Low-temperature Electrochemical Activation of Ethane for Co-production of Chemicals/Fuels and Hydrogen

WBS 2.1.10.2

Idaho National Laboratory/Massachusetts Institute of Tech/Univ of Wyoming

Project Period: May 2018-April 2020

Principal Investigator: Dong Ding, Ph.D
Idaho National Laboratory

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Overview

Timeline

- Project Started on May 2018
- Projected End date April 2020
- Project 60% complete

Barriers

Ethylene production via ethane steam cracking is energy-intensive and represents the most energy-consuming single process in chemical industry.

Budget

	FY 18 Costs	FY 19 Costs	FY 20 Costs	Total Planned Funding
DOE Funded	$200 K	$500 K	$ 300K	$ 1,000 K
Project Cost Share	$52 K	$125 K	$73 K	$250 K

Project Teams and Roles

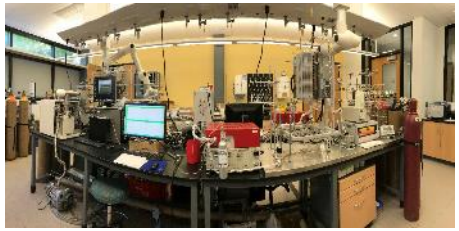
- Dr. Dong Ding, INL
  - Oversee the entire project
  - Development of electrochemical cells/membrane reactor
  - Catalyst incorporation
  - Electrochemical testing
- Prof. Ju Li, MIT
  - Modeling and simulation
  - Advanced Characterizations
- Prof. Maohong Fan, Univ. of Wyoming
  - Catalyst R&D towards ethane deprotonation/ethylene coupling

Project Objectives

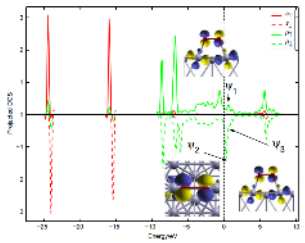
- Overall Goal
  - to fully exploit the potential of natural gas and natural gas liquids with 50% energy reduction (AMO goal in 10 years) and lower carbon emissions. Specifically, our goal is to achieve a process energy efficiency of 90%, corresponding to a process energy reduction of over 65% compared to the industrial ethane steam cracking, and a product selectivity of 90%.

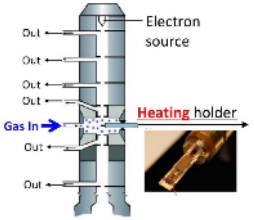
Demonstrate the proof of concept for co-production of chemicals/fuels and H_2 using ethane through a non-oxidative electrochemical deprotonation process at reduced temperatures

Develop new electrocatalysts that can be incorporated into electrochemical cells and have excellent catalytic properties towards ethane oxidation and ethylene coupling



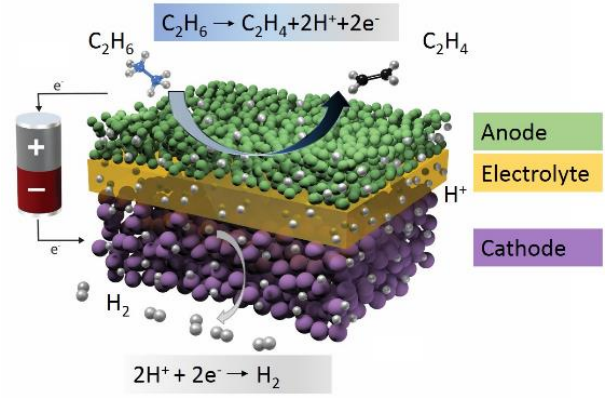
Implement advanced modeling and characterizations for rational design of materials/components





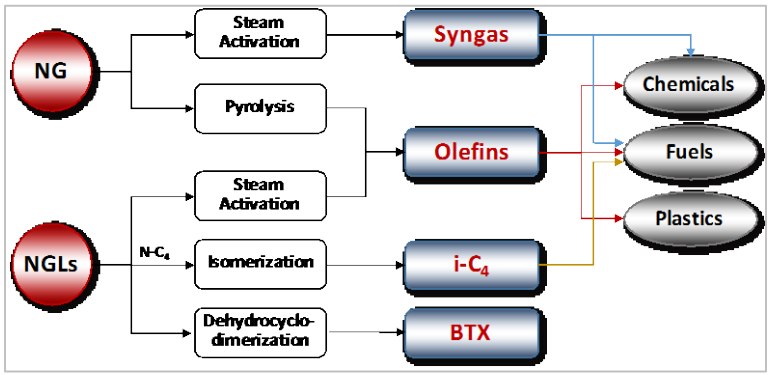
Technical Innovations

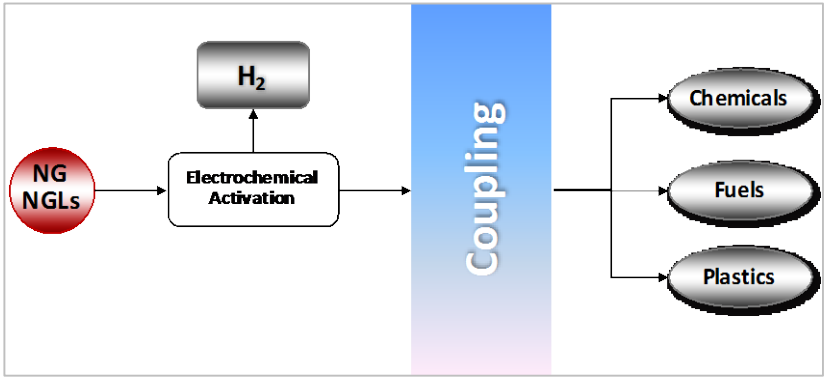
- State of the art:
  - Steam cracking: an energy-intensive method that contributes 60% of the final product cost and 65% of the manufacturing carbon footprint
  - Catalytic dehydrogenation: thermodynamic limitation
  - Oxidative dehydrogenation: product is easier to react than feedstock and increases CO_2 byproduct



- Proposed technology:
  - Electrochemical process: overcome thermodynamic limitation, thus operating at lower temperatures;
  - Highly selective catalysts: dramatically improve the reaction kinetics and increase the conversion rate and selectivity;
  - Intermediate temperature operation: Good balance by avoiding precious metal catalyst use at LT and alleviate fast degradation at HT;
  - Solid oxide cell: Modularity and can be readily incorporated with renewable energy

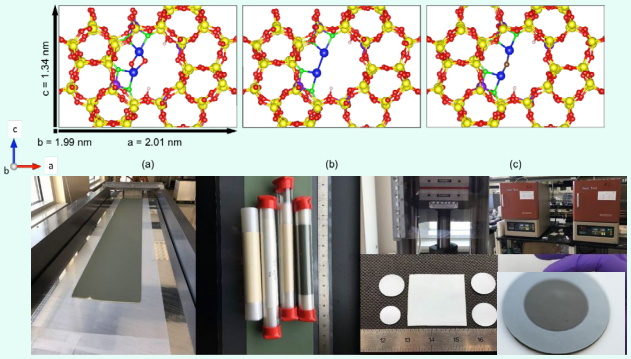
- Impact:
  - Providing a disruptive approach for petrochemical manufacturing, shifting the paradigm from thermal chemical practice to a clean energy regime;
  - Reduced thermal budget and carbon footprints compared to industrial steam cracking;
  - Capable of being integrated into industrial electrification and enables efficient use of renewable energies (e.g. nuclear, solar, etc.)



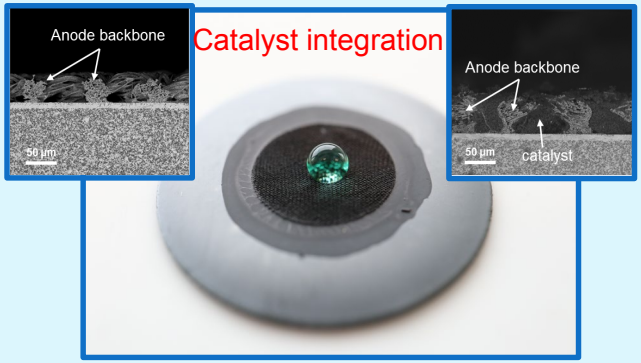


Technical Approach

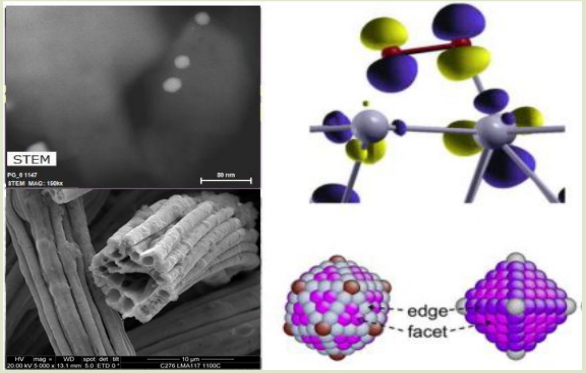
Cell fabrication and catalysts development



Catalyst integration and chemical/H_2 co-production



Advanced characterization and Ab initio modeling



INL: Membrane reactor design, fabrication and performance evaluation

UWy: Bi-functional catalyst development and characterization

MIT: Advanced material and structure modeling and characterization

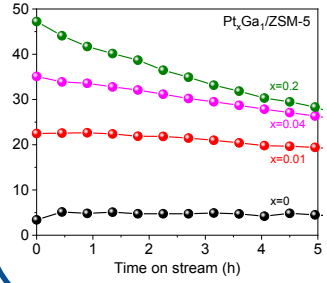
Results and Accomplishments

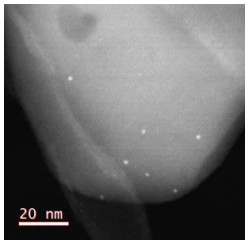
- Milestones: 12 progress milestones and 1 Go/NoGo milestone completed
- Award: *LoTempLene* won the finalist of 13th Idaho Innovation Award
- Publications
  - L. Wang, Y. Zhang, D. Ding et al. "Non-oxidative Dehydrogenation of Ethane to Ethylene over ZSM-5 Zeolite Supported Iron Catalyst". ***Applied Catalysis B: Environmental***. Accepted
  - Y. Gao, D. Ding, A. Gaffney, F. Li, et al. "Recent Advances in Intensified Ethylene Production – A Perspective". **ACS Catalysis**, under revision.
  - Y. Dong, L. Qi, J. Li, I. Chen. "Electron Localization Enhances Cation Diffusion in Transition Metal Oxides: An Electronic Trebuchet Effect". ***Science Advance***. Submitted
  - W. Wu, L. Wang. D. Ding et al. In preparation
- Presentations
  - D. Ding. 3rd World Congress Series: World Electrochemistry Congress. **Keynote**. Stockholm, Sweden, March 24-27, 2019
  - D. Ding, W. Wu, L. Wang. 2019 ACS Annual Meeting & Expo. **Invited Talk**. Orlando, FL. March 31-April 4, 2019.
  - D. Ding, W. Wu, L. Wang. 12th Natural Gas Conversion Symposium. **Invited Talk**. San Antonio, TX. June 2-6,2019.
  - L. Wang, W. Wu, D. Ding. 3rd International Conference on Catalysis and Chemical Engineering, Houston, TX. Feb 25-27, 2019.

University of Wyoming

Catalyst Research and Development (UW lead)

- ✓ **3 highly selective catalysts (CrCe/ZSM, PtGa/ZSM and Fe/ZSM) for ethane NDH ≤ 600°C**
- ✓ **Presence of C4+ product on ZSM based catalyst**

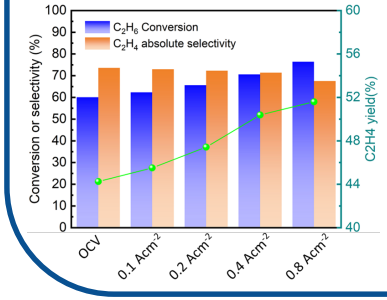


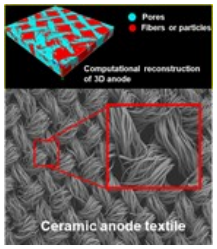


Idaho National Laboratory

Electrochemical Co-production Chemicals/fuels and H_2

- ✓ **SOC with super protonic conductor and 3D catalytic anode**
- ✓ **65% and 52% C_2H_4 yield at 600 and 550°C**
- ✓ **66% processing energy and 77% CO_2 emission reduction**
- ✓ **40% reduction in CAPEX and 35% in OPEX**

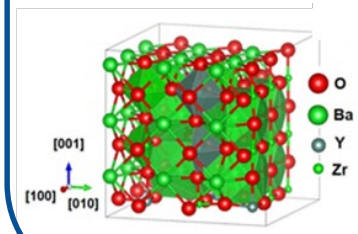


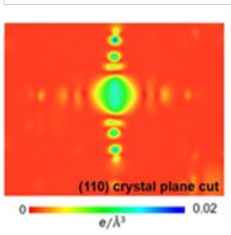


Massachusetts Institute of Technology

Advanced Characterization and Modeling (MIT lead)

- ✓ **In-situ TEM characterization of catalyst suggests active components loading ≤ 0.2 wt.%**
- ✓ **Ab initio modeling suggest effective approaches to suppress electronic leakage**





Transition

This project is playing a critical role in attracting industrial partners for product development and commercialization

- Technology Readiness level will increase to 3-4 by the end of the project

- 3 major petrochemical companies showed interest:
  - by direct funding (strategic partner program). Negotiation is underway
  - by monetary cost sharing partnership to leverage DOE funding (e.g. Technology Transfer agreement)

- Leveraged manufacturer capability for cell/stack scale-up (CRADA)
  - Focusing on large format solid oxide ceramic cell/membrane reactor/stack manufacturing

- Been approached by venture groups and started the conversations with them