How Green Ammonia is different from a conventional ammonia process?

- Energy source is renewable “kWh” that often fluctuates
- Hydrogen comes from water electrolysis
- Nitrogen is generated using renewable energy

- Plant excludes upstream hydrogen generation from natural gas/coal
- Hydrogen and nitrogen flows fluctuate, storage to balance variability
- System configuration and process control is unique

- Valorisation of renewable energy & incentivised by emission credits
- Chemical feedstock, green fertilizer, energy vector, low carbon fuel
- Value chain in centralised and distributed production
Plantwide control system embraces conventional elements & newcomers

The intermittency of renewables demands the ammonia loop to be more flexible, it imposes operational discontinuities on the process, and it increases the Levelized Cost of Ammonia (LCOgA).
Casale employs real power profiles to capture their impact on green ammonia cost.
LCOgA ≈ US$900-1650 per ton with the conventional «rigid» synthesis

Levelized Cost of Ammonia, $/MT for the different profiles

Results with Casale gNH₃ Optimizer
- All make 45MTD average NH₃
- H₂ buffer impacts 39-56% of LCOA, except PV Chile
- PV Chile favored by “moderately seasonal” power profile
- Optimal blend of grid & renewable electricity for PV

Key Assumptions
- Energy input 156GWh/y, 95% utilization
- Rigid synthesis 70-110% load change
- “Renewable” electricity 40$/MWh “Grid” electricity 100$/MWh
Casale Flexible Green Ammonia delivers 35% lower LCOgA from PV US than a «rigid» synthesis

<table>
<thead>
<tr>
<th>PV US</th>
<th>N₂ + H₂ Generation</th>
<th>H₂ Storage</th>
<th>gNH₃ Synloop</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>4% of Reference</td>
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<td>10-110% Ramps &gt;100%/h Peak 60 t/d</td>
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<td>CASALEASE FLEXIBLE gNH₃</td>
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<td>Reference</td>
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<td>RIGID 70-110% Peak 50 t/d</td>
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</tbody>
</table>

**Benefits of Casale Flexible gNH₃**

-421 $/MT For Wind Norden
-40 $/MT For PV Chile
“No storage” results in 40-95$/t higher LCOgA for PV & Wind US
How Casale Flexible Green Ammonia tackles key challenges of fluctuating profiles

**Challenges**

1. System flexibility needed to cope with fluctuation of renewables
2. Plant suffers from operational discontinuities of power: e.g. reactor shutoff, overpressure
3. Negative impact of fluctuations on LCOA
4. Site specific profiles impacting differently on gNH₃ concept
5. Novel nexus of ammonia synthesis to input electric power via H₂ & N₂ generation & storage

**CASALE Focus**

1. Adopt AmoMax™-Casale catalyst to new synthesis conditions and minimise poisoning
2. Own Casale Dynamic model of gNH₃ process to assess impact of fluctuations
3. gNH₃ Optimizer: lowest Levelized Cost of Green Ammonia by Casale gNH₃ plant
4. Analysis and Optimization of Real, Project Specific Input Profiles
5. Casale Embracing the Full Scope from Power input to Ammonia Storage
Deep understanding of dynamics is a stepping stone of Casale’s Flexible Green Ammonia

**gNH₃ Optimizer**

- Optimal component pre-sizing and energy utilization, to the target LCOgA
- Based on actual power profiles
- Leverage Casale design features of 10-110% load flexibility with > 100%/h load change

**gNH₃ Dynamic Model**

- Dynamic process model of the plant run in scenarios from real fluctuations of power profile
- <1 sec resolution, 1 day horizon with focus on e.g. reactor shut-off, over-pressurization
- Design verification for techno-economic targets
Dynamic Modeling of Casale H₂ + N₂ section under exemplary load changing ramp +/-50%/h confirms storage filling pressure and H₂ flows of Casale flexible gNH₃ control method.
Journey of Further Product Refinement and Process Improvement

- Leveraging experience of proven designs of A60 A600 A6000 and flexibility needed by green ammonia
- Superior controls and loop flexibility enables Casale to offer a green product line - newbuilds & retrofits
- Achieving lowest ammonia cost is where we engage with specific customer needs
- Serving customer with full or specific plant scope

Casale Flexible Green Ammonia available in scales from 3-6000 tonnes per day

- gNH3 optimizer + A-family

Continuous Development Effort to further maximise Casale Flexible Green Ammonia

- ARPA-E REFUEL and the REFUEL+IT pilot projects with RTI to further excel green ammonia technology
- Ongoing Casale’s-Clariant efforts to maximize the use of AmoMax™-Casale iron based catalyst for dynamic conditions of green ammonia
- … and others.

Durable AmoMax™
Casale Flexible Green Ammonia delivers the lowest LCOgA from fluctuating profile

Dynamic behaviour of the plant is a key enabler for deployment of Green Ammonia. Loop flexibility contributes in Green Ammonia cost.

Casale flexible $g\text{NH}_3$ combines control and process technology to convert real fluctuating power profiles into ammonia which is validated by Casale dynamic tools.

Casale $g\text{NH}_3$ Optimiser and $g\text{NH}_3$ Dynamic Model serve customers with a tailored plant, resulting in lowest LCOgA embracing the full scope operating on real profiles.

Flexible $g\text{NH}_3$ technology is the backbone of a green line of products of Casale, using proven solutions and AmoMax™-Casale catalyst. Continuously refined to excel the green ammonia technology.
THANK YOU