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MINISTRY OF ECONOMY AND SUSTAINABLE DEVELOPMENT OF GEORGIA

Technology Transfer Program

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GE-MANGANESE

High purity manganese products for lithium-ion battery manufacturing

NINO DVALIDZE
GITA – Technology Transfer Pilot Program

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APPLICATIONS

High-Purity Electrolytic Manganese Metal (HPEMM)

High purity manganese sulphate monohydrate (HPMSM)

TARGET MARKETS

Battery cell makers that buy HPMSM/HPEMM from the third parties

NMV cathode vendors that buy HPEMM/HPMSM

TECHNOLOGY READINESS

TRL 3-4: Technology has been tested on a prototype level.

INTELLECTUAL PROPERTY

Know how of optimized process settings as well as equipment design.

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TECHNOLOGY OFFER

HIGH PURITY MANGANESE PRODUCTS FOR LITHIUM-ION BATTERY MANUFACTURING

DESCRIPTION

The upcoming growth of Electric Vehicles in Europe will drive the production of Li-Ion batteries and their subcomponents like NMC (Nickel, manganese, Cobalt) cathodes. In turn, Manganese will emerge as a key primary ingredient in the production of electric vehicle, electronic and grid storage batteries. Manufacturing processes for NMC cathode require high-purity MSM (HPMSM).

More than 98% of MSM production is low purity (<99.9%) from Chinese vendors using Cr-Se based processes. The alternative process based on electrowinning is energy intensive and expensive.

Georgia, one of the few countries close to Europe with large Mn deposits, has long history (dating back from USSR) in high quality scientific research in Mn processing technologies.

The research team came up with an innovative process based on electro-leaching and autoclaving to convert the 40-50% rich Mn ore of Georgia into HPMSM for NMC cathode production.

VALUE PROPOSITION & UNIQUE SELLING POINTS

The novel hydro-electro-metallurgical technology has the following advantages:

- **Energy efficient:** use of autoclaving versus electrowinning (very energy intensive)
- **High purity:** Cr and Se-free process
- **Direct:** no need to first produce HPEMM to produce then HPMSM
- **Yield:** high MSM yield aligned on NMC market demand
- **Flexibility:** downstream (small loop) process can be added to produce 2 products (EMM, EMD) concurrently from MSM depending on market demand
- **Cost competitive** with another European based technology.

DEVELOPMENT STATUS: Technology has been developed and tested for 98.7% MSM production as well as concurrent production of EMM and EMD.

NEXT DEVELOPMENT PHASE: The phase will include development of purification stage to achieve 99.9% purity level from 98.7%.

TARGETED PARTNERSHIP: Collaborative research for process scale-up and licensing of the know-how, equipment design and foreground IP.

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2. OVERVIEW

2.1. MANGANESE AS A KEY INGREDIENT FOR RECHARGEABLE LITHIUM-ION BATTERIES

Manganese has emerged as an important cathode material and is increasingly being used as a primary ingredient in the production of electric vehicle, electronic and grid storage batteries. The function of manganese is in the storage and supply of electricity from batteries, including rechargeable lithium-ion batteries that are commonly used for portable electronics and electric vehicles. Nickel-Cobalt-Manganese (NMC) it the main cathode formulation for these batteries and is anticipated to be the dominant formulations in the rapidly growing market for electric vehicles.

Products of Conventional Process are Electrolytic Manganese Metal (EMM) or Manganese sulphate monohydrate (MSM). The manufacturing processes for Li-ion batteries require high-purity to ensure that the batteries meet the performance, safety and durability standards. It is forecasted that the demand for high-purity manganese metal and high-purity manganese sulphate will increase in the foreseeable future. For that reason the research and development effort into innovative materials for the manufacture of high performance lithium ion batteries have intensified in recent years.

Battery cell makers have a choice of either buying High-Purity Electrolytic Manganese Metal (HPEMM) and processing it to HPMSM inhouse, or to buy a readymade High purity manganese sulphate monohydrate (HPMSM) from the third parties.

98% of the world EMM production takes place in China, where 99.7% purity level is achieved through highly toxic element selenium containing process, which is problematic for high end applications such as rechargeable Li-ion batteries. Remaining 2% of 99.9% pure selenium-free EMM is sourced from South Africa and China. Currently, only 3 companies produce the EMM by a selenium-free process, which is attractive to demanding customers who require lower impurities and to those who prefer better health and environmental outcomes Vs. those achievable with EMM containing selenium. 50% of the produced HPEMM is used for NMS cathodes.

China is dominating in MSM production as well with around 85% of the world production. It should be noted that less than 20% of the global MSM production is classified as HPMSM. The conventional process HPMSM production is based on 2: HPEMM is produced first and later it is converted to HP MSM with additional heat energy intensive process.

Currently, HPMSM production costs are driven by ore contents, number of process steps (2-stage process), consumption of solvents and energy and targeted purity levels.

2.2. INVENTION

The research team came up with an innovative process based on electro-leaching and autoclaving to convert the 40-50% rich Mn ore of Georgia into HPMSM for NMC cathode production. Technology has been developed and tested for 98.7% MSM production as well as concurrent production of EMM and EMD.

IP is made out of know how **optimized process settings** (not disclosed in publications), **the design of an electrochemical leaching reactor**, a third party owned patent method on electrolysis and **a patent project on autoclaving stage** that is under development now.

In addition to the IP on autoclaving there is a potential of developing process recipe of the final purification stage, targeted by the TTPP project. As targeted market of the NMC cathode currently requires High Purity (HP) of MSM, the team shall including additional purification step in the process to reach the 99.9% purity.

3. BENCHMARK

The innovative solution delivers significant advantages over the prior art:

- The GE process is a direct Chromium and selenium-free process for converting Mn ore to MSM.
- The process requires much lower energy consumption to produce MSM 98.7%:
    - 7 times lower,
    - No roasting is required,
    - Electrowinning is replaced with autoclaving versus,
    - Heat pump is used for reducing energy consumption.
- No need to first produce HPEMM to get then HPMSM.
- Process results into high HPMSM yield, perfectly aligned with the NMS market demand.
- Downstream process (small loop) can be adjusted to produce either MSM or it can also simultaneously produce 3 products (EMM, EMD, MSM) depending on market demand.

4. GENERAL SUMMARY

4.1. LOW PRODUCTION COST AND HIGH PROFIT

Reduction of capital expenditure, energy and labor costs: The innovative process is based on a low energy consumption. The process involves autoclaving versus electrowinning, which is very energy intensive. Additionally, process uses a heat pump for reducing energy consumption in small loop.

Concurrent production of several valuable raw materials and maximum extraction of valuable components: Another important advantage that reduces the production costs is the direct process of achieving HPMSM, instead of the 2-stage process used in conventional industrial practises. The innovative process allows concurrent EMM/EMD production; it does not require production of HPEMM first to produce then HPMSM.

The business case presented here shows the cost of production 98.7% purity MSM, that have been already tested, and 99.9% purity that is yet to be developed.

Based on the cost calculations we can say that projected cost of HPMSM is cheaper than CZ product by 10% and can be profitable starting with 48% ore

CASH COST	MSM (98.7%)	HPMSM (99.9%)
Out of 48% oxide ore	426 US$/t	826 US$/t
EU plant - based of carbonate ore tails @ 7.5% Mn	Non available	900 US$/t

Cash cost = ore cost + energy cost + chemicals cost
Direct cost = cash cost + D&A
D&A *= US$ 100-150/t
Market price (HP) = US$ 1,300 to 2,600 $/t for 32,5% Mn content HPMSM

4.2. HIGH YIELD

GE process is aligned with industry needs (high MSM yield) and could be disruptive if MSM purity of 98,7% is enough for NMC cathodes. Otherwise an additional final purification step can be added to reach 99,9% purity. Team has to develop final purification step of the

4.3. AVAILABILITY OF THE MANGANESE DEPOSITS IN GEORGIA

Georgia, one of the few countries close to Europe with large Mn deposits is currently exporting only the manganese ore concentrate (44-48% Mn) and Ferro-Alloys.

TTPP team has investigated the availability of the manganese deposits in Georgia. Consultations with the National Agency for Mines suggest that there are significant manganese resources in Georgia, that have not been licensed yet and can be proposed to prospective licensee. Although it should be noted that all unlicensed resources need investigation to characterize existing resources. In this case we shall approach both the current licensee of existing operated mines and also potential new operators of non-operated deposits.

MINE	TYPE OF DEPOSIT	RESOURCES OF THE DEPOSITS ON AS (JAN. 2019)	STATUS
Chiatura manganese ore deposit	Based on origin and composition, Chiatura manganese ore deposits are divided as: I) deposited II) oxidized, III) metamorphosed and IV) infiltrated	A+B+C1+C2 – 198 MT	Fully licensed
Kvirila river depression manganese ore deposit	oxidized, carbonate and ferromanganese	P – 27 MT	Not licenced - exploration of the existing resources required
Chkhari-Ajameti manganese ore deposit	Oxidized, carbonate and ferromanganese	P – 52.663 MT	Partially licensed, exploration of the existing resources required
Shkmeri manganese ore deposit	Oxidized and carbonate	P – 0.838 MT	Partially licensed, exploration of the existing resources required

5. BUSINESS OPPORTUNITY

5.1. TARGETED PARTNERSHIP OPPORTUNITY

Collaborative research for process scale-up and licensing of the know-how, equipment design and foreground IP.

5.2. CONFIDENTIALITY

Information shown in this file is non confidential. Further discussions would be managed under signature of a NDA.

5.3. CONTACT

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6. REFERENCES

6.1. INVENTORS

Georgia has long history (dating back from USSR) in high quality scientific research in Mn processing technologies. The research team has been at a forefront of the research in the domain and have produced various publications as well as have obtained numerous patents in the field.

6.2. TTPP PROGRAM

The mission of Georgia's Innovation and Technology Agency (GITA) is the formation of an ecosystem which improves all kinds of innovations and technologies in the country, to promote a commercialization of knowledge and innovations, to stimulate using them in all fields of economy, to create an environment for the growth of innovations and high-tech products and developing high-speed internet nationwide.

Under the Increasing Institutional Capacity for Innovation Project, financed by the European Union, the Technology Transfer Pilot Program aims to support commercialization of Georgian scientific results that respond to market needs. The program duration is approximately three (3) years, started in April 2019. The program is implemented by the World Bank Group and Georgia's Innovation and Technology Agency (GITA). The team works closely with Georgian research organizations to detect and select the most promising ideas.

This program focuses on:

1. Building capacity of GITA and public partner organizations in technology transfer and commercialization process, from the initial disclosure until deal closing, and
2. Testing whether commercialization of inventions originating in public research and development institutions in Georgia are viable, and if so, demonstrate such viability;

The TTPP team works with universities including faculties and research and development institutes, as well as with the private sector, in order to:

- Identify projects with commercial readiness (triage)
- Obtain disclosures from researchers
- Fund activities that increase the technology readiness levels of inventions
- Assist researchers in developing and implementing a commercialization roadmap, including as it pertains to sourcing additional financing from external sources, and identifying key partners
- Demonstrate viability of technology transfer by successfully closing transactions (from negotiating to contracting stages) and providing support in the process (contract research, IP database search and competitive analysis, etc.)
- Monitor outcomes and recommend further steps necessary for successful commercialization

6.2.1. IMPLEMENTING AGENCY

The central institution responsible for implementation of the project is Georgia's Innovation & Technology Agency (GITA) under the Ministry of Economy and Sustainable Development of Georgia (MoESD). GITA is responsible for all project implementation. It coordinates the gathering and processing of the results of monitoring, reporting, fiduciary functions, and safeguard procedures in close cooperation with relevant institutions participating in the project.