Final Technical GATE Report, 1998-2006

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Submitted by:

GATE Fuel Cell Vehicle Center

Institute of Transportation Studies

University of California, Davis

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INTRODUCTION

In 1998, the U.S. Department of Energy (DOE) funded 10 proposals to establish graduate automotive technology education (GATE) centers of excellence at nine universities, each addressing a specific technological area. The University of California, Davis was chosen for two centers: Fuel Cell Center and Hybrid-Electric Vehicle Design Center (power drivetrains and control strategies). This report is specific to the Fuel Cell Center only, which was housed at the UC Davis Institute of Transportation Studies (ITS-Davis).

ITS-Davis created the Fuel Cell Vehicle Center, with the following goals: (1) create an interdisciplinary fuel cell vehicle curriculum that cuts across engineering, the physical sciences and, to a lesser extent, the social sciences; (2) expand and strengthen the then-emerging multidisciplinary fuel cell vehicle research program; (3) strengthen links with industry; (4) create an active public outreach program; and (5) serve as neutral ground for interactions between academia, the auto, energy, and technology industries, government, and public-interest non-governmental organizations. At the time of proposal, the Center had a solid track record in fuel cell research, strong connections with industry, strong campus support, a core group of distinguished and motivated faculty, and an established institutional foundation for fuel cell vehicle research and education.

The GATE award has enhanced all aspects of the Center. Some highlights during the period of review include:

- 42 graduate students funded via Fellowship (many for one year or more)
- Ten fuel cell-related courses and three modules developed and /or supported
- Expansion of the ITS-Davis graduate program, especially in fuel cell research
- An increase in affiliated faculty (up 100% since 1998)
- The hire of 7 new ladder-rank faculty, 3 Professional Researchers and 2 Project Scientists. Of these 12 new hires, 6 specialize in fuel cell research
- A strengthening of partnerships with a variety of outside companies and governments
- Enhanced visibility of ITS-Davis fuel cell activities (California Governor Arnold Schwarzenegger participated in the grand opening of the UC Davis hydrogen fueling station, the first such station on the California Hydrogen Highway)
- Recognition with a number of awards, most recently with the 2006 Robert M. Zweig Public Education Award of the National Hydrogen Association

RESEARCH ACTIVITIES

Fuel Cell research has continued to flourish at ITS-Davis, beginning with the Fuel Cell Vehicle Modeling Program (FCVMP), a five-year research consortium financially supported by twenty major automotive companies, suppliers of fuel cell related technologies and major energy suppliers, as well as the U.S. Department of Energy (DOE), the California Air Resources Board

and other government agencies. The program analyzed fuel cell vehicle performance, efficiency, and emissions utilizing the most likely fuel types and system combinations; organized consensus on key technical issues; and played an important role in fuel selection planning. Nine students earned their master's or Ph.D. while working on the program and almost 60 technical publications were generated through the FCVMP.

In 2002, ITS-Davis followed up with a new four-year research consortium entitled "Transportation and the Hydrogen Economy: Pathways and Strategies." The purpose of this program was to evaluate the technical, economic, environmental, business and policy implications of a hydrogen transportation future, and to engage energy, automotive, investment and government stakeholders. The program has 15 corporate and five governmental sponsors. To date, researchers have published and presented more than 100 papers, participated in key state, national and international meetings, and played key support roles in various public initiatives, including the California Hydrogen Highway initiative of the governor. The program has also hosted a number of conferences and workshops. There are currently 17 students supported through this program.

In January 2007, ITS-Davis will launch a new four-year multi-disciplinary research effort called the Sustainable Transportation Energy Pathways program (STEPS). This effort will supersede the successful four-year Hydrogen Pathways Program and will analyze the markets, infrastructure, economics, environmental impacts, and policy of four fuel and vehicle pathways: hydrogen, biofuels, electricity and fossil fuels.

Other related research initiatives since receipt of the initial GATE award:

- In 2000, ITS-Davis researchers engaged in a multi-year, multi-million dollar project to develop and test integrated fuel cell auxiliary power units (APU) that would power heavy-duty truck trailer refrigeration and other auxiliary systems, thereby eliminating the need for running the diesel engines while stopped. Funding sources included the DOE and South Coast Air Quality Management District.
- In 2000 and subsequent years, ITS-Davis, together with private industry and Unitrans, the student-run bus system serving UC Davis and the city of Davis, received $2.4 million from the US Federal Transit Administration, and $541,000 from other sources to build and test hydrogen-natural gas hybrid buses.
- In 2003, Toyota provided two fuel cell hybrid vehicles (FCHVs) that served as the backbone of a $1.3 million FCHV demonstration and market research program. ITS-Davis researchers conducted school assemblies, traveled to public events, and held ride-and-drives on campus and across the state, introducing political and industry leaders, scientists, academics, school children and the general public to the promising new technology. The initial program ended in December 2005, but Toyota asked ITS-Davis to continue the program for 30 more months.
- On April 20, 2004, California Governor Arnold Schwarzenegger participated in the grand opening of the UC Davis hydrogen fueling station, and took the opportunity to sign Executive Order S-7-04 to create a California Hydrogen Highway Network by 2010. The

UC Davis station is the first publicly-accessible station in the network. ITS-Davis faculty member Joan Ogden was named as the academic representative to the Hydrogen Highway Implementation Advisory Panel, which, over several months in late 2003, worked to develop a blueprint plan to implement the network by 2010.

- In 2004, ITS-Davis was one of two California institutions awarded a Hydrogen Technology Center under a solicitation through the DOE States Technology Advancement Collaborative. The purpose of the Center was to develop education and training materials, including curriculum and interpretive display materials for high school, community college and university students at the undergraduate and graduate level.
- In 2005, ITS-Davis became the first academic institution to join the California Fuel Cell Partnership (CaFCP), a public-private venture to demonstrate and promote fuel cell vehicles and fuel alternatives. In voting to include ITS-Davis in its membership, a move that has not been considered for other academic institutions, the CaFCP cited the institute's clear research leadership on issues that impact the future of transportation technology and fuels, and its practical experience in vehicle and fuels technology.
- In August 2005, ITS-Davis was named a *"Tier 2" University Transportation Center*, with $1 million in annual funding from the federal and state departments of transportation. The theme of this Center will be sustainable transportation, defined broadly as an approach to transportation that meets the needs of all segments of society while minimizing environmental, societal, and economic costs.
- Also in August 2005, ITS-Davis received a follow-on award to its GATE Center (one of eight nationwide) of nearly $600,000 to continue its education, research and industry collaboration functions.

EDUCATION ACTIVITIES

Student Fellowships

In a period of 20 years, from the time faculty leaders began organizing what became ITS-Davis, the scale and quality of transportation education has expanded dramatically. Transportation education, mostly concentrated in the Civil Engineering department, was practically invisible on the UC Davis campus. Since that time, a dramatic turnaround has occurred. ITS-Davis was the catalyst and, in many cases, the direct sponsor and instigator. This strong and growing commitment to education reflects a belief by the ITS-Davis faculty that Institute growth should be linked to graduate education and, indeed, that the quality and contribution of the Institute's work is premised on that link. The GATE award has contributed mightily to this belief.

Central to this premise was the creation and support of a new degree-granting graduate group (MS and Ph.D.) in Transportation Technology and Policy (TTP). The TTP degree program was formally approved by the UC Regents in February 1997. The motivation for creating this Graduate Group was to educate future transportation leaders who will design and build more sustainable transportation systems, as well as guide tomorrow's transportation policy. Our goal was to expose students to a rich and inspiring course of study that combines the

Institute's strong outreach component with extensive research, an engaging curriculum, and an unmatched connection to the real world. Today, we have 45 students enrolled in the TTP program with another 45 students affiliated with ITS through other disciplines.

Students benefit from our education programs in many ways. First and foremost, all students are directly involved in the writing of research publications and virtually all Ph.D. students and many master's students present their work at national and international conferences. Graduate students are co-authors on a significant number of ITS-Davis papers and reports. This productivity and conference experience is facilitated by strong research funding. The receipt of the GATE award was a significant boost to the TTP program specifically, and to graduate transportation education at UC Davis more generally. Dramatic increases in state fees and non-resident tuition over the past five years have boosted the cost of funding students so we are especially grateful for the support that the GATE award provided. From Fall quarter 1999 through Spring quarter 2006, the award granted fellowship support to 42 students **(Attachment A)**, from a spectrum of five different degree programs. Many of these awards were for one full academic year (or more, in some cases). Of those 42 students, four went on to earn Ph.D.'s, 16 earned Masters Degrees, 20 are still enrolled, and two did not finish.

Courses

The existence of the GATE Center provided a place where ITS-Davis could offer interdisciplinary courses, reflecting the trend in automotive engineering of the need to focus many skills on single projects. During the period of the grant, ITS-Davis faculty were encouraged to develop new courses and modules, as well as participate in courses offered by others (see **Attachment B** for list of participating faculty). The GATE award also enhanced our weekly seminar series featuring talks by transportation and energy researchers from UC Davis and other institutions, and by leaders in business, government, and other related fields. Students receive credit for attending the seminars.

Courses and modules supported directly or indirectly by the GATE award include:

- Fuel Cell Vehicle Systems Engineering. This course was taught by Dr. Robert Moore (head of Fuel Cell Vehicle Modeling program) and analyzed the design and performance of fuel cell systems and system components, with an emphasis on automotive applications. The focus was on analyzing the dynamic operation of fuel cell stacks, air compressors/expanders, and fuel reformers in a vehicular context – grappling with tradeoffs between energy consumption, fuel cycle and vehicular emissions of greenhouse gases and air pollutants, power, driveability, and cost.
- Processes and Materials in Polymer Electrolyte Fuel Cells. This course provided detailed description of the physicochemical processes in fuel cells and how they determine merit performance parameters of such energy conversion devices. The polymer electrolyte fuel cell was described from a physical electrochemistry perspective, highlighting the nature of electrode processes and transport processes in the polymeric membrane electrolyte. Structural materials requirements were examined highlighting perspectives of electrochemical stability in addition to mechanical properties. Such fundamental

examination of chemical & physical processes in the cell and relevant materials properties were tied to the performance of the polymer electrolyte fuel cell, including primarily energy conversion efficiency and power density.

- Fuel Cell Vehicle Research Seminar Series. This course was supervised by a different Fuel Cell Vehicle Center faculty member for each of several academic quarters. Lectures were presented on various aspects of fuel cell vehicle technology and policy by outside experts from government, national labs, industry, and NGOs, and by UC Davis faculty and senior grad students.
- Defect Chemistry and Transport Materials and Application to Electronic, Oxide Ion, and Proton Conductors. The goal of this course is to familiarize students coming from a variety of disciplines with the fundamental chemistry and physics which relate defect structure and transport. The course covers the basic structural chemistry of ceramic and other materials important to fuel cells, batteries, and related applications, the fundamentals of defect equilibria, and the role of defects in conductivity and diffusion. It stresses the fundamental mechanisms on the microscopic scale and the mathematical treatments necessary to obtain useful physical parameters.
- Fuel Conversion for Fuel Cell Vehicles. This course addressed reforming of hydrocarbon fuels ("synthetic" and biofuels), electrochemical conversion and the application of these technologies in fuel cells and electric vehicles.
- Advanced Energy Systems. This permanent Mechanical and Aeronautical Engineering course covers a review of options available for advanced power generation. Detailed study of basic power balances, component efficiencies, and overall powerplant performance for one advanced concept such as a fusion, magnetohydrodynamic, or solar electric powerplant.
- Fuel Cells and Energy Storage. The course focused on fuel cells, batteries, and ultracapacitors for transportation applications and included a laboratory section.
- Fuel Cell Systems. This Mechanical and Aeronautical Engineering course covers the basics of electrochemistry and fuel cell engines in mobile and stationary applications. Aspects of fuel cell energy converters and their subsystems including practice with existing fuel cell and hydrogen systems on campus. Offered in alternate years.
- The Hydrogen Economy – Technology, Pathways, Economics and Policy. The goal of the course is to introduce students to concepts and tools for analyzing the hydrogen economy. A multidisciplinary set of tools is required to fully understand the large technical, societal and economic efforts and impacts associated with a shift to the hydrogen economy. This course introduces these tools via a series of lectures on various topics. A class project will allows groups of students to utilize these tools to tackle specific areas within the broader range of H2 economy topics. Course has been taught twice so far.
- Transportation Energy Analysis and Modeling. The course covers many modeling issues, with a focus on life cycle analysis, uncertainty analysis and scenario development. Students work in teams to complete three modeling projects and will complete a final paper reviewing a particular modeling approach of their choice. The modeling topics include various alternative fuel cycles, including hydrogen, biofuel and electric-drive pathways.
- Module #1: Electrostatics And Electrochemistry Of Surfaces. This two-week module is in Chemical Engineering course number ECH 254, Colloid and Surface Phenomena, and

familiarizes students to the basic electrochemical and physical phenomena occurring at or near charged interfaces.

- Module #2: Mass Transfer in Electrodic Systems. This two-week module was introduced in Chemical Engineering course number ECH 253C, Advanced Mass Transfer, familiarizing students to the basic diffusion equation for mass transfer in ionic and electrodic systems.
- Module #3: Fuel Cell Materials Selection. This two-week module is taught as part of either Electrochemistry course number ECH 289 D the Fuel Cell Systems Engineering course. The module provides students with a synopsis of materials requirements for different components of fuel cells in direct relationship to the fundamental electrochemical and transport processes.

CONCLUSION

The importance of the GATE grant cannot be overstated. It allowed ITS-Davis to attract additional students, with more diverse backgrounds, to the study of transportation, encouraged the campus to create more transportation faculty positions, attracted outstanding new transportation faculty members in several different departments, allowed us to broaden and deepen the curricular offerings in transportation, fostered new research and education collaborations, developed innovative research approaches, discoveries, and solutions, as well as enriched the learning experience at UC Davis in a variety of ways. While the GATE grant was one among a number of funding sources contributing to the success of the transportation research and education program at UC Davis, it can confidently be said that the presence of the GATE grant contributed substantially to the image and reality of ITS-Davis having a vital, thriving program that warranted further investment on the part of others.

Since application for the GATE award, ITS-Davis has substantially expanded the number of faculty affiliating with the Institute. There are now 62 faculty associates, an increase of more than 100%. The Institute grew not only in number of faculty but in the diversity of programs represented: the faculty members listed in our initial proposal represented 12 campus units, compared to 18 currently. Thus, ITS-Davis has succeeded markedly in expanding its reach, attracting fresh thinking to transportation through the application of a variety of disciplinary approaches, and fostering new collaborations.

A major accomplishment of ITS-Davis since the awarding of the GATE Center includes the hiring of seven new ladder-rank faculty members across several different departments (many of these positions created through the initiative of ITS-Davis), as well as the hiring of three Professional Researchers and two Project Scientists. All are dedicated to transportation and committed to the interdisciplinary spirit of the Institute and our Transportation Technology & Policy graduate program, with six of the 12 specializing in fuel cell research. The GATE award certainly played a role in the acquisition of these outstanding new faculty and researchers. These new hires have immeasurably enhanced the depth and breadth of the educational curriculum and the campus transportation research enterprise.

Externally, ITS-Davis has been highly effective at creating partnerships with a wide variety of companies and governments, and close relationships with many environmental non-profit groups. Virtually every major automotive and energy company in the world, as well as every major government agency in California and the United States with transportation interests, is a sponsor of ITS-Davis. In most cases, these are true partnerships, with extensive interaction.

Our goal when applying for the GATE Center was to position UC-Davis as the leading university fuel cell vehicle center in the world, where state-of-the-art research ranging from fundamental study of fuel cells, systems, and vehicles to analyses of market demand and government policy took place. Our efforts have been validated in recent years with the selection as one of five finalists for the 2003 World Technology Energy Award, the receipt of the 2005 TRANNY ward for Organization of the Year by the California Transportation Foundation as well as receipt of the 2006 Robert M. Zweig Public Education Award of the National Hydrogen Association. While we have reached a relative level of success, we expect greater outputs from

ITS-Davis in the future. The pieces are in place to expand and enhance the Institute as the GATE award helped us strengthen a highly capable administrative and fundraising staff, a model graduate program, and an outstanding cadre of faculty.

ATTACHMENT A:

Students Awarded Fellowships from the GATE Fuel Cell Vehicle Center at UC Davis.

Anthony Eggert (1999 – 2000)

Abstract — Anthony Eggert was a graduate researcher on the Fuel Cell Vehicle Modeling Program (FCVMP) and was responsible for the water and thermal management model for three separate vehicle system types: 1) direct hydrogen, 2) indirect methanol and 3) indirect hydrocarbon fuel cell systems. Anthony was also, along with Karl Hauer, responsible for the overall systems integration of the vehicle model including process engineering and controls.

Results — The result of this work was a comprehensive comparison of the water and thermal management of the three fuel cell system types as well as three complete vehicle models for the three system types.

Degree(s) — Anthony received a Masters of Science degree in TTP in 2001 and went on to manage Ford's fuel cell vehicle partnership office in California. In 2003 Anthony returned to UC Davis as the Associate Director of the H2 Pathways program at the Institute of Transportation Studies.

Publications

A.R. Eggert, D. J. Friedman, S. Ramaswamy, K. Hauer, J. M. Cunningham, R. M. Moore, "Simulated Performance of an Indirect Methanol Fuel Cell System," SAE 2001 World Conference, Detroit, MI, March 5-8, 2001, Paper Number 2001-01-0544.

A.R. Eggert, D. J. Friedman, K. H. Hauer, R. M. Moore, J. M. Cunningham, S. Ramaswamy, "Simulation and Performance of an Indirect-Methanol PEM Fuel Cell System," Proceedings of the 17th International Electric Vehicle Symposium & Exposition, Montreal, Canada, October 15-18, 2000.

A.R. Eggert, D. J. Friedman, P. Badrinarayanan, S. Ramaswamy, Karl-Heinz-Hauer, "Characteristics of an Indirect Methanol Fuel Cell System," 35th Intersociety Energy Conversion Engineering Conference, Las Vegas, NV, 24-28, July 2000, Paper Number 2000-3040.

A.R. Eggert, Badrinarayanan, P., Friedman, D. and Cunningham, J., "Water and Thermal Management of an Indirect Methanol Fuel Cell System for Automotive Applications", Proc. of the 2000 ASME

International Mechanical Engineering Congress and Exposition - Heat Transfer Division, Ed. J.H. Kim, The American Society of Mechanical Engineers, New York, Vol. 1, pp 35-42, 2000.

2nd / Contributing Author

R.M. Moore, K.H. Hauer, D. Friedman, J. Cunningham, P. Badrinarayanan, S. Ramaswamy, A. Eggert, "A dynamic simulation tool for hydrogen fuel cell vehicles", Journal of Power Sources, May 2004

P. Badrinarayanan, Eggert, A. and Moore, R.M., "Minimizing the Water and Thermal Management Parasitic Loads in Fuel Cell Vehicles", International Journal of Transport Phenomena, 2001 (Accepted).

D. J. Friedman, A. Eggert, "Maximizing the Power Output of an Indirect Methanol PEM Fuel Cell System: Balancing Stack Output and Air Supply/Water and Thermal Management Demands," SAE 2001 World Conference, Detroit, MI, March 5-8, 2001, Paper Number 2001-01-0535.

Karl-Heinz Hauer, A. Eggert, R. M. Moore, S. Ramaswamy, "The Hybridized Fuel Cell Vehicle Model of the University of California, Davis," SAE 2001 World Conference, Detroit, MI, March 5-8, 2001, Paper Number 2001-01-0543.

P. Badrinarayanan, A. Eggert, Karl-Heinz Hauer, "Implications of Water and Thermal Management Parameters in the Optimization of an Indirect Methanol Fuel Cell System," 35th Intersociety Energy Conversion Engineering Conference, Las Vegas, NV, 24-28, July 2000, Paper Number 2000-3046.

P. Badrinarayanan, S. Ramaswamy, A. Eggert, R. M. Moore, "Impact of Fuel Cell System Dynamic Operation on Stack Water and Thermal Management," SAE 2001 World Conference, Detroit, MI, March 5-8, 2001, Paper Number 2001-01-0537.

Karl-Heinz Hauer, D. J. Friedman, R. M. Moore, S. Ramaswamy, A. Eggert, P. Badrinarayanan, "Dynamic Response of an Indirect-Methanol Fuel Cell Vehicle," Published in: Fuel Cell Power for Transportation (SP-1425), SAE Paper Number 2000-01-0370, Society of Automotive Engineers, Warrendale, PA, 2000.

D. J. Friedman, T. Lipman, A. Eggert, S. Ramaswamy, Karl-Heinz Hauer, "Hybridization: Cost and Efficiency Comparisons for PEM Fuel Cell Vehicles," Submitted to SAE Future Transportation Technology Conference, Costa Mesa, CA, August 21-23, 2000, SAE Paper Number 2000-01-3078.

S. Ramaswamy, M. Sundaresan, A. Eggert, R. M. Moore, "System Dynamics And Efficiency Of The Fuel Processor For An Indirect Methanol Fuel Cell Vehicle," 35th Intersociety Energy Conversion Engineering Conference, Las Vegas, NV, 24-28, July 2000, Paper Number 2000-3048.

J. M. Cunningham, M. A. Hoffman, A. R. Eggert, and D .J Friedman, "The Implications of using an Expander (turbine) in an Air System of a PEM Fuel Cell Engine," Proceedings of the 17th International Electric Vehicle Symposium & Exposition, Montreal, Canada, October 15-18, 2000.

Current position — Anthony is currently studying for his Ph.D. in the area of alternative fuel and advanced vehicle innovation systems.

Meena Sundaresan (1999 – 2000)

Abstract — During 1999-2000 Meena helped develop computer models based on first principles for indirect methanol fuel cell vehicle fuel processor components using Matlab/Simulink. The focus of the research was to investigate the effects of a catalytic burner on reformer performance in a thermally well-integrated configuration. Specifically, the work focused on the generation of a detailed numerical model incorporating kinetics and mass and heat transfer to accurately characterize the burner. Unlike a simple, thermodynamic model, the detailed model provides a level of complexity necessary to understand the impact of thermal integration on reformer transient response, reformate composition and emissions.

Results — The results of the work were the following: 1) varied catalyst loading can play a role in decreasing reformer temperature and CO emissions, 2) for the parameters used in the sensitivity analysis, a lag in the step input of the burner input methanol had a more pronounced, while still minimal, effect on certain thermal integration configurations (such as plate configuration) that had a higher heat transfer coefficient and lower thermal mass than the base case, 3) dynamic response can be greatly affected by thermal integration: a thermally well-integrated system can have an order of magnitude decrease in step response times, and 4) reducing burner temperature through thermal integration can minimize burner emissions such as nitric oxide.

Degree(s) — M.S. in Mechanical Engineering, UC Davis March 2002

Ph.D. in Transportation Technology and Policy, UC Davis 2004
A Thermal Model to Evaluate Sub-Freezing Startup for a Direct

Hydrogen Hybrid Fuel Cell Vehicle Polymer Electrolyte Fuel Cell Stack and System

Publications

M. Sundaresan, S. Ramaswamy, R.M. Moore, "Steam Reformer/Burner Integration and Analysis for an Indirect Methanol Fuel Cell Vehicle," 35th Intersociety Energy Conversion Engineering Conference, Las Vegas, NV, 24-28 July 2000, Paper Number 2000-3047

Meena Sundaresan, S. Ramaswamy, R.M. Moore, "Modeling a Catalytic Combustor for a Steam Reformer in a Methanol Fuel Cell Vehicle," Proceedings of the 2000 ASME International Mechanical Engineering Congress and Exposition, Orlando, FL November 5-10, 2000.

S. Ramaswamy, M. Sundaresan, A. Eggert, R.M. Moore, "System Dynamics and Efficiency of the Fuel Processor for an Indirect Methanol Fuel Cell Vehicle," 35th Intersociety Energy Conversion Engineering Conference, Las Vegas, NV, 24-28 July 2000, Paper Number 2000-3048

S. Ramaswamy, M. Sundaresan, R.M. Moore, "Characteristics of the Fuel Processor for an Indirect-Methanol Fuel Cell Vehicle," Proceedings of the 17th International Electric Vehicle Symposium & Exposition, Montreal, Canada, October 15-18, 2000.

Current position

Currently Meena is at DaimlerChrysler in Germany working on next generation fuel cell vehicle systems.

David Friedman (1999 – 2000)

Abstract

Mr. Friedman worked with Fuel Cell Vehicle Modeling, developing simulation tools to evaluate fuel cell technology for automotive applications. He also worked on the UC Davis FutureCar team to build a hybrid electric family car that doubled its fuel economy.

Results

Publications

Publications

Eggert, Anthony R., David J. Friedman, Sitaram Ramaswamy, Karl-Heinz Hauer, Joshua M. Cunningham, Robert M. Moore (2001) Simulated Performance of an Indirect Methanol Fuel Cell System. Society of Automotive Engineers Technical Paper Series (2001-01-0544)

Friedman, David J., Anthony R. Eggert, Paravastu Badrinarayanan,

Joshua M. Cunningham (2001) Balancing Stack, Air Supply, and Water/Thermal Management Demands for an Indirect Methanol PEM Fuel Cell System. Society of Automotive Engineers Technical Paper Series (2001-01-0535)

Eggert, Anthony R., David J. Friedman, Paravastu Badrinarayanan, Sitaram Ramaswamy, Karl-Heinz Hauer (2000) Characteristics of an Indirect-Methanol Fuel Cell System. American Institute of Aeronautics and Astronautics (2000-3040)

Hauer, Karl-Heinz, David J. Friedman, Robert M. Moore, Sitaram Ramaswamy, Anthony R. Eggert, Paravastu Badrinarayanan (2000) Dynamic Response of an Indirect-Methanol Fuel Cell Vehicle. Society of Automotive Engineers Technical Paper Series (2000-01-0370)

Friedman, David J., Timothy E. Lipman, Anthony R. Eggert, Sitaram Ramaswamy, Karl-Heinz Hauer (2000) Hybridization: Cost and Efficiency Comparisons for PEM Fuel Cell Vehicles. Society of Automotive Engineers Technical Paper Series (2000-01-3078)

Eggert, Anthony R., David J. Friedman, Joshua M. Cunningham, Sitaram Ramaswamy (2000) Simulation and Performance of an Indirect Methanol PEM Fuel Cell System. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RP-00-31

Current position: Research Director, Clean Vehicles Program at the Union of Concerned Scientists

Joshua Cunningham (1999 – 2000)

Abstract: As a graduate student at ITS-Davis, Joshua's research project was part of the Fuel Cell Vehicle Modeling Program (FCVMP) directed by Dr. Robert Moore. This was a comprehensive, multi-student program focused on developing detailed fuel cell system models for vehicle simulations using Matlab Simulink. The models were developed both for graduate student research development, but also as useable tools that the sponsors received directly. The area of focus in the modeling team was on the air supply sub-system for the fuel cell model. This involved creating new models that determined how much air mass flow and pressure is delivered to the fuel cell stack for any given system operating condition. Joshua worked closely with air compressor suppliers in the DOE's fuel cell program to gather real data for my model, and recruited experts to be advisors on the model's

results. In 2001 and 2002, he played a larger role in coordinating model components from various students to fully integrate the model for the sponsors. However, during the period of my GATE funding, my research focused solely on the air supply sub-system model. The technical and primary thesis advisor was Professor Myron Hoffman from the Mechanical & Aeronautical Engineering (MAE) Department at UC Davis.

Results

The results from the research and publications can be summarized into three areas. The GATE funding provided support for the research while Joshua was working on the first area.

- The first area focused solely on the modeling structure of an air system in the context of the fuel cell engine. It was found that to maximize the performance of a particular fuel cell system configuration, it is useful to have a model that can compare various air supply technologies in the context of the system operation.
- The second area of research presents findings from a study comparing a low pressure air system to that of a high pressure system. The results of the study demonstrate that equivalent direct hydrogen fuel cell peak net system power values (86kW) can be obtained with both types of air supply configurations but require different stack sizes. For the blower application, the stack size had to be increased by 16.3% (500 vs. 430 cells in this example) for the same peak net power of 86kW.
- The third area highlights an analysis comparing an air system with and without the use of an expander (turbine). It is shown that the use of the expander (turbine) results in an improvement to the system efficiency at peak power levels. However, under normal driving conditions, peak power levels are demanded only a small fraction of the time. Therefore, it becomes less clear as to whether the added complexity and cost of an expander (turbine) would be beneficial. For example, for a fixed fuel cell stack size, the net efficiency is improved by approximately 4 % in the higher power region above 24kW net compared to the system without the expander. However, net efficiency is almost unchanged in the lower power region used most of the time. Alternatively, for a fixed peak power, the stack size can be reduced by about 13% using an expander compared to the fuel cell stack size required in a system without an expander.

Degree(s)

Master of Science in Transportation Technology and Policy, UC Davis 2001

Publications

Cunningham, J.M., et al, “A Comparison of High Pressure and Low Pressure Operation of PEM Fuel Cell Systems”, SAE paper #2001-01-

0538, to be presented at the SAE World Congress, Detroit MI, March 2001.

Cunningham, J.M., et al, "The Implications of using an Expander (Turbine) in an Air System of a PEM Fuel Cell Engine", Electric Vehicle Symposium 17, Montreal Quebec, October 17, 2000.

Cunningham, J.M., et al, "Requirements for a Flexible and Realistic Air Supply Model for Incorporation into a Fuel Cell Vehicle System Simulation", SAE paper #1999-01-2912, presented at the SAE FTT Conference, Costa Mesa CA, August 1999.

Current position — Program Manager at ITS UC Davis

Richard Counts (1999 – 2000)

Abstract — An Integrated Policy for Market Based Elimination of Vehicle Sources of Emissions and Green House Gases.

Results — Master Degree and Publications

Degree(s) — Master Degree in Transportation Technology and Policy, 2001

Publications — Richard L. Counts. An Integrated Policy for Market Based Elimination of Vehicle Sources of Emissions and Green House Gases University of California, Davis, 2001.

R. Counts, R. Dorf, A. Eggert, "Fuel Cell Powered Vehicles: Big Business, Fast Cars, and Clean Air, Counts", Technology, Humans and Society – Toward a Sustainable World, chapter 22.3

Current position — Volunteers Programme Manager at United Nations in Papua New Guinea.

Kate Helean (1999 – 2000)

Abstract — Derivative fluorite structured materials, in particular pyrochlore. The materials used as solid oxide fuel cells are also generally interesting for their ionic and electronic conductivity as well as their utility as waste forms for actinides and fission products.

Results — PhD Degree and Publications.

Degree(s) Ph.D., Engineering and Materials Science, University of California, Davis, March 2002. Dissertation: Thermochemical investigations of zirconolite, pyrochlore, and brannerite: three phases relevant to issues of plutonium immobilization

Publications

Helean, K.B., A. Navrotsky, J. Lian, R.C. Ewing (2003) Thermochemical investigations of zirconolite, pyrochlore and brannerite: Candidate materials for the immobilization of plutonium. Materials Research Society Symposium Proceedings, Scientific Basis for Nuclear Waste Management, v.807, p.297-302.

Lian, J., J. Chen, L. Wang, R.C. Ewing, J.M. Farmer, L.A. Boatner and K.B. Helean, (2003) Radiation-induced amorphization of rare-earth titanate pyrochlores. Phys. Rev. B. 68(13), 134107/1-134107/9.

Helean, KB; Ushakov, SV; Brown, CE; Navrotsky, A.; Lian, J.; Ewing, RC; Lee, T.; Haire, R. (2003) Enthalpies of formation of cerium zirconate: $(Ce,Zr)O_2$ fluorite and $Ce_2Zr_2O_7$ pyrochlore, AIP Conference Proceedings; no.673, p.286-7.

Helean, K.B., A. Navrotsky, E.R. Vance, M.L. Carter, B. Ebbinghaus, O.Krikorian, J. Lian, L.M. Wang and J.G. Catalano (2002) Enthalpies of formation of Ce-pyrochlore, U-pyrochlore and Gd-pyrochlore: three materials relevant to the proposed waste form for excess weapons plutonium. J. Nucl. Mater. 303, 226-239.

Helean, K.B. (2002) Thermochemical investigations of zirconolite, pyrochlore and brannerite: three materials relevant to issues of plutonium immobilization. Dissertation. Ph.D. Materials Science and Engineering, University of California at Davis, Winter, 2002.

Helean, K.B., B. D. Begg, A. Navrotsky, B. Ebbinghaus, W. J. Webber, and R. C. Ewing (2001) Enthalpies of Formation of $Gd_2(Ti_{2-x}Zr_x)O_7$ Pyrochlores. Materials Research Society Symposium Proceedings, Scientific Basis for Nuclear Waste Management XXIV, vol. 663, 157.

Current position Senior Member of the Technical Staff, Sandia National Laboratories. Co-principal investigator (PI) In-Package Sequestration project for the Yucca Mountain Nuclear Waste Repository (YMR).

Ryan Melnick (1999 – 2000)

Abstract One hurdle in developing direct methanol fuel cells (DMFC) is the

inherently lower reaction rates associated with electro-oxidation of methanol as compared to electro-oxidation of hydrogen in hydrogen-based fuel cells. The principle source of the lower reaction rates was thought to be poisoning of the platinum catalyst with adsorbed carbon monoxide. In order to better understand the reaction mechanism of the electro-oxidation of methanol on electrocatalysts, Melnick's research sought to analyze the reaction using the electrochemical technique of impedance spectroscopy. Accordingly, Melnick obtained voltage-dependent and time-dependent impedance spectroscopy measurements of methanol and formic acid (a potential reaction intermediate) on various catalysts including platinum and platinum-ruthenium oxide.

Results — Impedance spectroscopy of the electro-oxidation of methanol on platinum detected the presence of an adsorbed intermediate and suggested several co-adsorbed oxygen containing species. These results suggest that one approach to future catalyst development is to tailor the catalysts to produce an excess of specific desirable oxygen containing species. Measurements in the presence of a platinum-ruthenium oxide catalyst indicated a significant response due to oxide formation and that the response varied with the composition of the catalysts. These results validated the use of impedance spectroscopy as a tool for DMFC catalyst development. Studies of formic acid electro-oxidation indicated fundamental differences in the reaction mechanism.

Degree(s) — Ph.D. in Chemistry, UC Davis 2002

Publications — Melnick, R.E., Palmore, G.T.R., "Impedance Spectroscopy of the Electro-oxidation of Methanol on Polished Polycrystalline Platinum," J. Phys. Chem. B, 105, 1012-1025.

Melnick, R.E., Palmore, G.T.R., "Time-Dependent Impedance of the Electro-oxidation of Methanol on Polished Polycrystalline Platinum," J. Phys. Chem. B, 105, 9449-9457.

Current position — Patent Attorney at the Intellectual Property firm of Knobbe, Martens, Olson, & Bear

Nathan Butlin (1999 – 2000)

Abstract

Results

Degree(s) PhD Chemistry, UC Davis September 2006.

Publications

Current position

Peter Hamilton (2000 – 2001)

Abstract Mr. Hamilton's research was on rural transportation in developing countries. He spent a month in rural China outside of Beijing studying the emergence of diesel-powered rural agriculture vehicles, and their use by farmers to transport goods to market. With Zhenhong Lin as an interpreter and colleague, Peter did semi-structured interviews at various village and market locations, collecting stories and assessing the economic impacts of this new transportation technology.

Results Master Degree and Publications

Degree(s) Master of Science in Transportation Technology and Policy, UC Davis, June 2002.

Publications Sperling, Daniel, David Z. Lin, Peter Hamilton (2004) Chinese Rural Vehicles: An Explanatory Analysis of Technology, Economics, Industrial Organization, Energy Use, Emissions, and Policy. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-04-01

Sperling, Daniel, David Z. Lin, Peter Hamilton (2005) Rural Vehicles in China: Appropriate Policy for Appropriate Technology. Transport Policy 12 (2), 105 – 119

Current position Peter Hamilton is currently in a 1-yr accelerated MBA program at Cornell's Johnson School of Management, graduating in May of '07. He is focused on finding ways for the private sector to achieve sustainable development, particularly in the fields of water and energy.

Brett Williams (2000 – 2001 and 2003 – 2004)

Abstract

Creating innovative value with hydrogen-fuel-cell vehicles. While the potential of hydrogen-fuel-cell vehicles (H2FCVs) to provide various benefits (e.g., reduced emissions) has been described in detail, it is often considered difficult to justify the private investment necessary to achieve these social benefits. This conundrum is particularly acute in private-vehicle markets where FCVs can justifiably be seen as expensive and inferior relative to today's cars and trucks. Accordingly, the commercialization pathways for H2 as a transportation fuel are unclear.

As part of UC Davis' Hydrogen Pathways program, Brett Williams focuses on how FCVs and other electric-drive vehicles, such as plug-in hybrids, might become valued in the marketplace. Two major approaches are: 1) strategic niche marketing and 2) creating innovative value, often from unique product-attribute/service combinations.

Results

Publications

Degree(s)

Currently PhD Student

Publications

Brett Williams: "H2 FCV Adoption in California: Mobile Energy Innovations, Early Markets." California Fuel Cell Partnership Working Meeting, June 6 2006.

Brett Williams: "H2FCV Adoption In California: Mobile Energy Innovation, Early Markets." NHA Annual Conference March 12 – 16 2006. Long Beach, CA.

Williams, B., "'Mobile Energy' Innovation and the Early Household Market for Light-Duty, Hydrogen Fuel Cell Vehicles in California," Grove Fuel Cell Symposium, London, UK, October 5, 2005.

Williams, B., "The Early Household Market for Light-Duty, Hydrogen Fuel Cell Vehicles in California," 2005 Fuel Cell Seminar, Palm Springs, CA, November 18, 2005.

Williams, B. and B. Finkelor, "Innovative Drivers for Hydrogen-Fuel-Cell-Vehicle Commercialization: Establishing Vehicle-to-Grid Markets," Proceedings of the 15th Annual NHA Hydrogen Conference, April 2004.

Williams, Brett D. and Kenneth S. Kurani (2006) Estimating the Early Household Market for Light-Duty Hydrogen-Fuel-Cell Vehicles and other "Mobile Energy" Innovations in California: A Constraints Analysis. Journal of Power Sources

Current position: PhD Student at UC Davis. Expected to graduate within three to six months.

Nicholas Lutsey (2001 – 2002)

Abstract: Public agencies and the trucking industry have recognized the idling of heavy-duty trucks as a considerable problem. Several potential technical solutions are in development, including the utilization of auxiliary power units (APUs). Using fuel cell APUs could be a promising alternative to idling with substantial fuel consumption, emissions, cost, and noise benefits, while serving as a niche for relatively early fuel cell technology market introduction. This research, using a probabilistic Monte Carlo framework, reports on efforts to characterize existing data on idling trucks, develop an ADVISOR-based vehicle APU model that accurately depicts how utilizing fuel cell APUs to replace heavy-duty truck idling could be implemented, quantify energy consumption reductions, and analyze the economic benefits of the APU.

Results: This research shows that if fuel cell research targets for APUs are met over the next decade, a market in the tens of thousands of units may be possible in the line-haul trucking industry, and substantial diesel consumption reductions would result.

Degree(s): MS in Transportation Technology and Policy, UC Davis (2003)

Publications:

Lutsey, Nicholas P., Christie-Joy Brodrick, Daniel Sperling, Carollyn Oglesby (2004) Heavy-Duty Truck Idling Characteristics: Results from a Nationwide Survey. Transportation Research Record (1880), 29 – 38

Lutsey, Nicholas P., Christie-Joy Brodrick, Daniel Sperling, Harry A. Dwyer (2003) Markets for Fuel-Cell Auxiliary Power Units in Vehicles. Transportation Research Record (1842), 118 - 126

Lutsey, Nicholas P. (2003) Fuel Cells for Auxiliary Power in Trucks: Requirements, Benefits, and Marketability. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-03-04

Brodrick, Christie-Joy, Timothy E. Lipman, Mohammad Farshchi, Nicholas P. Lutsey, Harry A. Dwyer, Daniel Sperling, S. W. Gouse, III, D. B. Harris, Foy G. King, Jr. (2002) Evaluation of Fuel Cell Auxiliary Power Units for Heavy-Duty Diesel Trucks. Transportation Research Part D 7 (4), 303 – 315

Current position PhD Student in Transportation Technology and Policy, UC Davis

Matthew Forrest (2001 – 2002)

Abstract Matt Forrest worked with other students to implement external control of a Ballard Mk V fuel cell. This consisted of removing the onboard computer and connecting the control devices to a National Instruments data acquisition and control system.

Results The modifications were carried out successfully, but the fuel cell was degraded to the point that it was no longer usable.

Degree(s) Master's Degree, Transportation Technology & Policy (December 2004)

Publications Grupp, David J., Matthew E. Forrest, Pippin G. Mader, Christie-Joy Brodrick, Marshall Miller, Harry A. Dwyer (2004) Design Considerations for a PEM Fuel Cell Powered Truck APU. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-04-16

Current position Researcher at DaimlerChrysler's facility at the California Fuel Cell Partnership, Sacramento

Jonathan Weinert (2002 – 2003)

Abstract The use of hydrogen energy-stations for hydrogen infrastructure development and potential implications for the transportation sector. The research characterizes the range of E-Station design configurations and identifies promising applications for each configuration. The applications are matched with E-Station attributes to assess the market potential of the stations. Estimated hydrogen costs for these stations are presented and compared to fueling-only hydrogen stations. The paper explores the implications that this new fueling paradigm may have on key stakeholders in the transportation

sector. While this paper was written in 2004, much of the research for it was done in 2003.

Weinert also did research on the lessons learned from building a hydrogen fueling station at Los Angeles Airport. This work was presented at the Annual National Hydrogen Association Conference in 2004.

Results — The result was a paper that was presented at TRB conference in 2005.

Degree(s) — Master of Science in Transportation Technology and Policy, 2005

Publications — Weinert, J., Lipman, T., Unnasch, S. (2004), "Bridging the Gap Between Transportation and Stationary Power: Hydrogen Energy Stations and their Implications for the Transportation Sector", pp.20, Transportation Research Board 2005 Annual Conference Proceedings, Washington D.C.

Weinert, J. (2004) "The LAX Hydrogen Fueling Station Development: A Historical, Technical, and Economic Overview with a Discussion of the Obstacles Encountered and Lessons Learned", pp.16, National Hydrogen Association Annual Conference Proceedings, Los Angeles, CA.

Current position — Weinert is currently pursuing PhD in Transportation Technology and Policy at ITS-Davis doing research on electric bike use and battery technology in China.

Daniel Rubins (2002 – 2003)

Abstract — Fuel cell auxiliary power unit (APU) technology may be economically viable, and has the potential to reduce heavy-duty truck emissions and fuel consumption, preliminary research shows. Having previously studied a concept demonstration vehicle built by Freightliner LLC, Rubins worked on a follow-on project to bring the concept closer to commercialization.

Results — Publications

Degree(s) — MS in Transportation Technology and Policy, September 2004.

Publications — Brodrick, Christie-Joy; Lutsey, Nicholas P; Keen, Quentin A; Rubins, Daniel I; Wallace, John P; Dwyer, Harry A; 2001. Truck Idling Trends: Results of a Pilot Survey in Northern California. Paper 2001-

01-2828.

Current position Consultant with Fehr and Peers

Zach McCaffrey (2002 – 2003)

Abstract Heavy duty engines are substantial contributors to NOX and PM emissions inventories in urban areas, and stringent emissions standards have been adopted as a consequence. Meeting emission standards, especially for NOX emissions, may be difficult for conventional transit bus technologies. The purpose of the Hydrogen Bus Technology Evaluation Program was to develop and evaluate hydrogen enriched natural gas (HCNG) engine technology in transit buses and to demonstrate NOX emissions reductions below CARB standards.

Results Master Degree and Publications

Degree(s) MS in Mechanical Engineering, UC Davis, March 2006

Publications Burke, Andrew F., Zach McCaffrey, Marshall Miller, Kirk Collier, Neal Mulligan (2005) Hydrogen Bus Technology Validation Program. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-05-29

Dwyer, Harry A., Zach McCaffrey, Marshall Miller (2004) Analysis and Prediction of in-Cylinder NOx Emissions for Lean Burn CNG/H2 Transit Bus Engines. *Society of Automotive Engineers Technical Paper Series* (2004-01-1994)

Current position PhD student at Vrije Universiteit Brussels, Belgium

Andy Burnham (2002 – 2003)

Abstract **Compendium of Hydrogen Refueling Equipment Cost Estimates (CHREC)**
The CHREC is an Access database that Jonathan Weinert developed for organizing cost information on hydrogen infrastructure from a wide variety of sources. It can be a tool to compare different cost estimates and to provide a useful information resource on the costs of hydrogen equipment. The data has been collected from reports written over the past 15 years on the cost of hydrogen technology, proposals for the construction of hydrogen stations, and information provided by

hydrogen technology suppliers. Mr. Burnham assisted Jonathan with the data collection and database construction.

H2-Enriched CNG Heavy-Duty Bus and Infrastructure Evaluation

The focus of Andy's research was to examine HCNG buses as an option for the 2007 CARB transit bus regulations. The major driver is the NOx standard, 0.2 g/bhp-hr, which, from preliminary testing, HCNG buses should meet. In addition, the costs estimates were made for HCNG buses (retrofit & purpose-built), refueling stations (various sizes), and transportation of H2 (various options). Then Mr. Burnham developed CA and national hydrogen demand scenarios, using various estimates of HCNG penetration for the next ~20 years.

Results: Degree and Publication

Degree(s): MS in Transportation Technology and Policy, UC Davis 2004

Publications: Burnham, A., A. Burke, K. Collier, M. Forrest, Z. McCaffrey, and M. Miller. 2004. "Hydrogen Bus Technology Validation Program: Analysis and Update," Proceedings, Annual Meeting of the National Hydrogen Association, Los Angeles, CA.

Current position: Researcher at Center of Transportation Research at Argonne National Laboratory

Matt Caldwell (2002 – 2003)

Abstract: While funded through the GATE program in 2002-03, my research reviewed the published scenario studies of hydrogen energy and fuel cell vehicle (FCV) introduction. Scenarios were analyzed for qualitative and quantitative attributes: methodology (e.g. analytical model, expert opinion), assumptions, key factors for comparison, FCV introduction rates and timelines, cross-report consistencies and differences, and novel approaches. Results show that "Business-as-Usual" scenarios often assume a lack of R&D success in lowering FC costs, continuing fossil energy abundance, difficulty changing the fuel infrastructure, and showcase the improving cleanliness and fuel economy of hybrids and new diesel technologies for transportation. Successful FC development and cost reduction underlie many "Advanced" scenarios, along with hydrogen infrastructure solutions, strong environmental policies, and federal investment. Also, successful scenarios assume a profitable business case (which can include federal subsidies) for introducing FCVs and hydrogen.

Hydrogen infrastructure implementation assumed resolving production uncertainty through codes and standards, though the low entry barriers for hydrogen production were thought to slow decisive action by possible providers. A consensus set of FCV introduction curves and hydrogen infrastructure scenarios were presented.

Results — The fuel cell vehicle introduction curves were incorporated into a study done for the California Energy Commission forecasting the possible future hydrogen demand for California.

Degree(s) — MS in Transportation Technology and Policy, UC Davis (June 2005)
PhD Candidate, TTP (expected 2007)

Publications — Miller, Marshall; Burke, Andrew; Caldwell, Matthew; Abeles, Ethan; Pedersen, Kenth. "Hydrogen Demand and Supply Analysis for California: Near-term and Long-term." Part of a California Energy Commission hydrogen infrastructure study, 2004.

Poster: "Analysis of Hydrogen and Fuel Cell Vehicle Scenarios", UCD Hydrogen Modeling Workshop, June 2004.

Current position — I am currently a PhD candidate in the Transportation Technology and Policy program at UC Davis. My dissertation is researching a transitional renewable hydrogen pathway from biofuels, wherein low-cost bio-alcohols (either hydrated ethanol or a mix of alcohols produced thermochemically) are used as hydrogen carriers for distributed production at the fueling station. This pathway leverages the current liquids infrastructure and knowledge and the biofuels investment. Research is divided into analysis and modeling the upstream cost reductions for producing crude alcohols and experimental autothermal reformation experiments of mixed alcohols.

David Vernon (2003 – 2004)

Abstract — From September 2003 until September of 2004 David Vernon worked on three research projects.

The first research project focused on determining the state of development of electrolysis systems for hydrogen production. In this project David completed a literature search on water electrolysis at low and high temperatures, contacted current manufacturers of electrolysis systems and worked with a group of students to design a hydrogen fueling station based on current electrolyzer technologies. The results of this work were presented in an NHA and DOE

sponsored student design competition.

The second research project was an investigation of catalyst degradation in reformers and electrochemical devices. In this project Mr. Vernon completed a literature search on the mechanisms of catalyst degradation, identified the major analytical techniques that could be used to detect and identify different types of degradation and used several techniques to characterize the steam reformation catalyst being used in the Hydrogen Production and Utilization Laboratory (HyPAUL). The results of this work have informed continuing research in the HyPAUL. Specifically This work identified catalyst degradation mechanisms as boundary point for reformer reactor design and operating conditions and informed a presentation on the possibility of reforming land fill gas at a workshop at the California Environmental Protection Agency [1].

The third research project was the beginning of a master's degree project focused on understanding the effects of reactor geometry and scale through temperature profiles in hydrogen production methanol steam reformers. This project continued for the following 2 years and lead to the completion of Vernon's master's thesis [2], a conference proceeding publication on heat transfer limitations in steam reformation [3] and two manuscripts in process. The results of this project show that geometry is a critical parameter in predicting reformer conversion efficiency and that reformer performance cannot be accurately predicted using the space velocity parameter alone.

Results

Through continuing work based on these projects David Vernon has earned a masters degree at UC Davis and am continuing to pursue a Ph.D. The doctoral research is focused on the possibility of using waste heat from internal combustion engines to reform a small amount of the primary fuel. This process can produce a hydrogen rich gas on-board a vehicle that can be used to enrich the typical air fuel mixture and can enable combustion with increased efficiency and significantly lower emissions. The continued support of the GATE program has made all of this work possible and for it he is very grateful.

Degree(s)

Master of Science in Mechanical Engineering, UC Davis (September 2006)

Publications

Vernon, David R., "Hydrogen Production from Landfill Gas", Presented at California Environmental Protection Agency work shop on Hydrogen's Role in Landfill Gas Utilization Workshop, January 11, 2006

Vernon, David R., "Understanding the Effects of Reactor Geometry

and Scaling through Temperature Profiles in Steam-Reforming Hydrogen Production Reactors," Masters Thesis, Mechanical and aeronautical Engineering Department, University of California Davis, 2006

3. Vernon, David R., David Davieau, Bryce Dudgeon, Paul Erickson, "Heat Transfer Limitations in Hydrogen Production Via Steam Reformation: The Effect of Reactor Geometry", Proceedings of the ASME 4th International Conference on Fuel Cell Science, Engineering and Technology, 2006. Irvine, CA.

Current position PhD Student in Mechanical Engineering and Currently GATE Fellow

Rusty Heffner (2003 – 2004)

Abstract Rusty Heffner's research focuses on consumer behavior, specifically why people buy certain vehicles and how they make their purchase decisions. In 2003, Rusty participated in an ITS-UCD study on consumer understanding of fuel economy led by Dr. Kenneth Kurani and Dr. Thomas Turrentine. In 2004, Rusty initiated a study into the buying behavior of hybrid vehicle owners. The study's goal was to better understand why consumers adopt a new type of vehicle technology.

Results A key finding from the hybrid vehicle study was that these vehicles served as symbols of larger ideas. Consumers purchased hybrid vehicles, at least in part, to access symbolic meanings such as preserving the environment or accessing the latest technology. These symbolic meanings were important to buyers because of their relevance to buyers' identities. For example, some buyers felt that their hybrid vehicles symbolized preserving the environment, and indicated to others that the owners were ethical people who cared about others. For hybrid owners in this study, what their vehicles symbolized was as important as how the vehicles performed.

Degree(s) Currently PhD Student

Publications Heffner, R.; Turrentine, T.; Kurani, K. (2006) *A Primer on Automobile Semiotics.* UCD-ITS-RR-06-01

Kurani, K.; Turrentine, T.; Heffner, R. (2006) "Narrative Self-Identity and Societal Goals: Automotive Fuel Economy and Global Warming Policy" in *A Policy Agenda for Global Climate Change*. Canon, J. and Sperling, D., eds. Elsevier Academic Press

Heffner, R.; Kurani, K; Turrentine, T. (2005) Effects of Vehicle Image in Gasoline-Electric Hybrid Vehicles. 21st Worldwide Battery, Hybrid, and Fuel Cell Electric Vehicle Symposium and Exhibition (EVS-21), Monaco.

Kurani, K.; Turrentine, T.; Heffner, R.; Congleton, C. (2003) "Prospecting the Future for Hydrogen Fuel Cell Vehicle Markets" in *The Hydrogen Energy Transition*. Canon, J. and Sperling, D., eds. Elsevier Press

Current position

Rusty continues to investigate buyers (or potential buyers) of new types of vehicles and the role that symbolism plays in their vehicle choices. His latest research focuses on early users of plug-in hybrid vehicles and the symbolic meanings that are becoming associated with these vehicles.

Adam Henry (2003 – 2004)

Abstract

Adam Henry's research during the 2003-2004 academic year was focused on an analysis of federal funding for energy research and development. This research argued that basic research conducted in universities are a key component to innovation in the energy sector, and that federal R&D funding to American universities lags far behind our needs.

Results

Data on DOE R&D investments provide a good indicator of overall federal funding for energy research. Using data available from the Office of Management and Budget (OMB), Adam found that funding for universities rarely follow overall trends in nationwide energy research funding. For example, investments in university-based energy R&D did not keep pace with the growth in overall energy R&D funding during the late 1970s and the late 1990s. While investments for energy research have, most recently, been increasing, an analysis of funding for individual energy R&D accounts shows that this may be because of a disproportionate support for fossil-fuel related research initiatives.

Degree(s)

MS in Transportation Technology and Policy, UC Davis, December, 2005

Publications

None

Current position — PhD Student at UC Davis. He is currently working on issues related to regional transportation and land use policy.

Nathan Parker (2003 – 2004)

Abstract — Nathan Parker worked on two projects while funded through GATE. The first was testing batteries and ultra capacitors in support of research by Dr. Andrew Burke and Dr. Marshall Miller. The second was a statistical analysis of natural gas pipeline construction costs. The pipeline analysis was undertaken to better understand future costs of hydrogen pipelines.

Results — The pipeline work resulted in a technical report that has been used by the Department of Energy's Hydrogen Analysis Group in the H2A model of hydrogen infrastructure costs.

Degree(s) — MS in Transportation Technology and Policy (March 2007)

Publications — Parker, Nathan. "Using Natural Gas Transmission Pipeline Costs to Estimate Hydrogen Pipeline Costs." UCD-ITS-RR-04-35. December 2004. This report has about 13,000 downloads from the ITS Website.

Burke, Andrew, Marshall Miller and Nathan Parker. "Ultra capacitor Technology: Present and Future Performance and Applications," presented at the 2004 World Summit on Advanced Capacitors, July 2004.

Current position — Nathan is currently a PhD student in the Transportation Technology and Policy program at UC Davis. His research focuses on the optimal design of infrastructure to produce biofuels from waste biomass accounting for real-world spatial distributions of the waste resources.

Kenth Pedersen (2003 – 2004)

Abstract — Kenth Pedersen's research focused on hydrogen and sustainable energy infrastructure investment risk mitigation. The objective was to analyze the extant hydrogen and sustainable fuel storage, dissemination, production and utilization technologies, identify risks to investing in each of these pathways, assign a metric to these, and then attempt to identify various means of mitigating these risks.

Results	The skills achieved resulting from this work, allowed Kenth, inter alia, to participate as a researcher for a California Energy Commission (CEC) Needs Assessment study analyzing how a Clean Energy Business Incubator might serve a Capital Corridor region extending from Reno to the East Bay. This study led to the creation of the CleanStart (http://www.cleanstart.org/) incubator. Clean energy incubation was one risk mitigation tool Mr. Pedersen identified.
Degree(s)	
Publications	Clean Energy Incubator Project Final Technical Report, October 2005 Clean Energy Incubator Project Final Report, October 2005
Current position	CEO and Founder of Hyphase Energy

Reed Benet (2004 – 2005)

Abstract	During this period, Mr. Benet concentrated mostly on completing the required PhD coursework, taking and completing over 20 credits during the year, which may be a record. With the time he kept current on the literature and particularly the new technology business world in the area of focus, namely foreign source petroleum displacing biofuels.
Results	Presentations
Degree(s)	Currently PhD Student
Publications	Google Tech Talk about Biofuels, viewed more than 5000 times online: Reed Benet, "Better Than Ethanol? BTL in plug-in hybrid diesel vehicles", http://video.google.com/videoplay?docid=-3638071373477145 45&q=Reed+Benet&hl=en
Current position	PhD Student at UC Davis

Brent Riffel (2004 – 2005)

Abstract	This work focused on determining production factors for methane, ozone and PM nitrate. A brief description of this project appears below.

Results The goal of this project is to investigate the overall global warming potential of NOx emissions in terms of CO2-equivalence factors and to incorporate these variables into the LEM. Finally the LEM will be used to calculate the net climate forcing resulting from NOx emission pulses in various regions; these calculations and the research behind the CEF NO x values will be published in a journal article. The net climate forcing is the sum of numerous atmospheric and surface effects. Positive climate forcing effects include increased tropospheric ozone levels (O 3) due to reaction with VOCs (volatile organic compounds), and increased N2O levels from soil nitrogen fixing. Indirect negative climate forcing effects are decreased CO2, decreases in methane levels and increased ambient lifetimes, and increased particulate nitrate levels. The overall expected effect is slightly negative climate forcing and sensitivity to emissions is uncertain.

Degree(s) Currently a Master Student at UC Davis

Publications

Current position Master Student at UC Davis

Eddie Jordan (2004 – 2005)

Abstract The first goal of my research during the spring quarter of 2005 was to conduct a literature survey of hydrogen bi-fueling research that has taken place. The second goal was to utilize and adapt an equilibrium combustion model to help predict the benefits of hydrogen enriched combustion.

Results The research involved developing an equilibrium combustion model to predict the benefits of hydrogen enrichment for various fuels and engines. For the purpose of this research the program has been utilized to model a 1.5 Liter Toyota Prius Atkinson Cycle Engine burning gasoline, ethanol and various hydrogen enriched ethanol mixtures for a range of equivalence ratios. The model showed that Ethanol and hydrogen enriched ethanol produces higher NOx between and equivalence ratio of 0.95 and 0.72 but produces much less NOx at the lower equivalence ratios. Operating at an equivalence ration of 0.5 or leaner will meet 2010 NOx emission standards. Amazingly, a 30% by volume fuel mixture of hydrogen will essentially produce no NOx at an equivalence ratio of 0.45. The model also showed that operating at the leaner limits with hydrogen and adding boost increased the thermal efficiency to over 45%. Most of the improvement is contributed to

ethanol hydrogen mixtures allowing higher boost levels, leaner fuel mixtures, and eliminating throttling losses. Through literature research hydrogen has shown to help reduce knock due to its high octane rating, reduce cycle to cycle MEP variation, and help increase combustion efficiency. Work done at the University of Babylon in Babylon Iraq found that the addition of 8% by mass of hydrogen with a 30% by volume of ethanol in a gasoline engine caused a 48.5% reduction in CO emissions, 31.1% reduction in NOx emissions and 58.5% reduction in specific fuel consumption. More over, the engine thermal efficiency and output power increased by 10.1% and 4.72% respectively. My future research hopes to further prove the benefits of hydrogen enriched ethanol.

Degree(s) Currently PhD Student

Publications Erickson, Paul A., David Vernon, Eddie Jordan, Dr. Kirk Collier, and Neal Mulligan, "Low NOx Operation and Recuperation of Thermal and Chemical Energy Through Hydrogen In Internal Combustion Engines", 16th Annual Hydrogen Conference of the National Hydrogen Association (NHA), 2005 Washington, D.C.

Current position PhD Student in Mechanical Engineering at UC Davis

Hyung Chul Yoon (2005 – 2006)

Abstract Hydrogen production via reformation of coal-based methanol was investigated. We have proven that coal–derived liquids such as commercially available methanol can be converted into hydrogen using both steam and autothermal reforming methods.

Results These studies have taken place at the Hydrogen Production & Utilization Laboratory at University of California Davis. Through chemical analysis, coal-based methanol has shown to have slightly higher amounts of trace hydrocarbons than chemical grade methanol derived from natural gas. While these trace hydrocarbons are typically inconsequential for some energy conversion devices, fuel cell applications require ultra pure hydrogen. Steam and autothermal reformers were investigated to find the optimal hydrogen production method in the existence of such trace impurities. Based on experimental results, steam-reforming of coal-based methanol has shown significant catalyst degradation caused by the trace impurities. Autothermal reformation of coal-derived methanol has demonstrated better performance with the trace impurities due to its higher operating temperature generated by the oxidation step. Autothermal

reformation can also avoid some of the energy penalties of steam reformation but generally has a lower concentration of hydrogen due to the diluent nature of nitrogen by adding air as the oxidizer. This investigation shows that hydrogen production from coal-based methanol is possible using both reformation methods when considering fuel cell applications.

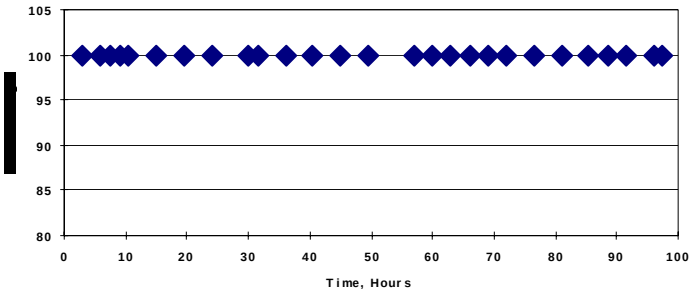

Figure 1 *Percent conversion of coal-derived methanol to hydrogen*

Data taken through 100 hours and 30 start up and shut-down cycles confirmed negligible degradation in hydrogen production using coal-derived methanol via autothermal reformation as shown in Figure 1. . High operating temperature by means of oxidation of methanol can potentially lead to catalyst degradation during start-up and shut down processes. Further research should be performed to optimize the start-up and shut-down procedures and further tests for longer time duration are warranted.

Degree(s) Master of Science in Mechanical Engineering, UC Davis, September 2006

Publications Yoon, H. C., and P.A. Erickson, "Hydrogen from Coal-derived Methanol via an Autothermal Reformation Process" in *Proceedings of the 23rd International Pittsburgh Coal Conference* ISBN #: 1-890977-23-3 Paper No. 23-5 pp 1-12 September, 2006.

Current position PhD Student in Mechanical and Aeronautical Engineering, expected finished in June 2007. The PhD will be a comparison of steam Reforming and autothermal reforming of methanol for Fuel Cell Systems.

Chang-hsien Liao (2005 – 2006)

Abstract Because of the potential for high efficiency and low emissions, hydrogen powered fuel cell systems are considered to be the next generation power source for both stationary and transportation applications. Providing a hydrogen source to feed a fuel cell is a

critical challenge. Steam reforming processes are demonstrated for producing hydrogen for fuel cell and other applications. Generating hydrogen via steam reformation requires that heat energy be transferred to the reactants to support the endothermic reaction. For a cylindrical steam-reforming reactor, large thermal gradients between the heat source (reactor wall) and reactor centerline create a non-ideal condition for complete conversion. This gradient is caused by insufficient heat transfer inside the catalyst bed. Passive flow disturbance inside the catalyst bed provides a potential to enhance the heat and mass transfer in the steam reforming process. My research is about an experimental investigation of the effect of changing the flow pathway inside the reactor to improve the heat and mass transfer and thus enhance fuel conversion. The results of this study contribute to the improvement of reformer design for better fuel processing system performance.

Results

In this study, a preliminary test using bluff bodies to create a passive disturbance within catalyst bed had been investigated. From the temperature profile and fuel conversion data out of the experiment, it is proven that the bluff body method can significantly enhance heat transfer in a methanol-steam reformation process. The simplicity of this method and the effective results show good promise for use in hydrogen generating processes.

Degree(s)

Master of Science in Mechanical Engineering, UC Davis, September 2006

Publications

Chang-hsien Liao and Paul A. Erickson, "Heat transfer enhancement of steam-reformation by passive flow disturbance inside the catalyst bed" ASME Technical Paper #HT 2005-72043, 2005 ASME Summer Heat Transfer Conference, San Francisco, California, pp. 1-7.

Paul A. Erickson and Chang-hsien Liao, "Heat transfer enhancement of steam-reformation by passive flow disturbance inside the catalyst bed" J. Heat Transfer, 2006 Oct. accepted, in review process.

Paul A. Erickson and Chang-hsien Liao, “Statistical validation and an empirical model of hydrogen production enhancement found by utilizing passive flow disturbance in the steam-reformation process” J. Experimental thermal and fluid science, under review.

Paul A. Erickson and Chang-hsien Liao, “The study of characteristic time as a universal descriptive parameter in steam reformation for hydrogen production processes”, under review.

Current position

Pursuing PhD degree in Mechanical and Aeronautical Engineering at

UC Davis.

Matt Caldwell (2005 – 2006)

Abstract — Caldwell's area is autothermal reformation techniques to research hydrogen production from the raw mixtures of bioalcohols produced from catalyst systems. Using the unpurified mixtures is potentially an energy and economically efficient renewable hydrogen source that leverages the existing distribution infrastructure and vehicle fleet for a smooth transition to hydrogen from biofuels.

Results — The alcohol sample was analyzed as received for content using Nuclear Magnetic Resonance spectroscopy (1H-NMR). Analysis of the resulting peaks indicates the presence of methanol, ethanol, likely trace amounts of n-butanol and 1-propanol, and other unknown compounds. Relative percentages can be theoretically found by dividing the integrated area of the peaks by the number of hydrogens which produced the peak.

Preliminary results for hydrogen production experiments using Autothermal Reformation of ethanol and a mixture of methanol and ethanol have been done. The results show a high hydrogen yield and selectivity and complete alcohol conversion. The temperature is seen to be dependent on the oxygen addition and stable even at low oxygen to carbon ratios.

Degree(s) — MS in Transportation Technology and Policy, UC Davis (June 2005)
PhD Candidate, TTP (expected 2007)

Publications — Caldwell's submission to the 2006 Fuel Cell Seminar, "Hydrogen via reformation of mixed, low cost bio-alcohols derived by thermochemical conversion" was accepted for a poster presentation, presented in November 2006.

Current position — PhD Student at Institute of Transportation Studies

Jonathan Hughes (2005 – 2006)

Abstract — Development of a Corporate Average Fuel Index (CAFI) for the reduction of CO2 emissions from motor vehicles. The project will evaluate the role of market based policies for the transportation fuel industry in a transition to a hydrogen based transportation system. The goal is to determine how policy may affect the development of a

hydrogen based transportation system. Of particular interest are policies to address transportation related greenhouse gas emissions such as emissions standards, carbon taxes, vehicle technology mandates, feebates, fuel economy standards, marketable emission licenses and fuel composition standards.

Results — Hughes has developed improved models for research area 1: Vehicle versus Fuel Regulation in Policies to Control CO2 Emissions from Light-Duty Vehicles. The phase I Matlab based social welfare computer model is almost complete. The model currently includes two fuel types: EtOH from corn using current technology and EtOH from cellulosic feedstock using future technology. The consumer welfare portion of the model has been developed to account for climate change and driving-related externalities, specifically criteria pollutant emissions, traffic accidents, congestion and oil dependency. The welfare calculations have been expanded to describe the distribution of costs and benefits to key stakeholder groups, namely: consumers; producers; and suppliers of factors of production.

Degree(s) — Currently a PhD Student

Publications

Current position — PhD Student in Transportation Technology and Policy at UC Davis

Bryan Jungers (2005 – 2006)

Abstract — This research project is concerned with the reactivation and improvement of the Fuel Cell Vehicle Modeling Program (FCVMP), which was completed and then terminated at U.C. Davis in 2002. The program used component data from industry and national laboratories to develop models for direct hydrogen, indirect methanol, and battery/fuel cell vehicles. The main focus of this GATE research project is to build upon the previous FCVMP work for direct hydrogen and battery/fuel cell models in order to make them applicable to generic fuel cell technologies and vehicle designs and thus more useful for ITS students and researchers.

Results — Jungers have been improving and validating three new component models (user-defined fuel cell stack, compressor/blower and lithium ion battery pack). Additionally, he has incorporated these components into two vehicle powertrain configurations, the direct hydrogen fuel cell (DHFC) model and the hybrid battery/fuel cell (HFC) model. Finally, these models are currently being redeveloped for integration

into the Powertrain Systems Analysis Toolkit (PSAT), a vehicle simulation modeling environment developed by Argonne National Laboratory (ANL).

Degree(s) MS in Civil and Environmental Engineering at UC Davis, 2005

Publications

Current position PhD Student in Transportation Technology and Policy at UC Davis

David McCollum (2005 – 2006)

Abstract As energy security becomes a higher national priority, there is increasing pressure to use domestic sources of energy. With the largest recoverable coal reserves in the world (~250 years at current consumption), it is likely that the U.S. will rely on coal, as a hydrogen feedstock, to meet energy demand in the future. This study seeks to identify existing capacity and potential constraints within the coal distribution infrastructure and to identify the costs of alleviating these constraints.

Results It is expected that the study will provide insight into when coal distribution will become constrained and whether converting to IGCC plants can postpone the constraints and, thus, postpone infrastructure investments. Given this information, the study will identify whether the economic disadvantages of building an IGCC plant might be overcome by the savings from avoiding investments in coal distribution infrastructure. Finally, the study will identify the additional coal demand that might result from hydrogen production for transportation fuels under two hydrogen vehicle market penetration levels (high and low). The analysis methodology developed for this analysis will be applied to other energy pathways in future studies.

Degree(s) Currently a PhD Student

Publications

Current position PhD Student in Transportation Technology and Policy at UC Davis

Nathan Parker (2005 – 2006)

Abstract This study is an economic optimization of a waste biomass-to-

	hydrogen industry in California. The transportation of the biomass feedstock and the product hydrogen is likely to make a significant contribution to total cost of the hydrogen. In order to obtain a good estimate of the availability of bio-hydrogen, transport distances need to be addressed. For this reason, a case study approach is being used. The case study will look at forestry, orchard, and vineyard thinning gasification, agricultural field residue gasification, dairy manure/biogas reforming, and landfill gas reforming.
Results	For this study, Parker has found that the least cost configuration for this particular scenario of hydrogen demand and feedstock supply is to site a large conversion facility in an area near feedstock supply. At the scale and density of demand studied here delivery by cryogenic truck gave nearly equal costs for all sites. The answer reached above will depend on the spatial distribution of both the demand and feedstock supply. Different results are feasible and more study will need to be conducted in order to understand which hydrogen supply configuration will be best for a given situation.
Degree(s)	MS in Transportation Technology and Policy (March 2007)
Publications	Optimal Design of Hydrogen Production From Agricultural Waste. Parker, Nathan (2006). Proceedings of the National Hydrogen Association Conference, Long Beach, California.
Current position	Nathan is currently a PhD student in the Transportation Technology and Policy program at UC Davis.

Brent Riffel (2005 – 2006)

Abstract	The goal of this project is to investigate the overall global warming potential of NOx emissions in terms of CO2-equivalence factors and to incorporate these variables into the Lifecycle Emission Model (LEM). Finally the LEM will be used to calculate the net climate forcing resulting from NOx emission pulses in various regions; these calculations and the research behind the CEF NO x values will be published in a journal article.
Results	The net climate forcing is the sum of numerous atmospheric and surface effects. Positive climate forcing effects include increased tropospheric ozone levels (O 3) due to reaction with VOCs (volatile organic compounds), and increased N2O levels from soil nitrogen fixing. Indirect negative climate forcing effects are decreased CO2, decreases in methane levels and increased ambient lifetimes, and

increased particulate nitrate levels. The overall expected effect is slightly negative climate forcing and sensitivity to emissions is uncertain.

Degree(s) Currently a Master Student

Publications

Current position Master Student in Transportation Technology and Policy, UC Davis

David Vernon (2005 – 2006)

Abstract Enriching common transportation fuels by adding small amounts of hydrogen to the fuel-air mixture can significantly change the characteristics of the combustion process. These enriched mixtures have been shown to have higher flame speeds, leaner flammability limits and to burn more completely even in very lean or very dilute mixtures. Due to the enhanced mixture combustion properties it is possible to use much leaner or much more dilute fuel-air mixtures and achieve much lower temperature combustion. Low temperature combustion offers significant benefits including greatly reduced NOx emissions and increased thermal efficiency.

Results Preliminary results show that hydrogen enrichment of stoichiometric gasoline air mixtures can increase efficiency 9-12%. This increase is expected to be greater using lean or dilute mixtures. At this point it is uncertain whether the unique properties of hydrogen are mainly responsible for the decrease in NOx or if the small, approximately 6% increase in equivalence ratio plays a significant role in the reduction.

Degree(s) Master of Science in Mechanical Engineering, UC Davis (September 2006)

Publications Vernon, David R., “Hydrogen Production from Landfill Gas”, Presented at California Environmental Protection Agency work shop on Hydrogen’s Role in Landfill Gas Utilization Workshop, January 11, 2006

Vernon, David R., Eddie Jordan, Jonathan Woolley, Paul Erickson, ”Hydrogen Enrichment Through Chemical Recuperation,” Presented at WestStart Clean Heavy-Duty Vehicle Conference, San Diego, CA, February 22-24, 2006

Vernon, David R., David Davieau, Bryce Dudgeon, Paul Erickson, "Heat Transfer Limitations in Hydrogen Production Via Steam Reformation: The Effect of Reactor Geometry", Proceedings of the ASME 4th International Conference on Fuel Cell Science, Engineering and Technology, 2006. Irvine, CA

Current position: PhD Student in Mechanical Engineering and Currently GATE Fellow

Jonathan Weinert (2005 – 2006)

Abstract: Annual electric bike (e-bike) sales in China grew from the 40,000 in 1998 to 10 million in 2005. This rapid transition from human-powered bicycles and gasoline-powered scooters to an all-electric vehicle/fuel technology system is special in the evolution of transportation technology and, thus far, unique to China. We examine how and why e-bikes developed so quickly in China with particular focus on the key technical, economic, and political factors involved. This case study provides an important lesson to policy makers in China and abroad on how strong regulatory policy, given the evolution of technology to a market acceptable product, can change the purchase choice of millions and the direction of a technology system. This lesson is especially important as China embarks on a large-scale transition to personal vehicles.

Results: We conclude that the following factors had a substantial impact on e-bike success in China:

1. Incomes of urban households and the share spent on transportation both rose considerably.
2. E-bike technology, specifically motors and batteries, improved significantly during the late 1990's while costs dropped slightly.
3. Simple technology, a vast supplier base, and weak intellectual property protection made it easier for e-bike makers to enter the industry, driving competition up and prices down.
4. National and local governments motivated by energy and air quality issues created favorable policies for e-bike growth and against gasoline-powered scooters.
5. National e-bike standards with loop-holes and flexible guidelines created a rich opportunity for manufacturers to create e-bikes that appealed to more users, namely, scooter-style electric bikes.

Degree(s): MS Transportation Technology and Policy, UC Davis 2005

Publications: The Transition To Electric Bikes In China: History And Key Reasons For Rapid Growth. Jonathan X. Weinert, Chaktan Ma, Chris Cherry,

UCD-ITS-RR-06-12, September 2006, Working Paper

Current position PhD in Transportation Technology and Policy at ITS-Davis

ATTACHMENT B:

PARTICIPATING FACULTY/STAFF ON GATE AWARD

- *Dr. Christie-Joy Brodrick,* Assistant Researcher, ITS-Davis. Specializes in energy and emissions technologies for heavy-duty vehicles. Collected no salary on the GATE award but advised a number of students funded through award.

- *Dr. Andrew F. Burke,* Researcher, ITS-Davis. Currently directs the Electric Vehicle Power Systems Laboratory at UC Davis. His interests with fuel cells are vehicle simulations, energy and environmental impacts, and hybridization strategies with other power sources. Team taught the *Hydrogen Economy – Technology, Pathways, Economics and Policy* course as well as the *Fuel Cells and Energy Storage* course several times during the period of the grant. He also advised several graduate students.

- *Dr. Mark Delucchi,* Researcher, ITS-Davis. Analyzes the social costs of transportation, the lifecycle environmental impacts of transportation systems, and the manufacturing and lifetime costs of battery, hybrid and fuel cell electric vehicles. Team taught the *Hydrogen Economy – Technology, Pathways, Economics and Policy* course as well as the *Advanced Energy Systems* course and advised a number of graduate students.

- *Dr. Paul Erickson,* Assistant Professor, Mechanical and Aeronautical Engineering. Specializes in energy conversion methods applied to transportation. Has team taught the *Hydrogen Economy – Technology, Pathways, Economics and Policy* course as well as the *Advanced Energy Systems* course.

- Dr. Andy Frank, Professor, Mechanical and Aeronautical Engineering. Research addresses issues of vehicle fuel economy, emissions and energy storage devices for hybrid and plug-in hybrid vehicles. He led research teams consisting of GATE students that designed advanced vehicles that won awards in the Super Mileage Vehicle, U.S.S DOE Hybrid Electric Vehicle, FutureCar, FutureTruck and Challenge X competions. Directs the successful Student Vehicle Design Center and is director of the GATE Hybrid Drivetrain Center.

- *Anthony Eggert,* Associate Director ITS-Davis *Transportation and the Hydrogen Economy: Pathways and Strategies (Hydrogen Pathways)* program. Former GATE Fellowship recipient, he supervised numerous MS and Ph.D. students in his role with the Hydrogen Pathways program.

- *Dr. Bruce Gates,* Professor, Chemical Engineering and Materials Science. Initial Co-PI of the GATE award and co-Director of the Fuel Cell Vehicle Center. His research specialized in catalysis, catalytic reactors, chemical reaction engineering, material microstructure, and sol-gel processing. Advised numerous students during the course period of the GATE award.

- *Professor Emeritus Myron A. Hoffman*, Mechanical Engineering and Aeronautical Engineering. His research interests are theoretical analysis and modeling of fuel cell system efficiency and air supply systems for fuel cell stacks based on fundamental thermodynamic and kinetic principles. He was actively involved in the Fuel Cell Vehicle Modeling project, focusing on air compressors.

- *Dr. Ken Kurani*, Associate Researcher, ITS-Davis. Develops methods to evaluate user responses to new transportation and information technologies. His ongoing research includes household response to electric, hybrid and fuel cell vehicles and consumer valuation of automotive fuel efficiency. Provided lectures on markets for H2 vehicles for the *Hydrogen Economy – Technology, Pathways, Economics and Policy* course developed through GATE and also gave talks on H2 vehicles at a series of one-day workshops. Advises students on conventional hybrid vehicle buyer behavior.

- *Dr. Marc Melaina*, Assistant Project Scientist, ITS-Davis. Conducting research on hydrogen infrastructure systems, including station networks in cities and rural areas, policy processes supporting infrastructure technology development and historical perspectives on energy transitions and alternative fuels. Team taught *Hydrogen Economy – Technology, Pathways, Economics and Policy* course and developed *Transportation Energy Analysis and Modeling* course and advised students during the period of the grant.

- *Dr. Marshall Miller*, Senior Research Engineer, ITS-Davis. Focuses on fuel cell vehicle modeling and co-directs the multi-million dollar DOT-funded Hydrogen Bus demonstration program. He managed the Hybrid Vehicle Propulsion Systems Laboratory where students study power and energy technology for vehicles, supervised several GATE students in the lab and served on their thesis committees, and taught the *Fuel Cells and Energy Storage* course.

- *Dr. Robert M. Moore*, was director of the now-defunct ITS-Davis Fuel Cell Vehicle (FCV) Modeling program. Dr. Moore co-chaired the Executive Committee, was a member of the GATE Student Fellowship Committee, taught the first fuel cell course in fall 1998, and devised and led the first GATE FCV Seminar Series in Winter 1999 (as well as directing the FCV Modeling Program).

- *Professor Alexandra Navrotsky*, Director, NEAT ORU; Edward Roessler Chair in Mathematical and Physcial Sciences Distinguished Professor; Interdisciplinary Professor of Ceramic, Earth and Environmental Materials Chemistry. Managed a large research team that conducted research in several areas that are relevant to fuel cell technology, including thermodynamic studies of ceramic materials, in particular zirconia based solid electrolytes and doped lanthanum compounds. She was also head of a program on nanoparticles, which had a fuel cell component. She was a member of the FCV Modeling Program executive committee and a member of the GATE Student Fellowship subcommittee.

- *Dr. Joan Ogden*, Professor, Environmental Science and Policy. Conducts technical and economic assessments of new energy technologies and is particularly interested in

alternative fuels production, the use of hydrogen as an energy carrier and applications of fuel cell technology in transportation and stationary power production. Joined UC Davis in 2003 after 20 years at Princeton University. Official instructor of the *Hydrogen Economy – Technology, Pathways, Economics and Policy* course and supervisor of many students participating in the ITS-Davis Hydrogen Pathways program.

- *Professor Ahmet Palazoglu*, Department of Chemical Engineering and Materials Science. His research group focused on fundamental and empirical dynamic modeling of chemical processes in an effort to design model-based control systems. Professor Palazoglu is now addressing control systems for fuel cell vehicles, focusing on the key process variables that must be maintained close to their desired levels during transient operation, while subject to safety, quality and design constraints. He chaired the search committee for a senior fuel cell vehicle faculty person and was a member of the GATE student fellowship subcommittee.

- *Professor G. Tayhas R. Palmore*, formerly in the Chemistry Department. Conducted research on catalysts and catalytic processes for direct methanol fuel cells. She was a member of the GATE Teaching Fellowship subcommittee and the GATE FCV Center Executive Committee.

- *Dr. Sitaram Ramaswamy,* Associate Director of the now-defunct ITS-Davis Fuel Cell Vehicle (FCV) Modeling program, ITS-Davis. Focused on fuel processor technology and fuel cell system integration issues. Organized seminars and gave lectures in early fuel cell classes led by Robert Moore.

- *Professor Subhash Risbud*, former chair of Chemical Engineering and Material Science. His research interests are in the area of synthesis and processing of new materials based on glass, ceramic and polymer composites. He now plans to use his team's glass/ceramic processing expertise to make new polymer- and glass-based H-ion-conducting fuel cell materials. He was a member of the GATE FCV Center Executive Committee.

- *Professor Daniel Sperling*, Professor and Director, ITS-Davis and co-director GATE Center. Founding director of the Institute of Transportation Studies at UC Davis and professor of Civil and Environmental Engineering and Environmental Science and Policy. He co-chaired the GATE FCV Center Executive Committee and chaired the subcommittees on GATE Teaching Fellowships and GATE Student Fellowships. Lectured in a number of classes and advised numerous students during the period of the grant.

- *Professor Pieter Stroeve,* Chemical Engineering & Materials Science Department and Co-Director of the NSF Center on Polymer Interfaces and Macromolecular Assemblies (CPIMA). He conducts research in multiphase transport phenomena and ultrathin film science, with a focus on chemical engineering applications. He was a member of the GATE FCV Center Executive Committee and the GATE Teaching Fellowship Subcommittee.

- *Dr. Tom Turrentine,* Assistant Researcher, ITS-Davis. Studies the relationship of travel and movement to culture, with an emphasis on mitigating the negative impacts of automobile infrastructure and use. Delivered annual seminar on “Consumers and Fuel Economy" to students and currently advised students on estimating potential markets for Plug-in Hybrid and Fuel cell electric vehicles in California.

- *Peter Vagadori*, Project Manager, ITS-Davis. Served as Project Manager of the Fuel Cell Vehicle Modeling program and administered various aspects of the GATE Center.

- *Emily Winston*, Program Manager, ITS-Davis. Program manager of the ITS-Davis Toyota Fuel Cell Vehicle Outreach and Demonstration Program. Has conducted extensive education and outreach activities centered around hydrogen fuel cell vehicles. These activities have included visits to elementary through college level classes, teaching them about how fuel cells work and address energy and environmental concerns, and demonstrating both a toy fuel cell vehicle as well as a full size Toyota prototype.

- *Dr. Chris Yang*, Assistant Project Scientist, ITS-Davis. Researching the design and economics of a future hydrogen transportation infrastructure. He is currently developing a number of sophisticated models that address the buildup of a hydrogen supply infrastructure. Chris organized and taught the second and third versions of the *Hydrogen Economy – Technology, Pathways, Economics and Policy* course.