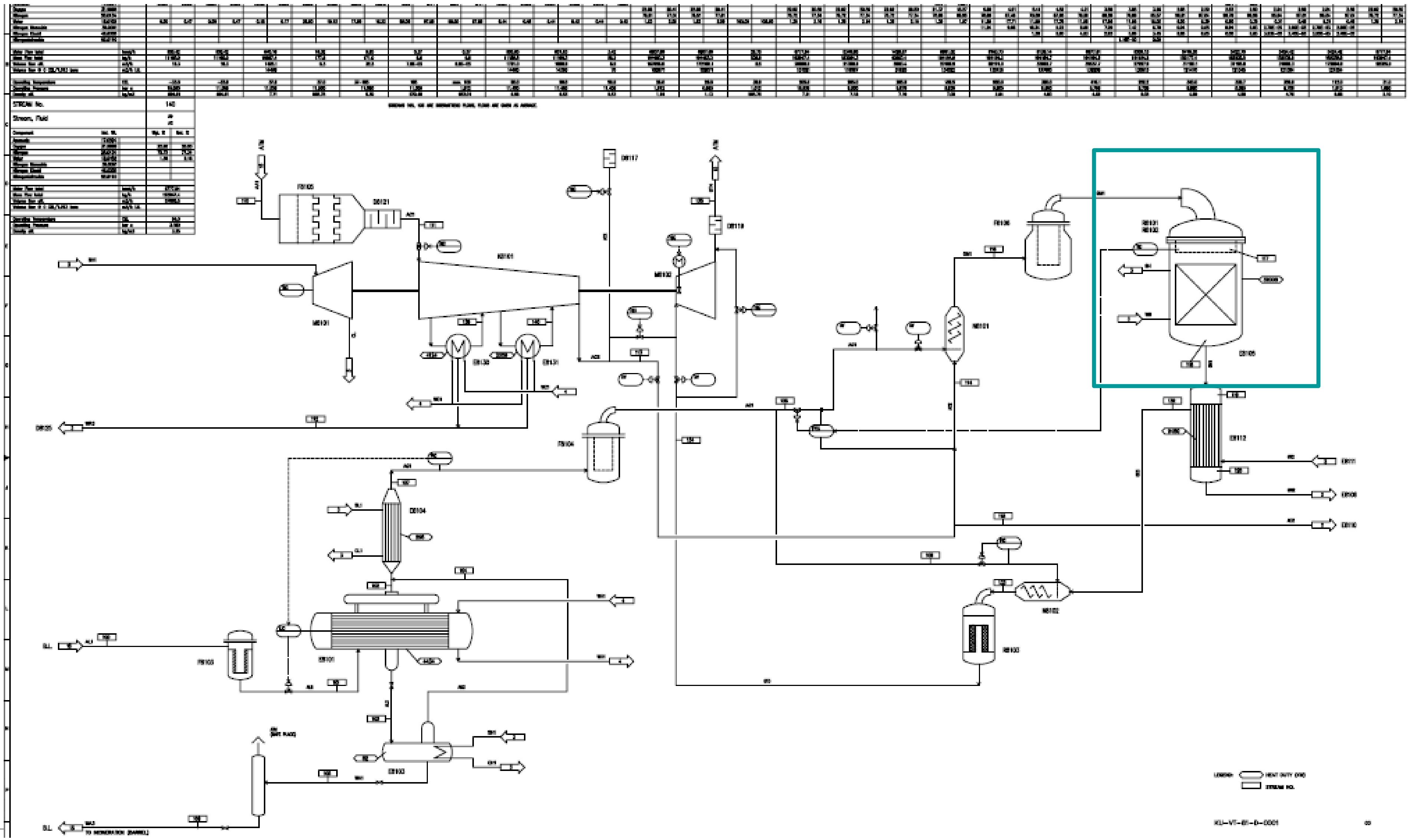
3 Est. Alm. Ácido Nítrico

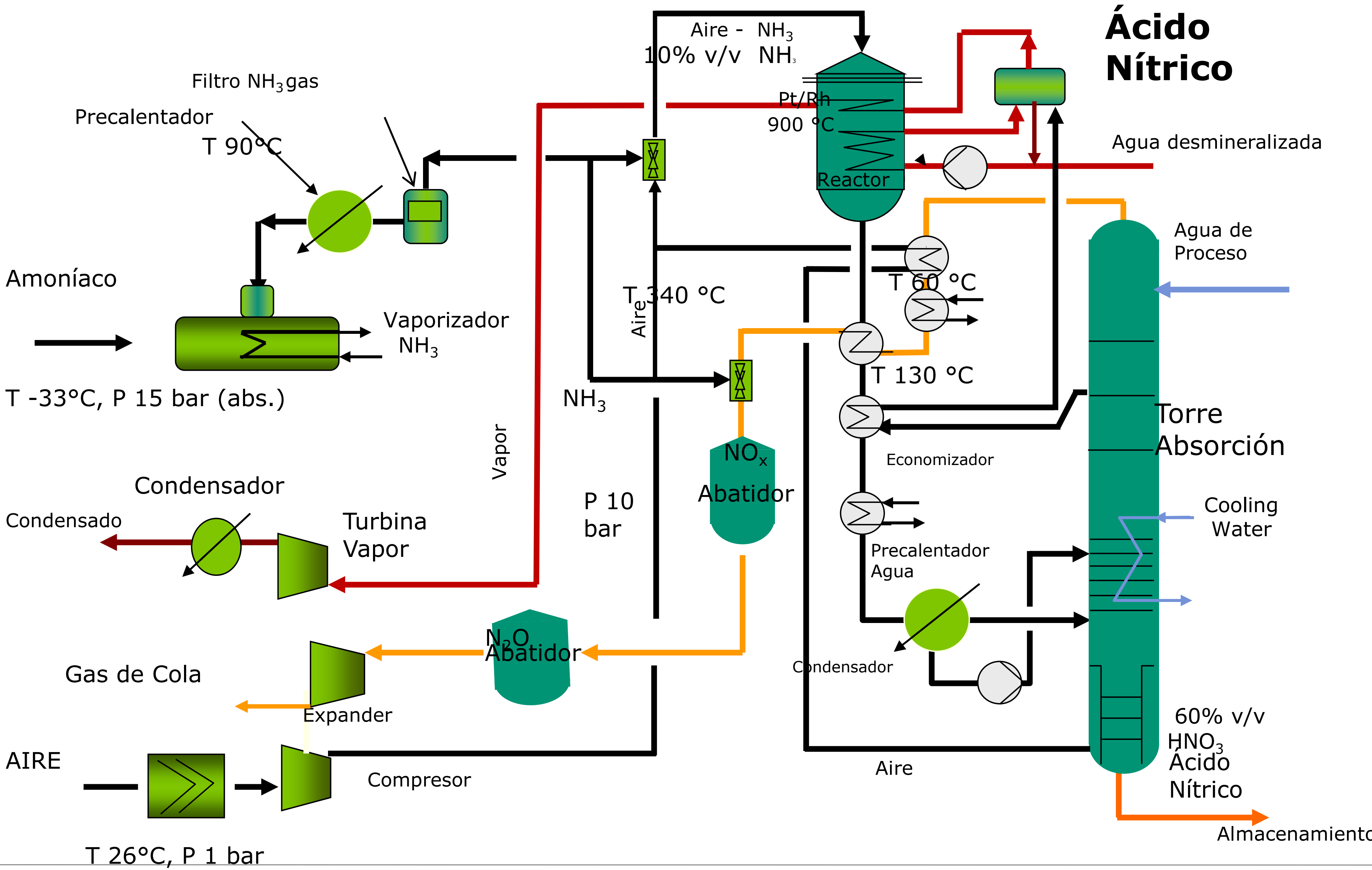
Capacidad Total: 6,000 ton

3 Est. Alm. Solución Nitrato de amonio

Capacidad Total: 1,100 ton

Nitric Acid Production Layout: PANNA 3





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Process Chemical Reactions :

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad \Delta H_{298} = -226 \, {}^{kJ}\!/_{mol}$$

Main Reaction

$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O \qquad \Delta H_{298} = -317 \, {}^{kJ}\!/_{mol}$$

$$4NH_3 + 4O_2 \rightarrow 2N_2O + 6H_2O$$

Secondary Reactions

Process Chemical Reactions :

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad \Delta H_{298} = -226 \, {}^{kJ}\!/_{mol}$$

Main Reaction

$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O \qquad \Delta H_{298} = -317 \, {}^{kJ}\!/_{mol}$$

$$4NH_3 + 4O_2 \rightarrow 2N_2O + 6H_2O$$

Secondary Reactions

Effect of Reaction Pressure and Temperature on Nitric Oxide Yield

Pressure (bar)	Temperature (°C)	Nitric Oxide Yield (%)
Below 1.7	810 to 850	97
1.7 to 6.5	850 to 900	96
Above 6.5	900 to 940	95

Drivers:

1. Efficiency losses by conversion of NH3 to N2
2. Efficiency losses by conversion of NH3 to N20 (Around 500ºC)
3. Descomposition of NH3 inside Reactor.
4. NO residence time
5. NH3 Oxidation Kinetic

NH3 Oxidation using high Temperature and Pressure – Catalitic effect of Rh/Pt Mesh :

- Characteristics :
  - ✓·16, woven gauzes (usual 4 a P_{atm} hasta 25 a altas presiones)
  - ✓Mesh Diameter · 3290mm (effective 3200mm),
  - ✓ Wire Diámeter 0.076mm
  - ✓Totel Weight ≈ 82 kg.
  - ✓ Catalyst Load is 2.12 kg/(Ton_{HNO3}/h). (Usual 1.5 a 1.9)

JM Johnson Matthey Catalysts

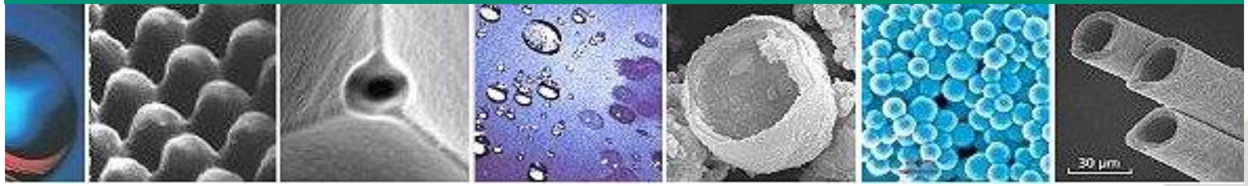
- Catalyst Performance changes over time:
  - ✓Efficency is affected for compositions and structural changes during operation
  - ✓At short times the catalitic effciency increase due to rough surface and metal migration to surface, increasing the catalitic area .
  - ✓The above changes reduce the structural performance of catalyst
  - ✓The catalyst surface is enriched with innactive Rodium Oxide (Rh_2O_3) and conversion efficency decline.

Current Catalyst Performance has high Economic Impact due to Catalyst Cost (US$2.5MM/mesh); Conversion Efficiency (93%; US$0.2MM/year)); Plant Downtimes (2 to 3/year; US$2.8MM/year) and Generation of greenhouse gases (US$0.1MM/Year)

Research Contract Highlights: Consultancy

Fraunhofer Nanotechnology Alliance

EMFT ENAS IAO IAP ICT IFAM IFF IGB IISB IKTS ILT IMWS IPA ISC ISE ISI ITEM IVV IWS



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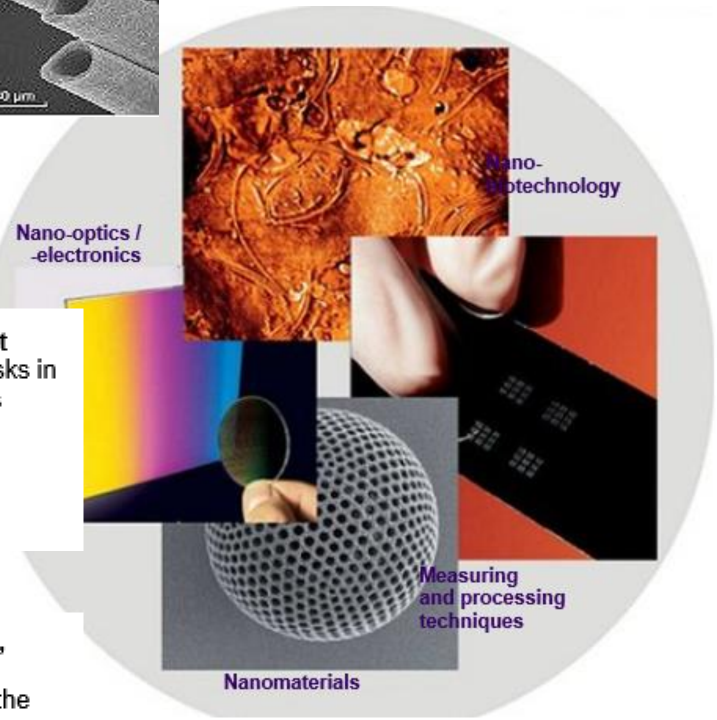


IPA

Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart
As your partner for contract research we develop and optimise solutions for different tasks in engineering sciences. In the range of coating technologies processes with high process reliability and reproducibility in coordination between material development and coating process are formed. Thereby planning, developments, modelling and simulations up to implementations suitable for production are in the front.
Details of the Institute's expertise

IFAM

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen
Most of IFAM's activities in the area of nano technology concern the interface between the surface of the nanoparticles and the polymer matrix. These activities include the manufacture of metallic nanoparticles, the surface modification of a wide range of nanoparticles, the compounding of nanoparticles with matrix polymers and the characterisation of nanocomposites right through to the development of new analytical methods. Other key areas of work concern surface and thin film technology and relevant analysis.
Details of the Institute's expertise

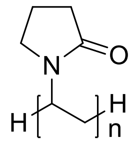
CONTRACT I. BACKGROUND INFORMATION

General Pt-NP Synthesis

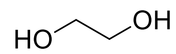
Pt-Nanoparticles:

$H_2PtCl_6 \cdot x\ H_2O$

5 g = 893.000 CLP-$



100 g = 100.000 CLP-$

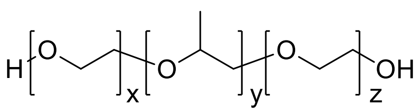


100 ml = 57.000 CLP-$

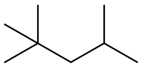
- controlled slow addition
- controlled stirring

F. Bonet et al., Nanostruct. Mater. **1999**, 11, 1277-1284.
Y. Dai et al., *Angew. Chem. Int. Ed.* **2010**, *122*, 8341-8344.

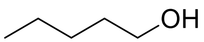
Pt-Ba-Hexaaluminate Nanocomposites:



250 ml = 64.000 CLP-$



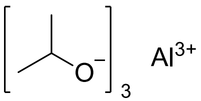
100 ml = 70.000 CLP-$



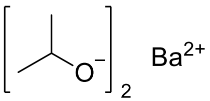
500 ml = 158.000 CLP-$

$H_2PtCl_6 \cdot x\ H_2O$

5 g = 893.000 CLP-$



10 g = 60.000 CLP-$



10 g = 324.000 CLP-$

T. Sanders et al., *Chem. Eng. J.* **2008**, *142*, 122-132.

CATALIZADOR

- La cinética de oxidación de NH_3 esta limitada a la transferencia de masa de las especies químicas (NH_3, O_2, NO y H_2O) y de la cercanía a la superficie del catalizador.
  - ✓Si la superficie del catalizador es mayor al área mínima para la reacción, la transferencia de masa limita la cinética.
  - ✓Si el área disponible es muy pequeña, la cinética está limitada por la superficie catalítica.
- El catalizador esta compuesto por Platino(≈90%), Rodio(5 a 10%) y Paladio (hasta 5%).
  - ✓El rodio entrega resistencia mecánica a las mallas y mejora el rendimiento.
  - ✓El paladio se utiliza para reemplazar una porción del rodio que es más caro.
  - ✓La eficiencia de conversión no aumenta si hay presente más de 5% de rodio.

CATALIZADOR

- Características:
  - ✓Número mallas: 16, Tipo tejidas (usual 4 a P_{atm} hasta 25 a altas presiones)
  - ✓Diámetro malla: 3290mm (efectivo 3200mm),
  - ✓Diámetro alambre: 0.076mm (varía inversamente con la presión)
  - ✓Peso total: ≈ 82 kg.
  - ✓La carga de catalizador es de 2.12 kg/(Ton_{HNO3}/h). (Usual 1.5 a 1.9)
- El desempeño del catalizador varía con el tiempo.
  - ✓La eficiencia se ve afectada por cambios en la composición y estructura.
  - ✓Después de un corto periodo de operación se incrementa la eficiencia debido a la superficie rugosa y a la migración de metal a la superficie formando pequeños crecimientos que aumentan la superficie catalítica.
  - ✓Este incremento en el crecimiento debilita la estructura y material catalítico se pierde.

CATALIZADOR

- La vida del catalizador depende de distintas variables:
  - ✓Operaciones a alta presión, requieren cambios más frecuentes.
  - ✓La presencia de cantidades trazas de hierro, calcio, MoS_2 y fósforo, en el amoniaco de alimentación, ha demostrado tener efectos nocivos en la vida del catalizador.
  - ✓Depósitos de óxido de hierro tienden a catalizar el NH_3 a N_2, O_2 y H_2O.
  - ✓Los contaminantes del aire pueden ser nocivos para el catalizador.
- Lo anterior, sumado a una pobre mezcla aire-NH_3 y a una mala distribución del gas en el catalizador puede disminuir la producción hasta en un 10%.
- El cambio de mallas catalíticas depende de la presión de operación.
  - ✓2 a 3 meses, alta presión.
  - ✓4 a 6 meses, mediana presión.
  - ✓8 a 12 meses, baja presión.
  - ✓La ventaja de la operación a baja presión es para compensar los costos de capital de los grandes equipos de proceso.