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Green Ammonia Opportunities in Utility Resilience/Storage and Logistics

November 10, 2021 | John F. Pierce and Jason Kuzma

Green Ammonia Opportunities in Utility Resilience/Storage and Logistics

This presentation will describe unnamed projects being undertaken in the Western United States utilizing low cost and redundant renewable energy resources to generate and distribute green hydrogen that can be converted to green ammonia. That ammonia may be utilized in various ways, but can provide a readily available source of energy for use as a resilient energy storage system by utilities (with a focus on municipal utilities), as well as by industry and consumer facing applications such as fleet fueling (as ammonia, hydrogen, and electrical power for EVs), stand-by and behind the fence generation, as well as maritime applications (duel or dedicated fueling and portside power.

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Potential for Ammonia (NH_3) as a Hydrogen Source

- Ammonia is safer than pure hydrogen and various other hydrogen sources like methanol, ethanol, methane, gasoline due to the following properties:
  - If escapes into the atmosphere it dissipates rapidly because its density is lighter than that of air.
  - It is self alarming: any leakage can be detected by nose in concentrations as low as 5 parts per million.
  - It has a narrow flammability range and therefore, it is generally considered non-flammable and presenting no explosion danger when properly transported.

Property	Gasoline	Natural gas	H_2	NH_3
Flammability limit, volumes % in air	1.4-7.6	5-15	4-75	16-25
Auto-ignition temperature, ^oC	300	450	571	651
Peak flame temperature, ^oC	1977	1884	2000	1850

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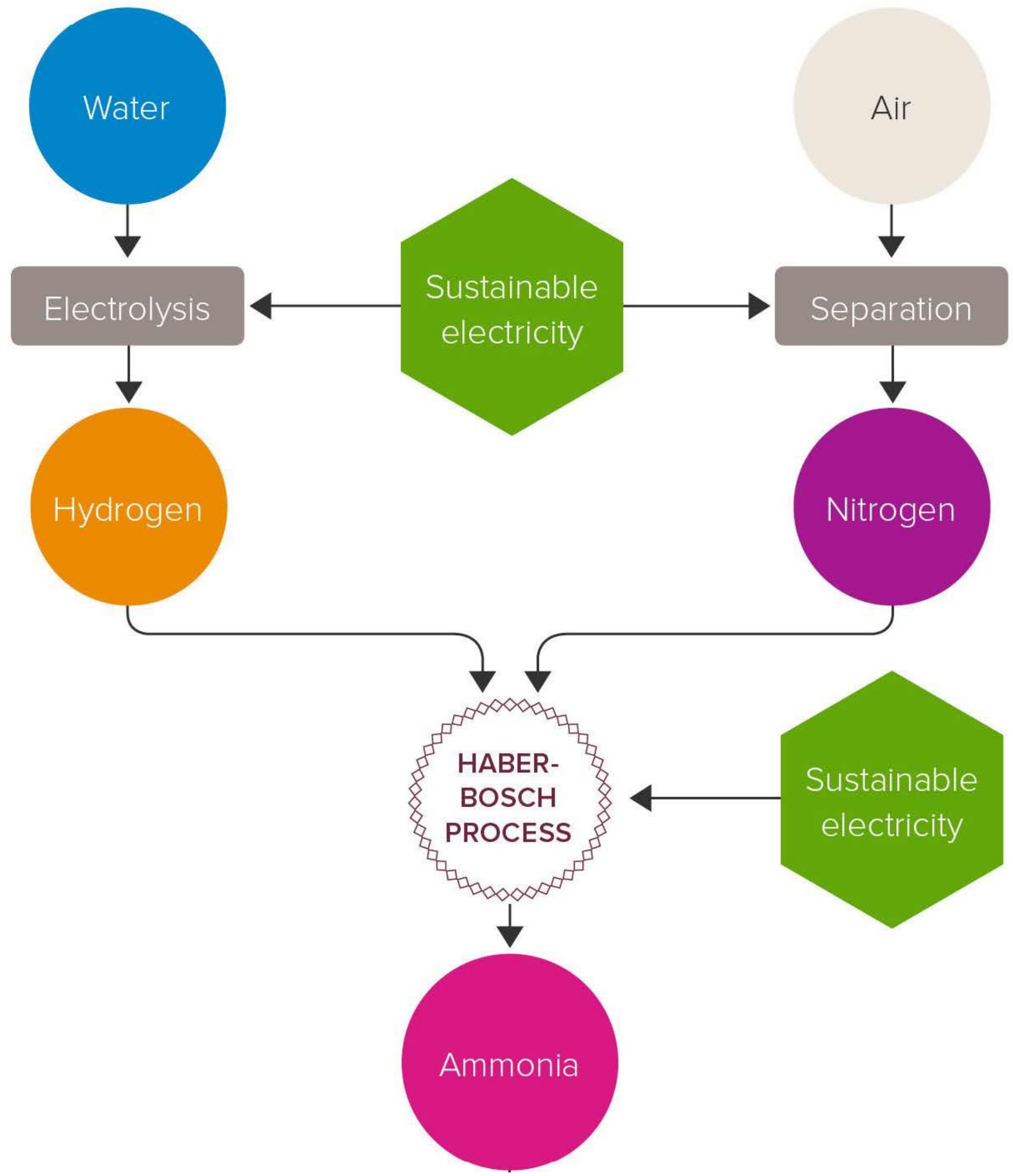
Green Ammonia – Explained and Issues

- At this event, this explanation should not necessary, but here it is:
    - Green ammonia production is where the process of making ammonia is 100% renewable and carbon-free.
    - Hydrogen generated from water electrolysis and nitrogen separated from the air fed into the Haber-Bosch process, all powered by sustainable electricity.

Green Ammonia – Explained and Issues

- Requires renewable energy inputs to be truly “green”
- The use of electrolyzers requires substantial amounts of both energy and water
    - These don’t always occur where green hydrogen is most desired, such as California
    - Drought and overall lack of this resource where and when wanted
    - Lack of renewable energy and intermittency issues
- Where it does exist – Washington State (Columbia Basin)
    - To a lesser degree in Oregon and Idaho



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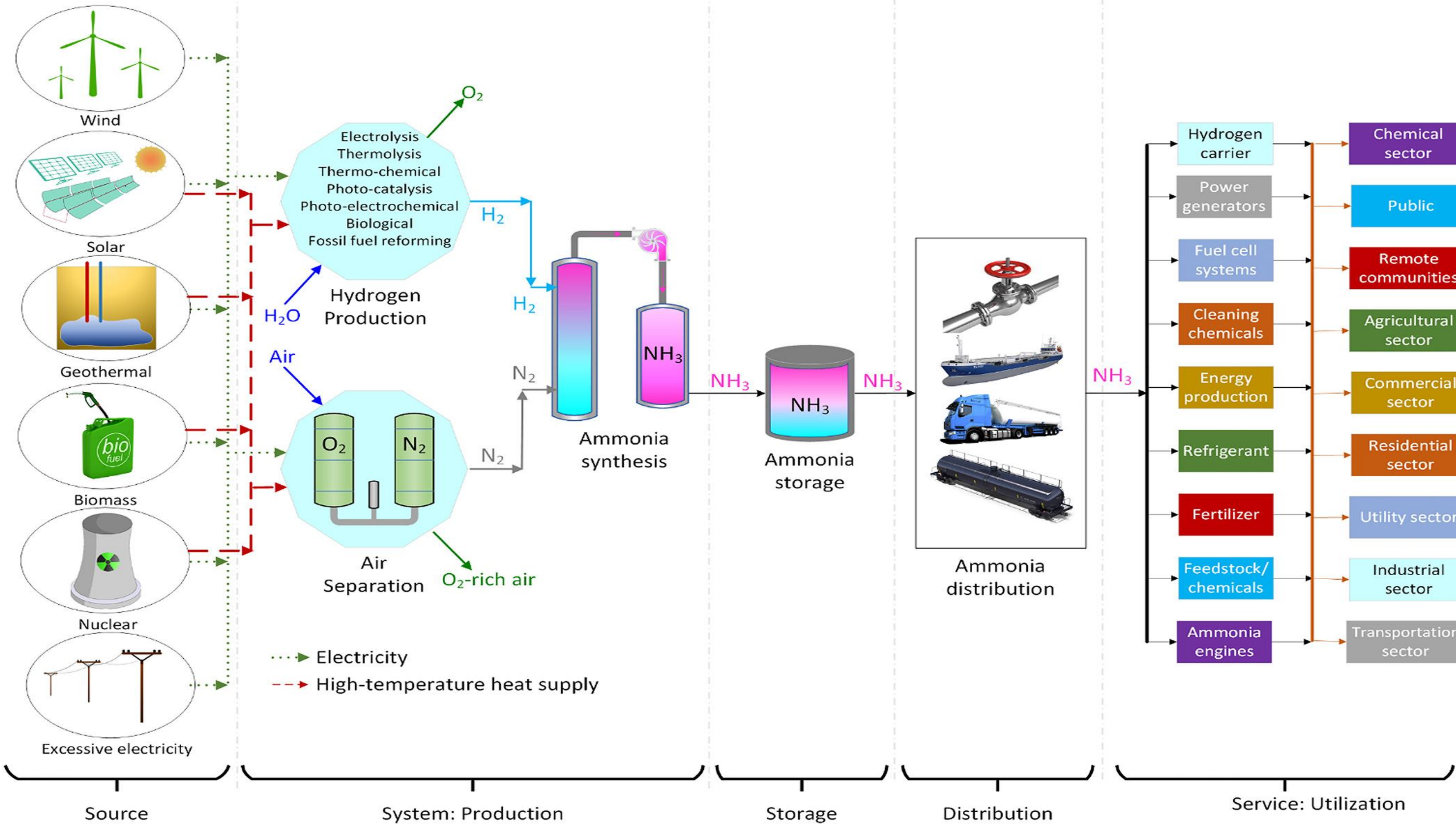
Economic Cycle of Green Ammonia from Production to Utilization



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ISSUES 1

- Electrolyzers
  - Costs
  - Availability
  - Scaling – Go large or parallel trains?
  - Alternatives – use of natural gas, autothermal units to produce blue hydrogen
    - Not green, but with carbon capture, utilization and sequestration the economic and environmental benefits can be enhanced
    - Conversion to green ammonia not an issue; better than bunker (anything is)

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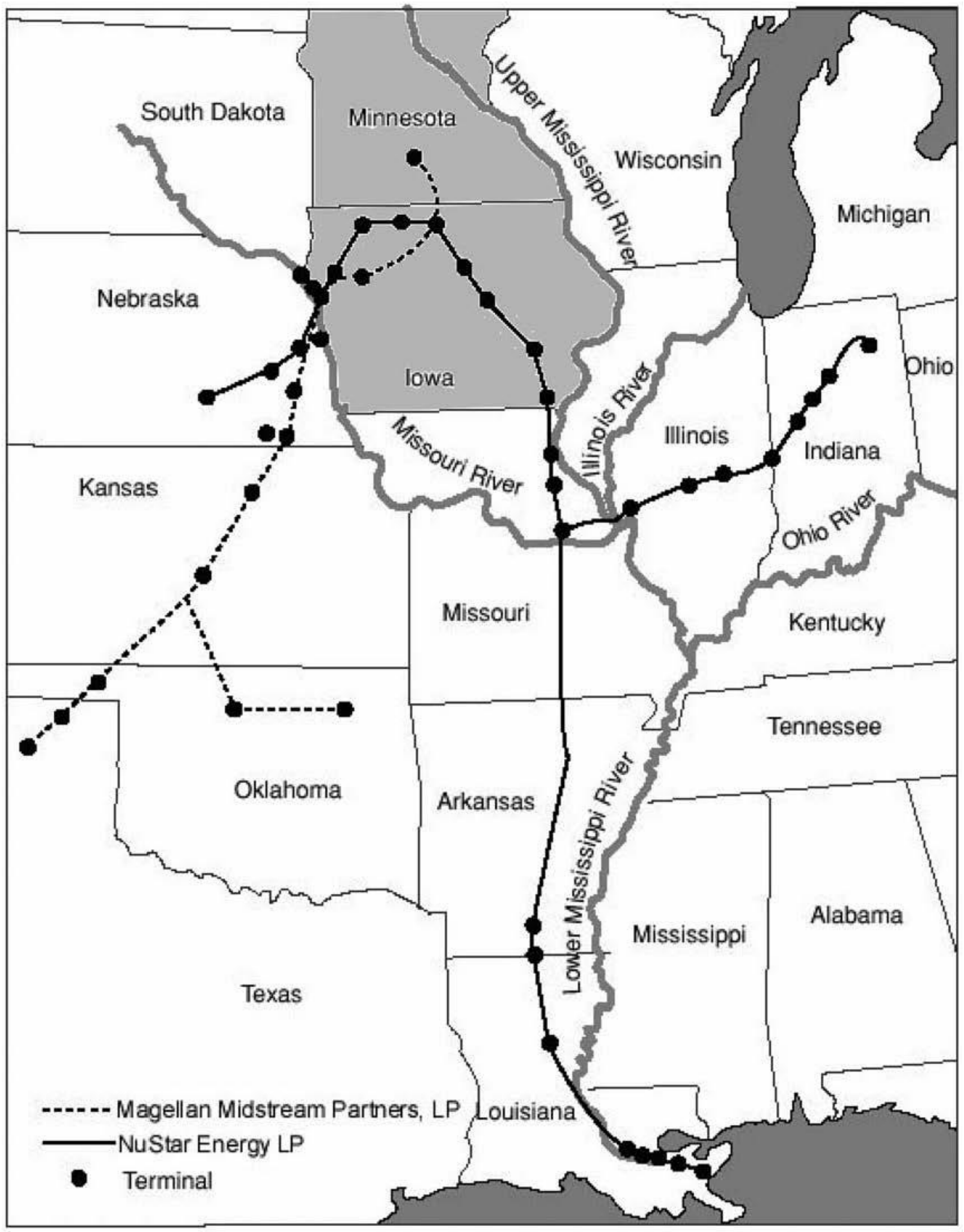
Ammonia Distribution Systems in the U.S.

- A safe, reliable, proven ammonia delivery and storage infrastructure already exists in the US.
- Approximately 3,000 miles of carbon-steel ammonia pipeline is in service in America's agricultural heartland, mainly in the Corn Belt.
- Almost a hundred large terminals for refrigerated
- ammonia storage are distributed along the pipeline.
- Barges, trains, and trucks round out the delivery system, which supplies the ammonia from the terminal to the farmer when needed for the growing season.
- The state of Iowa, alone, has over 800 retail outlets where farmers buy "anhydrous" or "nitrogen", the vernacular for ammonia fertilizer, NH_3.



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ISSUES 2

- **Transportation**
  - Interstate pipeline systems, intrastate pipeline systems, local and last-mile systems
  - Last-mile solutions are workable assuming permitting and economic permit
  - Personal bias – the Gulf Coast has the best available infrastructure and permitting regimes to get this product to market fastest
    - Global shipping mandates and markets can drive developments of both green and blue ammonia
    - **Example - Air Products $4.5 Billion Blue Hydrogen Clean Energy Complex in Eastern Louisiana**
      - Air Products will build, own and operate the megaproject, which will produce over 750 million standard cubic feet per day (MMSCFD) of blue hydrogen in Ascension Parish, Louisiana.
      - A portion of the blue hydrogen will be compressed and supplied to customers by Air Products' extensive U.S. Gulf Coast hydrogen pipeline network.
      - Balance of the blue hydrogen will be used to make blue ammonia that will be transported around the world and converted back to blue hydrogen for transportation and other markets.
      - The innovative megaproject will also feature the world's largest instance of CO_2 capture for permanent sequestration and produce only environmentally friendly blue products.
      - Projected Commercial Operation Date of 2026

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ISSUES 3

- **Overland carriage – rail and trucking for hydrogen**
    - Tankage an issue – lack of rolling stock
    - Economics of shipping
    - Prospective community resistance (similar to resistance to LNG)
    - Proximity to markets important
- **Safer alternatives?**
    - Conversion to ammonia – existing standards and regulations
    - Conversion to methanol – existing standards and regulations
    - Both have broader acceptance for overland carriage
    - Promotes more distributed production as it is less reliant on pipelines for transport - proximity to markets important
        - Example - British Columbia; water and potential for renewable power but not near markets

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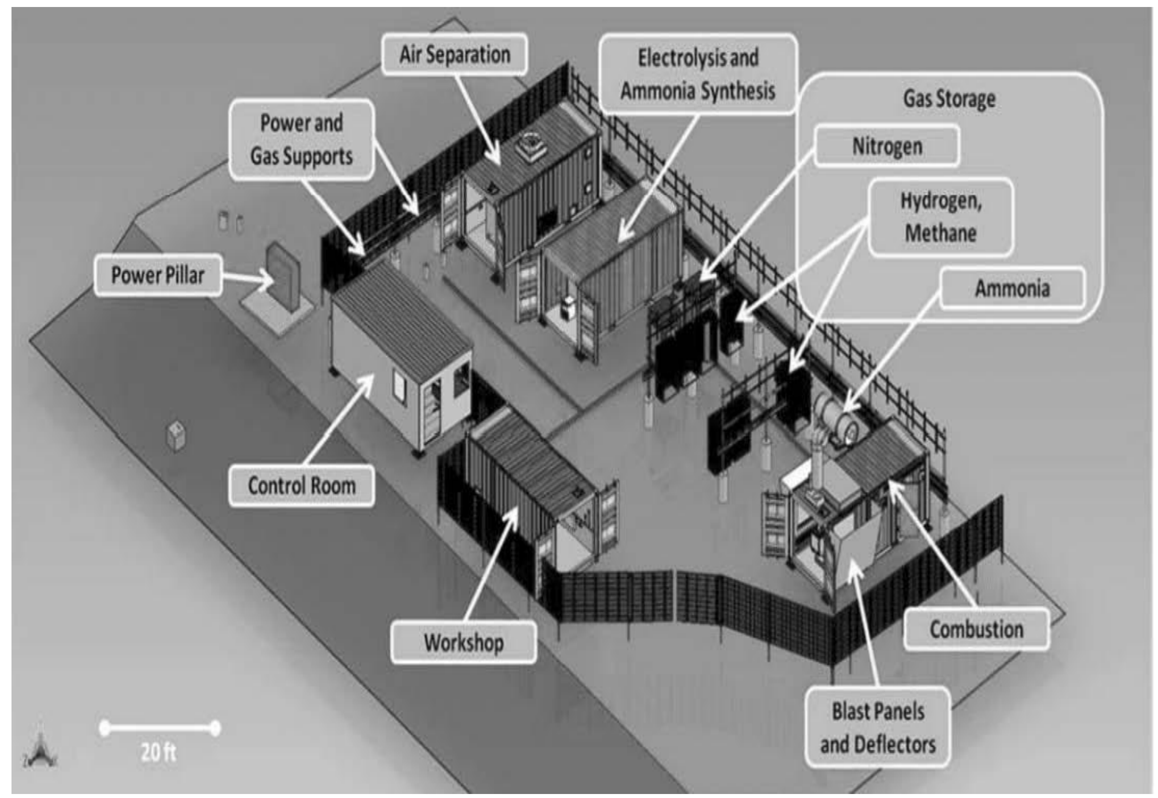
Energy Supply and Storage (Siemens Green Ammonia Demonstrator)

Location: Rutherford Appleton Laboratory in Harwell, Oxfordshire, U.K.

Parties: Siemens Energy, the Science and Technology Facilities Council, the University of Oxford, and Cardiff University

Technology: Proof of concept demonstration system that uses water electrolysis to provide a green hydrogen supply and extracts nitrogen from the air. The system combines the green hydrogen and nitrogen via a custom-built Haber-Bosch synthesis unit with a capacity of 30 kilograms of ammonia per day.



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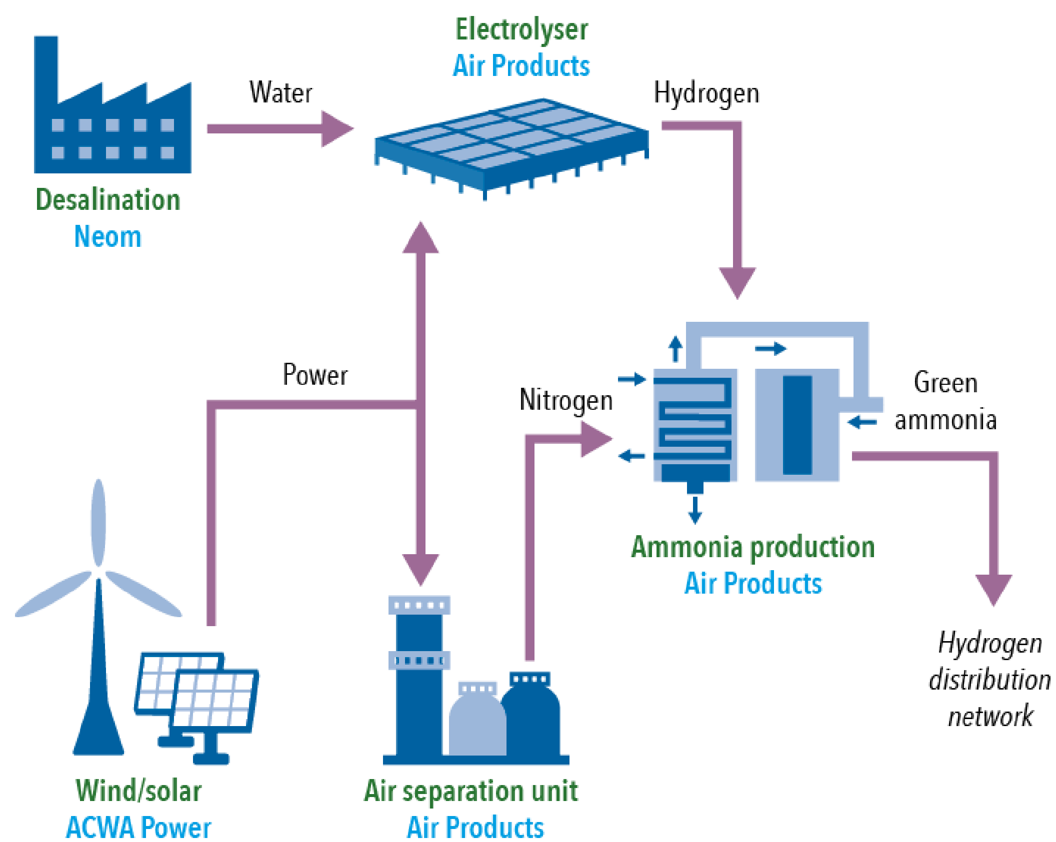
Energy Supply and Storage (NEOM Project)

Location: Neom, Saudi Arabia

Parties: Air Products & Chemicals, Inc., ACWA Power, and NEOM

Technology: Complex project that integrates over 4 GW of renewable power from solar, wind, and storage, the production of 650 tons per day of H_2 by electrolysis using thyssenkrupp technology, the production of N_2 by air separation using Air Products technology, for the production of 1.2 million tons of green ammonia per year using Haldor Ropsoe technology.



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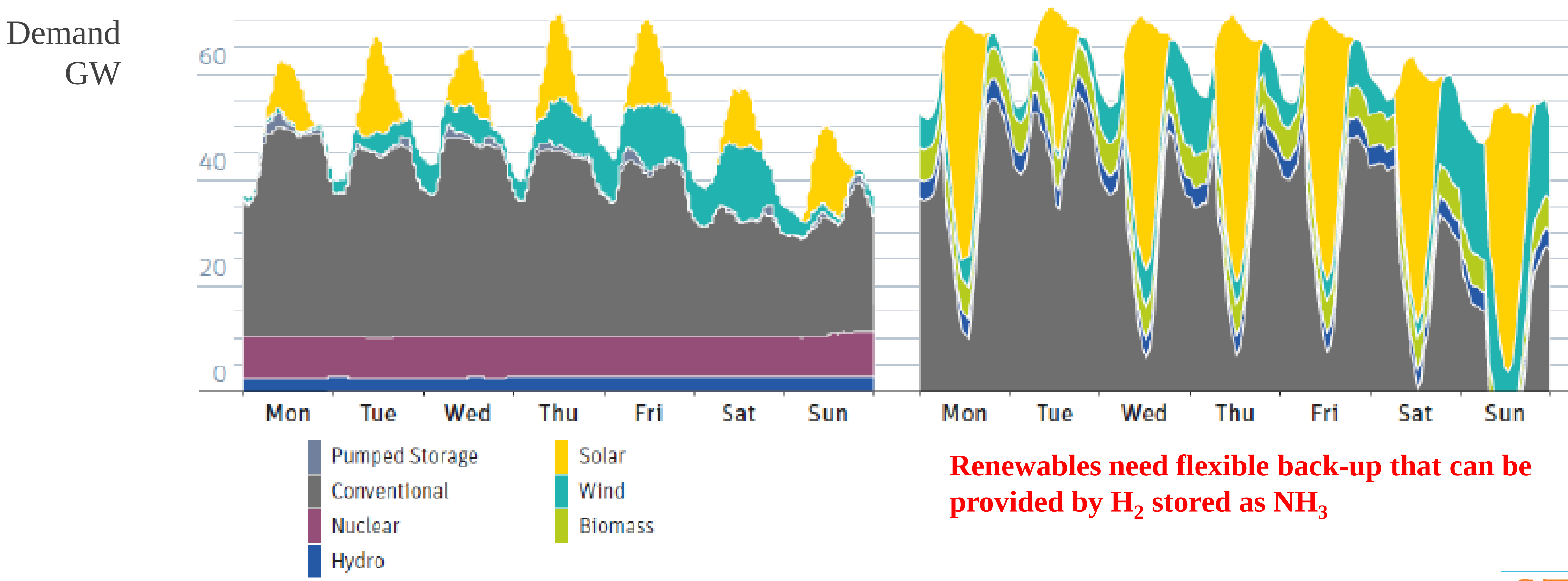
Application: Integration of Variable Energy Resources (Wind and Solar Power)

- **The levelized cost of energy for variable energy resources (wind and solar power) has become competitive**
  - Cost ≠ value, e.g. wind blows mainly at night in some places when prices are low
  - Mid-day dip produced by solar → back-up must be very flexible

Week in Germany in May 2012 May 2020



Renewables need flexible back-up that can be provided by H_2 stored as NH_3

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APPLICATIONS 1

- **Energy Storage**
  - Examples
    - Transformation of electrical power to another medium of energy – hydrogen to ammonia
    - Applications for large and small power generation needs
- **Resiliency**
    - Use of redundant or excess energy for later use
    - Load shifting
    - Scalable depending on need
- **Compatible Applications**
    - Utility–scale batteries
    - Standby generation, portside power, fleets,

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- **APPLICATIONS 2**
- **Consumer Facing Applications**
  - **With Battery System Installations**
    - Fueling Stations
      - Fleets – FedEx, UPS, Amazon, others
      - Port and Tarmac Equipment – Tugs, Forklifts, other
      - Personal Vehicles – Toyota Mirai
  - **Electric Vehicle Fueling/Charging**
    - Avoids Electrical Infrastructure Issues – lack of capacity and transmission
    - Potential for distributed resources
    - Potential to scale to suit need

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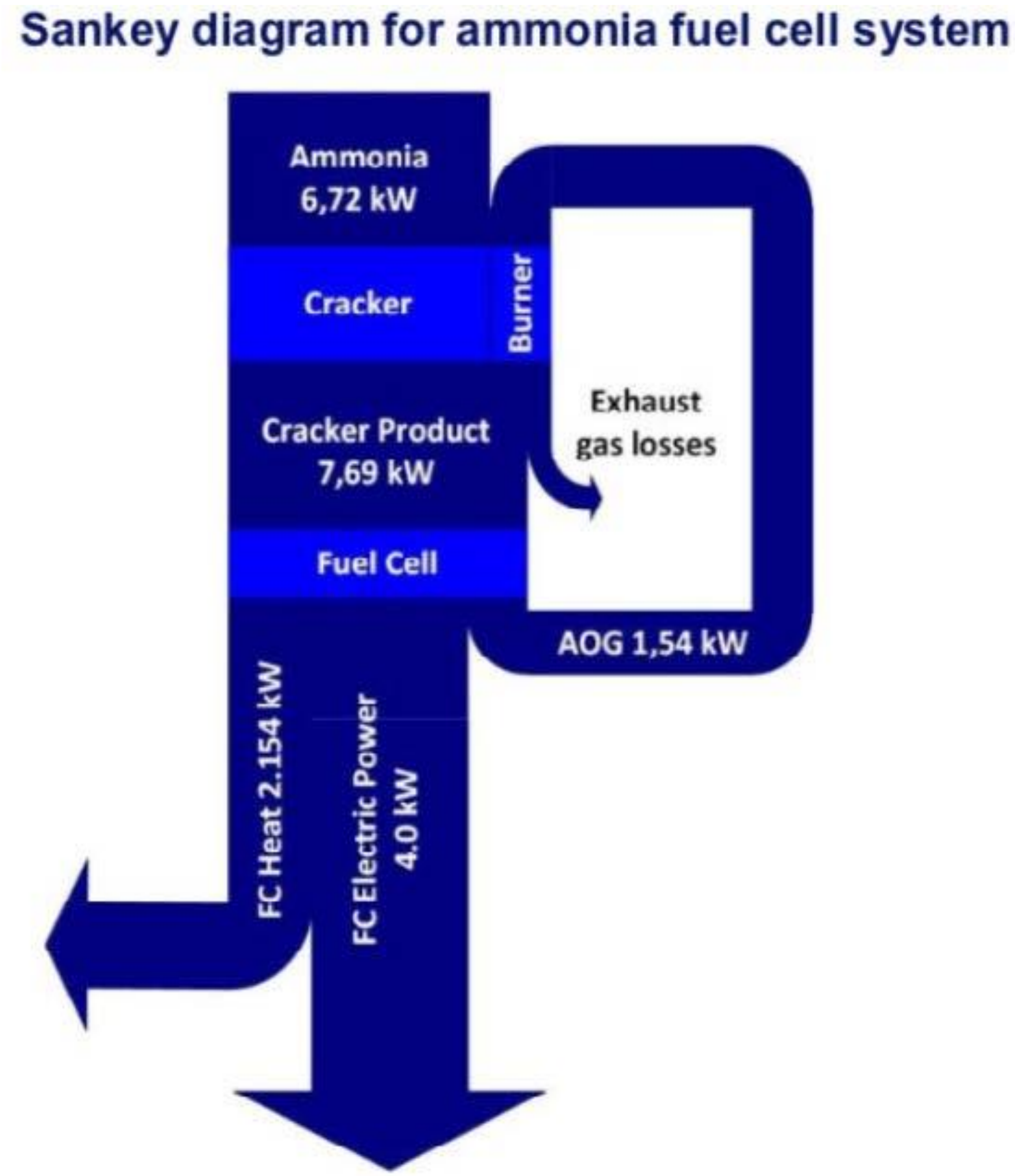
Application: Consumer-Facing Fuel Cells (ZBT Ammonia Cracker)

Location: Duisburg, Germany

Parties: Centre for Hydrogen and Fuel Cell Technologies GmbH (ZBT) and University of Duisburg-Essen (UDE)

Technology: Proof of concept demonstration system that uses a device to crack liquid ammonia into its component parts of hydrogen and nitrogen for a fuel cell that converts the gas into electricity.



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EXAMPLE 1 – WASHINGTON LOGISTICS

- Port of Tacoma, Washington
  - Infrastructure Heaven
    - Rail, Port Facilities, Pipelines, Interstate 5, Refineries, Very Pro-Business Local Government, State Support
      - Excess Renewable Energy; Lots of Water
  - Access to Markets - Diverse Public and Private
    - Fleets
    - State Ferry System (US largest)
    - Ports – Air and Marine
    - Defense Facilities
    - Utility-Scale Battery System

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Application: Marine Fuel

- **Ammonia availability and production scalability**
  - 120 ports already equipped with ammonia trading facilities worldwide
  - Annual ammonia production: 180 million tons
  - Conventional production over-capacity of 60 million tons/year ensures availability
  - Additional ammonia production to meet 30% marine fuel demand in 2050: 150 million tons/year
- **Demand for renewable energy to produce green ammonia**
  - 400 GW power needed to meet 30% of future marine fuel demand
  - In 2019 alone, 184 GW additional power production was installed
- **Cost of energy from Very Low Sulphur Fuel Oil (VLSFO) or Ammonia**
  - ~ $12.5–15/GJ for VLSFO
  - ~ $13.5/GJ for today's conventional ammonia
  - ~ $13.5–15/GJ forecasted cost for green ammonia from solar and wind energy in 2040–2050
  - ~ $16–21.5/GJ for carbon-neutral ammonia as dual fuel in 2025–2030

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Application: Marine Fuel

- Gulf Coast – Texas and Louisiana - A Quick Start
  - Preexisting Infrastructure
    - Gas Transmission Lines
    - Refineries
    - Port Facilities
    - Excess Renewable Energy (Texas); Lots of Water
  - Access to Markets - Diverse Public and Private
    - Number of large ports capable of handing and delivery
    - Vast number of support vessels
    - Concentration of pipelines, potential storage
    - ERCOT- Utility-Scale Battery System

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Emergency Planning and Community Right-to-Know Act (EPCRA)

- Enacted in 1986 after a catastrophic leak of methyl isocyanate killed nearly 8,000 people in Bhopal, India
- Created to help communities plan for emergencies involving hazardous substances
- Ammonia is listed as a “hazardous substance,” an “extremely hazardous substance,” and a “toxic chemical”
- Mandates emergency planning and notification, community right-to-know reporting, and annual release reporting
- A release of more than a “reportable quantity” of ammonia—100 pounds—during a 24-hour period triggers an immediate release reporting requirement
  - Specifically, the owner or operator of the facility must report an on-site ammonia release of more than the reportable quantity to the National Response Center within 15 minutes of discovery.
  - If more than the reportable quantity goes off-site, owner or operator of the facility must also make initial and follow-up reports to state and local authorities.
  - Failure to comply with these requirements, even in the absence of a catastrophic accident or spill, can give rise to hefty penalties and costly facility upgrades.

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Clean Air Act Amendments of 1990

- Added Section 112(r) ("Prevention of Accidental Releases“) in which Congress expressly included anhydrous ammonia among the "regulated substances" under the section.
- Section 112(r) imposes both a general duty and specific requirements for the prevention and management of chemical releases. The general duty provision requires that
  - (i) owners and operators must maintain a facility that is free of a hazard;
  - (ii) where the hazard is recognized by the owner/ operator or by the relevant industry;
  - (iii) the hazard from an accidental release is likely to cause harm; and
  - (iv) the owner/operator could have eliminated or reduced the hazard.
- Owners or operators of facilities (stationary sources under the Clean Air Act) that have processes containing more than a threshold quantity of a regulated substance are subject to the requirements of the regulation
- Anhydrous ammonia is listed as a "regulated toxic substance" with a threshold quantity of 10,000 pounds.
- Generally, the chemical accident prevention regulation requires covered facilities to undertake hazard assessment, develop and implement risk management programs and maintain documentation of these programs.
- Facilities must submit risk management plans to EPA and make the plans available to the public.

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OSHA Regulation and Enforcement

- Clean Air Act Amendments of 1990 required OSHA to issue a chemical process safety management standard.
- The Process Safety Management (PSM) Standard contains detailed requirements to proactively address hazards associated with various processes, typically in manufacturing industries that use, store, manufacture, handle or move "highly hazardous chemicals."
- PSM requirements are triggered at certain thresholds for various chemicals and flammable substances. For anhydrous ammonia, any process that "involves" 10,000 pounds or more of ammonia is subject to PSM.
- Process Hazard Analysis
  - Identifies, evaluates and determines how to control hazards and prevent the release of hazardous chemicals.
  - The process hazard analysis must be updated every five years.
  - The PSM also requires written operating procedures to safely conduct activities in each covered process, as well as initial employee training on those procedures and refresher training every three years.
  - Likewise, it requires employers to conduct compliance audits at least once every three years and to develop and retain audit reports.

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- John F. Pierce
  - Partner
- Stroock & Stroock & Lavan
- Email: jfpierce@stroock.com
- Cell: 206 351 2320

- Jason Kuzma
  - Partner
- Stroock & Stroock & Lavan
- Email: jkuzma@stroock.com
- Cell: 206 499 2438