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Overall, our goal was to accomplish by the end of the six year award, the development of new technologies in the fields of petroleum and wind energy, to transfer these technologies and results to industry, schools, and the public, and to strengthen the state's economic base by producing new jobs, providing better training, partnering with existing industry, and fostering new industries and businesses. All of these objectives have been met. An attached Excel spreadsheet documents presentation, publications, awards, related-contracts and grants, and other outcomes. It contains over 1000 entries.

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Several of our DOE/EPSCoR opportunities, as well as the two startup businesses were used to illustrate to our legislatures the importance and need to remove unnecessary impediments and to encourage orderly development of these opportunities. Thus, under our new DOE/EPSCoR Implementation award, we already have four new businesses in the state, several patents, and license agreements. As an example, Dr. Bromenshenk, the state-wide coordinator for DOE/EPSCoR formed his own company in May, 2003, received Regent's approval in September, has patents pending on two systems, and is negotiating licensing agreements with the University and with two other private companies.
Montana Organization for Research in Energy (MORE)
Montana DOE/EPCSCoR

Final Technical Report, 12/31/1999, Updated 12/31/03
DE-FG02-91ER75681


MT DOE/EPSCoR IMPLEMENTATION GRANT IN PETROLEUM RESERVOIR CHARACTERIZATION, WIND ENERGY, and HUMAN RESOURCE DEVELOPMENT

MORE's IMPLEMENTATION GRANT (September, 1994- December, 2000)

Dr. Jerry Bromenshenk, Statewide Director
MORE, Division of Biological Sciences
The University of Montana—Missoula

Dr. Daniel Bradley, Co-Director
Office of Vice Chancellor for Research
Montana Tech of The University of Montana

Dr. Hugo Schmidt, Co-Director
Department of Physics
Montana State University—Bozeman

Nina Klein, Anneliese Ripley/Amy Verlanic, HRD Coordinators
Technical Outreach,
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PROLOQUE

MORE administered Montana's 1st DOE/EPSCoR Implementation Award, which encompassed a seven year period. In 2000, MORE was awarded a new Implementation Award in the research area of electronic transfer materials and devices, one of only three states to receive a 2nd Implementation Award from DOE. MORE submitted a final technical report for its 1st Implementation Award in 2000. An Executive Summary was also posted to DOE's DEARS database site in 2000. This Summary has also been posted for more than two years on the state's DOE/EPSCoR web site. It can be accessed at: http://multimedia.mtech.edu/doe-epsco/PPTs/1998-2000/1998_2000overview.ppt.

In 2003, we received notice that DOE did not have a copy of our final report, including the financial and other close-out materials. This was surprising, since we had previously submitted
this information to DOE as part of the closure of this project, and had presented this information as an invited overview of the program at the DOE/NSF National EPSCoR meeting in Alabama. We also had a full and successful DOE site review in Montana in the fall of 1999. That review was at the end of the sixth year of the program, when the majority of the project was in its final, wrap-up phase. A Yr 2000, no-cost, extension was provided to allow a few, small projects to be completed and to provide bridge-funding until we received our new, 2nd Implementation Award on January 1, 2001.

The financial statements for this close-out have been submitted to DOE at least twice, before this current re-submission. Nevertheless, we gladly re-submit the required reports. However, since nearly three years have passed since the close of this project, we have taken this opportunity to update the Final Technical Summary, particularly with respect to longer-term outcomes of our 1st Implementation Grant.

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NARRATIVE:

MORE’s research partners included the region’s major power, oil, and gas industries. The research clusters were closely linked with DOE’s Fossil Fuels programs, the Renewable Energy Resources programs at Sandia (Sandia), and the National Renewable Energy Laboratory (NREL). The Human Resources Outreach Program (MORE-HRD) became a national model for technology and information transfer.

Our program emphasized statewide awareness and training in energy resources, brought scientists into K-12 schools and tribal community colleges, provided on-site training to rural schools, and emerged as a Connected Learning Community, featuring electronic communications and a mobile multi-media training laboratory.

A short synopsis of the structure and achievements of each component of the program is provided below, including a synopsis of the program at time of graduation in December, 2000. Following that is a more expanded discussion of the HRD, Petroleum, and Wind-Energy Research Clusters.

PETROLEUM RESERVOIR CHARACTERIZATION RESEARCH CLUSTER

Petroleum Reservoir Characterization
Dr. Charles Wideman, Department of Geophysical Engineering, Montana Tech of The University of Montana (now retired, working as an industry consultant)

This program was funded by MT DOE/EPSCoR program in collaboration with Burlington Resources, Marathon Oil, JN Oil and Gas and Ballard Petroleum. The objective of the research was to develop three-dimensional models of oil/gas fields for the most economic development of the resource. The project had specific application to lengthening the producing life of some of Montana’s older oil fields. A unique aspect of the research was the degree of integration of inter-
campus researchers from various disciplines including reservoir simulation, applied mathematics, computer visualization, geology, and geophysics. Advanced computing tools such as visualization graphics and artificial neural networks were used to correlate data sets of widely varying types and physical scale.

Final projects of the program focused on development of Self Organizing Feature Maps (SOFM) for the interpretation of seismic data and well log analysis techniques, petrographic image analysis using computer algorithms to automatically classify pore spaces by type and roughness, geologic models that are currently being used by JN Oil and Gas and Beartooth Oil, inversion techniques for reservoir parameter estimation, and 3-D seismic surveys from several of the region's oil fields covering most of the field types being studied under DOE CLASS program.

WIND ENERGY RESEARCH CLUSTER

Dr. John Mandell
Chemical Engineering Department
Montana State University—Bozeman

This program was funded by MT DOE/EPSCoR in collaboration with Montana Power, Headwaters Composites, Glacier Electric, Atlantic Orient Corporation (AOC), and other U.S. wind turbine companies. The research objectives were: 1) to develop wind turbine blades with improved strength, resistance to fatigue, buckling, and structural dynamics; and 2) to assist in the development of the substantial wind resources in Montana and the region.

Final research thrusts included improved blade structural design and manufacturing technology, modeling and testing of blade substructure elements including stiffeners, ply drops, and the development of improved reinforcing fabrics; measuring strains in the root section where the blade connects to the turbine, and validation of nonlinear buckling prediction technology, and a power quality study. A major avian study, funded by NREL, was completed.

Three wind turbine demonstration projects were conducted in Montana: a small stand-alone hybrid wind/photovoltaic installation at Red Bluff, a weak radial enhancement distributed generation project using a 50kW turbine at Madison Valley, and a 100 KW utility grade turbine on the Blackfeet Reservation. The Blackfeet project served as a catalyst for further development of the huge wind resource in the area and as a focus for education and technology programs at the Blackfeet Community College.

HUMAN RESOURCES DEVELOPMENT PROGRAM

Anneliese Ripley/Amy Verlanic
MT Tech Outreach Programs
MT Tech of The University of Montana

This program was initially funded by MT DOE/EPSCoR. Since its inception, it has grown to include the Department of Education, the Environmental Protection Agency, National Science
MORE-HRD emphasized one-on-one training and follow-up activities in schools that effectively use computers and electronic communications. Teachers and students from middle schools, high schools, and tribal colleges were involved in ongoing wind energy, petroleum, and environmental characterization research. Highlights of the program included sustained contact with teachers and students in rural schools, an annual summer Energy Camp, a Connected Learning Community, a Mobile Multi-Media-Training Laboratory, and a new Minority Engineering Program (MEP) at Montana Tech. In addition, MORE-HRD provided a means of researching the effectiveness of inquiry-based approaches to education in K-12 and college level classrooms, improved assessment methods, and the involvement of students in hands-on research, both via participation with the research clusters and via the conduct of real-time research over the Internet.

MANAGEMENT AND COORDINATION

Dr. Jerry Bromenshenk, Director
MORE, Division of Biological Sciences
The University of Montana—Missoula
Dr. Daniel Bradley, Co-Director
MORE, Office of Vice Chancellor for Research
(now President of Fairmont College, West Virginia)
Montana Tech of The University of Montana
Dr. Hugo Schmidt, Co-Director
Department of Physics
Montana State University—Bozeman

MORE's Directors maintained their own research programs, in addition to directing and coordinating the DOE/EPSCoR program. Dr. Schmidt has a NSF study of non-linear glassy and relaxer behavior in ferroelectrics, a DEFSCoR investigation of large amplitude electromechanical response and fatigue of PMN-PT and PZN-PT crystals, a NASA inquiry of advanced materials for active noise and position control, and a NSF REU to support summer research for undergraduates. Dr. Bromenshenk directed a US Army Center for Environmental Health Research (USA CEHR) contract to develop novel methods for monitoring air quality and the terrestrial environment and a Defense Advanced Research Projects Agency (DARPA) contract for bioreporting and seeking agents of harm. This latter contract supported more than 25 senior scientists from two universities (The University of Montana and Ohio State University), chemical analysis and instrumentation, microelectronics, and microbial bioengineering research groups at DOE’s Oak Ridge National Laboratory (ORNL), an explosives research group at Sandia National Laboratories (Sandia), a radio-frequency electronics group at Battelle Pacific Northwest National Laboratory, and microbiological specialists at the Monmouth Microbial Aerosol Laboratory in Oregon. This program ended with patents, a new business, and ongoing research/business relationships with S&K Electronics, MSU, SNL, and NOAA.
Partners in Montana’s Resources: MT Department of Energy EPSCoR, December 2000, Graduation

In December, 2000, The Montana Organization for Research in Energy (MORE) and MT DOE/EPSCoR announced the graduation of the Wind Energy and Petroleum Reservoir Characterization Research Clusters, as well as the start of a new set of research and human resource development initiatives. Begun in 1991, Montana’s DOE/EPSCoR program supported research clusters in Wind Energy Development and Petroleum Reservoir Characterization, along with a Human Resources Development Program that has reached over 90% of Montana’s rural K-12 schools and Tribal Community Colleges.

MORE is committed to enhancing energy research and training in Montana. Overall, the program supported about 39 investigators and a varying number of undergraduate and graduate students. An underlying theme has been to better employ Montana’s science and education to develop environmentally beneficial energy technologies that use our abundant resources.

Overall, the Montana DOE/EPSCoR programs have been very successful. The HRD component reached many of the rural schools in the state, especially on tribal lands. Many aspects of the HRD program have been identified by DOE reviewers as a national model for HRD. The core of the HRD program at MT Tech has grown substantially since the inception of the program. In addition, two education specialists at UM now have successful research and educational programs of their own, with one receiving a substantial award in 1998 from the Hughes Foundation to promote undergraduate research.

The Petroleum Research Cluster has successfully entered into partnerships with an expanding number of gas and oil industries and has received large contributions in terms of software, equipment, data sets, and student support. The Wind Energy program has developed into what appears to be the largest academically-based research group in Wind Energy in the U.S. Similarly, the DOE/EPSCoR M&C team has been very successful. Dr. Schmidt at MSU continues to receive NSF awards, Dr. Bradley is now a College President, and Dr. Bromenshenk directs large research programs funded under competitive programs from DoD. This latter project provides funding not only to UM but also to five research groups at three DOE National Laboratories.

Project Wrap-Up

For the final phase of the Implementation Award, Montana’s M&C efforts moved from putting programs in place to planning and encouragement of activities leading to development of self-sufficiency of activities with diversity of funding an important goal. In addition, planning efforts were conducted that allowed Montana to successfully compete for a new Implementation Award that started in 2001, and which has recently been notified of a 3 Yr renewal.

Reductions in DOE and State Match dollars caused our activities to become more tightly focused. The Management team worked closely with the Montana University System research vice presidents in developing budget projections and justifications for cost-sharing requests.
presented to the 1999 Montana legislature. The DOE/EPSCoR program was also presented at a Legislative Reception at the State Capital in Helena on April 6, 1999.

One of the state goals was to foster working relationships with the DOE national laboratories. Two of MORE's components have been particularly successful in this regard: 1) The Wind Energy Cluster continues to work with DOE on the next Generation of Turbine Development and also has been funded by non-EPSCoR awards from Sandia National Laboratories, and 2) the UM M&C whose Director put together a research team of 25 scientists from three DOE laboratories, EPA, the Navy, Ohio State University, and UM. This team will received three years of funding from DARPA at a total project cost of more than $2.3 million. At the time of submission of this proposal, Dr. Mateja of the National DOE/EPSCoR program, helped DOE investigators to identify appropriate contract avenues that would allow them to participate in a DARPA funded program coordinated by a University.

In 1998 and 1999, M&C also worked closely with the HRD program. This program has been so successful that several of the principal investigators have graduated to other sources of funding. MT Tech has developed a multi-agency program with federal and industry sponsors and has been working on web-based resources for teachers, as well as a mobile multimedia-training lab. As mentioned, that model was then duplicated at Western Montana College by Anneliese Ripley.

At UM, Drs. Brewer and Brown were very successful in establishing model programs in Inquiry-Based Education. In 1998, Dr. Brewer received a large Hughes Grant and Elaine Caton received a three-year NSF Schoolyard Ecology post-graduate award. In 1998, Dr. Bromenshenk, the DOE/EPSCoR M&C Director worked with Mr. George Bailey to tie the HRD program more closely with the UM School of Education. Together, they conducted a teacher education workshop in Colstrip, MT in September 1998. Shortly after, Mr. Bailey received a 3-year, $10.5 million award to establish an Earth Observing System Natural Resource Training Center (EOS) Center at UM. EOS ties NASA research into an educational outreach program for K-12 schools and builds on the GLOBE system of schools around the world. More recently, Mr. Bailey obtained a large grant from NASA to help transition space-platformed based technologies to the private sector.

MORE's directors have continued to pursue development of interactive web pages aimed primarily at undergraduate education. At MT Tech, the HRD program has vigorously promoted a variety of electronic communications systems and workshops for Montana's K-12 schools. At UM, Dr. Bromenshenk and his research partner, Dr. Smith set up web pages to support the National College Undergraduate Research Conference (NCUR), hosted at UM in the year 2000.

In addition, Dr. Bromenshenk has development a working model of undergraduate research with Mr. Bob Madsen and three undergraduate students at Dull Knife Community College in Lame Deer Montana. This team is actively engaged in cutting-edge research involving DARPA and several DOE laboratories. More recently, Mr. Madsen received a TCUP award to improve math and science education in tribal colleges. Dr. Bromenshenk is on this program’s Board of Directors. Also, Dr. Bromenshenk and Mr. Robert Seccomb helped design and maintain the DOE DEARS national database and have been actively involved in the use of DOE’s Argonne Laboratory’s Access Grid Node System for multi-media, audio-video communications among
investigators at Montana’s three campuses. In 2003, UM delivered a professional training course via this system to scientists at the DOE INL in Idaho Falls, Idaho

End of Program Milestones and Achievements

The core research investigators of both Research Clusters continued working towards establishing National Research Centers. The Petroleum Cluster hosted a joint meeting of The Billings Geophysical Society and the student Chapter of the Society of Exploration Geophysicists in September, 1998. One of the main objectives of the meeting was to obtain a professional review of our research effort by the petroleum industry. David Ballard of Ballard Petroleum, and Chairman of the Montana Board of the Oil and Gas Commission, along with Dan Piazzola of JN Oil and Gas served as the primary reviewers of the program. Also in attendance were representatives of NARCO and Johnson Geophysical. The technical review session was of four hours duration, and all phases of the work were reviewed. The outcome of this meeting were the partnerships with 14 businesses that were set in place by the end of the program.

Similarly, the M&C directors worked with Donna Prokop, the National DOE/EPSCoR Director to arrange a meeting and overview of the Wind Program for a DOE Basic Energy Sciences (BES) scientist (in October of 1998 in Bozeman, MT). The purpose of that program was to provide DOE with information relevant to DOE’s long-range planning and identification of critical research issues with respect to wind energy and turbine blade technology. An outcome of that activity is that the Wind Energy Research Group has continued work with Sandia on a national database concerning properties that influence the service life of turbine blades.

Recently, there is renewed interest by industry in developing wind energy resources in the NW and Montana. Both MSU and the new Dean of the COT in Missoula are taking leadership roles in establishing wind energy sources, a wind turbine test site and technicians program at UM, and steps toward moving Montana into a wind/hydrogen based energy-economy.

MORE HRD

During the final two years of the MORE-HRD program, human resource development was fostered by providing training and support to secondary math and science teachers, creating challenging opportunities for high school students that encourage them to pursue scientific research careers, and supporting undergraduate students in engineering programs. In all, 2,534 individuals were direct beneficiaries of services provided by this program. A full description of how they were served appears below.

I. Support of Secondary Teachers (80 served)

In May of 2000, 40 teachers from five communities attended a workshop which taught teacher's effective methods to incorporate calculators and other technologies into their curriculum. In addition, 21 teachers from ten communities attended a one-week stream ecology summer course in July of 1999 funded by MORE-HRD. As for classroom resources, MORE-HRD staff made visits to four tribal high schools in January and again in March of both 1999 and 2000. While at the schools, we provided teachers with 10 copies of 25 different multimedia teaching titles and
checked in on the computer systems which were previously donated to the schools. MORE-HRD funded three requests from our tribal school partners for field trip expenses and guest speakers. Through these funding, EPSCoR researchers and other professionals were able to guide school groups to area wind power generation sites, solar powered facilities, and water power generation sites.

II. Opportunities for High School Students (2426 served)

During both the 1999 and 2000 summers, Montana Tech hosted a "MORE Energy Camp". The camps were four week residential academies that served 24 students each. The curriculum focused on various energy types such as petroleum, wind, solar and geothermal. In addition, MORE-HRD Science Fair Awards were granted to the top five meritorious energy-related research projects at the state science fair and all four regional fairs in Montana in 1999 and to the top two in 2000. Therefore, 35 students were recipients of the awards. MORE-HRD staff hosted 46 mini-workshops on Montana Tech's campus during the reporting period. These workshops engaged 2,225 students in hands-on activities (i.e. building wind mills, constructing and racing solar powered cars, developing web sites for their classrooms, etc.). Workshops were marketed through the school visits made in January and March and provided teachers a quality educational field trip opportunity for their students at no expense to them, their students, or their school district.

III. Undergraduate Support (28 served)

Four undergraduate scholarships were awarded in 1999, which funded students to work on energy related research. The scholarship recipients published the following reports; "Control systems of the wind tracking" by J. Walden, "Rock bit modeling" by B. Bate, "Web page construction of the NASA EPSCoR project" by M. Ryan Fitzpatrick, and "Feasibility of using wind-generated electric power as a replacement for typical conventional power" by B. LaMere. The undergraduate scholarships were phased out in 2000, due to insufficient funds.

As a result of the MORE-HRD work with high school and undergraduate students, Montana Tech began an effort in December of 1998 to create an undergraduate engineering support program on campus. The first corporate funding was solicited and received in 1999. Some MORE-HRD staff time in 2000 was used to establish the program. Since then the program has flourished to receive funding from corporate, state, and national entities to the sum of $150,000 per year. This program, Succeeding Students in Engineering Programs (STEP) has sustained much of MORE-HRD's outreach efforts such as tribal high school visits, and hands-on workshops for visiting high school groups, and hosting summer programs for high ability high school students, the inaugural summer program served 24 students.

In addition to these workshops, Dr. Bromenshenk, George Bailey, and Bob Madsen hosted teacher education workshops in Great Falls (1999) and Colstrip (2000) Montana. Teachers came from many disciplines and from as far away as Ft Peck. In all, more than 40 teachers were served, many of whom elected to take the workshops for credit through UM's Office of Continuing Education.
Also, the MORE-HRD Staff Members made several presentations around the state, including:


Amy Verlanic, Meeting the Needs of Native American Undergraduate Engineering Students, Montana-Wyoming Indian Education Conference, October 1999.


Sheree Watson, Diversity in Engineering, Expanding Education and Equity for Women and Girls, AAUW, Montana State Convention, Butte, MT April 24-26, 1998

HRD Project Chronology and Sustainability:

Whereas the campus-wide research projects and the inquiry-based educational components at UM built and expanded upon existing programs, the core of the MORE-HRD at MT Tech displayed a remarkable evolution, one that merits discussion.

Nina Klein was an adjunct faculty member in the Montana Tech Chemistry Department in 1990. She was the first to embrace the concept that research based careers must be marketed long before the undergraduate level in order to effectively increase the numbers of professionals that ultimately choose careers in energy related research. As a result she solicited National Science Foundation and Department of Energy funds to create some high quality K-16 outreach efforts. In 1991, MORE-HRD was created. By 1993, the efforts had been so successful that other funding opportunities were beginning to arise. Upon Klien's resignation to move to another state, the campus created an entirely new position called an Outreach Coordinator to continue what Nina Klien had begun. Anneliese Ripley was hired in 1994. With the impacts of MORE-HRD and efforts to solicit additional funding Ripley was able to formalize the previous outreach efforts in the establishment of a Technical Outreach Department at Montana Tech with a mission of "Providing K-12 teachers and students with college-based programs that enrich statewide science, engineering, and technology education". By 1995, Technical Outreach had six full time employees and 11 grants in place to meet that mission.

Since 1995, the Department has continued to flourish. Although we are entirely funded by grants, we sustain. On September 10, 1999, Montana Tech was visited by EPSCoR director, Matt Varma. Technical Outreach staff reported to him what our strategic goals were in order to sustain when the MORE-HRD money was spent out. We have successfully met self-sufficiency beyond EPSCoR dollars. In fact in 2000, Technical Outreach had $1,431,785 in non-EPSCoR dollars to support eight projects. The program employs six full time positions, over thirty
undergraduate work-studies and 24 temporary summer positions. This significant level of activity and programming is a result of the MORE-HRD efforts.

Housing all the campus K-12 efforts allows programs to leverage resources, assets, and community contacts across the state. Technical Outreach now motivates youth in Montana to pursue math and science careers by:

- administering a Department of Education funded Upward Bound program, which serves 60 students annually from the Anaconda, Butte and Helena communities,
- running a Montana Campus Compact grant that places undergraduate tutors in the seven local elementary schools,
- hosting the annual Expanding Your Horizons Conference, a math and science career fair for area 6-8 grade students,
- coordinating the largest regional science fair in the state serving over 17 counties and 700 5-12 grade students per year,
- teaching college level math and science courses in 7 area high schools so that high ability students can earn college credits prior to high school graduation,
- continuing to administer the Math Science Resource Center so that area teachers, non-profit agencies, and tribal education departments have free access to technology needed to effectively teach science and math,
- going on an annual Tour of Nations where current Native American students and Technical Outreach staff visit tribal high schools and provide workshops to students and support and training to teachers,
- and, running a support program for minorities and underrepresented students in engineering program.

Finally, as previously mentioned, the program is now directed by Amy Verlanic, and Anneliese Ripley is now a Dean at Western Montana College, where a similar program has been put in place.

**Petroleum Reservoir Characterization**

The Montana Petroleum Reservoir Characterization project received a full DOE review in the fall of 1999, near the end of the program. Because this project involved very large models and databases, the Final Technical Report was provided as a web-based template that guided access to data sets, movies, and models. At this time, 3 years since the end of the project, many of these have been archived and as such may not appear when a link (URL) is clicked. Inquiries about access to these resources should be directed to Dr. Curtis Link at MT Tech. The template still functions to provide an overview of the program and its outcomes. This web-based report can be accessed via the [EPSCORPET\HOME.HTM](#) file attached to this report.
Wind Energy Research and Commercialization

The wind energy cluster continued to move strongly toward its specific program goals and the more general objective of a successful transition from DOE EPSCoR funding to self-sustaining external funding. Grants and Contracts awarded to cluster principal investigators in the last years totaled well over a million dollars, in addition to the $750 thousand total from earlier years. The distribution of externally funded programs was approximately evenly split between three PI's (Cairns, Mandell, and Nehrer) in three distinct technical areas, with funding from DOE National Labs, NSF, and industry.

Facilities saw substantial additions in the manufacturing, non-destructive evaluation, and computing areas, with funding from EPSCoR and other sources including Sandia National Laboratories and NSF. Publications and presentations have continued at a rapid pace, and undergraduate, graduate, and research associate participation has been strong. One new faculty member (Don Rabem, Civil Engineering, MSU, from Los Alamos) was added in the structural simulation area.

Involvement with industry continued to be very strong, including Montana Power Company's cooperative effort in the distributed generation project and the spin-off company, Headwaters Composites, involved in wind turbine blade manufacture. Thus, the research team and facilities have been strengthened significantly, and EPSCoR related competitive external funding developed at a rapid pace, with close ties to local industry.

FOCUS AREA I: WIND TURBINE BLADE DEVELOPMENT

Focus Area I included the development and operation of a Test Site, Rice Ridge Renewable Energy Park, which contained small turbines for experimental research including blade wear out studies. There were two turbines: one modified and instrumented Bergey 10 kW turbine in operation, an instrument shack, and a second turbine that was made functional.

Experimental blade sections for in-service wear out studies were developed and laboratory and field tested, with an apparatus for containing failures and limiting overloads. The program then moved into consideration of larger, 23 ft. long blades, with structural details, more representative of utility grade turbines. These blades were designed for the AOC 15/50 50kW turbine, and were designed and manufactured in close cooperation with Atlantic Orient Corporation and with the help of Mike Zuteck, a widely recognized industry consultant.

The effort to improve blade structural design and manufacturing technology included groups in Design/Analysis, Materials, Manufacturing, Full Scale Laboratory Structural Testing, and Instrumented Service Testing using an AOC 15/50 Turbine, purchased in 1997. Each of the groups worked toward establishing an advanced capability to serve the generic needs of the wind turbine industry as demonstrated with the AOC 15/50 blade.

Highlights of Focus Area I in the last two years included enhanced blade design/analysis capability with the addition of Don Rabern and a new main frame computer (SGI, Origin 200, Unix). In the manufacturing area, new resin transfer molding equipment was brought on line,
funded by Sandia National Laboratories. Blade sections were manufactured at Headwaters Composites (a spin off company from the EPSCoR program). The test bed facility at Rice Ridge (with two research turbines) produced large data sets, and improved section designs were implemented. Significant progress was made in modeling and testing blade substructure elements including stiffeners and ply drops, as well as in the basic materials fatigue database. The first images (Figure 1) of composite internal structure were obtained with the new CT Scanner at MSU (NSF and DOD funding, $350K). This nondestructive evaluation facility allows for clearer imaging of the internal reinforcement architecture and flaws in composite material structures.

One of the most difficult parts of the blade to design and manufacture is the root section where the blade connects to the wind turbine. For the AOC 15/50 23 foot-long blade, which was the focus of the study, the blade connects to the turbine by a series of bolts. The team made a resin transfer mold for this section, which will then be bonded into the main blade.

A unique aspect of this work was that several design options were explored, including two that were recently fabricated and tested at MSU by undergraduate researchers. In addition to the use of ceramic and other new-technology composites, some of the design and test samples included a balsa insert for reduced weight and improved manufacturing simplicity. The hurricane load design case required a load carrying capability of about 20,000 lbs. for each bolt. The balsa design failed at a static test load of 22,100 lbs., while the solid design failed at about 62,000 lbs. While both of these designs appear satisfactory, a modification of the solid design for improved manufacturing offered the greatest potential.

Another area of emphasis was the validation of nonlinear buckling prediction methodology. The ANSYS software used to predict buckling in the overall blade design was validated by two graduate students, Aaron Sears and Jay Eppinga. Their experimental studies included panel buckling with large, balsa-stiffened sheets, as well as beam sections intended to simulate the structural elements of blades. The results of these studies helped define the level of analysis necessary to accurately predict the buckling and post-buckling response of complex composite structure. These methods will then be applied to the full-scale analysis and tests of the AOC 15/50 blades.

FOCUS AREA II: WIND ENERGY DEVELOPMENT

Focus Area II had the objective of assisting in the development of the substantial wind resources in Montana and the region, working with the State Department of Environmental Quality, wind industry partners Zond and Atlantic Orient Corporation (AOC), and local power companies Montana Power Company (MPC) and Glacier Electric. An earlier collaborative effort resulted in a major innovative avian study ultimately funded by NREL, for which a final report is now available. For the final implementation year, this focus area consisted of three significant wind demonstration projects in the state, which continued to act as the major focus for the final year of EPSCoR and beyond. The small stand-alone hybrid wind/photovoltaic installation at Red Bluff brought collaboration with the Department of Animal and Range Science at MSU. The weak radial enhancement distributed generation project at Madison Valley used an AOC 15/50, 50kW turbine for which blades are being designed and manufactured, with an associated research study...
of power quality with Montana Power Company. The third demonstration project, a 100kW utility grade turbine on the Blackfeet Reservation served both as a catalyst for further development of this huge wind resource area, and as a focus for education and technology programs at the Blackfeet Community College.

The power quality study associated with the AOC 15/50 demonstration project made substantial progress, with doctoral student Stott Woods (MSU) supervised by Don Pierre (MSU) and Dan Trudnowski (MT Tech). The full turbine installation and instrumentation was completed in the Madison Valley, south of the Rice Ridge installations. Woods began modeling the system while working at NREL. Various simulation procedures showed that the turbine impact on line voltages should be small. This work continues with Dr. Trudnowski and his students at MT Tech. Additional turbines being considered for the site would cause greater voltage fluctuations, and could involve active control strategies. However, at this time, the turbine is scheduled to be moved to Missoula, where the UM COT and MT Tech will continue to operate it and conduct studies. Deregulation of the power industry in MT, the movement of MT Power away from power production and into communications, and the established of a new power supplier in MT, Northwestern Energy terminated plans for expansion of the Madison site. We are currently investigating whether a group of turbines could be located on a ridge-top east of Missoula to produce the power needed by the university, especially during the winter months when winds are particularly strong and cold temperatures increase the power draw by the campus.

A primary goal of the Rice Ridge Renewable Energy Park was to study the fatigue of various blade designs. Blade strain data and fatigue information provides key information for MSU researchers in the design of new blade materials and construction methods. To conduct the testing, a novel data acquisition system was developed and implemented by MT Tech researchers.

The Tech system allowed for telemetry data acquisition of rotor blade strain and for the remote data transfer and control of the wind machines from Tech through radio frequency communications. To bring nine channels of high-frequency strain gauge data from the spinning rotor to the ground with little or no corruption was a challenging problem. Data telemetry packages manufactured for this type of a system can cost anywhere from $20,000 to $30,000. The system designed on campus for this task cost around $2,000 installed with custom computer software. Overall, the system performed very well.

A secondary goal of the Rice Ridge Renewable Energy Park was to study new control methodologies for reducing fatigue. Tech researchers studied several methods involving varying the yaw angle of the rotor to control the rotor speed. Basically, as the wind increases, the rotor is turned out of the wind which in turn reduces the spinning torque. Because of the gusty random nature of the wind, this is a very challenging control problem. Tech developed two successful control methods. Final year research focused on analyzing the effect of the control methods on reducing blade fatigue.

A second test site is the Luzenac Renewable Energy Park. This Park, in the Madison valley, was developed through the combined efforts of the DOE and the Montana Power Company. Luzenac Mine, located adjacent to the Park, also provided significant support. As with the Rice Ridge
Park, Tech researchers lead the development and construction of the Park. This site is located approximately 20 miles south of Ennis, MT near the Madison river. A 50kW wind generator constructed by the Atlantic Orient Corporation was installed at the site and connected to the 12kV MPC distribution line near the site. The unit has a down-wind, horizontal-axis three-blade system and powered a three-phase induction generator. Each blade is 25 feet long and the entire system sits on an 80-foot tower.

The fundamental purpose of the Luzenac site was to study the interaction of a wind-turbine system with a long radial electrical distribution system. Montana contains many remote sites that require electrical power resulting in many long radial electrical lines. Because the capacity of these radial lines is limited, it is necessary to consider how future load additions will be served.

Two possible alternatives are: 1) the size of the lines could be increased, at considerable cost; or 2) distributed generation could be installed at appropriate points along the lines. When costs of building or up-grading transmission lines are weighed against the costs of distributed generation, it is easy to envision cases where distributed generation would be more cost effective.

In addition to economic concerns, questions regarding power quality, reliability, and stability needed to be addressed in the distributed generation case. Because of the gusty nature of the wind, distributed wind generators can cause detrimental voltage fluctuations and power quality problems in radial systems. Because of the radial nature and loading of the electrical grid at the Luzenac site, it provided a good test site.

In studying electrical system interaction, Tech researchers collaborated with Professor Don Pierre and Ph.D. graduate student Stott Woods, both in the Electrical Engineering Department at MSU. A detailed computer simulation model of the system was developed and the test site was into operation in spring of 1999. The site included detailed electrical instrumentation along with same strain-gauge blade instrumentation used at the Rice Ridge Park. Some of this research continues to this day, and as mentioned, the 50kW turbine will be moved to Missoula and erected in commemoration of Dr. David Westine, a key, young investigator with this project, who lost his battle with cancer.

OVERALL MILESTONES AND OUTCOMES

The majority of the technical outcomes were thoroughly discussed and reviewed by the 1999 site review team. The 2000 wrap-up consisted mainly of small projects being completed using remaining funds. The outcomes of the program, including related publications and presentations are included in the attached Excel spreadsheet entitled Final9403.xls. This data set contains over 1000 listings.