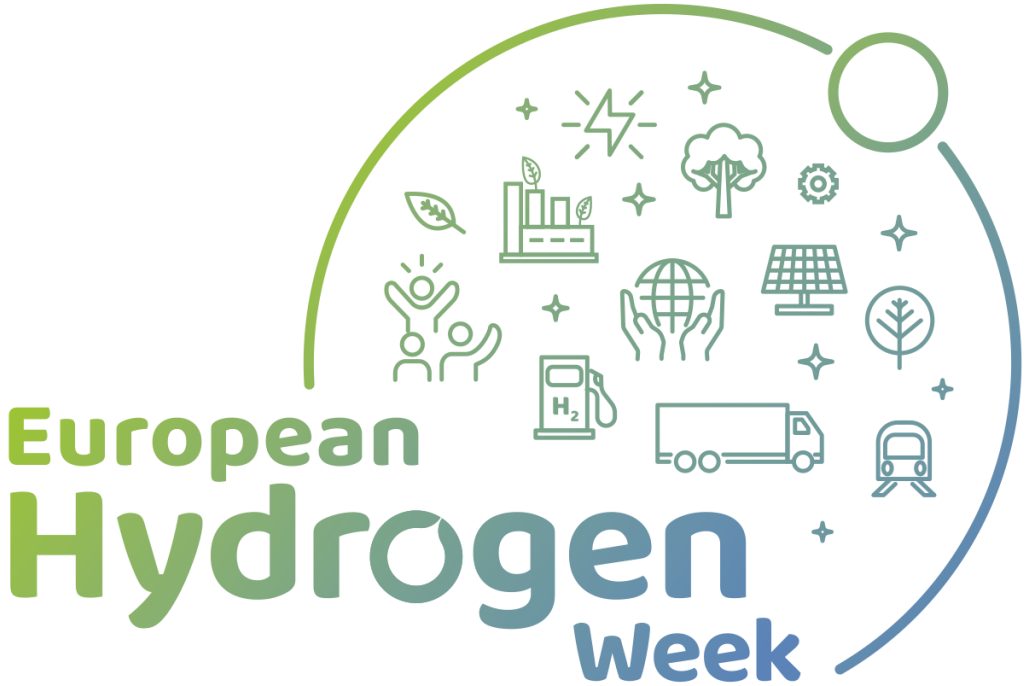
H2AEOLUS

Hydrogen-Aeolic Energy with Optimised eLectrolysers Upstream of Substation



Elodie PAHON

FEMTO-ST/FCLAB/UBFC

www.haeolus.eu

Federico.Zenith@sintef.no

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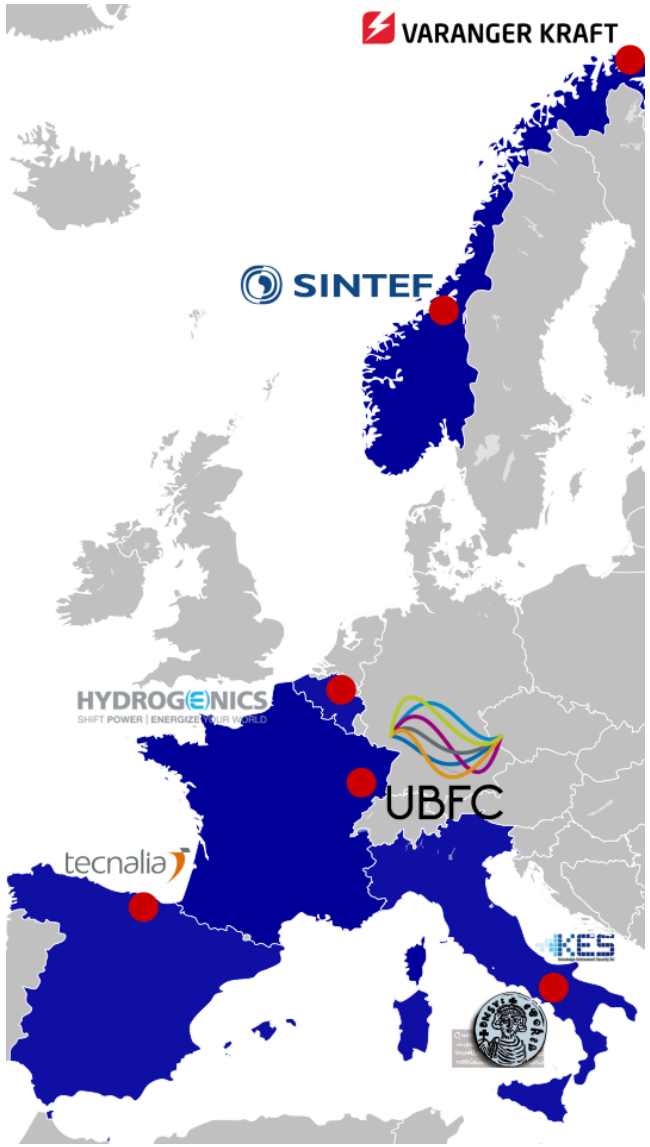
FCH

European Commission

Project Overview

- Call year: 2017
- Call topic: FCH-02-4-2017 - 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 01/11/2019: 65 %
- Total project budget: 7,793,995.00 €
- FCH JU max. contribution: 4,997,738.63 €
- Other financial contribution: 0 €
- Partners: SINTEF, UBFC, Tecnalia, UniSannio, Varanger Kraft, KES, Hydrogenics



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Project Summary

- Raggovidda wind park (45 MW built out of 200 MW)
  - Bottleneck to reach main grid
- 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 production based on the largest electrolyser in the world integrated within a wind farm
  - Remotely controlled and monitored, due to the remoteness of the location and its difficult accessibility (especially in winter)
  - Potential for technology transfer to offshore wind

- Application and market area:
  - Hydrogen production for export

Project Progress/Actions – Electrolyser Efficiency & Cost

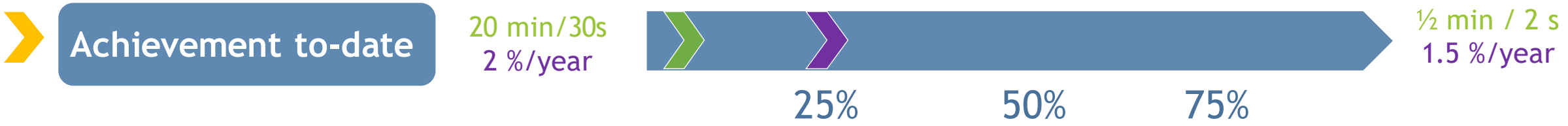
Achievement to-date

55 kWh/kg
3.7 M€/(t/d)

52kWh/kg
~2 M€/(t/d)

- Efficiency targets already met by Hydrogenics' latest stack
  - 52 kWh/kg is the MAWP 2020 target
- Cost is also met and exceeded (according to preliminary reports)
  - Will be verified at next financial reporting period (mid-2022)
  - Project target was 3 M€/(t/d)
  - MAWP 2020 target is 2 M€/(t/d)

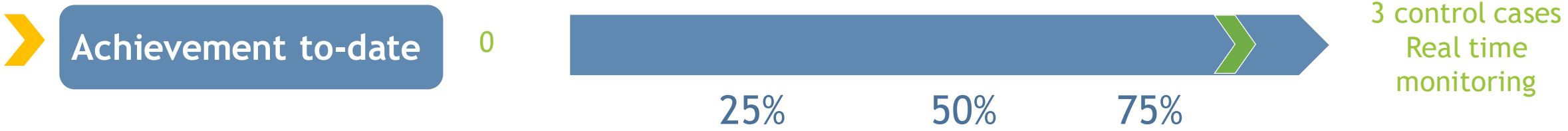
Project Progress/Actions – Electrolyser Performance



- Cold and hot start: optimization work will start next year along with operations
  - Project targets are MAWP 2020's
  - Next year: report on future developments of electrolysers

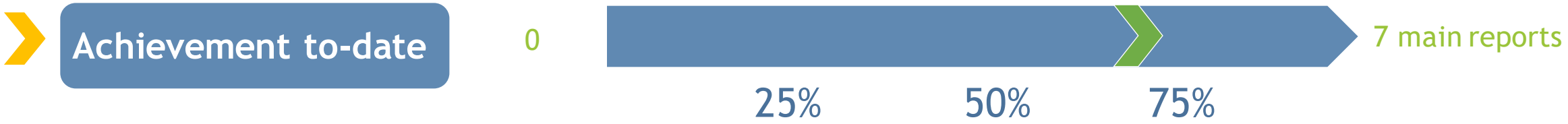
- Degradation will be verified during operation and compared with historical data series
  - Prognostic approach on system level (UBFC)
  - Ongoing study of historical data series provided by Hydrogenics
  - 1.5 %/year is MAWP 2020 target

Project Progress/Actions – Control & Monitoring System



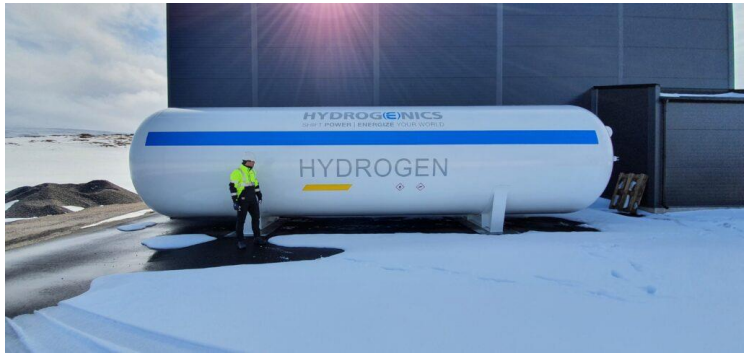
- 3 operation cases being considered
  - Energy storage (and re-electrification) ✓
  - Mini-grid (islanded operation or weak grid) ✓
  - Fuel production ✓
- Achieved:
  - Dynamic model and control algorithms for all cases
  - Durability algorithms infrastructure design
  - Remote access and control from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

Project Progress/Actions – Wind-hydrogen integration



- 7 public reports on various aspects of hydrogen-wind energy
  - 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 (expected 2022)
  - Roadmap to 2023 MAWP targets for electrolysers (expected 2022)

Risks, Challenges and Lessons Learned



Delays:

- Lost initial electrolyser supplier
  - Hydrogenics entered in April 2018
  - Lost 2018 construction season
- Problems in development of 2.5MW single stack
  - Reverted to double-stack solution
- Covid-19 & closed borders
  - Impact on Hydrogenics workshop

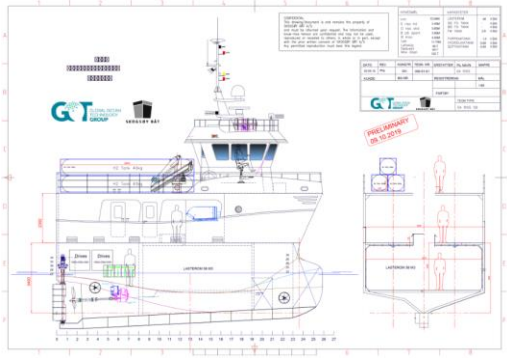
No accident during construction
Project progressed through pandemic
In-presence project meeting on site in January 2022

Exploitation Plan/Expected Impact

Exploitation

Hydrogen production for local consumption

- Biogas upgrade in neighbouring Båtsfjord
- Development of hydrogen fishing boats
- Possible introduction of hydrogen fast passenger ferry between Vadsø and Kirkenes



Impact

- Berlevåg Industrial Park
- Green Ammonia production
  - 100 MW of electrolysers scale-up
- Decarbonisation of Svalbard Islands
  - Currently last holdout of coal in Norway
- Regional hydrogen strategy of Troms & Finnmark county council

Communications Activities

Website: haeolus.eu

Dissemination Activities

2 Workshops organised by the project:

- Summer school "Microgrids" (1-5 July 2019, UBFC, France)
- Summer school "Control and optimization of renewable and green hydrogen energy systems" (30 June-1st July 2021, UniSannio & UBFC, online)

15 conferences/workshops that the project has attended

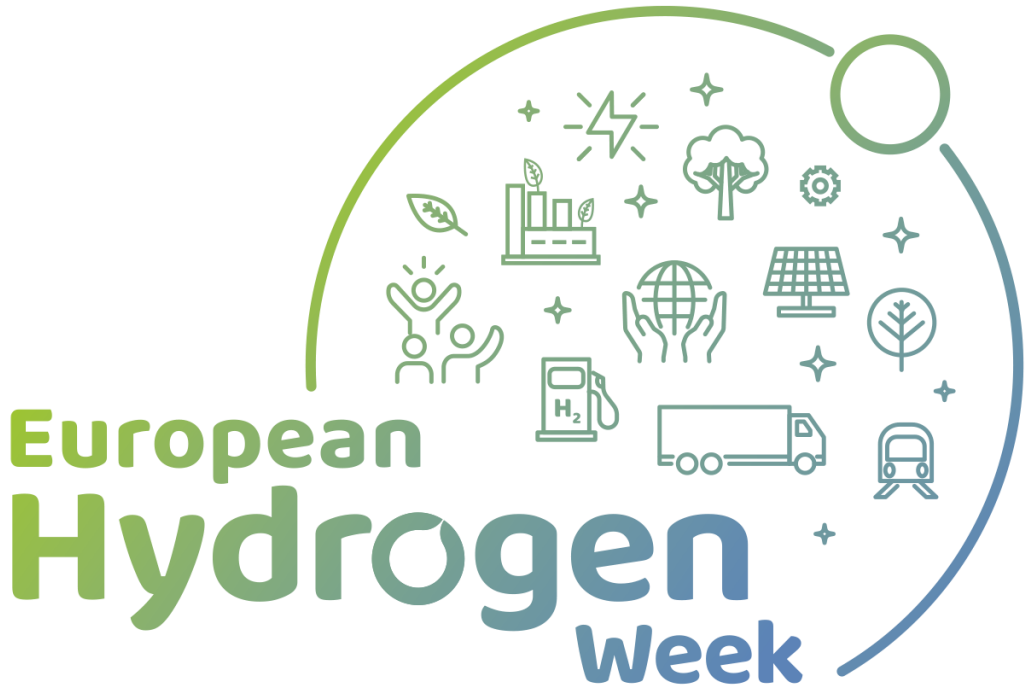
3 journal articles

1) M.B. Abdelghany, M.F. Shehzada, D. Liuzza, V. Mariani, L. Glielmo. Optimal operations for hydrogen-based energy storage systems in wind farms via model predictive control, International Journal of Hydrogen Energy, Vol. 46, Issue 57, 2021, pp. 29297-29313, https://doi.org/10.1016/j.ijhydene.2021.01.064

2) Meiling Yue, H. Lambert, E. Pahon, S. Jemei, D. Hissel. Hydrogen energy systems: A critical review of technologies, applications, trends and challenges, Renewable and Sustainable Energy Reviews, vol. 146, 2021, pp. 111180, https://doi.org/10.1016/j.rser.2021.111180

3) M. Yue, Z. Li, R. Roche, S. Jemei, N. Zerhouni. Degradation identification and prognostics of proton exchange membrane fuel cell under dynamic load, Control Engineering Practice, vol. 118, 2022, pp. 104959, https://doi.org/10.1016/j.conengprac.2021.104959

10 public deliverables (www.haeolus.eu)



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