FEASIBILITY STUDY OF AN UNDERGROUND PUMPED-HYDRO-STORAGE (UPHS)

IN AN EXISTING COAL MINE INFRASTRUCTURE „MINE PROSPER-HANIEL“ IN BOTTROP

Quelle: Voith Hydro

Quelle: RAG

30th of November 2017
FEASIBILITY STUDY OF UNDERGROUND PUMPED-HYDRO--storage
in an existing coal mine infrastructure „Mine Prosper-Haniel“ in Bottrop

Location in Germany: North Rhine-Westphalia

Population density

Settlements

Prosper-Haniel mine
Vianden PHS project (Luxembourg)

Source: Dillinger Hütte
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Classical Pumped-storage concept (PHS)
both reservoirs on the surface

Underground pumped-storage (UPHS)
at least one Reservoir underground

Source: Trianel, hydropower plant Nethe
Source: University of Duisburg-Essen
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Concept sketch UPHS

- Upper reservoir at 70 mASL
- Lower reservoir between 512 and 490 mBSL
- Location of machinery at ca. 522 mBSL

source: RAG AG
Map of former mining operations

http://www.ruhrkohlenrevier.de/zechenkarte.html

Coal mines before 1600
Coal mines of the 17th century
Coal mines of the 18th century
Coal mines of the 19th century
Coal mines of the 20th century
Geological sketch of the Ruhr Basin

- Marl
- Bochum
- Witten

Lippe

Type c

Emscher

Type b

Ruhr

GW stockwork
- descending and rising mine water
- Upper Carboniferous
- Cenomanian and Turanian

Buntsandstein (~Lower Triassic)
Zechstein (~Lopingian)
Coniacian and Lower Santanian (Emscher Schichten)
Lower Coniacian (Untersenon)

-2000 m b.s.l.

5 km

after Hahne & Schmidt
Tectonics of the research area

- complex structure of foldings and overthrusts
- succession of compressional and extensional tectonics
- heterogeneous formation of clastic sequences and seams

thrust faults
normal faults
strike-slip faults
Underground Pumped Storage

Franz Haniel
shaft 1 & 2
upper reservoir

overburden

new subterranean reservoir

carboniferous

2. level
3. level
5. level
6. level

+60 m a.s.l.
-300 m b.s.l.
-530 m b.s.l.
-groundwater table (future)
-1000 m b.s.l.
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Involved facilities and institutes

- University of Duisburg-Essen:
  - Institute of Hydraulic Engineering and Water Resources Management (WaWi)
  - Chair of Geology
- Rhein-Ruhr Institut für Sozialforschung und Politikberatung e.V. (RISP)

- Ruhr-Universität Bochum (RUB):
  - Chair of Energy Systems and Energy Economics (LEE)
- RAG AG
- DMT GmbH & Co. KG
- ILF (subcontract of RUB)
First phase of a stepped feasibility study

„Developing an implementation concept for reusing former coal mines as underground pumped-storage facilities“ (11/2012-04/2014)

Result: general feasibility

Ongoing: Research within the second phase (until 06/2018)
The funding Agreement was handed over by Minister Remmel (Ministry of Environment) at the 25th of August 2016

preliminary result: technical feasibility at the location „Bergwerk Prosper-Haniel“

funded by: total funding since 2012: 3,1 Mio. €
Work packages in the first phase (2012 – 2014)

WA1 Basic evaluation, data supply

WA 2 – structural implementation
- WP2.1 – development of a technical concept
- WP2.2 – Water management and supply concept
- WP2.3 – Geotechnical aspects
- WP2.4 – Sizing of machinery and electro-technics
- WP2.5 – Requirements for work safety
- WP2.6 – Integration of PHS into electrical grid
- WP2.7 – Geological/ geographical and urban planning aspects

WA 3 – additional research
- WP3.1 – Legal framework
- WP3.2 – Political and social acceptance
- WP3.3 – Preparation of ecosystem assessment
- WP3.4 – Impact of UPHS concepts on aquatic ecosystems
- WP3.5 – Economic assessment of UPHS concepts
- WP3.6 – Influence of UPHS on eternity costs (RAG Foundation)

WA4 Project management, coordination, public relation

WA = Work Area
WP = Word Package
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Relevant results and arguments of the 1st phase

Energy economical /-technical view
• The realization of this kind of energy storage solution contributes to Germany’s Energiewende
• Using the actual/well developed grid infrastructure in NRW
• Energy storage in an area with high energy demand (Ruhr Area: 5.2 Mio. inhabitants)
• Setting up the Energy Grid after Blackout: Possible
• Technical highlight placed at an innovative location (unique selling point, worldwide)

Social-/non-monetary aspects
• Sharpening this region as a region for energy efficiency and energy production and storage
• Significant contribution towards a sustainable post-mining landscape
• Technology leadership /mining knowledge provides an international perspective
• Generating economical effects within the Ruhr Area
• The UPHS system has only minor ecological effects compared to conventional PHES
Results according to a study of public acceptance

Poll on renewable energy:
• Very positive acceptance for renewables (> 80%)

Future use of the mining areas:
• Strong support for subsequent use for cultural purposes or local recreation areas (each over 80%)
• Strong support for a follow-up use by industry, Business or energy supply (63.7%)

• → much more acceptance within society for an UPHS compared to classical energy storage concepts
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Work packages for the 2nd phase (2016 – 2018)

WA 3 project management, network & public relations (WaWi)

WA 2 work packages (UPHS)

- **WP 2.1** Identification of measures and costs for securing the options for an implementation of an UPHS (RAG, DMT)
- **WP 2.2** Industry participation, Market and Business cases (RAG, WaWi, LEE)
- **WP 2.3** Investment- and operating costs for an UPHS (LEE)
- **WP 2.4** Detailed Investigation of the geological framework (Geology, DMT)
- **WP 2.5** Technical concept for an UPHS (WaWi, LEE, ILF, RAG, DMT)
- **WP 2.6** Restrictions due to construction and logistics; initial operation concept (DMT, ILF)
- **WP 2.7** construction and logistics incl. monitoring and safety concept (RAG, DMT, ILF)
- **WP 2.8** Stakeholder dialogue: regional economical effects and stakeholder Analysis (RISP)

WA = Work Area
WP = Word Package

WA 1 basic evaluation & provision of data (RAG, DMT)
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Existing infrastructure Prosper-Haniel
Location concept caverns

- Splited caverns
- One for the turbomachinery and one for electrical generators and energy transformation
- Cavern orientation is based on geological conditions (restrictions have to be considered)
- Ridges of the caverns are located in the sandstone layer
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Implementation of the exploration drilling in 2017

Shaft 1, 3rd level

drilling location 2 at the 3rd level

Machinery cavern

shaft 2, 3rd level

drilling location 1 at the 3rd level

Transformation cavern

drill 1

drill 2

<table>
<thead>
<tr>
<th>Location</th>
<th>Drill 1</th>
<th>Drill 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Height</td>
<td>489,10 mBSL</td>
<td>488,13 mBSL</td>
</tr>
<tr>
<td>Length</td>
<td>73,00 m</td>
<td>74,40 m</td>
</tr>
<tr>
<td>Inclination</td>
<td>47°</td>
<td>37°</td>
</tr>
<tr>
<td>Diameter</td>
<td>63 mm</td>
<td>63 mm</td>
</tr>
</tbody>
</table>
Geotechnical entrainment of drill cores at the machinery cavern
Cavernes and infrastructure

mining site of shafts Franz Haniel 1 & 2

(horizontal projection to subsurface)
Consortium UPHS

Slide 21

UDE / RUB / RAG / DMT / RISP

Layout of cavern construction

125 m
60 m
24 m
29 m
15 m
14 m

highest current construction (shaft 10)

machinery chamber

layout (horizontal projection)

transformer chamber
Positioning of caverns

3. level (488 m b.s.l.)
- siltstone
- seam B2 (0.50 m)
- sandstone
- seam A2 (1.50 m)
- shale
- seam Zollverein 1 (2.20 m)

(530 m b.s.l.)
New Storage Ring Structure

- Length: 15.5 km
- Volume: 600,000 m³
- Net discharge: 40 m³/s
- Water head: 560 m
- Power: 201 MW
- Energy per cycle: 835 MWh

Shafts I and II are used as penstock, communication lines, and energy connections.
# Location of Prosper-Haniel and exemplary plant specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>New Storage Ring</th>
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<tbody>
<tr>
<td>Length ring structure [km]</td>
<td>15.5</td>
</tr>
<tr>
<td>Volume [m³]</td>
<td>600,000</td>
</tr>
<tr>
<td>Water head [m]</td>
<td>560</td>
</tr>
<tr>
<td>Net discharge [m³/s]</td>
<td>40</td>
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<tr>
<td>Power [MW]</td>
<td>201</td>
</tr>
<tr>
<td>Energy per cycle [MWh]</td>
<td>835</td>
</tr>
<tr>
<td>Cavern [mBSL]</td>
<td>-530</td>
</tr>
</tbody>
</table>

![Map of the location of Prosper-Haniel and exemplary plant specifications](image)
FEASIBILITY STUDY OF UNDERGROUND PUMPED-HYDRO-STORAGE in an existing coal mine infrastructure „Mine Prosper-Haniel“ in Bottrop

Concept UPSW Prosper-Haniel (Result of the first phase)

- Access Shaft
  - ø = 6.5 m
  - Ventilation / Access / Power lines / Infrastructure lines
  - ...

- Penstock
  - ø = 2.3 m
  - max. discharge = 40 m³/s

- Transformer Chamber
  - L = 30 m / B = 20 m / H = 10 m

- Connection to Inclined Tunnel
  - Length = 3.6 km / ø = 5 m
  - Access / Operation / Maintenance

- Surge Tank

- Ring Storage
  - Length = 15.5 km / ø = 7 m
  - Volume = 500,000 m³

- Inlet/Outlet Structure
  - Transition of 2 lines (ø = 3 m) to ring storage (ø = 7 m)

- Machinery Chamber
  - L = 60 m / B = 20 m / H = 25 m
  - 2 Francis pump-turbines
    - (Q = 20 m³/s per machine)
    - (P = 100 MW per machine)
  - Water head = 560 m

- Cavern located at Franz Haniel
  - Shaft at ca. -529 mBSL

- Physical model of the building
  - in scale 1:10 in the experimental hall of the UDE

- Computational Fluid Dynamics
Map of the latest technical concept Haniel I and II
Machinery technical equipment

• 3 hydroelectric generating sets at 521,57 mBSL
  – Each consisting of
    Turbine, Pump and Generator → ternary system
    67 MW (→ total: 201 MW)

• Alternative:
  – Each consisting of
    Pumpturbine and Motor Generator → e.g. Francis-Turbine
    67 MW (→ total: 201 MW)
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Example for a Placement / Carring in process of turbine parts

Principle sketches

Runner shaft

Spiral casing

Return guide
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Aerial photograph of the mining location Franz Haniel
Upper reservoir - a technical construction (assumed as feasible)

• Upper reservoir can be located on the existing mining site

Press Releases (Extract)

The Wall Street Journal - Coal Mines Are Reimagined as a New Power Source (25.05.2017)

Connaissance des energies - Une mine de charbon allemande bientôt reconvertis en site de stockage? (29.03.2017)

arstechnica - German coal mine may be prime for pumped storage (27.03.2017)

Power Engineering International - Coal mine to be transformed into 200 MW pumped hydro plant (17.03.2017)

Badische Zeitung - Energie statt Kohle (25.02.2017)

Rheinische Post - Grüner Strom aus dem Pütz (01.09.2016)

SpiegelOnline - Bottroper Zechen hat das Zeug zur Riesenbatterie (25.08.2016)

Ruhrnachrichten - Neue Chance für Zeche als riesiger Stromspeicher (25.08.2016)

Wird Prosper Haniel zur Riesen-Batterie? (25.08.2016)

Bild - Wird Prosper-Haniel zur Riesen-Batterie? (25.08.2016)

WAZ, 26.08.2016

Es wäre ein Projekt mit großer Symbolkraft. Sollte die Zeche Prosper-Haniel in Bottrop nach dem Ende des Steinkohlenbergbaus tatsächlich zum großen Stromspeicher werden, wäre damit auch die Botschaft verbunden: Die letzte Zeche im Ruhrgebiet schließt, aber die Lichter in der Region gehen nicht aus. Und NRW könnte sich weiterhin als Energierand profilierten, auch wenn die großen Windradprojekte vor allem an der Küste entstehen.

Currently: new and more international interested parties

**THE WALL STREET JOURNAL.**

Pumped Up: Renewables Growth Revives Old Energy-Storage Method

How to Make Electricity in a Disused Coal Mine

- This Year: Publications from *Bloomberg* and *The Wall Street Journal*
- Requests from: Australia, China, Chile, South Korea, Spain, Slovenia, South Africa, Belgium, France, Ukraine, Poland, Czechia, USA, Italy…

→ This plant could become an unique showcase/demonstrator for the Ruhr area (e.g.: sustainable post-mining situation)
Operations and Research on UPHS worldwide

- USA
- Europe
- China
- South Korea
- South Africa
- Australia
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Operations and Research on UPHS in Europe

Map showing countries where operations and research on UPHS are conducted: Spain, France, Belgium, Germany, Poland, Ukraine, Czech Rep., Slovenia, Italy.
Thank you!

Quelle: Google Maps
Quelle: RAG AG

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