European Hydrogen Week

//EU HYDROGEN RESEARCH DAYS

15-16 NOVEMBER

Clean Hydrogen Partnership

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Haeolus

Hydrogen-Aeolic Energy with Optimised eLectrolysers Upstream of Substation

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SINTEF

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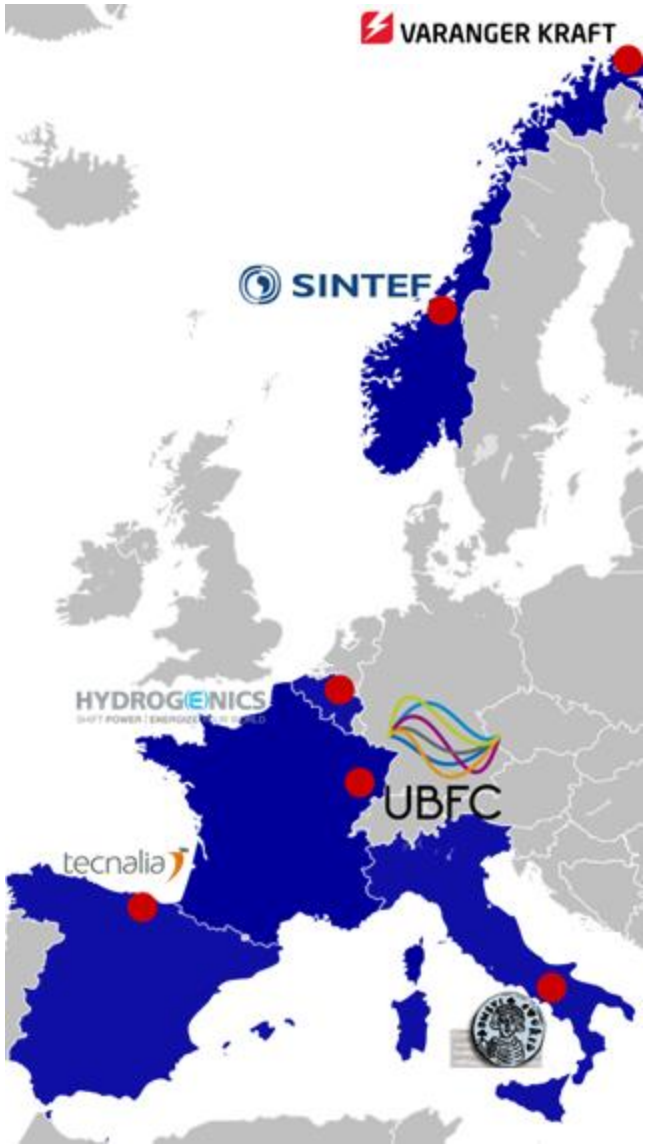
Project Overview

- Call year: 2017
- Call topic: Highly flexible electrolysers balancing the energy output inside the fence of a wind park
- Project dates: January 1, 2018 – December 31, 2023
- % stage of implementation 01/11/2023: 95%
- Total project budget: 7 779 761.25 €
- Clean Hydrogen Partnership max. contribution: 4 997 738.63 €
- Other financial contribution: 0 €
- Partners: SINTEF, UBFC, Tecnalia, UniSannio, Varanger Kraft, Cummins



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Project Summary

- Raggovidda wind park (45 MW built out of 200 MW)
  - Bottleneck to reach main grid
  - With grid extension, reached 97 MW
- Total potential is 2 GW (400 t/d of hydrogen)
- Low local consumption
  - Hydrogen as solution to export energy
- Location in Berlevåg Harbour
  - Still virtually "inside the fence" of wind park with dedicated power line
  - Access to road and sea for export

Project Summary

Raggovidda – March 2018

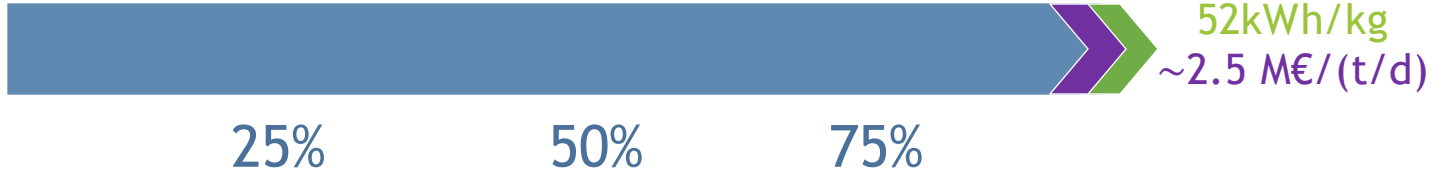
- Main Objectives:
  - ✓ Objective 1: Enable high wind-power penetration
  - ≈ Objective 2: Demonstrate multiple use cases
  - × Objective 3: Demonstrate 2.5MW PEM electrolysis technology
  - ✓ Objective 4: Demonstrate remote operation of wind-hydrogen plant
  - ✓ Objective 5: Disseminate new-found knowledge on wind-hydrogen systems
- Global positioning vs international state-of the art:
  - Green hydrogen from largest wind-hydrogen plant in the world
  - Remotely controlled and monitored, due to difficult accessibility
  - Potential for technology transfer to offshore wind, solar
- Application and market area:
  - Hydrogen production for export or local industry


Rotgrovsåsen Wind Farm

Project Progress/Actions – Electrolyser Efficiency & Cost

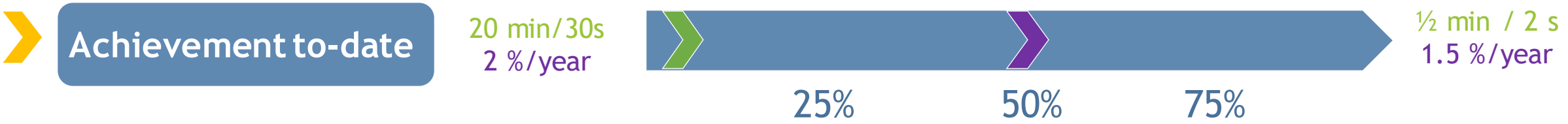
Achievement to-date

55 kWh/kg
3.7 M€/(t/d)



- Efficiency targets already met by Cummins' latest stack
  - 52 kWh/kg is the MAWP 2020 target
- Cost is also met and exceeded (verified by financial reports)
  - Cost includes stacks, BoP, installation & personnel
  - Project target was 3 M€/(t/d)
  - MAWP 2020 target is 2 M€/(t/d)

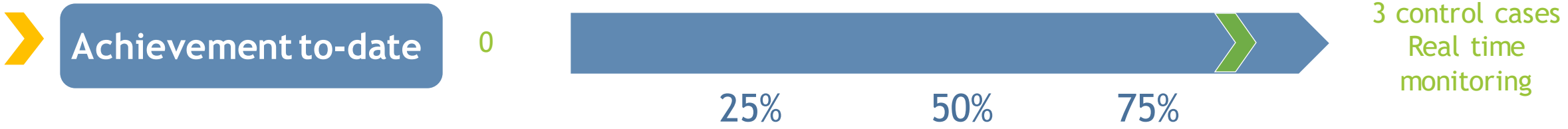
Project Progress/Actions – Electrolyser Performance



- Cold and hot start: target would require modifications to balance of plant
  - Project targets are MAWP 2020's

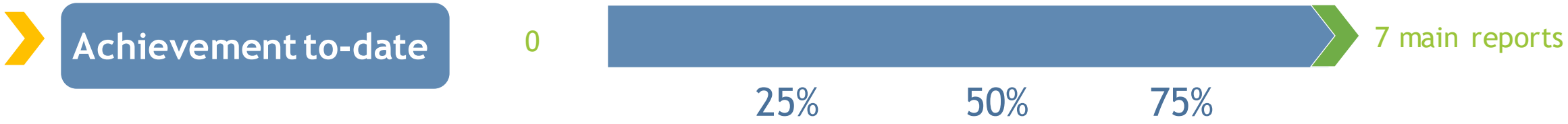
- Degradation difficult to verify due to limited demonstration time
  - Prognostic approach on system level (UBFC)
  - Study of historical data series provided by Cummins
  - 1.5 %/year is MAWP 2020 target

Project Progress/Actions – Control & Monitoring System



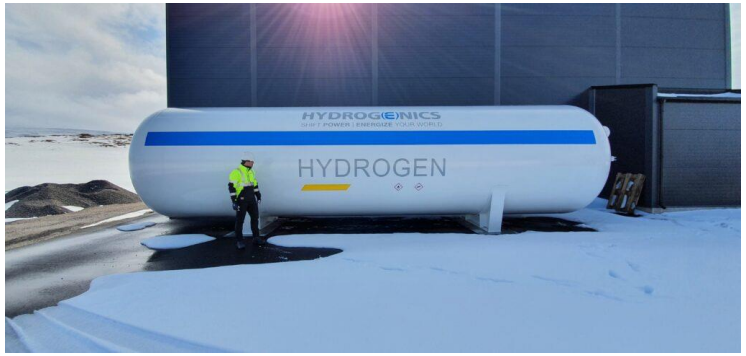
- 3 operation cases being considered
  - Energy storage (and re-electrification) ✓
  - Mini-grid (islanded operation or weak grid) ✓
  - Fuel production ✓
- Achieved:
  - Dynamic model and control algorithms for all cases
  - Durability algorithms infrastructure design
  - Remote access and control from Benevento (Italy) first activated in June 2021
- Remaining
  - Dynamic simulation of controlled systems

Project Progress/Actions – Wind-hydrogen integration



- 7 public reports on various aspects of hydrogen-wind energy (available on website)
  - Raggovidda energy analysis (hydrogen cost 4-5 €/kg) ✓
  - Valorisation plan for produced hydrogen ✓
  - Techno-economic analysis for multiple sites ✓
  - Impact of wind-hydrogen on energy systems & RCS ✓
  - Business case for wind-hydrogen in Europe ✓
  - Environmental performance analysis ✓
  - Roadmap to 2023 MAWP targets for electrolysers ✓

Risks, Challenges and Lessons Learned



Delays:

- Lost initial electrolyser supplier
- Problems in development of 2.5MW single stack
- Covid-19 & closed borders
- Post-covid supply chain issues & order backlog

Partner KES went bankrupt

- Software passed to SINTEF as open source

Safety:

- No accident during construction
- One event during commissioning (external leak)
- One false alarm during operation (midnight sun)

Exploitation Plan/Expected Impact

Exploitation

Varanger Kraft is building refilling station by 2024

- Customers: Biogas plant in Båtsfjord, power supply of telcos, armed forces and lighthouses, waste management, styrofoam factory in Tana
- Longer perspective: hydrogen fishing boats, Vadsø-Kirkenes passenger ferry, trucks
  - "Zero-emission fish" value chain
- Strategic cooperation with hydrogen companies
- Large-scale focus on green ammonia

Impact

- Berlevåg Industrial Park
- Green Ammonia production
  - 100 MW of electrolysers scale-up
- Green Ammonia Berlevåg (GAB) company established
- Cooperation with Wärtsilä, Grieg Edge for ammonia-driven ship
- Regional hydrogen strategy of Troms & Finnmark county council

Dissemination Activities

- 7 journal articles (4 UniSannio, 2 UBFC, 1 SINTEF)
- 31 contributions to conferences and workshops
- 3 seminars for MSc/PhD students
- 1 workshop at ECC19 conference (Naples)
- 1 student internship on-site (MSc thesis)
- 1 on-site visit event
- 16 public reports
- *Upcoming*: booth at industrial fair

  Off-Grid Expo, 7-8 December 2023

  Messe Augsburg, Germany

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