High Rate Ammonia Synthesis by Intermediate Temperature Solid-state Alkaline Electrolyzer

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Introduction

❑ Ammonia Synthesis Methods

(1) Haber-Bosch Process
- N2 and H2 reacting at 15–25 MPa and between 400–500°C
- Energy and capital intensive approach

(2) Electrochemical synthesis
- Low temperature, pressure, energy input, and emissions
- Enables networks of distributed scale and near point-of-use

❑ Issues of Current Electrochemical Synthesis Methods

- Only molten salt system operating at intermediate temperature range
- Low ammonia production rate due to lack of highly active NRR catalyst
- Low selectivity of nitrogen reduction due to HER
- Poor stability using liquid based and proton-conducting electrolyte

Our Approach

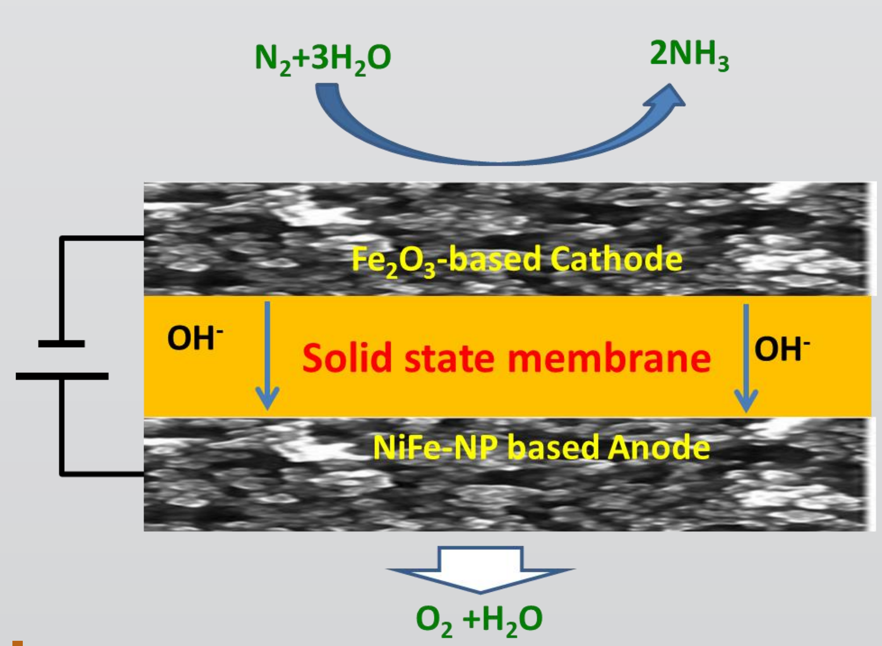
We will develop a game-changing intermediate temperature (100-300°C) solid-state alkaline electrolyzer (ITSAE) for high-rate ammonia production from nitrogen/air and steam electrolysis based on following innovations:

(1) Cost-effective and intermediate temperature highly OH^- conducting solid membrane

(2) Nanostructured Fe2O3-based bimetal oxide nitrogen reduction reaction (NRR) cathode catalyst

(3) Advanced solid composite electrode structure

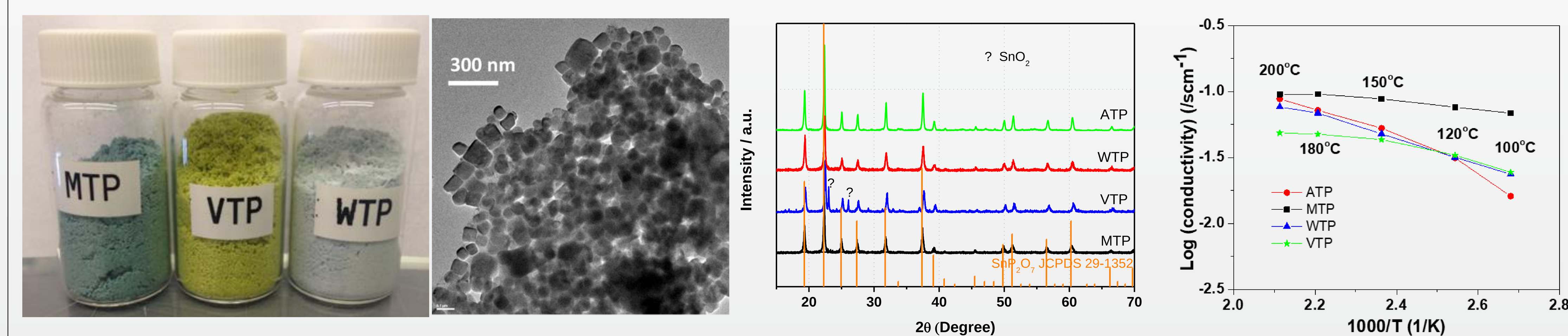
(4) Noble metal-free oxygen evolution reaction (OER) anode catalyst

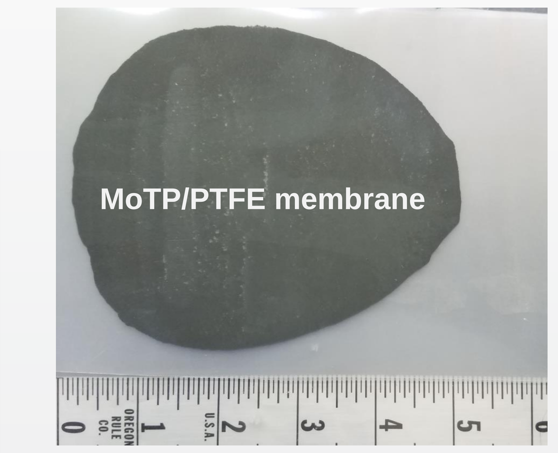


Work Plan

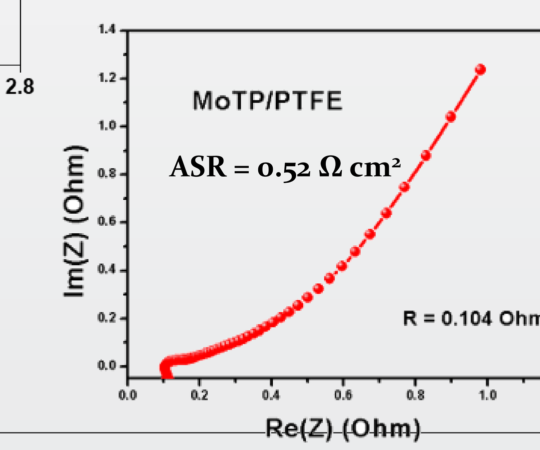
- Develop large ITSA membrane with thickness of ≤50 μm and ASR of ≤0.125 Ω cm²
- Develop highly active and selective Fe based bimetallic oxide NRR cathode
- Use DFT methods to elucidate elementary reaction mechanisms and guide catalyst design
- Optimize MEA and ITSAE operation conditions
- Demonstrate ITSAE stack with productivity of 100 g/day
- Techno-economic- analysis and Technology to Market

Membrane

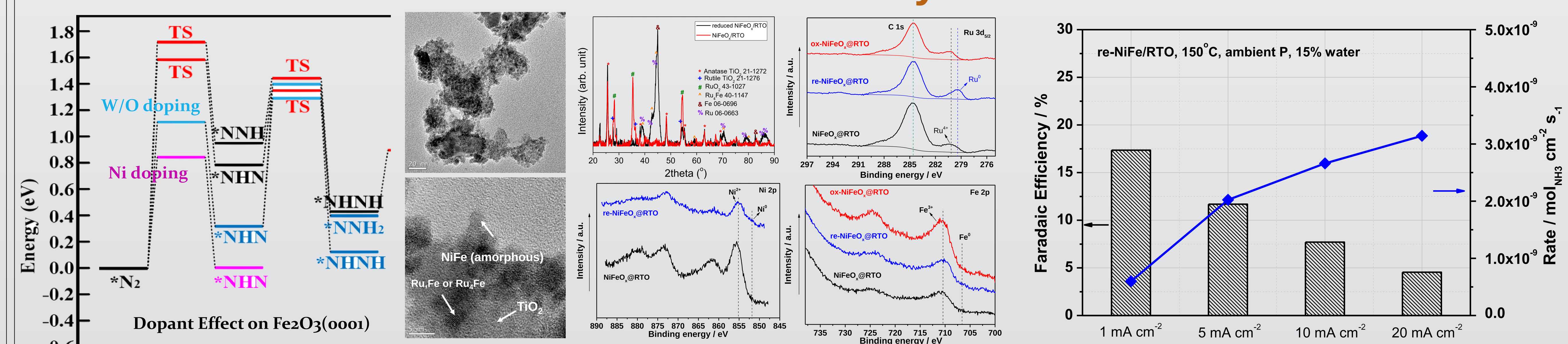




- Nanosized MTP (M=Sb, Mo, V, W) powder was synthesized with high purity (except VTP).
- The synthesized MoTP materials exhibits highest conductivity of 87 mS/cm at 150°C.
- Large MoTP/PTFE composite membrane was fabricated with thickness of < 300 μm
- The ASR of MoTP/PTFE membrane is around 0.52 Ω cm²



NRR Catalyst



- DFT calculation shows that Ni dopant facilitate N2RR in a robust way
- Partially reduced NiFeOx@RTO nanoparticles were fabricated as NRR catalyst
- ITSAE exhibited a Coulombic Efficiency of 4.54% and ammonia production rate of 3.14 X 10^{-9} mol/cm²/s at 150°C using 85%N_2+15% H_2O.

Technology to Market

(1) The cost of ammonia produced by 150 MW ITSAE plant is around 0.1133$/kWh. which is 10% lower than REFUEL target ($0.128/kWh).

(2) Main cost factors have been identified as electrode cost, ITSAE energy efficiency, and electricity cost.

(3) Distributed ammonia production systems with productivity of 1 and 10 ton/day were selected for the first market application.

Final Targets

Periods/Parameters	Phase I (Completed)	Phase II (Two Years)	Phase IIS (One Year)
Cell/Stack	5-cm² single cell	5-cm² single cell	Stack
Membrane conductivity (mS/cm)	>40	>100	>100
Membrane thickness (μm)	≤300	≤50	≤50
Current density (mA/cm²)	5.0	350	300
Coulombic Efficiency (%)	≥20	≥94	≥90
Ammonia production rate (mol/cm²/s)	≥3.5x10^{-9}	≥1.1x10^{-6}	≥9.4.0x10^{-7}
Energy Efficiency (%)	-	>65	>60

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