

Background

Ammonia (NH₃) is one of the most commonly produced industrial chemicals worldwide. Fertilizer for agriculture accounts for about 80% of NH₃ production. Furthermore, NH₃ is in consideration as a hydrogen carrier or as an energy vector in a deeply decarbonized energy system.

What are the drawbacks of the current Haber-Bosch (H-B) process?

- An energy-demanding conversion from H₂ and N₂ at 150-250 bar;
- The major source of H₂ and N₂, by reforming and combusting hydrocarbons, is highly carbon-intensive;
- The energy to provide process heat and pressure for NH₃ production also requires combustion of methane.

There is a strong incentive to develop a sustainable NH₃ synthesis pathway. For example, using concentrating solar irradiation for process heat and pursuing relatively low-pressure operating conditions will significantly help mitigate greenhouse gas emissions and enable flexible operations at a smaller scale than H-B.

Method

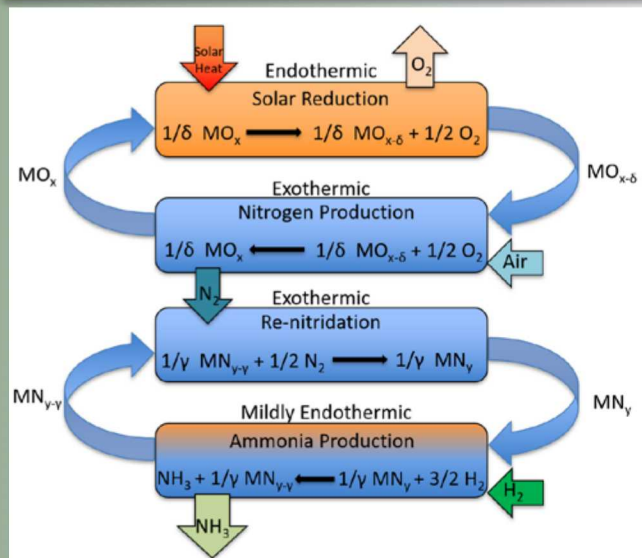


Figure 1: A solar thermochemical looping technology to produce and store N₂ from air for the subsequent production of NH₃ via an advanced two-state process.

What is the proposed NH₃ production method?

- Concentrated solar irradiation first drives the reduction of redox-active metal oxide particles; metal oxides are then re-oxidized by air, resulting in nearly O₂-free N₂ gas; H₂ can be produced from a net carbon-neutral process;
- H₂ reacts with a metal nitride to produce NH₃ and a nitrogen deficient nitride;
- The nitrogen deficient nitride reacts with sustainable N₂ to regenerate the initial nitride.

The target pressure for the NH₃ synthesis looping cycle is an order of magnitude lower than the H-B process.

Design Philosophy and Results

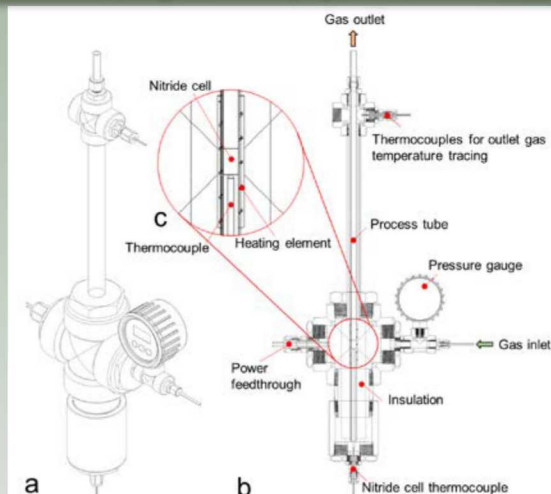


Figure 2: Illustration of the NH₃ synthesis reactor (ASR). (a) Isometric view. (b) Front cut-plane view with major components labeled. (c) Heated reaction zone.

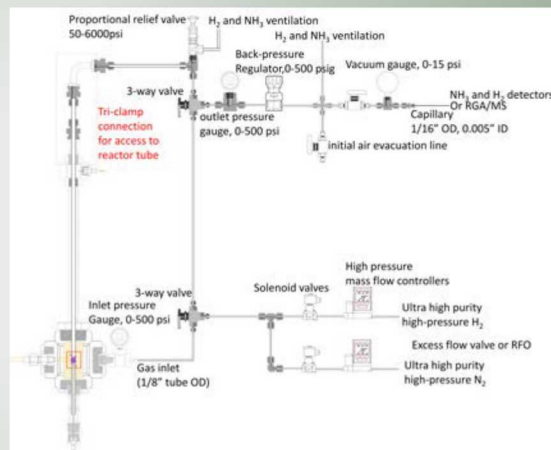


Figure 3: The process and instrumentation design for the ASR system.

Design of the benchtop NH₃ synthesis test reactor:

- NH₃ synthesis and re-nitridation reactions are achieved in one reactor cyclically by switching between pressurized (up to 30 bar) H₂ and N₂ inlet gas flows;
- The design purposely maximizes the utilization of commercial off-the-shelf components;
- Unnecessary dead volume in the pressurized zone is significantly minimized;
- The reactor volume (< 2L) captures the design features of a scaled-up unit to simulate heat transfer and material reactivity losses during cyclic operations.

The ASR enables cool inlet H₂/N₂ gases that fill an annulus between the “hot-wall” process tube and the “cold-wall” pressure vessel, to decouple the compound risk of high pressure and high temperature.

Acknowledgement

We would like to acknowledge the team and institutions involved in this work: Sandia, Georgia Institute of Technology and ASU. This material is based on work supported by the U.S. Department of Energy Solar Energy Technologies Office under Award No. DE-EE0001529. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.