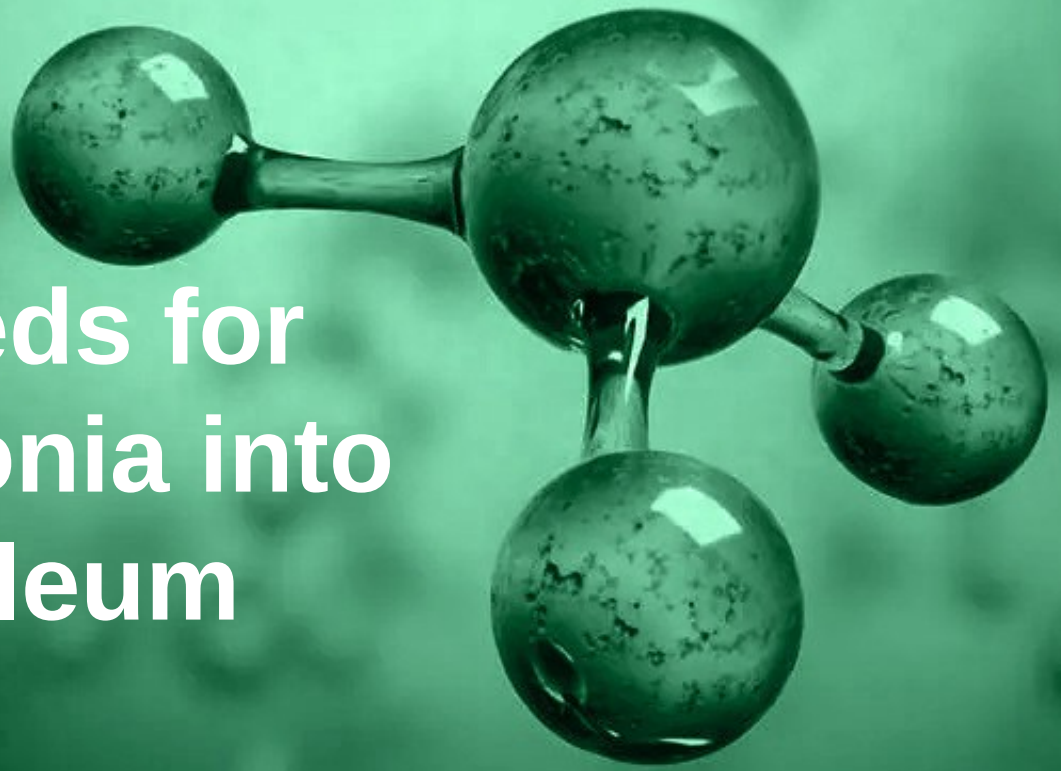
Starfire Energy

MAKING SUSTAINABLE ENERGY A REALITY



Hydrogen needs for making ammonia into the new petroleum

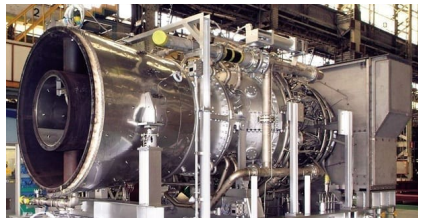
January 2024

Ammonia: It's not just for fertilizer any more

Grid Storage

Co-fired Coal

Gas Turbine



Maritime Fuel

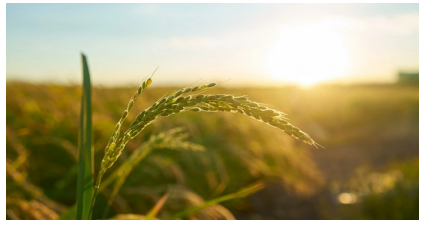
Industrial Heat

Mining

Hydrogen Delivery

Building & Water Heat

Agriculture



Pending markets

- Seasonal storage
- Grid firming
- Marine shipping
- Heavy equipment
- Aviation
- Building & water heat
- Hydrogen delivery

Ammonia solves hydrogen's storage & transport problems

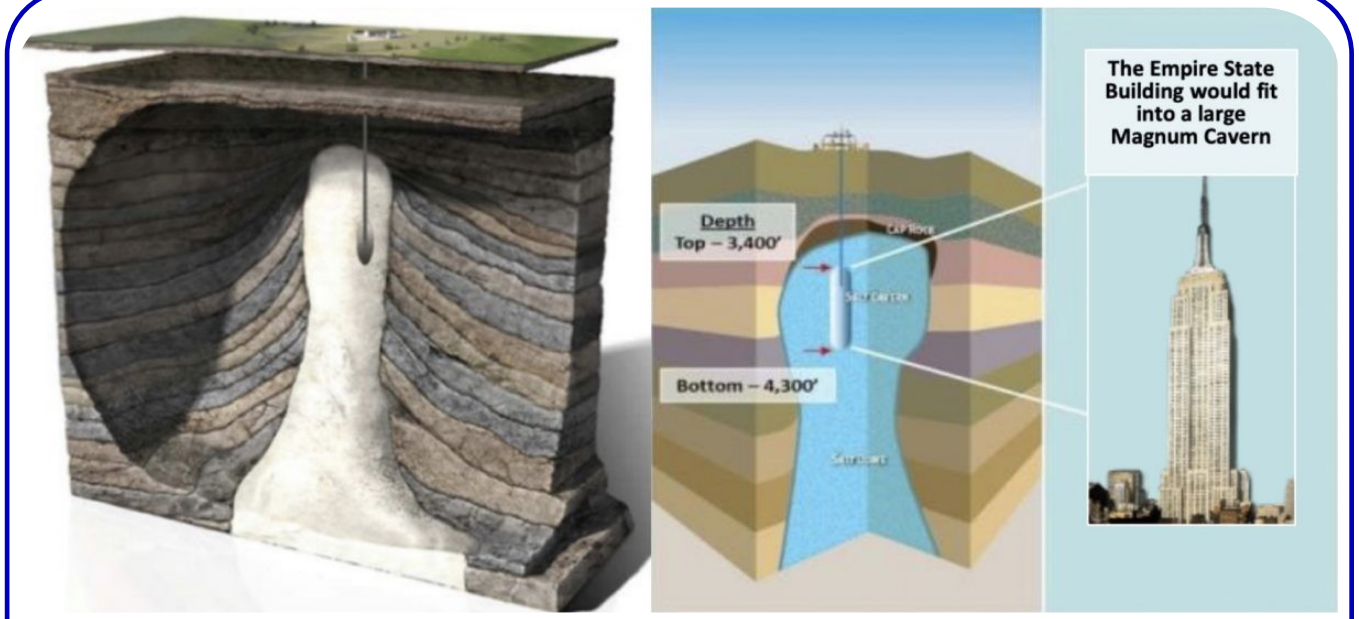
Hydrogen is difficult and expensive to handle.

Ammonia fixes these weaknesses

Ammonia's benefits

- Liquefies easily: -33 °C or 150 psi
- Inexpensive steel tanks and pipes
- Strong odor – leaks immediately noticed
- Nearly impossible to detonate
- Global distribution already developed

Ammonia allows TWh scale energy storage anywhere



Salt dome hydrogen storage is limited by geology

- Subsurface pressurized hydrogen
- 300,000 MWh
- Days of full power grid
- ~$30-$40M + cushion gas cost

Ammonia tanks can be located where needed

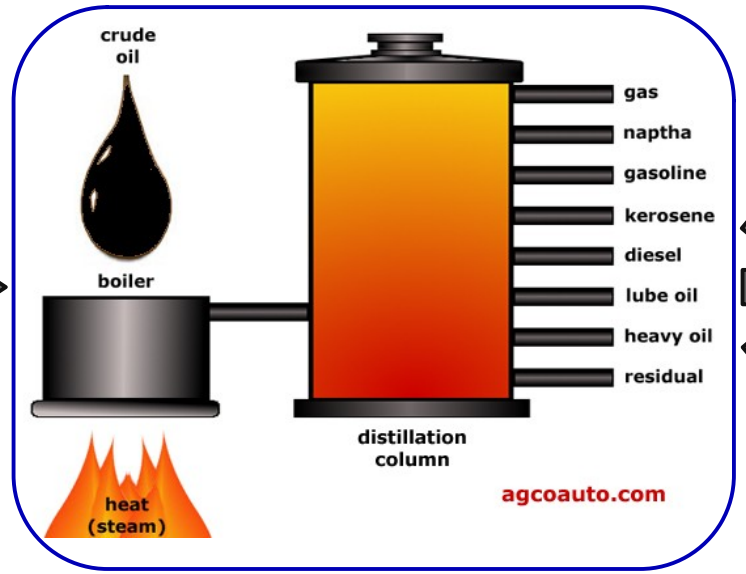
- Chilled liquid ammonia
- 312,000 MWh
- Days of full power grid
- ~$30M

Petroleum: easy storage & transport, refine into good fuels

Petroleum

- Easy storage
- Easy transport
- Lousy fuel

Refining



- Transform
- Blend together
- Better fuel

Gaseous fuels

Chemical feedstock

Liquid fuels

Gasoline is a highly engineered, multicomponent fuel

Gasoline

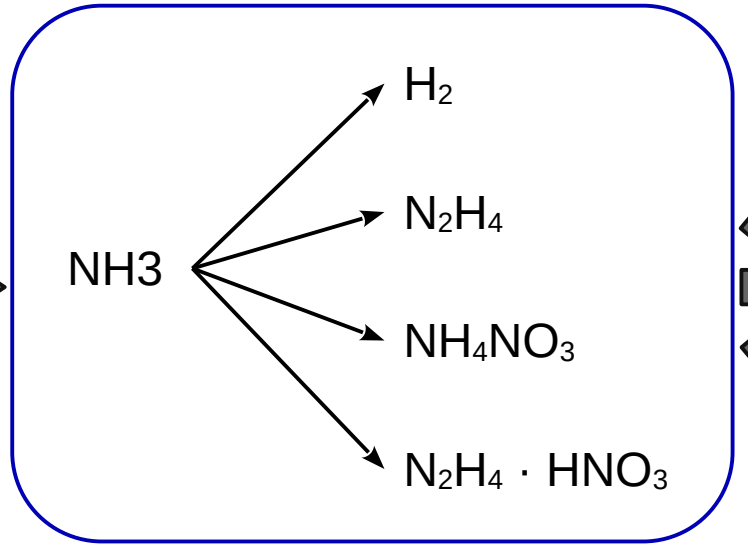
- 150 to 1,000 different chemicals
- Some left over from refining
- Some added to improve characteristics
- Why should carbon-free fuel be restricted to a pure single molecule?

We can make ammonia into the carbon-free petroleum

Ammonia

- Easy storage
- Easy transport
- Difficult ignition

Processing



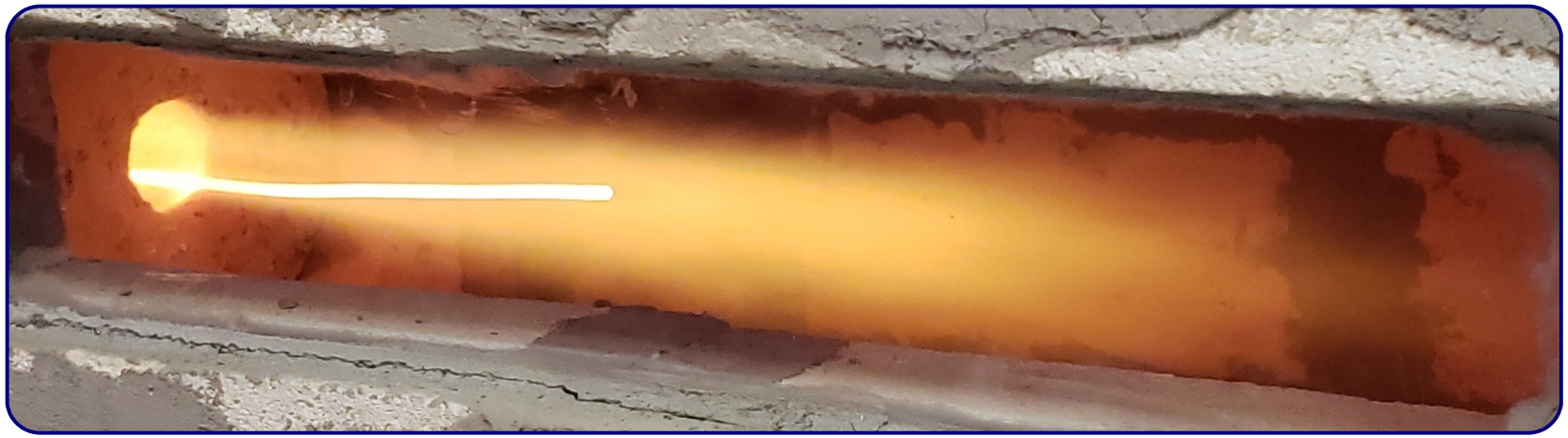
- Transform
- Blend together
- Better fuel

Gaseous fuels
$NH_3 + H_2$ blends

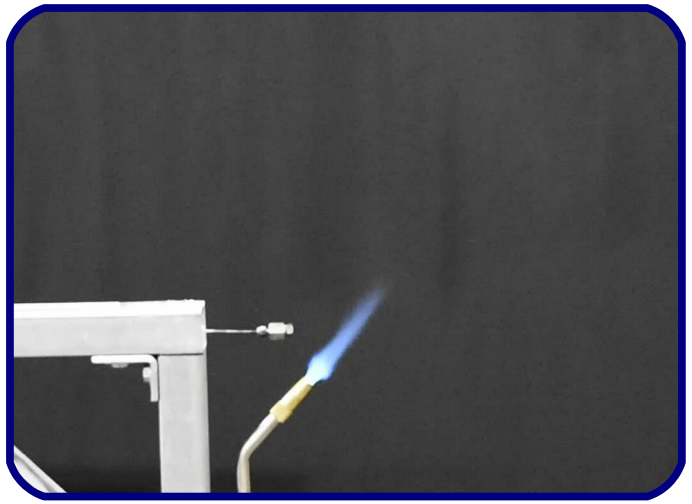
Chemical feedstock
NH_3 , H_2

Liquid fuels
$NH_3 + N_2H_4$, etc.

Carbon-free fuels for conventional engines & burners



- Gaseous fuel
- 70% pure + 30% cracked NH_3
- Natural gas burner



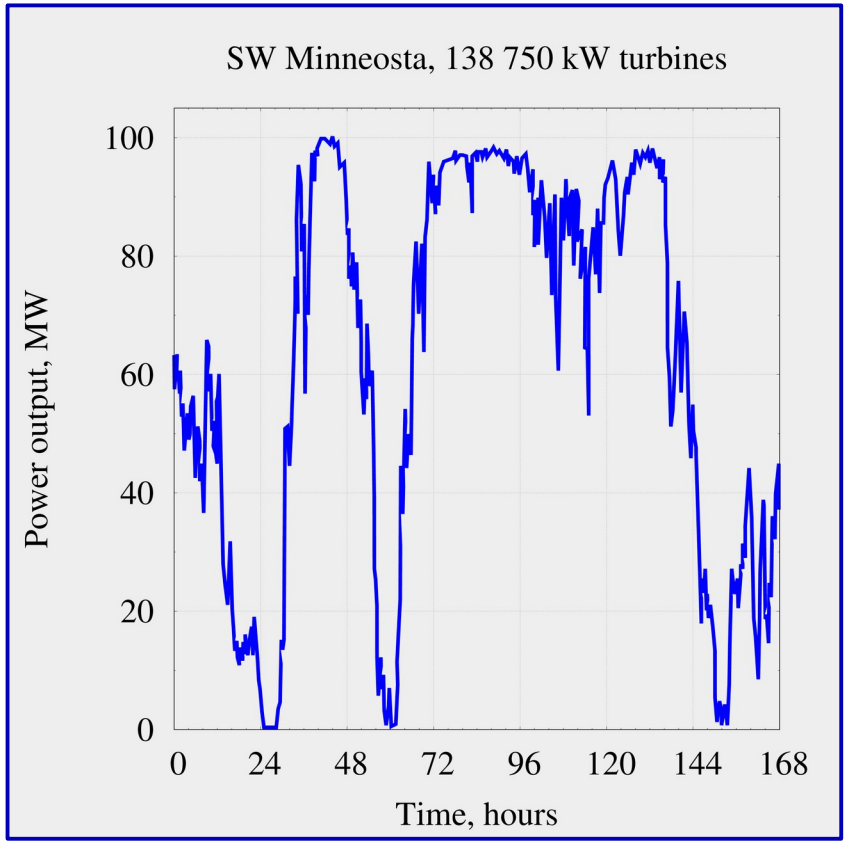
Test apparatus

Ammonia

Phoenix blend

- Liquid fuel
- NH_3 + derivatives
- Easy ignition

Need flexible electrolysis that can track wind power



Flexibility

- Off grid: must follow wind variability
- On grid: must follow utility signal
- Smaller projects have higher flexibility requirements

Need at least 30 bar hydrogen output pressure

Pressure

- Conventional Haber-Bosch: 100-300 bar
- Rapid Ramp: 30-50 bar
- Electrochemical compression from electrolyzer eliminates mechanical hydrogen compression

Need at least 99.99% hydrogen purity

Purity

- Residual oxygen will become water
- Water in Rapid Ramp system will be captured in adsorbent with ammonia
- Adsorbed water complicates ammonia harvesting

Need modular packaging that can live outdoors

Modularity

- Want to avoid needing buildings
- Want to minimize field labor & field time
- Ideally installable on ground screws or helical piers
- Module needs sufficient heating to operate subfreezing
- Module should tolerate freezing if water is drained

Need low capex, low maintenance modules

Affordability

- Off-grid solar: 20-35% capacity factor
- On-grid demand management: 50% CF
- Off-grid wind: 40-65% CF
- Off-grid wind+solar: 50-75% CF
- Low capacity factor amplifies all fixed costs
- Capex & maintenance must be low
- Should target less than $300/kW

THANK YOU

I’m happy to answer questions later