Starfire Energy’s 10 kg/day Rapid Ramp NH$_3$ System Development

Starfire Energy Inc
Joe Beach, CEO

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Starfire Energy is a clean energy company

- Research, development, deployment
- Solar, hydrogen, business background
- 7 full-time, 2 part-time staff
Clean power plants into clean fuel factories

New US Great Plains wind
- $0.012 – $0.020/kWh
- 50% – 65% capacity factor

New US Southwest solar
- $0.04 - $0.07/kWh
- 20% - 30% capacity factor
Clean power plants into clean fuel factories

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Fuel synth. must mesh with variable power

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“Rapid Ramp NH₃”: flexible ammonia synth.

- N₂ and H₂ used as they are made
- No massive reactant buffering
Monolith catalyst & NH$_3$ adsorption are key

**Monolith catalyst**
- High catalyst utilization
- Near-zero pressure drop

**NH$_3$ adsorption removal**
- No liquefaction constraints
- Any reactor P or T
Implementing process in 10 kg/day system

- PSA nitrogen
- AEM hydrogen
- 30 bar e-chem $\text{H}_2$ compress.
- Pneumatic $\text{N}_2$ press. boost
Building 10 kg/day system as we speak
10 kg/day is first of several iterations

- 10-25x scaling increments to 50 tpd
- Each scale has a purpose
- Integration, modularization, market validation, mass production
Modular systems reduce business risk

- Cost $10M’s instead of $1000M
- Add units as need increases
- Deploy near end-use
- Deploy near clean energy

Two ways to increase capacity

- Increase number of modular units
- Increase unit size

VS
• Assumes 65% CF, $0.01/kWh
• Unit size dictated by capex and desired initial NH$_3$ cost
• Mass production continues to drive down cost
Synthesis tech refinement continues

- Lower capex membrane-less H₂
- Variable-power membrane N₂
- Better adsorbent material & process
- Capex – operating pressure – NH₃ cost
Expanding into NH$_3$ fuel utilization

- Monolith NH$_3$ cracking catalysts
- Natural gas burner conversion
- High purity, high pressure H$_2$ from NH$_3$
Expanding Starfire Energy’s NH₃ team

<table>
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<th>Year</th>
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<td>2019</td>
<td>7 + 1 part-time</td>
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Questions?

- Monolith catalyst & NH$_3$ adsorption
- 10 kg/day system being built
- Iterate to 50 tpd modular system
- Mass produce to drive down costs
- Developing NH$_3$ fuel utilization tech
Additional slides
Synthesis rate ramps with reactant flow

Monolith catalyst at 10.5 bar

NH₃ synthesis rate, mmol g⁻¹ h⁻¹ vs. Space velocity, minute⁻¹

NH₃ synthesis rate, g h⁻¹ g⁻¹ cat

Operating Pressure, bar

Haber-Bosch
Rapid Ramp Capability
Low CapEx

Starfire Energy
“Rapid Ramp” demonstrated

- 75% H₂, 25% N₂
- Flow increased by opening recirculator throttle valve
- Rate follows flow very closely
- Rate ramp rate = flow ramp rate