

**POLYMER-ZEOLITE NANOCOMPOSITE
HIGH-TEMPERATURE
PROTON-EXCHANGE-MEMBRANE
FOR FUEL CELLS**

Prepared For:

California Energy Commission
Energy Innovations Small Grant Program

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FEASIBILITY ANALYSIS AND FINAL EISG REPORT

May 2005
CEC-500-2005-089

ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM

INDEPENDENT ASSESSMENT REPORT (IAR)

POLYMER-ZEOLITE NANOCOMPOSITE HIGH-TEMPERATURE PROTON-EXCHANGE-MEMBRANE FOR FUEL CELLS

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Grant #: 00-31

Grant Funding: \$75,000

Term: August 2001 – August 2002

PIER Subject Area: Environmentally Preferred Advanced Generation

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PREFACE

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- Residential and Commercial Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

The EISG Program Administrator is required by contract to generate and deliver to the Commission an Independent Assessment Report (IAR) on all completed grant projects. The purpose of the IAR is to provide a concise summary and independent assessment of the grant project in order to provide the Commission and the general public with information that would assist in making follow-on funding decisions. The IAR is organized into the following sections:

- Introduction
- Objectives
- Outcomes (relative to objectives)
- Conclusions
- Recommendations
- Benefits to California
- Overall Technology Assessment
- Appendices
 - Appendix A: Final Report (under separate cover)
 - Appendix B: Awardee Rebuttal to Independent Assessment (Awardee option)

For more information on the EISG Program or to download a copy of the IAR, please visit the EISG program page on the Commission's Web site at:

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Polymer-Zeolite Nanocomposite High Temperature Proton-Exchange-Membrane for Fuel Cells

EISG Grant # 00-31

Awardee: University of California, Riverside
 Principal Investigator: Yushan Yan
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 Grant Funding: \$75,000
 Grant Term: August 2001 – August 2002

Introduction

Natural gas fueled gas turbine combined cycle power plants are the primary choice for new power plants in California because they can achieve much higher thermal efficiency and lower air emissions than coal- or distillate-fired units. Reducing pollutant emissions of NO_x and CO to meet California's increasingly stringent air quality regulations remains a significant concern. Advanced generation technologies that improve efficiency and significantly reduce NO_x, CO and CO₂ emissions are in demand. Proton Exchange Membrane (PEM) fuel cells are potential candidates for residential distributed power production. Nafion is the most commonly used proton-exchange membrane in PEM fuel cells, but its economic viability faces significant technical roadblocks. Among these problems are: water management at the electrodes; CO poisoning of the anode catalyst; slow cathode kinetics; and the high cost of the platinum electrode catalyst.

If these difficulties were solved, PEM fuel cells could be used for added generation capacity both in distributed generation and at the central power plant. Cells using pure hydrogen produce almost zero regulated emissions, only water and heat. Additionally, Carnot's principle, which applies to and limits all heat engines, does not affect fuel cells because the electricity is generated by an electrochemical reaction.

Figure 1 illustrates the use of a PEM fuel cell in a residence. Lower energy use and a cleaner technology will reduce emissions. Actual reductions will vary depending on the air-pollution baseline in any given area.

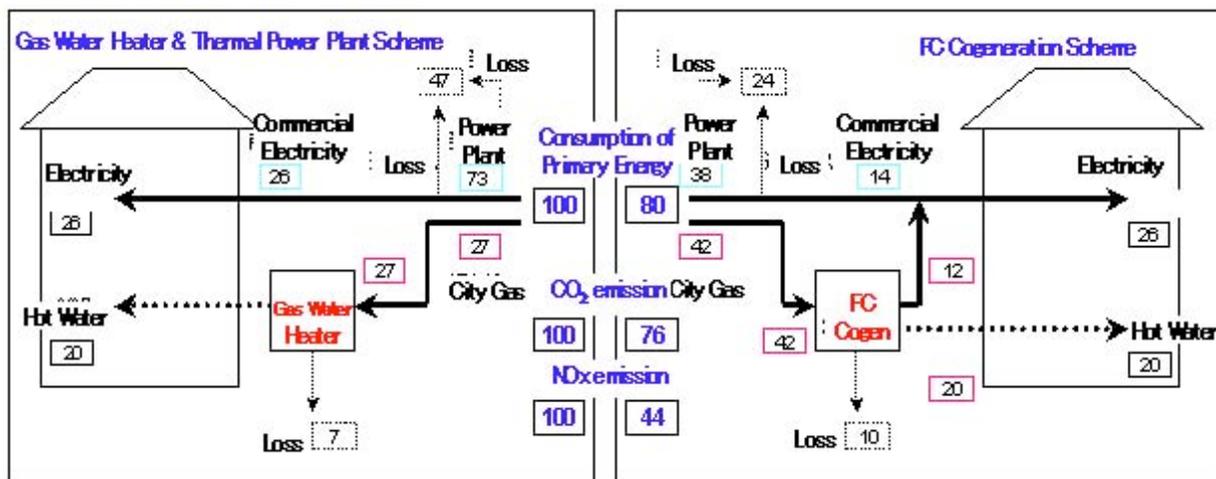


Figure 1. The left side shows a conventional combination of gas-heated water and grid electricity from a thermal power plant. The right side introduces cogeneration into the system by means of a proton-exchange-membrane (PEM) fuel cell. The expected benefits include reductions of 20% primary energy consumption, 24% CO₂ emission, and 56% NO_x emission.

The researcher in this project predicted that the problems associated with Nafion membranes could be eliminated or alleviated once the operating temperature of the PEM fuel cell exceeds 100°C. Above boiling point, water would not flood the cathode and thus prevent the oxygen from reaching the cathode catalyst. On the other hand, Nafion is an excellent proton conductor only when it is fully hydrated. To achieve a 100°C operating temperature, the researcher proposed using zeolite nanoparticles as an additive to Nafion to improve its water retention and cited several published research papers suggesting that zeolites functionalized with sulfonic groups will have comparable or superior proton conductivity to Nafion at high temperatures and low humidity. Because the local hydration and proton conductivity within the nanoparticles should be higher than in Nafion, the researcher hypothesized that the bulk properties of the Nafion with the nanoparticles would improve. The researcher suggested that nanoparticles would interrupt the host matrix less than micron-sized particles and result in improved mechanical properties of the host.

Objectives

The goal of this project was to determine the feasibility of using a zeolite nanoparticle additive to Nafion to improve its water retention and proton conductivity at high temperatures (120 – 150°C). The researcher established the following project objectives:

1. Synthesize mono-disperse zeolite X and/or Y nanocrystals with diameters controlled between 15 to 80 nm in diameter. Prepare uniform Nafion-zeolite X and/or Y nanocomposite membranes.
2. Demonstrate higher water adsorption capacity and proton conductivity in the Nafion-zeolite nanocomposite membrane at high temperatures (120 – 150°C) than those properties of the bare Nafion membranes at 80 °C.
3. Show that a PEM fuel cell system will be over 40% efficient with a 20% reduction of primary energy consumption and 24% and 56% reductions of CO₂ and NO_x emissions, if the proposed high-temperature membrane is successfully developed and integrated into a fuel cell system.
4. Show that the projected cost of a PEM fuel cell power system will be reduced to \$600 to \$700/kW from the current +\$1000/kW if the proposed high-temperature membrane is successfully developed and integrated into a fuel cell system.
5. Formulate a Nafion bi-functional silica nanocomposite membrane and test for water adsorption and proton conductivity.

Outcomes

1. The researcher synthesized zeolite Y nanocrystals with a mean diameter of 32 nm and developed a new fabrication method that avoids agglomeration of the particles. The researcher prepared Nafion-zeolite Y nanocomposite membranes with 10wt% zeolite loading.

2. The Nafion-zeolite nanocomposite membrane had slightly higher proton conductivity at 80°C than recast bare Nafion at 80°C. No tests were reported in the 120-150°C range.
3. Although the researcher's proposal cited work done by Tokyo Gas Company to demonstrate this objective, the work was apparently not augmented to evaluate efficiency and emissions objectives during the performance of this project.
4. The researcher did not address the potential cost reduction of a PEM fuel cell system based on the data generated in this project.
5. The researcher formulated a Nafion bi-functional silica nanocomposite membrane. Water adsorption and proton conductivity of the Nafion-silica material were somewhat superior to bare Nafion. The researcher hypothesized that the Nafion-silica nanocomposite membranes could maintain high water uptake at high temperatures.

Conclusions

The researcher in this project provided a new approach to reducing the cost of a PEM fuel cell by extending its operating temperatures. The data, while suggestive, do not appear sufficient to prove the feasibility of the concept.

1. Zeolite nanoparticles with a mean diameter in the range 15 to 80 nm can be fabricated and uniformly distributed in a Nafion membrane.
2. This project set no precise goals for water adsorption and proton conductivity. Its gains were minor but encouraging. Since no testing was reported in the 120 – 150°C range the PA cannot determine if the objective was met.
3. The researcher did not present any new information that would support claims of reduced power consumption and emissions.
4. Because the researcher did not provide any information, the PA cannot speculate on the possible cost reductions of PEM fuel cell systems.
5. Nafion with silica nanoparticles may offer promising high-temperature properties for PEM fuel cells.

Recommendations

Further optimization and more detailed characterization of the Nafion-zeolite nanocomposite membranes and/or the Nafion-silica membranes are necessary to develop the concept into a commercially viable product. The nanocomposite membranes have to be coupled with appropriate electrodes into the configuration of a membrane electrode assembly (MEA) so that the composite membrane concept can be tested in a fuel cell configuration.

The following questions should be considered before beginning additional work in this area:

1. Is there an advantage to the incorporation of mono-disperse zeolite nanoparticles as used? A distribution of particle sizes could be less expensive.
2. What is the mechanism that causes the nanoparticles to enhance macroscopic proton conductivity in the composite membranes? The particles are likely isolated in the Nafion matrix and therefore disconnected from each other. While local hydration and proton conductivity within the nanoparticles should be higher than in Nafion, it is not clear that these should contribute to increasing the water adsorption or proton transport properties of the bulk composite. The mechanism of proton conduction

across the nanoparticle Nafion interface is an important and likely limiting process step that should be examined more thoroughly.

3. Based on the proton conductivity results reported, the conductivities of the Nafion-zeolite membranes are slightly above “recast” Nafion and below that of commercial Nafion. These preliminary results appear not to be particularly promising for a significant improvement of PEM conductivity properties. What are the obstacles and how might they be overcome?
4. What are the economics of powering individual residences with fuel cells? Do the reliability and economics improve when several residences and small businesses are aggregated into micro-grids?

Benefits to California

Public benefits derived from PIER research and development are assessed within the following context:

- Reduced environmental impacts of the California electricity supply or transmission or distribution system.
- Increased public safety of the California electricity system
- Increased reliability of the California electricity system
- Increased affordability of electricity in California

The primary potential benefit to the ratepayer of this research would be reduced environmental impacts of the California electricity supply and transmission and distribution system. If the technology evaluated in this project were proven, developed into a commercial product, and applied to a residential energy system, it could reduce primary energy use by up to 20%. Savings result from the use of the fuel cell heat for residential water heating and from the reduction of transmission losses in electricity delivery. Since the technology is still far from commercialization, it is difficult to estimate the rate at which these benefits would accrue to California ratepayers.

Overall Technology Transition Assessment

As the basis for this assessment, the Program Administrator reviewed the researcher’s overall development effort, which includes all activities related to a coordinated development effort, not just the work performed with EISG grant funds.

Marketing/Connection to the Market

This project generated new information that was published in two (2) peer-reviewed papers. The researcher is preparing two additional papers for publication. This technology transfer activity contributes to the general knowledge base for PEM fuel cells.

Engineering/Technical

This project successfully synthesized zeolite Y nanocrystals with diameter of 32 nm, which is the smallest available. It has prepared Nafion-zeolite nanocomposite membranes with 10wt% zeolite loading. Preliminary data showed that the Nafion-zeolite nanocomposite membrane has slightly higher proton conductivity than recast bare Nafion, indicating that the nanocomposite membrane approach is promising. The project also demonstrated that Nafion-silica (functionalized) could be

potentially useful as high temperature membranes for fuel cells. Integrating the new membrane into a PEM fuel cell and performing tests have not yet been done.

Legal/Contractual

The researcher did not mention patent applications or discussions with potential commercializers.

Environmental, Safety, Risk Assessments/ Quality Plans

Due to the early stage research of this project, formal quality planning would be premature. Quality Plans include Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, and Product Safety and Environmental.

Production Readiness/Commercialization

This project is in the early stage research phase, and not yet ready for commercialization.

Appendices

Appendix A: Research Final Report (under separate cover)

Appendix B: Awardee Rebuttal to Independent Assessment (none submitted).

**ENERGY INNOVATIONS SMALL GRANT
(EISG) PROGRAM**

EISG FINAL REPORT

**POLYMER-ZEOLITE NANOCOMPOSITE HIGH-TEMPERATURE
PROTON-EXCHANGE-MEMBRANE FOR FUEL CELLS**

EISG AWARDEE

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Grant #: **52104A/00-31**

Grant Funding: \$75,000

Term: August 2001 – August 2002

PIER Subject Area: Advanced Generation

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Inquires related to this final report should be directed to the Awardee (see contact information on cover page) or the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

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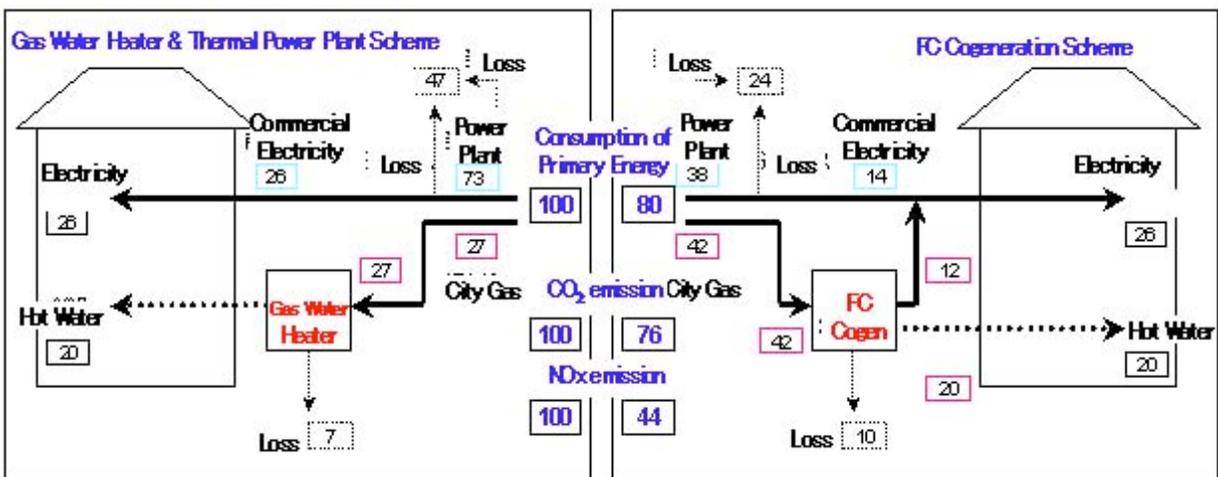


Figure 1. A comparison between a proton exchange membrane (PEM) fuel cell cogeneration system (Right side) and the conventional combination of city gas water heater and grid electricity from a thermal power plant (Left side). The expected benefits of a PEM fuel cell cogeneration system include reduction of 20% primary energy consumption, 24% CO₂ emission, and 56% NO_x emission. Adapted from reference 7.

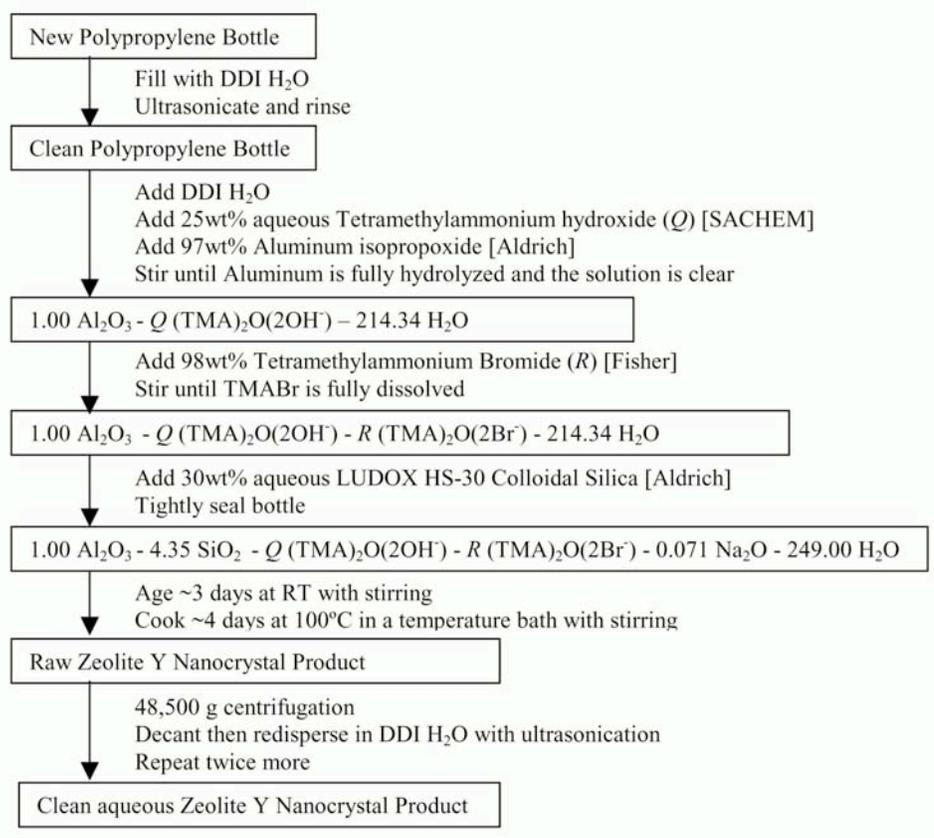


Figure 2. Synthesis procedure for zeolite Y nanocrystals. From ref. 11.

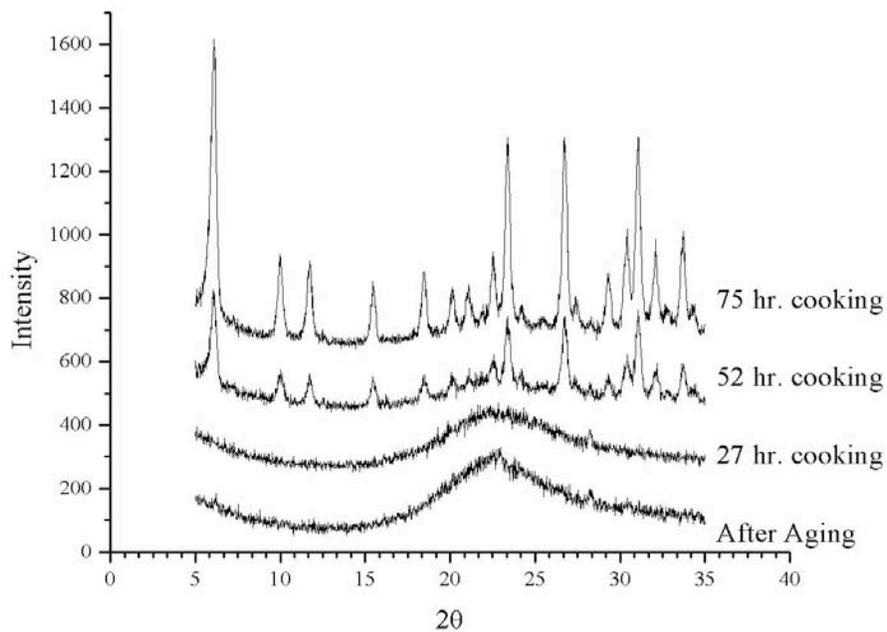


Figure 3. XRD patterns for solid products from zeolite Y nanocrystal synthesis using synthesis composition of T3.6 (see Table 2 for detailed composition for T3.6). From ref. 11

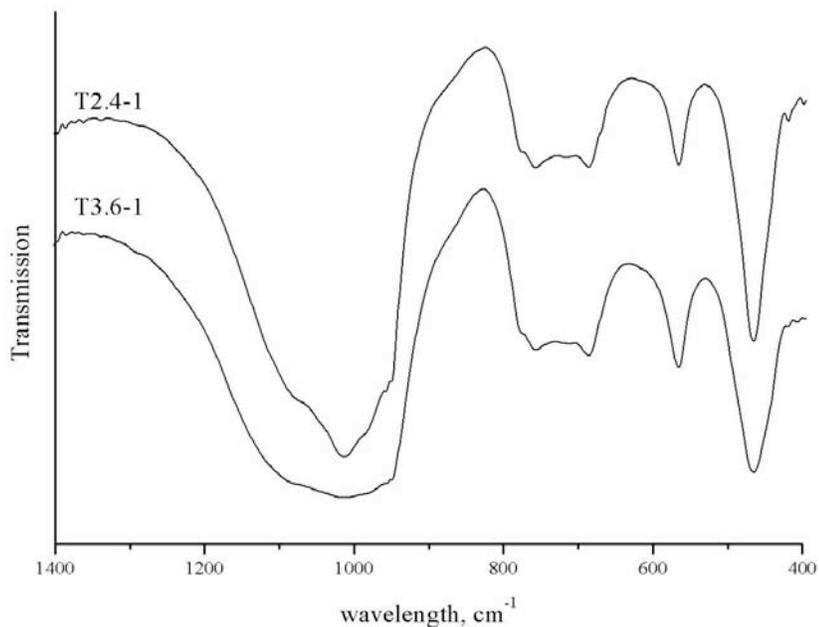


Figure 4. IR spectra of zeolite Y nanocrystals with two synthesis compositions (see Table 2 for detailed composition T2.4 and T3.6). From ref 11.

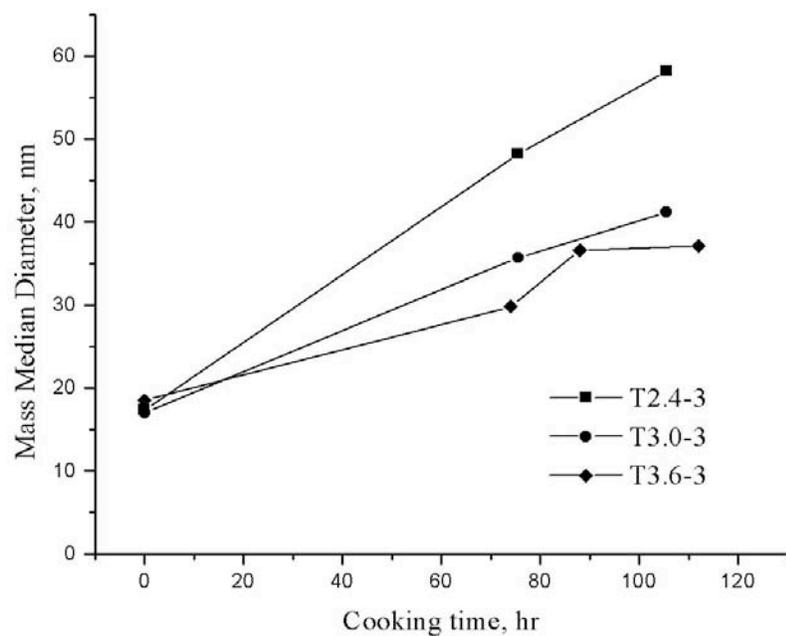


Figure 5. Dynamic light scattering of zeolite Y nanocrystals with three different synthesis compositions (see Table 2 for detailed composition for T2.4, T3.0, and T3.6). From ref. 11.

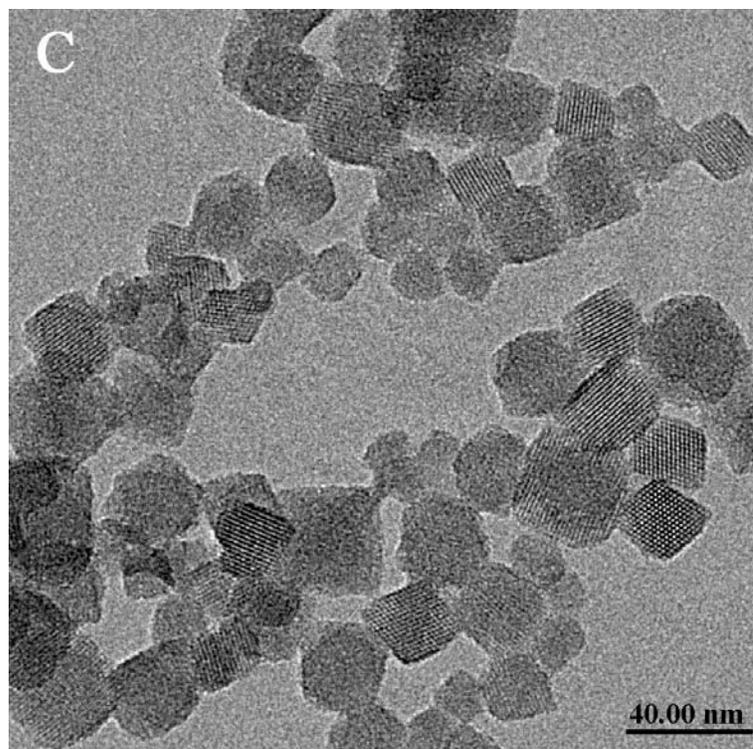


Figure 5. TEM images of zeolite Y nanocrystals from T3.6 (see Table 2 for detailed composition for T3.6). From ref. 11

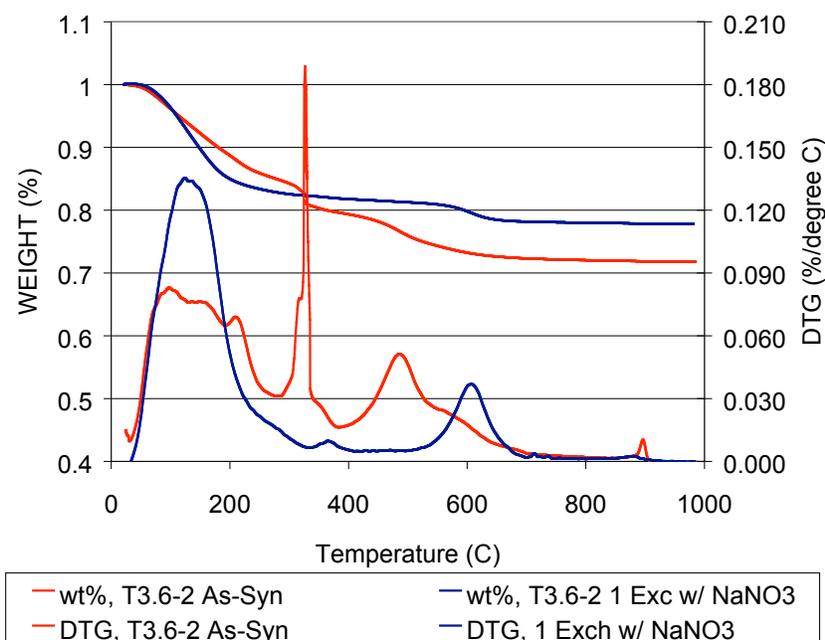


Figure 6. Thermal gravimetric analysis of as-synthesized zeolite Y nanocrystals (red line) and after NaNO₃ exchange (blue line) from T3.6 (see Table 2 for detailed composition for T3.6).

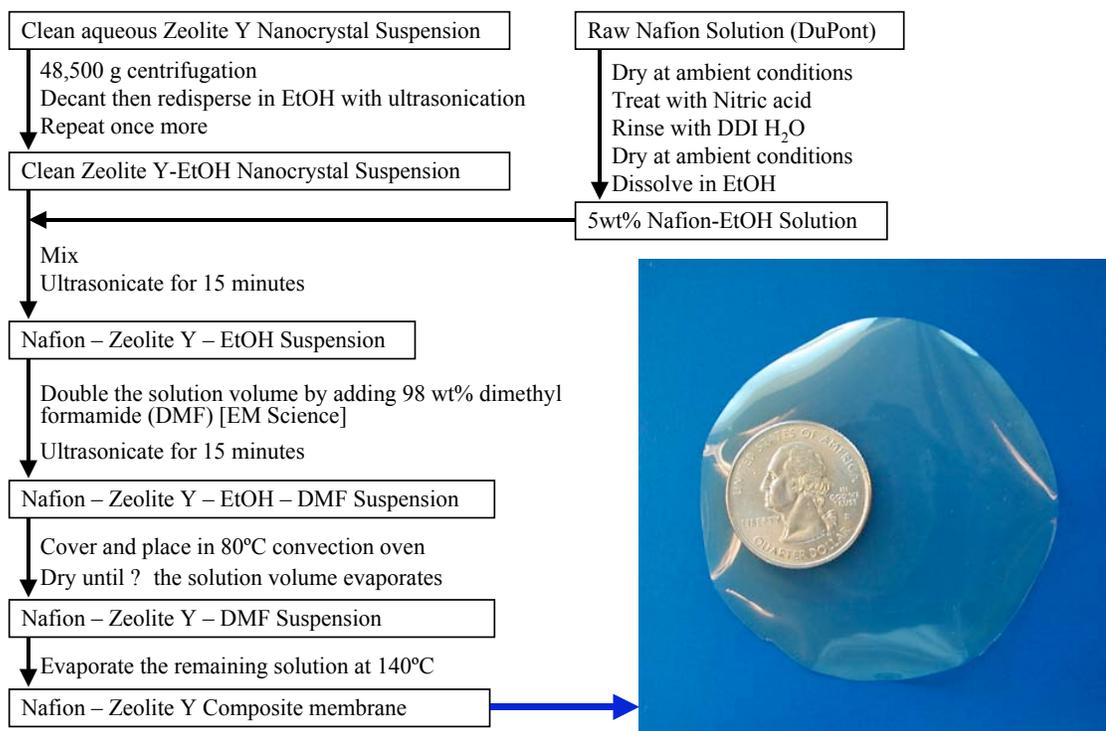


Figure 7. Preparation procedure of Nafion-zeolite nanocomposite membrane, and the SEM image of the corresponding composite membrane (The coin is beneath the nanocomposite membrane).

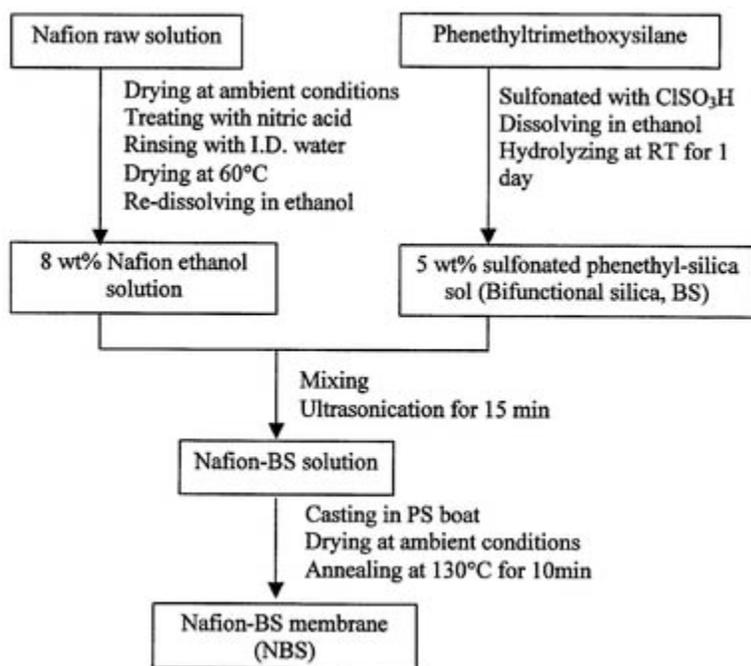


Figure 8. Preparation procedure for Nafion-silica nanocomposite membrane. From ref. 10.

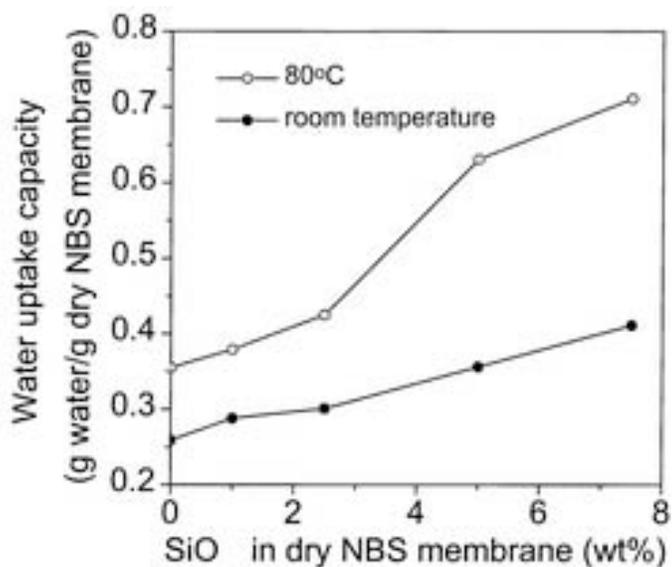


Figure 9. Water uptake of Nafion-silica nanocomposite membranes at two different temperatures. From ref. 10.

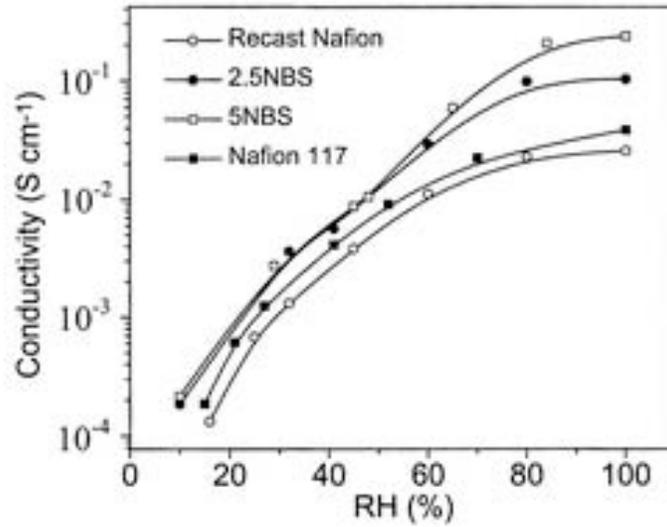


Figure 10. Proton conductivity of commercial Nafion 117, recast Nafion, Nafion-silica nanocomposite membranes with different amount of silica loading measured at different relative humidity. From ref. 10.

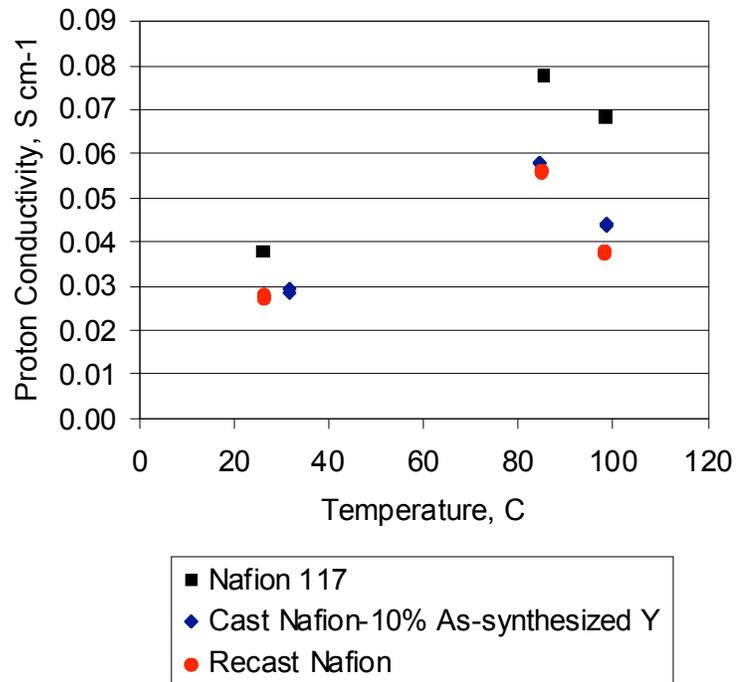


Figure 11. Proton conductivity versus of temperature for commercial Nafion (solid square), Nafion-zeolite composite (blue diamond), and recast Nafion (red solid circle).

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Table 1. Summary of impacts of a PEM fuel cell cogeneration system over the conventional combination of gas water heater and grid electricity from natural gas based thermal power plant. Adapted from reference 7.

	Primary energy consumption	NOx emission	CO ₂ emission
PEM fuel cell cogeneration system	80	44	76
Natural gas water heater + grid electricity from natural gas based thermal power plant	100	100	100

Table 2. Synthesis conditions for batches with increasing TMABr content. From ref. 11.

	Control	25% more (TMA) ₂ O/Al ₂ O ₃	50% more (TMA) ₂ O/Al ₂ O ₃
Batch	T2.4	T3.0	T3.6
Q , (TMA) ₂ O {2OH ⁻ }/Al ₂ O ₃	2.39	2.39	2.39
R , (TMA) ₂ O {2Br ⁻ }/Al ₂ O ₃	0.00	0.60	1.19
(TMA) ₂ O/Al ₂ O ₃	2.39	2.99	3.58
S , Br ⁻ /OH ⁻	0.00	0.25	0.50
[OH ⁻] (mol/L)	1.08	1.08	1.08
High Crystallinity	Yes	Yes	Yes
Average Mass Median Diameter (MMD)	54.9	39.0	35.0
MMD Standard Deviation	2.7	1.6	1.6

Abstract

Proton-exchange-membrane (PEM) fuel cells have been considered a potential candidate for environmentally benign advanced generation technology that is intrinsically efficient and clean. Current Nafion-based PEM fuel cells faces significant technology roadblocks that have to be overcome before they can become economically viable, and these include water management at the electrodes, CO poisoning of the anode catalyst, slow cathode kinetics, and high cost of the Pt electrode catalyst. It has been predicted that these problems will be eliminated once the operating temperature is increased to above 100 °C. The overall objective of this proposal is to study the feasibility of using zeolite nanoparticles as additive to Nafion to improve its water retention and proton conductivity at high temperatures. Specifically, we planned (1) to synthesize monodisperse zeolite X and/or Y nanocrystals with controllable nanometer crystal size (e.g., from 15 to 50 nm in diameter), (2) to prepare Nafion-zeolite X and/or Y nanocomposite membranes with uniform well-mixed matrix, (3) to perform tests to show that the novel polymer-zeolite nanocomposite membranes have comparable or higher water adsorption capacity and proton conductivity than the bare Nafion membranes at 80 °C. We have synthesized zeolite Y nanocrystals with diameter of 32 nm, which is the smallest available. We have prepared Nafion-zeolite nanocomposite membranes with 10wt% zeolite loading. The membrane is clear and transparent because of the nano-sized particles used. Our preliminary data showed that the Nafion-zeolite nanocomposite membrane has slightly higher proton conductivity than recast bare Nafion, indicating that our nanocomposite membrane approach is promising. We have also demonstrated that Nafion-silica (functionalized) could be potentially useful as high temperature membranes for fuel cells.

Key words: Fuel cell, proton exchange membrane, power generation, environmental, clean, composite, Nafion, zeolite.

Executive Summary

Hydrogen fuel cell is a device that combines hydrogen with oxygen electrochemically to produce electricity. One of the several types of fuel cells, proton-exchange-membrane (PEM) fuel cell has been considered as a potential candidate for environmentally benign advanced generation technology that is intrinsically efficient and clean. If pure hydrogen is used, the only byproduct of a PEM fuel cell is water. One key component of a PEM fuel cell is the proton exchange membrane, and currently Nafion is the most commonly used PEM. Nafion-based PEM fuel cell faces significant technology roadblocks that have to be overcome before it can become economically viable, and these include water management at the electrodes, CO poisoning of the anode catalyst, slow cathode kinetics, and high cost of the Pt electrode catalyst. It has been predicted that these problems will be eliminated/alleviated once the operating temperature is increased to above 100 °C.

The overall objective of this proposal is to study the feasibility of using zeolite nanocrystals as an additive to Nafion to improve its water retention and proton conductivity at high temperatures. Specifically, we planned (1) to synthesize monodisperse zeolite X and/or Y

nanocrystals with controllable nanometer crystal size (e.g., from 15 to 50 nm in diameter), (2) to prepare uniform Nafion-zeolite X and/or Y nanocomposite membranes, (3) to perform tests to show that the polymer-zeolite nanocomposite membrane has comparable or higher water adsorption capacity and proton conductivity than the bare Nafion membranes at 80 °C.

We have synthesized zeolite Y nanocrystals with diameter of 32 nm, which is the smallest available. We have prepared Nafion-zeolite nanocomposite membranes with 10wt% zeolite loading. The membrane is clear and transparent because of the nano-sized particles used. Our preliminary data showed that the Nafion-zeolite nanocomposite membrane has slightly higher proton conductivity than recast bare Nafion, indicating that our nanocomposite approach is promising.

Further optimization and more detailed characterization of the Nafion-zeolite nanocomposite membranes are necessary to develop the concept into a commercially viable product. The nanocomposite membranes have to be coupled with appropriate electrodes into the configuration of a membrane electrode assembly (MEA) so that the composite membrane concept can be tested in a fuel cell configuration.

If eventually implemented as a commercial product, the technology could reduce primary energy consumption by 20%, NO_x emission by 46%, and CO₂ emission by 24%.

Introduction

Natural gas based thermal generation is the primary source of electricity in California [1]. Gas based thermal power plants are much cleaner than coal or oil based ones (that are still in widespread use in other states of the country), but their pollutant emissions such as NO_x and CO₂ are still of significant concern because of the increasingly stringent air quality regulations in California [2]. As a result, environmentally benign advanced generation technologies that are intrinsically more efficient and clean (with significant reduction in NO_x, and CO₂ emissions) have been widely sought.

Studies have widely shown that PEM fuel cell cogeneration systems are very attractive for residential applications because they are highly efficient (especially at the relatively small maximum output that is suitable for residential applications) and quiet and can significantly reduce primary energy consumption and pollutant emissions [4-9]. For example, a very recent study carried out by Tokyo Gas has shown that a natural gas fueled PEM fuel cell system with an integrated fuel reformer can reach 90% thermal efficiency in a cogeneration configuration [7]. The study compares a PEM fuel cell cogeneration system with the conventional combination of gas water heater and grid electricity from a thermal power plant, and concludes that the PEM fuel cell system can reduce primary energy consumption by 20% while cutting CO₂ and NO_x emission by 24% and 56%, respectively (Figure 1 and Table 1). Fuel cell generation in a distributed generation system also improves the reliability and quality of electricity supply [3-5,8]. Clearly, there is great potential for a PEM fuel cell system for residential power generation, and this is especially true when a cogeneration configuration is considered. However, the current PEM fuel cell system still faces significant technology roadblocks that have to be overcome before it can become economically viable [3,4]. For example, the current Nafion-based low

temperature (80 °C) PEM fuel cell system still has several challenging problems such as water management at the electrodes, CO poisoning of the anode catalyst, slow cathode kinetics, and high cost of the Pt electrode catalyst [3,4]. The proposed research seeks to solve these problems by developing a novel polymer-zeolite nanocomposite membrane that allows a PEM fuel cell to operate at high temperatures (e.g., e.g., 110-150 °C).

Project Objectives

- Objective 1:** Synthesis of monodisperse zeolite X and/or Y nanocrystals with controllable nanometer crystal size (e.g., from 15 to 50 nm in diameter).
- Objective 2:** Preparation of Nafion-zeolite X and/or Y nanocomposite membranes with uniform well-mixed matrix.
- Objective 3:** Performance tests to show that the novel polymer-zeolite nanocomposite membrane has comparable or higher water adsorption capacity and proton conductivity at high temperatures (e.g., 110 – 150 °C) than the bare Nafion membranes at 80 °C.

Project Approach

For Task 1, we minimized the crystal size of zeolite Y nanocrystals by adding tetramethylammonium (TMA) bromide into the synthesis composition. We succeeded in removing the template from the super cage by ion exchange with NaNO_3 although we originally planned to use the polymer network barrier approach we developed previously [12]. We found the new method is advantageous because it does not need to take the crystals out of the solution. We have attempted to do proton exchange for the zeolite Y nanocrystals, but only partially successful because zeolite Y nanocrystals are not very stable under acidic conditions. We have begun to improve the acid stability of zeolite Y nanocrystals by dealumination.

For Task 2, we developed a protocol for the preparation of Nafion-zeolite nanocomposite membranes (Figure 7). The key here is to use of a common solvent/dispersant ethanol and the use of a high boiling point solvent DMF. The two-step drying is also important.

For Task 3, we performed water uptake as well as proton conductivity measurements on the nanocomposite membranes by using microbalance and a 4-electrode test protocol, respectively. General characterizations were also performed using scanning electron microscope (SEM), transmission electron microscope (TEM), dynamic light scattering (DLS), x-ray diffraction (XRD), infrared spectroscopy (IR), etc.

Project Outcomes

Overall, we have two peer reviewed journal articles already published and two are in preparation. One invention disclosure has been filed.

- We have synthesized zeolite Y nanocrystals of 32 nm in diameter with high yield. This the smallest diameter reported.

Figure 2 shows the synthesis procedure we developed for zeolite Y nanocrystals. This procedure coupled with an appropriate composition (T3.6 in Table 2 is the optimal composition) produces 32nm diameter zeolite Y crystals. This is the smallest diameter available with high yield. The crystalline phase and phase purity of the Y nanocrystals are confirmed by x-ray diffraction (XRD, Figure 3) and infrared spectroscopy (IR, Figure 4). Both clearly show that the crystals are zeolite Y with high purity. The crystal size of the Y nanocrystals is confirmed to be 32 nm by dynamic light scattering (DLS, Figure 5, T3.6) and transmission electron microscope (TEM, Figure 6).

- We have succeeded in removing organic template from the super cages by ion exchange with NaNO_3 .

We planned to remove the template using a procedure we recently developed for another sponsor [12]. However, during the course of this research, we came to discover that there is a better approach that does not need to take the nanocrystals out of the solution phase. Taking the nanocrystals out of the solution tends to cause agglomeration of nanocrystals. Figure 7 shows the thermal gravimetric curves of the Y nanocrystals before and after the ion exchange. The missing peaks in the blue line shows clearly that the organic template molecules in the super cage have been removed after the ion exchange.

- We have performed proton exchange for the Y nanocrystals, but only partially successful as these crystals appear to have limited stability in acidic conditions.

As a high-aluminum zeolite, zeolite Y is less stable to acids than high-silica zeolites. It appears that the nano-sized crystals are even less stable than the normal micron-sized crystals. We are developing proton exchange in mild conditions, which may eventually allow proton exchange into Y nanocrystals.

- We have developed an innovative and effective protocol to prepare Nafion-zeolite nanocomposite membranes as planned.

The procedure and the corresponding SEM images of the composite membrane are shown in Figure 8. This procedure produced very uniform nanocomposite membranes (see the picture in Figure 8). The key for this procedure is that a common solvent such as ethanol is used. Water was found to detrimental for the process. Another solvent with high boiling point such as MDF is also needed. The two-step evaporation is also critical.

- As part of the effort of this project, but not outlined in the original proposal, we have developed Nafion-bifunctional-silica nanocomposite membranes.

The detailed preparation procedure is shown in Figure 9. The corresponding water uptake and proton conductivity measurements are shown in Figure 10 and Figure 11. The data clearly show that Nafion-silica nanocomposite membranes can maintain high water uptake at high temperatures (Figure 10). The proton conductivity for the nanocomposite membranes is also higher than bare Nafion (2.5 NBS versus recast Nafion in Figure 11).

- We have carried out detailed characterization on Nafion-silica nanocomposite membranes.

We have carried out preliminary water uptake and proton conductivity measurements on Nafion-zeolite nanocomposite membranes. The proton conductivity of the nanocomposite

membranes is higher than recast Nafion (diamond versus solid circle in Figure 12). This shows that the composite approach is promising.

- We have carried out a comprehensive list of characterizations on the nanocrystals and the nanocomposite membranes as seen in the above sections of this report (Figure 2-12).

Conclusions

We have demonstrated that zeolite nanocrystals with nanometer-size can be synthesized. These crystals can be processed and incorporated into Nafion to make uniform nanocomposite membranes. The Nafion-zeolite nanocomposite membrane approach is a promising approach although more development work is needed in this area.

Recommendations

This study has provided the feasibility of the concept. The next steps would be to improve the acid stability of zeolite Y nanocrystals or develop other more acid-stable zeolite nanocrystals such as zeolite beta. Optimization of the nanocomposite membrane preparation is also needed to increase the zeolite loading. In addition to water uptake and proton conductivity measurements, preparation of membrane electrode assembly (MEA) is needed for real fuel cell testing, which is essential for commercialization.

Public Benefits to California

If eventually implemented as a commercial product, the technology could reduce primary energy consumption by 20%, NO_x emission by 46%, and CO₂ emission by 24%.

Endnotes

None

Glossary

None

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Appendices

We have published two journal articles as a result of this sponsorship, and these two papers will be included here in PDF form. Two more journal articles are in preparation.

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