# Climate neutral molybdenum process

**Presenter** Organisation
Lars-Olov Nordberg, Swerim AB

**Project leader**
Lars-Olov Nordberg, Swerim AB

**Partners**
Nordic Elements AB

**Program Day 2023**

SWEDISH MINING INNOVATION

Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovationsprogram

# Goals of the project

Develop a climate neutral Molybdenum process based on Hydrogen reduction, using a fluidized bed.

The Molydebnum produced is to be used in the steel industry, replacing the current ferromolybdenum, (FeMo) or molybdenum oxide ($MoO_3$) use. Both causing a $CO_2$-footprint due to the use of reduction agents, such as Al, ferrosilicon and carbon.





Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

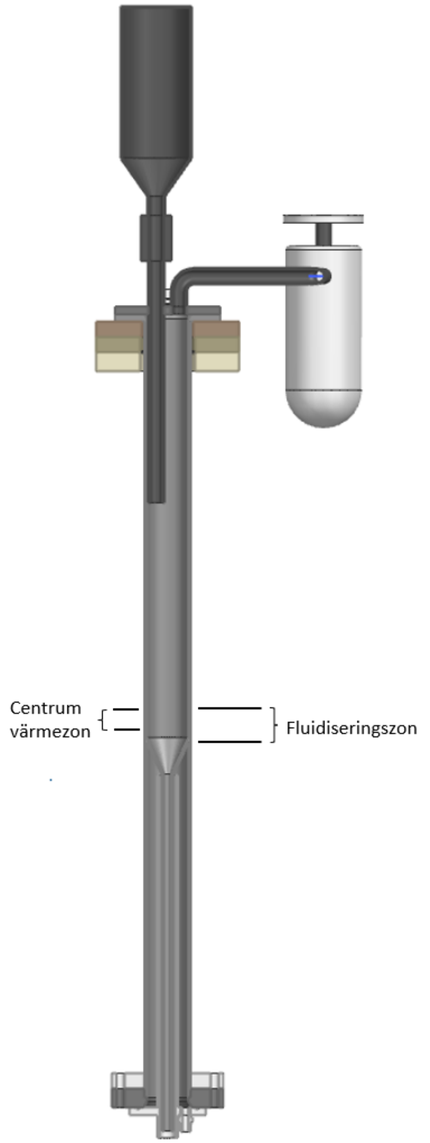
# Project Plan

WP1. Optimize the hydrogen reduction using a fluidized bed by testing and process characterization at different temperatures and hydrogen concentrations in nitrogen gas.

$$MoO_3 + H_2 \rightarrow MoO_2 + H_2O \quad \{1\}$$
$$MoO_2 + 2H_2 \rightarrow Mo\,(s) + 2H_2O \quad \{2\}$$

WP2. Detailed characterization on the reduced Mo-powder and intermediates.

WP3.Tecno-economic calculation on the hydrogen reduction process.






Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Project results so far WP2

## Test programme

| Test | Reduction step | H2 | Reduction temperature | Dwell | Weight in |
|---|---|---|---|---|---|
| # | | vol-% | °C | min | g |
| 1 | 1 | 10 | 590 | 120 | 200 |
| 2 | 1 | 10 | 590 | 120 | 200 |
| 3 | 2 | 10 | 1000 | 240 | 113 |
| 4 | 2 | 10 | 1000 | 240 | 122 |
| 5 | 1 | 50 | 590 | 60 | 200 |
| 6 | 1 | 50 | 590 | 60 | 200 |
| 7 | 2 | 50 | 1000 | 120 | 114 |
| 8 | 2 | 50 | 1000 | 90 | 120 |

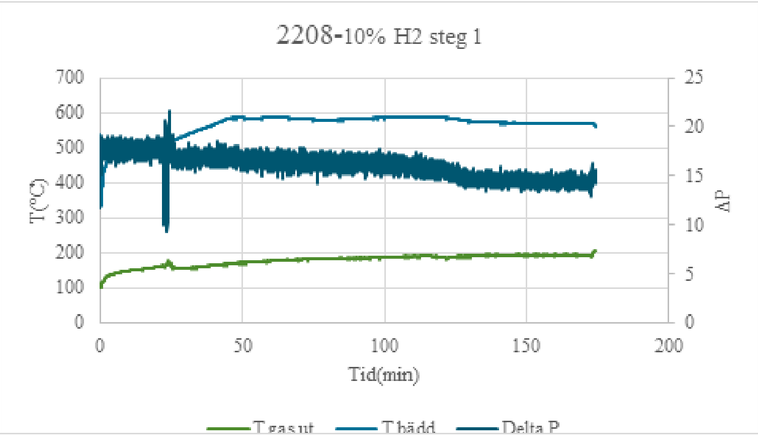


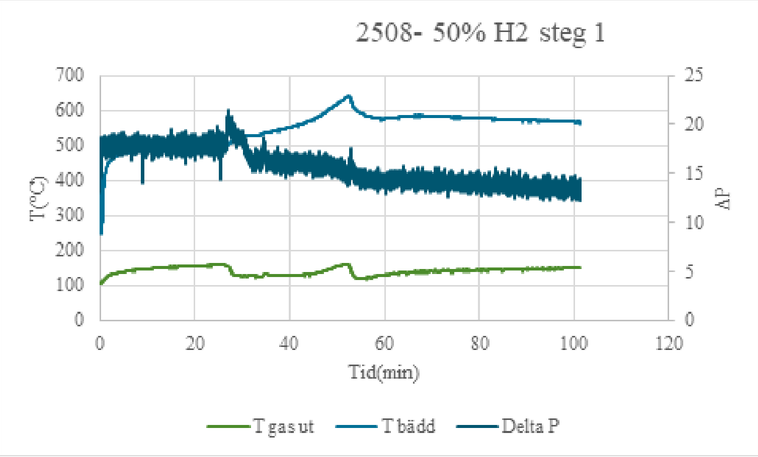


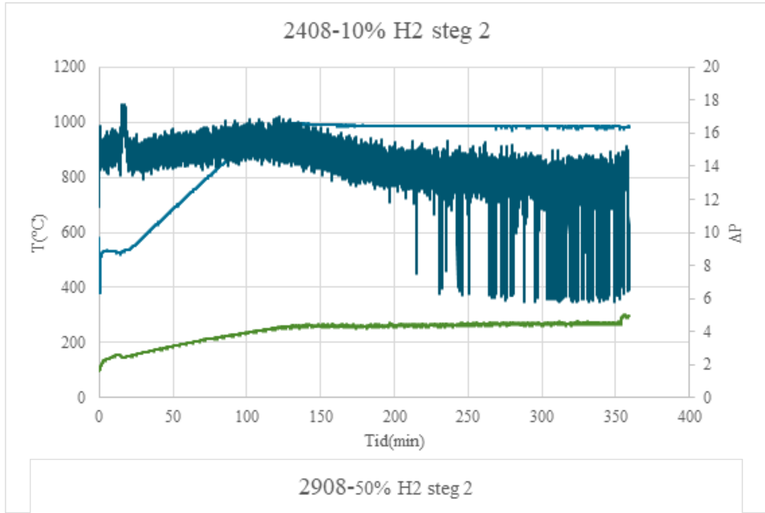
Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

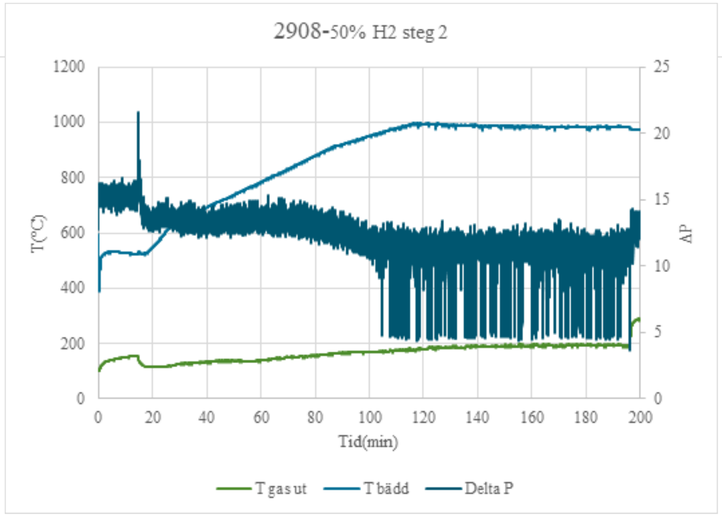
# Project results so far WP2

- Fluidization behaviour



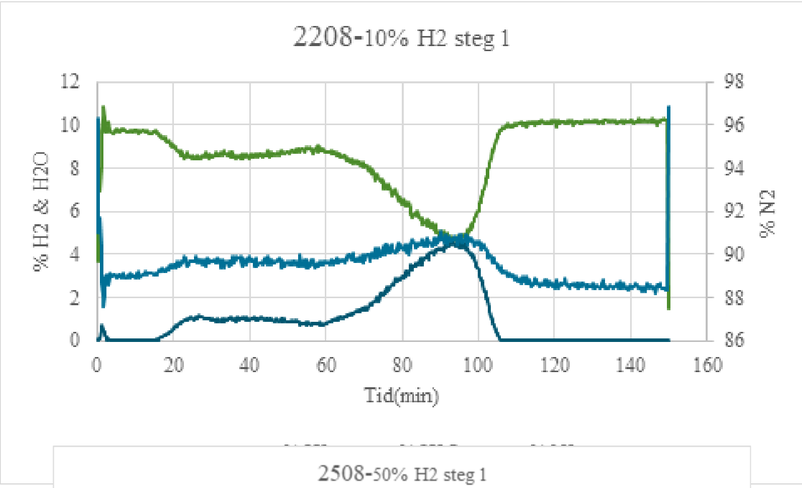



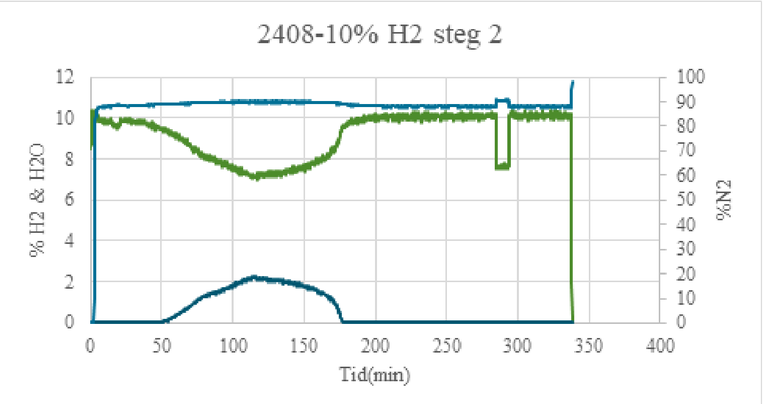


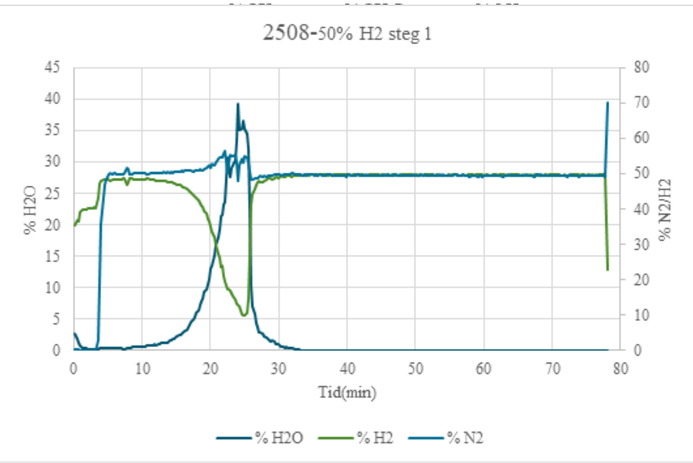

Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

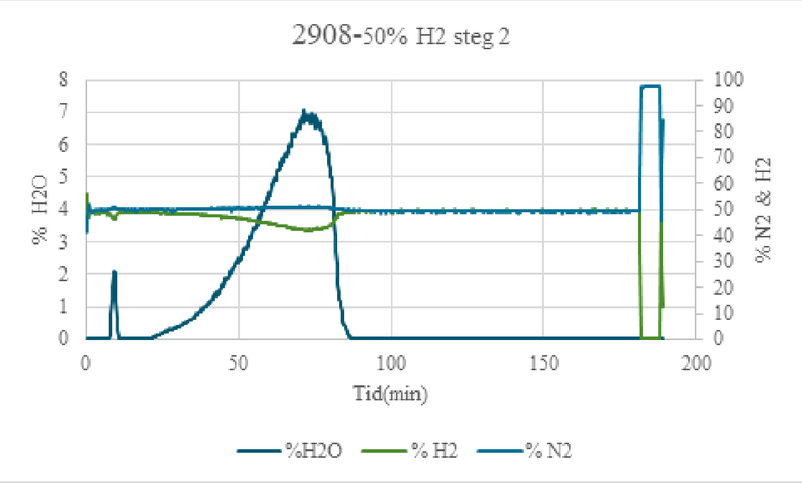
# Project results so far WP2

- Reduction behaviour as measured by mass spectroscopy






Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Project results so far WP3

- Powder size distributions

| Partikelstorleksfördelning | | | | |
|---|---|---|---|---|
| | Försök 2 | Försök 4 | Försök 5 | Försök 7 |
| | Steg 1 | Steg 2 | Steg 1 | Steg 2 |
| Dx (10)/ µm | 76.4 | 104 | 67.6 | 110 |
| Dx (50)/ µm | 141 | 172 | 143 | 179 |
| Dx (90)/ µm | 220 | 267 | 257 | 272 |





Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Project results so far WP3

- Chemical composition by XRD

| Prov | $MoO_2$ | Mo | $MoO_3$ | $SiO_2$ |
|---|---|---|---|---|
| 1 | 100% | | | |
| 2 | 100% | | | |
| 3 | 4,7% | 95,3% | | |
| 4 | 6,7% | 93,3% | | |
| 5 | 91,2% | | 8,8% | |
| 6 | 100% | | | |
| 7 | 19,8% | 57,8% | | 22,4 |
| 8 | 21,1% | 78,9% | | |



Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Project results so far WP2

- Oxygen content of Mo-powder by LECO

| Process | Test | O (%) | | | | |
|---|---|---|---|---|---|---|
| Reduction Step II | No | 1 | 2 | mv | sd | sd% |
| 10 vol-%H2 | 3 | 5,33 | 5,41 | 5,37 | 0,05 | 0,9 |
| 10 vol-%H2 | 4 | 6,23 | 5,46 | 5,84 | 0,55 | 9,3 |
| 50 vol-%H2 | 7 | 15,43 | 15,98 | 15,71 | 0,39 | 2,5 |
| 50 vol-%H2 | 8 | 10,62 | 10,83 | 10,73 | 0,15 | 1,4 |

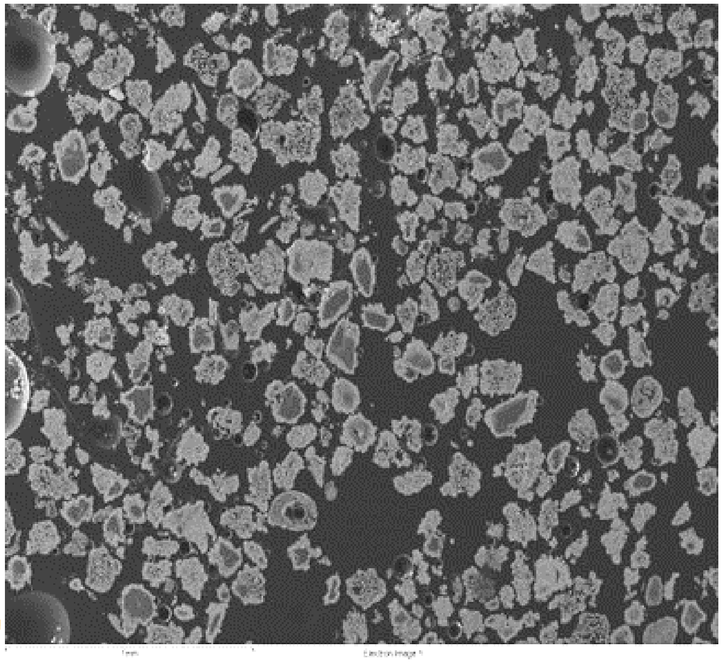




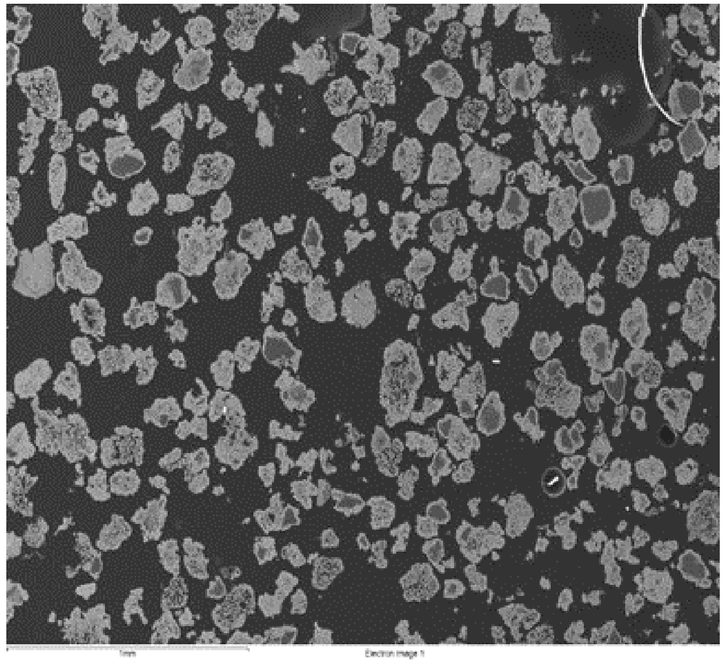
Med stöd från VINNOVA Sveriges innovationsmyndighet, Energimyndigheten, FORMAS, Strategiska innovationsprogram

# Project results so far WP3

- Microstructural overview of sample 4 and 7 by SEM



Sample 4



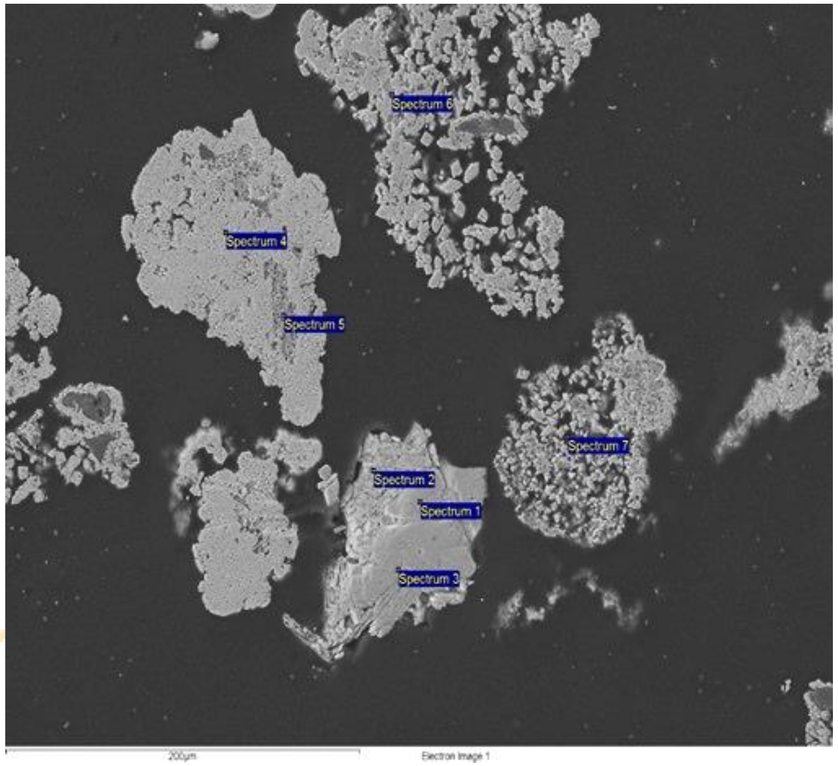
Sample 7



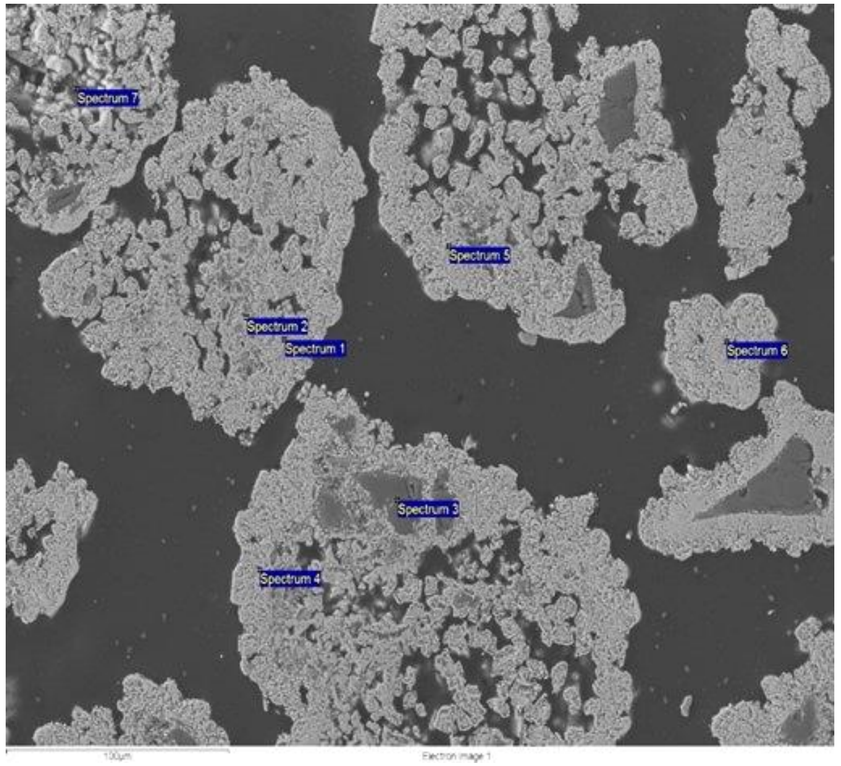
Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Project results so far WP3

- Microstructures of sample 4 and 7 by SEM




Sample 4




Sample 7



Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Project results so far WP3

- Techno-economic evaluation – material yield and productivity

| Test | Reduction step | H2 | Reduction temperature | Dwell | Weight in | Weight out | Loss in exhaust pipe | Material yield | Reduction time | Production rate |
|---|---|---|---|---|---|---|---|---|---|---|
| # | | vol-% | °C | min | g | g | g | % | min | g/h |
| 1 | 1 | 10 | 590 | 120 | 200 | 120 | - | 67 | 96 | 75 |
| 2 | 1 | 10 | 590 | 120 | 200 | 127 | 48 | 71 | 91 | 84 |
| 3 | 2 | 10 | 1000 | 240 | 113 | 50 | 30 | 55 | 133 | 23 |
| 4 | 2 | 10 | 1000 | 240 | 122 | 53 | 27 | 54 | 128 | 25 |
| 5 | 1 | 50 | 590 | 60 | 200 | 120 | 26 | 67 | 30 | 240 |
| 6 | 1 | 50 | 590 | 60 | 200 | 126 | 19 | 71 | 30 | 252 |
| 7 | 2 | 50 | 1000 | 120 | 114 | 47 | 25 | 45 | 67 | 42 |
| 8 | 2 | 50 | 1000 | 90 | 120 | 83 | 12 | 81 | 65 | 77 |

The reduction time is estimated to be the time when water vapour is formed and observed with a mass spectrometer.



Med stöd från VINNOVA Sveriges innovationsmyndighet, Energimyndigheten, FORMAS, Strategiska innovationsprogram

# Project results so far WP3

- Techno-economic evaluation –hydrogen yield

**Reduction step 1**

| Test | Weight in (g) | $MoO_3$ in (mol) | $H_2$ in (mol) | Weight out (g) | $MoO_2$ out (mol) | H2 yield / % |
|---|---|---|---|---|---|---|
| **1** | **200** | 1,39 | 84,35 | 120 | 0,94 | 1,4 |
| **2** | **200** | 1,39 | 81,80 | 127 | 0,99 | 1,5 |
| **5** | **200** | 1,39 | 292,99 | 120 | 0,94 | 0,4 |
| **6** | **200** | 1,39 | 159,09 | 126 | 0,98 | 0,7 |

**Reduction step 2**

| Test | Weight in (g) | $MoO_2$ in (mol) | $H_2$ in (mol) | Weight out (g) | $MoO_2$ out (mol) | H2 yield / % |
|---|---|---|---|---|---|---|
| **3** | 113 | 0,84 | 81,80 | 50 | 0,50 | 1,6 |
| **4** | 122 | 0,89 | 114,77 | 53 | 0,52 | 1,2 |
| **7** | 114 | 0,51 | 292,99 | 47 | 0,28 | 0,3 |
| **8** | 120 | 0,74 | 288,90 | 83 | 0,68 | 0,5 |

**Total**

| Test | $MoO_3$ in (mol) | $H_2$ in total (mol) | Mo ut total (mol) | H2 yield / % |
|---|---|---|---|---|
| **3** | 1,39 | 166,1 | 0,37 | 0,67 |
| **4** | 1,39 | 196,6 | 0,39 | 0,59 |
| **7** | 1,39 | 586,0 | 0,21 | 0,11 |
| **8** | 1,39 | 448,0 | 0,51 | 0,34 |



Med stöd från VINNOVA Sveriges innovationsmyndighet, Energimyndigheten, FORMAS, Strategiska innovationsprogram

# Dissemination

Share information with the project partner and the existing end users.
Publication of the test results as a short information at LinkedIn.
Detailed information to the member companies at Swerim.
Public Diploma work report.
Written publication.

UPPSALA UNIVERSITET

Examensarbete 30 hp
September 2023

Vätgasreduktion av MoO3
I en fluidbädd

Towa Eriksson



Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Next Steps

- Pilot scale testing with 10%H2, at higher feed rates.
- The existing fluidized bed pilot at Swerim has a capacity of about 1.5kg.
- Improved powder yield by the use of the cyclones attached to the Swerim equipment.
- Material produced to be evaluated by alloying in pilot scale melting during 2024.
- Pilot  and demo plant could be in place by 2026.





Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program

# Mining innovation for a sustainable future

SWEDISH MINING INNOVATION

Med stöd från
VINNOVA Sveriges innovationsmyndighet
Energimyndigheten
FORMAS
Strategiska innovations-program