Meeting Notes: Ammonia Combustion Technical Working Group Meeting #1
May 2, 2023 1:00 pm EST - 3:00 pm EST

Introductory remarks and working group overview, Clint Bedick

- 1st meeting - hope to have a series of meetings going forward
- Meeting to discuss ammonia combustion at any level
- Open to government, industry, academia
  - Anyone can participate
- "Open-to-the-public" disclaimer
- Format
  - Virtual meeting every 2 months
  - Voluntary participants
  - Meeting minutes to be published with presentations after each meeting
- Next meeting: July 5, 2023 1:00 pm EST - 3:00 pm EST

DOE turbines program overview and ammonia project highlights, Bob Schrecengost

- Hydrogen with Carbon Management Ammonia Combustion Activities
- Advanced Turbine Program
  - Using hydrogen-based fuels while maintaining low NOx and high performance
- FY21-22 FOAs in Hydrogen R&D
  - FY21 UTSR
    - Trying to develop some combustion fundamentals for ammonia combustion
    - Chemical kinetics, NOx, ignition delay, flame speed, etc
  - Slides with links to awarded projects

DOE Q&A

- Ammonia feed system and control system work will be conducted after combustion work to assess any difficulties in processing
- What about overall CO2 balance in producing NH3?
  - LCA work underway
- What is meant by rotating combustion?
  - Utilization of rotating detonation - success with hydrogen, no ammonia work yet
  - A number of DOE-funded RDE projects; contact Don Ferguson or Clint Bedick

Ammonia combustion emissions by Ammonia Energy Association, Kevin Rouwenhorst

- AEA is global industry association that promotes responsible use of ammonia in a sustainable energy economy
  - Over 200 members and growing
- Supply - decarbonize ammonia production
- Demand - adopt ammonia in energy markets
- Reports
  - Low-Carbon Ammonia Certification
  - Innovation Outlook
  - Maritime Fuel
  - Power Plants
- Ammonia demand: 85% fertilizers, 15% other, <1% for new uses such as maritime fuel or as hydrogen carrier
  - Projected to grow from < 200 Mt today to almost 700 Mt by 2050
- Production: production from renewable resources expected to grow
  - Today, most is produced from natural gas; some from coal and heavy fuel oil (HFO)
- Emissions
  - Upstream emissions

        - Currently about 3.1 t-CO2-eq / t-NH3
        - Case study: SCR for nitric acid production - abatement of N2O emissions
    - Conversion (direct and indirect) emissions
        - Pure NH3 combustion
            - NH3 slip - some ammonia not converted during combustion
            - Thermal NO formation
            - Additional pathways to form NO from NH3
        - Partially cracked - mixture of H2/NH3/N2
    - Strategies to minimize ammonia combustion emissions
        - 1. Optimize performance & minimize emissions
        - 2. After treatment for any leftover NO, NH3
- Applications
    - Transportation fuel: shipping, aviation, locomotives
        - Example: shipping
            - Engines using NH3 as fuel to be available by 2023-24
            - NOx and NH3 slip may be issues
            - Mitigation with SCR and EGR
    - Power generation: gas turbines, boilers, SOFCs
        - Low carbon ammonia utilization for power
            - Japan: co-firing in existing coal plants and gas turbines
                - Expect fully ammonia-fired power plants by 2040
                - 40 MW 100% NH3 gas turbine in 2025
            - Other countries may follow this path as well
            - Case study of producing NH3 in western Australia for shipment to Japan
                - Compare CO2 emissions between scenarios with NH3 production with CCS and renewables
    - Hydrogen production
    - Nitric acid fertilizer production
- Emission mitigation
    - SCR
    - SNCR
    - AMOX
    - EGR
    - Low NOx burners
    - Water & steam injection
    - Secondary air injection
- Key conclusions
    - Ammonia emissions require a value chain approach, including emissions during production
    - Downstream emissions from ammonia as zero-carbon fuel and hydrogen carrier should be essentially zero
    - Technologies for ammonia conversion mitigation are commercially applied

AEA Q&A

- Don Ferguson - Are there material compatibility issues for using NH3 in current gas turbine engines?
    - Perhaps not easy to retrofit for pure NH3, but co-firing may be easier
- Clint Bedick - When is it worth going from H2 to NH3, given that much of the cost is associated with H2 production?
    - Cheaper to store ammonia rather than hydrogen

    - Worthwhile to pay the 5-10% penalty for producing ammonia over hydrogen because of the ease of storage
- Nathan Weiland - Health concerns?
    - It's a matter of to what degree people are involved in the process
- Ganesan Subbaraman - Follow up on safety concerns
    - Ammonia handled routinely and regularly, safely
    - But what about safety specifically in NH3 usage for combustion?
        - Additional considerations for leaks into waterways
        - Need for updating regulations and code for ramping up ammonia usage/production
- Evan Granite - Is it realistic to ramp up NH3 production by 2x or 3x?
    - No technical challenge for NH3 production from fossil fuels with CCS
    - Production with renewables projected to increase rapidly
- Evan Granite - Any possibility to capture N2 and H2O?
- Evan Granite - Is there a way to produce nitric acid and heat and sale the nitric acid?
    - Would not produce as much energy as complete combustion of NH3
- Ramees Khaleel Rahman - Compare damages from NH3 pipeline compared to natural gas pipeline
    - Fuels are very different in terms of risks
    - Methane is a fire hazard and GHG
    - NH3 may be more dangerous to local environment and health
- Nathan Weiland - Any efforts underway on updating regulations?
    - Mostly focused on how to calculate carbon intensity

NETL interests in ammonia, Nate Weiland

- Overview of NETL organization
    - DOE carbon management research, including H2 and NH3, done here
- NETL core competencies
    - Carbon management
    - Efficient energy conversion
    - Resource sustainability
- The Center for Sustainable Fuels & Chemicals Technical Offerings
    - Includes H2 and NH3 work, carbon management
- Ammonia synthesis via microwave-assisted catalytic processes
    - Economic - lower pressure and temperature
- Cracking of ammonia using microwave enhanced processing
    - Could be used to partially crack, giving H2 & N2 in addition to NH3
- Review of TRLs of various hydrogen & ammonia technologies
    - Global Hydrogen Review 2021 (IEA)
- InsigH2t - data infrastructure to enable and accelerate H2 deployment

NETL RIC activities in ammonia combustion, Clint Bedick

- Review of work at Pittsburgh Fundamental Combustion Lab and future research activities
- Fundamental Combustion Lab capabilities
    - Operational since May 2022
    - Currently working with premixed flat flames (McKenna burner)
    - Mixtures with H2, CH4
    - Preheated air possible
    - Oxy-combustion possible
- Flame characterization of H2/NH3 and CH4/NH3 premixed flat flames
- Ammonia combustion modeling
    - 1D and 2D

    - PSR-PFR, 2-stage rich-lean configurations
- Large spread in combustion characteristics with different kinetic models
- CRN models
- Diagnostics
    - Generate data for laminar flame speed - still a large spread in available data
        - Using “heat-flux” method with FLIR camera thermometry
    - Species concentrations
        - FTIR spectrometer for NH3, NOx, H2O, and temperature
        - High temperature gas cell for generating line data
        - Potential for tunable diode lasers later
    - Future work
        - Reformer considerations
        - New model combustor for RQL approaches, global emissions sampling
- Future work at increased scales
    - Considering new furnace test facility

NETL Q&A

- Subith Vasu - More information on high temperature cell
    - Originally designed with RDE considerations
    - Up to 980 C and 480 psig
    - Full inconel cell with sapphire windows
- David Zamora - What grade of inconel?
    - 600 series
- Ganesan Subbaraman - TEA or LCA studies regarding the microwave technology?
    - A lot of the emissions depend on upstream processes
- David Wu - Any issues with mixing H2 and NH3?
    - No issues noticed so far
    - Possibly some difficulties when working at higher pressures

Interactive polls and discussion

- Results of polls will be shared

Closing remarks