Techno-economic analysis on enhancing combined cycle flexibility via power-to-ammonia solutions – preliminary results from FLEXnCONFU project

Dr. Rafael Guédez, Researcher – KTH Energy Department

José García, PhD Candidate – KTH Energy Department

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- Founded in 1827. Sweden’s oldest technical university
- Approximately 14000 students - 4000 employees
- Top 30-40 globally in engineering fields

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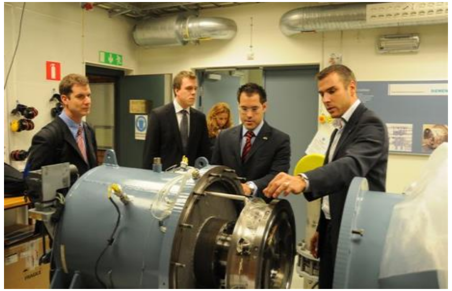
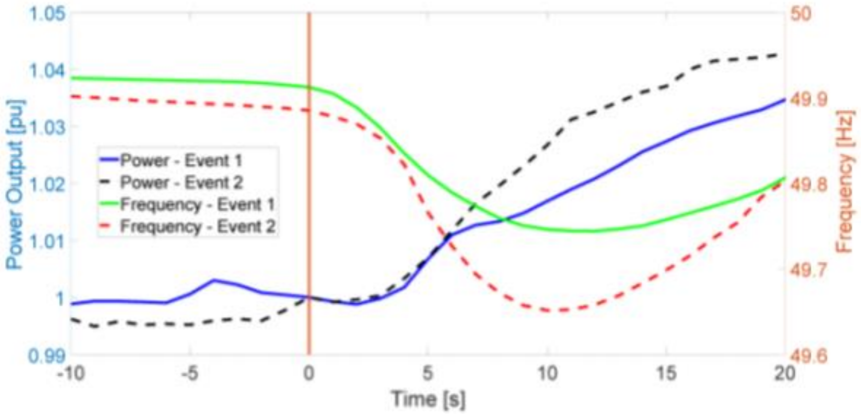
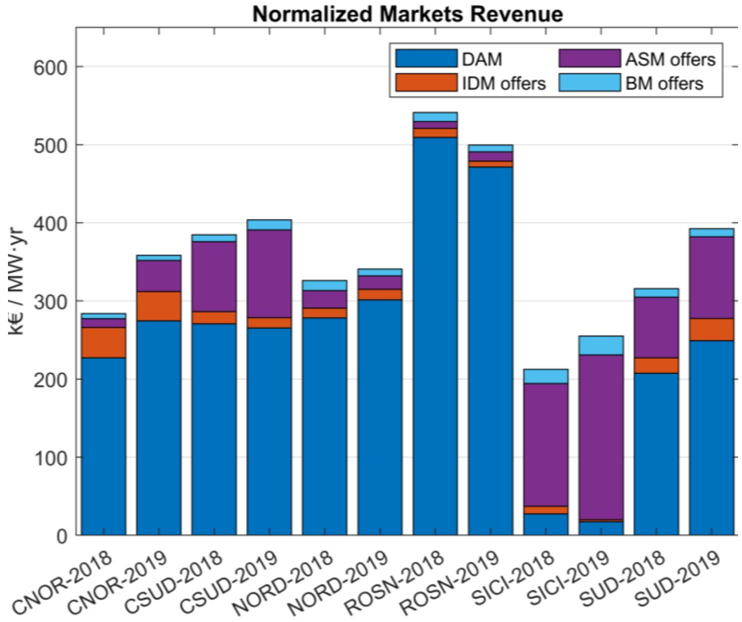


Background: flexibility in CCGTs

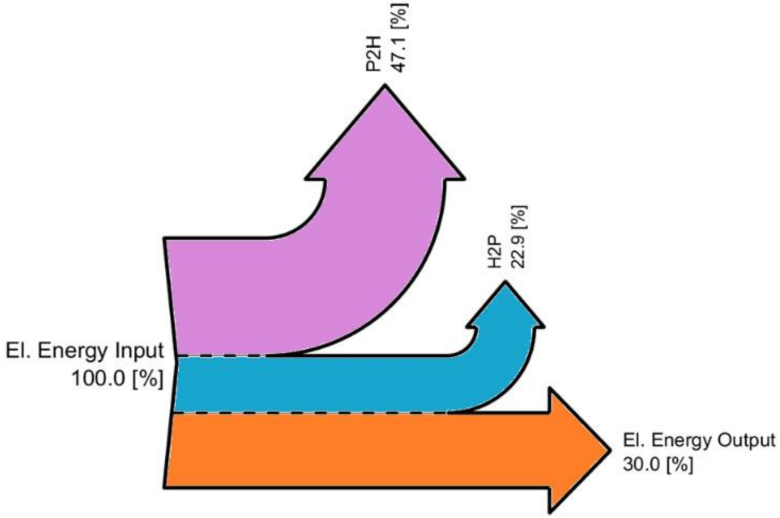
- Flexibility in the form of faster ramps, higher efficiency at part loads, and if possible fuel, is key for CCGTs market viability.
- At higher penetration of renewables, flexible CCGTs can make more profits on the ancillary service and balancing markets.
- Example of services needed: frequency regulation:

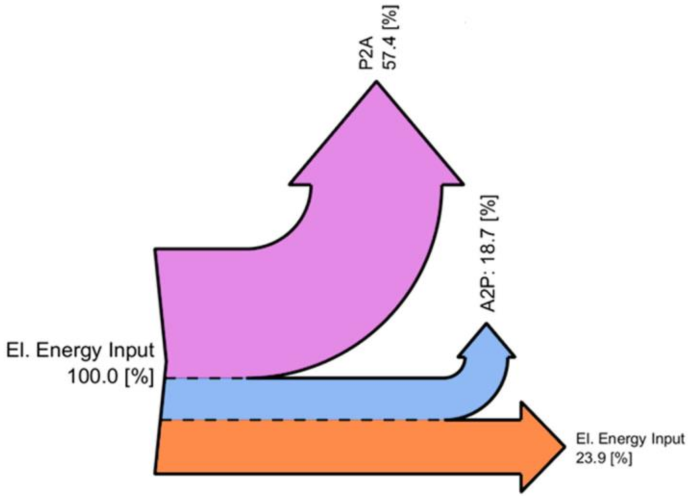




Background: why Ammonia?

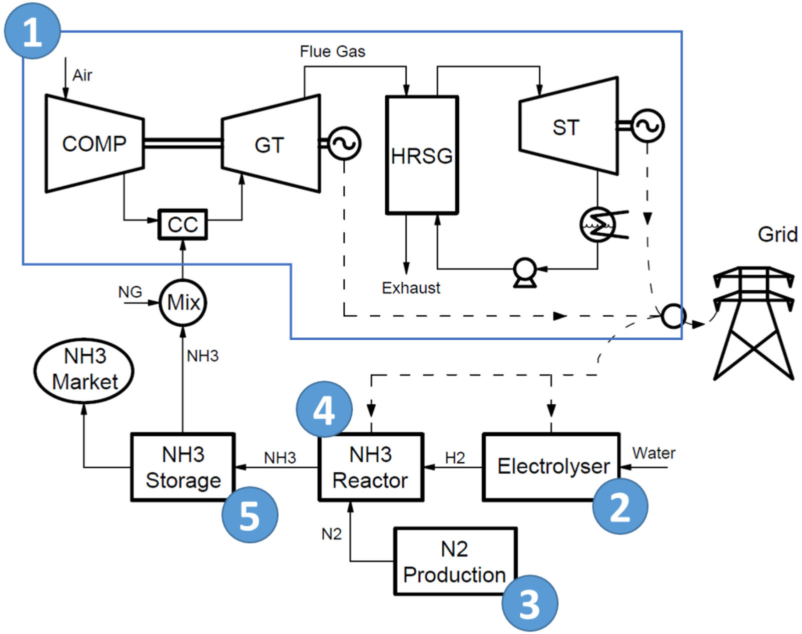
- “Easy” to store and transport → possible green H_2 energy vector role in near future.
- Regulation in place, “infrastructure” and market existing, with uses in other applications e.g. fertilizer.
- P2A process is more energy intensive and complex (in balance of system and components).
  It is less efficient than P2H → techno-economic feasibility for power generation not obvious, and market dependent.

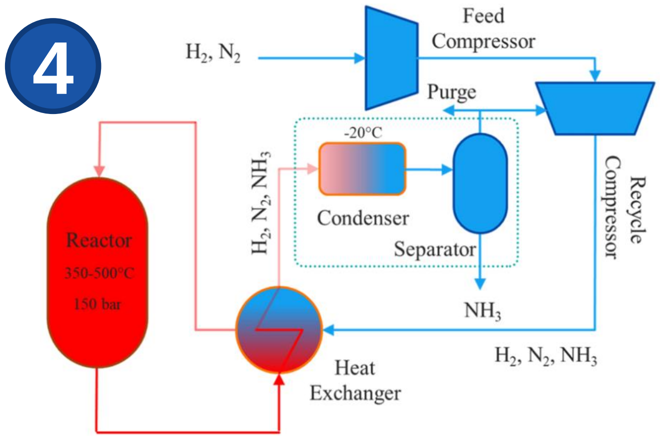




Power-to-Ammonia-to-Power (P2A2P) in CCGTs

- **5 Key Blocks:** CCGT, H2 production, N2 production, NH3 synthesis, storage
- Roundtrip P2A2P efficiency approx. 25%



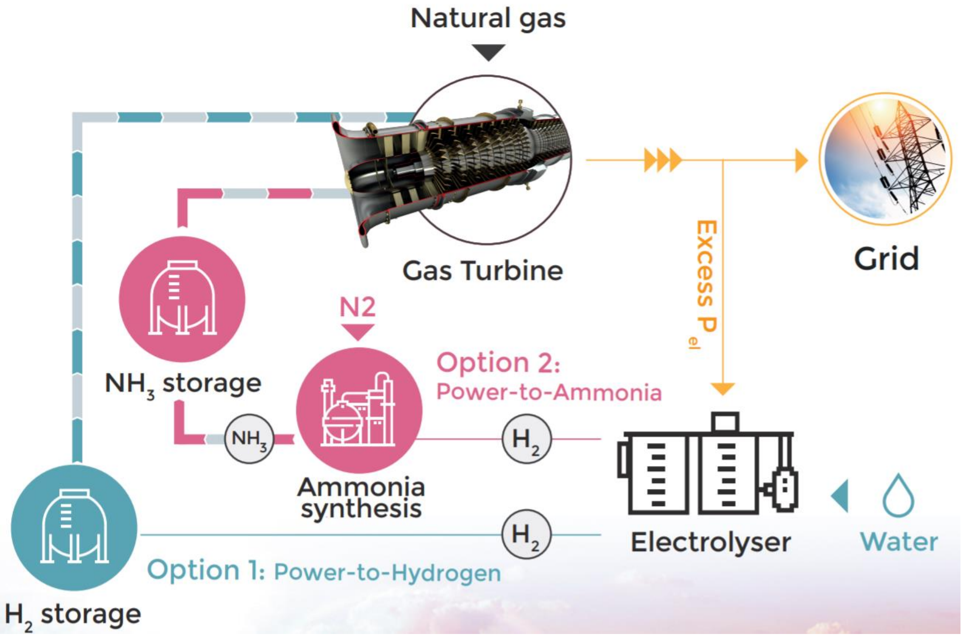


Source: Performance of a Small-Scale Haber Process: A Techno-Economic Analysis, Bosong Lin 2020

FLEXnCONFU H2020

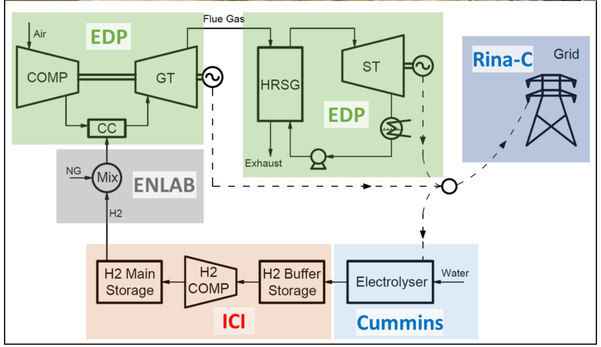
FLEXibilize combined cycle power plant through Power-to-X solutions using non-CONventional FUels

- April 2020 – March 2024. 21 partners.
- How to use non-conventional fuels to make CCGTs more flexible and enhance profits?
- 2 Demo sites (TRL4 -> TRL 6/7) integrating P2X components in system + 2 virtual replication sites
- 12.5M€ Budget (9.8M€ EU funding)

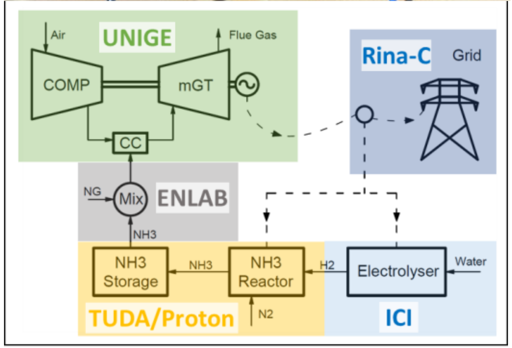


Demo sites in Flexnconfu

P2H2P demo (TRL 7)
at Ribatejo CCGT, Portugal



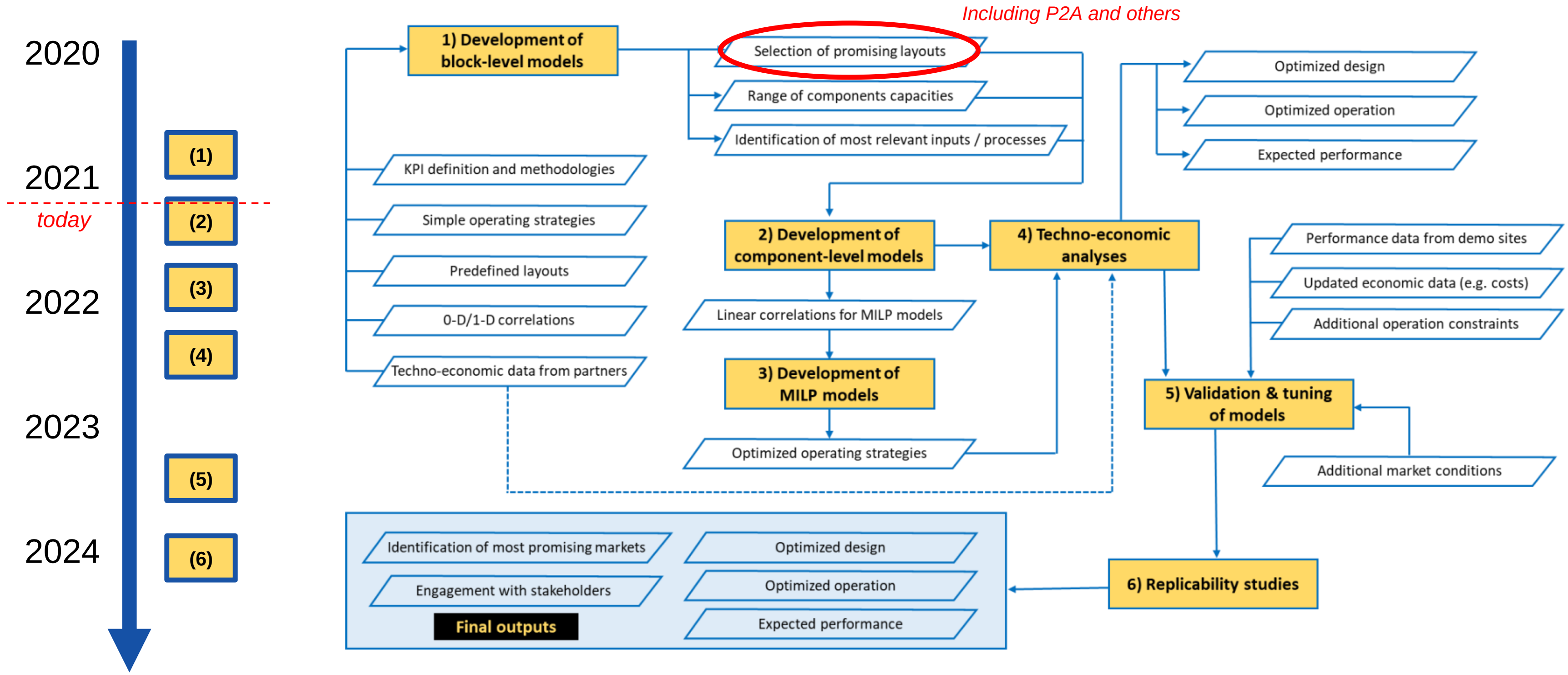
P2A2P demo (TRL 6)
at UNIGE Savona, Italy



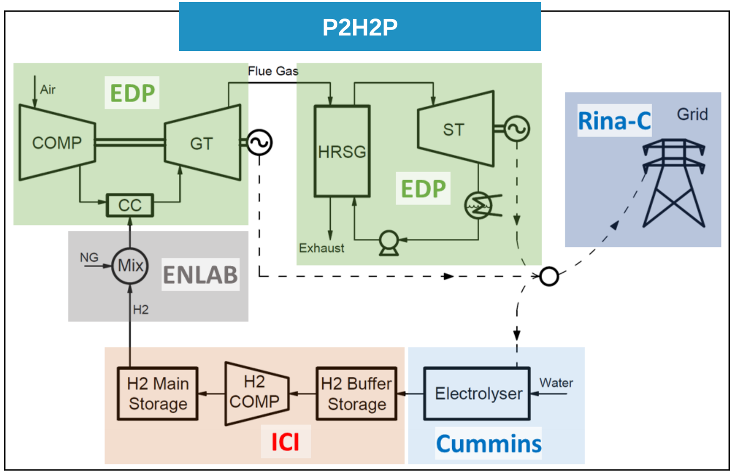
Replication / virtual demos
CCGT Herdersbrugge, Belgium
CCGT Tirreno Power, Italy

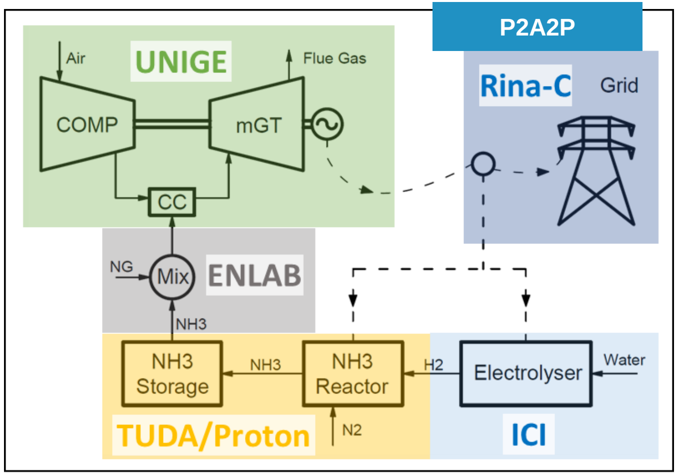
Techno-economic Modelling in Flexnconfu

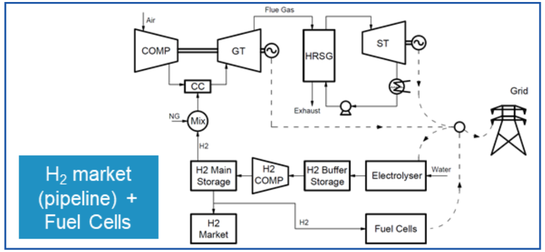
- KTH is responsible for techno-economic modeling in Flexnconfu. Work in progress.

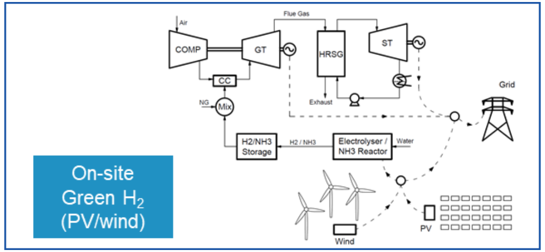


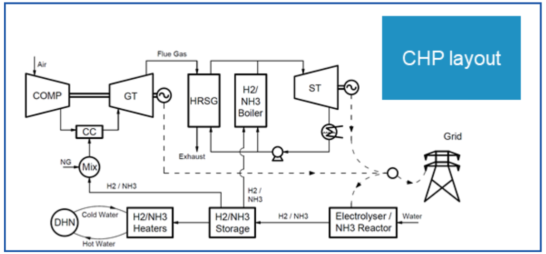
Techno-economic Layouts in Flexnconfu





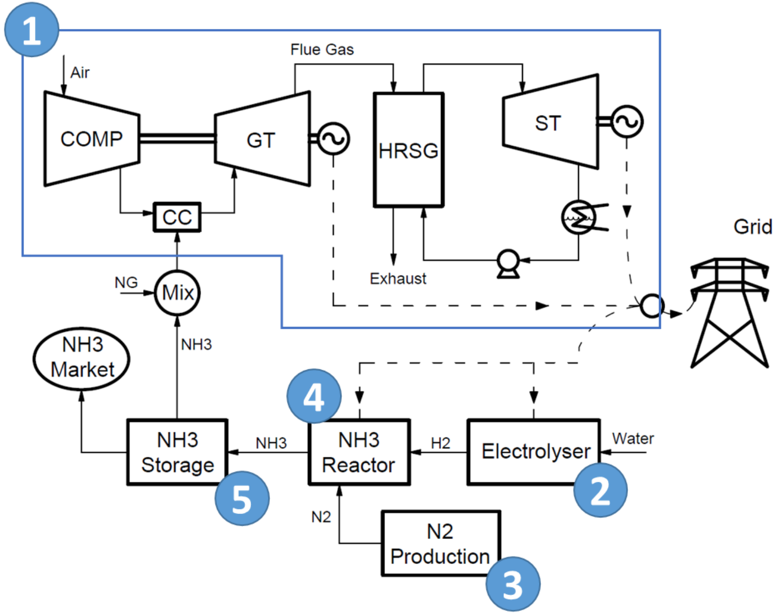






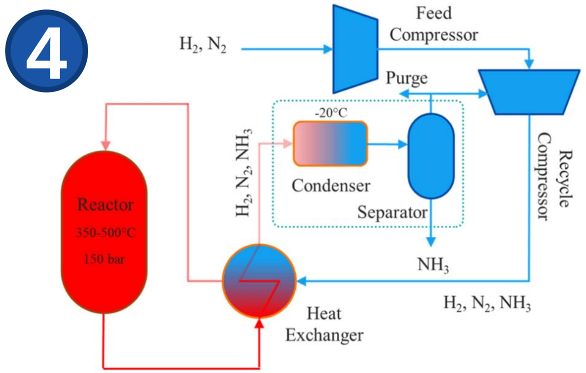
P2A2P Preliminary Analysis – Model setup

- **Basic model (quasi-steady / linear correlations)**
- **All 5 main blocks**
  - CCGT
  - Electrolyzer – PEM
  - N2 production – Air separation unit
  - NH3 production – Haber−Bosch
  - NH3 storage – Pressurized tanks
- **Basic cost functions**
  - Cost-scaling coefficients: $C^{NH3} = C_{ref}^{NH3} * \left(\frac{Cap^{NH3}}{Cap_{ref}^{NH3}}\right)^{\alpha}$
- **Main considerations include:**
  - Effect of temperature and part-load on component efficiency
  - User-defined dispatch strategy and market scenarios
- **Multiple revenue sources:**
  - Electricity – Day-ahead market
  - Electricity – Ancillary services
  - Direct product – Ammonia market



P2A2P Preliminary Analysis – Case study

- **Napoli, Italy**
  - Hour-based electricity price, demand, and temp.
- **CCGT**
  - 400 MWe
  - $\eta_{nom} = 56.7\%$
  - Natural Gas price: 24.03 €/MWh
  - Carbon tax: 25.32 €/tonCO2
  - Fixed and variable OPEX
  - NH3 in mix: 75%
- **Electrolyzer**
  - PEM technology
  - Specific consumption: 5 kWh/Nm3
  - Installed capacity: 100 MW
  - Stack lifetime 80000 h
  - Ref cost: 600 $/kW
- **N2 – Air separation unit**
  - Specific energy consumption: 0.11 kWh/kgN2
  - Sized according to electrolyzer capacity and stoichiometric H2/N2 ratio
- **NH3 synthesis loop**
  - Sized according to electrolyzer capacity and stoichiometric H2/NH3 ratio
  - Reactor @ 150bar, 480°C
- **NH3 storage**
  - 12 h (of NH3 production) ~ 2 h GT
  - Pressurized tanks
  - Ref cost: 2.85 $/kgH2



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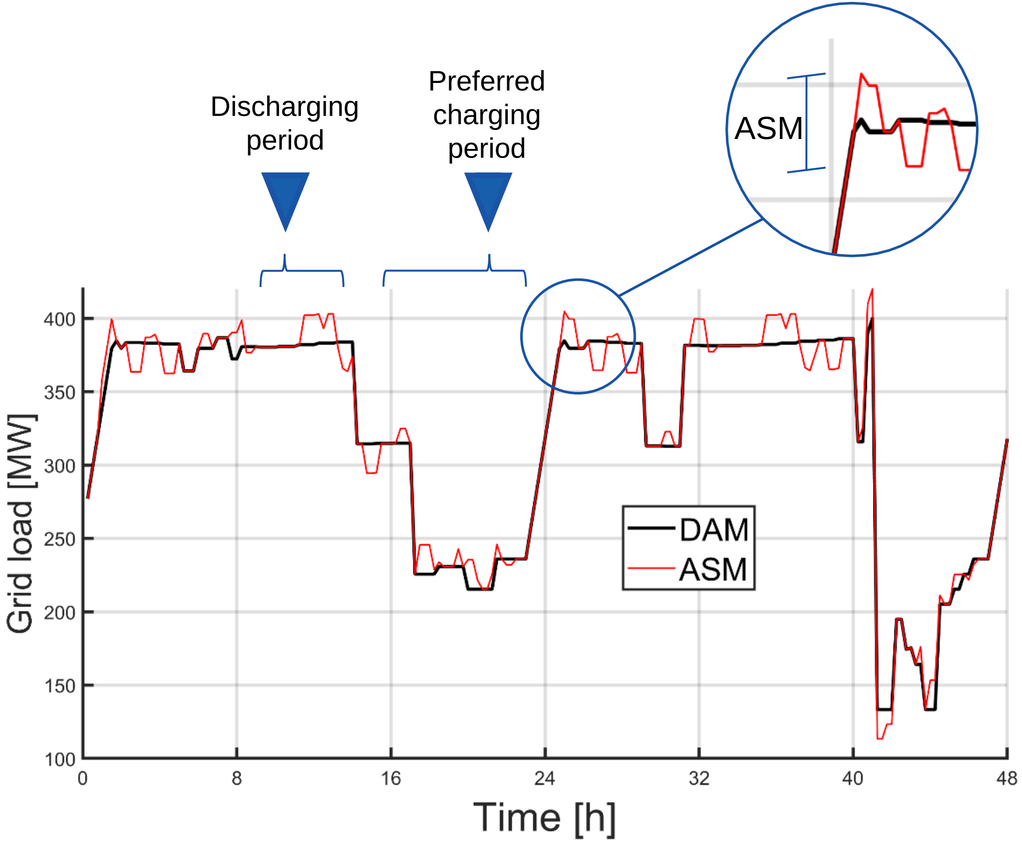
P2A2P Preliminary Analysis – Operation Logic

- **Day Ahead Market – DAM (from hist. data)**
  - Load & price
- **Ancillary Services Market – ASM**
  - Load (“made up” for developing models)
  - Price (bidding & offering prices averaged from data) – +/- 20 MW

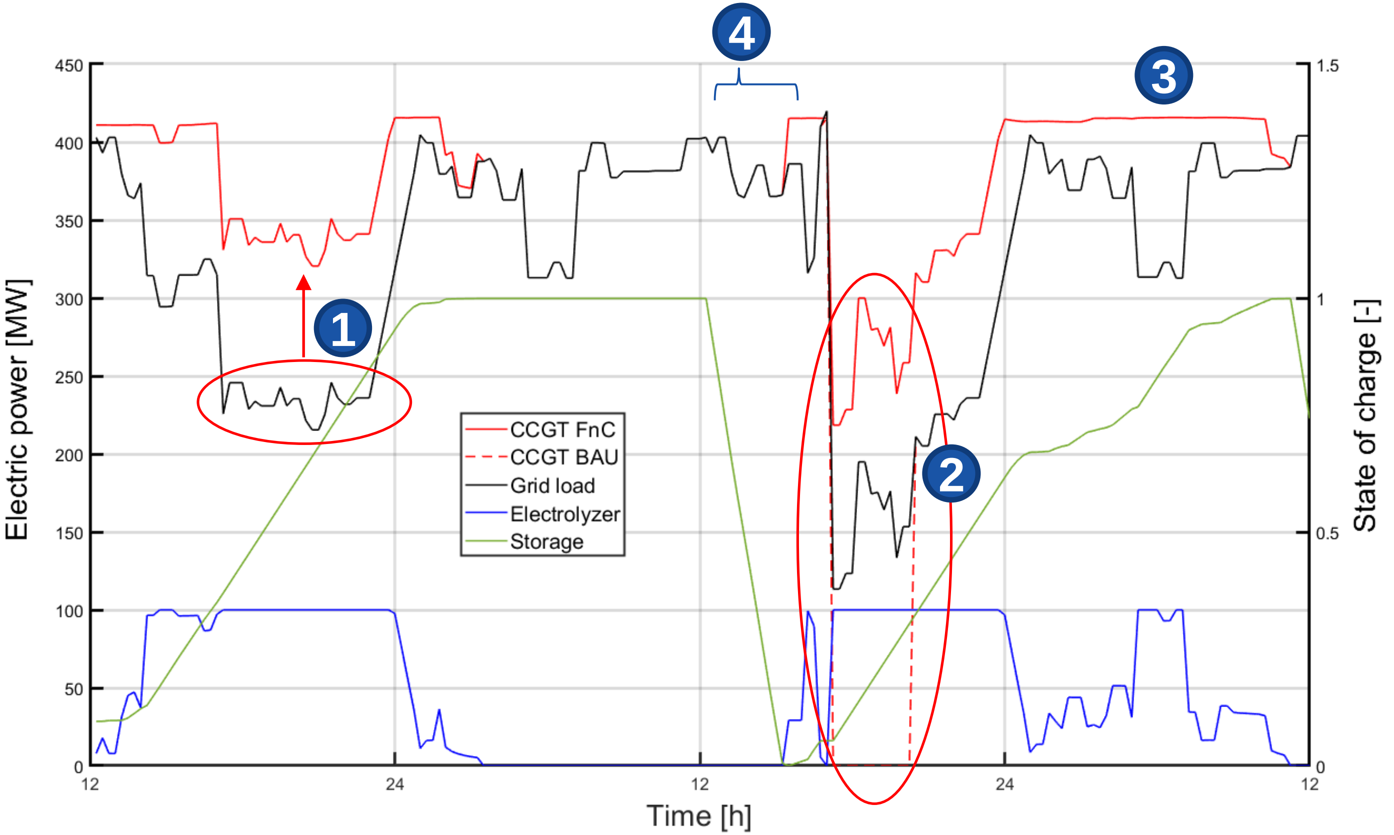
- **Discharging periods (NH3 usage)**
  - Based on identified peaks
- **Charging periods (NH3 production)**
  - Based on storage level and power availability from CCGT
  - Electricity 100% from CCGT

- **Comparison**
  - BAU case (conventional layout)
  - FnC case (with added P2A2P system)



P2A2P Preliminary Analysis – Results

- Charging periods: Closer to nominal conditions (1); avoided CCGT shut down (2); smoothens load (3)
- Discharging periods: emptying tanks for identified low grid peaks (4)
- FnC tracks better larger load changes in the electricity market
- 75% NH_3 in fuel mix (volume based) carries less than 50% of the energy required in fuel flow
- When 100% NH_3 in fuel mix → 12 hr production are consumed in 1 hr by CCGT



P2A2P Preliminary Analysis – Results

- P2A2P increases CCGT hours, increasing revenues from electricity sold
- P2A2P reduces **specific** CO_2 emissions due to more flexible CCGT operation
- Roundtrip efficiency ~23% → producing H_2/NH_3 with electricity from CCGT only is not profitable on its own.
- Layouts with renewable charging sources to be explored. This will lower specific CO_2.
- P2A2P could be economically feasible if the added flexibility compensates for investment
- Detailed analysis on CCGT OPEX reduction and participation in ASM required

	BAU	FnC (into GT)	FnC (to market)
CCGT installed capacity [MWe]	400	400	400
Electrolyzer capacity [MW]	0	100	100
Storage [h]	0	12	0.25
NG used case [kton]	357.19	412.03	450.80
NH3 produced [ton]	0	42383.75	60357.54
CCGT operating hours [hr]	7833.75	8399.25	8399.25
Electrolyzer operating hours [hr]	0	5182.25	7940.25
Revenue from elec. sold [M€]	164.14	172.30	172.30
Revenue from NH3 sold [M€]	0	0	36.21
P2A2P CAPEX [M€]	0	81.20	81.14
P2A2P OPEX [M€]	0	37.56	38.57
Specific CO2 emissions [ton/GWh]	352.21	427.21	467.41
P2A2P NPV [M€]	0	-68.82	-68.77
P2A2P footprint [m2]	0	7803.07	7506.31

Summary

- As the share of renewables increases, CCGT must adapt and become more flexible.
- Use of non-conventional fuels, e.g. H_2, is a way forward (preferably green produced).
- Several challenges are to be addressed: combustion, H_2 production, storage, integration, etc.
- Ammonia (NH_3) can be used as a vector to ease storage and transportation compared to H_2
- FLEXnCONFU H2020 aims at investigating and demonstrating these technologies (to TRL 6/7)
- Techno-economic feasibility of layouts is being performed. Project continues until 2024
- Preliminary analyses for P2A2P layouts show (work in-progress):
  - In spite of efficiency, P2A solutions can increase flexibility and potentially profitability
  - Hybridization with renewables is encouraged (or other grid-fed electricity)
- New markets and layouts to be assessed. Project to continue until 2024

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