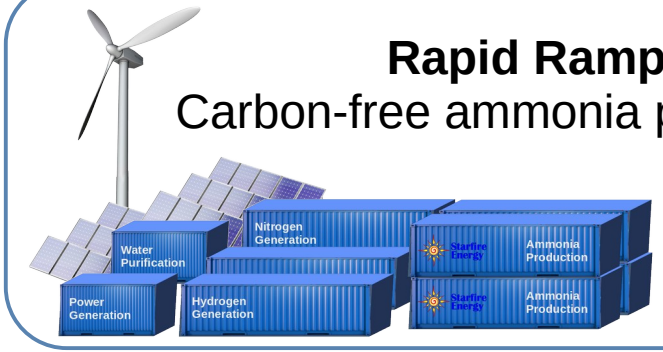
Starfire Energy

MAKING SUSTAINABLE ENERGY A REALITY

Prometheus ammonia cracking product development

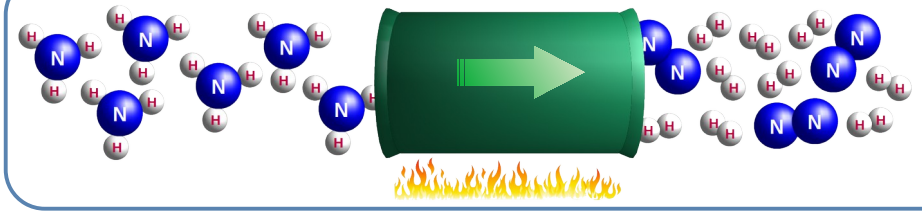
Joe Beach, CEO & Founder

Starfire Energy: ammonia fuel production & use

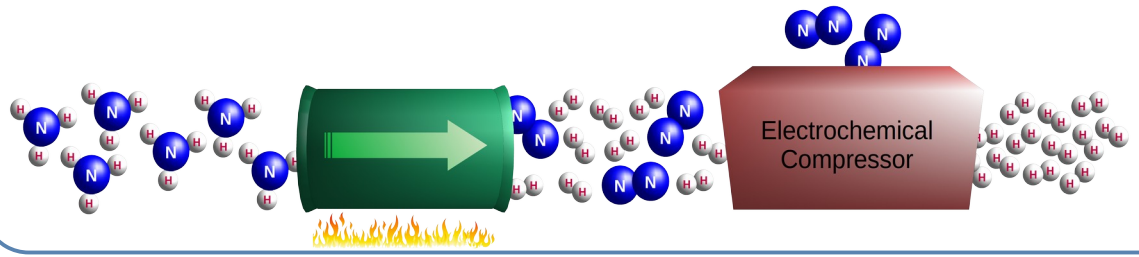


Rapid Ramp
Carbon-free ammonia production

- Three product lines
- Products share underlying technologies
- Goal: 100% CO_2-free energy system
  - All sectors, not just electricity

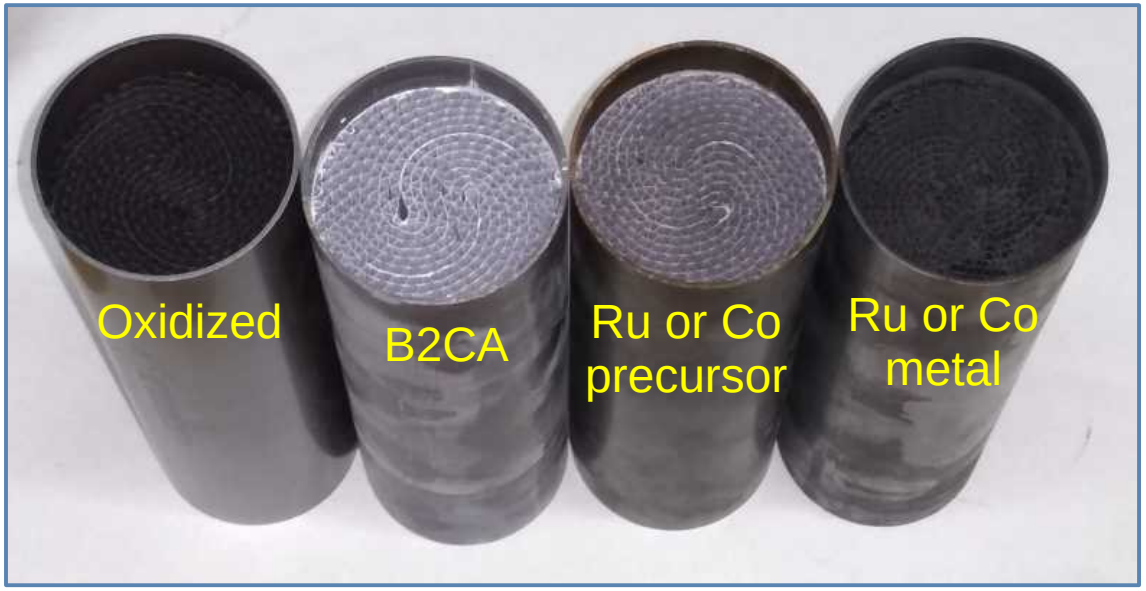


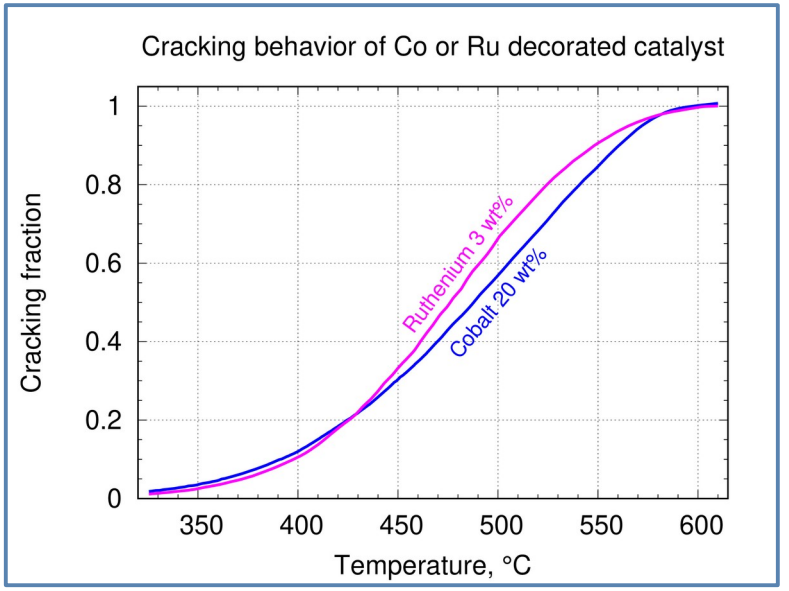
Prometheus Fire
Ammonia cracking for burnable ammonia-hydrogen blends



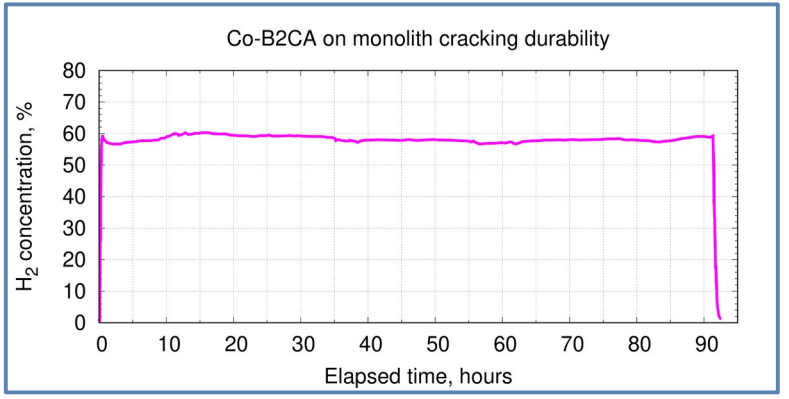
Prometheus Hydrogen
High purity, high pressure hydrogen from ammonia

Started at benchtop to prove catalyst





- Patent-pending B2CA catalyst support
- Ru or Co active metal decoration
- Robust bonding to metal substrate
- Lower temperature cracking
- Stable in 90 h test



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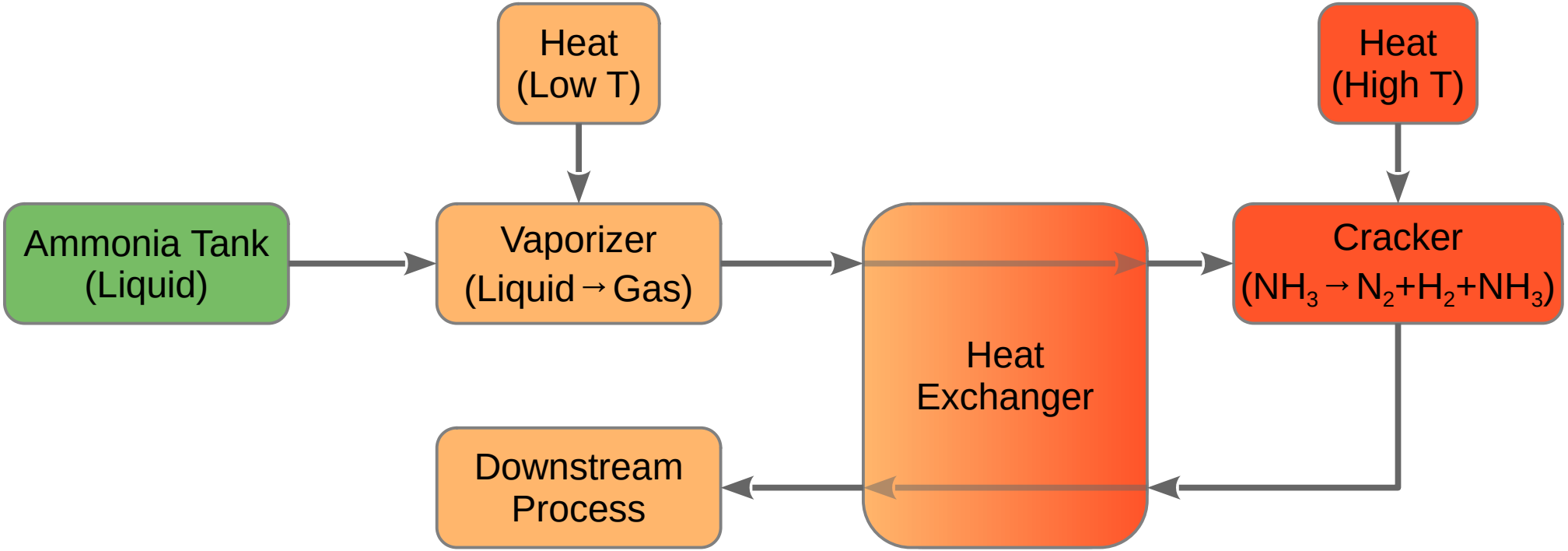
Modified commercial natural gas burner to use NH_3

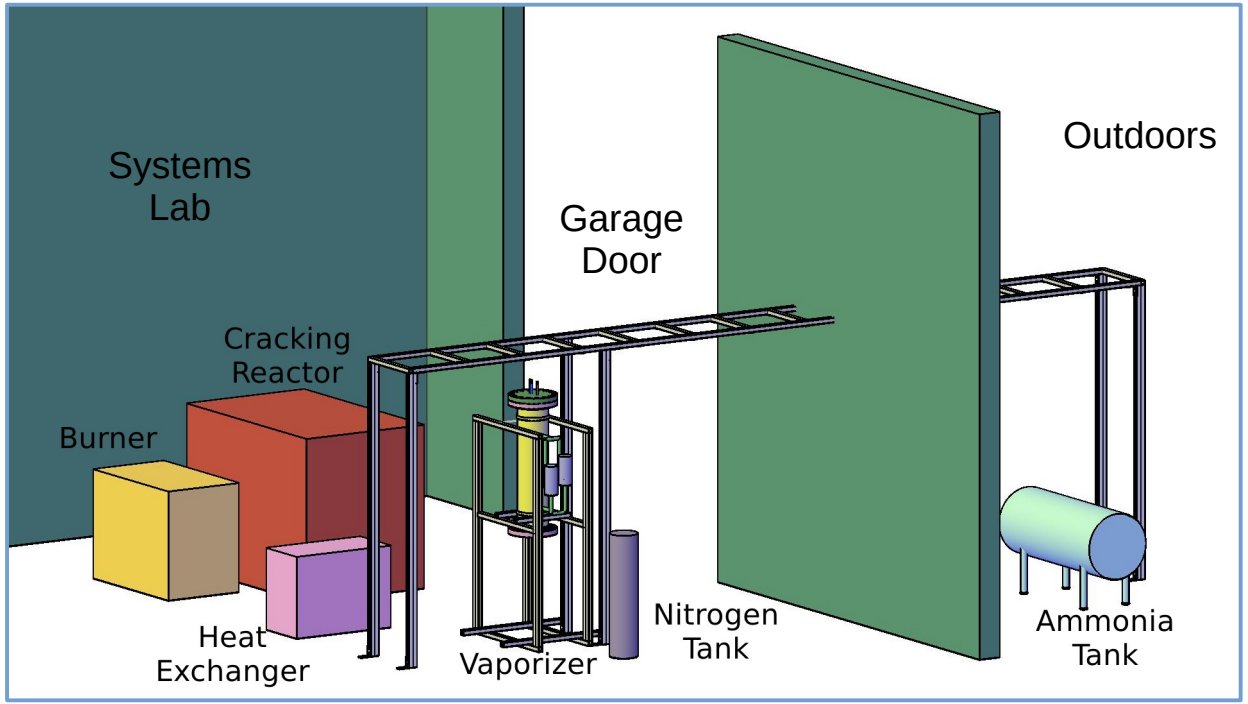
- Self-balancing array of 15 lab monoliths
- Heated by burner exhaust
- Lightly modified natural gas burner
- Self-sustaining CO_2-free operation
- Lesson: good heat transfer is **critical**

Bigger crackers need vaporizer & heat exchanger



- Cracker requires ammonia gas
- Vaporizer is essential for large ammonia gas flows
- Heat exchanger retains heat in cracker

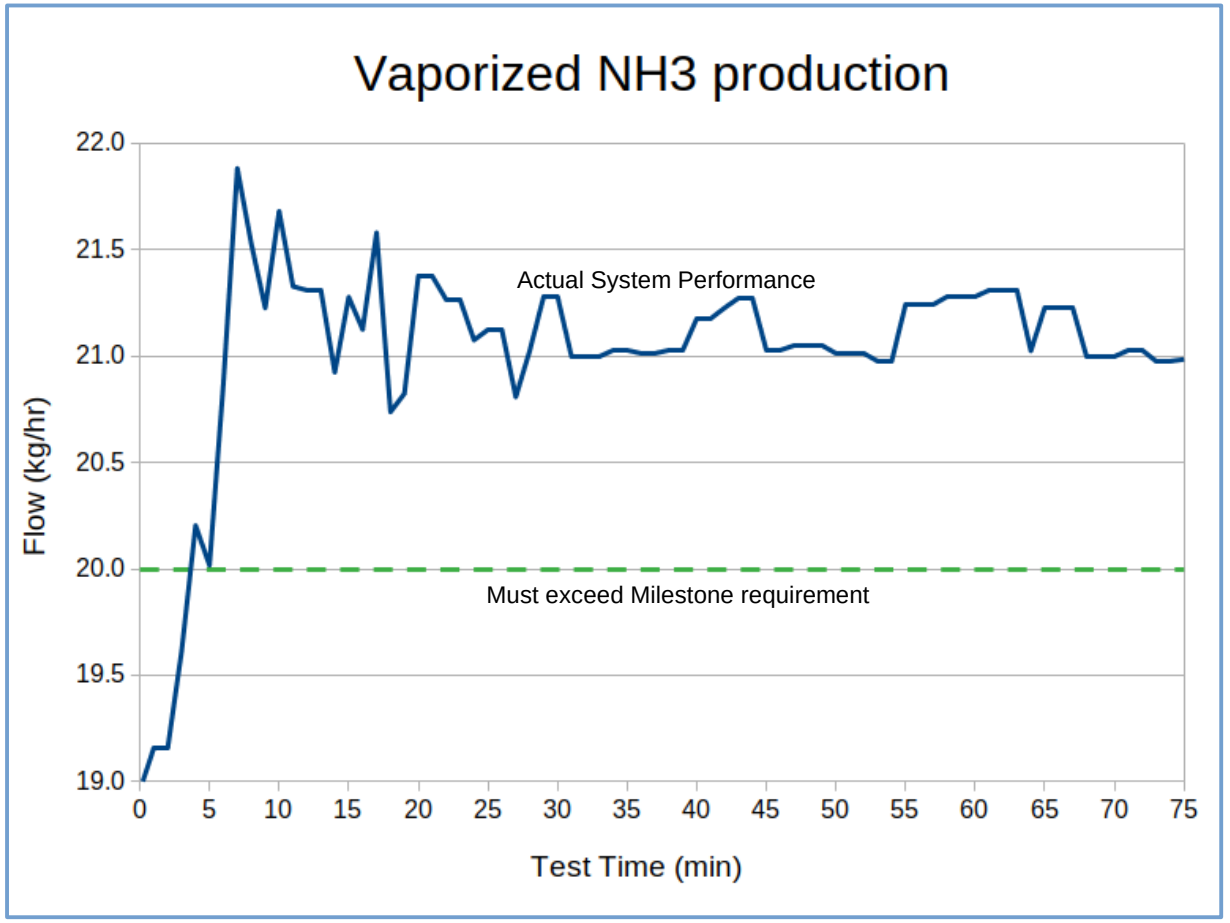
Building a 20 kg/h NH_3 cracker at our facility



- 20 kg NH_3/h vaporizer & cracker
- Electrically heated vaporizer
- Combustion heated cracker
- Two end-use options
  - 70/30 blend for 1.5M BTU/h burner
  - Cracked gas stream for 84 kg/day fuel cell grade H_2

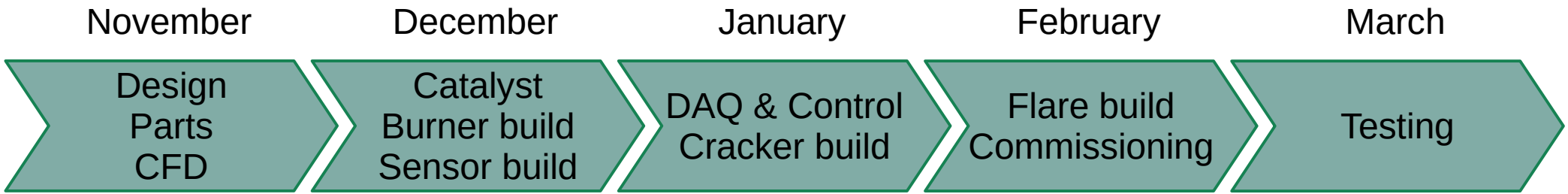
Vaporizer successfully designed & built

20 kg/h NH3 vaporizer designed & built



- 112-120 psig vapor to MFC
- 26-30 °C outlet vapor
- Heat trace on vapor tubing and MFC to prevent NH_3 condensation
- 37 °C vapor at MFC

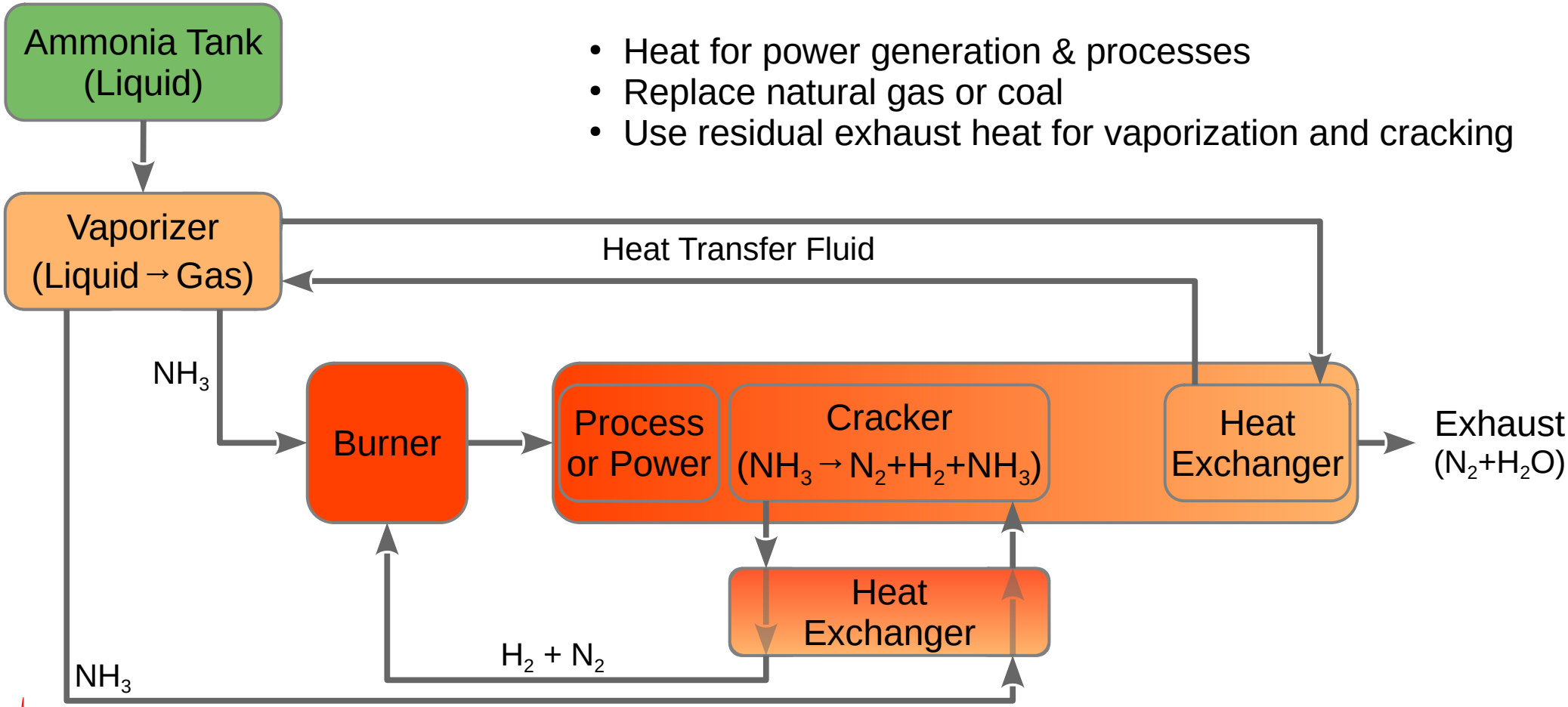
20 kg/h cracker ready to test in 2022-Q1



- Design nearly complete
- Ru/B2CA catalyst
- Novel heat exchanger design
- 1-10 barg, 400-600 °C, 1-20 kg/h
- Output composition characterization
- Foundation for Prometheus products

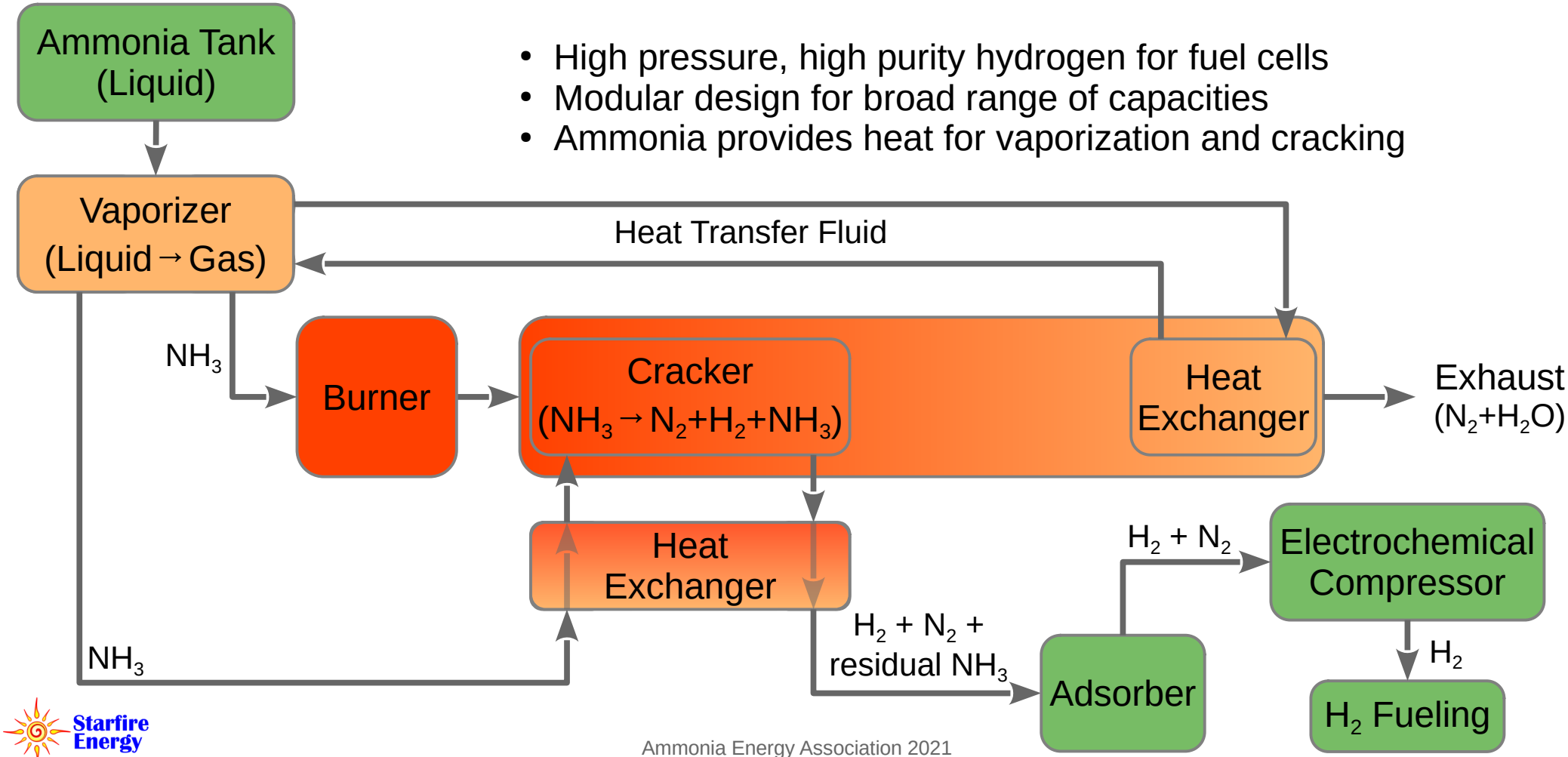
Prometheus Fire: Carbon-free combustion

- Heat for power generation & processes
- Replace natural gas or coal
- Use residual exhaust heat for vaporization and cracking



Prometheus Hydrogen: Modular hydrogen delivery

- High pressure, high purity hydrogen for fuel cells
- Modular design for broad range of capacities
- Ammonia provides heat for vaporization and cracking



Prometheus Hydrogen mitigates a strategic mistake

- Hydrogen's logistics problems are obvious
  - 700 bar (10,000 psi) is not okay
  - -253 °C is not okay
- Heavy focus on H_2 fuel has been a strategic mistake
  - We can make H_2 from NH_3, but direct NH_3 fuel is cheaper

Ammonia is strongest as a direct fuel

- Direct NH_3 fuel gives lowest cost
- Cracking aids NH_3 combustion
  - Crack just enough for needed properties
- We need to promote direct NH_3 fuel
  - Burners: turbines, process heat, space heat
  - Internal combustion engines
  - Fuel cells: high and low temperature

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Please ask questions during panel discussion

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