



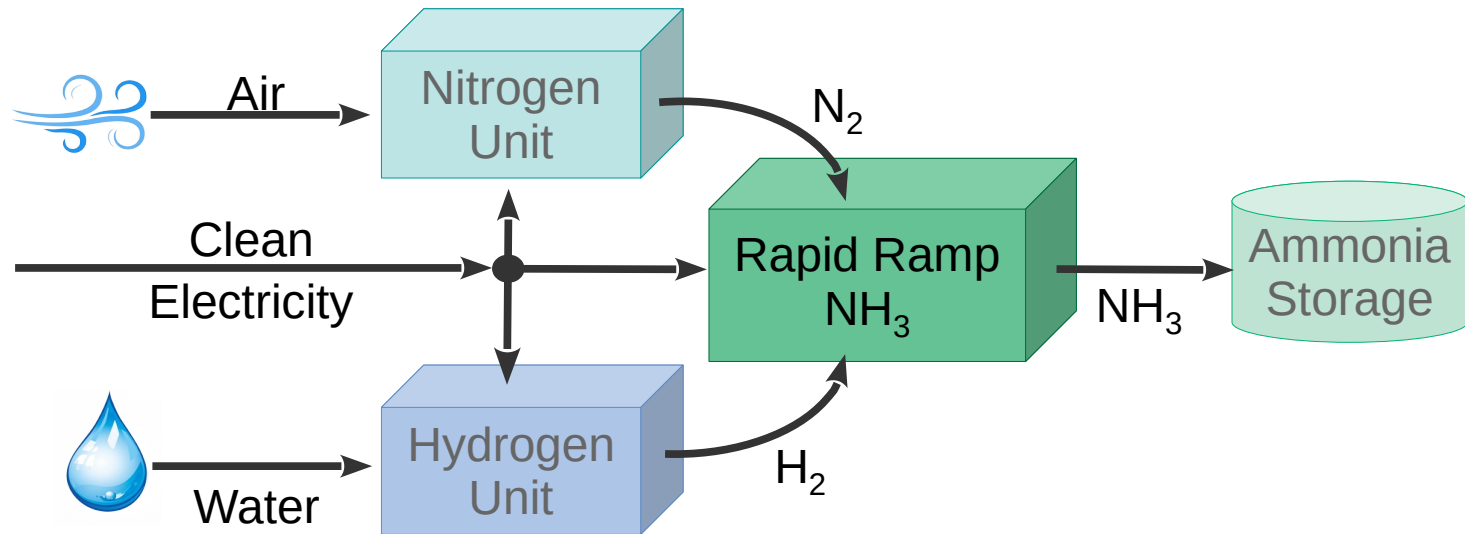
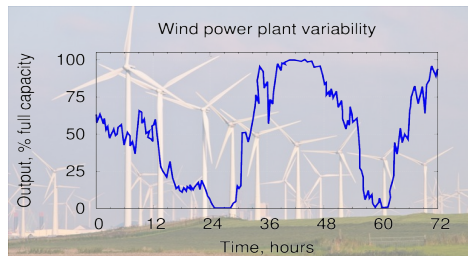
Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

100 kg/day Rapid Ramp NH_3 System Development

Rachel Gregg M.S. , Ammonia Production Engineer
AEA 2021

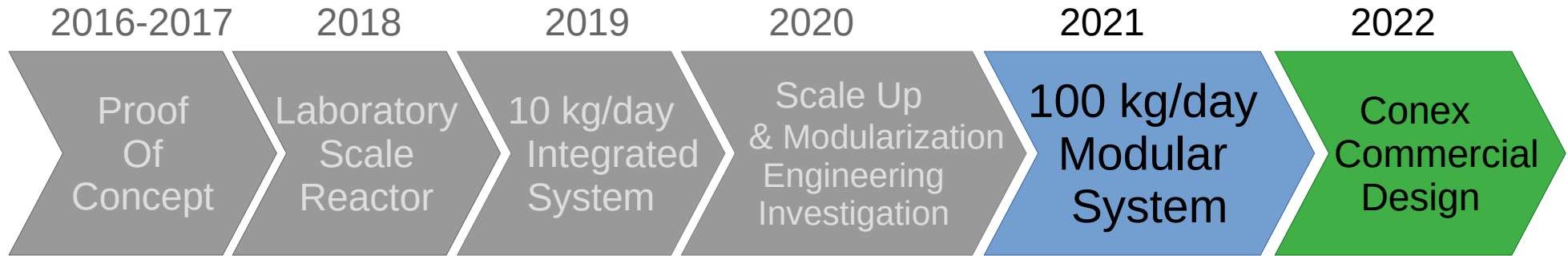
Starfire Energy is a clean energy company

Variable Renewable Power



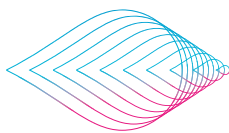
- Research, development, deployment- Ammonia Synthesis and Cracking
- Modular Ammonia Production following variable power
 - Approach since 2016
 - Ramp production based on power
 - N_2 and H_2 used as they are made

Starfire Energy's journey to 100 kg/day



- 100 kg/day system designed with modularization principals
- Conex building block is first commercial NH_3 synthesis product
 - Each unit scaled to maximum capacity of standard shipping container
 - Faster, simpler, cheaper plant construction
 - Build any size plant from modules

Successful close of Series A investment in 2021



APVentures
ADVANCE & PIONEER



NEW ENERGY TECHNOLOGY



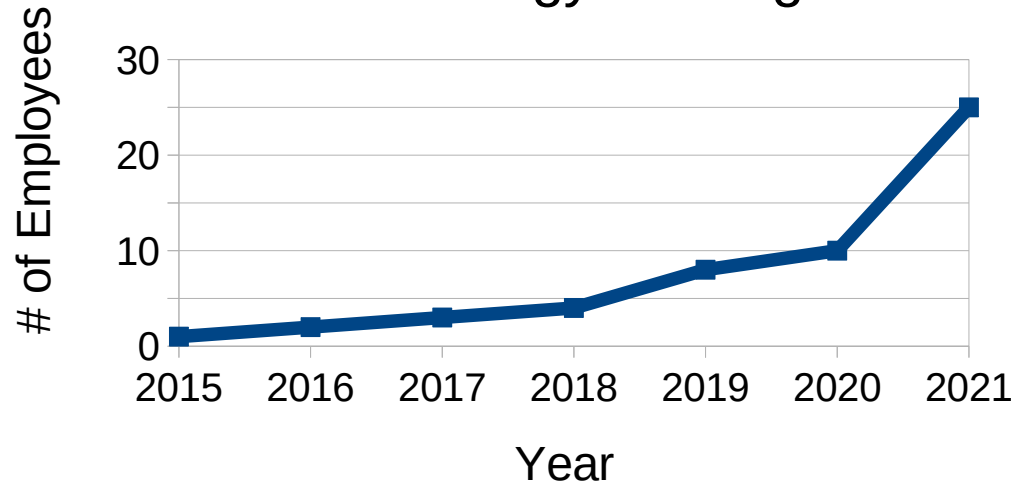
Funding transitioned from ARPA-E government funding to investment

The team and facility have expanded

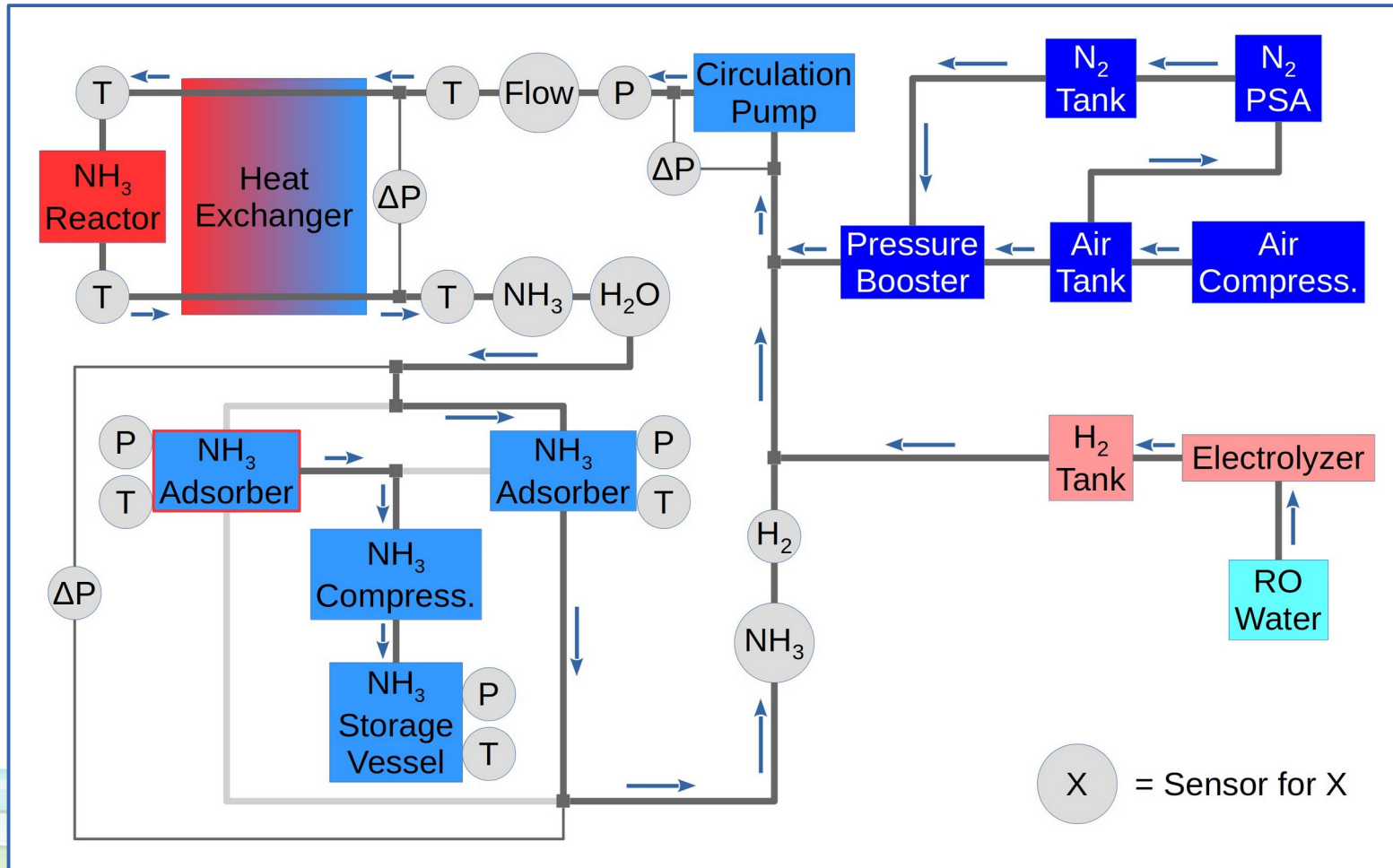
Expansion of NH_3 Synthesis team,
 NH_3 Cracking team, Fabrication
team, and Operations team

Facilities upgrade from
4,000 to 23,000 ft²

Starfire Energy Staffing



Process flow for NH_3 synthesis



Next development step is the 100 kg/day

**Circulation Pump
&
Liquefaction**

Reactor

Adsorption

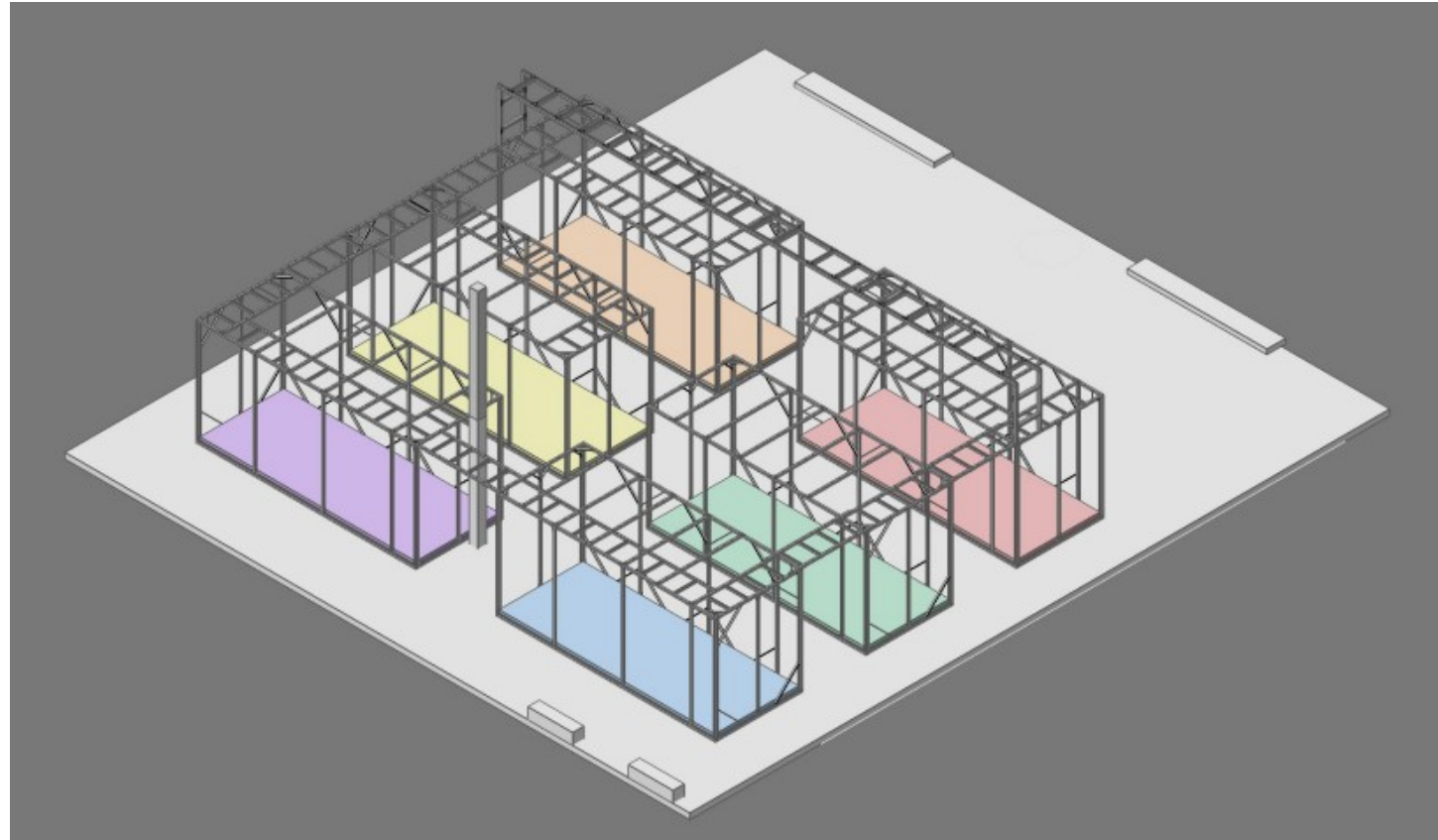
**Nitrogen
Generation**

**Control and
Power**

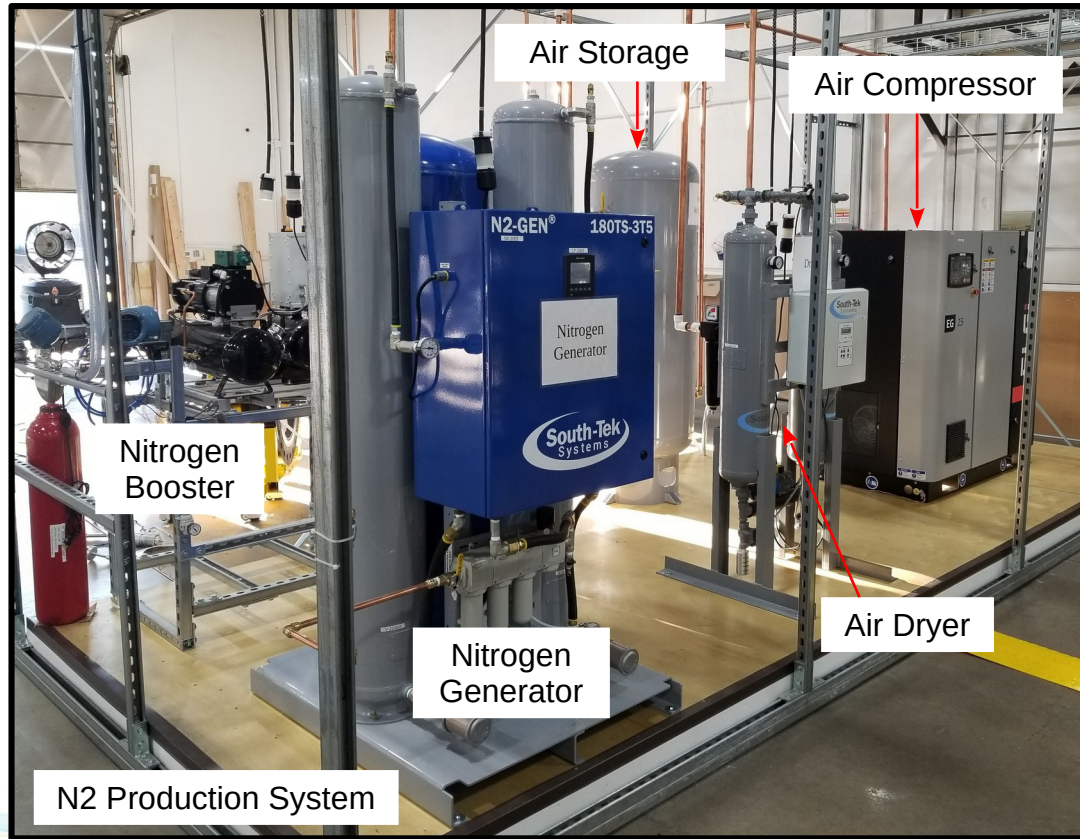
**Hydrogen
Generation**

100 kg/day system built in modules

- 6 main modules
- Platforms simulate 20 ft shipping containers



Nitrogen system fully installed and tested

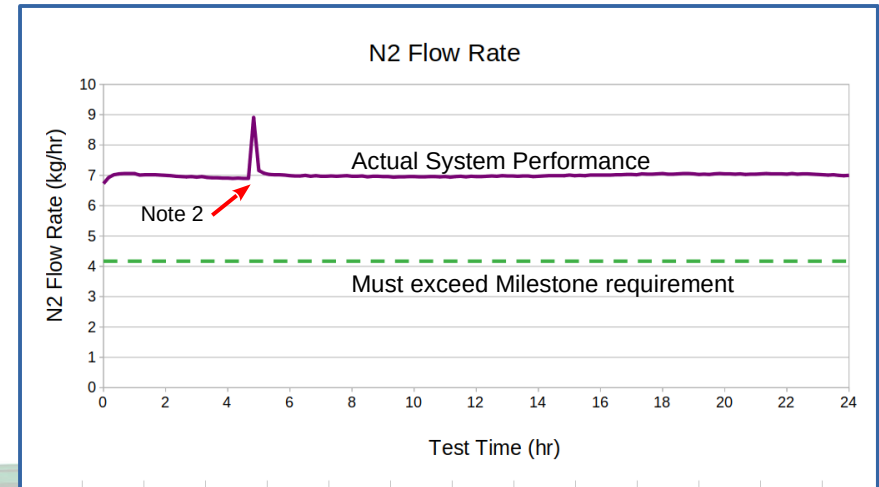
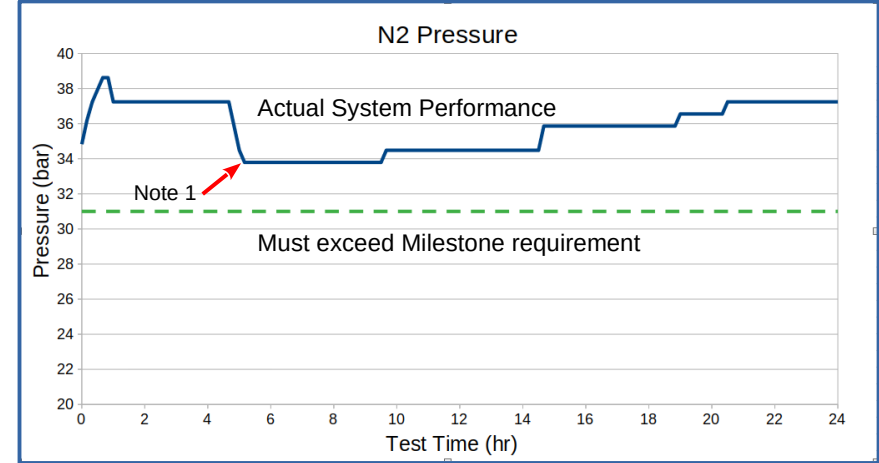
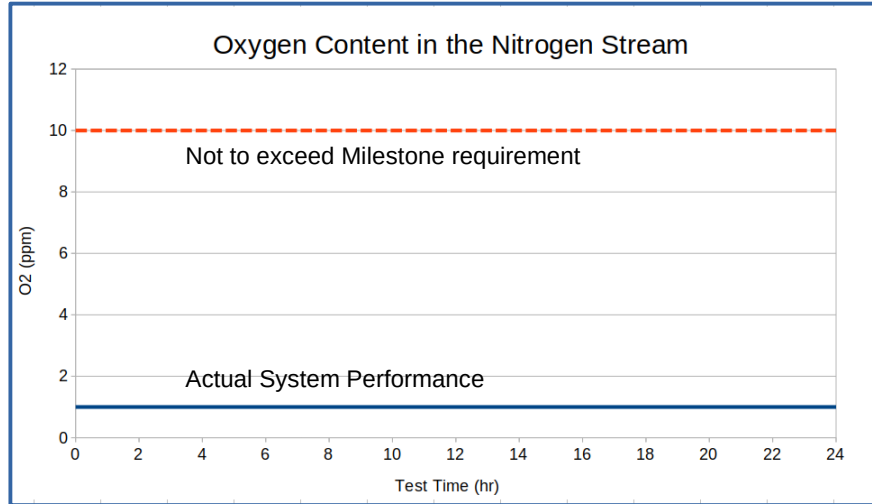


- Several components
 - Air compressor
 - Air dryer
 - Nitrogen generator
 - Boost compressor
 - Storage vessels
- 24 hour continuous test
 - 08:55 16-Aug to 08:55 17-Aug

N2 milestone complete in August 2021

Test was successful

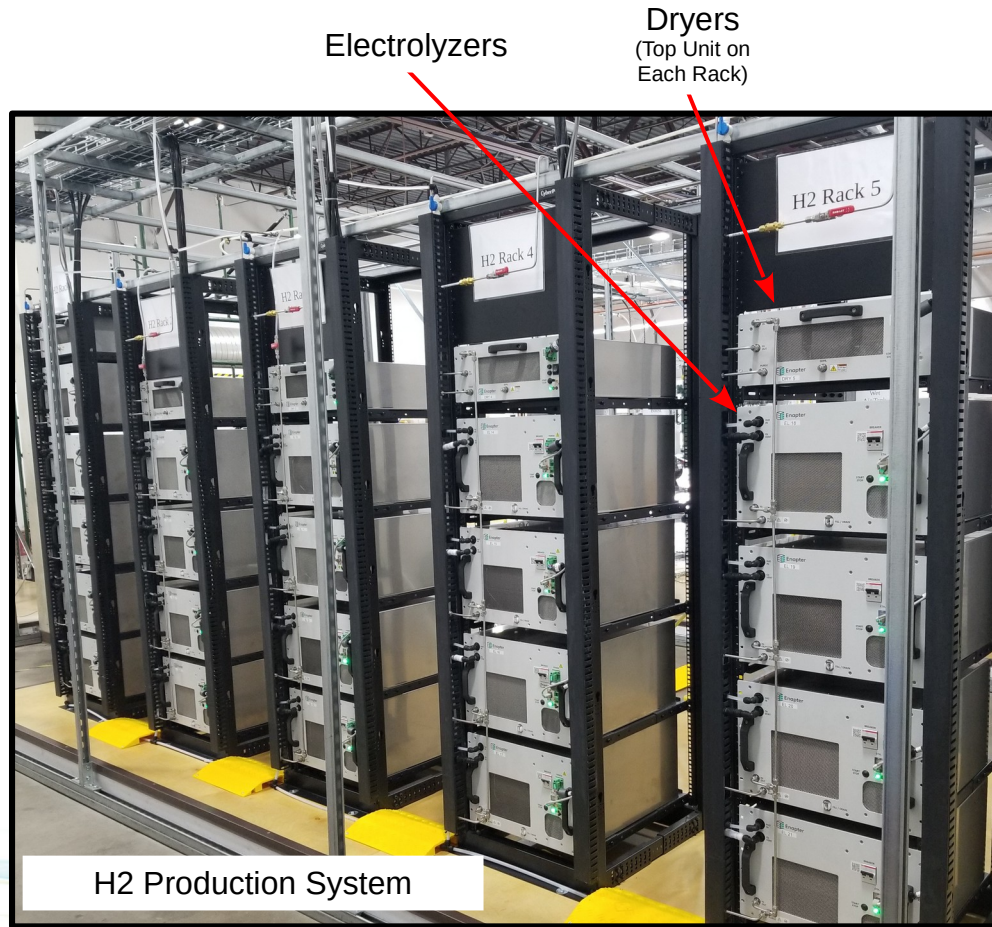
SKID achieved milestone requirements of pressure > 31 bar, flow > 100 kg/day (4.17 kg/hr), and oxygen content < 10 ppm



Notes:

1. Step changes in N₂ pressure are manual adjustments of pressure regulator.
2. Spike in N₂ flow rate resulted from rapid manual adjustment of regulator.

Hydrogen system fully installed and tested

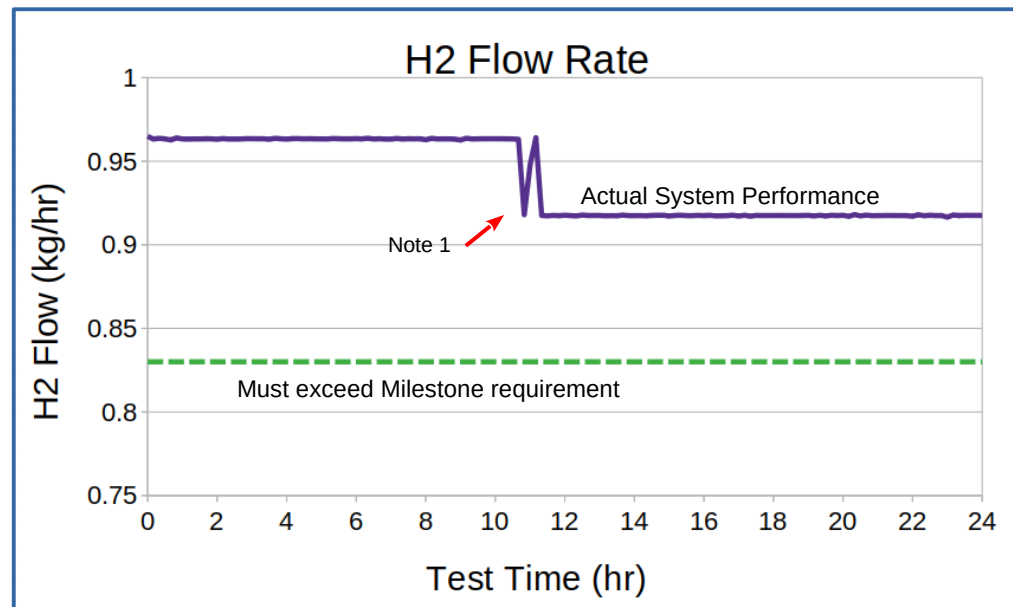
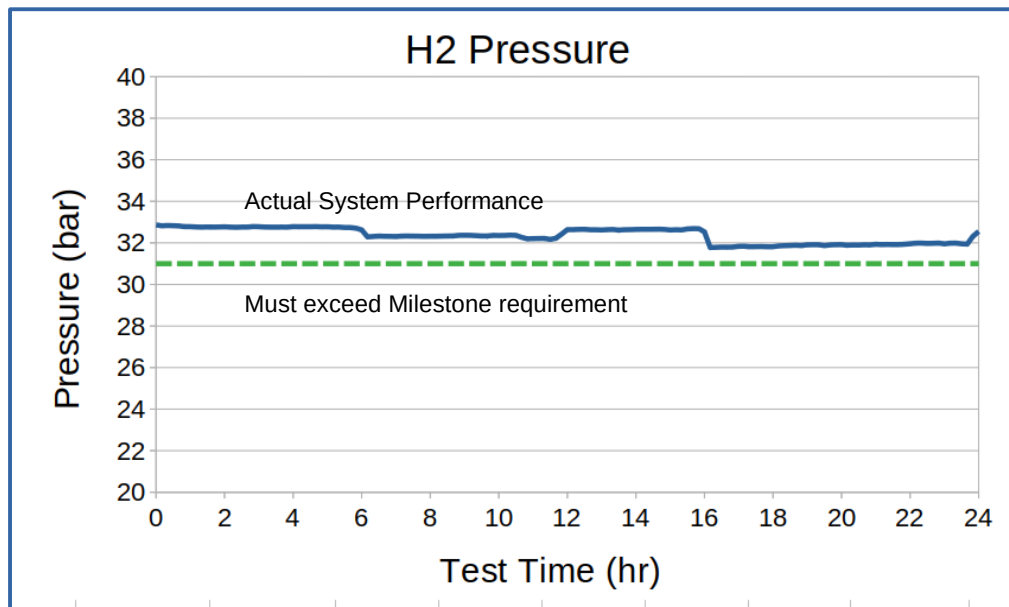


- 21 electrolyzers, 5 dryers
- External water purification system
- Enapter supported commissioning
- 24+ hour continuous test
 - 07:00 24-Aug to 08:00 25-Aug

H2 milestone complete in August 2021

Test was successful

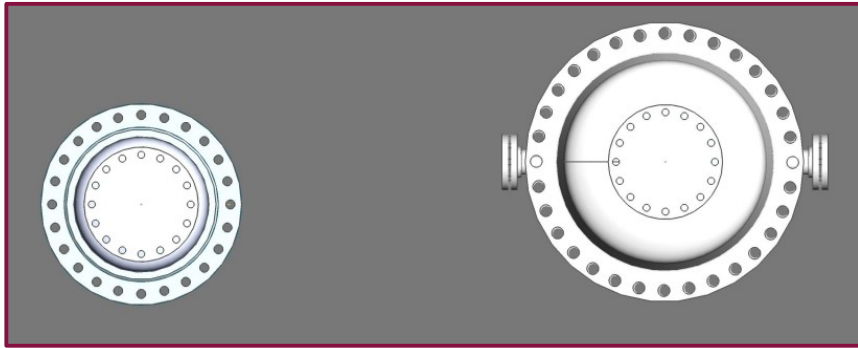
SKID achieved milestone requirements of pressure > 31 bar and flow > 20 kg/day (0.83 kg/hr)



Note 1. A power surge was experienced which shut down one electrolyser. Electrolyser was returned to operation after test completion.

Scaling the system resulted in design changes

- Reactor Vessel
 - Was: 24" pipe 24" long
 - Now: 36" pipe 24" long
- Output increased by factor of 13.2



24" Reactor vessel

36" Reactor vessel

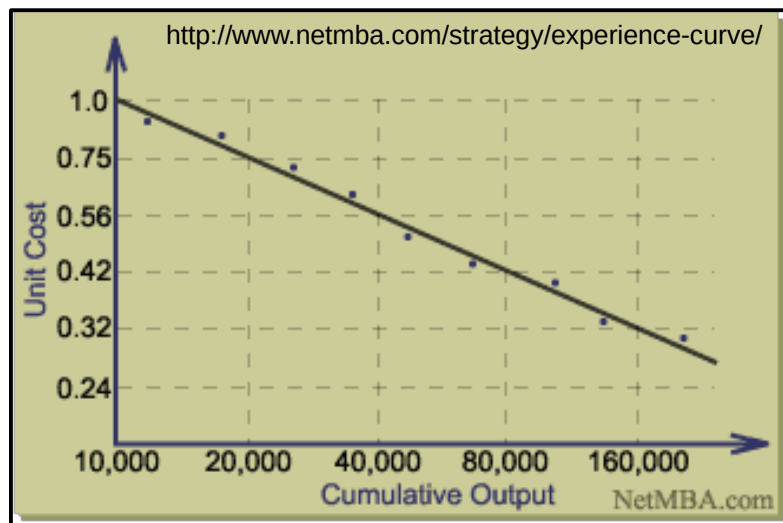
- Adsorber Vessel Regeneration

- Was: Thermal regeneration
 - Larger, Long Cycle Time
- Now: Novel regeneration technology
 - Smaller Size = Faster regeneration, Lower cost
 - More uniform flow



Previous adsorption bed

Experience curve drives cost reduction



Each doubling of cumulative production reduces cost 5 – 20%

- Ubiquitous in manufacturing
- Break the normal cost reduction approach to chemical synthesis
 - Traditionally reduce cost by increasing unit size
- Mass produced modules reduces cost for both large and small plants

Moving ahead



- Finish 100 kg design and fabrication
- Close Series B funding
- Continue growing the team
- Maximize capacity for conex building block
- Prepare for mass production

Questions?

