Low-Pressure Electrolytic Ammonia (LPEA) Production

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University of North Dakota (UND) Energy & Environmental Research Center (EERC)
North Dakota State University
Nel Hydrogen (NEL)/Proton OnSite
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Overview

Project Title: Low-Pressure Electrolytic Ammonia (LPEA) Production

Timeline:

Project Start Date: 06/15/2018

Budget Period End Date: 12/14/2019

Project End Date: 06/14/2021

Barriers and Challenges:

- Develop gas-tight, durable, high-proton-conductivity (0.01 siemens/cm (S/cm) proton exchange membrane capable of sustained operation at 300°C in acidic environment
- Integrate membrane with appropriate anode and cathode catalysts in a membrane–electrode assembly (MEA) to produce ammonia at ambient pressure

AMO MYPP Connection:

Advanced Manufacturing

➢ Process Intensification

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$2,399,591	$774,471	$3,174,062	24.4%
Approved Budget (BP-1&2)	$778,016	$251,106	$1,029,122	24.4%
Costs as of 3/31/19	$284,688	$91,883	$376,571	24.4%

Project Team and Roles:

- University of North Dakota/EERC (Lead): Direct membrane fabrication, catalyst selection, MEA fabrication; evaluate membrane and MEA (in unit cell) performance; assess LPEA process techno-economic viability
- North Dakota State University – Develop and optimize membrane fabrication technique
- NEL Hydrogen – Develop and optimize MEA fabrication technique

Project Objectives

- Current Haber Bosch- (HB-) based ammonia production processes need high pressure (1100–3000 psi) to achieve economically viable ammonia yields (15%–18% based on single-pass hydrogen conversion).
- High pressure translates to:
  - High capital cost (large compressor and system-wide high-pressure compatibility).
  - High energy consumption/operating cost (need to compress both new and recycled reactants).

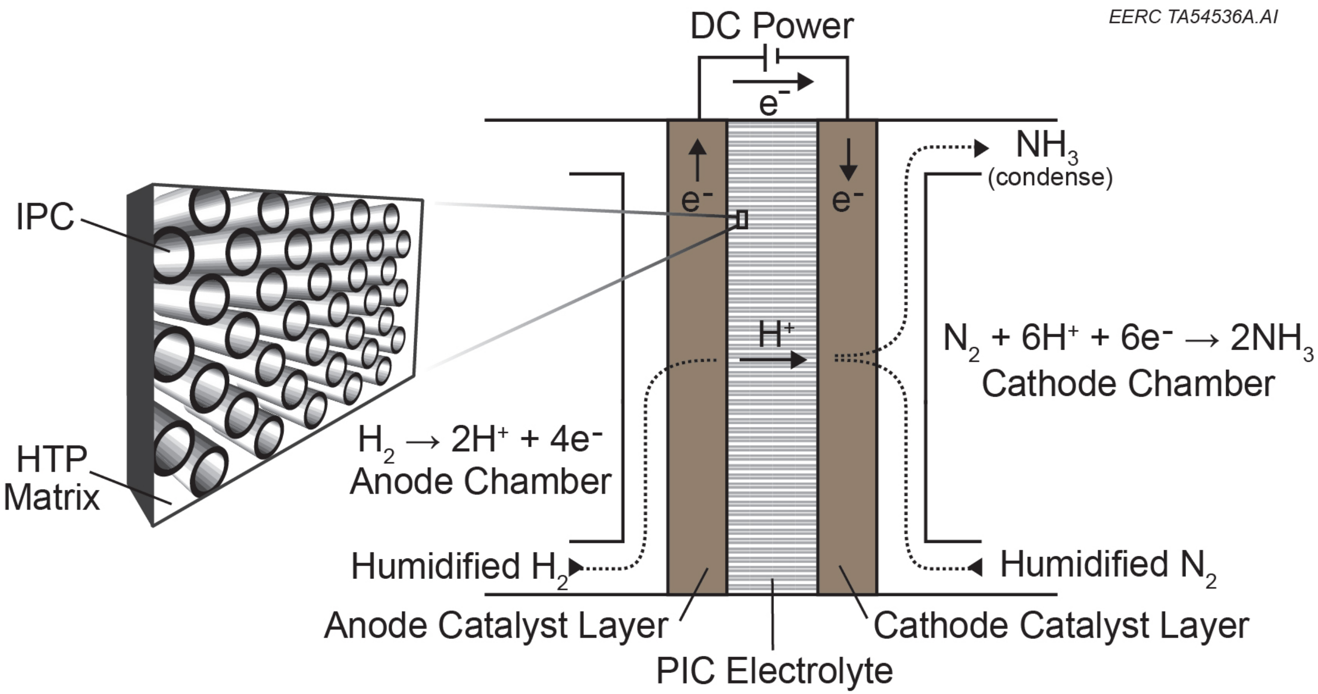
- Project Goal – Eliminate need for high pressure by optimizing electricity-driven process that enables control of ammonia formation reaction on catalyst surface, and achieve 25% input energy reduction versus HB-based processes—8530 to 6534 kWh/ton ammonia.
  - Key to success—and primary challenge—to achieving goal is optimization of high-temperature (300–325°C) high-proton-conductivity gas-impermeable polymer–inorganic composite (PIC) proton exchange membrane.

Technical Innovation–1

- Electrolytic ammonia synthesis technologies are typically focused on low-temp (ambient—150°C) or high-temp (≥500°C) regimes to enable use of low-temp polymer membranes or high-temp SOFC electrolytes.
- However, achieving high-rate/volume breaking of elemental di-nitrogen triple bond at low temp is difficult, and at temps above about 450°C, equilibrium dissociation of produced ammonia becomes problem.
- By offering high proton conductivity in gas-tight durable 300°C-capable PEM, PIC membrane enables operation at optimum temp for high-rate ammonia formation.

Technical Innovation–2

Core–shell IPC–HTP nanofibers serve as conduits to shuttle protons through IPC membrane



Advanced compositing process yields inorganic proton-conductor (IPC) nanofibers contained and aligned within high-temperature polymer (HTP) matrix.

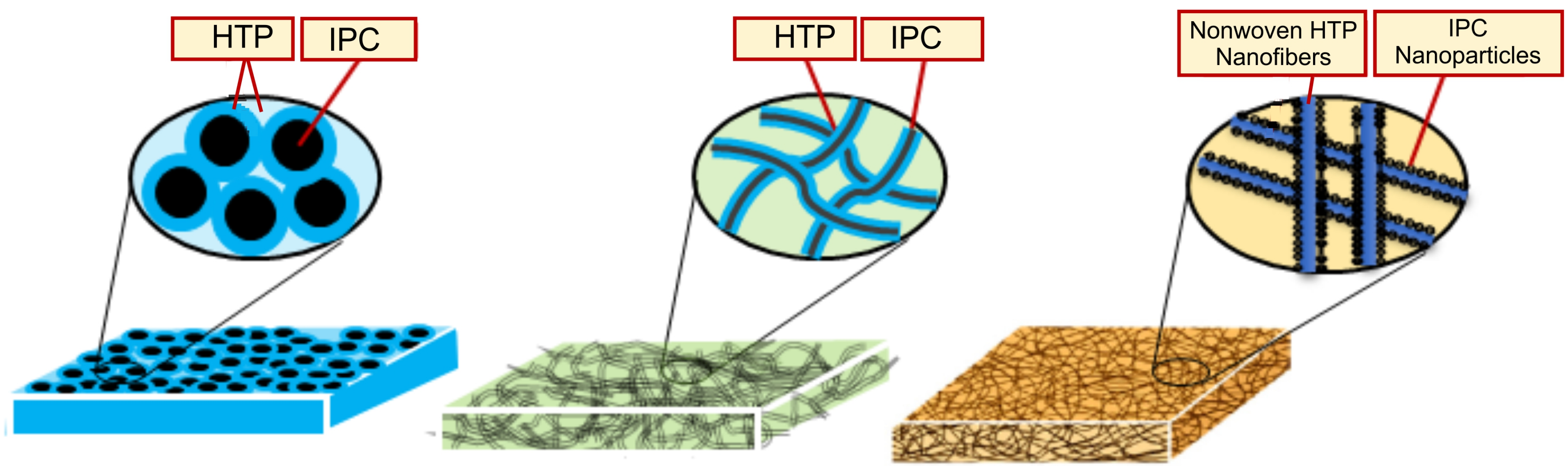
Resulting PIC membrane is gas-tight with high-proton-conductivity at 300°C operating temperature.

Key performance attributes:

- Turn on/off capability
- Modularity/scalability
- Solid state simplicity
- Ambient pressure means no compression cost

Technical Approach –1

- Characterize inorganic proton conductor (IPC) material properties and behavior at varying temp/humidity levels; establish optimal use regime.
- Optimize method for fabricating PIC Membrane Configuration 1 (MC1); if MC1 unachievable, move to lower risk MC2, then MC3, if needed.
- Screen and select cathode catalyst(s)
- Using PIC membrane and selected catalysts, manufacture membrane electrode assemblies (MEAs) for in-situ LPEA process optimization
- Design, fabricate, operate 100-g/day LPEA system
- Perform LPEA techno-economic analysis, develop commercialization plan



MC1 – Aligned IPC-Core-in-HTP-Shell Nanofibers

MC2 – Matted (nonwoven) IPC-Core-in-HTP-Shell Nanofibers

MC3 – Matted (nonwoven) IPC-Coat-on-HTP-Shell Nanofibers

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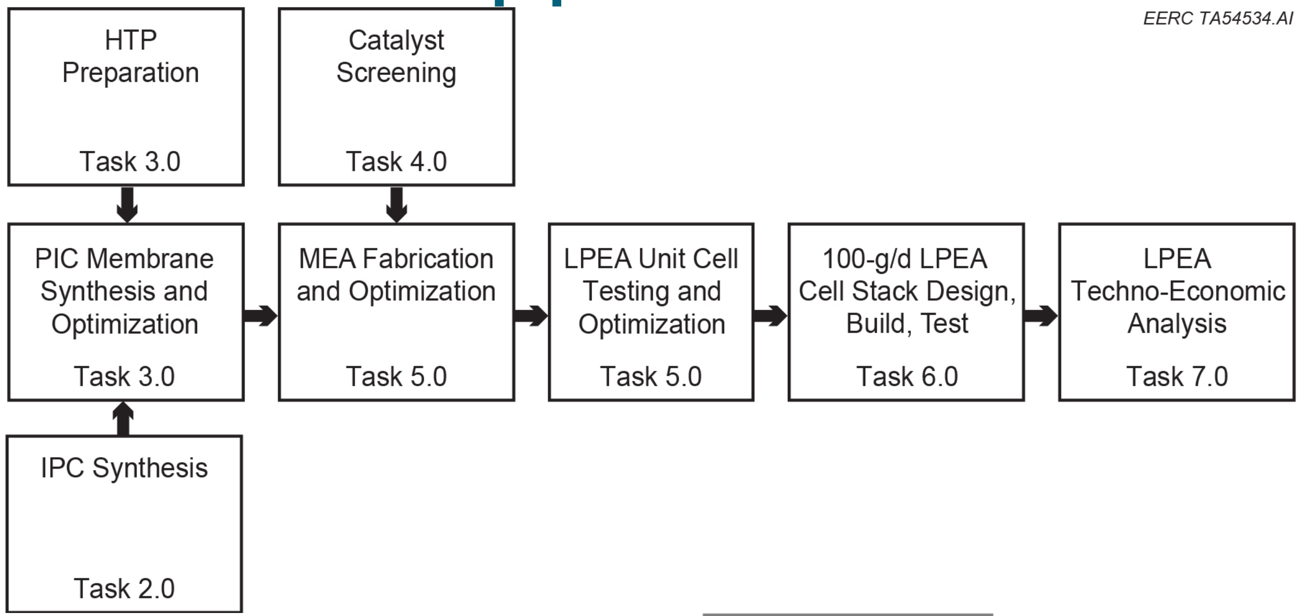
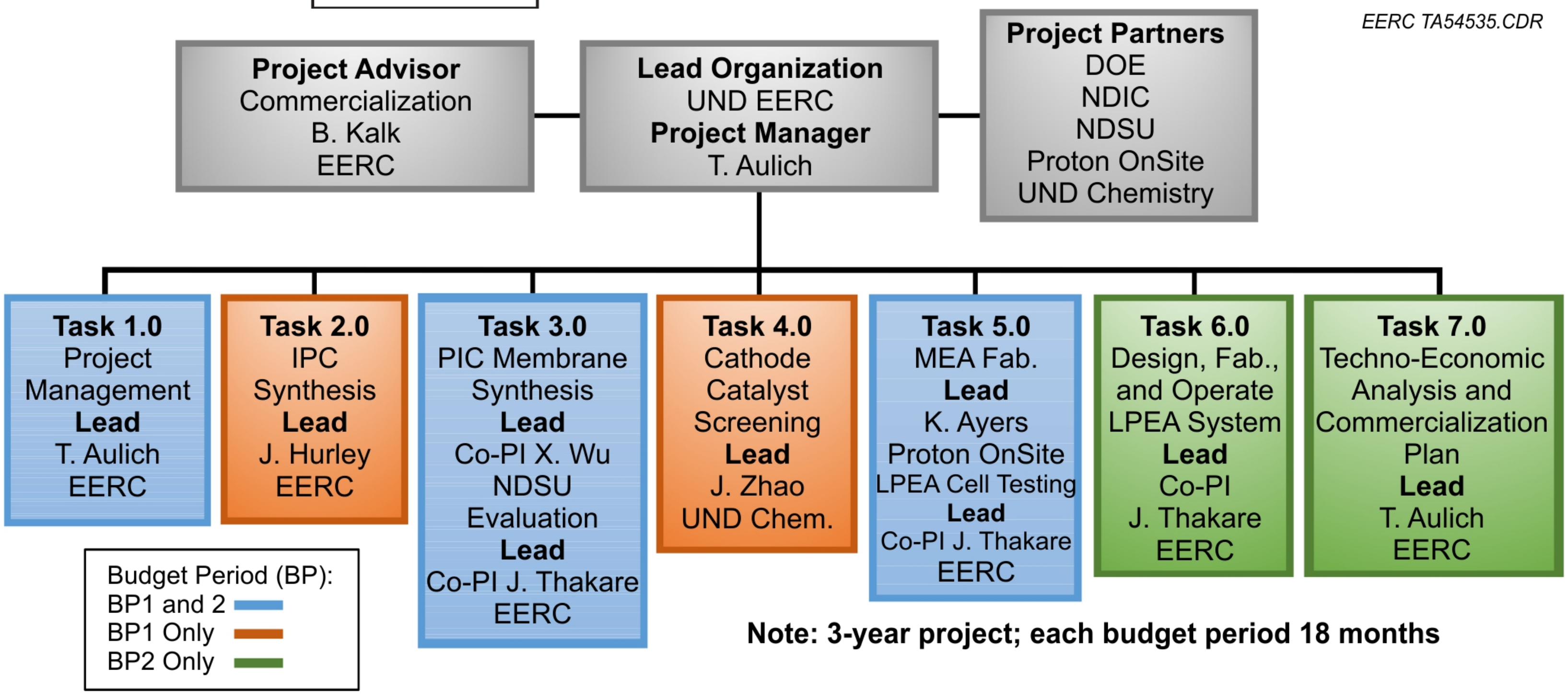
Technical Approach – 2

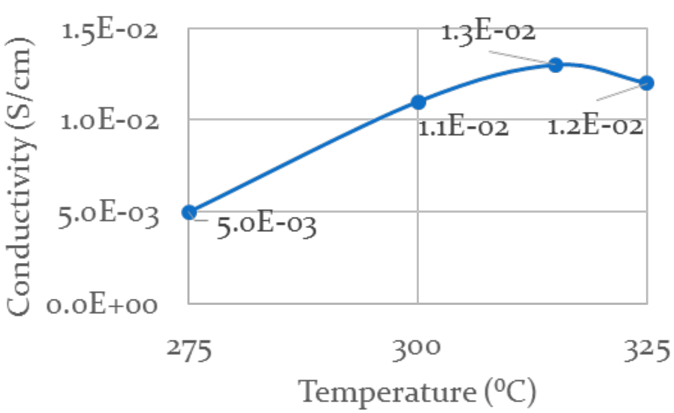
Project work flow (top) and team responsibilities (bottom)





Results and Accomplishments

#	Key Quantitative Milestone	Planned	Actual	Notes
3.2	ID ≥2 high-temp polymer (HTP) formulations; evaluate based on mechanical strength, electrochemical and thermo-oxidative stability at 300°C	12/14/18	12/14/18	Stability good to 350°C, more mechanical strength needed
2.1	Synthesize ≥1 inorganic proton conductor (IPC) with proton conductivity (PC) ≥10^{-2} S/cm at 300°C	3/14/19	3/14/19	Achieved ≥10^{-2} S/cm at 300°–325°C



IPC conductivity, S/cm

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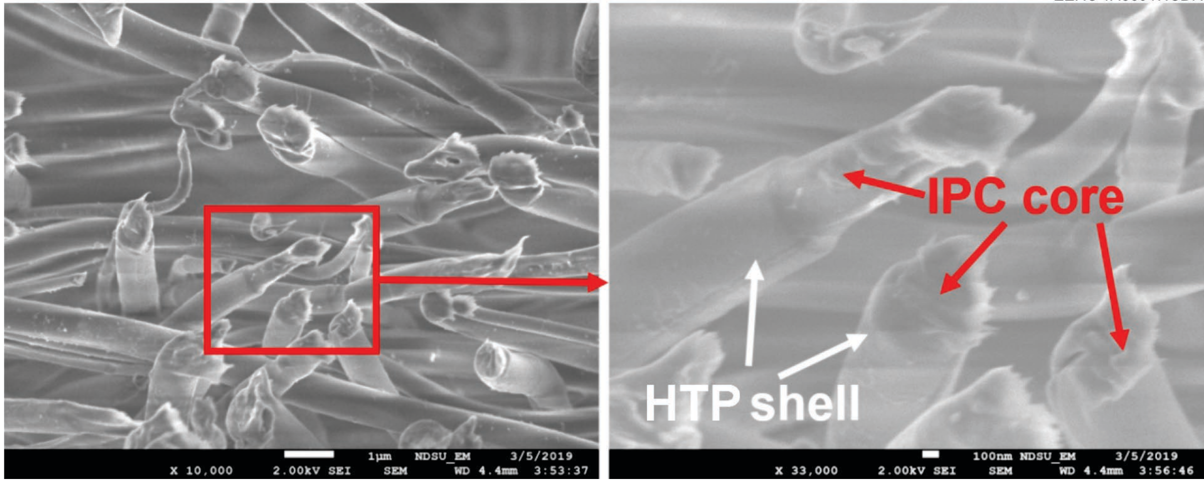

Matted (unaligned) IPC–HTP core–shell nanofiber membrane with proton conductivity of $0.3*10^{-3}$ S/cm at 300°C (project goal is $1*10^{-2}$)

Key upcoming objectives

Improve core–shell nanofiber structural consistency and durability via fabrication/heat-press optimization
Establish optimal humidity/temperature relationship to ensure membrane performance, integrity
Supply membrane and electrode materials to Nel for MEA manufacture

Transition (beyond DOE assistance)

- TRL of 4–5 anticipated at project end
- Use techno-economic analysis results to secure arrangements with utility or ammonia production facility for LPEA pilot-scale demo
- Use demo results to negotiate nonexclusive licenses with engineering/design firms that service ammonia, chemical, power industries
- Use demo results to market LPEA as:
  - Option for integration into existing ammonia supply chain to replace portions of and/or supplement current HB infrastructure
  - Means for monetizing renewable energy and/or utilizing low-cost off-peak power