



## Engaging US Engineering Students in Fuel Cell Research at a Foreign Site

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## Abstract

The department of mechanical engineering at Oakland University University was awarded by the National Science Foundation (NSF) a three year grant to support a group of US undergraduate and graduate engineering student to conduct fuel cell related research at Beijing Jiaotong University in China. The program has run successfully for three consecutive summers between 2010 and 2012. The program aimed to engage the engineering students in the fuel cell research at a foreign site as well as expose them to Chinese culture. A total of 17 students from 11 different universities have taken part in the program. More than a third of the participants were female engineering students. The student participants worked in teams with Chinese students on fuel cell related projects, and participated in other activities such as touring research lab and facilities at Chinese Universities, meeting with Chinese scholars and students, and attending conferences and seminars. Another important element of the program is culture exchange. The student participants took at least 24 hours Chinese language training for an 8-week program and explored many historical sites in Beijing. The purpose of this paper is to share the experience of organizing and running an international research program and to report the program outcomes and some assessments results. We believe that the results from this paper will benefit those who seek to run a similar international program.

## Introduction

Increasing globalization of economy and technology demands more and more college graduates who can take the challenge of collaborating internationally or working abroad upon graduation. Therefore, an international studying and/or living experience will be critical to prepare them for this challenge. For engineers to be successful in an increasing global economy, they must have an understanding and appreciation of culture and technology in other countries. One particularly important country is China, which already graduates three times as many engineers as the United States on a yearly basis<sup>1</sup>. In addition, China has become an international power in the area of manufacturing and alternative energy. It might eventually become center in the world.

Fuel cells produce electricity through the electrochemical reaction of an oxidant (oxygen from air) and fuel (methanol, natural gas, pure hydrogen, etc.)<sup>2-6</sup>. They have recently attracted considerable research interest due to their high power density, light weight and low emissions. However, their wide use has been limited due to high capital cost, multiple issues related to poor performance, material durability and availability, manufacturing ability, and design flexibility<sup>7-8</sup>. Vehicles powered by fuel cells will not be affordable, durable, or available to average consumers until 2010-2020<sup>9</sup>. As an arising energy conversion system, fuel cells have attracted many students' interest. However, not many universities in US offer fuel cell course or have fuel cell related projects.

With combined faculty expertise in fuel cells from Oakland University(OU) and Beijing Jiaotong University(BJTU) in China, the department of mechanical engineering at OU was awarded by

the National Science Foundation a three year grant to engage US engineering students in fuel cell research at a foreign site in China. The program started on Oct 1, 2009. The objective of the proposed IRES site is to annually provide five U.S. engineering students (four undergraduates and one graduate) with the unique opportunity to work on fuel cell collaborative research between OU and BJTU in Beijing, China. In the past three summers, a total of 17 students (6 females) have taken part in the IRES program. These students stayed in BJTU for 8 weeks and worked on 7 different projects related to fuel cells. An international advising team including both US and China faculty advisors worked closely with each student for the duration of the program. Students are also exposed to Chinese culture through all kinds of arranged culture exchange activities. In this paper we will discuss some of the experience that we gained from organizing this international research program over the past 3 years. Some of the planning, logistics, procedures and outcomes will be described and analyzed based on the results from program survey. Some suggestions to keep the sustainability of the program will be also provided. This type of information will be useful for peers who seek to run a similar program.

### **Application and Recruiting**

The program ran for eight weeks in each summer of 2010-2012, starting in middle of May and ending in early July. Nine months before the program started, the NSF IRES flyer was prepared and was advertised through different channels including the ASME ME departmental chair email list, the professional society advisors of SWE, SAE, ASME, SME and IHAE and individual faculty members at various institutions. The program was also promoted in the classroom by engineering professors at OU. The previous NSF IRSE fellows were good advocates for the program. A website was created to advertise this program and an on-line application system was created for the convenience of application. The application deadline was usually close to the end of January. This deadline is much earlier than most of other summer REU or internship programs. The reason is that extra time is needed to prepare documents for international travel and logistics and accommodation arrangement.

We received more than 70 outstanding applications (the average GPA was 3.7) from more than 60 different universities across the US including top schools such as Princeton University and Northwestern University. Of all the recruiting efforts used, the most effective in the first year were the messages sent to the ASME ME departmental chair e-mail list and previous NSF IRES participants in the second and third years. We have received more than 10 applications from ZZ University. Three of them, i.e. one for each summer, were chosen as the IRES final participants.

Each application was very carefully reviewed by faculty committee at OU. The top five were selected as IRES participants. Another five students were on the waiting list. The NSF grant provided funding for five students. However, given the success of the application request and the number of qualified applicants, additional funding was sought and obtained from Oakland University's Office of the Provost and Vice President for Academic Affairs to support one additional OU student, bringing the total number of student participants in the first and second year to six in each year. The program director made calls to each candidate to confirm their interest in the program. An official offer letter was sent out to the candidates, and all the students had to return the signed letter to confirm their participation in two weeks. An email was then sent

to notify those applicants who were not selected for the program. A brief profile of the 2010-2012 NSF IRES Participants is shown in Tables 1.

Table 1 – Gender, affiliation, major, class level and ethnicity of 2010-2013 NSF IRES participants

	<b>Gender</b>	<b>Class</b>	<b>Ethnicity</b>	<b>Major</b>	<b>Affiliation</b>
2010	F	Jr.	Caucasian	ME	The George Washington Univ.
	M	Jr.	Caucasian	ME	Northwestern Univ.
	M	Jr.	Caucasian	AE	State Univ. of New York at Buffalo
	F	Jr.	Asian /American	CE	New York Univ.
	M*	Grad.	Caucasian	ME	Oakland Univ.
	M	Grad.	Caucasian	ME	Michigan Technological Univ.
2011	F	Jr.	Asian/Hawaii	ME	Illinois Institute of Technology
	F	Sr.	Caucasian	ME	George Washington University
	M	Grad.	Caucasian	ME	Oakland University
	M	Jr.	Caucasian	ME	George Washington University
	M	Jr	Caucasian	CE	Lafayette College
	M*	Sr.	Asian/American	ME	Oakland University
2012	M	Grad.	Caucasian	ME	Oakland University
	M	Jr.	Caucasian	ME	University of Maryland
	F	Jr.	Caucasian	ME	Oakland University
	F	So.	Asian/American	CE	Cornell University
	M	Jr.	Caucasian	ME	Washington University in St. Louise

\*This student was supported by Oakland University Provost Office, School of Engineering and Computer Science and the Department of Mechanical Engineering.

The GPAs of the students varied between 3.3 and 3.94. Six out of the seventeen students funded through the NSF were female. Four were graduate students. Two students knew how to speak Mandarin, each in 2010 and 2012; none of the students knew how to speak mandarin in 2011. When selecting final participants, priority was given to those applicants who have no prior international research or travel experience. Among all the final participants, none of the students had prior research experience in China; only two students travelled to China for a short period of time with family member at their childhood. One third of student participants never had any research or internship experience, two students have the international experience of studying in Germany, and others either have an internship or REU experience.

### **Program Structure and Activities**

The program runs for 8 weeks during the summer. Student participants receive \$4000 stipend as well as meal allowance and a free Chinese language training course. International travel expense and lodging are covered by the program as well.

We ran the program in two modes. In the first two years, instead of having an on-site orientation at Oakland University before departure, we met the students at BJTU directly. In the third year, we had students stay at BJTU for the first 3 weeks, then 3 weeks in China, and the last 2 weeks at OU again. From the program survey, students seem to like both modes of program. No matter which mode of the program, here are some things we have to keep in mind while arranging the program that Chinese Universities implement a different academic calendar from US Universities. The summer semester usually ends by the end of July at Chinese Universities. Therefore, our program has to finish before their final exam week (Middle July). The US schools, however, usually end their semesters on different dates in May. It is not easy to find a common week in early May for US students to gather at OU before leaving for China. The middle May was usually the earliest date that most of the IRES participants are available. Therefore, if the IRES participants are all from the same universities or from schools in the same state which usually run a similar academic calendar, it might be easier to set up a firm starting date of the program.

Different from other regular domestic research program, this NSF IRES program does require a significant amount of efforts to prepare the participants to study abroad successfully. The international travel documents preparation takes most of efforts for preparation such as passport and visa application, airticket reservation and travel insurance purchase. Special attention must be paid to the students to overcome their fear, doubt or concern of studying and living in China for 8 weeks. In the first two years, the program director made a conference call to all the NSF IRES participants two weeks before departure. This served as an informal off-site program orientation. A comprehensive handbook prepared by the program director was sent to students. The handbook includes what to bring and not bring list, what to do and not do, some simple Chinese greeting words, Chinese Monetary information, and some basic living guide. Students all felt that the handbook helped them significantly in preparing for this trip. They felt much more comfortable after reading the handbook. This handbook has been improved year by year by adding former IRES participant's personal experiences.

Numerous activities were conducted for the program. An example of program activities (2010 summer) is listed in Table 2. Many activities have been carried out in the following years such as seminars, lab and facilities tours. Small adjustments have been made each year based on the availability of resources such as additional seminar speakers and attending conferences. In each summer, each IRES participant was ensured to take 24~36 hours of Chinese language instruction depending on the duration of the stay in China. The Chinese language training turned out to be one of best experiences students had in China. This can be seen from students' comments- "Chinese class was an essential and exciting part of the program. It really helped to navigate the language barrier." (2011 IRES participants); "The Chinese language class was very good and our teacher was very helpful. I wish I would have studied more Chinese before starting the program." (2010 IRES participants)

Other activities were also arranged to improve students' understanding of fuel cell technology and exposed them to Chinese culture. Te lab and facilities tours have been one of activities loved by all the participants. Not only are they able to learn the fuel cell related research facilities at Chinese Universities; they also visited some teaching labs such as thermodynamics teaching lab. They constantly compared what they had in their class in US with those in China. Also, the IRES

students were arranged to mingle with Chinese students at the end of lab tour, where they usually exchange their college life and made friends.

**Table 2: 2010 IRES Group Activities -Short Schedule**

	<b>Date and Time</b>		<b>Group Activities</b>
Week 1	May 16-May 18		Airport pickup; Registration; Campus Tour
	May 19	9:00am-12:00pm 2:00pm-4:00pm	Program Introduction; Lab Visit Seminar: Introduction to Fuel Cells
	May 20	10:00am-12:00pm 3:00pm-4:00pm	Presentation: Project Introduction Seminar: How to Conduct Literature Search
	May 21	10:00am-12:00pm	Group Meeting: Project Assignment
Week 2	May 25	10:00am-12:00pm	Short Course: Comsol Training
	May 26	10:00am-12:00pm	Seminar: How to Conduct Research?
	May 28	10:00am-12:00pm	Group Meeting
Week 3	June 03	2:00pm-5:00pm	Field Trip: Visit the University of Science and Technology Beijing
	June 04	9:00am-10:00pm 10:00am-12:00pm	Presentation: Research Ethics Group Meeting
Week 4	June 11	10:00am-11:00am 11:00am-12:00am 2:00pm-5:00pm	Seminar: Introduction to Heat Pipes Group Meeting (Mid-term project presentation) Field Trip: Visit Beijing Aeronautics and Astronautics University
Week 5	June 14	1:00pm-4:00pm	Field Trip: Visit Fuel Cell Research Laboratory at Shanghai Jiaotong University
	June 18		Graduate Student Symposium: Tianjing University of Business and Finance
Week 6	June 25	10:00am-12:00pm	Group Meeting
		1:00pm-4:00pm	Attended Presentation Competition for Young Investigator in North China Electrical Power University
Week 7	June 29	10:00am-12:00pm 16:00pm-17:00pm	Seminar: How to give a professional presentation? Meet with the Chair of the Department of Mechanical Engineering,
		July 01	10:00am-12:00pm
	July 02	10:00am-12:00pm	Group Meeting
Week 8	July 06	10:00am-11:00am	Presentation: How to Apply to Graduate School?
	July 08	10:00am-12:00pm	Final Project Presentation
	July 09	10:00am-12:00pm 12:00pm 6:00pm	Program Survey Project Report Due Farewell Dinner

The research focus of this program is fuel cell related projects. Based on the existing infrastructure at OU and BJTU, seven different projects were selected as the final projects for the NSF IRES group. Before introducing the project, PI gave two lectures on fundamentals of fuel cells to ensure that all the participant have the basic knowledge of fuel cell first. Then PI presented each project to the IRES group, including the project objectives, required knowledge

and skill, and some related references. The project is finally assigned based on student's preference, academic preparation and skill. Listed below is a list of project topics:

- 1) Development of a Method for Optical Measurement of Water Droplet Formation in the Cathode Flow Channel of a PEM Fuel Cell:
- 2) Correlation of Breakthrough Pressure to GDL Thickness in PEM Fuel Cells
- 3) Optimization of Flow Distribution in Fuel Cell Channel Design
- 4) Effect of Cathode Stoichiometric Ratio on PEMFC Cold Start Performance
- 5) An Investigation on the Effects of Temperature on Fluid Transport across the Gas Diffusion Layer in a Proton Exchange Membrane Fuel Cell
- 6) Water Removal Investigation on Gas Diffusion Layer of Proton Exchange Membrane Fuel Cell
- 7) Effects of Hydrophobic Polymers in Microporous Layer on Proton Exchange Membrane Fuel Cell Performance

Even though students conducted research project only for 8 weeks, some interesting and useful results have been found. Some of the IRES participants have presented their research projects in various meetings such as symposium at their own schools<sup>10-11</sup> and national conferences<sup>12-16</sup>.

### **Assessment**

The program was assessed through the pre-program application and post program surveys that the student participants have completed. A few IRES participants have been in touch with the PI through emails. The PI also learned other students' situation through these students. It is still early to gauge the long term effects of this program on the student participants; a few things can be still summarized. Table 3 is a summary of the current status of 2010 students and 2011 students. In the first year (2010), two students out of four undergraduate students indicated plans to go to graduate school after graduation in their application essay. By the post-IRES survey, that number had increased to three, and the fourth student mentioned that he would like to work first and then go to graduate school. By Dec 2102, four students are actually doing their PhD study in different schools. Two of them are working in the area related to fuel cells. One student was awarded the National Science Foundation Graduate Research Fellowship. In the second year program (2011), three students out of five undergraduate students indicated plans to go to graduate school after graduation in their application essay. By the post-IRES survey, that number had increased to four. Two of them are doing Ph.D directly from bachelor's degree, and the other two are doing their MS study. In the third year program(2012), all four undergraduate students indicated plans to go to graduate school after graduation in their application essay. Two of them have taken the GRE test during the past summer. None of them have graduated yet. All of them are interested in continuing research in the area of alternative energy.

On a scale of 1 to 5, with 1 being poor and 5 being excellent, students rated their overall IRES experience as a 4.8 for three continuous years and all indicated that they would recommend the program to their friends. Most of the activities received ratings above a 4.0. The research facility at the host Chinese school was rated below 4.0 in the first two years. The research laboratory at BJTU has limited resources and support. Ordering or machining any part takes a significantly long time. Additionally, the lab space is more crowded with an extra 5 or 6 students from US.

However, this is the situation most of universities in China are facing. This is also part of learning experience in China as indicated by one student’s comments in the post program survey “The general disorganization was difficult to deal with. However, the status of the lab required us to be resourceful, which was a good experience anyways. ” (2010 IRES participant) Because of issues of facility, we changed the operation mode of the program in the last year. We conducted projects partially at OU, and partially at BJTU. Student seems to like this better. They rated the “the availability of research facilities to you for your individual research project” as 4.5 and “the research facilities at the host institute” at 4.8.

**Table 3: Summary of affiliation, gender, race of current status of NSF IRES students (2010-2011)**

	<b>Gender/Race<sup>1</sup></b>	<b>Previous Affiliation</b>	<b>Current Status (2012)</b>
2010	F/CA	The George Washington Univ.(Undergrad)	Stanford University (Ph.D Student)
	M/CA	Northwestern Univ. (Undergrad)	System Engineer at DMC Engineering
	M/CA	State Uni. of New York at Buffalo (Undergrad)	University of Colorado, Denver (Ph.D student)
	F/AP	New York Univ. (Undergrad.)	University of Pennsylvania (Ph.D student)
	M/CA	Oakland Univ. <sup>2</sup> (Grad)	Oakland University ( Ph.D Student)
	M/CA	Michigan Technological Univ. (Grad)	Continental Tire (Explore Engineering Trainee)
	2011	F/AP	Illinois Institute of Technology (Undergrad)
F/CA		George Washington University(Undergrad)	George Washington University(Master Student)
M/CA		Oakland University (Grad.)	Oakland University(Master Student)
M/CA		George Washington University (Undergrad.)	Space Exploration Technologies(Production Engineer)
M/CA		Lafayette College (Undergrad)	University of California at Davis(PhD student)
M/AP		Oakland University <sup>2</sup> (Undergrad)	Oakland University (Master Student) Product Engineer at Chrysler LLC

All of the people involved in the program feel that this was a successful program and would highly recommend to others. Here are a few comments selected from the end-of-program survey from the IRES participants: “I would definitely recommend this IRES program to other students because it offers a great cultural and academic learning experience.” (2012 fellow); “This IRES program has helped me learn more about fuel cells and has taught me to conduct meaningful research. I have improved my experimental skills, critical thinking skills, data analysis skills, and presentation skills”(2012 fellow); “This was an incredibly well organized international trip...” (2012 fellow); “This program has made me more interested in graduate school and also finding a career that will allow me to travel.” (2011 IRES Fellow); “My fundamental knowledge of fuel cells has significantly improved. I have also polished up my experiment building,

<sup>1</sup> CA = Caucasian; AA = African American; AP = Asian, Pacific Islander; LA = Latino, Hispanic; AR = Arab American

<sup>2</sup> Supported by funding from Oakland University’s Office of the Provost and Vice President for Academic Affairs

communication, and writing skills through this program.” (2011 IRES Fellow); “I would certainly recommend this program to other students. It provides incredible opportunities to develop skills involving communication, presentations, learning a new language, hands-on research, cultural awareness, and international networking.” (2011 IRES Fellow); “This program is a remarkable combination of international research and cultural experience, which is truly invaluable. Being an American in China showed me the extreme differences between cultures and approaches to research. Coming to China allowed us to bridge some of these gaps and develop as students and as individuals.” (2011 IRES Fellow); “ it was a great research and cultural experience that you can learn a lot from” (2010 IRES Fellow); “ I found it a valuable experience both culturally and academically and overall enjoyed the atmosphere.”(2010 Fellow); “Definitely because it was an amazing experience that I'm going to remember forever.” (2010 Fellow).”

### **Conclusions**

This international research program takes a significant amount of efforts to make it successful since it involves conducting research and living at a foreign site. The IRES student fellows have been rewarded with both research experience on exiting topics in fuel cells and Chinese cultural experience. Through all kinds of on-site activities, the IRES participants also develop skills involving communication, presentations, and international networking. The research and cultural experience gained from this program hope to prepare the students more readily to meet challenges of increasing world globalization.

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11. "Development of a Method for Optical Measurement of Water Droplet Formation in the Cathode Flow Channel of a PEM Fuel Cell," by Hannah Stuart, Kristopher Inman, and Xia Wang, in SEAS R&D showcase in George Washington University, March, 2011. (Won the first award), poster presentation.
12. "Investigation of Through-plane Thermal Gradients on PEMFCs performance," by Kristopher Inman, at 222nd ECS meetings, Honolulu, HI, Oct 11, 2012, oral presentation.
13. "Design of a Non-Invasive Optical Fiber Sensor for in Situ Measurement of Temperature in a Proton Exchange Membrane Fuel Cell," by Kristopher Inman, Xia Wang and Brian Sangeorzan, 222nd ECS Meetings, Honolulu, HI, Oct, 2012.
14. Poster Presentation: "Correlation of Breakthrough Pressure to GDL Thickness in Proton Exchange Membrane Fuel Cells," by Liana Vaccari, Eric West, and Xia Wang, in New York State's Premier Conference for Advanced Energy 2010, NY, Nov 8-9, 2010, poster presentation.
15. "Development of Optical Thermal Sensor for PEM Fuel Cell Temperature Measurement Using Phosphor Thermometry," presented by Kris Inman at International Heat Transfer Conference (IHTC-14) at Washington DC, Aug 8-13, 2010, poster presentation.
16. "Optimization of Extrusion Mold Design" by James Peitzmeier, at the Competition for Research Presentation by Young Investigators at North China Electric Power University, China, June 25th, 2010, oral presentation.