High-Performance Tungsten Powders

ReWiMet-Symposium 2023

Black2Black – About 100 Years Experience in Metal Refining and Recycling

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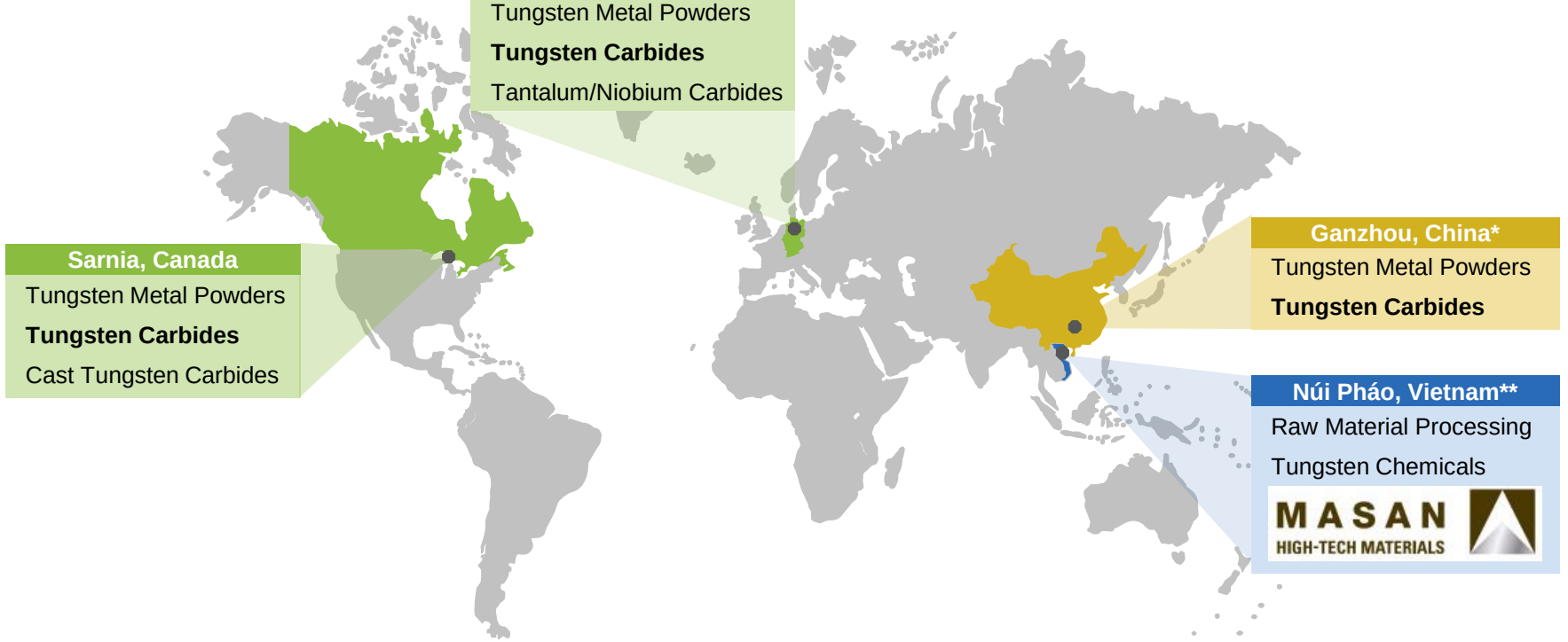
H.C.Starck
Tungsten Powders
Member Masan High-Tech Materials Group

Outline „Black2Black“

1. Company introduction
2. Tungsten recycling value chain
3. Re-entering battery business – a view back in HCS battery powders history
4. Expanding circular economy approach from Tungsten to LIB materials
5. Current initiatives beyond black mass recycling in energy business
6. Strategy

Our Global Footprint

H.C. Starck Tungsten (HCS) belongs to Masan High-Tech Materials Corp (MHT). MHT acts – as member of Masan Group – as globally integrated material platform. HCS operates three plants in all major regions of the world including a joint venture in China. HCS is focusing on high-tech tungsten powders and battery solutions.



- In Goslar processing of tungsten since 1899, first recycling in 1930s

- 1986 BAYER acquires HC Starck Group
- 2007 HC Starck Group taken over by Advent International and Carlyle Group
- 2020 MHT acquires Tungsten business of HCST Group

** H.C. Starck Tungsten Powders joint venture with Jiangxi Rare Metals Tungsten Holding Group Co. Ltd.*
*** operated by Masan High-Tech Materials, owner of H.C. Starck Tungsten*

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H.C. Starck Tungsten (HCS), Goslar/Germany

Site impression

Site description

Establishment	1920
FTEs	377
Key metals/ product	• Tungsten carbide, Tungsten metal powder, Tungsten chemicals, Carbide special (Ta/Nb carbides)
Certifications	• ISO 9001, ISO 14001, OHSAS 18001/ISO 45001, EMAS • Traceability, transparency, and compliance with far-reaching ethical, social, and environmental principles
Site area	c.60,000 m^2

Asset highlights

Rotary reduction kiln

Technical center

Carburization pusher furnaces

Scrap melting furnace

APT production tower

Selected products

WC

W

APT, AMT, W-Acid

Carbide special

End markets

Industrial use

Mining & Construction

Medical

Transpor-tation

Chemical

Defense

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Nui Phao Mining Company (NPMC), Nui Phao/Vietnam

Site impression

Site description

Establishment	2013
FTEs	1,132
Key metals/ product	• Tungsten concentrate, Fluorspar, Copper concentrate, Bismuth cement and sulphide concentrate
Certifications	• Top 100 Vietnam Gold Star Award 2021 • Certificate of excellent enterprise of Thai Nguyen 2021 • Certificate of “Enterprise for employees 2019 – 2021”
Site area	c.630 ha

Asset highlights

Crushing area

Grinding area

Tungsten gravity separator

Fluorite flotation

Bismuth flotation

Selected products

Tungsten conc

Acidspar

Copper conc

Bismuth cement

End markets

Transportation

Industrial use

Chemical

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Masan Tungsten Company (MTC), Nui Phao/Vietnam

Site impression

Site description

Establishment	2013
FTEs	336
Key metals/ product	• Sodium tungstate, Ammonium paratungstate, Blue tungsten oxide, Yellow tungsten oxide
Certifications	• ISO 9001:2015, ISO 14001:2015 • Responsible Minerals Initiative (RMI) compliance • Certificate of Hi-tech Enterprise No. 70/DNCNC
Site area	c.10,600 m^2

Asset highlights

Leach reactors

APT drying machine

Product blending station

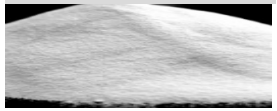
Calcine furnaces

Crystallizers

Selected products

Sodium Tungstate

APT



BTO

YTO

End markets

E-Mobility

Transportation

Chemical

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H.C. Starck Tungsten, Sarnia/Canada

Site impression

Site description

Establishment	1995
FTEs	49
Key metals/ product	• Tungsten carbide, Cast tungsten carbide, Tungsten metal powder
Certifications	• ISO 9001:2015, ISO 14001:2015 • Member of the MPIF and the “BASES” group • Member of the Sarnia Lambton Chamber of Commerce
Site area	c.56,000 m^2, in which 85% (c.47,600 m^2) used for HCS

Asset highlights

Packaging machine

Pusher reduction

Melting coil

Pusher reduction

CTC Screening

Selected products

WC

W

CTC

Carbide special

End markets

Industrial use

Energy

Transportation

Mining & Construction

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H.C. Starck Tungsten, Ganzhou/China

Site impression

Asset highlights

Carbonization station

Rotary furnace

Pusher furnace

Annealing station

ICP-OES

Site description

Establishment	2012
FTEs	148
Key metals/ product	• Tungsten carbide, Tungsten metal powder
Certifications	• ISO 9001:2015, ISO 14001:2015, ISO 45001:2018 • Work safety certification
Site area	c.29,600 m^2

Selected products

WC

W

End markets

Mining & Construction

Energy

Transportation

Industrial use

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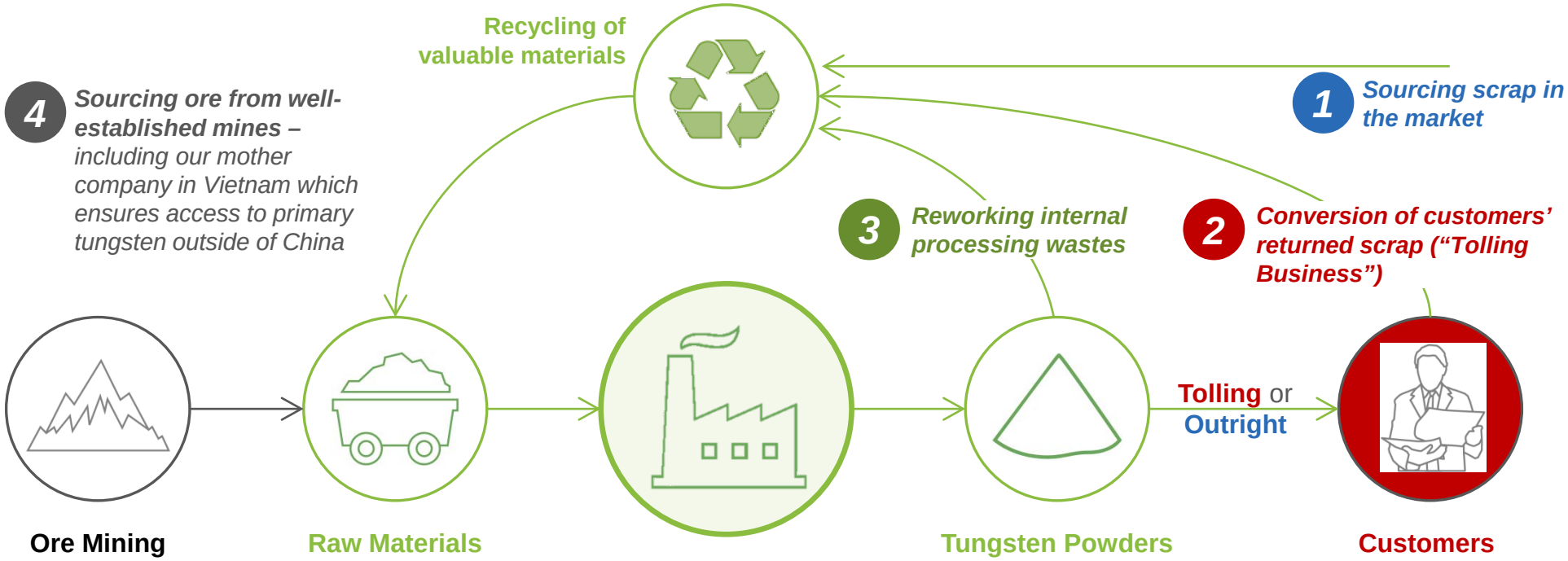
Closed Loop Tungsten Recycling as Integral Part of HCS Business

Raw Material: Secondary / Primary	Tungsten Recycling	Tungsten Chemicals	Tungsten Metals	Tungsten Carbides	*Cemented Carbides* (= Hard metals)



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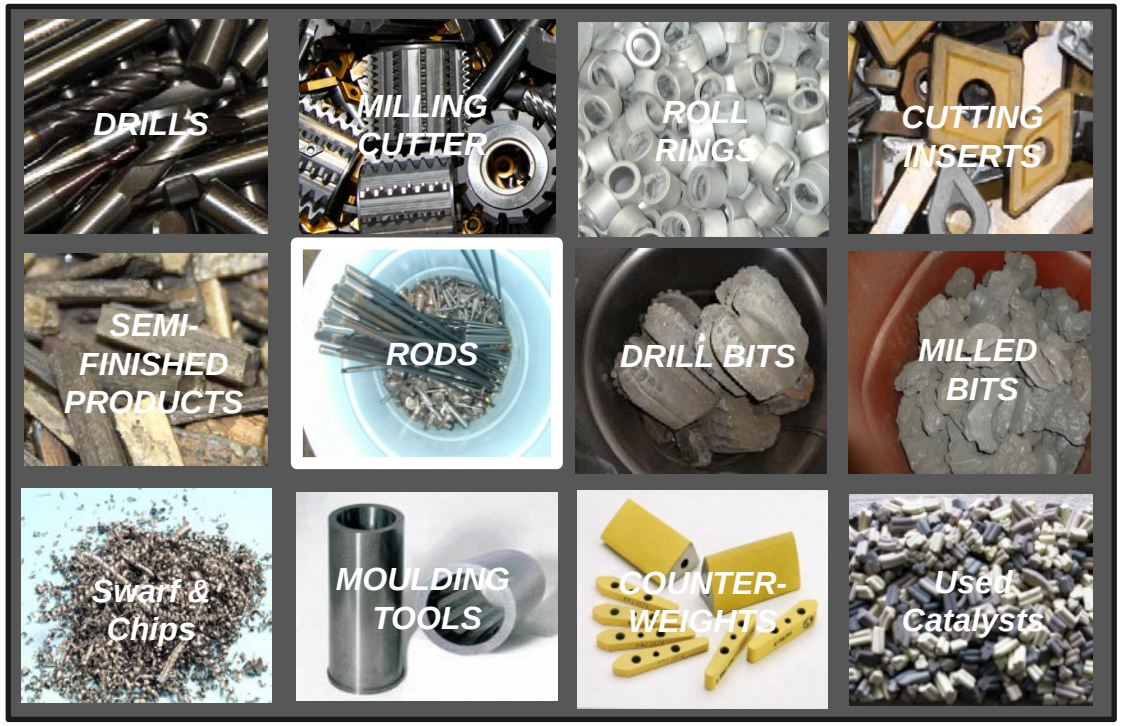
Black2Black – Tungsten Recycling @ HCS: Processing Hard and Soft Scrap to APT

Hard Scrap



Typical hard metals:

- ❑ WC-Co (5-20 %Co)
- ❑ WC-Co/Ni/Fe

Typical heavy metals:

- ❑ W-Fe/Ni,
- ❑ W-Cu/Ag

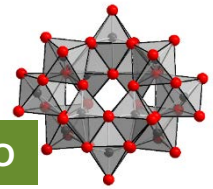
Tungsten metals in all forms

Soft Scrap

Economical processing of a large variety of tungsten containing hard scraps requires comprehensive know-how in smelting and complex hydrometallurgical cleaning/purification steps.

First crystalline, chemically "virgin" Tungsten compound is Ammonium Paratungstate (APT).

$[H_2W_{12}O_{42}]^{10-}$



$APT = (NH_4)_{10}[H_2W_{12}O_{42}] \cdot 4\,H_2O$

Wastes out of HM production like grinding sludges or sweep dirts, are normally highly contaminated with other elements.

Soft scrap contains often additionally organic, oily components, and cellulose which require customized pre-processing, before material can follow standard hard scrap processing.

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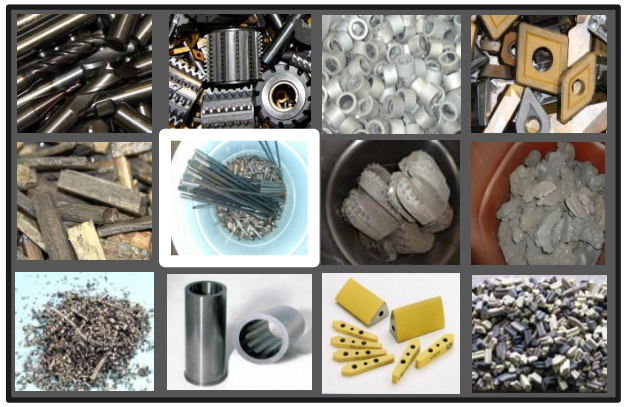
Black2Black – Tungsten Recycling @ HCS: Full Downstream Process



Smeltery
(optional Roasting)
&
Complex Hydrometallurgy

Calcination

Special Treatments

Tungsten Chemicals

Reduction

Carburization

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Expanding Recyling Horizon beyond Tungsten

With integration of HCS in MHT, strategical approach had been defined to reestablish former HCS inhouse Co recycling plant

Recycling of Co out of CoTaW sludges:

- **Since decades Co containing sludges are by-product of HCS tungsten hardmetal recycling** – Co influx anyway, since 2004 recovery of Co units over external service providers
- **Long-time experience in and understanding of processing Cobalt (virgin + recycling) and Nickel** – till 2003 own commercial production of several hundred tpa of Co metal powder at Goslar site
- **To improve economy of scale and to open new business opportunities** HCS is – since about 2 years – zooming in on the development of an efficient innovative BM recycling out of LIB

Why LIB recycling?

=> HCS has a long track record in cathode powder business for Ni/Co based secondary batteries

Target for BM recycling out of Ni/Co based Li ion/polymer cells:

Recover not only Co and Ni, but also Li units (as well as Mn and graphite) over a high-yield, low-cost and sustainable processing

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HCS – Experience in Cobalt and Nickel Chemistry *(Powders for Battery Cathodes)*

More than 50 years experience in production and recycling of Cobalt and production of Nickel compounds required for batteries

Co metal for hard metals tools and Co oxide/suboxide for battery applications

- **In 1950s commercial processing of Co started at Goslar (DE) site**, focus within the next decades on Co metal production ex hard metal scrap recycling and out of primary sources like Co briquettes or ingots
- **In 1990s additionally at site Laufenburg (DE) a Co suboxide** production for battery applications had been implemented
- In total **up to 500 tons** per year capacity
- **Closed 2003 due to**
  - **all time low of Co metal price**
  - **in combination with increased H&S necessities** (which would have requested significant investments in old hydrometallurgical Cobalt plants and reduction furnaces)
- **From 2004 ongoing: further processing of Co-containing sludges** out of HCS tungsten production via external service contractors

Ni chemicals for battery applications and Ni metal for catalysis

- **Started commercial production of regular nickel hydroxides (400 tpy) at Goslar (D) in mid 1960s** for primary coin cells and 1st generation secondary batteries (Nickel-Cadmium), later on also a small Raney Ni metal powders production for catalysis in Laufenburg (D) had been installed
- **In the 1990s at Goslar site extensive research activities started on spherical nickel hydroxides** as basic active cathode material for evolving NiMeH secondary battery market (overall target: overcome memory effect of Ni-Cd batteries and additionally increase volumetric density of rechargeable batteries), **including the launch of a 50 tpy pilot plant and set-up of inhouse application engineering labs for cathode material cell testing**
- **1999 set-up of a commercial plant for spherical nickel hydroxides in Sarnia (CAN) with capacity at the end of 4000 tpa,** used as cathode active material for Ni-MeH batteries as well as so called pCAMs for LIBs. **Sold 2007 to Toda Kogyo Corp.**
- **2010 set-up of a commercial plant for LNCAO and LNCMO in Minamata (JPN),** so called CAMs for LIB, under the JV Chisso Starck Energy Materials (CSEM). **Sold 2017 to Umicore**.

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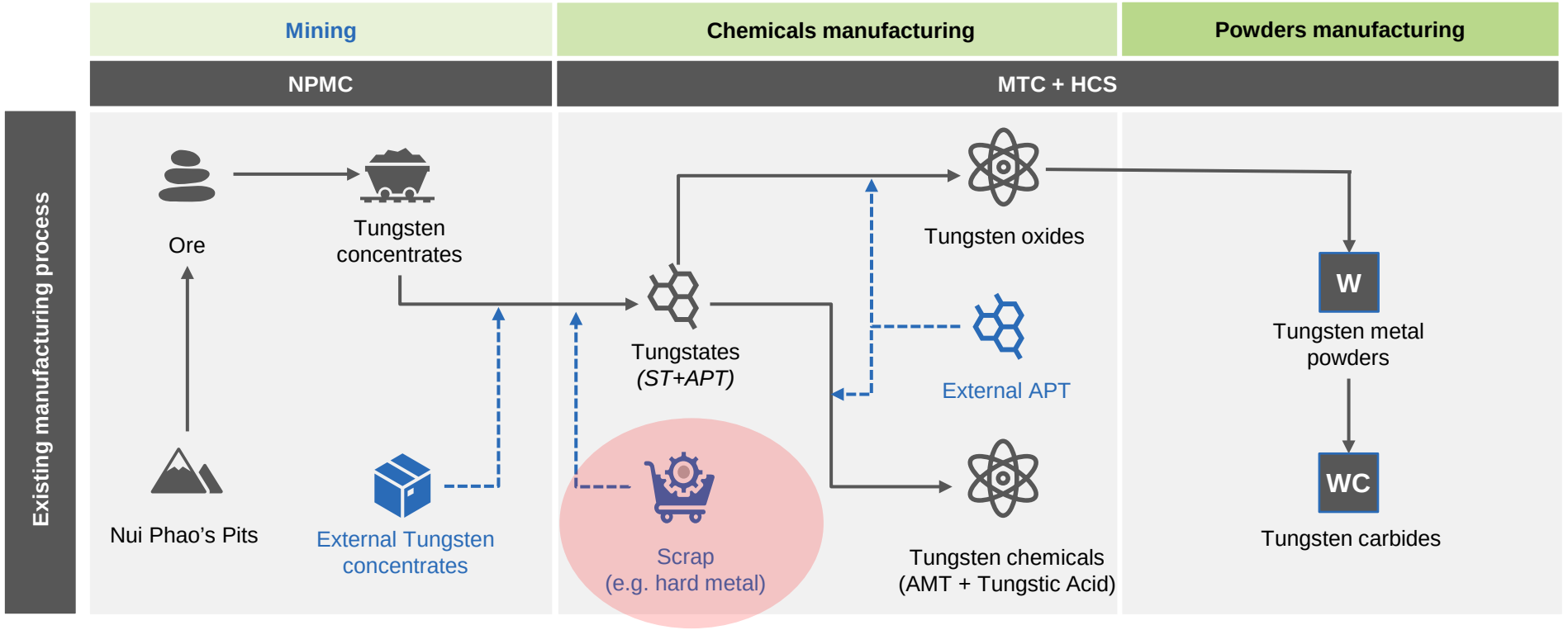
Circular Economy – for HCS not a Buzzword but Fundament of Long-term Business Success in Tungsten



Internal production

External procurement

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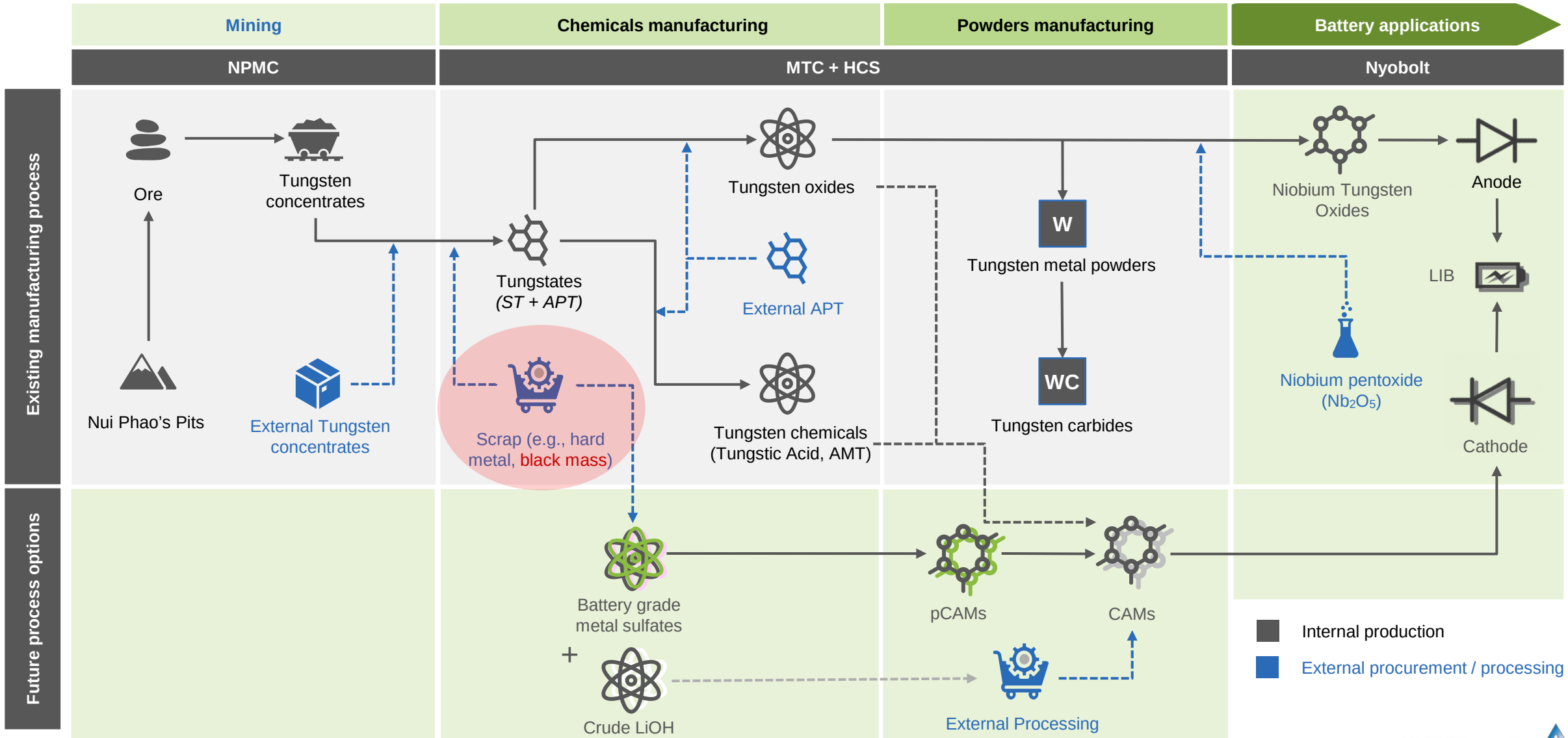
Circular Economy – Expansion from Tungsten to Battery Applications / Technological Fit



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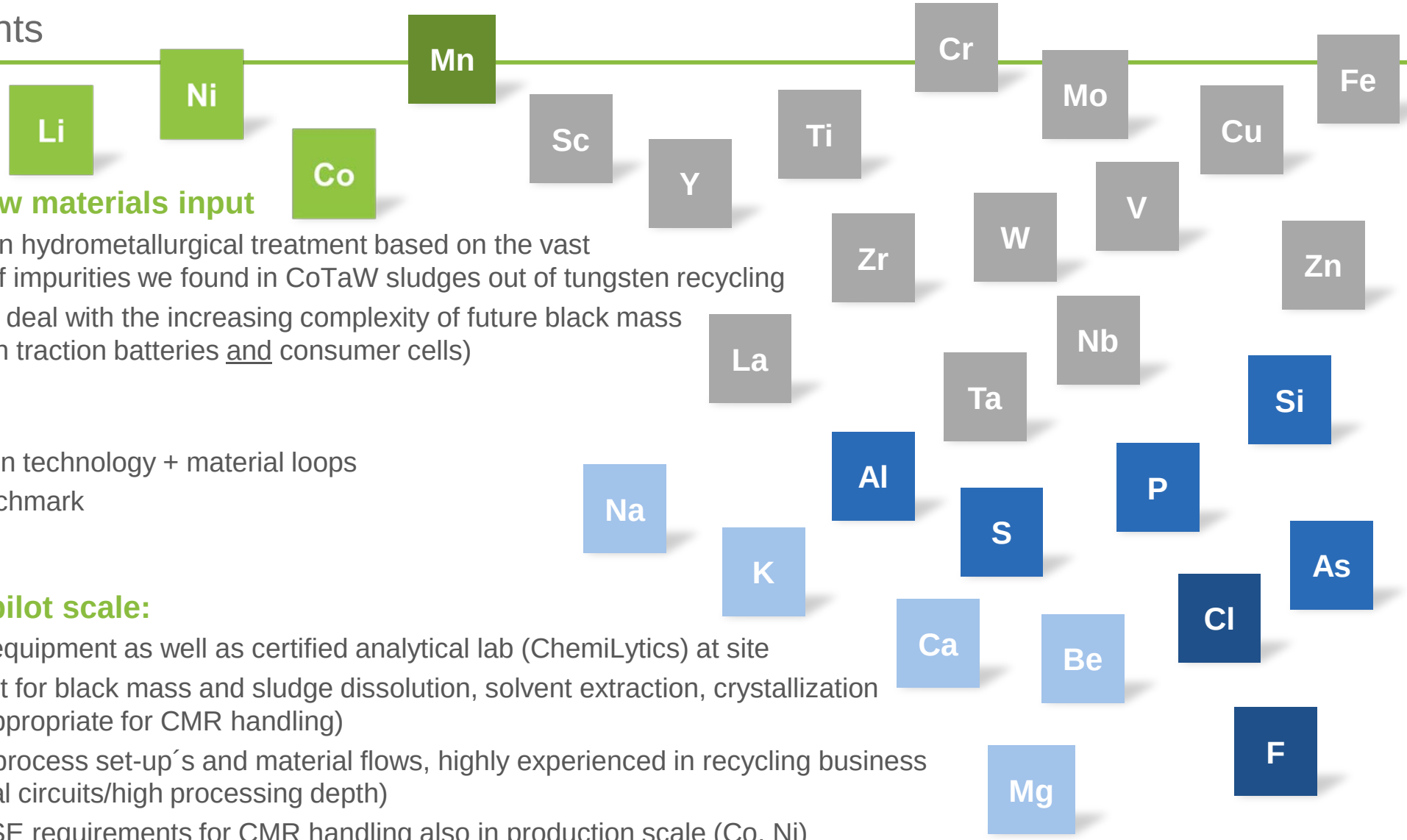
Charles Robert Darwin – Adaptability to Change

1809-1882

„It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.“

Charles Darwin

HCS Unique Selling Points



- **High flexibility regarding raw materials input**
  - Sophisticated know how in hydrometallurgical treatment based on the vast variety and high portion of impurities we found in CoTaW sludges out of tungsten recycling
  - Thus, HCS will be able to deal with the increasing complexity of future black mass compositions (out of Li ion traction batteries and consumer cells)
- **Innovation fields:**
  - Li-First approach + column technology + material loops
  - Process costs below benchmark
  - Sustainable footprint
- **Future-proof R&D in lab & pilot scale:**
  - Sophisticated lab + pilot equipment as well as certified analytical lab (ChemiLytics) at site
  - Dedicated pilot equipment for black mass and sludge dissolution, solvent extraction, crystallization and thermal treatment (appropriate for CMR handling)
  - Used to handle complex process set-up´s and material flows, highly experienced in recycling business (with aggregated technical circuits/high processing depth)
  - Used to meet rigorous HSE requirements for CMR handling also in production scale (Co, Ni)
  - Extensive know how in analyzing black masses originating from various sources with different impurities
  - Highly skilled and experienced staff

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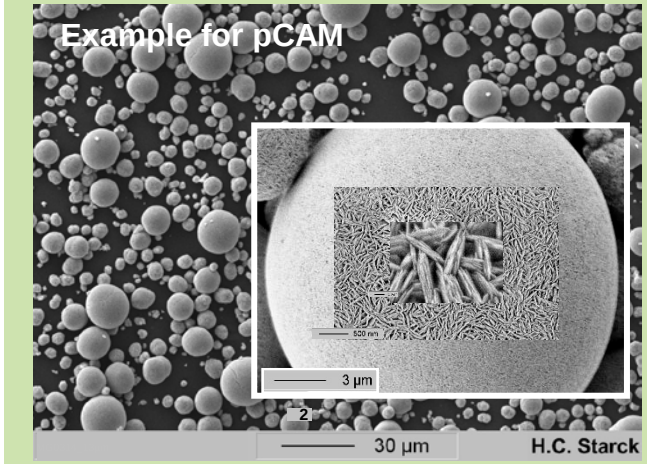
Black2Black – Black Mass Recycling @ HCS: Process Options



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First Prototype Production Plant for BM Recycling: 20 000 tpy

Black mass recycling plant at Goslar site, production start 2027

Cooling tower

Photovoltaic system

Truck docking station

Design draft of the new recycling plant

HCS Current Activities beyond BM and Sludge Recycling in Engergy Business

- 2022 Registration of Tungsten chemicals **trade mark "Starck2Charge"** (AAM precusor and CAM additives)
- 2022 **Start of research contract on development of special tailor-made Tungsten chemicals for coating of LIB cathode materials** to improve further capacity, life-time and battery safety, together with **top tier battery research institute**

- 7/2022 **"Nyobolt Deal" - HCS Tungsten invests** in battery solutions company Nyobolt that leverages HCS's advanced tungsten materials in its anode in form of Nb-W bronzes **for a 15 % equity interest** on a fully diluted basis

Nyobolt CEO and Co-Founder Dr. Sai Shivareddy and Masan High-Tech Materials Chairman Danny Le

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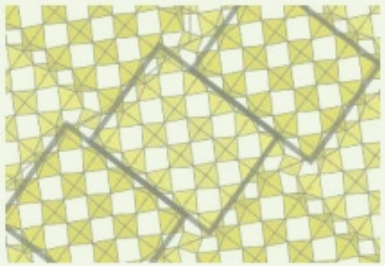
Our recent investment in Nyobolt's Tungsten fast charging, high power, low degradation battery solution…

- **Nyobolt is** commercialising Li-ion batteries with record power density and ultra-fast charge capabilites
- **Nyobolt has** assembled a world-leading implementation team combining decades of experience in pioneering companies across the electric vehicle and battery value chains through operations in UK, US, and Asia
- **Nyobolt is** currently building prototyping and production facilities to address demand from industrial automation, tools and appliances and high power electric vehicles

Record fast Charge	10x Power	Competitive Energy	10x Durability	Cost Competitive	Improved Safety
<5 min charge allows high up-time and productivity	Highest power density, smaller, lighter battery	>20x more energy density than supercapacitors; similar to Li-ion	Expected cycle life >10,000 cycles	Lowest cost per kW and per kWh used	No Li plating risk, wider temperature performance & reduced fire risk



The Nyobolt Advantage:

Proprietary Metal Oxide based Anode

- Crystal structure of customized Nb-W bronzes enables fastest Li+ transport

nyobolt

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…solves critical unmet needs in the market

Electric vehicles

Solving charge anxiety with record fast charge capability (>2x range from existing chargers); and record power density for performance EVs

<5min charge time

Industry and automation

Improved productivity with record uptime due to multiple <5min charge cycles compared to hours today

>3x uptime

Cordless tools

Enabling new classes of cordless devices with unparalleled power density & fast charge

10x power & torque

Decarbonising EVs & industry

High regen capable, smaller and longer lasting batteries, reducing carbon footprint

>1Gton CO_2 savings

nyobolt

HCS is going to apply its know-how in battery materials and high-tech tungsten R&D to accelerate Nyobolt's commercialization of its fast-charging battery technology.

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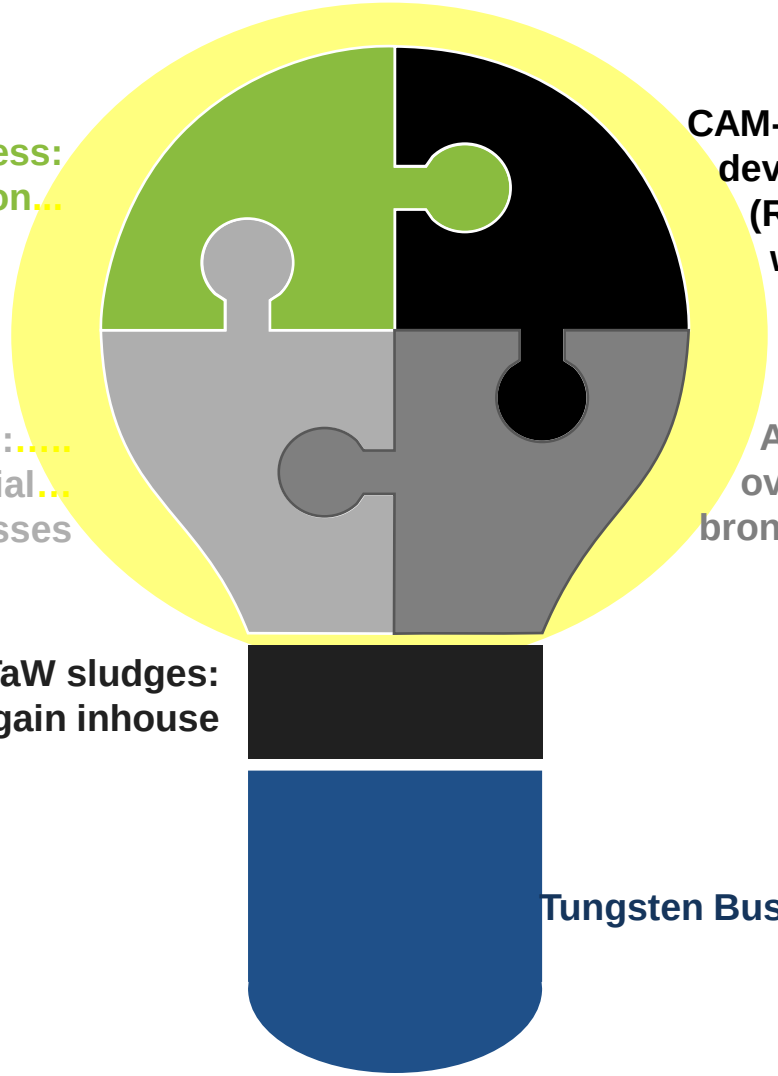
A Holistic Closed-loop Approach for the Li-ion Battery Market

Long-term strategy: Combination of BM Recycling not only with pCAM or CAM materials business, rather also with enhanced Li ion battery business, leveraging Nyobolts competencies in cell assembly

pCAM-Business:
targeting revival of pCAM inhouse production…

CAM-Business:
development and production of enhanced CAMs (R&D cooperation on surface-refining with W chemicals)



Recycling Business:……
Prototype recycling plant for commercial… processing of black masses

AAM-Business:
over Nybolt involved in AAM production (Nb-W bronzes and next gen graphite materials)

Co recycling of CoTaW sludges:
currently externally, perspectively again inhouse

Tungsten Business: ongoing scrap recycling

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? Questions ?

TIG thanks for your attention!

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