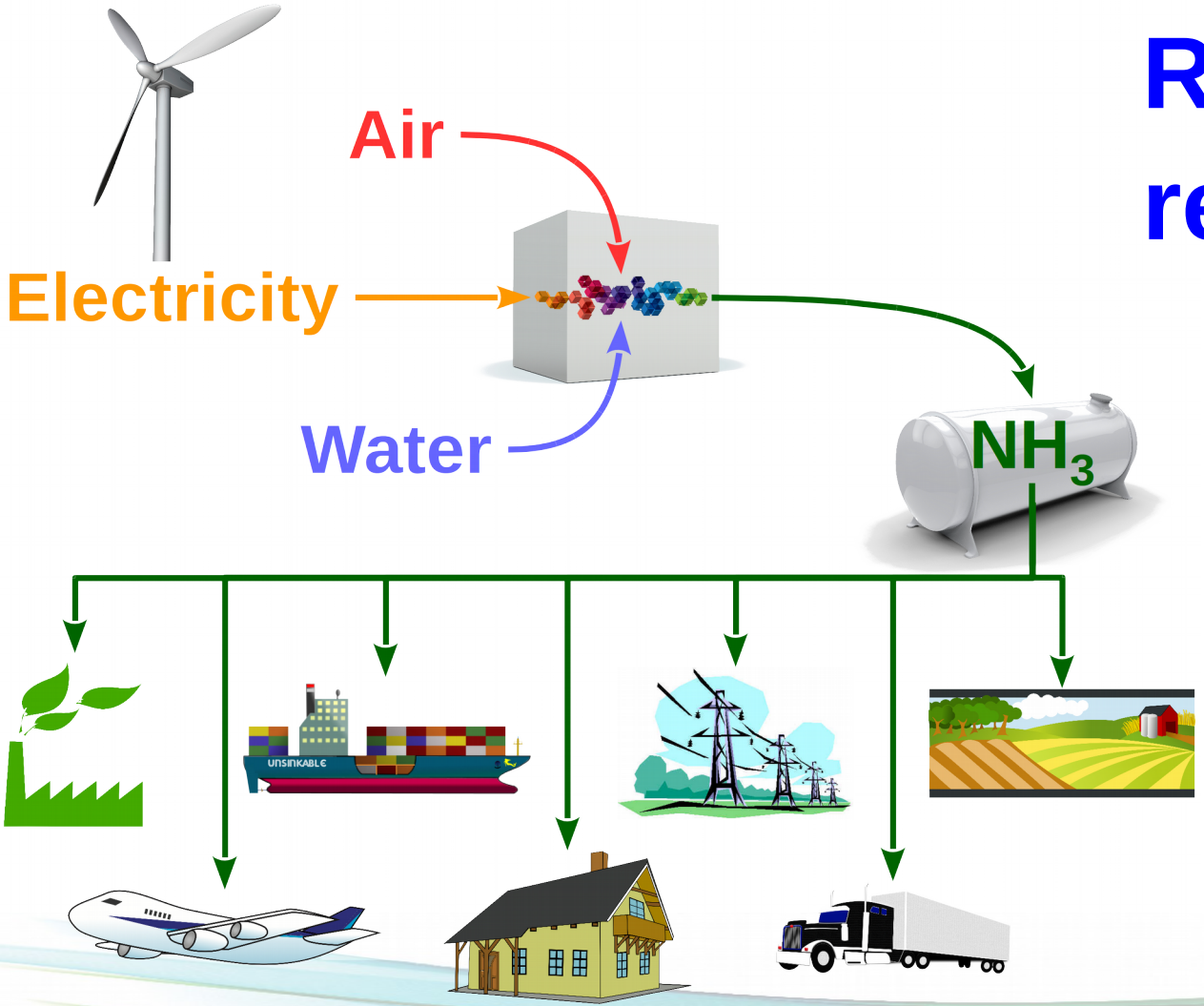
Rapid Ramp NH_3 reactor update

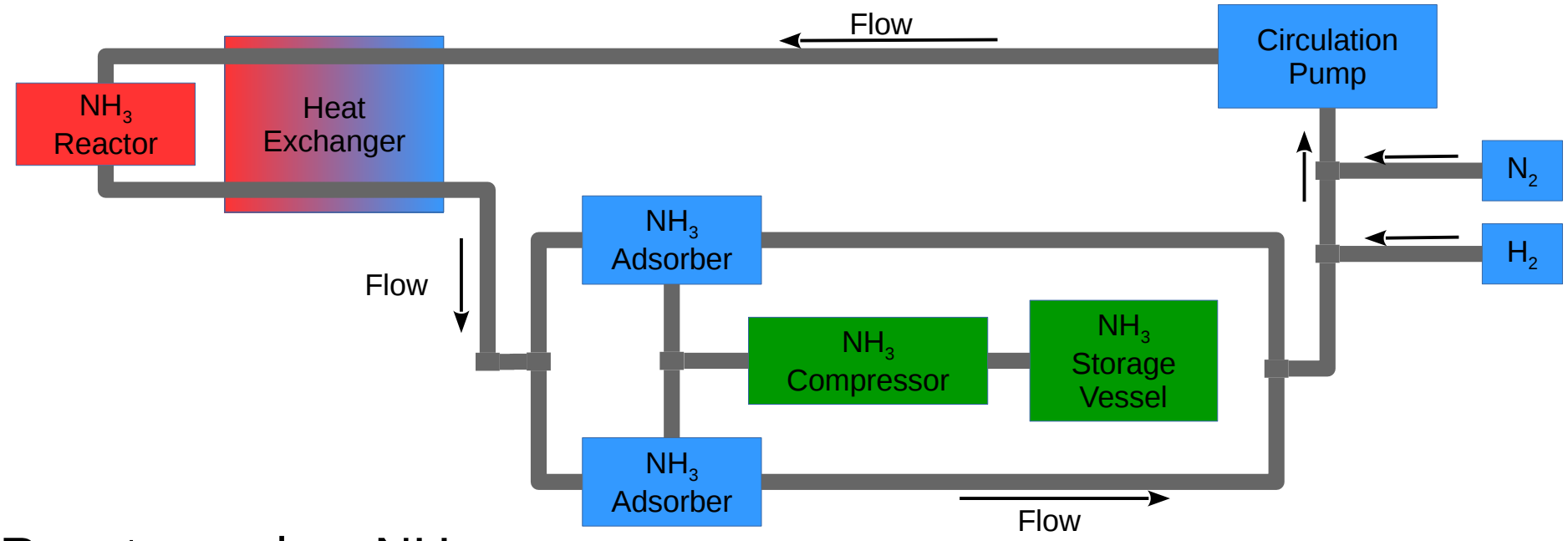


Starfire Energy Inc
Joe Beach
Jon Kintner
Adam Welch

Funded by ARPA-E 2015 Open
Award # DE-AR0000685

Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

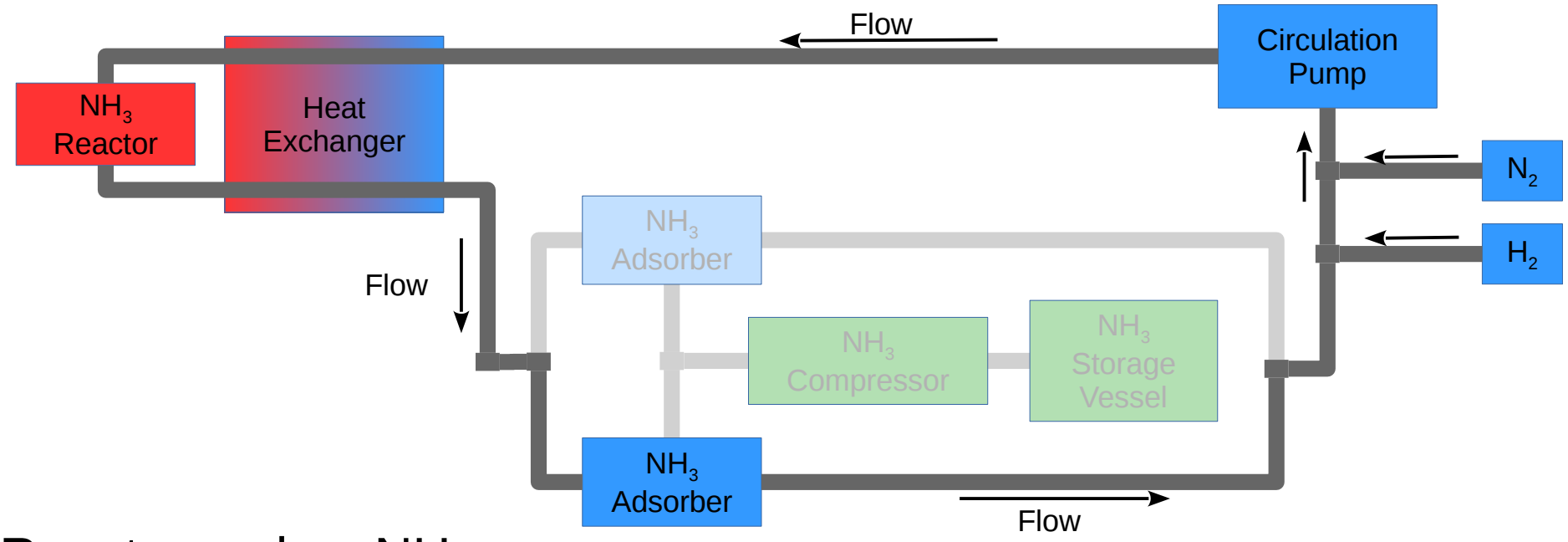
Prototype reactor



- Reactor makes NH_3
- NH_3 removed by one of adsorption cannisters
- Unused reactants recirculated
- Adsorber regeneration makes liquid NH_3

Starfire Energy
Making Sustainable Energy A Reality

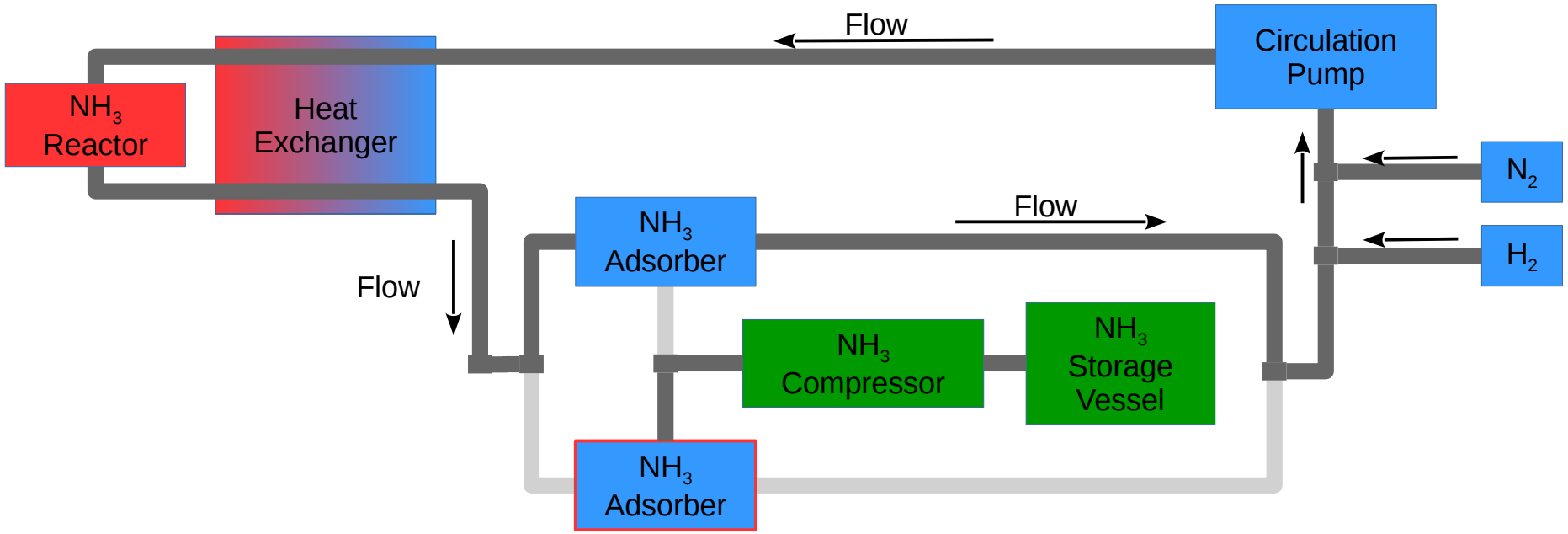
Prototype reactor



- Reactor makes NH_3
- NH_3 removed by one of adsorption cannisters
- Unused reactants recirculated
- Adsorber regeneration makes liquid NH_3

Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

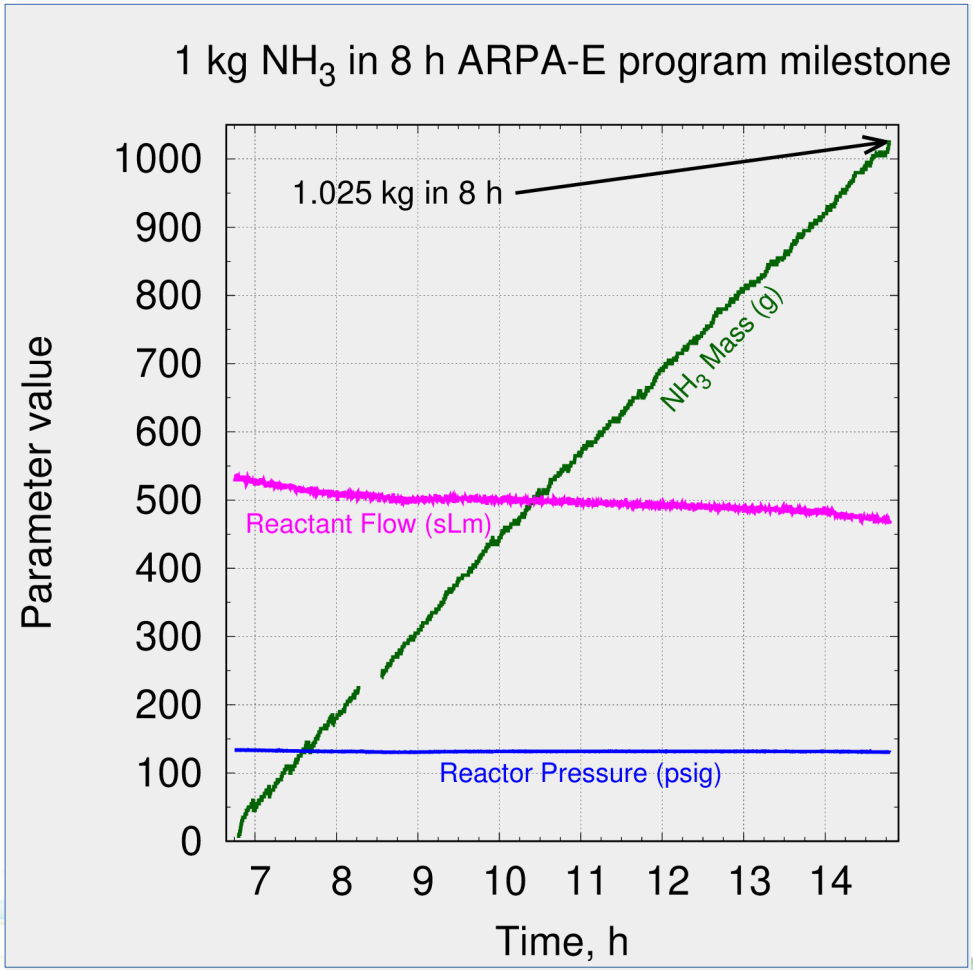
Prototype reactor



- Reactor makes NH_3
- NH_3 removed by one of adsorption cannisters
- Unused reactants recirculated
- Adsorber regeneration makes liquid NH_3

Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

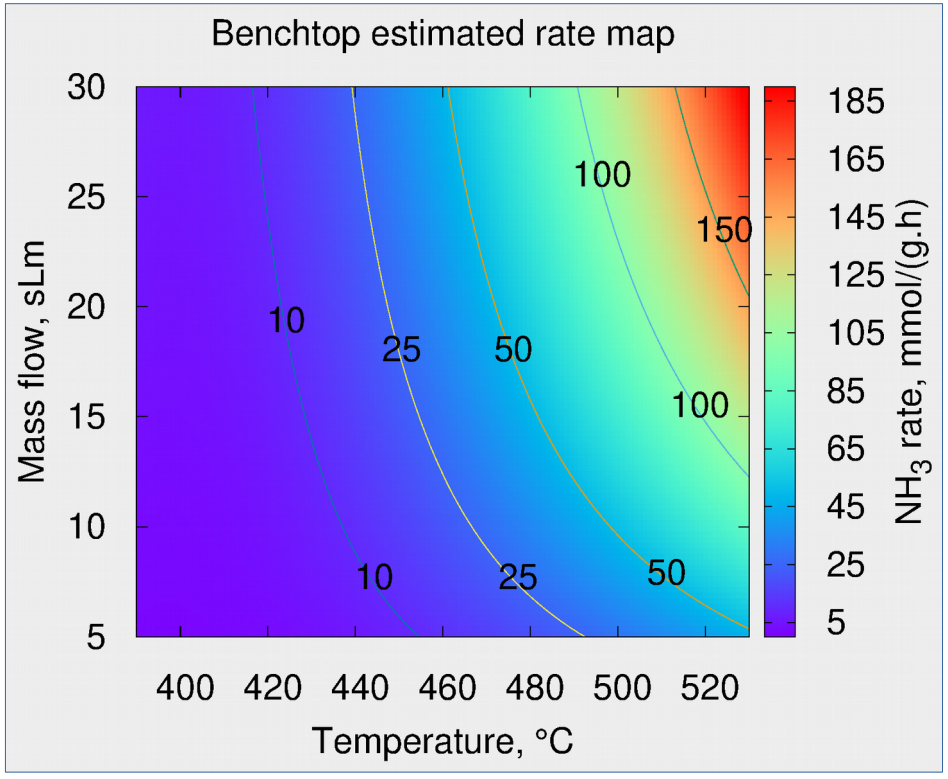
Achieved ARPA-E project target

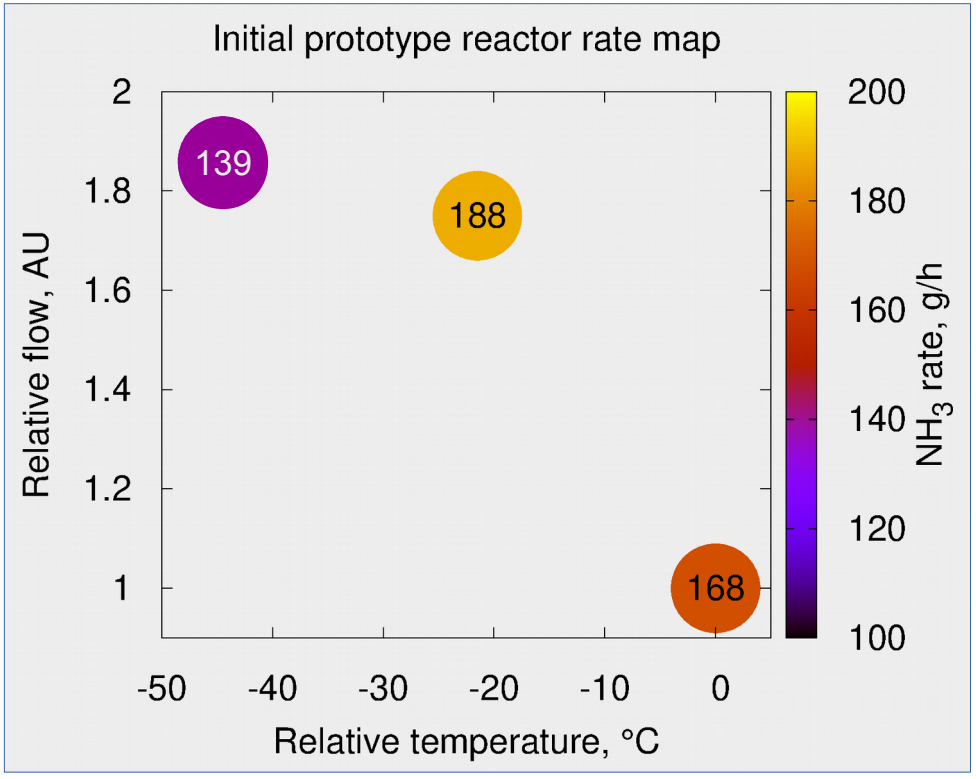


- 0.4 kg Starfire Energy catalyst powder on inert support
- 10 bar total pressure
- 75% H_2 + 25% N_2
- Measured mass accumulation in adsorber
- Achieved program milestone

Starfire Energy
Making Sustainable Energy A Reality

Prototype rate seems to mimic benchtop

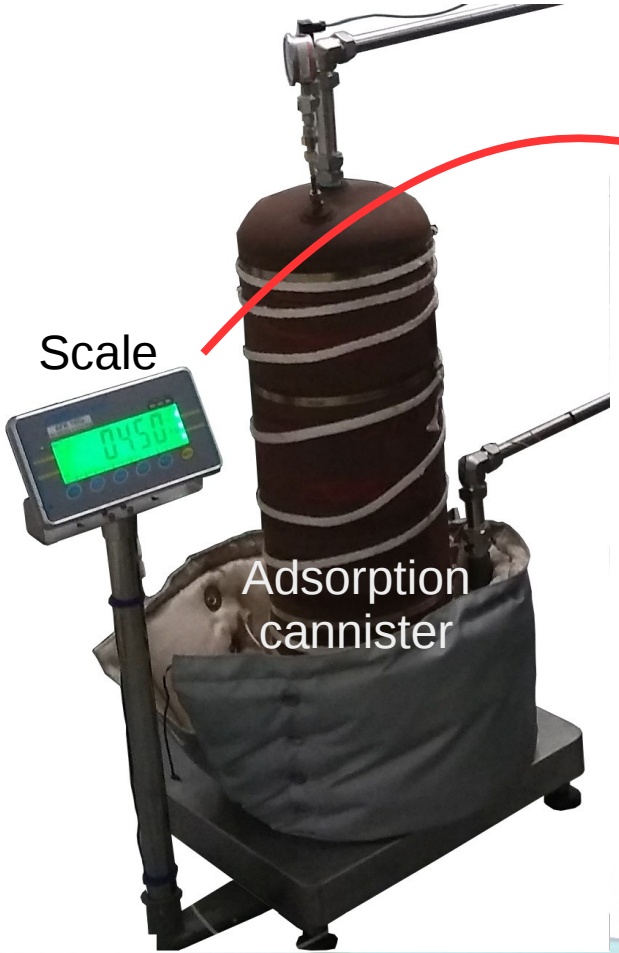




- Benchtop data shows ramp with flow and temperature
- Prototype initial data suggests similar trends

Starfire Energy
Making Sustainable Energy A Reality

NH_3 sensors improve feedback

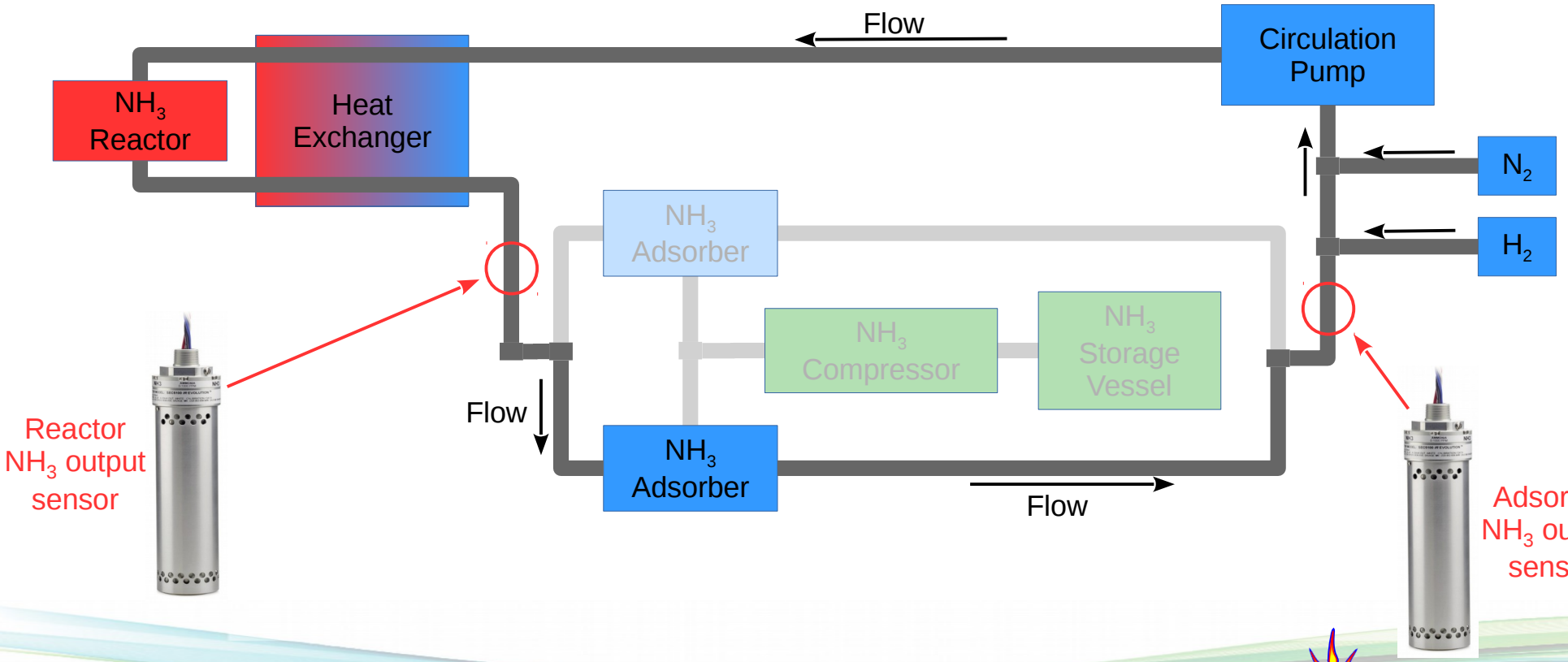


NDIR sensor

- Scale works in steady state, but noisy in changing conditions
- RGA is costly
- NDIR is low cost, but had to modify for this application
- Possible area of interaction with RAPID program

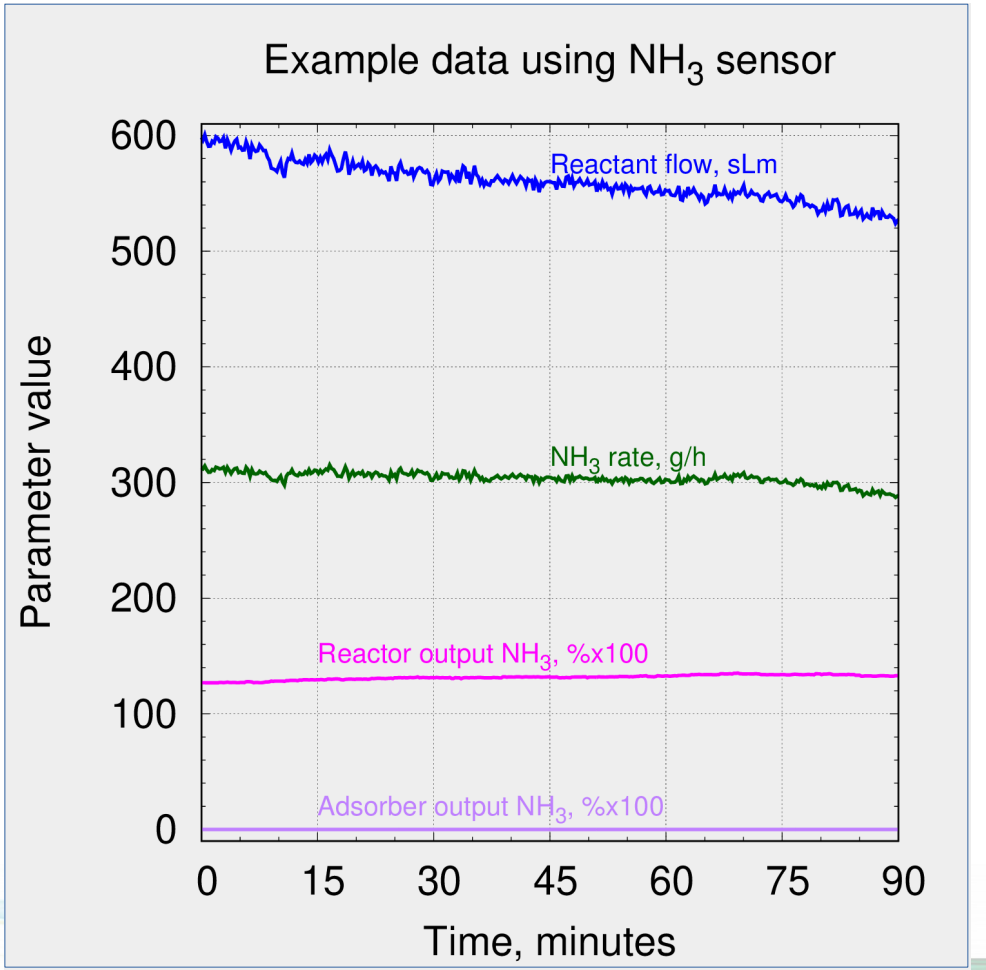
Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

Prototype reactor



Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

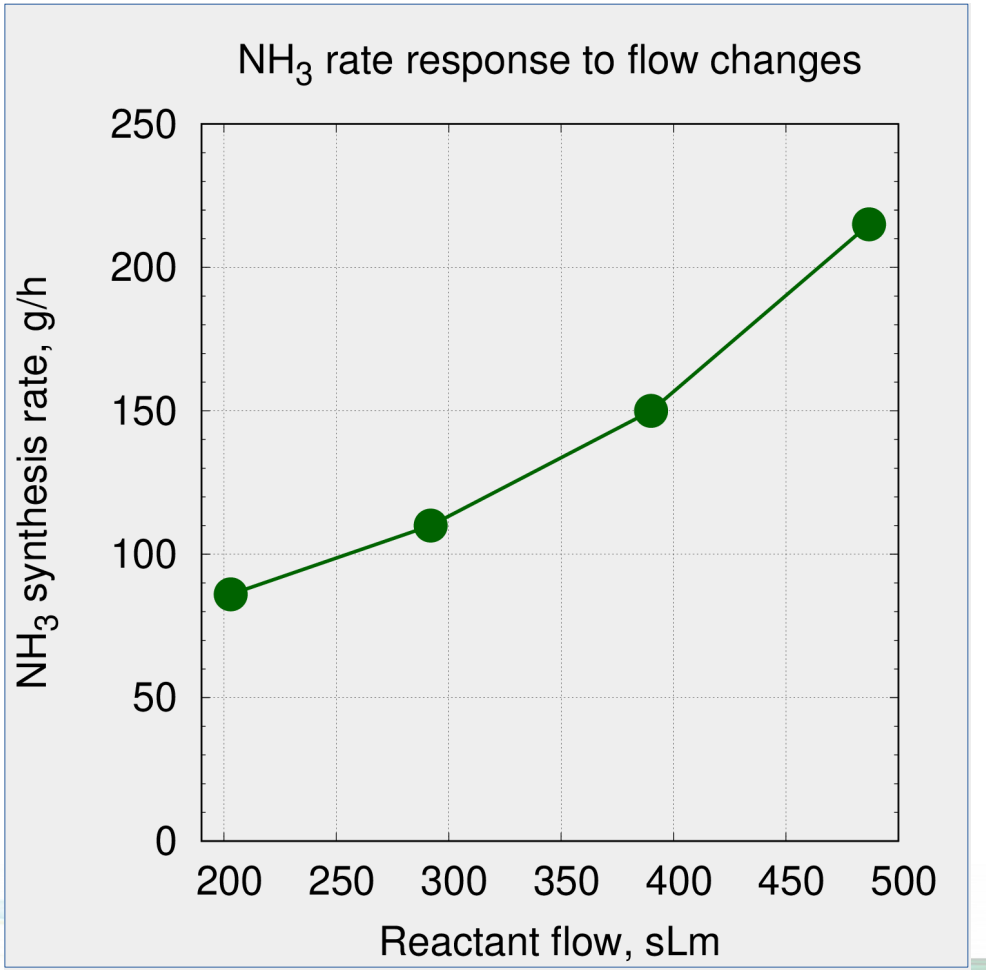
Rapid Ramp NH_3 works with Fe catalyst



- Tested commercial Fe catalyst due to concerns expressed about Ru
- 7.2 kg Fe catalyst, as opposed to 0.4 kg Starfire powder on inert support
- Sensors provide quick NH_3 rate feedback
- No detectable NH_3 exiting adsorber

Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

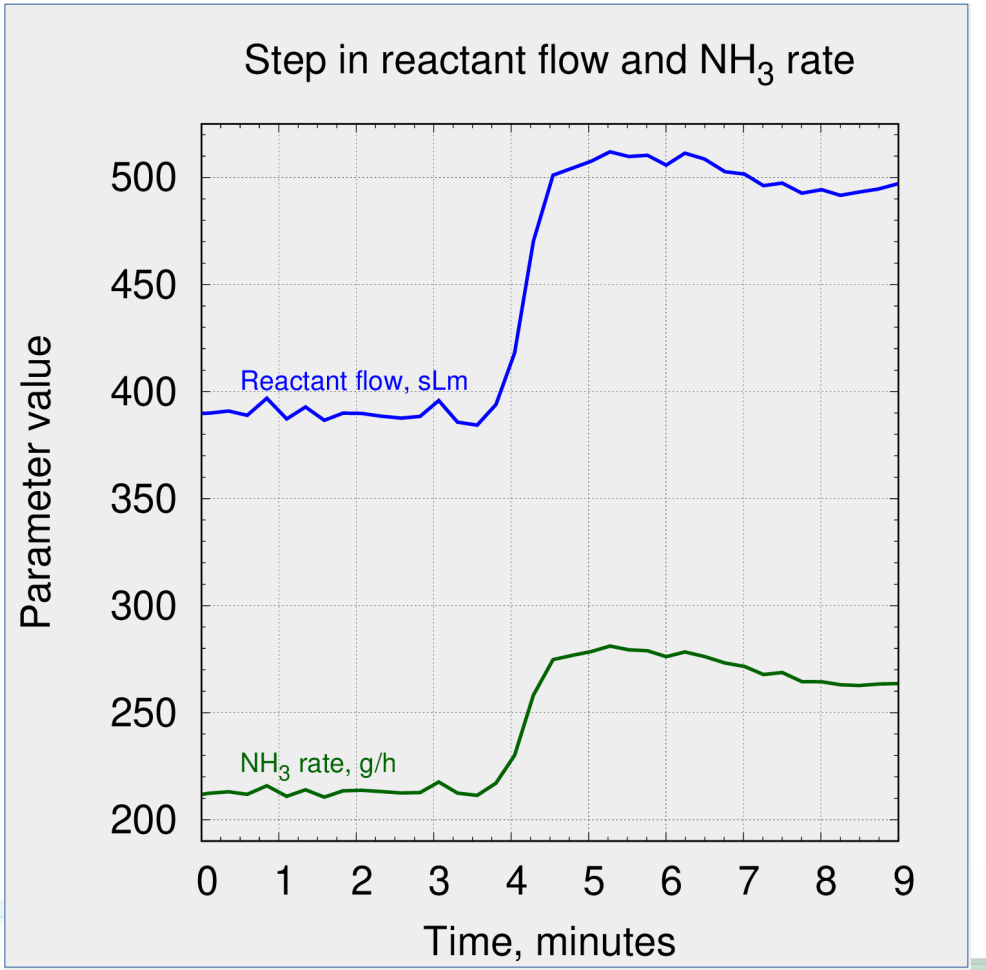
Synthesis rate ramps with flow



- 75% H_2, 25% N_2
- Flow varied using bypass on constant speed recirculator
- Roughly linear rate increase with flow

Starfire Energy
Making Sustainable Energy A Reality

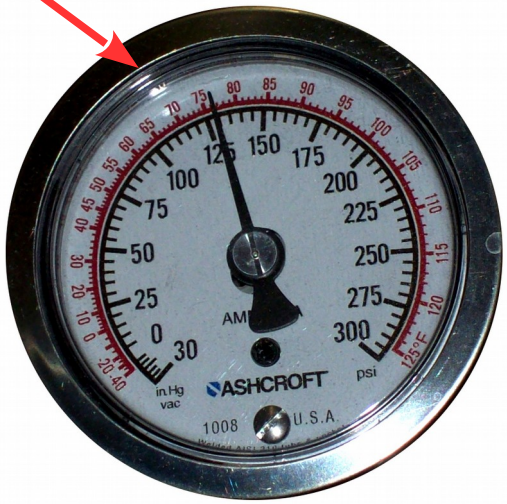
“Rapid Ramp” demonstrated



- 75% H_2, 25% N_2
- Flow increased by opening recirculator throttle valve
- Rate follows flow very closely
- Rate ramp rate = flow ramp rate

Starfire Energy
Making Sustainable Energy A Reality

NH_3 recovered as liquid



- NH_3 extracted from adsorber & liquefied
- 13.5 bar compressor, cooled storage vessel
- Liquefied NH_3 agreed with adsorber mass accumulation
- Final product P vs T indicates nominally pure NH_3

Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

Process works, refinement continues

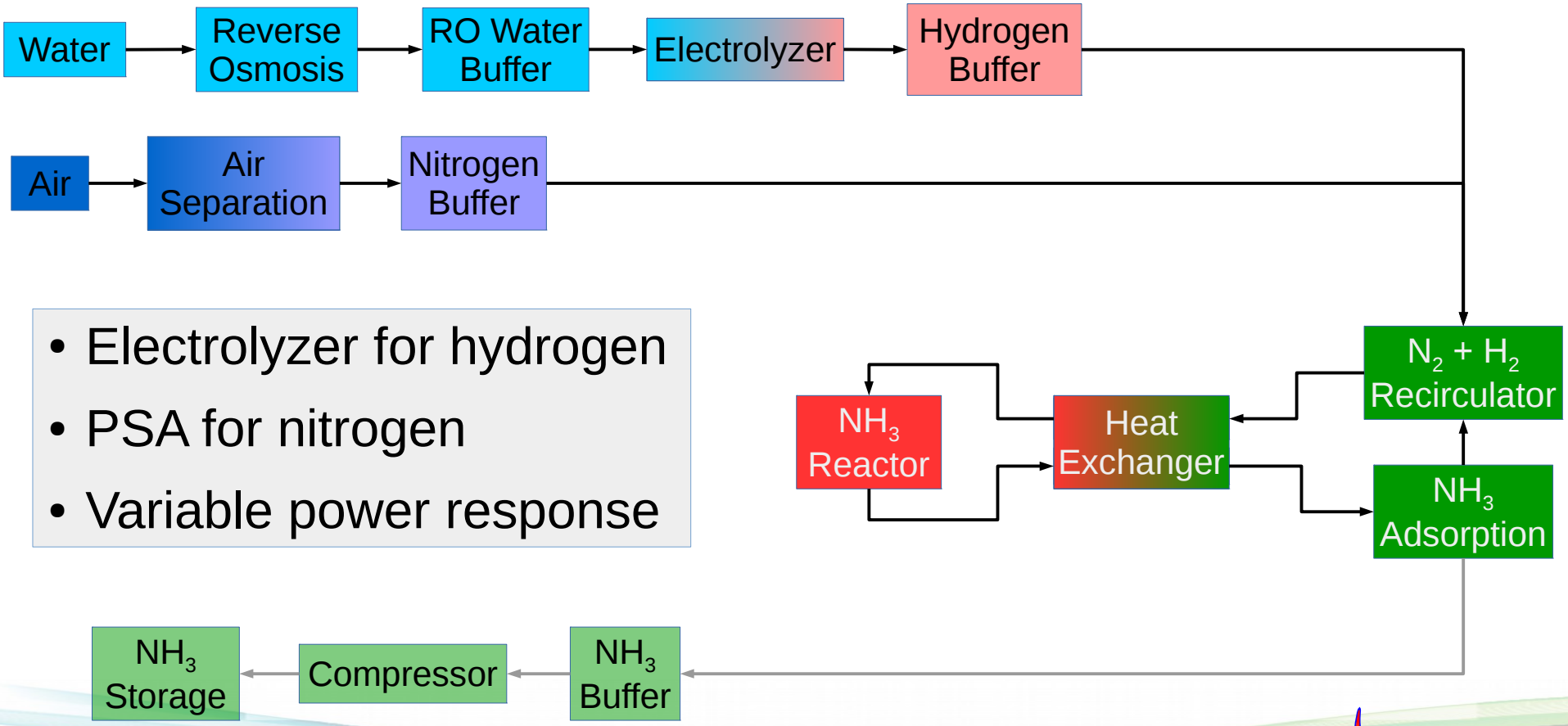
Starfire catalyst powder

Commercial catalyst granules

- Catalyst granules and pellets
- Catalyst bed design
- Adsorption bed design
- Regeneration optimization

Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

Next phase: 10 kg/day system



- Electrolyzer for hydrogen
- PSA for nitrogen
- Variable power response

Starfire Energy
Making Sustainable Energy A Reality

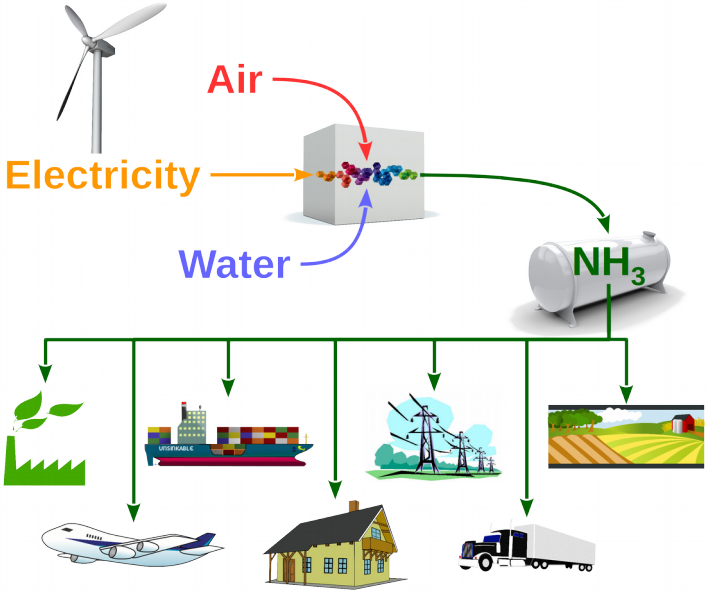
Business development proceeding well

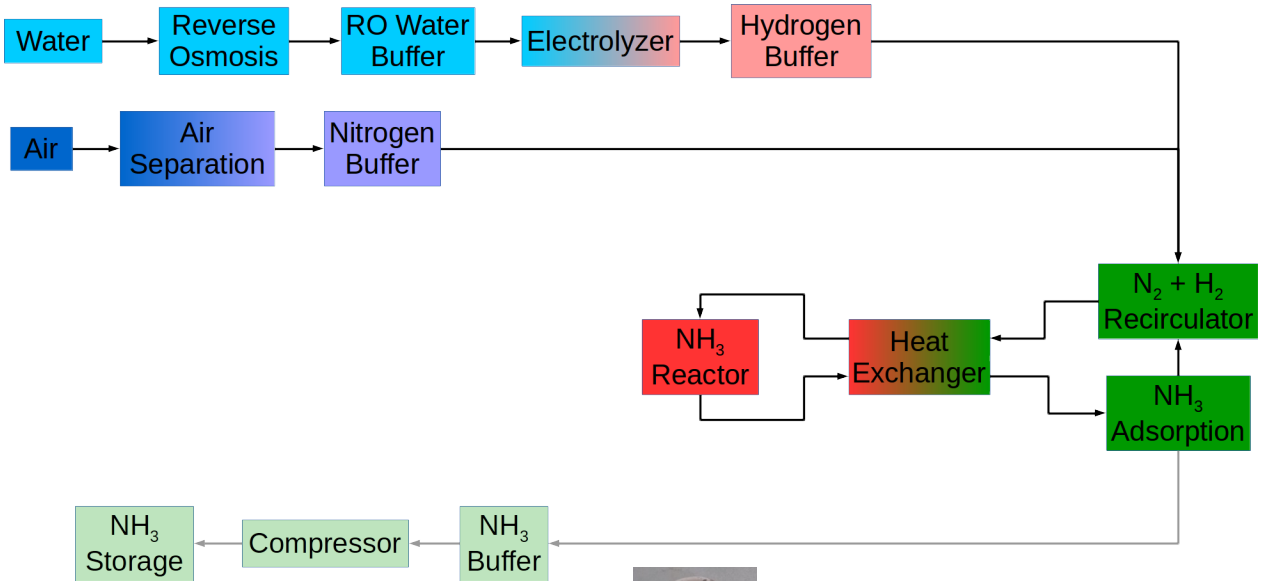
UNITED STATES
PATENT AND TRADEMARK OFFICE
uspto

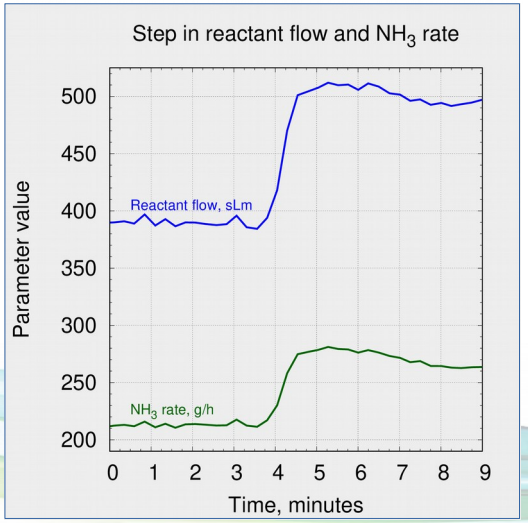
- Patents pending
- ARPA-E funding addition
- Increasing staff & space
- Creative Destruction Lab
- RAPID program
- Hello Tomorrow Top 500
- Supply chain developing
- Investors & partners engaged

Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY

Questions?







Starfire Energy
MAKING SUSTAINABLE ENERGY A REALITY